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Foreword

This foreword is not part of NEMA ST 20 Dry-Type Transformers for General Applications.

This standard references applicable ANSI and other national standards.

This update maintains or incorporates applicable sections of documents in the Reference Section to provide a “one source” technical requirement standard.

This standard incorporates sound level requirements.

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Senior Technical Director, Operations
National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, Virginia  22209

This standards publication was developed by the Dry-Type and Specialty Transformer Products Section of the National Electrical Manufacturers Association. 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.                 Cooper Power Systems by Eaton
Raleigh, NC               Waukesha, WI
Eaton                    Cleveland, OH
Federal Pacific          Bristol, VA
General Electric         Fairfield, CT
Hammond Power Solutions, Inc.  Guelph, Ontario
L-3 Communications Power Paragon  Anaheim, CA
MGM Transformer Company  Commerce, CA
Mirus International Inc.  Brampton, Ontario
ONYX Power Inc.           Santa Ana, CA
Power Quality International Corp.  Odessa, FL
Powersmiths International Corp.  Brampton, Ontario
Schneider Electric-      Palatine, IL
Siemens Industry         Norcross, GA
SolaHD                   Rosemont, IL
Scope

This standards publication applies to single-phase and polyphase dry-type transformers (including autotransformers and non-current-limiting reactors) for supplying energy to power, heating, and lighting circuits and designed to be installed and used in accordance with the National Electrical Code®.

It applies to transformers with and/or without accessories having ratings of 1.2 kV class, 0.25 kVA through 4000 kVA. Transformers not covered by this standard may be covered by NEMA TR 1.

This standards publication applies to transformers, commonly known as general-purpose transformers for commercial, institutional and industrial use in nonhazardous locations both indoors and outdoors. The publication includes ratings and information on the application, design, construction, installation, operation, inspection, and maintenance as an aid in obtaining a high level of safe performance. These standards, except for those for ratings, may be applicable to transformers having other than standard ratings. These standards, as well as applicable local codes and regulations should be consulted to secure the safe installation, operation, and maintenance of dry-type transformers. Also included are unit substation transformers and transformers in distribution centers.

This publication does not apply to the following types of specialty transformers: control, industrial control, Class 2, signaling, oil- or gas-burner ignition, luminous tube, cold cathode lighting, incandescent, mercury lamp, and instrument transformers.
Section 1
REFERRED STANDARDS AND DEFINITIONS

1.1 REFERENCED STANDARDS

The following publications are adopted, in whole or in part as indicated by reference in this standards publication. Copies are available from the indicated sources.

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

ANSI S1.4-1983 Specification for Sound Level Meters

Institute of Electrical and Electronics Engineers
345 East 47th Street
New York, NY 10017

IEEE C2 National Electrical Safety Code
IEEE C57.94 IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers
IEEE C57.96 Guide for Loading Dry-Type Distribution and Power Transformers
IEEE C57.12.91 IEEE Standard Test Code for Dry-Type Distribution and Power Transformers
IEEE C57.12.01 IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those With Solid Cast and/or Resin-Encapsulated Windings
IEEE C57.12.70 Terminal Markings and Connections for Distribution and Power Transformers
IEEE 100 IEEE Standard Dictionary of Electrical and Electronics Terms
IEEE 259 Systems of Insulation for Specialty Transformers, Standard Test Procedure for Evaluation of
IEEE 4 Techniques for High-Voltage Testing
IEEE 142 IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems

National Fire Protection Association
Battery March Park
Quincy, MA 02269

NFPA 70 National Electrical Code®

National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, VA 22209

NEMA 250 Enclosures for Electrical Equipment (1000 Volts Maximum)
NEMA TP 1 Guide for Determining Energy Efficiency for Distribution Transformers
NEMA TP 2 Standard Test Method for Measuring the Energy Consumption of Distribution Transformers

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1.2 DEFINITIONS

If a conflict of definitions occurs between this standard and IEEE 100 the Electrical Dictionary IEEE 100 should be used.

1.2.1 Accessible

(As applied to dry-type transformer) Admitting close approach because not guarded by locked doors, elevation, or other effective safeguards.

1.2.2 Accessible, Readily

Capable of being reached quickly for operation, renewal, or inspections, without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, chairs, etc.

1.2.3 Accessories

Devices that perform a secondary or minor duty as an adjunct or refinement to the primary or major duty of a unit of equipment.

1.2.4 Alternating Current

A periodic current having an average value over a period of time of zero. Unless distinctly specified otherwise, the term “alternating current” refers to a current that reverses at regularly recurring intervals of time and that has alternately positive and negative values.

1.2.5 Ampacity

Current-carrying capacity, expressed in amperes, of a wire or cable under stated thermal conditions.

1.2.6 Circuit

1.2.6.1 Single-Phase Circuit

A circuit energized by a single alternating electromotive force usually supplied through two wires. The current in these two wires, counted outward from the source, differs in phase by one-half of a cycle (i.e. 180 degrees).

1.2.6.2 Six-Phase Circuit

A combination of circuits energized by alternating electromotive forces that differ in phase by one-sixth of a cycle (i.e. 60 degrees).

Note: In practice, the phases may vary several degrees from the specified angle.
1.2.6.3 Three-Phase Circuit
A combination of circuits energized by alternating electromotive forces that differ in phase by one-third of a cycle (i.e. 120 degrees).

Note: In practice, the phases may vary several degrees from the specified angle.

1.2.6.4 Two-Phase Circuit
A polyphase circuit energized of three, four, or five distinct conductors intended to be so energized that in the steady state the alternating voltages between two selected pairs of terminals of entry, other than the neutral terminal when one exists, have the same periods, are in equal amplitude, and have a phase difference of 90 degrees. When the circuit consists of five conductors, but not otherwise, one of them is a neutral conductor.

1.2.7 Combustible Materials
Materials that are external to the apparatus and made of or surfaced with wood, compressed paper, plant fibers, or other materials that will ignite and support flame.

1.2.8 Contactor
A device for repeatedly establishing and interrupting an electric power circuit.

1.2.9 Cooling Systems
1.2.9.1 Dry-Type Self-Cooled Transformer (Class AA)
A dry-type transformer that is cooled by the natural circulation of air.

1.2.9.2 Dry-Type, Self-Cooled/Forced Air-Cooled Transformer (Class AA/FA)
A dry-type transformer that has a self-cooled rating with cooling obtained by the natural circulation of air and a forced-air-cooled rating with cooling obtained by the forced circulation of air.

1.2.9.3 Dry-Type Forced-Air-Cooled Transformer (Class AFA)
A dry-type transformer that derives its cooling by the forced circulation of air.

1.2.9.4 Dry-Type Self-Cooled/Future-Forced-Air-Cooled Transformer (Class AA/FFA)
A dry-type transformer that has a self-cooled rating with cooling obtained by the natural circulation of air and which contains provision for the addition of forced-air-cooling equipment at a later date.

1.2.10 Crest
1.2.10.1 Crest Value (Peak Value)
The maximum absolute value of a function when such a maximum exists.

1.2.10.2 Crest Factor Of A Function
The ratio of its crest (peak, maximum) value to its root-mean-square (rms) value.

1.2.11 Current
1.2.11.1 Eddy Currents
The currents that are induced in the body of a conducting mass by the time variation of magnetic flux.

Note: The variation of magnetic flux is the result of a varying magnetic field or of a relative motion of the mass with respect to the magnetic field.

1.2.11.2 Excitation Current of A Transformer
The current that flows in any winding used to excite the transformer when all other windings are open-circuited. It is usually expressed in percent of the rated current of the winding in which it is measured when the winding is energized at rated voltage.
1.2.12 Cycle
The complete series of values of a periodic quantity that occurs during a period. (It is one complete set of positive and negative values of an alternating current.)

1.2.13 Diagrams
1.2.13.1 Letter Designations
Those that are used in general outline drawings.

A = overall height.
B = maximum floor dimensions along a line parallel to the front of the enclosure, or along a line parallel to the largest dimension of a core and coil.
C = maximum floor space dimension along a line at right angles to dimension B.

1.2.13.2 Illustrative Diagram
A diagram whose principal purpose is to show the operating principle of a device or group of devices without necessarily showing actual connections or circuits. Illustrative diagrams may use pictures or symbols to illustrate or represent devices or their elements. Illustrative diagrams may be made of electric, hydraulic, pneumatic, and combination systems.

1.2.13.3 One-Line Diagram (Or Single-Line)
A diagram that shows by means of single lines and graphic symbols, the course of an electric circuit or system of circuits, and the component devices or parts used therein.

1.2.13.4 Schematic Diagram Or Elementary Diagram
A diagram that shows, by means of graphic symbols, the electrical connections and functions of a specific circuit arrangement. The schematic diagram facilitates tracing the circuit and its functions without regard to the actual physical size, shape, or location of the component device or parts.

1.2.13.5 Connection Diagram
A diagram which shows the connections of an installation or its component devices, controllers, and equipment. It may cover internal or external connections, or both, and shall contain such detail as is needed to make or trace connections that are involved. It usually shows the general physical arrangement of devices and device elements and, also, accessory items, such as terminal blocks, resistors, etc.

A connection diagram excludes mechanical drawings, commonly referred to as wiring templates, wiring assemblies, cable assemblies, etc.

1.2.14 Dielectric Testing
1.2.14.1 General
Tests which consist of the application of a voltage higher than the rated voltage, for a specified time, to assure the withstand strength of insulation materials and spacing.

1.2.14.2 Applied Dielectric Test
Dielectric tests in which the test voltages are low-frequency alternating voltages or dc from an external source applied between conducting parts and ground without exciting the core of the transformer being tested. The purpose of this test is to test the insulation between windings and between windings and ground.
1.2.14.3 Induced Dielectric Test
Dielectric tests on transformer windings in which the appropriate test voltages are developed in the windings by magnetic induction.
Note: Power for induced voltage test is usually supplied at higher-than-rated frequency to avoid core saturation and excessive excitation current.

1.2.14.4 Impulse Tests
Insulation test in which the voltage applied is an impulse voltage of specified wave shape (applied between windings and between windings and ground).

1.2.15 Distance
1.2.15.1 Creepage Distance
The shortest distance between two conducting parts measured along the surface or joints of the insulating material between them.

1.2.15.2 Striking Distance
The shortest unobstructed distance, measured through a dielectric medium such as liquid, gas, or vacuum; between parts of different electric potential.

1.2.16 Distribution Center (Secondary Distribution)
Enclosed apparatus that consists of automatic protective devices connected to bus bars, to subdivide the feeder supply and provide control and protection of sub-feeders or branch circuits.

1.2.17 Duty
A requirement of service that defines the degree of regularity of the load.
1.2.17.1 Continuous Duty
Operation at a substantially constant load for an indefinitely long time.
1.2.17.2 Intermittent Duty
A requirement of service that demands operation for alternate periods of (a) load and no load or (b) load and rest or (c) load, no load, and rest; as specified.
1.2.17.3 Periodic Duty
Intermittent operation in which the load conditions are regularly recurrent.
1.2.17.4 Short-Time Duty
A duty that demands operation at a substantially constant current for a short and definitely specified time.
1.2.17.5 Varying Duty
A requirement of service that demands operation at loads, and for periods of time, both of which may be subject to wide variation.

1.2.18 Enclosures
A surrounding case or housing used to protect the contained equipment against external conditions and prevent personnel from accidentally contacting live parts.

1.2.19 Equipment
A general term including material, fittings, devices, appliances, fixtures, apparatus, and the like as a part of, or in connection with, an electrical installation.
1.2.20  FCAN
FCAN (Full Capacity Above Nominal) refers to the fact that the taps are designed to carry the full capacity of the transformer at voltages above the nameplated nominal input voltage.

1.2.21  FCBN
FCBN (Full Capacity Below Nominal) refers to the fact that the taps are designed to carry the full capacity of the transformer at voltages below the nameplated nominal input voltage.

1.2.22  Frequency
The number of periods occurring per unit time.

1.2.23  Grounded
Connected to earth or to some extended conducting body that serves instead of the earth, whether the connection is intentional or accidental.

1.2.24  Hertz
The unit of frequency, one cycle per second.

1.2.25  Impedance
1.2.25.1  Impedance Voltage of a Transformer
The voltage required to circulate rated current through one of two specified windings of a transformer when the other winding is short-circuited, with the windings connected as for rated voltage operation.  
Note: It is usually expressed in per unit, or percent, of the rated voltage of the winding in which the voltage is measured.

1.2.25.2  Impedance kVA
The kVA measured in the excited winding with the other winding short-circuited and with sufficient voltage applied to the excited winding to cause rated current to flow in the winding.

1.2.26  Insulation
1.2.26.1  Insulating Material
A substance or body, the conductivity of which is zero or, in practice, very small.

1.2.26.2  Insulation System
An assembly of insulating materials in a particular type, and sometimes size, of equipment.

1.2.27  Interlock
A device actuated by the operation of some other device with which it is directly associated, to govern succeeding operations of the same or allied devices.

1.2.28  IR-drop Compensation
A provision in the transformer by which the voltage drop due to transformer load current and internal transformer resistance is partially or completely neutralized. Such transformers are suitable only for one-way transformation, that is, not interchangeable for step-up or step-down transformations.

1.2.29  K Factor
A rating optionally applied to a transformer indicating its suitability for use with loads that draw nonsinusoidal currents. The formula for calculating a K Factor is referenced in Section 5.5 of UL1561.
1.2.30 Load (output)
The apparent power in mega-volt amperes, kilo-volt amperes, or volt-amperes that may be transferred by the transformer.

1.2.31 Losses
1.2.31.1 Total Losses
The sum of the no-load and the load losses, excluding losses due to accessories.

1.2.31.2 No-Load (Excitation) Losses
Those losses incident to the excitation of the transformer. No-load losses include core loss, dielectric loss, conductor loss in the winding due to exciting current, and conductor loss due to circulating current in parallel windings. These losses change with the excitation voltage.

1.2.31.3 Load Losses
Those losses incident to the carrying of a specified load. Load losses include $I^2R$ loss in the windings due to load and eddy currents; stray loss 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.

1.2.32 Nonenclosed
Not surrounded by a medium that will prevent a person accidentally contacting live parts.

1.2.33 Overcurrent Protection
A form of protection(s) that operates when current exceeds a predetermined value.

1.2.34 Part
1.2.34.1 Dead-Metal Part
A part, accessible or inaccessible, which is conductively connected to the grounded circuit under conditions of normal use of the equipment.

1.2.34.2 Live-Metal Part
A part consisting of electrically conductive material which can be energized under conditions of normal use of the equipment.

1.2.35 Rating
1.2.35.1 Rating of a Transformer
The rating of a transformer consists of a volt-ampere output together with any other characteristics, such as voltage, current, frequency, power factor, and temperature rise, assigned to it by the manufacturer. It is regarded as a rating associated with an output that can be taken from the transformer under prescribed conditions and limitations of established standards.

1.2.35.2 Continuous Rating
The maximum constant load that can be carried continuously without exceeding established temperature rise limitations under prescribed conditions.

1.2.35.3 Primary Voltage Rating
The input-circuit voltage for which the primary winding is designed, and to which operating performance characteristics are referred.

1.2.35.4 Secondary Voltage Rating
The load-circuit voltage for which the secondary winding is designed.
1.2.35.5 Short-Time Rating
The maximum constant load that can be carried for a specified short time, without exceeding the established temperature rise limitations, under prescribed conditions.

1.2.35.6 Voltage Rating Of A Grounding Transformer
The maximum "line-to-line" voltage at which it is designed to operate continuously from line to ground without damage to the grounding transformer.

1.2.35.7 Winding Voltage Rating
The voltage for which the winding is designed.

1.2.35.8 Withstand Voltage Rating
The test voltage that the transformer is capable of withstanding without failure or disruptive discharge when tested under specified conditions.

1.2.36 Ratio
1.2.36.1 Turn Ratio of a Transformer
The ratio of the number of turns in a higher voltage winding to that in a lower voltage winding.
Note: In the case of a constant voltage transformer having taps for changing its voltage ratio, the nominal turn ratio is based on the number of turns corresponding to the normal rated voltage of the respective windings, to which operating and performance characteristics are referred.

1.2.36.2 Voltage Ratio of a Transformer
The ratio of the rms terminal voltage of a higher voltage winding to the rms terminal voltage of a lower voltage winding, at no load.

1.2.37 Reactor
An electromagnetic device, the primary purpose of which is to introduce inductive reactance into a circuit.

1.2.37.1 Current-Limiting Reactor
A reactor intended for limiting the current that can flow in a circuit under short-circuit conditions, or under operating conditions such as starting, synchronizing, etc. It is also a reactor connected in series with the phase conductors for limiting the current that can flow in a circuit under short-circuit conditions, or under other operating conditions, such as capacitor switching, motor starting, synchronizing, arc stabilization, etc.

1.2.38 Regulation of a Transformer
The change in output voltage as the load current is varied. It is usually expressed as a percentage of the rated load voltage when the load current is changed by its rated value.

\[ \text{Percent regulation} = \frac{100(E_1 - E_2)}{E_2} \]

where \( E_1 \) is the no-load voltage and \( E_2 \) is the voltage at rated load current and the line voltage is held constant at rated value.

1.2.39 Resistant (used as a suffix)
So constructed, protected or treated that damage will not occur readily when the device is subjected to the specified material or condition.
1.2.40 Taps

1.2.40.1 Tap (in a Transformer)
A connection brought out of a winding at some point between its extremities to permit changing the voltage, or current, ratio. Also, an available connection that permits changing the active portion of the device in the circuit.

1.2.40.2 Rated kVA Tap (in a Transformer)
A tap through which the transformer can deliver its rated kVA without exceeding the specified temperature rise.

1.2.40.3 Reduced kVA Tap (in a Transformer)
A tap through which the transformer can deliver an output less than rated kVA without exceeding the specified temperature rise. The current is usually that of the rated kVA tap.

1.2.41 Temperatures

1.2.41.1 Ambient Temperature
The temperature of the medium such as air, water, or earth into which the heat of the equipment is dissipated.
Notes: 1. For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate vicinity of the equipment.
2. For air- or gas-cooled equipment with forced ventilation or secondary water-cooling, the ambient temperature is taken that of the ingoing air or cooling gas.
3. 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.

1.2.41.2 Inside Top Air Temperature
The temperature of the air inside a dry-type transformer enclosure, measured in the space above the core and coils.

1.2.41.3 Hottest-Spot Temperature
The highest temperature inside the transformer winding. It is greater than the measured average temperature (using the resistance change method) of the coil conductors.

1.2.41.4 Hot Spot Differential
The assumed difference between the average coil temperature determined by the change-of-resistance method and the hottest-spot temperature at some point in the coil (1.2.41.3).

1.2.41.5 Limiting Temperature
The maximum temperature at which a component or material may be operated continuously with no sacrifice in normal life expectancy.

1.2.41.6 Limiting Insulation System Temperature (Limiting Hottest – Spot Temperature)
The maximum temperature selected for correlation with a specified test condition of the equipment with the object of attaining a desired service life of the insulation system.

1.2.42 Transformer
A static electric device consisting of two or more coupled windings, with a magnetic core, for introducing mutual coupling between electric circuits. Transformers are extensively used in electric power systems to transfer power by electromagnetic induction between circuits at the same frequency; usually with changed values of voltage and current.
1.2.42.1 Autotransformer
A transformer in which part of one winding is common to both the primary and the secondary circuits associated with that winding.

1.2.42.2 Buck-Boost Transformer
A transformer that is equipped with one or more primary windings and one or more secondary windings, designed to be (a) used as a step down insulating transformer, or (b) field connected as an autotransformer to buck a supply voltage down or boost a supply voltage up.

1.2.42.3 Compound-Filled Transformer
A transformer in which the windings are enclosed with an insulating fluid that becomes solid, or remains slightly plastic, at normal operating temperatures.
*Note:* The shape of the compound-filled transformer is determined in large measure by the shape of the container or mold used to contain the fluid before solidification.

1.2.42.4 Dry-Type Transformers
A transformer in which the core and coils are in a gaseous or dry compound insulating medium.

1.2.42.5 Gas-Filled Transformer
A sealed transformer, except that the windings are immersed in a dry gas which is other than air or nitrogen.

1.2.42.6 Grounding Autotransformer
A zig-zag connected transformer intended primarily to provide a neutral point for grounding three-phase, 3-wire ungrounded systems.

1.2.42.7 Indoor Transformer
A transformer which, because of its construction, must be protected from the weather.

1.2.42.8 Insulating Transformer
A transformer used to insulate one circuit from another.

1.2.42.9 Isolating Transformer
A transformer inserted in a system to separate one section of the system from undesired influences of other sections.
*Note:* Isolating transformers are commonly used to isolate system grounds and prevent the transmission of undesired currents.

1.2.42.10 Main Transformer
The term “main transformer,” as applied to two single-phase Scott-connected units for three-phase to two-phase operation, or for two-phase to three-phase operation, designates the transformer that is connected directly between two of the phase wires of the three-phase lines.
*Note:* A tap is provided at the midpoint for connection to the teaser transformer.

1.2.42.11 Nonventilated Transformer
So constructed as to provide no intentional circulation of external air through the enclosure.

1.2.42.12 Outdoor Transformer
A transformer of weather-resistant construction suitable for service without additional protection from the weather.
1.2.42.13 Sealed Transformer
A dry-type transformer with a hermetically sealed tank.

1.2.42.14 Shielded Transformer
Type I—A transformer having electrical insulation and electrostatic shielding between its windings such that it can provide isolation between parts of the system in which it is used. It is suitable for use in a system that requires a guard for protection against common-mode interference.

Type II—A transformer having electrical insulation and metallic shield (barrier) between its windings such that it can provide isolation between parts of the system in which it is used. The metallic shield (barrier) shall have sufficient current carrying capacity to withstand fault currents, without causing electrical insulation breakdown between the input and output circuit(s).

1.2.42.15 Step-Down Transformer
A transformer in which the power transfer is from a higher voltage circuit to a lower voltage circuit.

1.2.42.16 Step-Up Transformer
A transformer in which the power transfer is from a lower voltage circuit to a higher voltage circuit.

1.2.42.17 Teaser Transformer
As applied to two single-phase Scott-connected units for the three-phase to two-phase or for two-phase to three-phase operation, designates the transformer that is connected between the midpoint of the main transformer and the third-phase wire of the three-phase system.

1.2.42.18 Ventilated Dry-Type Transformer
A dry-type transformer that is so constructed that the ambient air may circulate through its enclosure to cool the transformer core and windings.

1.2.43 Knockout
A knockout is a portion of the wall of an enclosure so fashioned that it may be removed readily by a hammer, screwdriver, and pliers at the time of installation in order to provide a hole for the attachment of an auxiliary device or raceway, cable, or fitting.

1.2.44 Twistout
A twistout is a ring member surrounding a knockout and similarly fashioned so that it may be removed after the knockout in order to provide a larger hole than that provided for by the removal of the knockout only.

1.2.45 Multiple Knockout
A “multiple knockout” is a knockout surrounded by one or more twistouts.

1.2.46 Windings
1.2.46.1 Common, or Shunt, Winding of an Autotransformer
That part of the autotransformer winding that is common to both the primary and the secondary circuits.

1.2.46.2 High-Voltage and Low-Voltage Windings
The terms “high-voltage” and “low-voltage” are used to distinguish the winding having the greater from that having the lesser voltage rating.

1.2.46.3 Primary Winding
The winding on the energy input side.
1.2.46.4 Secondary Winding
The winding on the energy output side.

1.2.46.5 Series Windings of an Autotransformer
That portion of the autotransformer winding which is not common to both the primary and the secondary circuits, but is connected in series between the input and output circuits.

1.2.46.6 Stabilizing Windings
A delta connected auxiliary winding used particularly in Y-connected three-phase transformers for such purposes as the following:

- To stabilize the neutral point of the fundamental frequency voltages.
- To minimize third-harmonic voltage and the resultant effects on the system.
- To mitigate telephone influence due to third-harmonic current and voltages.
- To minimize the residual direct-current magnetomotive force on the core.
- To decrease the zero-sequence impedance of transformers with Y-connected windings.

Note: A winding is regarded as a stabilizing winding if its terminals are not brought out for connection to an external circuit. However, one or two points of the winding which are intended to form the same corner point of the delta may be brought out for grounding, or grounded internally to the tank. For a three-phase transformer, if other points of the winding are brought out, the winding should be regarded as a normal winding as otherwise defined.

1.2.47 Wiring or Busing Terminal, Screw, and/or Lead
Terminal, screw or lead to which a power supply will be connected in the field.
Section 2
RATING STANDARDS

2.1 RATINGS AND PRIMARY TAPS

Primary taps for single-phase and three-phase transformers and for autotransformers, should be guided by Table 2-1 and Table 2-2. For intermediate kVA ratings not listed in Table 2-1 and Table 2-2, the next larger kVA rating should be used to determine the recommended number of taps. All taps listed in these tables are based on average temperature rise and insulation systems per table 3-3. The factory should be consulted for tap ratings greater than 1500kVA.

An input voltage variation above or below the nameplate voltage will be reflected in the same proportion in the output voltage. Primary taps are used to compensate for lower or higher input voltages. Proper installation and use of primary taps permit installers to achieve output voltages close to the rated transformer output. Primary taps should be chosen based on the stability of the power system. Advancements in power management and equipment flexibility have reduced the need for taps.

2.2 VOLTAGE RANGES

Transformers should operate within ±5% of rated tap voltages.

System voltages other than those listed in Table 2-1 and Table 2-2 are sometimes used. Table 2-3 identifies some common equivalent voltage designations.

Transformers with taps may be necessary to compensate for applications with voltages different than the rated voltages.
Table 2-1  
KILOVOLTAMPERE AND VOLTAGE RATINGS AND PRIMARY TAPS FOR SINGLE PHASE TRANSFORMERS  
HAVING PRIMARY VOLTAGES UP THROUGH 600 VOLTS*  

<table>
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<tr>
<th>Single-Phase kVA Rating</th>
<th>Primary Voltage</th>
<th>0.05</th>
<th>0.1</th>
<th>0.25</th>
<th>.5</th>
<th>.75</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>7.5</th>
<th>10</th>
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<td>120</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
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<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>277</td>
<td>X</td>
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<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
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<td></td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Single Voltages less than 300 not listed above</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Single Voltage Greater than or equal to 300 not listed above</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>A</td>
<td>D</td>
<td>E</td>
<td>X</td>
<td>A</td>
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<td>120x240</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td>Other Dual Voltages not listed above</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Primary Voltage</td>
<td>15</td>
<td>25</td>
<td>37.5</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>167</td>
<td>250</td>
<td>333</td>
<td>500</td>
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</tr>
<tr>
<td>277</td>
<td>X, A</td>
<td>X, A</td>
<td>X, A</td>
<td>X, A</td>
<td>X, A</td>
<td>X, A</td>
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<td>X, A</td>
<td>X, A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X  NO TAPS  
A 2 - 5% FCBN  
B 4 – 2.5% FCBN (Series Connected) 2 – 5% FCBN (Parallel Connected)  
D 6 – 2.5% FCAN, 4 FCBN.  
E 4 – 2.5% 2 FCAN, 2 FCBN  
F 2 – 5% 1 FCAN, 1 FCBN  
H 3 – 5% 1 FCAN, 2 FCBN  
J 6 – 2.5% 4- FCBN, 2- FCAN, (Series Connected) 3 – 2.5% FCBN 1-5% FCAN (Parallel Connected)  

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Table 2-2
KILOVOLTAMPERE AND VOLTAGE RATINGS AND PRIMARY TAPS FOR THREE PHASE TRANSFORMERS
HAVING PRIMARY VOLTAGES UP THROUGH 600 VOLTS*

<table>
<thead>
<tr>
<th>Three-Phase kVA Rating</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>75</th>
<th>112.5</th>
<th>150</th>
<th>225</th>
<th>300</th>
<th>500</th>
<th>750</th>
<th>1000</th>
<th>1500</th>
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<tbody>
<tr>
<td>Primary Voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>120</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

X  NO TAPS
A  2 - 5% FCBN
C  4 – 2.5% FCBN (Series Connected) 2 – 5% FCBN (Parallel Connected)
D  6 – 2.5% 2 FCAN, 4 FCBN.
E  4 – 2.5% 2 FCAN, 2 FCBN
F  2 – 5% 1 FCAN, 1 FCBN
H  3 – 5% 1 FCAN, 2 FCBN
J  6 – 2.5% 4- FCBN, 2- FCAN, (Series Connected) 3 – 2-5% FCBN 1-5% FCAN (Parallel Connected)
<table>
<thead>
<tr>
<th>Nominal Systems Voltage, Volts</th>
<th>Other Designations for Identical Systems, Volts</th>
</tr>
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<tbody>
<tr>
<td>120</td>
<td>110, 115, or 125</td>
</tr>
<tr>
<td>120/240</td>
<td>110/220 or 115/230</td>
</tr>
<tr>
<td>208Y/120</td>
<td>199Y/115</td>
</tr>
<tr>
<td>240</td>
<td>220 or 230</td>
</tr>
<tr>
<td>400</td>
<td>380 or 415</td>
</tr>
<tr>
<td>400Y/230</td>
<td>380Y/219 or 415Y/240</td>
</tr>
<tr>
<td>480Y/277</td>
<td>440Y/254 or 460Y/265</td>
</tr>
<tr>
<td>480</td>
<td>440 or 460</td>
</tr>
<tr>
<td>600</td>
<td>550 or 575</td>
</tr>
</tbody>
</table>
Section 3
DESIGN AND MARKING

3.1 DESIGN AND CONSTRUCTION
Transformers shall be so designed and constructed as to permit their installation in accordance with the National Electrical Code.

3.2 MEANS OF HANDLING
Enclosures and/or frames for transformers over 60 pounds in weight shall be provided with brackets, holes or other means for lifting.

3.3 TRANSFORMER ENCLOSURE
3.3.1 General
A transformer which is intended for use within the enclosures of other equipment shall be permitted to be of the open core and coil type. All other transformers shall be provided with an enclosure of noncombustible, moisture-resistant material so designed as to afford mechanical protection for their windings and terminations and to satisfy the requirements of NEMA 250 for at least Types 1, 2, or 3R. This standard shall take precedence in cases of conflicts, e.g., “cases openings larger than 0.50” as permitted in 3.4.

A metallic enclosure shall be judged with respect to its size, shape, thickness of material, kind of material, and its suitability for the particular application, in consideration of the intended use of the complete transformer. Among the factors that are taken into consideration when judging the suitability of a nonmetallic enclosure are:

- All factors for judging metals.
- Physical strength.
- Resistance to impact.
- Moisture-absorptive properties.
- Combustibility.
- Resistance to distortion at temperatures to which the material may be subjected under conditions of normal (limited to test conditions in clause 4.4) or abnormal usage.

The enclosure shall surround the coils, terminal, and/or wiring compartment, accessories, etc.

Sheet metal enclosures shall meet the requirements of Table 3-1. Thinner metals or alternate materials may be used if they successfully pass the compression test outlined in 4.4.

For un-reinforced flat surfaces in general, cast metal shall be not less than 0.125 inch thick; malleable iron shall be not less than 0.094 inch thick; and die-cast metal shall be:

- Not less than 0.094 inch thick where the area is greater than 24 square inches or any dimension is greater than 6 inches, and
- Not less than 0.063 inch thick where the area is 24 square inches or less and no dimension is greater than 6 inches. The area limitation is obtained by the provision of suitable reinforcing ribs subdividing a larger area.

3.3.2 Corrosion Resistance
An enclosure of iron or steel shall be protected against corrosion by cleaning and the application of a protective coating, such as galvanizing, plating, phosphatizing, painting, or enameling.
3.3.3 Outdoor

The enclosure shall be of sheet steel having an average thickness of not less than 0.053 inch (No. 16 Manufacturers’ Standard Gage). Other metal or materials which provide equivalent strength and corrosion-resisting properties equivalent to those of steel are acceptable. Nonmetallic materials, if used, shall be suitable for the particular application with respect to strength, moisture resistance, and combustibility.

When a hole is provided for conduit in the enclosure, it shall be threaded, unless it is located wholly below the lowest live-metal part of a transformer (insulated wire leads are not considered to be live-metal parts). A hole for conduit shall provide not less than 0.250 inch of thread and shall be tapered unless a conduit end stop is provided. A bushed hole for open wiring shall not be located in the top or back of the enclosure unless a special hood fitting is provided; if a bushed hole is located in a side above live-metal parts, it shall provide for the wire to leave the enclosure in a downward direction.

There shall be provision for drainage of the enclosure if knock-outs or unthreaded conduit openings are provided. The enclosure shall be provided with external means for mounting, except that internal means for mounting may be employed if they are so designed as to prevent water from entering the enclosure. Hinges and other attachments shall be resistant to corrosion. Metals shall not be used in such combination as would cause galvanic action which will affect adversely any part of the transformer.

Outdoor enclosures shall be permitted to have multiple knockouts and do not require overlap between the bottom cover and enclosure.
<table>
<thead>
<tr>
<th>Group</th>
<th>Maximum Dimensions of Enclosure</th>
<th>Average Thickness of Sheet Metal, Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length or Width, Inches</td>
<td>Area, Square Inches</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>II</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>III</td>
<td>12</td>
<td>90</td>
</tr>
<tr>
<td>IV</td>
<td>18</td>
<td>135</td>
</tr>
<tr>
<td>V</td>
<td>24</td>
<td>360</td>
</tr>
<tr>
<td>VI</td>
<td>48</td>
<td>1200</td>
</tr>
<tr>
<td>VII</td>
<td>60</td>
<td>1500</td>
</tr>
<tr>
<td>VIII</td>
<td>Over 60</td>
<td>Over 1500</td>
</tr>
</tbody>
</table>

*Other materials or metals which provide equivalent strength and corrosion-resisting properties equivalent to those of steel are acceptable. Nonmetallic materials, if used, shall be suitable for the particular application with respect to strength, moisture resistance and combustibility. If thinner materials are used for flat surfaces such as panels, those surfaces shall be reinforced by embossing, bending, or some other means and tested in accordance with paragraph 4.4.

Note: The figures in parentheses are the Manufacturers' Standard Gage number (for uncoated steel). Thickness is the Manufacturers' Standard Gage.
3.4 OPENINGS

3.4.1 Enclosure

Openings in an enclosure, including perforated holes, louvers, and openings protected by means of wire screening, expanded metal or perforated covers, shall be of such size or shape that no opening will permit passage of a straight rod having a diameter of more than 0.50 inch, except that openings may be larger if they are baffled or located so as to prevent a test rod from passing within 4 inches of a live uninsulated part. The test rod shall be 33/64 inch (13.1 mm) in diameter if the plane of the opening is less than 4 inches (102 mm) from a live insulated part or 49/64 inch (19.4 mm) in diameter if the plane of the opening is 4 inches or more from such a part. Where metal wire screens are used, the wires shall be not less than No. 16 AWG. Sheet metal employed for expanded metal mesh and perforated sheet metal shall have an average thickness of not less than 0.042 inch (No. 18 Manufacturers’ Standard Gage) if the mesh openings or perforations are 0.50 square inches or less in area and shall have an average thickness of not less than 0.093 inch (No. 12 Manufacturers’ Standard Gage) for larger openings. Other metals or materials which provide strength and corrosion-resisting properties equivalent to those of steel may be used. Nonmetallic materials, if used, shall be suitable for the particular application with respect to strength, moisture resistance, and combustibility.

3.4.2 Wiring and/or Terminal Compartment

3.4.2.1 A wiring and/or terminal compartment shall provide adequate space within its confines to accommodate the size of cable (copper or aluminum) which provides the ampacities required by the National Electrical Code.

The clear wiring space for 250- and 600-volt conductors, independent of all projections, obstructions, or interference from moving parts, shall be no less in total area than 250 percent of the total cross-sectional area of the maximum number of insulated cables which may be used in such space. The minimum dimension in the plane of the cable bend shall be five times the outside diameter of the cable.

For terminating insulated metallic- and nonmetallic-sheathed power cables (except gas-filled cables) without potheads, 1 inch per kV line to line shall be provided for creepage over the cable insulation.

3.4.2.2 A wiring compartment shall have a flat surface surrounding any knockouts or openings provided for conduit. The surface shall have sufficient area to permit the assembly to the compartment of steel conduit of a size corresponding to the size of the knockout. A hexagonal or equivalent shaped locknut and conduit bushing having a maximum diameter corresponding to the size of the conduit as indicated in Table 3-2 shall be used. The resulting assembly shall be mechanically secure and shall provide a good electrical bond between the compartment and the conduit.

3.4.2.3 The location of a wiring compartment, and/or terminal compartment in which power-supply connections to the transformer are to be made, shall be such that these connections may be readily made and inspected after the transformer has been installed as intended. This requirement does not preclude placing the compartment and its access cover on the bottom surface of a transformer.
### Table 3-2
**KNOCKOUTS**

<table>
<thead>
<tr>
<th>Nominal Size of Conduit Inches</th>
<th>Knockout Diameter, Inches*</th>
<th>Throat Diameter of Conduit, Inches</th>
<th>Maximum Diameter of Conduit, Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nominal</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>½</td>
<td>0.875</td>
<td>0.859</td>
<td>0.906</td>
</tr>
<tr>
<td>¾</td>
<td>1.109</td>
<td>1.094</td>
<td>1.141</td>
</tr>
<tr>
<td>1</td>
<td>1.375</td>
<td>1.359</td>
<td>1.406</td>
</tr>
<tr>
<td>1-1/4</td>
<td>1.734</td>
<td>1.719</td>
<td>1.766</td>
</tr>
<tr>
<td>1-1/2</td>
<td>1.984</td>
<td>1.969</td>
<td>2.016</td>
</tr>
<tr>
<td>2</td>
<td>2.469</td>
<td>2.453</td>
<td>2.500</td>
</tr>
<tr>
<td>2-1/2</td>
<td>2.969</td>
<td>2.953</td>
<td>3.000</td>
</tr>
<tr>
<td>3</td>
<td>3.594</td>
<td>3.578</td>
<td>3.625</td>
</tr>
<tr>
<td>3-1/2</td>
<td>4.125</td>
<td>4.094</td>
<td>4.156</td>
</tr>
<tr>
<td>4</td>
<td>4.641</td>
<td>4.609</td>
<td>4.672</td>
</tr>
<tr>
<td>5</td>
<td>5.719</td>
<td>5.688</td>
<td>5.750</td>
</tr>
<tr>
<td>6</td>
<td>6.183</td>
<td>6.781</td>
<td>5.844</td>
</tr>
</tbody>
</table>

*These diameters are for single or concentric types only and exclude any projection of breakout ears or tabs. The tolerances shall be:

Nominal Size of Conduit, Inches Tolerances, Inches
½ through 3 +0.031, -0.016
3-1/2 through 6 +0.031, -0.031

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3.4.3 Conduit Entrance Threaded
If threads for the connection of conduit are tapped all the way through a hole in a transformer enclosure, or if an equivalent construction is employed, there shall be not less than 3.50 nor more than five threads in the metal, and the construction shall be such that a conduit bushing can be properly attached. If threads for the connection of conduit are tapped only part of the way through the hole in the enclosure, there shall be not less than five full threads in the metal, and there shall be a smooth well-rounded inlet hole for the conductors which shall afford protection to the conductors equivalent to that provided by a conduit bushing. The inlet hole shall have a throat diameter within the limits shown in Table 3-2 corresponding to the nominal size of conduit involved.

3.4.4 Conduit Entrance Knockouts
A knockout for the entrance of conduit to a terminal compartment or wiring compartment of a transformer shall have a diameter in accordance with Table 3-2.

3.4.5 Cord and Wire Entry Holes
A cord or wire entry hole in an entrance or a partition shall be smooth and well rounded without burrs or fins which might injure the conductor insulation.

3.4.6 Covers, Bottoms, or Panels
Removable covers, bottoms, or panels of an enclosure shall be secured in place in a reliable manner and, if necessary for removal to permit the connection of circuit conductors, shall not be provided with means for the connection of conduit or armored cable.

3.5 WALL-MOUNTED ENCLOSURES
An enclosure shall be provided with a means for mounting in a reliable manner. The design shall be such that, when the enclosure is mounted on a plane surface, it will make contact with the surface at points of support only. When so mounted, there shall be a spacing through air of not less than 0.25 inch between the supporting surface and the enclosure. This spacing is not required when the transformer is designed to be mounted on the cover of an outlet box or is intended for use within the enclosure of other electrical equipment.

A transformer designed to be supported by rigid conduit shall have conduit hubs with not less than five full threads or other equivalent supporting means of such strength that these parts will withstand the following:

- A direct pull of 200 pounds,
- A bending moment of 600 pound inches, and
- A torque of 600 pound inches.

Each force shall be applied in turn for a period of 5 minutes.

3.6 TESTING A KNOCKOUT SURROUNDED BY MULTIPLE TWISTOUTS
This test is used to determine that a combination consisting of an inner knockout surrounded by twistouts has been made so that, when one or more of its elements are removed, there will be no change in the remaining twistouts, if any, or in the enclosure in which the combination is located. This shall hold true either during removal or when the conduit has been properly secured in place.

Samples for testing shall be in the form of complete enclosures or of sample plates which will fulfill the requirements of Figure 3-1. The enclosure shall be securely held during the test.

The following tests shall be applied:
The knockout shall remain in place when the sample is subjected to a steadily applied load of 10 pounds applied for not less than 1 minute perpendicular to the face of the plate by means of a mandrel with a 0.25 inch-diameter flat end. The mandrel shall be applied at the point most likely to cause movement of the knockout in the direction in which it was originally punched.

A load of 50 pounds shall be steadily applied for not less than 1 minute, first in compression and then in tension, through conduit properly installed in the knockout opening. When conducting this test, the conduit shall be not more than 5 degrees from the normal to the surface. There shall be no appreciable distortion of the twistouts or fracture of the ties. The knockout and each twistout, starting at the smallest, shall be capable of being easily and cleanly removed without disturbing the other twistouts or distorting the box.

![Diagram of Test Plate Showing Area of Support with Respect of Area to Twistouts](image)

**Figure 3-1**

**DIAGRAM OF TEST PLATE SHOWING AREA OF SUPPORT WITH RESPECT OF AREA TO TWISTOUTS**

### 3.7 THERMAL RATING

Temperature is a major factor affecting the life of dry-type transformers through thermal degradation of their insulation systems. Atmospheric and/or environmental conditions, such as moisture, chemical contamination, mechanical and electrical stress, and the use of incompatible materials in the insulation system may increase the rate of thermal degradation of materials and contribute to early failure. The temperature limits for dry-type transformers should be so chosen that the transformers will have a satisfactory life under usual operating conditions. In addition, permissible emergency temperature limits and corresponding ratings may be established, including the duration and frequency of the emergency operations to which these limits apply.

### 3.8 CLASSIFICATION OF INSULATING MATERIALS

Classes of insulating materials are relative definitions and the temperatures indicated are not intended as limiting temperatures in rating transformers. Temperature classes of insulating materials have traditionally been established by definitions based on the composition of the materials but are increasingly being based on the results of thermal evaluation tests.
3.9 CLASSIFICATION OF INSULATION SYSTEMS

3.9.1 Systems Testing
Experience has shown that the thermal life characteristics of composite insulation systems generally cannot be reliably inferred from information concerning component materials. To assure satisfactory service life, insulating systems need to be evaluated by service experience or life tests. Accelerated life tests are being used increasingly to evaluate systems using the many new synthetic insulating non-cellulosic, and other high temperature materials that are available, thus shortening the period of service experience required before they can be used with confidence. Insulation systems are comprised of two categories, Major Components - The components of an insulation system that are relied upon to prevent a risk of electric shock or fire. Examples of this type of insulation include ground, interwinding, turn, encapsulant, and varnish. Minor Components - The components of an insulation system that are used typically in mechanical or thermal conduction capacities, and are not relied upon to prevent risk of fire or electric shock.

Tests on complete insulation systems are necessary to confirm the performance of materials for their specific functions in the transformer. Insulation system testing for dry-type transformers should be conducted in accordance with the UL 1446.

3.9.2 System Limiting Temperature
The system limiting temperature is the maximum temperature allowed within a transformer’s insulation system and yield satisfactory service life. Therefore, the temperature rating of the insulation system must be greater than or equal to the system limiting temperature. System limiting temperatures of 105°C, 130°C, 155°C, 180°C, 200°C, 220°C and 240°C are approved for materials suitable for the average winding rises shown in table 3-3A and 3-3B. System limiting temperatures should not be confused with the values used for identification and classification of the materials themselves. Refer to 3.9.3 to 3.9.9 for more details on typical materials used in these systems.

3.9.3 Typical Materials Used in 105°C Insulation Systems
Examples of flexible insulating materials found suitable, from experience or test, for 105°C hottest spot insulation systems are: (1) cotton, silk, paper, and similar organic materials when impregnated; (2) molded and laminated materials with cellulose filler, phenolic resins, and other resins of similar properties; (3) films and sheets of cellulose acetate and other cellulose derivatives of similar properties; (4) varnishes (enamel) as applied to conductors. Other materials or combinations of materials may be included in this insulation system if, by experience or accepted tests, they can be shown to be capable of operation at 105°C.

Note: An insulation is considered to be “impregnated” when a suitable substance replaces the air between its fibers, even if this substance does not completely fill the spaces between the insulated conductors. The impregnating substances, in order to be considered suitable, should have good insulating properties; should entirely cover the fibers and render them adherent to each other and to the conductor; should not produce interstices within themselves as a consequence of evaporation of the solvent or through any other cause; should not flow during the operation of the apparatus at full working load, or at the temperature limit specified; and should not unduly deteriorate under prolonged exposure to operating temperature.

Care should be taken not to impair the electrical and mechanical properties of the insulated winding by the application of the hottest-spot temperature permitted for the specific insulation system. The word “impaired” is here used in the sense of causing any change that could disqualify the insulating material from continuously performing its intended function, whether it is creepage spacing, mechanical support, or dielectric barrier action.

3.9.4 Typical Materials Used in 130°C Insulation Systems
Examples of flexible insulating materials found suitable, from experience or test, for 130°C hottest spot insulation systems are: impregnated paper, nylon, polyester, polyester film, polyester glass, epoxy and phenolic glass.
Other materials or combinations of materials may be included in this insulation system if, by experience or accepted tests, they can be shown to be capable of operation at 130°C.

3.9.5 Typical Materials Used in 155°C Insulation Systems
Examples of flexible insulating materials found suitable, from experience or test, for 155°C hottest spot insulation systems are polyester, polyester film, inorganic, hybrid inorganic and aramid insulation, modified silicone and epoxy. A small proportion of 105°C rise materials may be used for structural purpose only. Glass fiber or magnet-wire insulations are included in this insulation system. These may include supplementary organic materials, such as polyvinyl acetal or polyamide films.

Other materials or combinations of materials may be included in this insulation system if, by experience or accepted tests, they can be shown to be capable of operation at 155°C.

3.9.6 Typical Materials Used in 180°C Insulation Systems
Examples of flexible insulating materials found suitable, from experience or test, for 180°C hottest spot insulation systems are materials or combinations of materials such as silicone, silicone glass, silicone rubber, inorganic, hybrid inorganic and aramid insulation and ester-imide. Other materials or combinations of materials, not necessarily inorganic, may be included in this insulation system if by experience or accepted test, they can be shown to be capable of operation at 180°C.

3.9.7 Typical Materials Used in 200°C Insulation Systems
Examples of flexible insulating materials found suitable, from experience or test, for 200°C hottest spot insulation systems are materials or combinations of materials such as inorganic, hybrid inorganic and aramid insulation, Amide-imide overcoated ester-imide, and amide-imide overcoated polyester. Other materials or combinations of materials may be included in this insulation system if, by experience or accepted tests, they can be shown to be capable of operation at 200°C.

3.9.8 Typical Materials Used in 220°C Insulation Systems
Examples of flexible insulating materials found suitable, from experience or test, for 220°C hottest spot insulation systems are materials or combinations of materials such as silicon elastomer, mica, glass fiber, aramid fiber, inorganic insulation other than mica, etc., with suitable bounding substances such as appropriate silicon resins. Other materials or combinations of materials may be included in this insulation system if, by experience or accepted tests, they can be shown to be capable of operation at 220°C.

3.9.9 Typical Materials Used in Insulation Systems rated above 220°C
Examples of flexible and/or rigid insulating materials found suitable, from experience or test, for over 220°C hottest spot insulation systems are mica, porcelain, glass, quartz, and similar inorganic materials. Other materials or combinations of materials may be included in this insulation system if, by experience or accepted tests, they can be shown to have the required thermal life at temperatures over 220°C.

3.10 COIL INSULATION

Coils shall be so constructed as to provide adequate insulation between the various windings, and between the windings and the core and the enclosure.

Coil insulation, including coil conductor insulation, unless inherently moisture-resistant, shall be so treated as to improve its resistance to moisture.

Coil insulation shall be selected so as to be compatible with the hottest temperature that it will encounter in the insulation system under usual service conditions.
3.11 INTERNAL WIRE, CABLE, AND BUS

The internal wiring of a transformer is considered to be all of the interconnecting wiring beyond the point where the power supply enters the enclosure, that is, beyond the wiring terminals or leads for power supply connection. This includes internal wire, cable, and bus connect units and components within the transformer, i.e., coil connections to terminations, including wiring, connections to switches, etc.

The maximum current to be carried by the circuit shall not cause insulated wire, cable, or bus to exceed the maximum rated temperature of the insulation based on the ambient temperature surrounding the wire, cable, or bus. The wire, cable, or bus shall be insulated for the potential to which it is subjected.

Wire, cable, and bus shall be supported and arranged so that it will withstand abrasion, flexing, etc. Clamping shall be such that it will not damage the insulation. Where the relative motion of components connected by conductors is normal during the operation of the transformer or normal maintenance, provision shall be made for furnishing an adequate size of wire, cable, or bus and insulation, for sufficient flexibility, for avoiding strain on the terminals to which such conductors are connected, and for preventing the abrasion of insulation by relative motion between conductors or between conductors and fixed components.

3.12 CORROSIVE MATERIALS

Corrosive materials used in any of the manufacturing processes shall be removed or neutralized effectively so that no corrosion will result from such use.

3.13 FLEXIBLE CORDS

A flexible cord which is supplied as a component of a transformer shall be suitable for use at a voltage no less than the rated voltage of the connected winding and shall have a current-carrying capacity in accordance with the National Electrical Code but not less than the current rating of the transformer.

An attachment plug, when supplied on the flexible cord, shall be suitable for use at a current not less than 125 percent of the rated current and at a voltage equal to the rated voltage of the connected winding.

The flexible cord of a cord-connected transformer shall include a grounding conductor which shall have a continuous solid green color or a continuous green color with yellow stripe identification as required by the National Electrical Code. The grounding conductor shall be secured to the frame or enclosure of the transformer by means of a screw or other reliable means that are not liable to be removed during ordinary servicing. Solder alone shall not be used for securing the grounding conductor. The grounding conductor shall be connected to the ground blade or the equivalent fixed contacting member of the attachment plug.

3.14 SWITCHES, CIRCUIT BREAKERS, CONTROL DEVICES, ETC.

A switching mechanism (switch, circuit breaker, control device, etc.) supplied as an accessory for a transformer shall:

a. be adequate for use at a voltage no less than the rated voltage of the connected circuit
b. have a current-carrying capacity in accordance with the National Electrical Code but not less than that of the load which it controls.
c. have a short-circuit current rating or interrupting rating suitable for the point of installation

3.15 CAPACITORS

Capacitors shall be permitted to be accessories in transformer installations. For the purposes of connecting the capacitor to a power circuit, the transformers shall have a kVA rating not less than 135 percent of the capacitor kVA rating.

Capacitors shall be provided with a means of draining the stored charge.
The residual voltage of a capacitor shall be reduced to 50 volts or less within 1 minute after the capacitor is disconnected from the source of supply in the case of capacitors rated 600 volts or less and in 5 minutes in the case of capacitors rated above 600 volts.

The discharging circuit shall be either permanently connected to the terminals of the capacitor or capacitor bank or provided with automatic means for being connected to the terminals of the capacitor bank or the removal of voltage from the line. Manual means for switching or connecting the discharge circuit shall not be used. The windings of transformers, or of other equipment directly connected to capacitors without a switch or overcurrent device interposed, constitute a discharge means.

The ampacity of capacitor circuit conductors shall be not less than 135 percent of the rated current of the capacitor.

3.16 LIMITS OF WINDING TEMPERATURE RISE FOR CONTINUOUSLY RATED TRANSFORMERS

Average winding temperature rise is the change in average winding temperature when measured by the change of resistance method and tested in accordance with the applicable provisions of UL 1561. The maximum winding temperature rise is the change in temperature from the hottest spot at some point in the winding to the ambient temperature. The difference in temperature between the average and maximum winding temperature rises is the hot-spot differential (see 1.2.41.4). The sum of the maximum ambient temperature, average winding temperature rise and hot-spot differential shall not exceed the insulation system temperature rating.

Limits of winding temperature rise are a function of the maximum ambient temperature, the hot-spot differential and limited by the insulation system temperature. Winding temperature rises can be easily understood by the following relationship.

\[ T_{wavg} = T_{sys} - T_{mamb} - T_{hsd} \]

- \( T_{wavg} \) = Average Winding Temperature Rise measure by change in resistance method
- \( T_{sys} \) = Insulation System Temperature
- \( T_{mamb} \) = Maximum Ambient Temperature
- \( T_{hsd} \) = Hot-Spot Differential

### Table 3-3A

AVERAGE WINDING TEMPERATURE RISE FOR TRANSFORMERS 10 kVA AND BELOW

<table>
<thead>
<tr>
<th>Insulation System Temperature, Degrees C</th>
<th>Maximum Ambient Temperature, Degrees C</th>
<th>Average Winding Temperature Rise By Resistance, Degrees C</th>
<th>Hot-Spot Differential, Degrees C</th>
<th>Hottest-Spot Winding Temperature Rise, Degrees C</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>25</td>
<td>70</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>130</td>
<td>25</td>
<td>95</td>
<td>10</td>
<td>105</td>
</tr>
<tr>
<td>155</td>
<td>25</td>
<td>115</td>
<td>15</td>
<td>130</td>
</tr>
<tr>
<td>180</td>
<td>25</td>
<td>135</td>
<td>20</td>
<td>155</td>
</tr>
<tr>
<td>200</td>
<td>25</td>
<td>150</td>
<td>25</td>
<td>175</td>
</tr>
<tr>
<td>220</td>
<td>25</td>
<td>165</td>
<td>30</td>
<td>195</td>
</tr>
<tr>
<td>240</td>
<td>25</td>
<td>185</td>
<td>30</td>
<td>215</td>
</tr>
</tbody>
</table>
### Table 3-3B
AVERAGE WINDING TEMPERATURE RISE
FOR TRANSFORMERS ABOVE 10 kVA

<table>
<thead>
<tr>
<th>Insulation System Temperature, Degrees C</th>
<th>Maximum Ambient Temperature, Degrees C</th>
<th>Average Winding Temperature Rise By Resistance, Degrees C</th>
<th>Hot-Spot Differential, Degrees C</th>
<th>Hottest-Spot Winding Temperature Rise, Degrees C</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>40</td>
<td>55</td>
<td>10</td>
<td>65</td>
</tr>
<tr>
<td>130</td>
<td>40</td>
<td>60</td>
<td>30</td>
<td>90</td>
</tr>
<tr>
<td>155</td>
<td>40</td>
<td>85</td>
<td>30</td>
<td>115</td>
</tr>
<tr>
<td>180</td>
<td>40</td>
<td>110</td>
<td>30</td>
<td>140</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
<td>130</td>
<td>30</td>
<td>160</td>
</tr>
<tr>
<td>220</td>
<td>40</td>
<td>150</td>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>240</td>
<td>40</td>
<td>170</td>
<td>30</td>
<td>200</td>
</tr>
</tbody>
</table>

**Note:** Manufacturers may design and produce transformers suitable for ambient temperatures different than those in table’s 3-3A and 3-3B upon proper evaluation including testing if necessary. For example, a maximum ambient temperature of 50°C would be acceptable in a 220°C insulation system provided the average winding temperature rise was 140°C and hot-spot differential did not exceed 30°C (50 + 140 + 30 <= 220).

Transformers with a specified average winding temperature rise may have an insulation system which utilizes any combination of insulating materials, provided that the insulation system has been evaluated in accordance with 3.9.

### 3.17 MAXIMUM ALLOWABLE TEMPERATURE RISE FOR MATERIALS AND COMPONENT PARTS

The maximum allowable temperature rise for materials and component parts shall be as shown in Table 3-4. See 4.2.12 for Tests.

### Table 3-4
MAXIMUM ALLOWABLE TEMPERATURE RISES
FOR MATERIALS AND COMPONENT PARTS

<table>
<thead>
<tr>
<th>Item</th>
<th>Materials and Component Parts</th>
<th>&lt;= 10 kVA 25°C Maximum Ambient Temperature</th>
<th>&gt; 10 kVA 40°C Maximum Ambient Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Enclosures and exposed cores</td>
<td>65 (except as provided in 3.19)</td>
<td>50 (except as provided in 3.19)</td>
</tr>
<tr>
<td>3</td>
<td>Terminals for external connection</td>
<td>50 (see Note I)</td>
<td>35 (see Note I)</td>
</tr>
<tr>
<td>4</td>
<td>Contacts and fuses</td>
<td>80</td>
<td>65</td>
</tr>
<tr>
<td>5</td>
<td>Cords – Types S, SJ, SJO, SO Rubber or thermoplastic</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>Sealing compounds</td>
<td>Melting point minus 40°C</td>
<td>Melting point minus 55°C</td>
</tr>
<tr>
<td>7</td>
<td>Capacitors</td>
<td>Marked temperature minus 25°C</td>
<td>Marked temperature minus 40°C</td>
</tr>
<tr>
<td>8</td>
<td>At any point on or within a terminal box or on the supply conductors</td>
<td>50 (except as provided in 3.20)</td>
<td>35 (except as provided in 3.20)</td>
</tr>
</tbody>
</table>
### 3.18 REFERENCE TEMPERATURE FOR EFFICIENCY, LOSSES, IMPEDANCE, AND REGULATION

The reference temperature to which efficiency, losses, impedance, and regulation are corrected at full load shall be equal to the average temperature rise plus 20 in degrees Celsius as shown in Table 3-5.

<table>
<thead>
<tr>
<th>Transformers rated 10 KVA and Below</th>
<th>Transformers rated above 10 KVA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Winding Temperature</strong></td>
<td><strong>Average Winding Temperature</strong></td>
</tr>
<tr>
<td><strong>Rise</strong></td>
<td><strong>Rise</strong></td>
</tr>
<tr>
<td>Degrees C</td>
<td>Degrees C</td>
</tr>
<tr>
<td>70</td>
<td>55</td>
</tr>
<tr>
<td>95</td>
<td>60</td>
</tr>
<tr>
<td>115</td>
<td>85</td>
</tr>
<tr>
<td>135</td>
<td>110</td>
</tr>
<tr>
<td>150</td>
<td>130</td>
</tr>
<tr>
<td>165</td>
<td>150</td>
</tr>
<tr>
<td>170</td>
<td>170</td>
</tr>
</tbody>
</table>

*Note*: Data reported at other conditions shall be specified with the reference temperature.

### 3.19 TRANSFORMER SURFACE TEMPERATURES

#### 3.19.1 Transformer Surface Temperature of 90°C (194°F) or Less

Transformers shall have a maximum surface temperature of 90°C (194°F), unless the transformer is evaluated and marked as covered in 3.19.2 and 3.19.3. For example, transformers above 10kVA with a 50°C (122°F) rise are presumed to have a maximum of 40°C (104°F) ambient.

#### 3.19.2 Transformer Surface Temperature Greater than 90°C (194°F)

Transformer surface temperatures may exceed 90°C (194°F) provided the conditions of sections 3.19.2 and 3.19.3 are met.
Table 3-5A
MAXIMUM TRANSFORMER ENCLOSURE TEMPERATURE RISE WHEN MOUNTED IN ALCOVE

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
<th>Column 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVA</td>
<td>Maximum Ambient Temperature Rise (°C)</td>
<td>Maximum Enclosure Temperature Rise (T) in °C</td>
<td>Maximum Alcove Temperature Rise</td>
</tr>
<tr>
<td>10 or below</td>
<td>25</td>
<td>65 &lt; T ≤ 80 max</td>
<td>65 °C (149°F)</td>
</tr>
<tr>
<td>greater than 10</td>
<td>40</td>
<td>50 &lt; T ≤ 65 max</td>
<td>50 °C (122°F)</td>
</tr>
</tbody>
</table>

Note: The maximum enclosure temperature rise for transformers rated 10 kVA and below is 80°C (25°C maximum ambient). The maximum enclosure temperature rise for transformers rated above 10 kVA is 65°C (40°C maximum ambient).

The enclosure temperature rises that fall within the ranges shown in column 3 of Table-3-5A according to its kVA rating shall be permitted provided the following conditions are met.

a. The transformer is tested while mounted in an alcove, as described in 4.2.12.12 and Figure 3-2
b. The temperature rise at any point on the inner surfaces of the alcove does not exceed the maximum temperature rise shown in column 4, and
c. The transformer is marked in accordance with paragraph 3.19.3.

3.19.3 Marking
If the temperature rise on the transformer enclosure falls within the range of column 3 of Table 3-5A in accordance with paragraph 3.19.2, the transformer shall be clearly marked to indicate the minimum separations (X, Y, and Z in Figure 3-2) between the enclosure and the adjacent surfaces necessary to prevent attainment of temperatures greater than 90°C (194°F) on those adjacent surfaces. The marking shall be so located that it will be plainly visible after the transformer has been installed as intended. Other clearances need not be clearly marked on the transformer if the transformer is marked according to other standards or certifications which specify the clearances.

Note: Transformers with integrated mounting brackets do not require clearance markings in the Z direction.

A transformer with an enclosure temperature rise falling within the ranges shown in column 3 of Table 3-5A according to its kVA rating shall be marked in letters not less than ½ inch (12.7 mm) high where readily visible after installation:

“WARNING: Do not place combustible materials on or near transformer.”
3.20 TEMPERATURE RISE OF TRANSFORMER TERMINATIONS FOR FIELD CONNECTIONS

3.20.1 The transformer terminations used for making field connections to cable(s) shall be limited to a maximum temperature of 90°C. Thus the sum of the termination temperature rise and maximum ambient shall not exceed 90°C.

3.20.2 In a wiring compartment (including the outlet box on which the transformer is mounted if it is intended to be so supported), the temperature obtained on a field installed cable and the temperature of any surface which such a lead might contact shall not exceed 90°C.

3.20.3 Where cables rated above 90°C and/or busses are used for field connections, the temperature rise of the cable and bus and of the transformer terminations shall be coordinated functionally with the insulation system of which they are a part.

3.20.4 When the temperature on a field-installed lead or on a surface of the wiring compartment which the lead might contact exceeds 60°C (140°F), the transformer shall be marked with the following statement, or the equivalent, at or near the points where field connections will be made, and so located that it will be readily visible during installation. The temperature value to be used in the blanks shall be in accordance with Table 3-6.

FOR FIELD CONNECTIONS, USE WIRES SUITABLE FOR AT LEAST ______ °C (______ °F) AND SIZED ON THE BASIS OF 75°C AMPACITY

<table>
<thead>
<tr>
<th>Value to be Used in Marking</th>
<th>Temperature Rises Attained During Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transformers rated 10kVA and below</td>
</tr>
<tr>
<td></td>
<td>More Than</td>
</tr>
<tr>
<td>75°C (167°F)</td>
<td>35°C (95°F)</td>
</tr>
<tr>
<td>90°C (194°F)</td>
<td>50°C (122°F)</td>
</tr>
</tbody>
</table>

3.21 CLEARANCE BETWEEN TERMINALS FOR FIELD CONNECTIONS

Regarding terminals for field connections, the clearance between uninsulated live-metal opposite-polarity terminals and between uninsulated live-metal terminals and a dead-metal part, which may be grounded when the transformer is installed, shall be not less than those indicated in Table 3-7.

<table>
<thead>
<tr>
<th>Voltage Involved</th>
<th>Minimum Spacings Between Uninsulated Live Parts of Opposite Polarity and Between an Uninsulated Live Part and a Grounded Part of Conductive Material&lt;sup&gt;(a)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Through Air&lt;sup&gt;(b)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Inch (mm)</td>
</tr>
<tr>
<td>0-50</td>
<td>0.13</td>
</tr>
<tr>
<td>51-250</td>
<td>0.50</td>
</tr>
<tr>
<td>251-600</td>
<td>1.00</td>
</tr>
</tbody>
</table>

<sup>(a)</sup> An isolated part of conductive material (such as a screw head or washer) interposed between uninsulated live parts of opposite polarity or between an uninsulated live part and grounded dead metal is considered to reduce the spacing by an amount equal to the dimension of the interposed part along the path of measurement.

<sup>(b)</sup> A minimum of 1 inch (25.4 mm) is required between a live part and a metal enclosure.
3.22 BONDING OF CORE

The transformer core shall be bonded to the transformer frame and enclosure, if supplied.

EXCEPTION: If the core(s) and coil(s) are encapsulated, such that the transformer core is not accessible, the core may or may not be bonded to the transformer frame and enclosure.

3.23 CONTACT SURFACES OF GROUNDING TERMINALS

Surfaces having a protective coating of non-conducting materials, such as enamel or varnish, shall have that coating thoroughly removed from threads and surface areas involved in a ground circuit to obtain the requisite good connection. All surfaces shall be free from rust, scale, etc., in the area where the ground connections are to be attached.

3.24 MARKING

Markings shall be of a permanent nature. Paper labels, stampings, decals, and their equivalents, when used, shall be located where they will not be exposed to mechanical or thermal damage. For outdoor transformers, markings shall be appropriate for environmental protection.

3.25 NAMEPLATES

A nameplate, including case stamping or embossing, shall be a permanent part of each transformer. If the nameplate is an attached plate, it shall be made of corrosion-resistant material. The following minimum information shall be given on the nameplate:

The identification “transformer”
- Classes of cooling other than AA shall be specified; e.g., AA/FA, AFA, etc.
- Number of phases.
- Frequency (ies).
- kVA rating(s).
- Voltage rating(s).
- Temperature rise(s).
- Name of manufacturer.

Date of manufacture shall be given, but is not required to be on the nameplate. This may be in code.

The following minimum information shall be provided either on the nameplate or on the connection diagram:

- Vector diagram (for three-phase transformers only).
- Tap voltage(s).
- Percent impedance(s) (for ratings 25 kVA and over).
- Connection diagram.
- Approximate total weight (if over 100 pounds).

Where more than one rating or value is involved, each shall be shown.

3.26 DESIGNATION OF VOLTAGE RATINGS OF WINDINGS

3.26.1 General

A long dash (-) shall be used to separate the voltage ratings of separate windings. A slant (/) or X shall be used to separate voltages obtained by delta or Y connections, by the use of taps, or by series-parallel connection in the same winding.
3.26.2 Single-Phase

E shall indicate a winding of E volts which is suitable for delta connection on an E volt system. Example: 480.

E/E1Y shall indicate a winding of E volts which is suitable for delta connection on an E volt system or for Y connection on an E1 volt system. Example: 120/208Y.

E/2E shall indicate a winding, the sections of which can be connected in parallel for operation at E volts; or which can be connection in series for operation at 2E volts; or connected in series with a center terminal, for three-wire operation at 2E volts between the extreme terminals and E volts between the center terminal and each of the extreme terminals with only 50% kVA available, from midpoint to each extreme terminal. Example: 120/240.

2E/E shall indicate a winding for 2E volts, two-wire full kVA between extreme terminals, or 2E/E volts, three-wire service with only 50% kVA available, from midpoint to each extreme terminal.

ExE1 shall indicate a winding for only parallel or series operation, but not suitable for 3-wire service. Example: 240 x 480.

3.26.3 Three-Phase

E shall indicate a winding which is permanently delta connected for operation on an E volt system. Example: 480.

E1Y shall indicate a winding which is permanently Y connected without a neutral brought out (isolated) for operation on an E1 volt system. Example: 208Y.

E1Y/E shall indicate a winding which is permanently Y connected with a fully insulated neutral brought out for operation on an E1 volt system, with E volts available from line to neutral. Example: 208Y/120.

E/E1Y shall indicate a winding which may be delta connected for operation on an E volt system, or may be Y connected without a neutral brought out (isolated) for operation on an E1 volt system. Example: 120/208Y.

E/E1Y/E shall indicate a winding which may be delta connected for operation on an E volt system, or may be Y connected with a fully insulated neutral brought out for operation on an E1 volt system, with E volts available from line to neutral. Example: 120/208Y/120.

E1GrdY/E shall indicate a winding with reduced insulation which is permanently Y connected, with a neutral brought out and effectively grounded for operation on an E1 volt system with E volts available from line to neutral. Example: 208GrdY/120.

E/E1GrdY/E shall indicate a winding with reduced insulation which may be delta connected for operation on an E volt system, or may be connected Y with a neutral brought out and effectively grounded for operation on an E1 volt system, with E volts available from line to neutral. Example: 120/208GrdY/120.

ExE1 shall indicate a winding, the sections of which may be connected in parallel to obtain one of the voltage ratings (as defined in items 1 through 5) of E, or may be connected in series to obtain one of the voltage ratings (as defined in items 1 through 5) of E1. Examples: 120 x 240 – 208Y/120 x 416Y/240.

3.27 AUTOTRANSFORMERS

An autotransformer shall be marked to indicate that it is such.

A three-phase autotransformer with a common or neutral connection shall be marked with “H0X0,” “Common,” white lead or terminal; or a polarized attachment plug or receptacle shall be used.
A single-phase autotransformer with a common connection shall be marked with “H2X2,” “Common,” white lead or terminal; or a polarized attachment plug or receptacle shall be used.

An autotransformer which is intended for operation on a circuit of 150 volts or less to ground shall have one of the secondary terminals or leads identified for the connection of a ground circuit conductor and shall be directly connected to a similarly identified primary terminal or lead.

When provided, cord and plug sets and receptacles shall be of the polarized type so that the autotransformer will always be properly connected to the ground side of the branch circuit.

3.28 TAP

If a transformer is provided with tap(s) other than those specified in 2.1, it should be marked to indicate whether they are full- or reduced-capacity taps. Such a marking might be “FC” for full capacity or “RC” for reduced capacity. In the absence of such a marking, the taps are considered to be reduced-capacity taps.

3.29 TERMINAL MARKINGS

3.29.1 Scope and Purpose

This standard specifies the markings of power connection terminals. Other terminals shall be marked with numbers in any manner which will permit convenient reference and which cannot be confused with the markings of the power connection terminals.

The purpose of applying uniform markings to the terminals of transformers is to aid in making connections to other parts of the electric power system and to avoid improper connections which may result in unsatisfactory operation or damage.

3.29.2 Precautions

Although this system of marking terminals with letters and numerals gives information which facilitates the connecting of transformers, there is the possibility of finding terminals marked without system or in accordance with some other system. There is the further possibility that internal connections may have been changed or that errors may have escaped detection. It is advisable, therefore, before connecting transformers to power supply systems to make the usual check tests for phase rotation, phase relation, polarity, and equality of voltage.

3.29.3 Location of Markings

The markings shall be placed on or directly adjacent to terminals to which connections must be made from outside circuits or from auxiliary devices which must be disconnected for shipment.

3.29.4 Markings

The markings shall consist of a capital letter followed by an Arabic numeral.

3.29.5 Significance of the Terminal Letter

The letter shall indicate the character or function of the winding which is brought to the terminal. Table 3-8 gives the terminal letters assigned to the different types of windings and their functions (see 3.29.10):

<table>
<thead>
<tr>
<th>Winding Identification</th>
<th>Lead Markings</th>
<th>Winding Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding No. 1</td>
<td>H1, H2, H3, etc.</td>
<td>H Winding</td>
</tr>
<tr>
<td>Winding No. 2</td>
<td>X1, X2, X3, etc.</td>
<td>X Winding</td>
</tr>
</tbody>
</table>

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3.29.6 Significance of the Numeral 0 (Zero)
A terminal letter followed by the numeral 0 designates a neutral connection.

3.29.7 Significance of Numerals on Terminals
On single-phase transformers the numerals indicate the polarity relation between terminals of the H Winding and the other windings. Thus, during that part of the alternating-current cycle when H winding terminal H1 is positive (+) with respect to H2, then during the same part of the cycle the X winding terminal X1 is positive with respect to X2. The idea is further carried out in single-phase transformers having tapped windings by so applying to the taps the numerals 1, 2, 3, 4, 5, etc., that the potential gradient follows the sequence of the numerals.

When one winding of a transformer receives energy over the connecting leads and another winding delivers energy to its connected circuit, the relation of current flow in the windings is reversed with respect to the polarity of the voltage at the terminals. Therefore, it is important to take note of the difference between the practice of assigning numerals to direct-current generators and motors according to the direction of the current flow and to the case of single-phase transformers where numerals are assigned according to the terminal voltage.

In the case of polyphase transformers, the terminal numerals are so applied that if the phase sequence of voltage is in the time order H1, H2, H3, etc., on the H winding terminals, it is in the time order X1, X2, X3, etc., on the X winding terminals and also in the time order Y1, Y2, and Y3, etc., on the Y winding terminals, etc.

3.29.8 Definition of Phase Sequence
Phase sequence is the order in which the voltages successively reach their maximum positive values between terminals.

3.29.9 Direction of Rotation of Vectors
Vector diagrams should be drawn so that an advance in phase of one vector with respect to another is in the counterclockwise direction. In Figure 3-3, vector 1 is 120 degrees in advance of vector 2, and the phase sequence is 1, 2, 3. See 3.29.8.

3.29.10 Markings of Terminals and Identification of Windings
In general, the windings of a transformer shall be distinguished from one another as follows:

- Two-winding transformers shall have their windings designated as high voltage (HV or H) and low voltage (LV or X).
- Transformers with more than two windings shall have their windings designated as H, X, Y, and Z.
The sequence of designation is determined as follows:

The highest voltage windings shall be designated as HV or H, except for transformers designed for three-phase to six-phase transformation. See 3.29.13.

The other windings, in order of decreasing voltage, shall be designated as X, Y, and Z.

If two (or more) windings have the same voltage and different kVA ratings, the higher kVA windings shall receive the prior letter designation of the two (or more) letters available, according to the sequence by voltage as explained above.

If two or more windings have the same kVA and voltage rating the designation of these windings shall be arbitrarily assigned.

In general, power connection terminals shall be distinguished from one another by marking each terminal with a capital letter, followed by a number. The terminals of the H-winding are marked H1, H2, H3; the terminals of the X-winding are marked X1, X2, X3, etc.

A neutral terminal of a three-phase transformer shall be marked with the proper letter followed by the numeral 0; e.g., H0, X0, etc. A neutral terminal common to two or more windings of a single- or three-phase transformer shall be marked with the combination of the proper winding letters, each followed by the numeral 0; e.g., H0X0, as in the case of autotransformers.

A terminal which is brought out from the winding for some other use than that of a neutral terminal (e.g., a 50 percent starting tap) shall be marked as a tap terminal.

If a transformer has a two-terminal winding with one terminal grounded and the other ungrounded, the number 2 terminal shall be the grounded terminal.

3.29.11 Single-Phase Transformers
Order of Numbering Terminals of Different Windings – The numbering of the terminals of the H winding and the terminals of the X winding shall be applied so that when the lowest numbered H terminal and the lowest numbered X terminal are connected together and voltage applied to the transformer, the voltage between the highest numbered H terminal and the highest numbered X terminal will be less than the voltage of the H winding.

When more than two windings are used, the same relationship shall apply between each pair of windings. See Figure 3-4.

Parallel Operation – Transformers having terminals marked in accordance with these rules shall be operated in parallel by connecting similarly marked terminals together, provided their ratios, voltages, resistances, reactances and ground connections are such as to permit parallel operation. See Figure 3-5 and 3-6.
In some cases, designs may be such as to permit parallel operation, even though the terminals to be connected together are not similarly marked due to a difference in the number of tap terminals.

![Diagram of simple H winding with taps series-parallel X winding](image)

**Figure 3-5**
SIMPLE H WINDING WITH TAPS
SERIES-PARALLEL X WINDING

Autotransformers — Autotransformer terminals shall, so far as practicable, be marked in accordance with the requirements of 3.28, 3.29.11.a. and Figure 3-7.

![Diagram of series-parallel H winding with taps series-parallel X winding](image)

**Figure 3-6**
SERIES-PARALLEL H WINDING WITH TAPS
SERIES-PARALLEL X WINDING

**3.29.12 Three-phase Transformers**

Marking of Full Winding Terminals — The three terminals for each winding which connect to the full phase windings shall be marked H1, H2, H3, X1, X2, X3, Y1, Y2, Y3, etc., respectively.

Relation Between Highest Voltage Winding and Other Windings — The markings shall be so applied that if the phase sequence of voltage on the highest voltage winding is in the time order H1, H2, H3, it will be in the time order of X1, X2, X3 and Y1, Y2, Y3, etc., on the other windings.
The markings of terminal connections between phases of three-phase transformers shall indicate definite phase relations and shall be in accordance with one of the three-phase groups shown in Figure 3-8. The angular displacement between the H winding and the X winding is the angle in each of the voltage vector diagrams (see Figure 3-8) between the lines passing from its neutral point through H1 and X1, respectively.

When more than one low-voltage winding is used, the angular displacement between the H winding and each of the other low-voltage winding is established in the same manner, using H1 and Y1; H1 and Z1, etc., respectively.

Tap Terminals – Where tap power connection terminals are provided (neutral terminal excepted), they shall be marked with the proper letter followed by the figures 4, 7, etc., for one phase, 5, 8, etc., for another phase, and 6, 9, etc., for the third phase. See Figure 3-8.

The delta tap terminal numbering shall be as follows: 4, 7, etc., from terminal 1 toward terminal 2; 5, 8, etc., from terminal 2 toward 3; and 6, 9, etc., from terminal 3 toward terminal 1. See Figure 3-8.

Parallel Operation – Transformers having terminals marked in accordance with the foregoing rules may be operated in parallel by connecting similarly marked terminals together, provided their angular displacements are the same and provided also their ratios, voltages resistances, reactances, and ground connections are such as to permit parallel operation.

In some cases, designs may be such as to permit parallel operation even though the terminals to be connected together are not similarly marked due to a difference in the number of tap terminals.

Autotransformers – Autotransformers’ terminals shall, as far as practicable, be marked in accordance with the requirements for the corresponding multi-winding transformers. See Paragraph 3.28 and Figure 3-9.
Terminals and Voltage Diagrams for Three-Phase Transformer Connections

Group 1
Angular Displacement 0°
- Delta-Delta Connection
- Y-Y Connection

Group 2
Angular Displacement 30°
- Delta-Zy Connection
- Zy-Delta Connection

Group 3
Angular Displacement 30°
- Delta-Y Connection
- Y-Delta Connection

Three-Phase Transformers without Taps

Three-Phase Transformers with Taps

NOTES:
(1) This figure is included to illustrate the method of marking transformer terminals that are brought out of the case. Dash lines show angular displacement between high- and low-voltage windings.
(2) Angular displacement is the angle between a line drawn from neutral to H1 and a line drawn from neutral to X1 measured in a clock-wise direction from H1 to X1.
(3) The zig-zag connections shown in group 1 may also be achieved using the following internal connections:

Figure 3-8
TERMINAL MARKINGS AND VOLTAGE DIAGRAMS FOR THREE-PHASE TRANSFORMER CONNECTIONS

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3.29.13 Three-Phase to Six-Phase Transformers

General – The markings for three-phase to six-phase transformers shall be based on the three-phase winding always being the H winding.

Marking of Full Winding Terminals – The three terminals which connect to the three-phase winding shall be marked H1, H2, H3, and the six terminals which connect to the full six-phase winding shall be marked X1, X2, X3, X4, X5, X6. See Figure 3-9.

Relation Between Three-phase and Six-phase Windings – The markings shall be so applied that if the phase sequence of voltage on the three-phase terminals is in the order H1, H2, H3, it is in the time order X1, X2, X3, X4, X5, X6, on the six-phase terminals.

In order that the markings of terminal connections between phases will indicate definite phase relations, they shall be made in accordance with one of the six-phase groups shown in Figure 3-10. The angular displacement between the three-phase and six-phase windings is the angle in each of the voltage vector diagrams from its neutral through H1 and X1, respectively.

Tap Terminals – Where tap power connection terminals from the six-phase windings are provided (neutral terminal excepted), they shall be marked as follows:

The double-wye (diametrical) tap terminals shall be marked from the two ends of each phase winding toward the middle or neutral point in the following order:
- X7, X13, etc., from X1 toward neutral
- X8, X14, etc., from X2 toward neutral
- X9, X15, etc., from X3 toward neutral
- X10, X16, etc., from X4 toward neutral
- X11, X17, etc., from X5 toward neutral
- X12, X18, etc., from X6 toward neutral
See Figure 3-9.

A tap from the middle point of any phase winding, not intended as a neutral, shall be given a number determined by counting from X1, X2, or X3 and not from X4, X5, or X6; e.g., if the only taps brought out are 50 percent starting taps, they will be numbered X7, X9, and X11.

The double-delta tap terminals shall be marked in the following order:
- X7, X13, etc., from X1 toward X3;
- X8, X14, etc., from X2 toward X4;
- X9, X15, etc., from X3 toward X5;
- X10, X16, etc., from X4 toward X6;
- X11, X17, etc., from X5 toward X1;
- X12, X18, etc., from X6 toward X2.
See Figure 3-9

For starting purposes, it is generally customary to bring out only two taps from one delta and start three phase.
Note 1: Dash lines show angular displacement between high- and low-voltage windings.

Note 2: Angular displacement is the angle between a line drawn from neutral to H₁ and a line drawn from neutral to X₁ measured in a clockwise direction from H₁ to X₁.

Note 3: (b), (c) (g), and (h) show mid tap brought out of one phase on the low-voltage side.

**Figure 3-9**

**ANGULAR DISPLACEMENT AND TERMINAL MARKINGS FOR SIX PHASE TRANSFORMERS**

*Note:* The six-phase circuits shown in Figure 3-9 are primarily used for semiconductor rectifier transformer circuits. Standard IEEE C57.18.10 (IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers) describes these circuits in great detail. This IEEE standard uses the letter “R” for the secondary terminal designations instead of the letter “X”. Therefore, the use of “X” or “R” shall be considered to be an acceptable means of terminal markings for six-phase transformers or other rectifier circuits described in this standard.

3.30 **FIELD CONNECTIONS**

If a dry-type transformer can be readily adapted upon installation for connection to a power supply circuit of either two or more different voltages, complete instructions (including appropriate identification of terminals) for making the connection suitable for the different voltage should be furnished with each transformer, preferably on the nameplate.

3.31 **CONNECTION OF TRANSFORMERS FOR SHIPMENT**

When interconnections are supplied, the following shall be observed:

- Single-phase and three-phase transformers shall be shipped with both high- and low-voltage windings connected for their highest rated voltage. Transformers having taps above rated voltage shall be shipped connected for the rated voltage.
- Single-phase transformers designed for both series-multiple and three-wire operation shall be shipped connected in series with the midpoint out for three-wire operation. Single- and three-phase transformers designed for series-multiple operation only shall be shipped connected in series.
Three-phase transformers designed for both delta and wye operation shall be shipped connected for the wye voltage.

### 3.32 AUDIBLE SOUND LEVELS

Transformers shall be so designed that the average audible sound level will not exceed the values given in Table 3-9 when tested in accordance with clause 4.2.10.

**Table 3.9**

**AVERAGE SOUND LEVEL**

<table>
<thead>
<tr>
<th>Equivalent Winding kVA Range</th>
<th>SELF COOLED VENTILATED</th>
<th>SELF COOLED SEALED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>K Factor = 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.00 and below</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>3.01 to 9.00</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>9.01 to 15.00</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>15.01 to 30.00</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>30.01 to 50.00</td>
<td>45</td>
<td>48</td>
</tr>
<tr>
<td>50.01 to 75.00</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>75.01 to 112.50</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>112.51 to 150.00</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>150.01 to 225.00</td>
<td>55</td>
<td>58</td>
</tr>
<tr>
<td>225.01 to 300.00</td>
<td>55</td>
<td>58</td>
</tr>
<tr>
<td>300.01 to 500.00</td>
<td>60</td>
<td>63</td>
</tr>
<tr>
<td>500.01 to 700.00</td>
<td>62</td>
<td>65</td>
</tr>
<tr>
<td>700.01 to 1000.00</td>
<td>64</td>
<td>67</td>
</tr>
<tr>
<td>Greater than 1000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note 1: Consult factory for non-linear requirements exceeding a K-factor rating of 20.*

*Note 2: When the fans are not running columns A & B apply.*

*Note 3: Sound levels are measured using the A-weighted scale (dB (A)).*
4.1 CLASSIFICATION OF TESTS

4.1.1 Routine Tests
Tests made by the manufacturer at the factory on each transformer to insure that the design performance is maintained in production.

4.1.2 Design Tests
Tests made by the manufacturer on a sufficient number of transformers and ratings to demonstrate compliance with these standards. These tests need not be repeated unless the design of the transformer is changed so as to modify the reliability of predicted results.

4.1.3 Prototype Tests
Tests on prototype transformers, devices, parts, or components to prove conformance of their prototype feature(s) with applicable standards. Upon satisfactorily passing the prototype test, the feature(s) shall be permitted to be used on units of other sizes and designs without repetitive testing.

4.1.4 Tests for Dry-Type Transformers
Tests for dry-type transformers are shown in Table 4-1.
### Table 4-1

**TESTS FOR DRY TYPE TRANSFORMER**

<table>
<thead>
<tr>
<th>Classification of Test</th>
<th>Routine</th>
<th>Design</th>
<th>Prototype</th>
<th>See Paragraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Section 3</td>
</tr>
<tr>
<td>Ratio-tests on the rated voltage connection and all tap connections</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4.2.1</td>
</tr>
<tr>
<td>Polarity and Phase Relation-tests on the rated voltage connection</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4.2.2 to 4.2.4</td>
</tr>
<tr>
<td>No-load Losses and Excitation Current-at rated voltage on the rated voltage connection *</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4.2.6 and 4.2.7</td>
</tr>
<tr>
<td>Impedance and Load Loss (less than 501 kVA) *</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>4.2.8</td>
</tr>
<tr>
<td>Impedance and Load Loss (501 kVA and larger)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4.2.8</td>
</tr>
<tr>
<td>Dielectric-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied potential and induced potential</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4.2.9</td>
</tr>
<tr>
<td>Impulse</td>
<td>...</td>
<td>X</td>
<td></td>
<td>4.2.9</td>
</tr>
<tr>
<td>Audible Sound Level</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>4.2.10</td>
</tr>
<tr>
<td>Resistance Measurements-of all windings on the rated voltage tap extremes of the first unit made on a new design</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>4.2.11</td>
</tr>
<tr>
<td>Temperature</td>
<td>...</td>
<td>X</td>
<td>X</td>
<td>4.2.12</td>
</tr>
<tr>
<td>Short-circuit capability</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>4.2.13</td>
</tr>
<tr>
<td>Insulation</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>3.9</td>
</tr>
<tr>
<td>Weather Classification</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>3.3</td>
</tr>
<tr>
<td>Enclosure Compression Test</td>
<td>...</td>
<td>...</td>
<td>X</td>
<td>4.4</td>
</tr>
</tbody>
</table>

* Statistical sampling may be used for these tests (see section 4.2.5).
4.2 ROUTINE, DESIGN, AND PROTOTYPE TESTS

Note: In the following sections, voltmeters, ammeters, and wattmeters may be shown as separate devices however due to technology advancements they may now be combined into one device.

4.2.1 Ratio Tests

4.2.1.1 General

The turn ratio of a transformer is the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding.

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

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

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

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

For three-phase transformers in which each phase is independent and accessible, single-phase power should preferably be used although, when convenient, three-phase power may be used.

Transformers having a capacity of 500 volt-amperes or less and an exciting current of more than 10 percent shall be tested only at normal voltage and frequency.

If a case should arise wherein the high-voltage windings are connected in star and the neutral point is inaccessible, then three-phase voltage should be applied and the test procedure carried on in a manner similar to that described for single-phase transformer.

4.2.1.2 Voltage Tolerances

Uncompensated Turns Ratio Transformers – With rated voltage impressed on one winding of a transformer, all other rated voltages at no-load shall be correct within one-half of 1 percent of the nameplate markings.

Rated nominal and tap voltages shall correspond to the voltage of the nearest turn if the voltage per turn exceeds one-half of 1 percent of the desired voltage.

Voltage Tolerances for IR-compensated Transformers – An IR-compensated transformer shall be so designed that, when rated voltage is applied to the primary winding, the secondary winding will deliver rated kVA at approximately rated voltage. Transformers shall be compensated at the proper reference temperature to deliver rated kVA at 100 percent power factor, at approximately rated voltage, from one winding when rated voltage is applied to the other winding.

When rated voltage is impressed on one winding, the no-load voltage of all other windings shall be correct within one-half of 1 percent of the designed turns ratio.

4.2.1.3 Ratio Test Methods

There are three methods of making ratio tests:

- Voltmeter method (see 4.2.1.4).
- Comparison method (see 4.2.1.5). (This is the most accurate of the three because the voltmeter or detector indicates the difference in voltage.)

- Ratio by Ratio Bridge method (see 4.2.1.6).

4.2.1.4 Ratio by Voltmeter Method

Two voltmeters are used (with potential transformers if necessary), one to read the voltage of the high-voltage winding, the other that of the low-voltage winding.

The two voltmeters shall be read simultaneously.

A second set of readings shall be taken with the instruments interchanged, and the average of the two sets of readings taken, to compensate for instrument errors.

Potential-transformer ratios should be such as to yield about the same readings on the two voltmeters; otherwise compensation for instrument errors by an interchange of instruments will not be satisfactory, and it will be necessary to apply appropriate correction to the voltmeter readings.

Tests shall be made at not less than four voltages in approximately 10 percent steps, and the average result shall be taken as the true value. These several values shall be permitted to check within 1 percent. Otherwise, the tests shall be repeated with other voltmeters.

When several transformers of duplicate rating are to be tested, work may be expedited by applying the foregoing tests to only one unit, and then comparing the other units with this one as a standard, in accordance with the comparison method discussed in 4.2.1.5.

4.2.1.5 Ratio by Comparison

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

The transformer to be tested shall be excited in parallel with a transformer of the same nominal ratio and the two secondaries connected in parallel, but with a voltmeter or detector in the connection between two terminals of similar polarity (Figure 4-1).
4.2.1.6 Alternate Comparison Method

The transformer to be tested shall be excited in parallel with a transformer of a known ratio and the voltmeters arranged to measure the two secondary voltages (Figure 4-2). The voltmeters shall be interchanged and the test repeated. The average of the test results is the correct ratio.

![Figure 4-2](image)

**Figure 4-2**

**ALTERNATE COMPARISON METHOD**

4.2.1.7 Ratio by Ratio Bridge

A ratio bridge having a suitable range, preferably graduated in terms of the ratio of the tapped portion to the total, may be used to determine the transformer ratio when arranged as shown in Figure 4-3.

The ratio bridge is adjusted until the detector reads zero. Then the ratio of the ratio bridge \( R/R_1 \) equals the transformer ratio.

![Figure 4-3](image)

**Figure 4-3**

**RATIO BY RATIO BRIDGE**

4.2.2 Polarity and Phase-Relation Tests

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

Polarity tests on single-phase transformers shall be made in accordance with one of the following methods (see 4.2.3):

- Comparison
- Inductive kick
- Alternating voltage
Each phase of a polyphase transformer shall have the same relative polarity when tested in accordance with one of the methods described in 4.2.3.

Phase-relation tests on polyphase transformers shall be made in accordance with one of the following methods (see 4.2.4).

The readings are repeated after the following:

- Test for phasor diagram
- Phase-sequence test

4.2.3 Method of Polarity Test

4.2.3.1 Polarity by Comparison

When a transformer of known polarity and of the same ratio as the unit under test is available, the polarity may be checked by comparison, as follows, similar to the comparison method used for the ratio test. (See Figure 4-1)

- Connect the high-voltage windings of both transformers in parallel by connecting similarly marked leads together.
- Connect also the low-voltage leads, X2, of both transformers together, leaving the X1 leads free.
- With these connections, apply a reduced value of voltage to the high-voltage windings and measure the voltage between the two free leads.

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

An alternate method of checking the polarity is to substitute a low-rated fuse or suitable lamps for the voltmeter.

This is recommended as a precautionary measure before connecting the voltmeter.

- Connect the high-voltage windings of both transformers in parallel by connecting similarly marked leads together.
- Transfer the voltmeter lead connected to H1 to X1 and that connected to H2 and X2.
- Break direct-current excitation, thereby inducing a voltage in the low-voltage winding (inductive kick), which will cause a deflection in the voltmeter.

The polarity is subtractive if the pointer swings in the opposite (negative) direction.

The polarity is additive if the pointer swings in the same (positive) direction.
4.2.3.3 Polarity by Alternating Voltage Test

For transformers having a ratio of transformation of 30 to 1 or less, the H1 and X1 leads shall be connected together (see Figure 4-6). Any convenient value of alternating voltage shall be applied to the full high-voltage winding and readings taken of the applied voltage and the voltage between the H2 and X2 leads.

- If the latter reading is greater than the former, the polarity is additive.
- If the latter reading is less than the former, indicating the approximate difference in voltage between the high-voltage and low-voltage windings, the polarity is subtractive.
4.2.3.4 Polarity by Ratio Bridge

The ratio bridge used for the ratio test (see Figure 4-3) also checks the polarity of the transformer, at the same time and in much the same manner as the comparison method. The polarity shall be as shown in Figure 4-7.

For this test the potentiometer leads shall be connected to H2, X2, and the common point between X1 and H1, the same as in the ratio test. If the polarity of the winding is not as indicated, it will be impossible to get a ratio test because the detector voltage is twice the X1 – X2 voltage rather than zero.

![Polarity by Ratio Bridge](image)

Figure 4-7
POLARITY BY RATIO BRIDGE

4.2.4 Phase-Relation Tests

4.2.4.1 Test for Phasor Diagram for Transformers having a Ratio of Transformation of 30 To 1 or Less

The phasor diagram of any three-phase transformer, defining both the angular displacement and phase sequence, can be verified by connecting the H1 and X1 leads together, exciting the unit at a suitably low three-phase voltage, taking voltage measurements between various pairs of leads, and then either plotting these values or comparing them for their relative order of magnitude with the help of the corresponding diagram shown in Figures 4-8 and 4-9. These figures indicate typical check measurements to be taken in their relative magnitudes. Six-phase windings having no neutral connection should be temporarily connected in delta or wye for the test for phasor diagram.
<table>
<thead>
<tr>
<th>Angular Displacement</th>
<th>Diagram for Check Measurement</th>
<th>Check Measurement</th>
</tr>
</thead>
</table>
| **Group 1 Angular Displacement 0°** | ![Diagram](image) | Connect H1 to X1  
Measure H2 - X2  
H3 - X2, H1 - H2  
H2 - X3  
Voltage Relations  
1. H2 - X3 = H3 - X2  
2. H2 - X2 < H1 - H2  
3. H2 - X2 < H2 - H3 |
| **Group 2 Angular Displacement 30°** | ![Diagram](image) | Connect H1 to X1  
Measure H3 - X2  
H3 - X3, H1 - H3,  
H2 - X2, H2 - X3  
Voltage Relations  
1. H3 - X2 = H3 - X3  
2. H3 - X2 < H1 - H3  
3. H2 - X2 < H2 - X3  
4. H2 - X2 < H1 - H3 |

**Figure 4-8**  
DETAILS OF PHASE RELATION TESTS FOR THREE-PHASE TRANSFORMERS
<table>
<thead>
<tr>
<th>Group Angular Displacement</th>
<th>Angular Displacement</th>
<th>Diagram for Check Measurement</th>
<th>Check Measurement</th>
</tr>
</thead>
</table>
| Group 1 Angular Displacement 0° | ![Diagram](image1) | ![Diagram](image2) | Connect H1 to X1 to X4  
Measure H2 - X3, H1 - H2,  
H2 - X5, H2 - X6,  
H3 - X2, H2 - X2,  
H3 - X3  
Voltage Relations  
1. H2 - X5 = H3 - X3  
2. H2 - X3 < H1 - H2  
3. H2 - X3 < H2 - H5  
4. H2 - X6 = H3 - X2  
5. H2 - X6 > H1 - H2  
6. H2 - X2 < H2 - X6 |
| Group 2 Angular Displacement 30° | ![Diagram](image3) | ![Diagram](image4) | Connect X2 to X4 to X6; H1 to X1  
Measure H2 - X3, H3 - X3  
H1 - H2, H2 - X5  
Voltage Relations  
1. H2 - X5 = H3 - X3  
2. H2 - X3 < H1 - H2  
3. H2 - X3 < H2 - X5 |

**Figure 4-9**

DETAILS OF TEST FOR PHASE RELATIONSHIPS FOR SIX-PHASE TRANSFORMERS
4.2.4.2 Phase-Sequence Test

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

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

The indicator is then transferred to the low-voltage side of the transformer, connecting to X1 the lead which was connected to H1, connecting to X2 the lead which was connected to H2, and connecting to X3 the lead which was connected to H3.

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

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

Six-phase secondaries, having no neutral connection, shall be connected temporarily in delta or wye for this test. If a six-phase neutral is available, the phase-sequence indicator leads shall be transferred from H1 to X1, from H2 to X3, and from H3 to X5, respectively, and the direction of rotation noted. The test shall then be repeated by transferring the leads from H1 to X2, from H2 and X4, and from H3, to X6, respectively, and noting the indication, which should be the same as before.

This phase-sequence test does not disclose the angular displacement of the transformer.

4.2.5 Total Losses

Total losses of a transformer shall be the sum of the no-load losses and the load losses determined for rated voltage, current, and frequency. The load-loss component shall be based on a reference temperature (see 3.18) equal to the rated average temperature rise plus 20°C.

4.2.5.1 Tolerances on Measured Losses

The losses represented by testing a transformer, or transformers, on a given order shall not exceed the specified losses by more than the percentages given in Table 4-2.

<table>
<thead>
<tr>
<th>Number of Units On One Order</th>
<th>Basis of Determination</th>
<th>No-Load Losses (%)</th>
<th>Total Losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 unit</td>
<td>+10</td>
<td>+6</td>
</tr>
<tr>
<td>2 or more</td>
<td>Each unit</td>
<td>+10</td>
<td>+6</td>
</tr>
<tr>
<td>2 or more</td>
<td>Average of all units</td>
<td>+0</td>
<td>+0</td>
</tr>
</tbody>
</table>

4.2.6 No-Load Losses (Excitation Losses)

4.2.6.1 General

No-load losses shall be determined at rated voltage and frequency.

The no-load losses shall be measured by exciting the uncompensated turns winding.

The excitation loss of a transformer consists principally of the iron loss in the transformer core and is a function of the magnitude, frequency, and wave shape of the impressed voltage.

The excitation loss and current are particularly sensitive to differences in wave shape; and, therefore, excitation-loss measurements will vary markedly with the wave shape of the test voltage.

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Peaked voltage waves (form factor greater than 1.11), resulting generally from the distorted character of the excitation-current load of the transformer on the test generator, give smaller excitation losses than sine-wave voltage.

Flat-topped waves, rarely encountered in such tests, give larger excitation losses.

Ordinary variations of temperature do not influence excitation losses materially and no correction for temperature variation is made. 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 ±10°C of the true average core temperature.

The excitation loss determination shall be based on a sine-wave voltage unless a different wave form is inherent in the operation of the transformer.

The average-absolute-voltage-reading voltmeter shall be used for correcting the measured excitation losses to a sine-wave voltage basis.

4.2.6.2 Average-Voltage Voltmeter Method for Single-Phase Transformers

The measured excitation loss should be corrected to a sine-wave voltage basis in accordance with the following:

The excitation loss is largely a hysteresis loss, and this is a function of the maximum flux density in the core, independent of the wave shape of the flux. The maximum flux density corresponds to the average absolute value of the voltage (not to the rms value) and, therefore, if the average value of the test voltage is adjusted to be the same as the average value of the desired sine-wave of voltage and the proper frequency is held, hysteresis loss will be the desired sine-wave value.

If the flux wave has more than one maximum and one minimum value per cycle, average-voltage voltmeter readings will not be correct, but the voltage wave then is not suitable for use. The average-voltage voltmeter method*, therefore, utilizes an average-voltage indicating voltmeter consisting of a d’Arsonval voltmeter having, in series with itself, a full-wave rectifier. These instruments are generally graduated to give the same numerical indication as an rms voltmeter on sine-wave voltage; that is, they are marked in equivalent sine-wave rms values.

Figure 4-10 shows the necessary equipment and connections when no instrument transformers are needed; Figure 4-11, when they are needed, which is the general case. As indicated in Figure 4-11, the voltmeter should be connected nearest to the load, the ammeter nearest to the supply, and the wattmeter between the two with its potential coil on the load side of the current coil.

**Figure 4-10**

CONNECTIONS FOR THE EXCITATION TEST OF A SINGLE-PHASE TRANSFORMER WITHOUT INSTRUMENT TRANSFORMERS
Large transformers are not suitable for use as instrument transformers since they introduce a large tare as potential transformers and large ratio and phase errors as current transformers. [Tare is that portion of an observed reading which is deducted for the power consumed by a measuring instrument(s).]

Resistance multipliers may be used in series with the potential coil of instruments instead of potential transformers if desired, provided suitable precautions are taken to make their use safe.

When such multipliers are used they shall be calibrated with the instruments.

Low-power-factor wattmeters shall be used to obtain accurate results.

Where –

- **F** = frequency meter or source of known frequency
- **A** = ammeter
- **W** = wattmeter
- **V** = voltmeter
- **AV** = average-voltage voltmeter
- **CT** = current transformer
- **PT** = potential transformer

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

Adjust the frequency to the desired value as indicated by the frequency meter, and the voltage to the desired value by the average-voltage voltmeter. Record the simultaneous values of frequency, rms voltage, watts, average-voltage voltmeter readings and amperes. Then disconnect the transformer under test and read the tare on the wattmeter which represents the losses of the connected instruments (and potential transformer if used), and which is to be subtracted from the earlier wattmeter reading to obtain the excitation loss of the transformer under test.

The eddy-current loss in the core varies with the square of the rms value of the excitation voltage and is substantially independent of the voltage wave shape. When the test voltage is held at rated voltage with the average-voltage voltmeter, the actual rms value of the test voltage may not be the rated value, and the eddy-current loss in the test will be related to the correct eddy-current loss at rated voltage by Equation 4.2.6.2-2.

The correct total excitation loss of the transformer is to be determined from the measured value by means of the following equation:
\[ P = \frac{P_m}{P_i + kP_2} \]  
(Equation 4.2.6.2-1)

\[ k = \left( \frac{E_i}{E_a} \right)^2 \]  
(Equation 4.2.6.2-2)

where—
- \( E_i \) = test voltage measured by rms voltmeter
- \( E_a \) = test voltage measured by average-voltage voltmeter
- \( P \) = excitation loss at voltage \( E_a \), corrected to a sine-wave basis
- \( P_m \) = excitation loss measured in test
- \( P_1 \) = per unit hysteresis loss, referred to \( P_m \)
- \( P_2 \) = per unit eddy-current loss, referred to \( P_m \)

Correct the no-load loss to the reference temperature by using the following equation:

\[ P_{nc} = P_{ncl} (1 + 0.00065 (T_{nm} - T_{nr})) \]  
(Equation 4.2.6.2-3)

where—
- \( P_{nc} \) = the no-load losses corrected for waveform distortion and then to the reference temperature of 20°C
- \( P_{ncl} \) = the no-load losses corrected for waveform distortion, at temperature \( T_{nm} \)
- \( T_{nm} \) = the core temperature during the measurement of no-load losses
- \( T_{nr} \) = the reference temperature, 20°C

The actual percentage of hysteresis and eddy-current losses should be used, but, in the absence of definite knowledge as to the relative values, the values shown in Table 4-3 may be taken as typical.

<table>
<thead>
<tr>
<th>Type of Core Material</th>
<th>Hysteresis, %</th>
<th>Eddy-Current, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-rolled silicon steel</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Cold-rolled, oriented grain silicon steel</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

4.2.6.3 Test Method for Three-Phase Transformers

Paragraph 4.2.6.2 also applies to three-phase transformers, with the following additions and modifications:

In measuring the core loss of three-phase transformers with two-wattmeters (Figure 4-12), three entirely separate sets of readings should be taken by using each of the three lines in succession as the common line. The average value of the three sets of readings is recorded as the true no-load loss.
In using the two-wattmeter method, great care should be exercised in reading the wattmeters accurately. Because of the low power factor, the reading of one of the wattmeters will be negative and will be subtracted from the other. The two readings may be of the same general order of magnitude, so that slight inaccuracies in their values may lead to large percentage errors in their small difference. Under such difficult conditions greater accuracy may be obtained by the following procedure.

Measurements may be made with three wattmeters, each potential circuit being connected from one line to the three-phase neutral, when available (Figure 4-13). The three readings are added to obtain the excitation loss.

If the three-phase neutral is not available, an artificial neutral may be derived (Figure 4-14). If potential transformers are necessary, the open delta connection should be used to supply the Y-connected wattmeters.

![Two-wattmeter method diagram](image1)

![Three-wattmeter method diagram](image2)
4.2.7 Excitation Current (No-Load Current)

4.2.7.1 Excitation Current Test

Circuit connections for the measurement of excitation current shall be the same as those for the measurement of the excitation loss. The different methods of measurement, based on the instruments used, shall be as follows:

a. Rms Voltmeter and Ammeter – Measurements of excitation current shall be made with rms voltmeters and ammeters. This method of measurement is reasonably accurate only when the applied voltage is practically of sine-wave form. In cases where the voltage-wave shape departs appreciably from a sine-wave, as when a transformer is large in rating compared with the generator used for test, the excitation current will be lower in value than that obtained with a sine-wave of applied voltage.

The value so obtained shall be corrected to a sine-wave basis.

b. Average-voltage Voltmeter and Rms Ammeter – When using an average-voltage voltmeter and an rms ammeter, the measured rms value of excitation current will generally be higher than that obtained with a sine-wave of voltage, when the voltage-wave shape departs appreciably from a sine-wave. When the value obtained by this method is within the specified limits, no correction is required.

c. Correction of Excitation Current to a Sine-Wave Basis – The measurement of the excitation current shall, when necessary, be corrected to a sine-wave basis by one of the following methods:

1. Excitation by Form-factor Method – This method is based on the fact that a substantially straight-line relation exists between the rms value of the excitation current and the form-factor of the applied-voltage wave over a wide range of form-factors.

It is the most accurate method of measurement when waves of sufficiently different form-factor to provide effective extrapolation are available (Figure 4-15).
Excitation current is measured with an rms ammeter at two or more applied voltages having different form-factors, but held at the same value with an average-voltage voltmeter, such as is used for the reduction of excitation loss to a sine-wave basis.

Form-factors may be varied conveniently by changing the excitation of the generator field or by inserting an impedance in the test circuit. Form-factors may be determined by taking simultaneous voltage readings with rms and average-voltage voltmeters; their values will be indicated by the ratio of the rms reading to the average-voltage voltmeter reading, provided that the reading indicates the rms value of the equivalent sine-wave voltage.

\[ I_1, I_2 = \text{exciting currents at form factors } F_1, F_2 \]

The excitation current \( I_s \) corresponding to sine-wave voltage shall be determined from the foregoing data by the following equation:

\[
I_s = I_2 - \frac{I_2 - I_1}{F_2 - F_1} (F_2 - 1.11) \tag{Equation 4.2.7.1-1}
\]

Where \( I_1 \) and \( I_2 \) are the rms currents corresponding, respectively, to the form factors \( F_1 \) and \( F_2 \).

2. Excitation by Crest-ammeter Method – In the crest-ammeter method, use is made of an average-voltage voltmeter (the same instrument used for sine-wave basis) and a crest ammeter for reading the instantaneous maximum value of the corresponding currents.

Simultaneous readings are taken on these two instruments at 100 percent, 86.6 percent, and 50 percent voltage. These data determine approximately the fundamental, third, and fifth harmonics of the excitation current.

The excitation current \( I_s \) corresponding to sine-wave voltage shall be determined from the foregoing data by the following equation:

\[
I_s = \sqrt{\frac{I_1^2}{6} + \frac{I_2^2}{6} + \frac{I_3^2}{6}} \tag{Equation 4.2.7.1-2}
\]
In which \( I_1, I_2 \) and \( I_3 \) are the instantaneous maximum values of excitation current corresponding to excitation voltages of 100 percent, 86.6 percent, and 50 percent of rated voltage.

This method applies not only to single-phase transformers, but, in a slightly modified form, also to those three-phase transformers which are free from large third-harmonic voltages, that is, in practice, transformers having one or more windings or those having a three-legged, three-phase core.

Readings are obtained as indicated in the preceding paragraphs, but now the line current consists of only the fundamental and the fifth harmonic components of the required ampere-turn excitation. Since only two important components are present, only two readings are necessary (\( I_1 \) at 100 percent excitation voltage and \( I_2 \) at 86.6 percent voltage), and the excitation current \( (I_s) \) corresponding to sine-wave voltages may be determined by the following equation:

\[
I_s = \sqrt{0.25I_1^2 + 0.338I_2^2}
\]

(Equation 4.2.7.1-3)

4.2.7.2 Excitation by Average Method

When the voltage wave shape is not too distorted, the following simplified method may be used. This method is based on the fact that the value of excitation current obtained is too low when a voltmeter is used (see 4.2.7.1.a) and too high when an average-voltage voltmeter is used (see 4.2.7.1.b). The procedure is as follows:

a. First, determine the excitation current as in 4.2.7.1.a.

b. Second, determine the excitation current as in 4.2.7.1.b, reading also the rms voltage.

c. If the rms reading of voltage, and the average-voltage voltmeter reading of voltage in the test made according to 4.2.7.1 do not differ by more than 10 percent, the excitation current on a sine-wave basis is taken as the average of the values obtained by the tests described in 4.2.7.1.b and 4.2.7.1.b.

4.2.8 Impedance and Load Loss

4.2.8.1 Impedance Voltage

The impedance voltage comprises an effective resistance component corresponding to the impedance losses, and a reactance component corresponding to the leakage-flux linkages of the windings.

It is not practical to measure these components separately, but after the total impedance loss and total impedance voltage are measured, the components may be separated by calculation.

The voltage required to circulate the rated current under specified short-circuit conditions is the impedance voltage of the transformer as viewed from the terminals of the excited winding. The watts loss measured is the impedance loss at the test temperature.

The impedance voltage value generally falls between 3 percent and 15 percent of the rated voltage of the excited winding, and this fact may be used as a guide in planning for the voltage supply for the impedance test.

Note: Load losses include \( I^2R \) loss in the windings due to load current; stray loss due to stray fluxes in the windings, core clamps, magnetic shields, enclosure or tank walls, etc., and also to circulating currents, if any, in parallel windings.
4.2.8.2 Interlacing Impedance Voltage of a Scott-Connected Transformer

The interlacing impedance voltage of Scott-connected transformers is the single-phase voltage applied from the midtap of the main transformer winding to both ends connected together, the voltage being sufficient to circulate in the supply lines a current equal to the rated 3-phase line current. The current in each half of the winding is 50 percent of this value.

The percent interlacing impedance is the measured voltage expressed as a percent of the teaser voltage.

The percent resistance is the measured watts expressed as a percentage of the rated kVA of the teaser winding.

4.2.8.3 Tolerances for Transformer Impedance

a. The impedance of a two-winding transformer shall have a tolerance of plus and minus 7.5 percent of the established value.

Differences of impedance between two duplicate two-winding transformers, when two or more units of a given rating are produced by one manufacturer at the same time, shall not exceed 7.5 percent of the established value.

b. The impedance of a transformer having three or more windings or having zig-zag windings shall have a tolerance of plus and minus 10 percent of the established value.

Differences of impedance between duplicate transformers, when two or more units of a given rating are produced by one manufacturer at the same time, shall not exceed 10 percent of the established value.

c. The impedance of an autotransformer shall have a tolerance of plus and minus 10 percent of the established value.

Differences of impedance between duplicate autotransformers, when two or more units of a given rating are produced by one manufacturer at the same time, shall not exceed 10 percent of the established value.

d. Transformers shall be permitted to be considered for operation in parallel if their impedances come within the limitations of the foregoing paragraphs, provided turn ratios and other controlling characteristics are suitable for such operation.

4.2.8.4 Impedance and Load Loss Tests

a. Test Method for Transformer – Resistance and reactance components of the impedance voltage are determined by the use of the following equations:

\[ E_r = \frac{P}{I} \]

(Equation 4.2.8.4-1)

\[ E_x = \sqrt{E_z^2 - E_r^2} \]

(Equation 4.2.8.4-2)

where –
$E_r = \text{resistance voltage, in-phase component}$

$E_x = \text{reactance voltage, quadrature component}$

$E_z = \text{impedance voltage}$

$P_z = \text{watts measured in impedance test}$

$I = \text{current in amperes in excited winding}$

Per unit values of the resistance, reactance, and impedance voltage are obtained by dividing $E_r$, $E_x$, and $E_z$ by the rated voltage. Percentage values are obtained by multiplying per unit values by 100. The $I^2R$ component of the load loss increases with the temperature. The stray-loss component diminishes with the temperature. Therefore, when it is desired to convert the load losses from one temperature to another, the two components of the load loss are converted separately. Thus,

$$P_r = P_{rc} \frac{T_k + T}{T_k + T_m}$$

(Equation 4.2.8.4-3)

$$P_s = P_{sc} \frac{T_k + T_m}{T_k + T}$$

(Equation 4.2.8.4-4)

where –

$P_r$ and $P_s =$ desired resistance and stray losses, respectively, at the specified temperature $T$.

$P_{rc}$ and $P_{sc}$ = calculated resistance and stray losses, respectively, at temperature $T_m$.

$T_k$ = 234.5 for copper and 225 for aluminum.

Note: 225 applies for pure or EC aluminum. $T_k$ may be as high as 230 for other grades of aluminum.

One of the two windings of the transformer (either the high-voltage winding or the low-voltage winding) is short-circuited, and voltage at rated frequency is applied to the other winding and adjusted to circulate rated currents in the windings (Figure 4-16).

![Figure 4-16](image)

**Figure 4-16**

**SINGLE-PHASE TRANSFORMER CONNECTION FOR IMPEDANCE-LOSS AND IMPEDANCE VOLTAGE TESTS**

Note: Instrument transformers to be added when necessary.

With current and frequency adjusted to the rated values as nearly as possible, simultaneous readings should be taken on the ammeter, voltmeter, wattmeter, and frequency meter. The transformer under test
should then be disconnected and tare readings taken on the wattmeter, representing the losses of the measuring equipment, similar to the procedure in the excitation-loss test.

It is sufficient to measure and adjust the current in the excited winding only, because the current in the short-circuited winding will be correct value (except for a negligible excitation current error) when the current in the excited winding is correct. To introduce measuring equipment in series with the short-circuited winding in order to measure its current, may introduce a greater error into the impedance data due to the losses and voltage drop of that equipment.

The temperatures of the windings are to be taken immediately before and after the impedance measurements in a manner similar to that described in 4.2.11. The average is taken as the true temperature.

Conductors used for short-circuiting, low-voltage, high-current transformers should have a cross section equal to, or greater than, the corresponding transformer leads. They should be as short as possible and should be kept away from magnetic masses. Contacts should be clean and light. These precautions are important in avoiding extraneous impedance voltage and losses which might otherwise be introduced into the measurements. The $I^2R$ losses of the two windings are calculated from the ohmic resistance measurements (corrected to the temperature at which the impedance test was made) and the currents which were used in the impedance measurement. These $I^2R$ losses, subtracted from the impedance watts, give the stray losses of the transformer at the temperature at which the load loss test was made.

b. Test Method for Autotransformer – An autotransformer may be tested for impedance with its internal connections unchanged.

The test may be made by short-circuiting its input (or output) terminals, and applying voltage to the other terminals to cause its appropriate rated line current to flow, the external connections being as in Figure 4-17.

![Figure 4-17](connections.png)

**Figure 4-17**

**CONNECTIONS FOR IMPEDANCE-LOSS AND IMPEDANCE-VOLTAGE TESTS OF AN AUTOTRANSFORMER**

The series and common windings of the autotransformer may be treated as separate windings, one being short-circuited, the other excited, for the impedance test.

When this procedure is followed, the current held is the rated current of the exciting winding, which may or may not be the same as the line current indicated in preceding paragraphs.

With foregoing precaution followed, the impedance watts and volt-amperes will be the same by either method.

The impedance voltage measured across the series winding will correspond to that between the high-voltage terminals of the autotransformer, while that measured across the common winding will correspond to that between the low-voltage terminals of the autotransformer, while that measured across the
common winding will correspond to that between the low-voltage terminals of the autotransformer. The two-watt meter method is no longer recommended due to the inherent probability of large errors.

c. Test Method for Three-phase Transformer with Single-phase Voltage – To test the impedance of a three-phase unit with single-phase voltage, the winding to which voltage is to be applied must be connected in delta, and a corner of the delta opened to apply the single-phase voltage. The other winding must be either connected in delta (in which case no short-circuiting is necessary); or, if it is in Y, its terminals must be short-circuited to its neutral. The procedure is otherwise like a single-phase impedance test. The voltage obtained in this manner is three times the impedance voltage of one phase of the transformer, and this fact must be considered in converting the values into percent or per-unit quantities. Use the following formula:

\[
\text{Percent impedance volts} = 100 \frac{\text{measured impedance volts}}{3 \times \text{rated voltage of excited windings in } \Delta}
\]

(Equation 4.2.8.4-5)

This method of test does not duplicate the three-phase impedance condition very exactly and tends to give higher losses by introducing irrelevant zero-phase-sequence losses (mostly losses in the enclosure) into the measurement. This effect is more pronounced for core-type transformers. Therefore, it is not suitable for the higher reactance transformer.

An alternative single-phase test is applicable regardless of whether windings are connected delta, Y, zig-zag, or any combination of these. The neutral terminals, if any, are not used, and it is not necessary to open a corner of the delta.

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 and adjusted to circulate rated line current. Three successive readings are taken on the three pairs of leads, as for example: H1 and H2, H2 and H3, H3 and H1. Then

\[
\text{Measured impedance watts} = \frac{1.5(P_{12} + P_{23} + P_{31})}{3}
\]

(Equation 4.2.8.4-6)

\[
\text{Measured impedance volts} = \frac{0.866(E_{12} + E_{23} + E_{31})}{3}
\]

(Equation 4.2.8.4-7)

where –

P and E = individual readings of measured impedance loss and voltage, respectively and indicated by subscripts

The stray-loss component of the impedance watts shall be obtained by subtracting from the latter \( i^2 R \) losses of the transformer. Let \( R_1 \) be the resistance measured between two high-voltage terminals and \( R_2 \) that between two low-voltage terminals; and let \( I_1 \) and \( I_2 \) be the respective rated line currents. Then, the total \( i^2 R \) loss of all three phases will be

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\[ Total I^2R = 1.5\left(I_1^2R_1 + I_2^2R_2\right) \text{watts} \]

(Equation 4.2.8.4-8)

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

Temperature correction shall be made as in 4.2.8.4.a.

d. Test Method of a Three-winding Transformer – In a three winding transformer, which may be either single-phase or three-phase, two winding impedance measurements are made with each pair of windings (which means three different impedance measurements), following the same procedure as for two-winding transformers.

If the kVA capacities of the different windings are not alike, the current held for the impedance test should correspond to the capacity of the lower rated winding of the pair of windings under test. However, all of these data when converted into percentage form should be based on the same output kVA, preferably that of the primary winding.

The individual equivalent impedance characteristics of the separate windings may be determined with the following expressions:

\[ Z_3 = \frac{Z_{12} - Z_{23} + Z_{31}}{2} = M_{23} \]

(Equation 4.2.8.4-9)

\[ Z_2 = \frac{Z_{23} - Z_{31} + Z_{12}}{2} = M_{31} \]

(Equation 4.2.8.4-10)

\[ Z_3 = \frac{Z_{31} - Z_{12} + Z_{23}}{2} = M_{12} \]

(Equation 4.2.8.4-11)

where –

\[ Z_{12}, Z_{23}, Z_{31} = \text{measured impedance values between pairs of windings, as indicated all expressed on the same kVA base.} \]

\[ M = \text{equivalent mutual impedance between pairs of windings.} \]

These equations involve complex numbers, but they may be used for the resistance (in phase) component, or reactance (quadrature) component, of the impedance voltage, or of impedance volt-amperes.

The treatment of the individual impedance losses for temperature correction, etc., is the same as for two-winding single-phase transformers.

The total loss for a three-winding transformer is approximately the sum of the losses in the three windings as determined for the load conditions of the windings.
e. Impedance Bridge Method – The impedance bridge method may be used as an alternate to the wattmeter-voltmeter-ammeter method for the measurement of impedance and impedance losses. The impedance bridge method is advantageous for low-power-factor measurements where special wattmeters and techniques are ordinarily required. While many configurations of impedance bridge networks are possible, the choice of a particular network is determined by the measurement problem at hand and the testing facilities available.

1. Impedance Bridge Networks for Measurement of Losses – The general form of the impedance bridge is an electrical network so arranged that a voltage proportional to the current through the transformer under test can be compared with a reference voltage which is a function of the applied test voltage \( E_t \) (Figure 4-19).

![General Impedance Bridge Network](image)

The voltage comparison is made by adjusting one or more of the bridge arms \( Z_1, Z_2, \) and \( Z_3 \) until the voltage across \( Z_2 \) and \( Z_3 \) are exactly equal in magnitude and phase. Voltage balance is indicated by a null reading of the detector \( \text{Det} \). The impedance characteristics of the transformer under test can be calculated from the values of \( Z_1, Z_2, \) and \( Z_3 \).

2. Potentiometer-type Networks – A convenient form of the impedance bridge for transformer testing is a double alternating-current potentiometer-type network using a phase shifter (Figure 4-20). The two potentiometers (A and B) are either connected directly or through a voltage transformer (VT) to the terminals of the transformer under test. The phasor sum of the voltage drops (A and B) in quadrature is then compared with the voltage drop (C) across the secondary of the current transformer (CT). The constants of this network can be arranged so that the balance position of potentiometer (A) is directly proportional to the loss in the transformer under test. This network can be connected in place of the usual dynamometer-type wattmeter and is readily adaptable to automatic testing.

![Potentiometer-Type Networks Using a Phase Shifter](image)
Another configuration of the double potentiometer-type network employs a mutual inductor to obtain the quadrature voltage drop required for balance (Figure 4-21). In this case, the phasor sum of the voltage drops (B) and (C) is compared with the voltage drop (A). For operation at a fixed frequency (normally 60 hertz) the constants of the circuit can be arranged so that the balance position of potentiometer (B) is directly proportional to the loss in the transformer under test for low power factors.

![Figure 4-20](image)

**Figure 4-20**

**POTENTIOMETER-TYPE NETWORK USING A MUTUAL INDUCTOR**

The configuration of a direct-reading-type potentiometer network for measuring loss is usually determined by the parameter (voltage or current) to be held during the test. For excitation loss, where voltage is the reference parameter, the in-phase and quadrature voltage drops required for balance are advantageously derived from the voltage portion of the test circuit. For impedance loss, where load current is the reference parameter, these voltage drops are advantageously derived from the current portion of the test circuit.

Three-phase Bridge Measurements – Loss measurements on three-phase apparatus are made by connecting the bridge network to each phase in turn and calculating the total loss from the three single-phase measurements. This is analogous to the three-wattmeter method of measuring losses using a single wattmeter.

4.2.8.5 Load Loss on a “K” Rated Transformer

A K-rated transformer is designed to accommodate the additional heating which occurs as a result of nonlinear loading which can be characterized by a “K-factor”. Methods for computing these additional losses are defined in UL 1561 and IEEE C57.110.

4.2.9 Dielectric Tests

4.2.9.1 General

The purpose of dielectric tests in the factory is to check the insulation and workmanship and, when required, to demonstrate that the transformer has been designed to meet specified insulation levels.

Unless otherwise specified, dielectric tests shall be made in accordance with IEEE Standard 4.

It is recognized that dielectric tests impose a severe stress on the insulation and, if applied frequently, will hasten breakdown or may cause breakdown, the stress imposed, of course, being the more severe the higher the value of the applied voltage. Hence, practice in this matter has varied widely among operating companies, and the advisability of periodic testing may be questionable.

It is recommended that field tests of insulation (dielectric tests on transformers subsequent to factory tests) not be in excess of 75 percent of the factory test voltage; that for old apparatus rebuilt in the field, tests should not be in excess of 75 percent of the factory test voltage; and that periodic insulation tests in
the field should not be in excess of 65 percent of the factory test voltage. These recommendations relate to dielectric test applied between windings and ground and to induced-voltage tests.

Under some conditions transformers may be subjected to a periodic insulation test using direct voltage from kenotron sets. In such cases, the test direct voltage shall not exceed the original factory test rms alternating voltage; e.g., if the factory test was 4 kilovolts root mean square (kV rms), then the routine test direct voltage shall not exceed 4 kV.

Dielectric tests consist of the following:

b. Induced potential test.

The sequence of tests shall be impulse test (when required) followed by applied and induced potential tests.

4.2.9.2 Applied-Potential Test

a. For transformers designed for delta-connection, or designed so that either terminal of a winding can be used as the line terminal, the applied potential test shall be made by applying between each winding, and all other windings connected to ground, a low-frequency voltage from an external source in accordance with Table 4-4.

<table>
<thead>
<tr>
<th>Nameplate Voltage Rating, Volts</th>
<th>Test Potential, kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-250</td>
<td>2.5</td>
</tr>
<tr>
<td>251-1200</td>
<td>4</td>
</tr>
</tbody>
</table>

If a number of previously tested components are assembled to form a single electrical unit, the assembly may be tested with a voltage 15 percent lower than the lowest voltage required for any of the individual components, but in no case less than 900 volts.

b. The terminal ends and taps of the winding under test should all be electrically joined together and also joined to the line terminal of the testing transformer.

All other terminals and parts (including core and case) should be connected to ground and to the other terminal of the testing transformer.

The ground connections between the apparatus being tested and the testing transformer must be a substantial metallic circuit. All connections should make good mechanical joints without forming sharp corners or points.

No appreciable resistance should be placed between the testing transformer and the one under test. It is permissible, however, to use reactive coils at or near the terminals of the testing transformer. The high-voltage conductor from the testing transformer should preferably be at least 1/8 inch in overall diameter.

c. The duration of the applied-potential test shall be 1 minute. As an alternative to the 1-minute test, equipment shall be tested for 2.0 seconds with a voltage 20 percent higher than the 1-minute test voltage where the specified test voltage would be 4800 volts or less.

d. Dielectric failure is considered to exist when the test voltage applied to the sample cannot be maintained at the specified value. If the impedance of the testing transformer is too high, its secondary voltage will drop appreciably with the flow of any current in the secondary and, thus, the prescribed dielectric stress will not be maintained. For this reason, a testing transformer of a minimum rated capacity
of 500 volt-amperes should be used for the testing of transformers up through 10 kVA. For large or special transformers, a larger capacity testing transformer may be required. 

Note: Alternately transformers with high leakage current may be tested from dc source at magnitude equal to Peak of ac test voltage.

e. A relief gap set a voltage 10 percent or more in excess of the specified test voltage may be connected during the applied-potential test.

4.2.9.3 Induced-Potential Tests

a. The induced-potential test for transformers which receive the full standard applied-potential test shall be made by applying, between the terminals of one winding, voltage of twice the normal voltage developed in the winding.

b. The induced-potential test shall be applied for 7200 cycles. The duration shall not exceed 60 seconds.

c. As the induced-potential test overexcites the transformer, the frequency of the applied potential should be high enough to prevent the exciting current of the transformer under test from exceeding about 30 percent of its rated load current. Ordinarily this requirement necessitates the use of a frequency of 120 hertz or more, when testing 60 hertz units.

When frequencies higher than 120 hertz are used, the severity of the test is abnormally increased and for this reason the duration of the test should be reduced in accordance with Table 4-5.

<table>
<thead>
<tr>
<th>Frequency, Hertz</th>
<th>Duration, Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 and less</td>
<td>60</td>
</tr>
<tr>
<td>180</td>
<td>40</td>
</tr>
<tr>
<td>240</td>
<td>30</td>
</tr>
<tr>
<td>360</td>
<td>20</td>
</tr>
<tr>
<td>400</td>
<td>18</td>
</tr>
</tbody>
</table>

The voltage should be started at one-quarter or less of the full value and be brought up gradually to full value in not more than 15 seconds. After being held for the time specified in Table 4-5, it should be reduced slowly (in not more than 5 seconds) to one-quarter of the maximum value or less, and the circuit opened.

d. When transformers have one winding grounded for operation on a grounded-neutral system, special care should be taken to avoid high electrostatic stresses between the other windings and ground. In the case of transformers having one end of the high-voltage winding grounded, the other windings should be grounded during the induced-potential test. This ground on each winding may be made at a selected point of the winding itself or of the winding of a step-up transformer used to supply the voltage or merely connected for the purpose of furnishing the ground.

Three-phase transformers may be tested with single-phase voltage. The specified test voltage is induced, successively, from each line terminal to ground and to adjacent line terminals. The neutrals of the windings may or may not be held as ground potential during these tests.

When the induced test on a winding results in a voltage between terminals of other windings in excess of the low frequency test voltage specified in these standards, the other windings may be sectionalized and grounded. Additional induced tests should then be made to give the required test voltage between terminals of windings that were sectionalized.

4.2.10 Audible Sound Level Tests

Transformer shall be so designed that the average audible sound level will not exceed the values given in Table 3-9 when measured as follows.
4.2.10.1 Test Conditions
Measurements shall be made in an ambient environment with a sound level significantly lower than the sound level of the ambient and transformer combined. A sound level difference of at least 5 decibels is required, and a sound level difference of 10 decibels or more is preferred. The ambient sound level shall be the average of the measurements taken immediately before and immediately after the transformer is tested at the locations as indicated in this standard. Corrections shall be applied in accordance with Table 4-6.

The transformer shall be so located that there is no acoustically reflecting surface, other than the floor, within 10 feet of the transformer.

An ambient measurement shall be taken immediately before the test. The transformer shall be energized at rated voltage and frequency, with no load, for measurements at all reference points. An ambient measurement shall be taken immediately after the test.

<table>
<thead>
<tr>
<th>Difference in Decibels between the Average Sound Level of Transformer and Ambient Combined and Average Sound Level of Ambient</th>
<th>Corrections in Decibels to be Applied to Average Sound Level of Transformer and Ambient Combined to Obtain Average Sound Level of Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>-1.6</td>
</tr>
<tr>
<td>6</td>
<td>-1.3</td>
</tr>
<tr>
<td>7</td>
<td>-1.0</td>
</tr>
<tr>
<td>8</td>
<td>-0.8</td>
</tr>
<tr>
<td>9</td>
<td>-0.6</td>
</tr>
<tr>
<td>10</td>
<td>-0.4</td>
</tr>
<tr>
<td>Over 10</td>
<td>-0.0</td>
</tr>
</tbody>
</table>

4.2.10.2 Measurements
a. Sound levels shall be measured with an instrument which is in accordance with ANSI S1.4.
b. The average sound level is defined as the arithmetic mean of the sound level readings taken in accordance with 4.2.10.2.d and 4.2.10.2.e and 4.2.10.2.f.
c. The major sound producing surface of a transformer is a vertical surface which follows the contour traced by a string stretched around the horizontal projection of the transformer outline. This outline is to include the transformer enclosure with primary and secondary switchgear compartments when applicable.
d. For transformer enclosures having an overall height of less than 8 feet, measurements shall be made at approximately half height. For transformer enclosures having an overall height of 8 feet and above, measurements shall be made at approximately 1/3 and 2/3 height.
e. For transformer enclosures having an overall height of 4 feet or less, a measurement shall be made above the center of the top surface.
f. Starting from a point at the front center of the transformer and proceeding clockwise around the major sound producing surface of the transformer, mark off reference points at 3-foot intervals measured in a horizontal direction along the major sound producing surface. There shall be no fewer than four reference points, which can result in intervals of less than 3 feet for small transformers. One sound measurement shall be taken at each reference point. The microphone shall be located 1 foot from, and facing, the major sound producing surface on a perpendicular line to the major sound producing surface at the reference point. For measurements above the center of the top surface, the microphone shall similarly be 1 foot above the major sound producing surface.

4.2.11 Resistance Measurements
4.2.11.1 Importance of Measurements
Resistance measurements are of fundamental importance for three purposes:
a. For the calculation of the $I^2R$ component of conductor losses.

b. For the calculation of winding temperatures at the end of a temperature test.

c. As a base for assessing possible damage in the field.

4.2.11.2 Determination of Cold Temperature

The cold temperature of the winding shall be determined as accurately as possible when measuring the cold resistance. The precautions in a and b below shall be observed.

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

b. Transformer Windings. The temperature of the windings shall be recorded as the average readings of several thermometers or transducers inserted between the coils, with care used to see that their measuring points are as nearly as possible in actual contact with the winding conductors. It should not be assumed that the windings are at the same temperature as the surrounding air.

The temperature of the windings may be considered equal to the ambient air temperature provided the transformer has been in a stable ambient which has not changed by more than 3ºC for 3 hours prior to the test, draft-free area for 24 hours, with internal temperature measurements,(surface temperature measurements for sealed units) that not differ from the test area ambient by more than 2ºC, and provided that neither voltage nor current has been applied to it for 24 to 72 hours, depending on size.

4.2.11.3 Conversion of Resistance Measurements

Cold winding resistance measurements are normally converted to a standard reference temperature equal to the rated average winding temperature rise plus 20ºC. The conversions are accomplished by the following formula:

$$R_s = R_m \left(\frac{T_s + T_{k}}{T_m + T_{k}}\right)$$

where—

- $R_s$ = resistance at desired temperature $T_s$
- $R_m$ = measured resistance
- $T_s$ = desired reference temperature
- $T_m$ = temperature at which resistance was measured
- $T_{k}$ = 234.5 for copper
- $T_{k}$ = 225 for aluminum, EC

Note: The value of $T_{k}$ may be as high as 230 for alloyed aluminum.

4.2.11.4 Resistance Measurement Methods

a. Bridge Method. Bridge methods (or high-accuracy digital instrumentation) are generally preferred.. Note: For resistance values of 1 Ohms or more a Wheatstone bridge (or equivalent) is commonly used; for values less than 1 Ohms a Kelvin bridge (or equivalent) is commonly used. Some modern resistance bridges have capability in both ranges.

b. Voltmeter-Ammeter Method. The voltmeter-ammeter method is sometimes more convenient than the bridge method. It should be employed only if the rated current of the transformer winding is 1 ampere or more. Digital voltmeters and digital ammeters of appropriate accuracy are commonly used in connection with temperature-rise determinations.

1. Measurement is made with direct current, and simultaneous readings of current and voltage are taken using the connections of Figure 4-22. The required resistance is calculated from the readings in
accordance with Ohm’s law. A battery or filtered rectifier will generally be found to be more satisfactory as a DC source than will a commutating machine. The latter may cause the voltmeter pointer to vibrate because of voltage ripple.

2. In order to minimize errors of observation:

   (a) The measuring instruments shall have such ranges as will give reasonably large indication.

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

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

![Figure 4-21](image_url)

**CONNECTIONS FOR THE VOLTMETER-AMMETER METHOD OF RESISTANCE MEASUREMENT**

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

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

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

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

When measuring the cold resistance preparatory to making a heat run, the time required for the readings to become constant should be noted. The period thereby determined should be allowed to elapse before taking the first reading when final winding hot-resistance measurements are being made.

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

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

The current used shall not exceed 15 percent of the rated current of the winding whose resistance is to be measured. Larger values may cause inaccuracy by heating the winding and thereby changing its temperature and resistance.

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

4.2.12.1 General
Transformers shall be tested under a loading condition that will give losses approximate to those obtained when the transformer is operating at rated primary voltage and delivering rated kVA output at:

a. Rated secondary voltage.
b. Rated parallel secondary voltage when the transformer has series-parallel windings.

If provided with taps in the primary winding, the transformer shall deliver rated kVA output at the secondary voltages specified above when excited on the rated kVA tap of lowest voltage.

Temperature testing requires a slight over-excitation. The resultant increase in total loss has a negligible effect on the kilovolt-ampere output. It is therefore not considered in the temperature rise test methods described herein.

Various methods are available for this test. These are:

a. Actual Loading – The actual loading method is the most accurate of all methods, but its energy requirements are excessive for large transformers.

Transformers of small output may be tested under actual load conditions by loading them on a rheostat, bank of lamps, water box, and so forth.

b. Simulated Loading –

1. Short-circuit Method for Self-cooled Transformers Only (Separate Load-Loss and Excitation Test) – The short-circuit method necessitates an accurate predetermination of excitation losses and conductor losses, including stray losses at operating temperature. It has the advantage of permitting a direct measurement of the watts and current being held during the temperature rise test. This method requires a smaller amount of testing facilities and energy consumption. It is particularly suitable for large size transformers, and is equally satisfactory for small transformers.

2. Loading-back (Opposition) Method for Self-cooled and Forced-cooled Transformers – The loading-back (opposition) method requires a greater amount of testing facilities auxiliary equipment, and energy consumption. Because of these requirements, the loading-back method becomes increasingly difficult to perform as the size of the transformer increases.

3. Impedance kVA Method – This is a method for testing a single three-phase transformer or three single-phase transformers having delta windings or connectable to two delta windings. One delta winding should be open so that the impedance kVA can be supplied.

4.2.12.2 General Requirements for Temperature Rise Tests
Transformers shall be completely assembled.

If the transformers are equipped with thermal indicators, bushing-type current transformers, and so forth, such devices shall be assembled with the transformer.

The temperature rise test shall be made in a room which is as free from drafts as practicable. Ambient stability should be maintained as noted in Section 4.2.11.2.

The ambient temperature shall be the average of the readings from at least three thermocouples or thermometers, spaced uniformly around the transformers under test.
They should be located at about one-half the height of the transformer, and at a distance of 3 to 6 feet from the transformer. They should be protected from drafts and abnormal heating.

To reduce to a minimum the errors due to time lag between the temperature of the transformers and the variations in the ambient temperature, the thermocouples, or thermometers, shall be placed in suitable containers which shall have such proportions as will require not less than 2 hours for the indicated temperature within the container to change 6.3°C if suddenly placed in air which has a temperature 10°C higher, or lower, than the previous steady-state indicated temperature within the container.

When measured, the temperature rise of metal parts (other than the winding conductor) in contact with, or adjacent to, insulation, and of other metal parts, shall be determined by thermocouple or by thermometer.

Provision shall be made to measure the surface temperature of iron or alloy parts surrounding or adjacent to the outlet leads or terminals carrying large currents. Readings shall be taken at intervals or immediately after shutdown.

The determination of the temperature rise of metal parts within the case, other than winding conductors, is a design test and shall be made when so specified unless a record of this made on a duplicate, or essentially duplicate, unit can be furnished. Comparisons with other transformers having metal parts of similar design and arrangement, but not necessarily having the same rating, will in many cases be adequate.

A thermocouple is the preferred method of measuring surface temperature. When used for this purpose, the thermocouple should, when practical, be soldered to the surface. When this is not practical, the thermocouple shall be placed in intimate contact with the surface being measured. The thermocouple is to be attached to maintain firm contact against the surface. In either case, the thermocouple should be thoroughly insulated thermally from the surrounding medium.

It is permissible to shorten the time required for the test by the use of initial overloads, restricted cooling, or any other suitable method.

The temperature rise of the windings shall be determined by the change of resistance method.

The ultimate temperature rise is considered to be reached when the temperature rise becomes constant, i.e., when the temperature rise does not vary more than 2°C during a consecutive 3-hour period.

When the ambient air temperature is other than 30°C, a correction shall be applied to the temperature rise of the winding by multiplying it by the correction factor C which is given by the ratio:

\[ C = \frac{(T_r + T_k + 30)(T_r + T_k + T_a)}{T_k} \]  

(Equation 4.2.12.2-1)

in which \( T_a \) = the ambient air temperature.
\( T_k = 234.5 \) for copper
\( T_k = 225 \) for aluminum

When the temperature rise has become constant, the test voltage and current should be removed and the blowers, if used, shut off. Immediately thereafter the thermocouple should be read continually in rotation until the temperature begins to fall. If any of the thermocouple temperatures are higher than those observed during the run, the highest temperature should be recorded as the final thermocouple temperature.

The ambient temperature for a self-cooled unit shall be taken as that of the surrounding air which should be not less than 10°C nor more than 40°C.
For a forced-cooled unit, the quantity of cooling air in cubic feet per minute and the temperature of the ingoing and outgoing air shall be determined.

The ambient temperature shall be taken as that of the ingoing air and shall be not less than 10°C nor more than 40°C.

The load-back method is a basic method for testing dry-type transformers and may be used when more than one unit is available for test.

The separate load-loss and excitation-loss test method may be used on all ventilated dry-type transformers.

The load-loss test plus an additive factor may be used for all ventilated dry-type transformers when empirical data is available establishing the proper value of the additive factor.

The separate load-loss and excitation-loss test method cannot be used for nonventilated dry-type transformers.

4.2.12.3 Temperature Rise of Single-Phase Transformers by the Loading-Back Method
Duplicate single-phase transformers may be tested by the load-back method by connecting both high-voltage windings in parallel, and both low-voltage windings in parallel, and by applying rated excitation voltage at rated frequency to one set of paralleled windings. (Figure 4-23)

![Figure 4-22](image)

**Figure 4-22**
TEMPERATURE RISE OF SINGLE-PHASE TRANSFORMERS BY THE LOADING-BACK METHOD

Circulate load current by opening the connections of either pair of windings at one point and impress a voltage across the break just sufficient to circulate rated current through the windings.

a. This current should preferably (but not necessarily) be at rated frequency.
b. The correction to be applied when the circulating current is not at rated frequency is given in 4.2.12.10. Run until equilibrium conditions are attained.

Then shut down, measure the winding resistance, and calculate the average winding rises over the ambient temperature. Correct these rises back to the instant of shutdown.

4.2.12.4 Temperature Rise Test of Three-Phase Transformers by the Loading-Back Method
Duplicate three-phase transformer may be tested by the load-back method by connecting both the high-voltage and low-voltage windings in parallel (Figure 4-24).
It is desirable to connect similarly marked leads together rather than attempt to connect windings in parallel by symmetry alone.

Rated excitation voltage at rated frequency shall be applied to one set of windings.

Circulate rated current by joining either set of windings through an auxiliary source of three-phase loading voltage (Figure 4-24).

The circulated current should preferably (but not necessarily) be at rated frequency.

The correction to be applied when the circulating current is not at rated frequency is given in 4.2.12.10.

Run until equilibrium conditions are attained.

Then shut down, measure the winding resistance, and calculate the average winding rises over the ambient temperature.

Correct these rises back to the instant of shutdown.

4.2.12.5 Temperature Rise Tests of Three-Phase Transformers or Three Single-Phase Transformers by The Impedance kVA Method

A single three-phase transformer shall be permitted to be tested by itself, as shown in Figure 4-25, if both the high- and low-voltage windings can be connected in delta. Rated three-phase voltage at rated voltage at rated frequency shall be applied to one of the deltas.
Figure 4-24
TEMPERATURE RISE TESTS OF THREE-PHASE TRANSFORMERS OR THREE SINGLE-PHASE TRANSFORMERS BY THE IMPEDANCE kVA METHOD

A corner of either delta connection shall be opened and a voltage from an auxiliary single-phase source shall be impressed across the break. This voltage shall be just sufficient to circulate rated current through the windings.

The circulated current should preferably be at rated frequency.

Since this method of loading sometimes introduces extraneous zero-phase-sequence losses, the circulated current shall be adjusted to yield the true impedance losses of the transformer (the sum of all three phases).

4.2.12.6 Short-Circuit Test (Separate Load Loss and Excitation Tests)
Temperature tests on individual self-cooled, ventilated, dry-type units may be made by utilizing the rises obtained in two separate tests, one with load loss alone, and one with excitation loss alone.

Individual winding temperature rises, $T_c$, are measured immediately following the run with full load current flowing in one winding and the other winding short-circuited. $T_c$ shall be corrected if ambient is other than 30˚C per equation 4.2.12.2-1 or if test current is different than the rated per equation 4.2.12.10-1.

Individual winding temperature rises, $T_e$, are measured immediately following the run with normal excitation on the core.

The total winding rise, $T_t$, with full load current in the winding and normal excitation on the core can be calculated by the following formula:

$$T_t = T_c \left[ 1 + \left( \frac{T_c}{T_e} \right)^{1.25-0.80} \right]$$

(Equation 4.2.12.6-1)

4.2.12.7 Load Loss Test plus Additive Factor
The total winding rise, $T_t$, of a single ventilated dry-type transformer may be calculated by applying an additive factor, delta $T_e$, to the rise, $T_c$, as outlined in the next paragraph.
The additive factor, delta $T_e$, is an empirically determined temperature difference between the winding temperature rise obtained by load-back test (per 4.2.12.3 or 4.2.12.4) and the winding temperature rise measured with load loss on (per 4.2.12.6). It should be established by test data on units of similar construction.

The total winding rise, $T_t$, is given by:

$$T_t = T_c + \Delta T_e$$

(Equation 4.2.12.7-1)

### 4.2.12.8 Determination of Average Measured Winding Temperature and Average Winding Temperature Rise by the Hot-Resistance Method

The average measured temperature of a winding may be determined by either of the following equations:

$$T = \frac{R}{R_o} (T_k + T_o) - T_k$$

(Equation 4.2.12.8-1)

$$T = \frac{R - R_o}{R_o} (T_k + T_o) + T_o$$

(Equation 4.2.12.8-2)

The average winding temperature rise may be determined by the following equation:

$$T_r = T - T_a$$

(Equation 4.2.12.8-3)

where –

- $T$ = temperature in degrees Celsius corresponding to hot resistance $R$
- $T_o$ = temperature in degrees C corresponding to cold resistance $R$
- $T_r$ = average temperature rise in degrees C
- $T_a$ = ambient temperature in degrees C corresponding to hot resistance $R$
- $R_o$ = cold resistance determined in accordance with rules in this standard
- $R$ = hot resistance
- $T_k$ = 234.5 for copper and 225 for aluminum (may be as high as 230 for alloyed aluminum.)

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

When transferring leads from one winding to another, maintain the same relative polarity with regard to the measuring leads and the transformer terminals.

Record the elapsed time between the instant of shutdown and each hot resistance measurement.
4.2.12.9 Correction of Observed Temperature Rise for Variation in Altitude

When tests are made at an altitude not exceeding 3300 feet (1000 meters) above sea level, no altitude correction shall be applied to the temperature rise.

When a transformer which is tested at an altitude less than 3300 feet is to be operated at an altitude in excess of 3300 feet, it shall be assumed that the observed temperature rise will increase in accordance with the following equation:

\[
\text{Increase in temperature rise at altitude } A \text{ (feet)} = \text{Observed rise} \times \frac{(A - 3300)}{330} F
\]

(Equation 4.2.12.9-1)

Where \( F \) is an empirical factor given in Table 4-7.

<table>
<thead>
<tr>
<th>Type of Cooling</th>
<th>Empirical Factor, ( F )</th>
</tr>
</thead>
<tbody>
<tr>
<td>For dry-type, self-cooled (AA)</td>
<td>0.005</td>
</tr>
<tr>
<td>For dry-type with auxiliary forced-air cooling</td>
<td>0.006*</td>
</tr>
<tr>
<td>( \text{(AA/FA)} )</td>
<td></td>
</tr>
<tr>
<td>For dry-type forced-air cooled (AFA)</td>
<td>0.0100</td>
</tr>
</tbody>
</table>

*Applies to forced-cooled rating only.

The “observed rise” in Equation 4.2.12.9-1 is the winding rise over the ambient temperature for dry-type transformers.

4.2.12.10 Correction to be Applied When Temperature Test Must Be Corrected for a Difference in Total Loss

If the load losses under test differ from their true values, a correction for the winding rise shall be required.

This correction may be calculated provided the loading frequency does not differ from the rated frequency by more than 10 percent.

The corrected winding rise may be calculated using:

\[
T_c = T_m \left( \frac{W}{w} \right)^n
\]

(Equation 4.2.12.10-1)

where –

\( T_c \) = corrected winding rise
\( T_m \) = measured winding rise
\( W \) = required total loss
\( w \) = total loss during temperature tests
\( n \) = 0.80 for self-cooled and 0.70 for sealed

Alternatively, the corrected winding rise may be calculated using:
\[ T_c = T_m \left( \frac{I_r}{I_t} \right)^n \]

(Equation 4.2.12.10-1)

where –

- \( T_c \) = corrected winding rise
- \( T_m \) = measured winding rise
- \( I_r \) = rated current
- \( I_t \) = test current
- \( n \) = 0.80 for self-cooled, 0.70 for sealed, and 1.0 for forced air

These methods may be used as long as the required values of no-load loss, load loss or total loss, do not differ by more than 10 percent from their corresponding values during test.

4.2.12.11 Correction Back to Shutdown, Cooling Curve Method
IEEE C57.12.91 Section 11.5 is an applicable reference for this section.

4.2.12.12 Alcove Construction for Temperature Rise Test
The side-wall and the top of the test alcove represented in Figure 3-2 are of 0.38 inch thick fir plywood, and the rear wall (on which the transformer is mounted) is of 0.75 inch thick plywood. The inner surfaces of the test alcove are to be painted dull black, and the transformer is to be mounted in the intended manner. The horizontal dimensions of the alcove are to extend beyond transformer dimensions at least 1 foot.

4.2.12.13 Temperature Rise Test on a K Factor Transformer
When a temperature test is made on a “K” rated transformer, the load current is increased to compensate for the increase load loss as calculated in Section 4.2.8.5. Alternatively, K rated transformers may be loaded with a non-linear load drawing non-sinusoidal currents appropriate to the K rating of the transformer.

4.2.13 Short-Circuit Capability
Transformers shall be capable of withstanding without injury the mechanical and thermal stresses caused by short circuits on the external terminals of any winding, under the conditions covered in 4.2.13.1 and 4.2.13.2.

4.2.13.1 Short-Circuit Test
To demonstrate short-circuit strength, a transformer shall be subjected to tests as covered in IEEE C57.12.91, except that the number of tests, the magnitude of the test current, and the duration of the test shall be as covered in A, B, & C and short-circuit thermal requirements shall be as covered in 4.2.13.2.

a. Each phase of the transformer shall be subject to one test with the magnitude of the rms symmetrical current as indicated in B, below. The test circuit shall be closed such that the maximum asymmetry is produced in a single-phase test and in one phase of a three-phase test.

b. The magnitude of the rms symmetrical current in any winding shall be as shown in the following table.

c. The duration of the short circuit is limited to the time periods shown in the following table. Intermediate values may be determined by interpolation.
### Table 4-8

<table>
<thead>
<tr>
<th>Percent Impedance</th>
<th>Rms Symmetrical Current in Any Winding</th>
<th>Time Period, Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 or less</td>
<td>25 times rated current</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>20 times rated current</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>16.6 times rated current</td>
<td>2</td>
</tr>
<tr>
<td>7 or more</td>
<td>*</td>
<td>2</td>
</tr>
</tbody>
</table>

* Extended values may be determined by extrapolation.

### EXCEPTIONS:

1. The short-circuit current of transformers that are directly connected to apparatus having inherent impedance may be considered to be limited by the combined impedances of the transformer and the directly connected apparatus if the apparatus is located only a few feet from the transformer and connected to it by buses or cables so arranged that there will be no practical possibility of short circuit occurring between the apparatus and the transformer.

2. Autotransformers having a part of their winding common to both the primary and the secondary circuits may be subjected to exceptionally severe short circuits, unless protected by current-limiting means. Because of the cumulative detrimental effects of successive severe short-circuits, it is practically impossible to determine by test the maximum safe short-circuit current that autotransformers will withstand successfully. It is recommended, therefore, that current-limiting reactors be installed where necessary to limit the short-circuit current to 25 times rated current.

### 4.2.13.2 Short-Circuit Thermal Requirements

The final temperature of the conductor in the windings of general-purpose transformers, under the short-circuit conditions described above, shall not exceed the values in the table, when calculated using the following equations:

#### Table 4-9

<table>
<thead>
<tr>
<th>Insulation System, Degrees C</th>
<th>Assumed Initial Average Temperatures of Winding, Degrees C</th>
<th>Final Temperatures, Degrees C</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>95</td>
<td>250</td>
</tr>
<tr>
<td>155</td>
<td>120</td>
<td>350</td>
</tr>
<tr>
<td>180</td>
<td>155</td>
<td>400</td>
</tr>
<tr>
<td>220</td>
<td>190</td>
<td>450</td>
</tr>
</tbody>
</table>

The final temperature for copper may be computed by means of the following formula, which is based on the assumption that all heat is stored:

\[
\theta = Ft \left( \frac{f}{2v_1} + \frac{618.4K}{f} \right) + \theta_0
\]

(Equation 4.2.13.2-1)

The final temperature for aluminum may be computed by means of the following formula, which is based on the assumption that all heat is stored:

\[
\theta = Ft \left( \frac{f}{2v_1} + \frac{602K}{f} \right) + \theta_0
\]

(Equation 4.2.13.2-2)
where –

\[ \nu = \text{final temperature, degrees C} \]

\[ \nu_0 = \text{assumed initial temperature, degrees C} \]

\[ \nu_1 = (\nu_0 + 234.5) \text{ for copper} \]
\[ = (\nu_0 + 226) \text{ for aluminum} \]

\[ t = \text{time, in seconds} \]

\[ K^* = \text{ratio of eddy current loss to the } R \text{ loss at 75^o C} \]

\[ F^* = \text{(for copper)} = \frac{\text{watts per pound (at } \nu_0)}{180} \]

\[ \text{or } (4.6 \times 10^{-11}) \text{ or } \frac{75 \nu_1}{M^2} \]

\[ = \text{(for aluminum)} (10.71 \times 10^{-11}) \]

\[ f = 2\nu_1 + Ft \]

\[ S^* = \text{amperes per square inch of conductor} \]

\[ M^* = \text{circular mils per ampere.} \]

* Based on short-circuit current, in rms symmetrical amperes.

4.3 REGULATION AND EFFICIENCY

4.3.1 Regulation of a Transformer

4.3.1.1 Impedance Watts and Impedance Volts

The impedance watts and impedance volts for use in the computation of regulation may be measured at any convenient temperature and corrected to the reference temperature of the transformer insulation system.

4.3.1.2 Regulation Computation

Formulæ for the calculation of regulation are:

a. When the load is lagging

\[ \text{reg} = \sqrt{(r + p)^2 + (x + q)^2} - 1.0 \]

(Equation 4.3.1.2-1)

b. When the load is leading

\[ \text{reg} = \sqrt{(r + p)^2 + (x - q)^2} - 1.0 \]

(Equation 4.3.1.2-2)
where –

\[ p = \text{power factor of load} \]
\[ q = \sqrt{1 - p^2} \]
\[ r = \text{resistance factor of transformer} = \frac{\text{impedance loss in kW}}{\text{rated kVA}} \]
\[ z = \text{impedance factor} = \frac{\text{impedance kVA}}{\text{rated kVA}} \]

The quantities \( p, q, x, \) and \( r \) are on a per unit basis so the result should be multiplied by 100 to get the regulation in percent. The approximate formulae gives results very close to those of the exact formulae.

For convenience, some of the corresponding values of \( p \), which is the power factor, and \( q \), which is the reactive factor, are given in Table 4-10.

<table>
<thead>
<tr>
<th>( p )</th>
<th>( q )</th>
<th>( p )</th>
<th>( q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.00</td>
<td>0.65</td>
<td>0.760</td>
</tr>
<tr>
<td>0.95</td>
<td>0.312</td>
<td>0.60</td>
<td>0.800</td>
</tr>
<tr>
<td>0.90</td>
<td>0.436</td>
<td>0.50</td>
<td>0.866</td>
</tr>
<tr>
<td>0.85</td>
<td>0.527</td>
<td>0.40</td>
<td>0.916</td>
</tr>
<tr>
<td>0.80</td>
<td>0.600</td>
<td>0.30</td>
<td>0.954</td>
</tr>
<tr>
<td>0.75</td>
<td>0.661</td>
<td>0.20</td>
<td>0.980</td>
</tr>
<tr>
<td>0.70</td>
<td>0.714</td>
<td>0.10</td>
<td>0.995</td>
</tr>
</tbody>
</table>

4.3.1.3 Tolerance for Regulation

The regulation shall have a tolerance of plus and minus 7.5 percent of the established regulation at established power factors for two-winding transformers, or 10 percent for three-winding transformers, auto-transformers and zig-zag transformers.

4.3.2 Efficiency

The efficiency of a transformer is the ratio of its useful power output to its total power input.

Efficiency shall be calculated on the basis of the reference temperature for the transformer insulation system.

\[
\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{input} - \text{losses}}{\text{input}}
\]

\[
= 1 - \frac{\text{losses}}{\text{input}} = 1 - \frac{\text{losses}}{\text{output} + \text{losses}}
\]

4.4 ENCLOSURE COMPRESSION TEST

4.4.1 Transformer enclosures as defined in paragraph 3.3 shall be capable of withstanding a force of 100 pounds (445 N), as described in paragraph 4.4.2.
4.4.2 An outside force of 100 pounds is to be directed toward the inside of the transformer on each of the five surfaces of the assembled transformer enclosure. (The transformer core and coil need not be installed in the enclosure during this test unless the core and coil are a part of the structural strength of the finished transformer.) The force is to be applied gradually at 90 degrees ±5 degrees to each of the thinner metal surfaces in any area that is most likely to cause the greatest deflection. The force is to be transmitted through a rod, having a flat, steel face with 0.50 square inches of contact area at the transformer surface. The results are acceptable if there is no inward deflection greater than 0.50 inch.
Section 5
APPLICATION

5.1 SELECTION OF RATED TRANSFORMER kVA

The rated transformer kVA should be selected with due regard to:

a. Connected load currents and possible start-time overload currents of the circuit, including sustained harmonics. The harmonic factor shall not exceed 0.05 per unit. Harmonic Factor is the ratio of the root-mean-square (rms) value of all the harmonics to the rms value of the fundamental (IEEE Std 100-1988).
b. Repetitive transient currents of the circuit, such as transformer magnetizing in-rush current, motor starting current, capacitor in-rush current and ferro-resonance current.
c. Coordination with other circuit components and protective devices.
d. Life expectancy and maintenance requirements of auxiliary equipment such as fans and controls.
e. Multiple thermal ratings. Typically transformers with lower temperature rise ratings operate more efficiently at higher loads while higher temperature rise ratings operate more efficiently at lower loads. NEMA TP-1 Section 2 explains how to use the equivalent first cost method (EFC) to evaluate the economic value of electrical losses over the useful life of the transformer.

5.2 USUAL TEMPERATURE AND ALTITUDE SERVICE CONDITIONS

Equipment conforming to these standards shall be capable of operating at its nameplate rating provided that:

a. For transformers greater than 10kVA the maximum ambient temperature for any 24-hour period does not exceed 40°C. For transformers less than or equal to 10kVA the maximum ambient temperature for any 24-hour period does not exceed 25°C,
b. The altitude does not exceed 3300 feet (1000 meters).

5.3 UNUSUAL TEMPERATURE, ALTITUDE, AND ENVIRONMENTAL SERVICE CONDITIONS

5.3.1 Higher or Lower Ambient Temperatures

Equipment may be applied at higher or lower ambient temperatures than those specified in 5.2, but its performance may be affected and consideration should be given to these applications.

5.3.2 Application at Altitudes Greater than 3300 Feet

Dry-type transformers, since they depend upon air for their insulating and cooling medium, will have a higher temperature rise and a lower withstand voltage when operated at altitudes above 3300 (1000m).

Equipment may be applied altitudes greater than 3300ft(1000m) but its performance may be affected and consideration should be given to these applications. An available reference is IEEE C57.96-2013.

The dielectric strength of dry-type transformers varies with altitude. IEEE C57.12.01 contains a table for adjusting dielectric strength.

An altitude of 15,000 (4500 m) feet is considered to be a practical maximum for dry-type transformers conforming to this standard.

5.3.3 Environmental Conditions

Other unusual environmental conditions which may affect design and application can exist and are not necessarily covered by these standards. These conditions should be brought to the attention of those responsible for the design and application of the equipment.
Examples of such conditions are:

a. Damaging fumes and vapors, excessive and abrasive dust, steam, salt spray, excessive moisture, and dripping water, etc.
b. Abnormal vibration, shocks, and tilting.
c. Excessively high and low temperatures.
d. Unusual transportation and storage conditions.
e. Unusual space limitations.
f. Difficulty of maintenance, poor wave form, unbalanced voltage or unusual operating duty, frequency of operation, insulation requirements, etc.
g. Areas which may contain hazardous materials in sufficient quantity to cause an explosion.

5.3.4 Impact Loading

ON-OFF switching of loads, such as full voltage starting of motors can place severe mechanical stress on the winding conductors and support components. Where this type of loading is anticipated, transformer specifications should describe loading duty. Special design measures may be necessary to restrain the mechanical forces.

5.3.5 Overexcitation

Operation at voltages in excess of rating may cause core saturation and excessive stray losses. This can result in overheating and abnormally high noise levels. Special care should be taken where overexcitation is anticipated. See ANSI/IEEE C57.12.01.

5.4 LOADING

5.4.1 In general, dry-type transformers are designed to operate continuously at their nameplate kilovoltampere rating. ANSI/IEEE C57.96 provides guidance for loading under unusual conditions including:

a. Ambient temperatures higher or lower than the basis for rating
b. Short term loading in excess of nameplate kilovoltampere with normal life expectancy
c. Loading that results in reduced life expectancy

5.4.2 The most commonly used insulation system classes for dry-type transformers are 150°C, 180°C, and 220°C for average winding temperature rises of 80°C, 115°C, and 150°C, respectively. Consideration should be given to the specific application of the transformer, such as the nature of the load to be served, the space available for the installation, and any weight restrictions, before specifying the class of insulation system to be used.

5.5 PARALLEL OPERATION

To obtain balanced division of load current, transformers should have the same rated percent impedance and be operated on the same voltage ratio tap.

5.6 AUTOTRANSFORMERS

5.6.1 Advantages and Disadvantages

The advantages of an autotransformer are that the size and weight per kVA of output are reduced and efficiency is improved, since all of the kVA output is not transformed. Typically, the impedance, regulation, and exciting current are lower than that of an insulating transformer of equal output.

The disadvantages of the autotransformer are the electrical connection between input and output circuits and the possibility of rather high voltages in the output circuit should the common winding become open-circuited. The electrical connection between input and output prohibits their use in circuits where high direct-current potentials exist between the two sides. The metallic connection between input and output circuits permits electrical disturbances originating on either side to be readily transmitted to the other. For
instance, a ground on one side automatically becomes a ground on the other and may subject connected
equipment to high voltage. Portable apparatus, which may be connected to the mains through a
reversible plug and socket, may have the potential between one side of the output and ground quite high
in one direction of plugging-in, although the potential difference between the two output terminals may be
quite moderate. The fact that the effective percent impedance of an autotransformer connection is lower
when compared with its value in transformer connection, increases the short-circuit current by the inverse
ratio and the short-circuit stresses by the square of the inverse ratio.

The problem of insulation stresses in autotransformers is rather complicated, involving not only
fundamental frequency voltages, but also third-harmonic and transient voltages.

5.6.2 Autotransformer Delta Systems Grounding
A delta circuit with one corner grounded requires that care be taken that there be no other ground (see
Figure 5-1). Autotransformers which are properly grounded and connected can be used on the grounded
phases but not on the ungrounded phase.

![Figure 5-1](#)

DELTA CIRCUIT WITH ONE CORNER GROUNDED

A delta circuit with the midpoint of one phase grounded requires that care be taken that there be no other
ground (see Figure 5-2). Autotransformers which are properly grounded and connected can be used on the grounded
phases but not on either of the two ungrounded phases.

![Figure 5-2](#)

DELTA CIRCUIT WITH THE MIDPOINT OF ONE PHASE GROUNDED

5.6.3 Autotransformers in Wye Systems
Autotransformers in wye systems should be connected line-to-neutral. The use of autotransformers
connected line-to-line on a three-phase wye circuit is not recommended.

5.6.4 Precautions in Connecting Autotransformers
The use of single- or three-phase autotransformers on three-phase circuits should be approached with
cautions. It is recommended that the following precautionary steps be taken before an autotransformer is
connected and energized:

a. Check the supply circuit for grounds.
b. Check the load circuit for grounds.
c. Check for possible other grounded equipment not in the circuit at the time.
d. Check the circuit for shorts after making connections to ground. The core and coil assembly should be grounded, but no winding is to be grounded.
e. It should be recognized that transformers within the scope of this Standards Publication may be connected as autotransformers to lines of a higher insulation level than that of the transformer.
f. On wye systems, any neutral connection must be connected to neutrals of both the primary and secondary circuits.

5.7 SINGLE-PHASE TRANSFORMER CONNECTIONS FOR THREE-PHASE BANKS

Single-phase transformer connections for three-phase banks are shown in figures 5-3 and 5-4.

5.8 USE OF TRANSFORMERS IN CONNECTING SYSTEMS OF VARIOUS PHASE DISPLACEMENTS

Assume two systems, the one with phase terminals arbitrarily by A, B, C and the other by a, b, c. The phase displacement of “a” with respect to “A” may be from 0 to 330 degrees, in steps of 30 degrees. In
the following groups, examples are shown of transformer connections which may be made for any of these displacements.

5.8.1 0-Degree Phase Displacement – Delta-Delta or Y-Y
The examples shown are for delta-delta connections with system displacements of 0, 120, and 240 degrees.

![Figure 5-5](image)

**Figure 5-5**
0-DEGREE PHASE DISPLACEMENT – DELTA-DELTA OR Y-Y

5.8.2 30-Degree Phase Displacement – Delta-Y or Y-Delta
The examples shown are for Delta-Y connections with system displacements of 30, 150, and 270 degrees.

![Figure 5-6](image)

**Figure 5-6**
30-DEGREE PHASE DISPLACEMENT – DELTA-Y OR Y-DELTA

5.8.3 60-Degree Phase Displacement – Delta-Y or Y-Delta
To connect systems of 60-, 180-, or 300-degree phase displacement, two consecutive similar “30-degree phase displacement” transformations can be made. This can be done in one transformation by the “180-degree phase displacement” delta-delta or Y-Y voltage diagrams which are no longer considered standard. In either case, the methods described in 5.8.1 and 5.8.2 can be followed to obtain all three angles.

5.8.4 90-Degree Phase Displacement
To connect systems with 90-, 210-, or 330-degree displacements, the procedure described in 5.8.2 is followed, except that the sequence of connecting system terminals to the transformer is reversed by reversing any pair of terminals on both systems, such as B, C and b, c.
Using again the Delta-Y diagram:

When the diagram is shown in the usual form, the change in sequence of connections results in a reversal of phase rotation. Expressed in the recognized counter-clockwise rotation, the equivalent diagrams are:

Table 5-1
SUMMARY OF PRECEDEING EXAMPLES

<table>
<thead>
<tr>
<th>System Displacement</th>
<th>See Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>120°</td>
</tr>
<tr>
<td>30°</td>
<td>150°</td>
</tr>
<tr>
<td>60°</td>
<td>180°</td>
</tr>
<tr>
<td>90°</td>
<td>210°</td>
</tr>
</tbody>
</table>
Section 6
INSTALLATION

6.1 INSPECTION PRIOR TO ENERGIZATION

6.1.1 After a transformer is moved, or if it is stored before installation, the inspection should be repeated before placing the transformer in service.

6.1.2 After the transformer is placed in permanent position, shipping braces should be removed, and shipping bolts, if present, should be loosened or removed per manufacturer’s recommendations.

6.1.3 Before placing in service, check the operation of fans, motors, relays, and other auxiliary devices. Verify the selection of taps and ratio connections. Check tightness and clearance of all electrical connections.

6.1.4 Before placing a sealed dry transformer in service the tank should be checked for pressure tightness, and to assure the gauge indicates the proper pressure at the specific ambient temperature recorded. If the tank pressure is appreciably less than that indicated on manufacturer’s charts for a given ambient temperature, the unit should be checked for leaks, repaired, and make-up gas added per manufacturer’s maintenance instructions.

6.2 HANDLING

6.2.1 Handling in Inclement Weather
If it is necessary to handle ventilated indoor dry-type transformers outdoors during inclement weather, they should be thoroughly protected against the entrance of dust, rain, or snow.

6.2.2 Precautions in Lifting
Dry-type transformers can be handled much like liquid-immersed transformers except that greater care may be required because of the lighter case or higher center of gravity. When lifting a transformer, the lifting cables should be held apart by spreader to avoid bending the lifting lugs or other parts of the structure. Lifting cable pull angles should not be greater than 30 degrees from the vertical. Lifting of sealed dry transformers with the tank covers removed is not recommended.

6.2.3 Skidding or Rolling
When a transformer cannot be handled by a crane, it may be skidded or moved on rollers. Care must be taken not to damage the base or overturn the transformer.

6.2.4 Protection of Accessories
Care must be exercised not to jolt or jar the transformer in the handling process. Do not attempt to move a transformer by attaching to filling valves or other attachments. Where a transformer is required to be tilted for movement through restricted passages, the manufacturer should be consulted relative to acceptable tilt angles.

6.3 GROUNDING

Consideration must be given to equipment grounding (case and core grounding) and to system grounding (such as neutral or other grounding). Grounding methods and practices are well established and are beyond the scope of this recommended practice. ANSI/IEEE Std 142 (The Green Book) contains an extensive bibliography.
6.4 ROOM REQUIREMENTS

6.4.1 Dry-type transformers located indoors should comply with the application requirements of ANSI/NFPA 70, Article 450.

6.4.2 The room in which dry-type transformers are located should be sized to permit locating transformers with sufficient spacing between units, and sufficient clearances to walls and other obstructions, to permit the free circulation of air around each unit. Sufficient space should also be provided to permit routine inspection and maintenance (see 6.6, Maintenance Accessibility).

6.4.3 Adequate ventilation is essential for the proper cooling of transformers. Clean, dry air is desirable. Filtered air at, or above, atmospheric pressure may reduce maintenance if dust or other contaminants present a particular problem. When transformers are located in rooms or other restricted spaces, sufficient ventilation should be provided to hold the air temperature within established limits when measured near the transformer inlets. This will usually require approximately 100 ft$^3$/min of air per kilowatt of transformer loss. The area of ventilating opening required depends upon the height of the room, the location of openings, and the maximum loads to be carried by the transformer. Room ventilation should not impede normal circulation of air through the transformer.

When possible, the air inlet to the room should be near the floor with the outlet in the opposite upper end of the room. The exhausting air should not exceed 15°C over the inlet air temperature. When necessary, forced air exhaust should be used to maintain this maximum differential. For self-cooled transformers, the required effective area should be at least 3 in$^2$ of inlet and outlet area per kilovoltampere of transformer capacity in service, except the required effective area should be at least 1 ft for any capacity under 50 kVA, after deduction of the area occupied by screens, gratings, or louvers.

6.5 OUTDOOR APPLICATIONS

6.5.1 Dry-type transformers may be used in outdoor locations with suitable protective measures such as weather-resistant enclosures, vehicular traffic guards and adequate drainage.

In addition, accessories such as gauges, control, and terminal chambers must be suitably protected. When located in areas accessible to the general public, the transformer enclosure must be tamper-resistant and must otherwise meet the requirements of ANSI/IEEE C2.

6.5.2 The weather-resistant enclosure may be an integral part of the transformer or separate from the transformer. The enclosure should be constructed to limit the entry of water (other than flood water) so as not to impair the operation of the transformer. All ventilating openings should be specified to have baffles, grills, or barriers which effectively prevent the entry of rain, sleet, or snow.

6.5.3 Nonventilated dry-type transformers should be provided with a weather-resistant enclosure when used in outdoor applications.
6.6 MAINTENANCE ACCESSIBILITY

6.6.1 Accessibility for maintenance should be considered when locating dry-type transformers. Transformers should be so located that there are sufficient clearances from walls and other obstructions, and sufficient spacing between transformers, to permit the unrestricted opening of hinged or removable doors, covers, and panels for the purpose of inspection, maintenance, and testing. Adequate space should be provided to accommodate such barriers and guards as are necessary to protect personnel performing these functions.

6.6.2 When located inside buildings, transformer rooms, or enclosures, means should be provided to permit the removal and replacement of a unit in the event of a failure. A route should be available which provides entrances, doorways, and passages with sufficient clearances to permit removal of the transformer. Electrical and mechanical connections of the transformer to other electrical equipment should be of a type which will permit the removal of the transformer without removal or major disassembly of the other equipment.

6.6.3 Dry-type transformers located in high rise buildings represent a particular problem of accessibility. In many instances, particular attention to the design of the transformer may permit the use of the building elevator system for removing and replacing damaged units. Removal of the transformer enclosure and partial disassembly of the core and coils may further increase the size of a unit that can be moved by the building elevators. When transformers are too large to be removed by elevator, a means of removing these transformers should be provided. In many cases, mobile cranes can be a satisfactory alternate. When mobile cranes are not available, or the height of the building is beyond their capability, booms or cranes mounted on the roof of the building, either permanently or temporarily, should be considered.

6.7 PERSONNEL AND PUBLIC SAFETY

6.7.1 Dry-type transformers should be specified to have all necessary protection and safeguards so that they do not represent a hazard to the general public, workmen in the area, or personnel working on the transformers. To the extent that it is practical, rooms and spaces in which dry-type transformers are installed should be so arranged with fences, screens, partitions or walls, or other means, to prevent entrance by unauthorized persons. Warning signs should be prominently displayed at all entrances.
Section 7
MAINTENANCE

7.1 MAINTENANCE

Dry-type transformers require occasional external cleaning, repainting, internal cleaning of air ducts, etc., and periodic care and inspection. Where periodic inspection of any kind cannot be made, it should be recognized that the life of the transformer may be affected.

The frequency of inspection will depend on the atmospheric and/or environmental conditions at a given transformer installation or location. A transformer may operate satisfactorily for many years without attention, but, under unusual service conditions, maintenance may be required in a matter of months.

If it is known that a transformer has been subjected to heavy short-circuit current stress, special efforts should be made to inspect it at the earliest possible time, since the ability of the transformer to carry rated load current or fault current may be seriously impaired if the windings have shifted.

Maintenance should be done with the transformer in a de-energized condition. This would include such things as tap changing, internal inspection and cleaning, locating causes of faulty performance, replacing parts, internal painting, etc. Corrective maintenance should be performed by a person who is familiar with the construction and operation of the apparatus and the hazards involved. In conducting corrective maintenance, such a person should:

a. After power has been disconnected from the transformer, attach ground leads or their equivalent to the input and output terminals of the transformer.

b. Inspect insulators, terminals, and terminal boards for discharge (tracking), breaks, cracks, or burns. Clean the insulators where abnormal conditions such as salt deposits, dust, or acid fumes prevail. This is necessary to avoid flashover as a result of the accumulation of foreign substance on their surface.

c. Inspect terminals for alignment, tightness, pressure, burns, or corrosion. Replace pitted or badly burned terminals. If pitting or burning is of a minor nature and plating is not damaged, smooth down the surface with clean, fine sandpaper (not emery) or follow the manufacturer’s recommendations.

d. Inspect for moisture conditions which may cause corrosion or harmful lowering of insulation levels.

e. Inspect air ducts for the accumulation of dust and foreign substances; if necessary, blow out the accumulation.

f. See that bolts, nuts, washers, pins, and terminal connections, including ground connections, are in place and in good condition.

g. Periodically inspect ground connections and ground contact surfaces for looseness of connections, erosion, corrosion and/or other conditions deleterious to a good low-impedance and current carrying connection.

h. Check insulated joints for localized heating and the condition of the insulation around the joints. When localized joint heating is present, the joint should be reconstituted and reinsulated. Any noted insulation deterioration should be cause for reinsulating the joint.
Appendix A
LOADING

The American National Standard Guide for Loading Dry-Type Distribution and Power Transformers ANSI/IEEE C57.96 provides the recommended practice and procedures for the loading of dry-type transformers covered in this standards publication.
APPENDIX B
UNITED STATES EFFICIENCY REGULATIONS

Introduction
It is the purpose of this appendix to make users of this standard aware of legislation affecting many of the products which are covered in the scope NEMA ST-20. This appendix is not intended to be an exhaustive explanation of the federal regulations regarding low-voltage dry-type distribution transformers. It is the manufacturer’s responsibility to accurately understand and abide by these regulations.

Background
The U.S. Secretary of Energy was mandated in Part C of Title III of the Energy Policy and Conservation Act (EPCA) to prescribe testing procedures and energy conservation standards for transformers which the Secretary determines that standards would be technologically feasible, economically justified and would result in significant energy savings. As of January 1st, 2007, certain low-voltage distribution transformers are mandated by federal law to have minimum efficiency levels.

U.S. Code of Federal Regulations (CFR)
The regulations pertaining to low-voltage dry-type distribution transformers at the time this standard was published are listed below.

From the United States Code of Federal Regulations

Title 10 – Energy
Chapter II – Department of Energy
Subchapter D – Energy Conservation

Part 429 Certification, Compliance and Enforcement for Consumer Products and Commercial Industrial Equipment


Numerous requirements are noted within the latest versions of 10 CFR 429 and 10 CFR 431. For covered distribution transformers, the requirements of 10 CFR 429 and 10 CFR 431 shall prevail and are not fully identified herein.

At the time of publication the above government regulations can also be found at: http://www.gpo.gov, and http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/66