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STANDARDS PUBLICATION NO. ST 20

nema

Dry-Type Transformers for General Applications

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA STANDARDS PUBLICATIONS NO. ST 20-1992

DRY-TYPE TRANSFORMERS FOR GENERAL APPLICATIONS

Reaffirmed with Revisions, January 1992

Published by

National Electrical Manufacturers Association
2101 L Street N.W., Suite 300
Washington, D.C. 20037-1526

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Foreword

This foreword is not part of ST-20 NEMA Standards for 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. The "Authorized Engineering Information" has been retained as a background and tutorial source to hopefully help the user to better understand and use this standard.

Since Audible Sound Levels do not exist in ANSI standards, this data has been retained in this standard until future revisions of ANSI standards incorporate the sound level data.

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

In preparation of this Standards Publication, input of users and other interested parties has been sought and evaluated by the Dry-Type and Specialty Transformer Section of NEMA.

Suggestions for improvements, comments, and proposed future revisions should be submitted to:

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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 the following ratings:

1. 1.2 kV class (600 volts nominal and below), 0.25 kVA and up.
2. Above 1.2 kV class sound level limits are supplied. These limits are applicable to commercial, institutional, and industrial transformers.

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.

This publication does not apply to the following types of specialty transformers: control, industrial control, Class 2, signalling, oil- or gas-burner ignition, luminous tube, cold cathode lighting, incandescent and mercury lamp. Also excluded are network transformers, unit substation transformers, and transformer distribution centers.

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DRY-TYPE TRANSFORMERS FOR GENERAL APPLICATIONS

Section 1
REFERENCED 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 C2-1984	*National Electrical Safety Code*
ANSI/IEEE C57.94-1982	*IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers*
ANSI C57.96-1989	*Guide for Loading Dry-Type Distribution and Power Transformers*
ANSI S1.4-1983	*Specification for Sound Level Meters*
ANSI C57.12.91	*IEEE Standard Test Code for Dry-Type Distribution and Power Transformers*
ANSI C57.12.01-1989	*IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those With Solid Cast and/or Resin-Encapsulated Windings*
ANSI C57.12.70-1978	*Terminal Markings and Connections for Distribution and Power Transformers*
ANSI 100-1984	*IEEE Standard Dictionary of Electrical and Electronics Terms*

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

IEEE 259-1974 (R1980)	*Systems of Insulation for Specialty Transformers, Standard Test Procedure for Evaluation of*
IEEE 4-1978	*Techniques for High-Voltage Testing*

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

NFPA 70-1990	*National Electrical Code*

National Electrical Manufacturers Association
2101 L Street, N.W., Suite 300
Washington, DC 20037-1526

NEMA 250-1991	*Enclosures for Electrical Equipment (1000 Volts Maximum)*

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

UL-1561, First Edition	*Standard for Dry-Type General Purpose and Power Transformers*

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1.2 DEFINITIONS

1.2.1 Accessible

(As applied to dry-type transformers) means admitting close approach to contact by persons due to lack of locked doors, elevation or other effective safeguards.

1.2.2 Accessible, Readily

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

NEMA Standard 1-8-1992

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 dry-type transformer.

NEMA Standard 1-8-1992

1.2.4 Alternating Current

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

NEMA Standard 1-8-1992

1.2.5 Ampacity

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

NEMA Standard 1-8-1992

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 180 degrees or half cycle.

NEMA Standard 1-8-1992

1.2.6.2 SIX-PHASE CIRCUIT

A combination of circuits energized by alternating electromotive forces which differ in phase by approximately one-sixth of a cycle, i.e., 60 degrees.

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

NEMA Standard 1-8-1992

1.2.6.3 THREE-PHASE CIRCUIT

A combination of circuits energized by alternating electromotive forces which differ in phase approximately one-third of a cycle, i.e., 120 degrees. In practice, the phases may vary several degrees from the specified angle.

NEMA Standard 1-8-1992

1.2.6.4 TWO-PHASE CIRCUIT

A combination of circuits energized by alternating electromotive forces which differ in phase by approximately one-quarter of a cycle, i.e., 90 degrees.

NEMA Standard 1-8-1992

1.2.7 Combustible Materials

Those materials which are external to the transformer and made of or surfaced with wood, compressed paper, plant fibers, or other materials that will ignite and support flame.

NEMA Standard 1-8-1992

1.2.8 Contactor

An electromagnetic device for repeatedly establishing and interrupting an electric power circuit.

NEMA Standard 1-8-1992

1.2.9 Cooling Systems

1.2.9.1 DRY-TYPE SELF-COOLED TRANSFORMER (CLASS AA)

A dry-type transformer which 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 which 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 which 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 which 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.

NEMA Standard 1-8-1992

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.

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1.2.11 Current

1.2.11.1 EDDY CURRENTS

Those currents that exist as a result of voltages induced in the body of a conducting mass by a 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.

NEMA Standard 1-8-1992

1.2.11.2 EXCITATION CURRENT OF A TRANSFORMER

The current which maintains the excitation of the transformer expressed in per unit, or in percent, of the rated current of the winding in which it is measured.

NEMA Standard 1-8-1992

1.2.12 Cycle

The complete series of values of a periodic quantity which occurs during a period. (It is one complete set of positive and negative values of an alternating current.)

NEMA Standard 1-8-1992

1.2.13 Diagrams

1.2.13.1 LETTER DESIGNATIONS

Those which 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 which 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 which 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 that 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.

NEMA Standard 1-8-1992

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 test in which the test voltages are low-frequency alternating voltages from an external source applied between conducting parts and ground without exciting the core of the transformer being tested. The purpose of the 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 tests is usually supplied at higher-than-rated frequency to avoid core saturation and excessive excitation current. The purpose of the test is to test the turn-to-turn and layer-to-layer insulation.

1.2.14.4 IMPULSE TESTS

An insulation test in which the voltage applied is a high frequency voltage of specified wave shape applied between windings and between windings and ground.

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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.

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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.

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1.2.16 Distribution Center (Secondary Distribution)

A point at which is located equipment consisting generally of automatic overload protective devices connected to buses, the principal function of which is subdivision of supply and the control and protection of feeders, subfeeders, or branch circuits, or any combinations of feeders, subfeeders, 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

A duty that demands 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; such alternate intervals being definitely specified.

1.2.17.3 PERIODIC DUTY

An 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 load for a short and definitely specified time.

1.2.17.5 VARYING DUTY

A requirement of service that demands operation at loads, and for intervals of time, both of which may be subject to wide variation.

NEMA Standard 1-8-1992

1.2.18 Enclosures

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

NEMA Standard 1-8-1992

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.

NEMA Standard 1-8-1992

1.2.20 Frequency

The number of periods occurring in unit time.

NEMA Standard 1-8-1992

1.2.21 Grounded

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

1.2.22 Hertz

The unit of frequency (cycles per second).

NEMA Standard 1-8-1992

1.2.23 Impedance

1.2.23.1 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.

It is usually expressed in per unit, or percent, of the rated voltage of the winding in which the voltage is measured.

NEMA Standard 1-8-1992

1.2.23.2 IMPEDANCE KVA

The kVA measured in one winding with the other winding short-circuited and with sufficient voltage applied to the energized winding to cause rated current to flow in that winding.

NEMA Standard 1-8-1992

1.2.24 Insulation

1.2.24.1 INSULATING MATERIAL.

A substance or body, the conductivity of which is zero or, in practice, very small.

1.2.24.2 INSULATION SYSTEM

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

1.2.25 Interlock

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

NOTE: Interlocks may be either electric or mechanical.

NEMA Standard 1-8-1992

1.2.26 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 and step-down transformations.

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1.2.27 Knockout

A portion of the wall of a box or cabinet so fashioned that it may be readily removed by a hammer, screwdriver, and pliers at the time of installation in order to provide a hole, for the attachment of a raceway cable or fitting.

NEMA Standard 1-8-1992

1.2.28 Load (output)

The apparent power in kilovoltamperes, or voltamperes, that may be transferred by the transformer.

NEMA Standard 1-8-1992

1.2.29 Losses

1.2.29.1 TOTAL LOSSES

The sum of the no-load and the load losses, excluding losses due to accessories.

1.2.29.2 NO-LOAD (EXCITATION) LOSSES

Those losses which are incident to the excitation of the transformer. No-load (excitation) 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.

1.2.29.3 LOAD LOSSES

Those losses which are 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.

NEMA Standard 1-8-1992

1.2.30 Nonenclosed

Not surrounded by a medium which will prevent a person accidentally contacting live parts.

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1.2.3 Overcurrent Protection

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

NEMA Standard 1-8-1992

1.2.32 Part

1.2.32.1 DEAD-METAL PART

A part, accessible or inaccessible, which is conductively connected to the grounded circuit under conditions of normal use of the transformer.

1.2.32.2 LIVE-METAL PART

A part consisting of electrically conductive material which can be energized under conditions of normal use of the transformer.

NEMA Standard 1-8-1992

1.2.33 Rating

1.2.33.1 RATING OF A TRANSFORMER

Consists of a voltampere 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 which can be taken from the transformer under prescribed conditions and limitations of established standards.

1.2.33.2 CONTINUOUS RATING

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

1.2.33.3 PRIMARY VOLTAGE RATING

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

1.2.33.4 SECONDARY VOLTAGE RATING

The load-circuit voltage for which the secondary winding is designed.

1.2.33.5 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.

1.2.33.6 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.

1.2.33.7 WINDING VOLTAGE RATING

The voltage for which the winding is designed.

1.2.33.8 WITHSTAND VOLTAGE RATING

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

NEMA Standard 1-8-1992

1.2.34 Ratio

1.2.34.1 TURN RATIO OF A TRANSFORMER

The ratio of the number of turns in the higher voltage winding to that in the lower voltage winding.

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.

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1.2.34.2 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, under specified conditions of the load.

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1.2.35 Reactor

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

1.2.35.1 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.

NEMA Standard 1-8-1992

1.2.36 Regulation of a Transformer

The change in output (secondary) voltage which occurs when the load is reduced from rated value to zero, with the applied (primary) voltage maintained constant, expressed in per unit, or percent, on the base of the rated output (secondary voltage at full load).

NEMA Standard 1-8-1992

1.2.37 Resistant (used as a suffix)

Apparatus is designated as acid-resistant, moisture-resistant, fume-resistant, etc., when so constructed, protected or treated that it will not be damaged readily when subjected to the specified material or conditions for a specified time.

NEMA Standard 1-8-1992

1.2.38 Taps

1.2.38.1 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.

1.2.38.2 RATED KVA TAP (IN A TRANSFORMER)

A tap through which the transformer can deliver its rated kVA output without exceeding the specified temperature rise.

1.2.38.3 REDUCED KVA TAP (IN A TRANSFORMER)

A tap through which the transformer can deliver only an output less than rated kVA without exceeding the specified temperature rise. The current is usually that of the rated kVA tap.

NEMA Standard 1-8-1992

1.2.39 Temperatures

1.2.39.1 AMBIENT TEMPERATURE

The average temperature of the air in the immediate neighborhood of the transformer.

1.2.39.2 INSIDE TOP AIR TEMPERATURE

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

1.2.39.3 HOTTEST-SPOT TEMPERATURE

The highest temperature inside the transformer winding. It is greater than the measured average temperature of the coil conductors (using the resistance change method of temperature measurement) and is calculated by adding a differential temperature to the measured average conductor temperature. The differential value changes depending on the temperature rise. This hottest-spot temperature is the temperature which determines the insulation system.

1.2.39.4 LIMITING TEMPERATURE

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

1.2.39.5 LIMITING INSULATION SYSTEM TEMPERATURE (LIMITING HOTTEST-SPOT TEMPERATURE)

The maximum temperature selected for correlation with a specified test condition of the transformer with the object of attaining a desired service life of the insulation system.

NEMA Standard 1-8-1992

1.2.40 Transformer

A static electric device consisting of a winding, or two or more coupled windings, with or without 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.

1.2.40.1 AUTOTRANSFORMER

A transformer in which at least two windings have a common section.

1.2.40.2 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.

1.2.40.3 COMPOUND-FILLED TRANSFORMER

A transformer in which the windings are enclosed with an insulating fluid which may be combined with solid inert electrical insulating materials, and becomes solid, or remains slightly plastic, at normal operating temperatures. 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.

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1.2.40.4 DRY-TYPE TRANSFORMERS

A transformer in which the windings are in a gaseous or dry compound insulating medium.

1.2.40.5 GAS-FILLED TRANSFORMER

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

1.2.40.6 GROUNDING AUTOTRANSFORMER

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

1.2.40.7 INDOOR TRANSFORMER

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

1.2.40.8 INSULATING TRANSFORMER

A transformer used to insulate one circuit from another.

1.2.40.9 ISOLATING TRANSFORMER

A transformer inserted in a system to separate one section of the system from undesired influences of other sections.

1.2.40.10 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 which is connected directly between two of the phase wires of the three-phase lines. A tap is provided at the midpoint for connection to the teaser transformer.

1.2.40.11 NONVENTILATED TRANSFORMER

A dry-type transformer which is so constructed as to provide no intentional circulation of external air through the transformer, and operating at zero gauge pressure.

1.2.40.12 OUTDOOR TRANSFORMER

A transformer of weather-resistant construction suitable for service without additional protection from the weather.

1.2.40.13 SEALED TRANSFORMER

A dry-type transformer with a hermetically sealed tank.

1.2.40.14 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).

1.2.40.15 STEP-DOWN TRANSFORMER

A transformer in which the power transfer is from a higher voltage source circuit to a lower voltage circuit.

1.2.40.16 STEP-UP TRANSFORMER

A transformer in which the power transfer is from a lower voltage circuit to a higher voltage circuit.

1.2.40.17 TEASER TRANSFORMER

The term "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.

1.2.40.18 VENTILATED TRANSFORMER

A dry-type transformer which is so constructed that the ambient air may circulate through its enclosure to cool the transformer core and windings.

NEMA Standard 1-8-1992

1.2.41 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.

A "multiple knockout" is a knockout surrounded by one or more twistouts.

NEMA Standard 11-11-1971

1.2.42 Windings

1.2.42.1 COMMON, OR SHUNT, WINDING OF AN AUTOTRANSFORMER

That part of the autotransformer winding which is common to both the primary and the secondary circuits.

1.2.42.2 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.

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1.2.42.3 PRIMARY WINDING

The winding on the energy input side.

1.2.42.4 SECONDARY WINDING

The winding on the energy output side.

1.2.42.5 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.

1.2.42.6 STABILIZING WINDINGS

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

a. To stabilize the neutral point of the fundamental frequency voltages.
b. To minimize third-harmonic voltage and the resultant effects on the system.
c. To mitigate telephone influence due to third-harmonic current and voltages.
d. To minimize the residual direct-current magnetomotive force on the core.
e. 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.

NEMA Standard 1-8-1992

1.2.43 Wiring or Busing Terminal, Screw, and/or Lead

That terminal, screw or lead to which supply or load conductors will be connected in the field.

NEMA Standard 1-8-1992

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Section 2
RATING STANDARDS

2.1 RATINGS AND PRIMARY TAPS

Kilovoltampere and voltage ratings, and primary taps for single-phase and three-phase transformers and for autotransformers, shall be in accordance with Table 2-1.

NEMA Standard 1-8-1992

NOTE: To convert self-cooled ratings above 500 kVA to ventilated forced-cooled ratings, increase the kVA ratings in the above table by one third. The auxiliary equipment shall remain operational.

Authorized Engineering Information 1-8-1992

2.2 VOLTAGE RANGES

Transformers should operate over the voltage spread in the favorable zone as stated in Table 2-2.

Authorized Engineering Information 1-8-1992

In order that other numerical designations for system voltages which are sometimes used may be interpreted in terms of the values shown in Table 2-2, Table 2-3 has been prepared. It should be emphasized that all of the different values on any one line refer to the same value as defined by its zone values in Table 2-2.

Table 2-1
KILOVOLTAMPERE AND VOLTAGE RATINGS AND PRIMARY TAPS FOR TRANSFORMERS HAVING PRIMARY VOLTAGES UP THROUGH 600 VOLTS*

	Single-Phase kVA Rating																			
Voltage Rating of Transformer, Volts	**0.250**	**0.500**	**0.750**	**1.0**	**1.5**	**2.0**	**3.0**	**5.0**	**7.5**	**10.0**	**15.0**	**25.0**	**37.5**	**50.0**	**75.0**	**100.0**	**167.0**	**250.0**	**333.0**	**500.0**
Transformers																				
120 x 240 - 120/240	x	x	x	x	x	x	x	x	x	x	x	x	..	..	..	..	..	..	..	..
480 - 120/240	..	..	..	..	..	..	A	A	A	A	A	D	D	D	D	D	E	E	F	F
240 x 480 - 120/240	x	x	x	x	x	x	x	x	x	x	x	x	x	x	C	C	C	..	..	..
600 - 120/240	x	x	x	x	x	x	A	A	A	A	A	D	D	D	D	D	E	E	F	F
120 x 240 - 16/32	x	x	x	x	x	x	x	x	..	..	..	..	..	..	..	..	..	..	..	..
120 x 240 - 12 x 24	x	x	x	x	x	x	x	..	..	..	..	..	..	..	..	..	..	..	..	..
Autotransformers																				
240/120	x	x	x	x	x	x	x	x	x	x	x	..	..	..	..	..	..	..	..	..

	Three-Phase kVA Rating														
Voltage Rating of Transformer, Volts	**3.0**	**6.0**	**9.0**	**15.0**	**30.0**	**45.0**	**75.0**	**112.5**	**150.0**	**225.0**	**300.0**	**500.0**	**750.0**	**1000**	**1500**
480 - 208Y/120	x	x	A	A	D	D	D	D	D	D	D	E	E	E	F
600 - 208Y/120	x	x	A	A	D	D	D	D	D	D	D	E	E	E	F

*See 4.2.1.2

X-designates a transformer having no primary taps.

A-designates a transformer having two 5 percent full-capacity primary taps below rated voltage.

C-designates a transformer having two 5 percent full-capacity primary taps below rated voltage on the 240-volt winding and four 2.50 percent full-capacity primary taps below rated voltage on the 480-volt winding.

D-designates a transformer having four 2.50 percent full-capacity primary taps below rated voltage and two 2.50 percent full-capacity primary taps above rated voltage.

E-designates a transformer having two 2.50 percent full-capacity primary taps below rated voltage and two 2.50 percent full-capacity primary taps above rated voltage.

F-designates a transformer having one 5 percent full-capacity primary tap below rated voltage and one 5 percent full-capacity primary tap above rated voltage.

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Table 2-2
NOMINAL VOLTAGE RATINGS FOR DRY-TYPE TRANSFORMERS

Nominal Systems Voltage, Volts*	Favorable Zone of Primary Transformer Voltage Volts ** Minimum	Maximum
120	110	126
120/240	110/220	126/252
208Y/120	191Y/110	218Y/126
240	220	252
480Y/277	440Y/254	504Y/291
480	440	504
600	550	630

*Except for the first and second lines which indicate the usual single-phase two-and/or three-wire systems, the voltages refer to three-phase systems. Delta-connected transformers may be applied on both delta and wye systems.

**Transformers will, in general, operate throughout the zone, except that modification of loading may be required.

An input voltage variation above or below the nameplate voltage will be reflected in the same proportion in the output voltage. For a given output voltage a transformer with a tapped input may be required.

Table 2-3
OTHER DESIGNATIONS FOR SYSTEMS IDENTICAL TO THE NOMINAL VOLTAGE

Nominal Systems Voltage, Volts	Other Designations for Identical Systems, Volts
120	110, 115, or 125
120/240	110/220 or 115/230
208Y/120	199Y/115
240	220 or 230
480Y/277	440Y/254 or 460Y/265
480	440 or 460
600	550 or 575

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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.

NEMA Standard 1-8-1992

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.

NEMA Standard 1-8-1992

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 Standards Publication 250 "Enclosures for Electrical Equipment, (1000 volts maximum)" for 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.

Authorized Engineering Information 1-8-1992

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:

a. All factors for judging metals.
b. Physical strength.
c. Resistance to impact.
d. Moisture-absorptive properties.
e. Combustibility.
f. Resistance to distortion at temperatures to which the material may be subjected under conditions of normal 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-case metal shall be:

a. 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
b. 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.

NEMA Standard 1-8-1992

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, or enamelling.

NEMA Standard 1-8-1992

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.

NEMA Standard 1-8-1992

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 the enclosure.

NEMA Standard 1-8-1992

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Table 3-1
THICKNESS OF SHEET METAL*

Group	Maximum Dimensions of Enclosure: Length or Width, Inches	Maximum Dimensions of Enclosure: Area, Square Inches	Minimum Average Thickness of Sheet Metal, Inches: Steel: Without Supporting Frame	Steel: With Supporting Frames or Equivalent Reinforcement	Copper, Brass, or Aluminum: Without Supporting Frame	Copper, Brass, or Aluminum: Without Supporting Frame or Equivalent Refinforcement
I	3	6	0.020 (24)	0.020 (24)	0.023 (22)	0.023 (22)
II	8	30	0.026 (22)	0.020 (24)	0.036 (18)	0.029 (20)
III	12	90	0.032 (20)	0.020 (24)	0.045 (16)	0.029 (20)
IV	18	135	0.042 (18)	0.032 (20)	0.058(14)	0.045 (16)
V	24	360	0.053 (16)	0.042 (18)	0.075 (12)	0.056 (14)
VI	48	1200	0.067 (14)	0.053 (16)	0.095 (10)	0.075 (12)
VII	60	1500	0.093 (12)	0.053 (16)	0.122 (8)	0.075 (12)
VIII	Over 60	Over 1500	0.123 (10)	0.053 (16)	0.153 (6)	0.075 (12)

*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) and the American Wire Gage numbers (for copper, brass, or aluminum) which provide the specified minimum average thickness of metal.

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 larger rod from passing within 4 inches of a live un-insulated 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 inch 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.

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Table 3-2
KNOCKOUTS

Nominal Size of Conduit Inches	Knockout Diameter, Inches			Throat Diameter of Conduit, Inches		Maximum Diameter of Inches
	Nominal	Minimum*	Maximum	Maximum	Minimum	
1/2	0.875	0.859	0.906	0.622	0.591	1.152
3/4	1.109	1.094	1.141	0.824	0.783	1.450
1	1.375	1.359	1.406	1.049	0.997	1.804
1-1/4	1.734	1.719	1.766	1.380	1.311	2.309
1-1/2	1.984	1.969	2.016	1.610	1.529	2.598
2	2.469	2.453	2.500	2.067	1.964	3.175
2-1/2	2.969	2.953	3.000	2.469	2.346	3.562
3	3.594	3.578	3.625	3.068	2.915	4.250
3-1/2	4.125	4.094	4.156	3.548	3.371	4.803
4	4.641	4.609	4.672	4.026	3.825	5.402
5	5.719	5.688	5.750	5.047	4.795	6.674
6	6.183	6.781	5.844	6.065	5.762	7.934

*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
1/2 through 3	+1/32, -1/64
3-1/2 through 6	+1/32, - 1/32

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.

NEMA Standard 1-8-1992

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

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

NEMA Standard 1-8-1992

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:

a. 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

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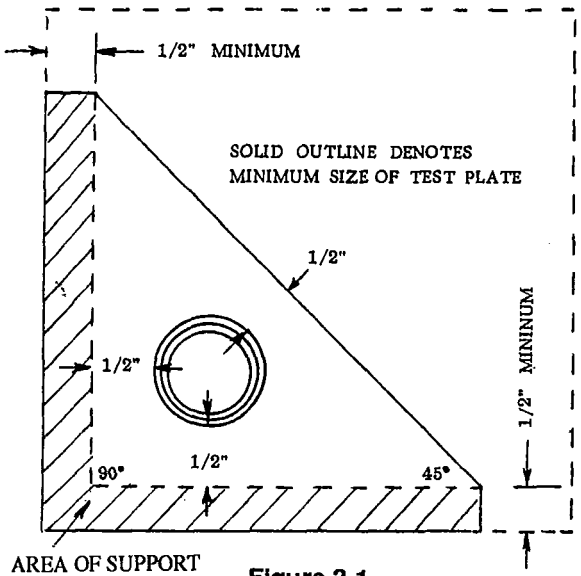


Figure 3-1
DIAGRAM OF TEST PLATE SHOWING AREA OF SUPPORT WITH RESPECT TO LOCATION OF TWISTOUTS

mandrel shall be applied at the point most likely to cause movement of the knockout in the direction in which it was originally punched.

b. 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.

NEMA Standard 1-8-1992

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.

Authorized Engineering Information 1-8-1992

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.

Authorized Engineering Information 1-8-1992

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 materials that are available, thus shortening the period of service experience required before they can be used with confidence.

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 IEEE Standard 259.

NEMA Standard 5-19-1986

3.9.2 System Limiting Temperature

The limiting temperatures of 105°C, 130°C, 150°C, 185°C, 200°C, and 220°C are approved for 55°C, 60°C, 80°C, 115°C, 130°C, and 150°C average winding rise materials, respectively, only when used in the insulation systems of apparatus within the scope of this standard. These temperatures should not be confused with the values used for identification and classification of the materials themselves.

NEMA Standard 1-8-1992

3.9.3 105°C Insulation System for 55°C Average Winding Rise Transformers

Component 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 ac-

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cepted 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.

3.9.4 130°C Insulation System for 60°C Average Winding Rise Transformers

Component insulating materials found suitable, from experience or test, for 130°C hottest spot insulation systems are: impregnated paper, nylon, 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.

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3.9.5 150°C Insulation System for 80°C Average Winding Rise Transformers

Component insulating materials found suitable, from experience or test, for 150°C hottest spot insulation systems are polyester, 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 150°C.

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3.9.6 185°C Insulation System for 115°C Average Winding Rise Transformers

Component insulating materials found suitable, from experience or test, for 185°C hottest spot insulation systems are materials or combinations of materials such as silicone, silicone glass, silicone rubber, and ester-imide. Other materials or combinations of materials, not necessarily inorganic, may be included in this insulation system if by experience or accepted tests, they can be shown to be capable of operation at 185°C.

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3.9.7 200°C Insulation System for 130°C Average Winding Rise Transformers

Component insulating materials found suitable, from experience or test, for 200°C hottest spot insulation systems are materials or combinations of materials such as 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.

NEMA Standard 1-8-1992

3.9.8 220°C Insulation System for 150°C Average Winding Rise Transformers

Component 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, 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.

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3.9.9 Over 220°C Insulation System for Over 150°C Average Winding Rise Transformers

Component 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.

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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.

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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.

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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 where located. 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.

NEMA Standard 1-8-1992

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.

NEMA Standard 1-8-1992

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 grounding blade or the equivalent fixed contacting member of the attachment plug.

NEMA Standard 1-8-1992

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 be adequate for use at a voltage no less than the rated voltage of the connected circuit and shall have a current-carrying capacity in accordance with the National Electrical Code but not less than that of the load which it controls.

NEMA Standard 1-8-1992

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.

NEMA Standard 1-8-1992

3.16 LIMITS OF WINDING TEMPERATURE RISE FOR CONTINUOUSLY RATED TRANSFORMERS

The average winding temperature rise of dry-type transformers above the ambient temperature, when measured by the change of resistance method and tested in accordance with the applicable provisions of C57.12.91, shall not exceed the values shown in Table 3-3.

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Table 3-3
AVERAGE WINDING TEMPERATURE RISE

Insulation System Temperature, Degrees C	Average Winding Temperature Rise by Resistance, Degrees C	Hottest-spot Winding Temperature Rise, Degrees C
105	55	65
130	60	90
150	80	110
185	115	145
200	130	160
220	150	180

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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.

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3.17 MAXIMUM ALLOWABLE TEMPERATURE RISE

The maximum allowable temperature rise shall be as shown in Table 3-4.

NEMA Standard 1-8-1992

3.18 REFERENCE TEMPERATURE FOR EFFICIENCY, LOSSES, IMPEDANCE, AND REGULATION

The reference temperature to which efficiency, losses, impedance, and regulation are corrected shall be as shown in Table 3-5.

3.19 TRANSFORMER SURFACE TEMPERATURES

3.19.1 Transformer Surface Temperature Rise of 65°C or Less

Transformers shall have a maximum surface temperature rise of 65°C, unless the transformer is mounted in an alcove.

3.19.2 Transformer Surface Temperature Rise When Mounted In An Alcove

The temperature rise on the enclosure of a transformer shall be permitted to exceed 65°C (117°F), but shall not exceed 80°C (144°F) if:

a. The transformer is 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 65°C (117°F)
c. The transformer is marked in accordance with paragraph 3.19.3.

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3.19.3 Marking

If the temperature rise on the transformer enclosure is greater than 65°C (117°F) 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 surfaces. The marking shall be so located that it will be plainly visible after the transformer has been installed as intended.

A transformer with an enclosure temperature rise between 65°C (117°F) and 80°C (144°F) shall be marked in letters not less than 1/2 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 shall be limited to a 50°C rise in an ambient temperature of 40°C (90°C maximum total).

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:

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FOR FIELD CONNECTIONS, USE WIRES SUITABLE FOR AT LEAST _____°C (____°F)

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Table 3-4
MAXIMUM ALLOWABLE TEMPERATURE RISES BASED ON A 24-HOUR AVERAGE AMBIENT TEMPERATURE OF 30°C

Item	Materials and Component Parts	Allowable Temperature Rise Degrees C	
1	Windings in insulation systems of (see 1.2.23.2)	Average Winding	Hottest Spot Winding
	105°C	55	65
	130°C	60	90
	150°C	80	110
	185°C	115	145
	200°C	130	160
	220°C	150	180
2	Enclosures and exposed cores	65 (except as provided in 3.19)	
3	Terminals for external connection	35 (see Note II)	
4	Contacts and fuses	65	
5	Cords - Types S, SJ, SJO, SO rubber or thermoplastic	35	
6	Sealing compounds	melting point minus 40°C	
7	Capacitors	marked temperature minus 25°C	
8	At any point on or within a terminal box or on the supply conductors	35 (except as provided in 3.21)	
9	Phenolic materials	125 (see Note II)	
10	Leads - FFH-2, RH, and RFH-2	50	
11	Leads - FF-2, R, RF-2, RU, T, TF, TEF, and TW	35	

NOTE I: When the temperature rise of terminals for external connections exceeds 35°C, information should be furnished with each transformer specifying the minimum temperature rating of the insulation of the external conductors to be used. See 3.20.

NOTE II: The limitation on phenolic materials and on thermoplastic and rubber insulations does not apply to compounds which have been investigated and recognized as having special heat-resisting properties.

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T - Transformer
X -Minimum spacing between top of transformer enclosure and surface above transformer.
Y -Minimum spacing between hotter end of transformer and adjacent side wall.
If the temperature of the right end of the transformer is higher than that of the left end, the side wall is to be to the right instead of the left as shown.
Z -Minimum spacing between rear of transformer and adjacent wall.

Figure 3-2
TRANSFORMER MOUNTED IN AN ALCOVE

Table 3-5
REFERENCE TEMPERATURE

Average Winding Temperature Rise by Resistance, Degrees C	Reference Temperature, Degrees C
55	75
60	80
80	100
115	135
130	150
150	170

NEMA Standard 1-8-1992

The temperature value to be used in the preceding statement shall be in accordance with Table 3-6.

Table 3-6
WIRING COMPARTMENT MARKING

Temperature Attained During Test		Value to Be Used In Marking
More Than	But Not More Than	
60°C (140°F)	75°C (167°F)	75°C (167°F)
75°C (167°F)	90°C (194°F)	90°C (194°F)

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3.21 CLEARANCE BETWEEN 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. The dimensions apply only to the immediate terminals.

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Table 3-7
MINIMUM SPACINGS AT FIELD WIRING TERMINALS

	Minimum Spacings Between Uninsulated Live Parts of Opposite Polarity and Between an Uninsulated Live Part and a Grounded Part of Conductive Material [a]			
	Through Air [b]		Over Surface [b]	
Voltage Involved	Inch	(mm)	Inch	(mm)
0 - 50	0.13	3.2	0.25	6.4
51 - 250	0.50	12.7	0.50	12.7
251 - 600	1.00	25.4	1.00	25.4

(a) 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.

(b)A minimum of 1 inch (25.4 mm) is required between a live part and a metal enclosure.

3.22 GROUNDING OF CORE

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

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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 grounded to the transformer frame and enclosure.

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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.

NEMA Standard 1-8-1992

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.

NEMA Standard 1-8-1992

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:

a. The identification "transformer."
b. Classes of cooling other than AA shall be specified; e.g., AA/FA, AFA, etc.
c. Number of phases.
d. Frequency(ies).
e. kVA rating(s).
f. Voltage rating(s).
g. Temperature rise(s).
h. Name of manufacturer.

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

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

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

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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

a. E shall indicate a winding of E volts which is suitable for delta connection on an E volt system. Example: 480.
b. 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.
c. E/2E shall indicate a winding, the sections of which can be connected in parallel for operation at E volts; or which can be connected 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

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to each extreme terminal.
Example: 120/240.

d. 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.

e. 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

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

b. 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.

c. 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.

d. 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. 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.

f. 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.

g. E/E_1GrdY/E shall indicate a winding having 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.

h. 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.

NEMA Standard 5-19-1986

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.

NEMA Standard 1-8-1992

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.

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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.

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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

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to make the usual check tests for phase rotation, phase relation, polarity, and equality of voltage.

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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.

NEMA Standard 5-19-1986

3.29.4 Markings

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

NEMA Standard 5-19-1986

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 3-8
TERMINAL LETTER

Winding Identification	Lead Markings	Winding Designatgion
Winding No.1	H1, H2, H3, etc.	H Winding
Winding No.2	X1, X2, X3, etc.	X Winding
Winding No.3	Y1, Y2, Y3, etc.	Y Winding
Winding No.4	Z1, Z2, Z3, etc.	Z Winding

NEMA Standard 5-19-1986

3.29.6 Significance of the Numeral 0 (Zero)

A terminal letter followed by the numeral 0 designates a neutral connection.

NEMA Standard 5-19-1986

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.

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3.29.8 Definition of Phase Sequence

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

NEMA Standard 5-19-1986

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.

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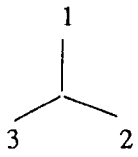


Figure 3-3
VECTOR ROTATION

3.29.10 Markings of Terminals and Identification of Windings

a. 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.

b. 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.

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

c. 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.

d. 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.

e. 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.

NEMA Standard 5-19-1986

3.29.11 Single-Phase Transformers

a. 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.

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b. 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.

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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.

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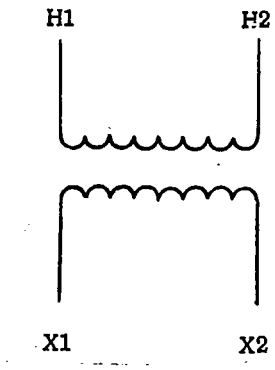


Figure 3-4
SIMPLE H AND X WINDINGS WITHOUT TAPS

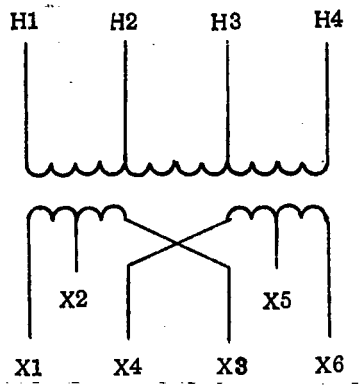


Figure 3-5
SIMPLE H WINDING WITH TAPS
SERIES-PARALLEL X WINDING

c. 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.

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3.29.12 Three-Phase Transformers

a. 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.

b. Relation Between Highest Voltage Winding and Other Windings—The markings shall be so applied that if the phase sequence of voltage on the

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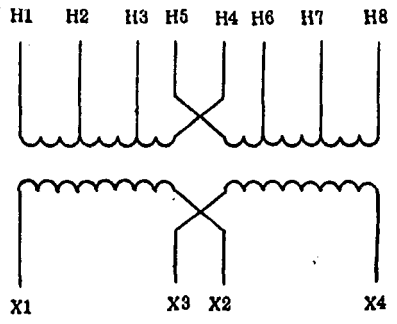


Figure 3-6
SERIES-PARALLEL H WINDING WITH TAPS SERIES-PARALLEL X WINDING

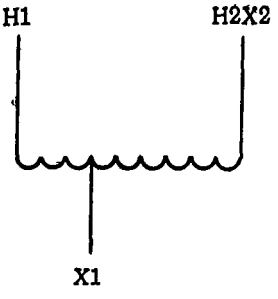


Figure 3-7
AUTOTRANSFORMER

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 3-9 and 3-10. The angular displacement between the H winding and the X winding is the angle in each of the voltage vector diagrams (see Figure 3-9 to 3-10) 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 windings is established in the same manner, using H1 and Y1; H1 and Z1, etc., respectively.

c. 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 3-10.

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 3-10.

NEMA Standard 5-19-1986

d. 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.

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e. 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.

NEMA Standard 5-19-1986

3.29.13 Three-Phase to Six-Phase Transformers

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

b. 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 3-8.

c. 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 four six-phase groups shown in Figure 3-8. 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.

d. Tap Terminals—Where tap power connection terminals from the six-phase windings are provided

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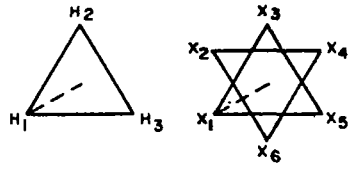
(neutral terminal excepted), they shall be marked as follows:
The double-wye (diametrical) tap terminals shall be marked from the two ends of each phase winding toward the middle or neutral point in the following order:
X7, X13, etc., from X1 toward neutral
X8, X14, etc., from X2 toward neutral
X9, X15, 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 3-8.
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 3-8.

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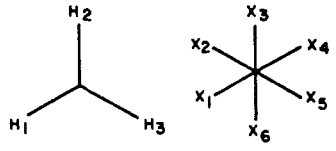
For starting purposes, it is generally customary to bring out only two taps from one delta and start three phase.

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Group 1
Angular Displacement 0°

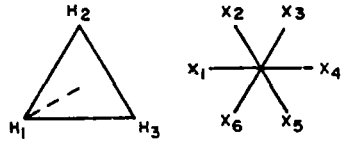


(a)

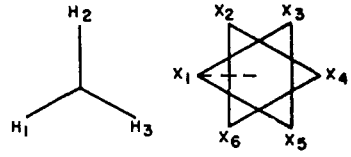


(b)

Group 2
Angular Displacement 30°



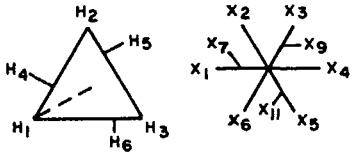
(c)



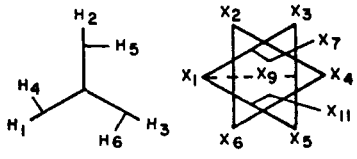
(d)

Six-Phase Transformers without Taps

Group 3
Angular Displacement 30°



(e)



(f)

Six-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 H_1 and a line drawn form neutral to X_1 measured in a clockwise direction from H_1 to X_1.

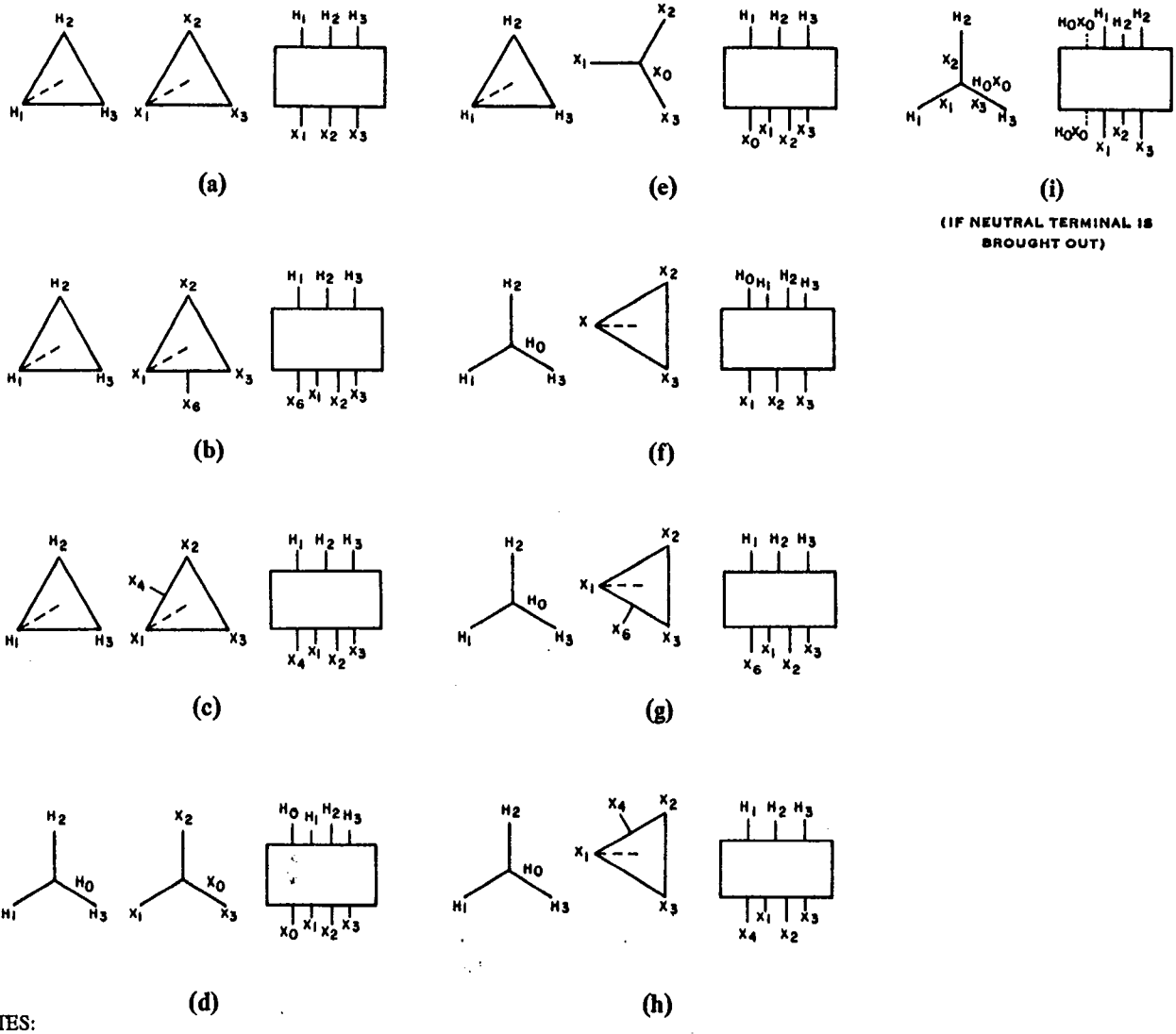
Figure 3-8
TERMINAL MARKINGS AND VOLTAGE PHASOR DIAGRAMS FOR USUAL SIX-PHASE TRANSFORMER CONNECTIONS

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Group 1
Angular Displacement 0°

Group 2
Angular Displacement 30°

Group 3
Autotransformers



NOTES:

(1) Dash lines show angular displacement between high- and low-voltage windings.

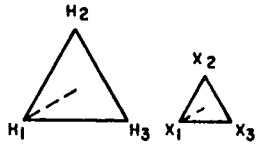
(2) Angular displacement is the angle between a line drawn from neutral to H_1 and a line drawn from neutral to X_1 measured in a clockwise direction from H_1 to X_1.

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

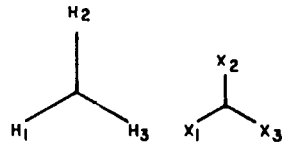
Figure 3-9
ANGULAR DISPLACEMENT AND TERMINAL MARKINGS FOR THREE-PHASE TRANSFORMERS

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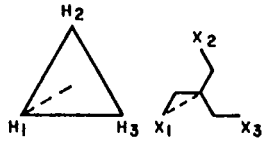
Group 1
Angular Displacement 0°



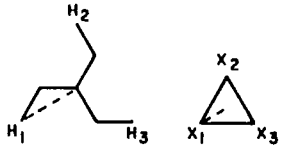
DELTA-DELTA CONNECTION



Y-Y CONNECTION

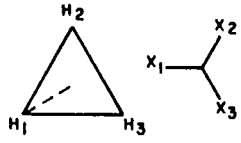


DELTA-ZZ CONNECTION

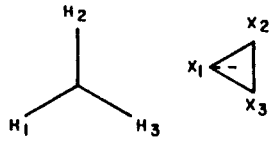


ZZ-DELTA CONNECTION

Group 2
Angular Displacement 30°



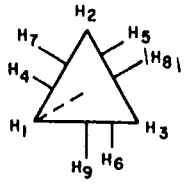
DELTA-Y CONNECTION

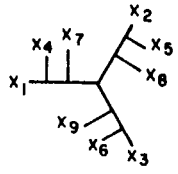


Y-DELTA CONNECTION

Three-Phase Transformers without Taps

Group 3
Angular Displacement 30°





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 winding.

(2) Angular displacement is the angle between a line drawn from neutral to H_1 and a line drawn from neutral to X_1 measured in a clockwise direction from H_1 to X_1.

(3) The zig-zag connections shown in group 1 may also be achieved using the following internal connections:

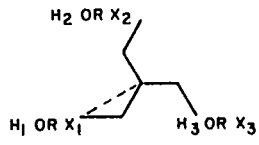


Figure 3-10
TERMINAL MARKINGS AND VOLTAGE DIAGRAMS FOR THREE-PHASE TRANSFORMER CONNECTIONS

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3.29.14 Terminal Markings—Single-Phase Transformers

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3.29.15 Terminal Markings and Voltage Vector Diagrams Usual Six-Phase Transformer Connections

The following figure is included to illustrate the method of marking transformer terminals.

3.29.16 Angular Displacement and Terminal Markings Three-Phase Transformers

The following figures are included to illustrate the method of marking transformer terminals. Dash lines show the angular displacement between high- and low-voltage windings.

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3.30 FIELD CONNECTIONS

If a dry-type transformer can be readily adapted upon installation for connection to a power supply circuit of either of 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.

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3.31 CONNECTION OF TRANSFORMERS FOR SHIPMENT

When interconnections are supplied, the following shall be observed:

a. 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.

b. 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.

c. Three-phase transformers designed for both delta and wye operation shall be shipped connected for the wye voltage.

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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.

Table 3-9
AVERAGE SOUND LEVEL

	Average Sound Level, Decibels				Average Sound Level, Decibels
	Self-cooled Ventilated Line to Line				
Equivalent Two-Winding kVA	Up to 1.2 kV (1)	Above 1.2 kV (2)	Self-cooled Sealed (3)	Equivalent Two-winding kVA	Ventilated Forced-air-cooled* (4)
0 - 9	40	45	45	0-1167	67
10- 50	45	50	50	1168-1667	68
51-150	50	55	55	1668-2000	69
151-300	55	58	57	2001-3333	71
301-500	60	60	59	3334-5000	73
501-700	62	62	61	5001-6667	74
701-1000	64	64	63	6668-8333	75
1001-1500	65	65	64	8334-10000	76
1501-2000	66	66	65		
2001-3000	68	68	66		
3001-4000		70	68		
4001-5000		71	69		
5001-6000		72	70		
6001-7500		73	71		

*Does not apply to sealed-type transformers

Columns 1,2, and 3 —Class AA rating

Column 4—Class FA and AFA rating

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Section 4
TESTING

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.

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4.1.4 Tests for Dry-Type Transformers

Tests for dry-type transformers are shown in Table 4-1.

4.1.5 This standard does not preclude the use of digital measuring equipment.

4.2 ROUTINE, DESIGN, AND PROTOTYPE TESTS

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.

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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.

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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.

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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.

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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 transformers.

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4.2.1.2 VOLTAGE TOLERANCES

a. 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 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.

b. 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.

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4.2.1.3 RATIO TEST METHODS

There are three methods of making ratio tests:

a. Voltmeter method (see 4.2.1.4).
b. 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.)
c. Ratio by Ratio Bridge method (see 4.2.1.6).

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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.

NEMA Standard 1-8-1992

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.

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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.

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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.

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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.

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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).

Table 4-1
ROUTINE TESTS

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

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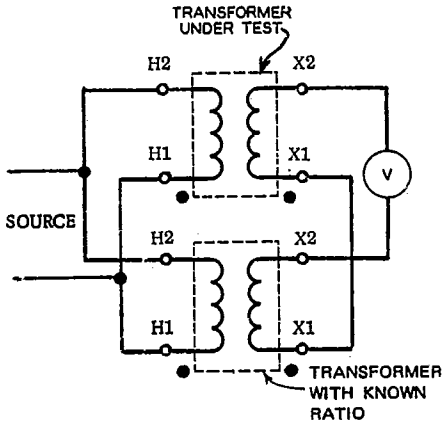


Figure 4-1
VOLTMETERS ARRANGED TO READ THE DIFFERENCE BETWEEN THE TWO SECONDARY VOLTAGES

NOTE: This is the more accurate of the comparison methods because the voltmeter or detector indicates the difference in voltage.

The voltmeters shall be interchanged and the test repeated. The average of the test results is the correct ratio.

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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.

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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.

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

a. Comparison.
b. Inductive kick.
c. Alternating voltage.
d. Ratio Bridge.

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).

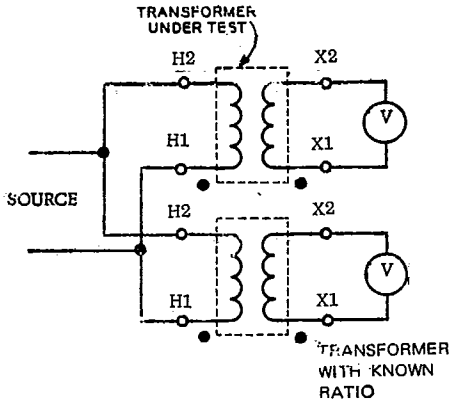


Figure 4-2
VOLTMETERS ARRANGED TO READ THE TWO SECONDARY VOLTAGES

The readings are repeated after

a. Test for phasor diagram.
b. Phase-sequence test.

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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)

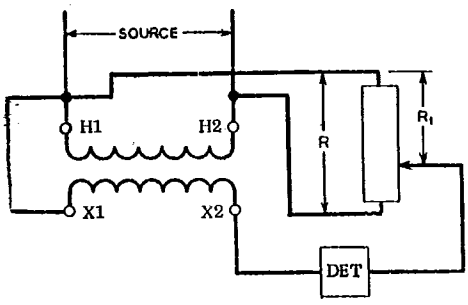


Figure 4-3
RATIO BRIDGE FOR RATIO TEST

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a. Connect the high-voltage windings of both transformers in parallel by connecting similarly marked leads together.
b. Connect also the low-voltage leads, X2, of both transformers together, leaving the X1 leads free.
c. 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.

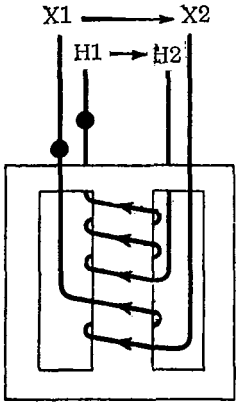
4.2.3.2 POLARITY BY INDUCTIVE KICK

The polarity of transformers with leads arranged as shown in Figure 4-4 and 4-5 may be determined at the time of making the resistance measurements as follows:

a. With direct current passing through the high-voltage winding, connect a high-voltage direct-current voltmeter across the same winding so as to get a small deflection of the pointer.
b. Transfer the voltmeter lead connected to H1 to X1 and that connected to H2 and X2.
c. 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.



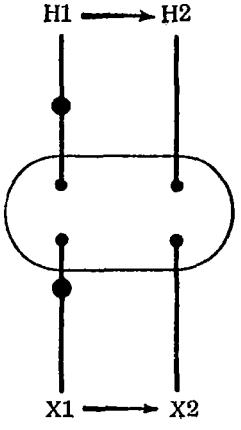


Figure 4-4 **Figure 4-5**

POLARITY BY INDUCTIVE KICK TEST

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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.

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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.

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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.

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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.

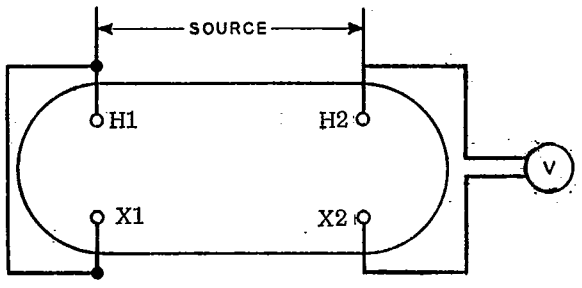


Figure 4-6
POLARITY BY ALTERNATING-VOLTAGE TEST

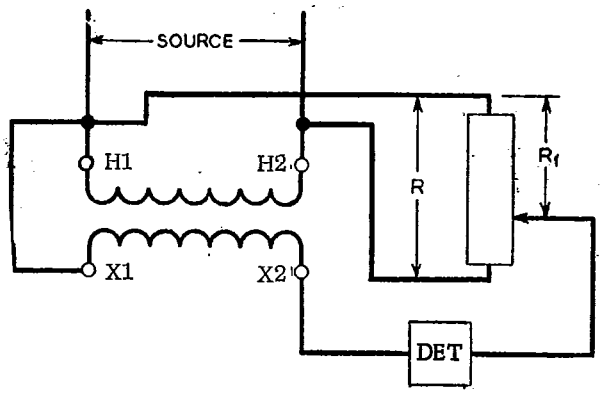


Figure 4-7
RATIO BRIDGE
FOR POLARITY TEST

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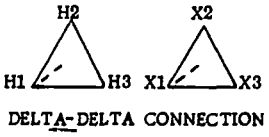
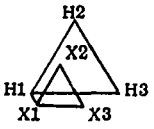
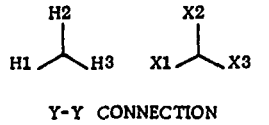
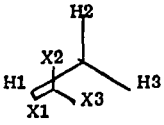
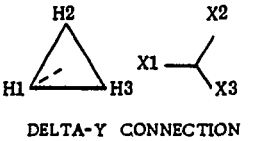
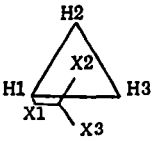
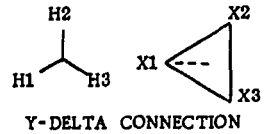
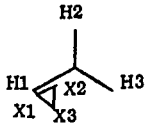
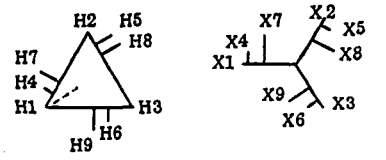
	Angular Displacement	Diagram for Check Measurement	Check Measurements
Group 1 Angular Displacement 0°	 DELTA-DELTA CONNECTION		Connect H1 to X1 Measure H2 – X2, H3 – X2, H1 – H2 H2 – X3 Voltage Relations 1. H2 – X3 = H3 –X2 2. H2 – X2 < H1 – H2 3. H2 – X2 < H2 – H3
	 Y-Y CONNECTION		
Group 2 Angular Displacement 30°	 DELTA-Y CONNECTION		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
	 Y-DELTA CONNECTION		
	THREE-PHASE TRANSFORMERS WITH TAPS 		

Figure 4-8
TRANSFORMER LEAD MARKINGS AND VOLTAGE-PHASOR DIAGRAMS FOR THREE-PHASE TRANSFORMER CONNECTIONS

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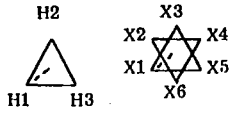
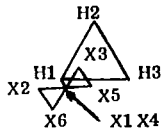
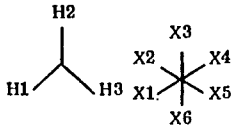
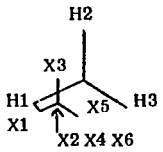
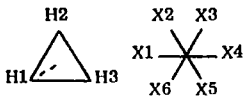
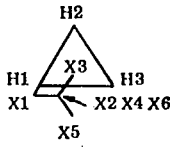
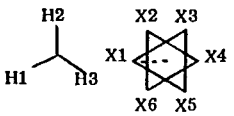
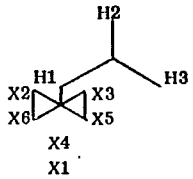
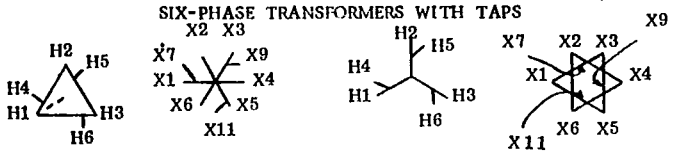
	Angular Displacement	Diagram for Check Measurement	Check Measurements
Group 1 Angular Displacement 0°	 DELTA-DOUBLE DELTA		Connect H1 to X1 to X4 Measure H2 – X3, H1 – H2, H2 – X5, H2 – X6, H3 – X2, H2 – X2, H3 – X3 Voltage Relations 1. H2 – X5 = H3 – X3 2. H2 – X3 < H1 – H2 3. H2 – X3 < H2 – H5 4. H2 – X6 = H3 – X2 5. H2 – X6 > H1 – H2 6. H2 – X2 < H2 – X6
	 Y-DIAM		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
Group 2 Angular Displacement 30°	 DELTA DIAM		Connect X2 to X4 to X6; H1 to X1 Measure H3 – X3, H3 – X5, H1 – H3, H2 – X3, H2 – X5 Voltage Relations 1. H3 – X3 = H3 – X5 2. H3 – X3 < H1 – H3 3. H2 – X3 < H2 – X5
	 Y-DOUBLE DELTA		Connect H1 to X1 to X4 Measure H3 – X3, H3 – X5, H1 – H3, H2 – X3, H2 – X5, H3 – X2, H3 – X6, H2 – X2, H2 – X6 Voltage Relations 1. H3 – X3 = H3 – X5 2. H3 – X3 < H1 – H3 3. H2 – X3 < H2 – X5 4. H3 – X2 = H3 – X6 5. H3 – X2 > H1 – H3 6. H2 – X2 < H2 – X6
	SIX-PHASE TRANSFORMERS WITH TAPS 		

Figure 4-9
TRANSFORMER LEAD MARKINGS AND VOLTAGE-PHASOR DIAGRAMS FOR SIX-PHASE TRANSFORMER CONNECTIONS

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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.

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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.

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.

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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.

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.

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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, the hysteresis loss will be the desired sine-wave value.

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If the flux wave has more than one maximum and one minimum value per cycle, average-voltage voltmeter read-

Table 4-2
TOLERANCES FOR SINGLE-PHASE AND THREE-PHASE TRANSFORMERS LOSSES

Number of Units on One Order	Basis of Determination	No-Load Losses (%)	Total Losses (%)
1	1 unit	10	6
2 or more	Each unit	10	6
2 or more	Average of all units	0	0

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ings 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.

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.

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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

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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

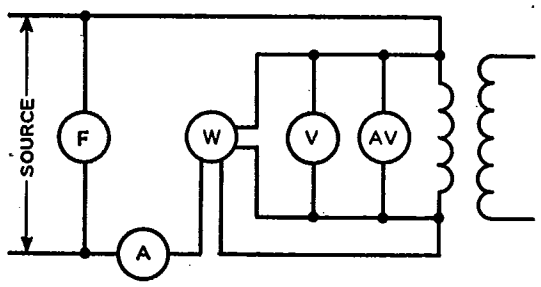


Figure 4-10
CONNECTIONS FOR THE EXCITATION TEST OF A SINGLE-PHASE TRANSFORMER WITHOUT INSTRUMENT TRANSFORMERS

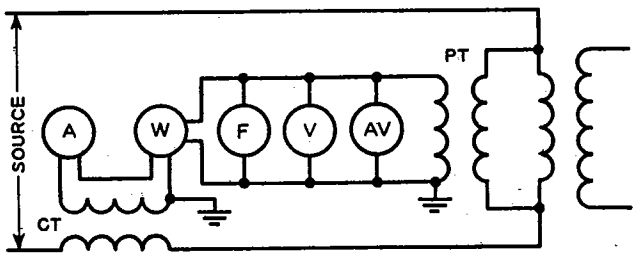


Figure 4-11
CONNECTIONS FOR THE EXCITATION TEST OF A SINGLE-PHASE TRANSFORMER WITH INSTRUMENT TRANSFORMERS

*The temperature error of an average-reading voltmeter utilizing a rectifier (especially instruments for less than 75 volts) is likely to be greater than that of rms voltmeters; therefore the temperature characteristic of such an instrument should be ascertained and a suitable correction applied.

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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 2.

The correct total excitation loss of the transformer is to be determined from the measured value by means of the following equation:

$$P = \frac{Pm}{P_1 + kP_2} \qquad \text{(Equation 4.2.6.2-1)}$$

$$k = \left(\frac{Er}{Ea}\right)^2 \qquad \text{(Equation 4.2.6.2-2)}$$

where—

E_r = 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

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 4-3
HYSTERESIS AND EDDY-CURRENT VALUES

Type of Core Material	Hysteresis, %	Eddy-Current, %
Hot-rolled silicon steel	80	20
Cold-rolled, oriented grain silicon steel	50	50

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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:

a. 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.

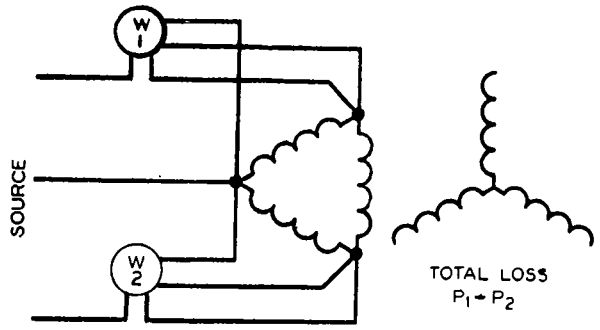


Figure 4-12
TWO-WATTMETER METHOD

b. 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.

c. 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.

d. 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.

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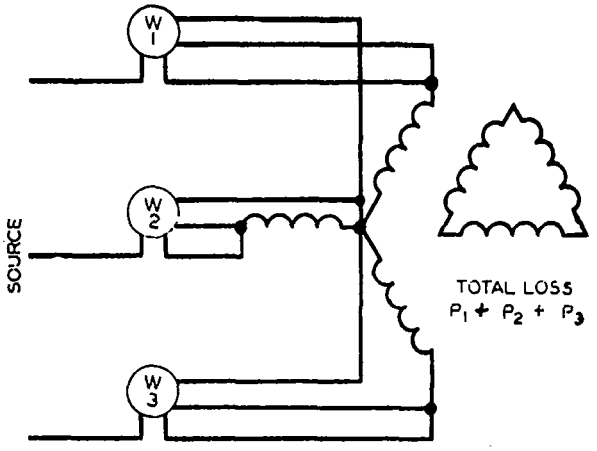


Figure 4-13
THREE-WATTMETER METHOD,
WITH TRANSFORMER NEUTRAL AVAILABLE

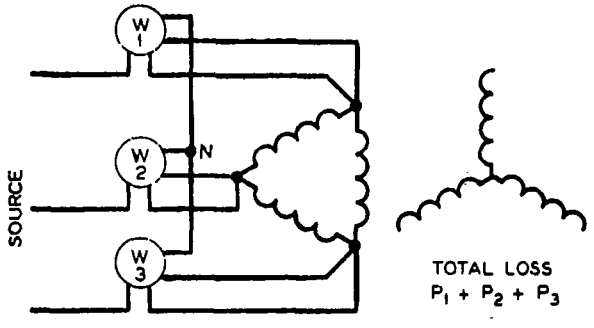


Figure 4-14
THREE-WATTMETER METHOD,
USING ARTIFICIAL WATTMETER NEUTRAL N

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:

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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.

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

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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.

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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:

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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).

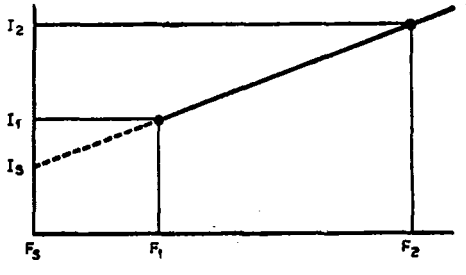


Figure 4-15
FORM-FACTOR PLOT TO REDUCE EXCITATION
CURRENT TO SINE-WAVE BASIS (IsFs)

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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.

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I_1, I_2 = 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:

$$I_s = I_2 - \frac{I_2 - I_1}{F_2 - F_1} \quad (F_2 - 1.11)$$

(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.

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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.

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

$$I_s = \sqrt{\frac{I_1^2}{6} + \frac{I_2^2}{6} + \frac{I_3^2}{6}}$$

(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.

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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:

$$I_s = \sqrt{.25I_1^2 + .338I_2^2}$$

(Equation 4.2.7.1-3)

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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.

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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

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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.

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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.

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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.

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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:

$$E_r = \frac{P_z}{I}$$

(Equation 4.2.8.4-1)

$$E_x = \sqrt{E_z{}^2 - E_r{}^2}$$

(Equation 4.2.8.4-2)

where—

E_r = resistance voltage, in-phase component
E_x = reactance voltage, quadrature component
E_z = impedance voltage
P_z = watts measured in impedance test
I = 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 fre-

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quency is applied to the other winding and adjusted to circulate rated currents in the windings (Figure 4-16).

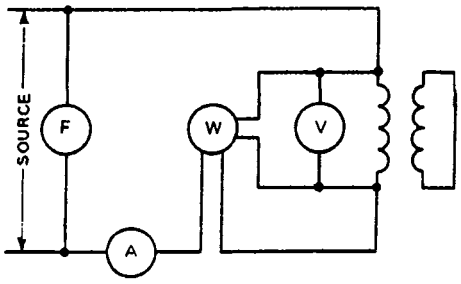


Figure 4-16
SINGLE-PHASE TRANSFORMER CONNECTION FOR IMPEDANCE-LOSS AND IMPEDANCE VOLTAGE TESTS
Instrument transformers to be added when necessary.

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 the 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 tight.

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.

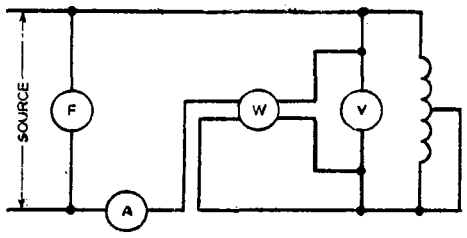


Figure 4-17
CONNECTIONS FOR IMPEDANCE-LOSS AND IMPEDANCE-VOLTAGE TESTS OF AN AUTOTRANSFORMER

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.

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With the 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.

c. Test Method for Three-phase Transformer With Three-phase Voltage—All three terminals of either the high-voltage winding or the low-voltage windings are short-circuited together, and balanced three-phase voltages of rated frequency and suitable magnitude are applied to the terminals of the other winding to force the rated currents to circulate (Figure 4-18).

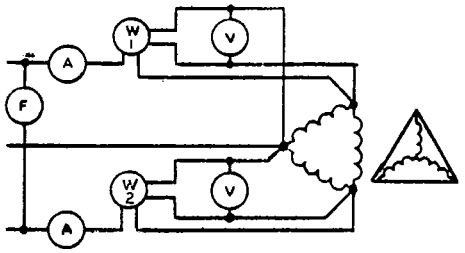


Figure 4-18
THREE-PHASE TRANSFORMER CONNECTIONS FOR IMPEDANCE-LOSS AND IMPEDANCE-VOLTAGE TESTS OF AN AUTOTRANSFORMER. Instrument transformers to be added when necessary

The procedure is similar to that described for single-phase units except that all connections and measurements are three-phase instead of single-phase.

Wattmeter readings may be taken as described for the excitation test.

If the three line currents cannot be balanced, their average rms values should correspond to the desired value.

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d. 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 transformers.

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^2R losses of the transformer. Let R1 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^2R loss of all three phases will be

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

(Equation 4.2.8.4-8)

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

Temperature correction shall be made as in 4.2.8.4.a.

e. 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:

$$Z_1 = \frac{Z_{12} - Z_{23} + Z_{31}}{2} = M_{23}$$

(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} = measured impedance values between pairs of windings, as indicated, all expressed on the same kVA base.

M = 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.

f. Impedance Bridge Method—The impedance bridge method maybe 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).

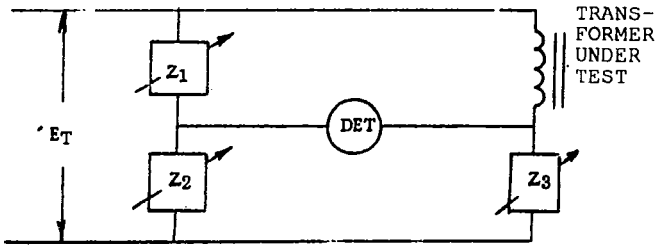


Figure 4-19
GENERAL IMPEDANCE BRIDGE NETWORK

The voltage comparison is made by adjusting one or more of the bridge arms (Z_1, Z_2, and Z_3) until the voltages across Z_2 and Z_3 are exactly equal in magnitude and phase. Voltage balance is indicated by a null reading of the detector (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)

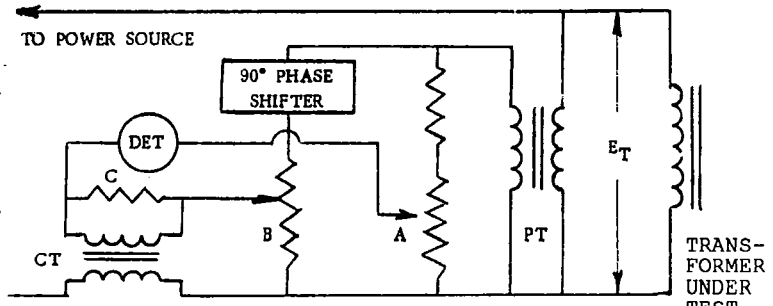


Figure 4-20
POTENTIOMETER-TYPE NETWORK USING A PHASE SHIFTER

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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.

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.

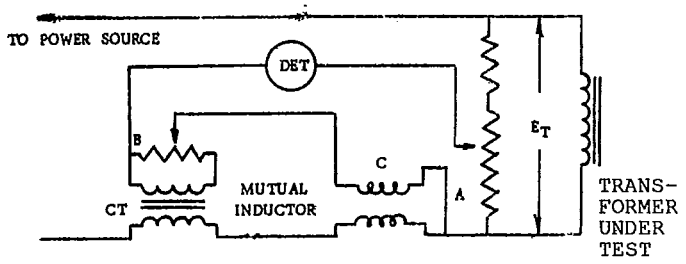


Figure 4-21
POTENTIOMETER-TYPE NETWORK USING A MUTUAL INDUCTOR

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.

3. 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.

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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.

NEMA Standard 1-8-1992

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 tests applied between windings and ground and to induced-voltage tests.

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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:

a. Applied potential test.
b. Induced potential test.

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

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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.

NEMA Standard 5-19-1986

Table 4-4
APPLIED POTENTIAL TEST VOLTAGES

Nameplate Voltage Rating, Volts	Test Potential, kV
0–250	2.5
251–1200	4

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.

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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.

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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.

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

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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, a 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.

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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 4-5
INDUCED-POTENTIAL TEST DURATION

Frequency, Hertz	Duration, Seconds
120 and less	60
180	40
240	30
360	20
400	18

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

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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 at 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.

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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 Figure 3-11 when measured as follows.

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4.2.10.1 TEST CONDITIONS

Measurements shall be made in an ambient having a sound level of at least 5 decibels, and preferably 10 decibels or more, lower than the sound level of the transformer and ambient combined. The ambient sound level shall be the average of the measurements taken immediately before and immediately after the transformer is tested at each of 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.

The transformer shall be energized at rated voltage and frequency, with no load.

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4.2.10.2 MEASUREMENTS

a. Sound levels shall be measured with an instrument which is in accordance with ANSI S1.4, 1983.
b. The average sound level is defined as the arithmetic mean of the sound level readings taken in accordance with 4.2.10.2.4 and 4.2.10.2.5.
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 primary and secondary switchgear compartments.
d. For transformers having an overall height of less than 8 feet, measurements shall be made at approximately half height. For transformers having an overall height of 8 feet and above, measurements shall be made at approximately 1/3 and 2/3 height.
e. Starting at a point opposite the front center of the transformer and proceeding clockwise around the transformer as viewed from above, 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 opposite each reference point. When the overall height of the transformer is 4 feet or less, an additional sound level measurement shall be made above the center of the top surface. The microphone shall be located on a straight line which is perpendicular to the major sound producing surface at the reference point. The microphone shall be 1 foot from the major sound producing surface.

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Table 4-6
SOUND LEVEL CORRECTIONS

Difference In Decibels Between the Average Sound Level of Transformer and Ambient Combined and Average Sound Level of Ambient	Corrections In Decibels to be Applied to Average Sound Level of Transformer and Ambient Combined to Obtain Average Sound Level of Transformer
5	- 1.6
6	- 1.3
7	- 1.0
8	- 0.8
9	- 0.6
10	- 0.4
over 10	- 0.0

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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 draft-free area for 24 hours 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 20°C. In addition, it may be necessary to convert the resistance measurements to the temperature at which the impedance-loss measurements were made. The conversions are accomplished by the following formula:

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

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 because of their accuracy and convenience, since they may be employed for the measurement of resistances up to 10,000 Ohms. They should be used in cases where the rated current of the transformer winding to be measured is less than 1 ampere.

NOTE: For resistance values of 1 Ohm or more a Wheatstone bridge (or equivalent) is commonly used; for values less than 1 Ohm 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

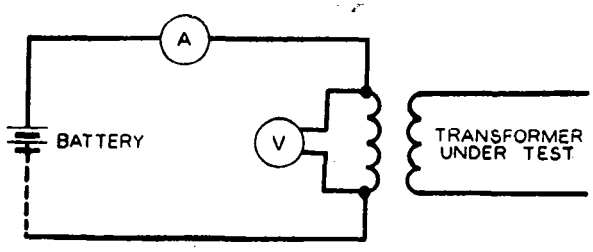


Figure 4-22
CONNECTIONS FOR THE VOLTEMETER-AMMETER METHOD OF RESISTANCE MEASUREMENT

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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.

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 are used. The average of the resistances calculated from these measurements shall be considered to be the resistance of the circuit.
   The current used shall not exceed 15 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 connected as per its nameplate rating.

For this test, the transformer shall be operated from a circuit of rated primary voltage and shall deliver 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.

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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

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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.

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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.

The ambient temperature shall be the average of the readings from at least three thermocouples or thermometers, spaced uniformly around the transformers under test.

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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.

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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 test 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.

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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.

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

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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.

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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

$$C = \frac{T_k + 30}{T_k + T_a}$$

(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

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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.

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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.

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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.

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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 can be used for nonventilated dry-type transformers.

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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)

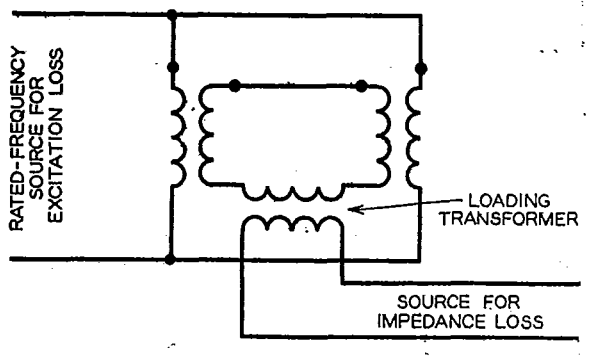


Figure 4-23
TWO SINGLE-PHASE TRANSFORMERS IN OPPOSITION

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.

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4.2.12.4 TEMPERATURE RISE TEST OF THREE-PHASE TRANSFORMERS BY THE LOADING-BACK METHOD

Duplicate three-phase transformers may be tested by the load-back method by connecting both the high-voltage and low-voltage windings in parallel (Figure 4-24).

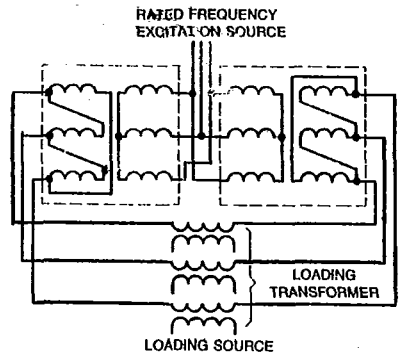


Figure 4-24
TWO WYE-DELTA CONNECTED TRANSFORMERS

It is desirable to connect similarly marked leads together rather than attempt to connect windings in parallel by symmetry alone.

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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).

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

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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.

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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 frequency shall be applied to one of the deltas.

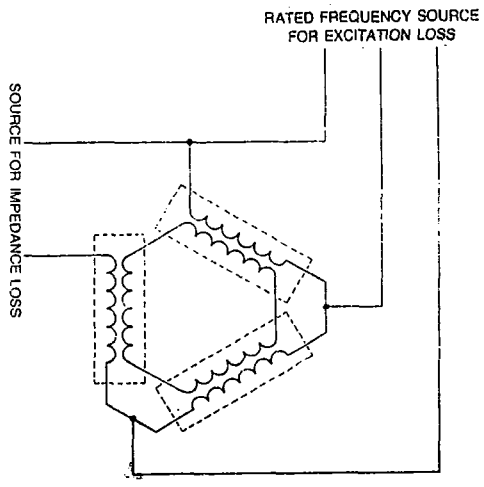


Figure 4-25
DELTA-DELTA CONNECTION FOR THREE SINGLE-PHASE UNITS FOR ONE THREE-PHASE UNIT

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.

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The circulated current should preferably be at rated frequency.

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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).

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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.

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:

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

(Equation 4.2.12.6-1)
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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)
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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)

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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.

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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:

Increase in temperature rise at altitude A (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 4-7
EMPIRICAL FACTOR F

Type of Cooling	Empirical Factor, F
For dry-type, self-cooled (AA)	0.005
For dry-type with auxiliary forced-air cooling (AA/FA)	0.006*
For dry-type forced-air cooled (AFA)	0.0100

* Applies to forced-cooled rating only.

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

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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.

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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

This method may be used as long as the required values of no-load loss, load loss or total loss, do not differ by more than 20 percent from their corresponding values during test.

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4.2.12.11 CORRECTION BACK TO SHUTDOWN, COOLING CURVE METHOD

Take a series of at least four, preferably more, readings on one phase of each winding, and record the time after shutdown for each reading.

The readings shall be time spaced to assure accurate extrapolation back to shutdown.

The overall reading time shall exceed 4 minutes and shall extend considerably beyond.

The first reading on each winding must be taken as quickly as possible after shutdown, but not before the measuring current has become stable, and must be taken within 4 minutes.

Plot the resistance time data on suitable coordinate paper and extrapolate the curve back to instant of shutdown.

The resistance value so obtained shall be used to calculate the average winding temperature at instant of shutdown.

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The resistance time curve obtained on one phase of the primary winding, or of the secondary winding, and so forth, may be used to determine the correction back to shutdown for the other phases of the primary, or secondary, windings, and so forth, provided the first reading on each

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of the other windings has been taken within 4 minutes after shutdown.

If necessary, the temperature test may be resumed so that the first readings on any group of windings may be completed within the required 4 minutes.

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4.2.12.12 ALCOVE CONSTRUCTION FOR TEMPERATURE RISE TEST

The side-wall and the top of the test alcove represented in Figure 3-3 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.

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4.2.13 Short-Circuit Capability

For short circuit duty requirements, see ANSI C57.12.01. For the details of testing a dry-type transformer to determine its ability to withstand a specified short current, see ANSI C57.12.91.

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.

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4.3.1.2 REGULATION COMPUTATION

Formulae 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 4.3.1.2-1)

where —

p = power factor of load

$q = +\sqrt{1} - P2$

r = resistance factor of transformer $= \dfrac{\text{impedance loss in kW}}{\text{rated kVA}}$

z = impedance factor $= \dfrac{\text{impedance kVA}}{\text{rated kVA}}$

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 4-8.

Table 4-8
POWER FACTOR AND REACTIVE FACTOR

p	q	p	q
1.00	0.00	0.65	0.760
0.95	0.312	0.60	0.800
0.90	0.436	0.50	0.866
0.85	0.527	0.40	0.916
0.80	0.600	0.30	0.954
0.75	0.661	0.20	0.980
0.70	0.714	0.10	0.995

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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.

NEMA Standard 1-8-1992

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.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{input} - \text{losses}}{\text{input}}$$

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

NEMA Standard 1-8-1992

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 a 0.50 inch square contact area at the transformer surface. The results are acceptable if there is no inward deflection greater than 0.50 inch.

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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.

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.

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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. The average ambient temperature for any 24-hour period does not exceed 30°C, and the maximum ambient temperature does not exceed 40°C.

b. The altitude does not exceed 3300 feet (1000 meters).

NEMA Standard 1-8-1992

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.

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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 feet (1000m).

a. Temperature. Dry-type transformers designed for temperature rise in accordance with 5.2 may be used at altitudes greater than 3300 feet (1000m) without exceeding the temperature limits, provided that either, or a combination of, the following conditions prevails:

1. The temperature of the cooling air is less than the limiting ambient temperature, by an amount corresponding to the change in temperature rise due to altitude, or does not exceed the maximum values of column "d" of Table 5-1.
2. The load to be carried is less than the rating of the transformer by an amount corresponding to the appropriate altitude correction.

b. Insulation. The dielectric strength of dry-type transformers varies with altitude. Table 5-1 shows the approximate relative dielectric strength for altitudes above 3300 feet (1000m) at any given temperature.

Table 5-1
ALTITUDE CORRECTION FACTORS

Altitude		Altitude Correction Factor to be applied to			
		(a)	(b)	(c)	(d)
Feet	Meters	Dielectric Strength	Current Rating	Ambient Temperature	Maximum Temperature of the Cooling Air Degrees C
3300	1000	1.00	1.00	1.00	40
4000	1200	0.98	0.995	0.992	39
5000	1500	0.95	0.99	0.98	37.5
6000	1800	0.92	0.985	0.968	36
7000	2100	0.89	0.98	0.956	34.5
8000	2400	0.86	0.97	0.944	33
9000	2700	0.83	0.965	0.932	31.5
1000	3000	0.80	0.96	0.92	30
12000	3600	0.75	0.95	0.896	27
14000	4200	0.70	0.935	0.872	24
15000	4500	0.67	0.93	0.86	22.5

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c. Altitude Correction Factors. The maximum current at which the transformer is used should not exceed the transformer rating multiplied by the altitude current correction factor from column "b" of Table 5-1. A transformer of a given temperature rise may be used at its equivalent nameplate current rating, without exceeding ultimate temperature limits, provided that the ambient temperature does not exceed the ambient allowed in 5.2 multiplied by the altitude ambient temperature correction factor from column "c" of Table 5-1. The correction factors in columns "b" and "c" of Table 5-1 are not to be applied at the same time. The dielectric strength should be multiplied by the altitude correction factor from column "a" of Table 5-1. If the derating, as determined from the table, is serious, transformers of a higher rating should be chosen to meet the requirements after the derating factors have been applied.

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

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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.

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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 C57.12.01-1989.

5.4 Loading

5.4.1 In general, dry-type transformers are designed to operate continuously at their nameplate kilovoltampere rating. ANSI C57.96-1989 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, 185°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.

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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

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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.

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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.

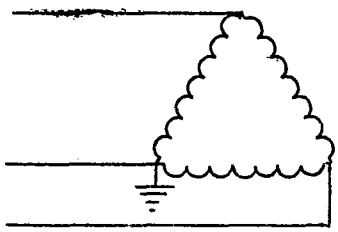


Figure 5-1
DELTA CIRCUIT WITH ONE CORNER GROUNDED

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 phase but not on either of the two ungrounded phases.

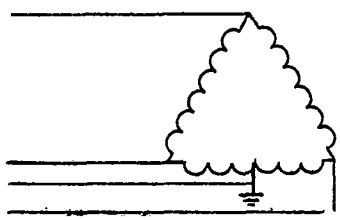


Figure 5-2
DELTA CIRCUIT WITH THE MIDPOINT OF ONE PHASE GROUNDED

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.

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5.6.4 Precautions in Connecting Autotransformers

The use of single- or three-phase autotransformers on three-phase circuits should be approached with caution. 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.

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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.

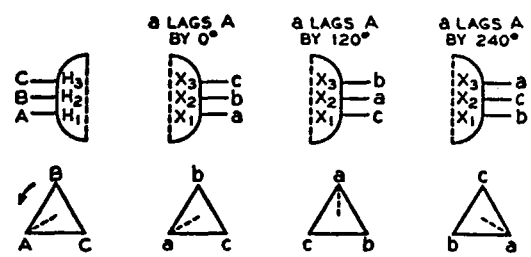
NEMA Standard 5-19-1986

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.



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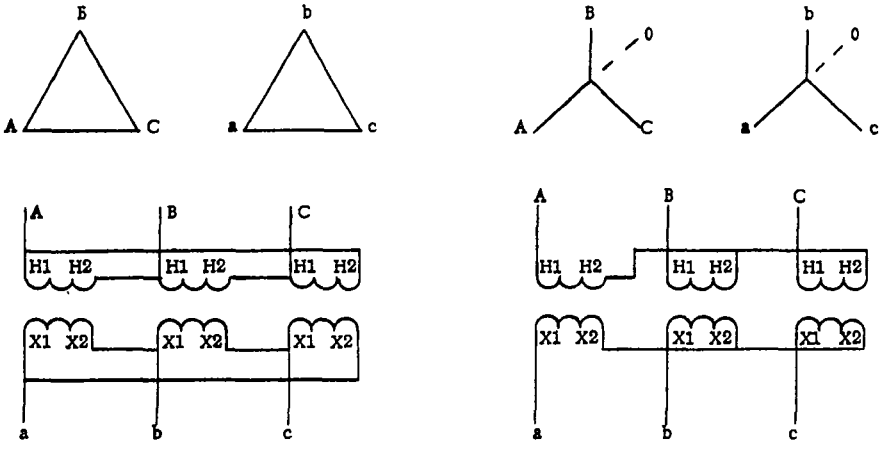


Figure 5-3*
ANGULAR DISPLACEMENT AND CONNECTIONS — SINGLE-PHASE TRANSFORMERS CONNECTED DELTA-DELTA AND Y-Y IN THREE-PHASE BANKS WITH 0-DEGREE ANGULAR DISPLACEMENT

*Dash lines show angular displacement between high- and low-voltage windings.

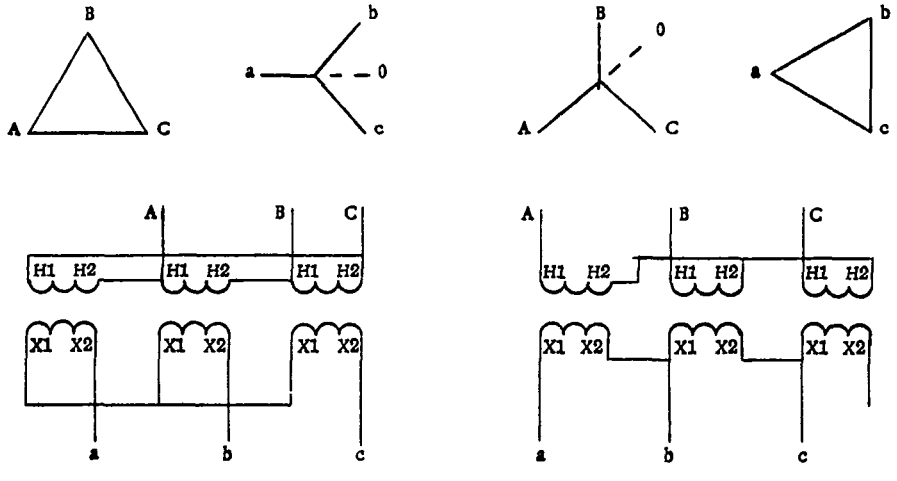


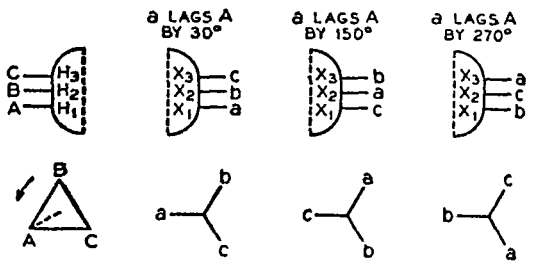
Figure 5-4*
ANGULAR DISPLACEMENT AND CONNECTIONS — SINGLE-PHASE TRANSFORMERS CONNECTED DELTA-Y AND Y-DELTA IN THREE-PHASE BANKS WITH 30-DEGREE ANGULAR DISPLACEMENT

*Dash lines show angular displacement between high- and low-voltage windings.

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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.



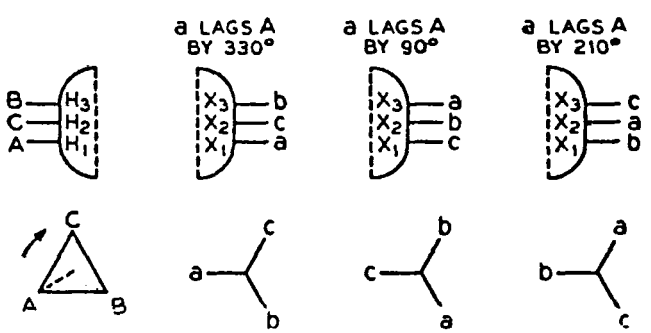
5.8.3 60-Degree Phase Displacement—Delta-Y or Y-Delta

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.

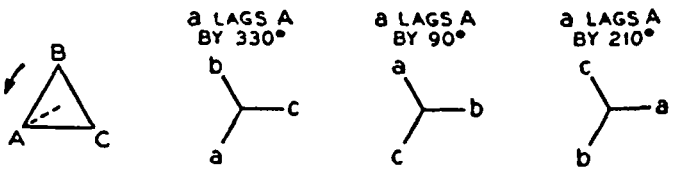
5.8.4 90-Degree Phase Displacement

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:



SUMMARY OF PRECEDING EXAMPLES			
System Displacement			See Section
0°	120°	240°	5.8.1
30°	150°	270°	5.8.2
60°	180°	300°	5.8.3
90°	210°	330°	5.8.4

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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 a 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 142-1982 (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 70-1990, Section 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^2 for any capacity under 50 kVA, after deduction of the area occupied by screens, gratings, or louvers.

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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 C2-1981.

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.

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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.

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Appendix
LOADING

(Authorized Engineering Information 1-8-1992)

The American National Standard *Guide for Loading Dry-Type Distribution and Power Transformers* ANSI C57.96-1989 provides the recommended practice and procedures for the loading of dry-type transformers covered in this Standards Publication.

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA Standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

(Standardization Policies and Procedures, p. 1)

Definition of a Standard

A Standard of the National Electrical Manufacturers Association defines a product, process or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 2)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 8)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 7 & 16)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 7 & 16)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to authorized engineering information and not to procedures required for compliance with the standard.

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