9009279 0002590 30T

NEMA 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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

NEMA ST 20-1986

ST 20

DRY-TYPE TRANSFORMERS FOR GENERAL APPLICATIONS

Published by

National Electrical Manufacturers Association
2101 L Street N.W.
Washington, D.C. 20037

© Copyright 1986 by National Electrical Manufacturers Association

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Table of Contents

		Page
	FOREWORD	i
	SCOPE	ii
Section 1	REFERENCED STANDARDS AND DEFINITIONS	
	Referenced Standards	1
	Definitions	1
Section 2	RATING STANDARDS	
	Ratings and Primary Taps	8
	Voltage Ranges	9
Section 3	DESIGN AND MARKING	
	Design and Construction	10
	Means of Handling	10
	Transformer Enclosure	10
	Openings	11
	Wall-mounted Enclosures	13
	Testing a Knockout Surrounded by Multiple Twistouts	13
	Thermal Rating	14
	Classification of Insulating Materials	14
	Classification of Insulation Systems	14
	Coil Insulation	15
	Internal Wire, Cable and Bus	15
	Corrosive Materials	16
	Flexible Cords	16
	Switches, Circuit Breakers, Control Devices, Etc.	16
	Capacitors	16
	Limits of Temperature Rise for Continuously Rated Transformers	17
	Maximum Allowable Temperature Rise	17
	Reference Temperature for Efficiency, Losses, Impedance and Regulation	17
	Transformer Surface Temperatures	17
	Alcove for Testing When Temperature Rise on a Transformer Enclosure is Above 65°C	17
	Temperature Rise of Transformer Terminations for Field Connections	17
	Clearance Between Terminals for Field Connections	19
	Grounding of Core	19
	Contact Surfaces of Grounding Terminals	19
	Marking	19
	Nameplates	19
	Designation of Voltage Ratings of Windings	20
	Autotransformers	20
	Tap	21
	Terminal Markings	21
	Field Connections	26
	Connection of Transformers for Shipment	26

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Table of Contents (*continued*)

Section 4 TESTING

Classification of Tests ... 26
Routine Tests ... 26
Design Tests ... 26
Tests for Dry-Type Transformers ... 26
Prototype Tests ... 26
Routine, Design and Prototype Tests ... 27
Ratio Tests ... 27
Polarity and Phase Relation Tests ... 28
Method of Polarity Test ... 29
Phase-Relation Tests ... 30
Total Losses ... 30
No-Load Losses (Excitation Losses) ... 33
Excitation Current (No-Load Current) ... 35
Impedance ... 37
Dielectric Tests ... 42
Audible Sound Level Tests ... 43
Resistance Measurements ... 44
Temperature Tests ... 46
Short-circuit Capability ... 50
Regulation and Efficiency ... 52
Regulation of a Transformer ... 52
Efficiency ... 52

Section 5 APPLICATION, INSTALLATION AND MAINTENANCE

Selection of Rated Transformer kVA ... 53
Usual Temperature and Altitude Service Conditions ... 53
Unusual Temperature, Altitude and Environmental Service Conditions ... 53
Overcurrent Circuit Protection ... 54
Overvoltage Circuit Protection ... 54
Parallel Operation ... 54
Autotransformers ... 54
Single-phase Transformer Connections for Three-Phase Banks ... 55
Use of Transformers in Connecting Systems of Various Phase Displacements ... 56
General Precautions During Installation ... 57
Grounding of Enclosure and Conductor ... 57
Sound ... 57
Location ... 58
Accessibility (Working Space About Dry-Type Transformers) ... 58
Ventilation ... 58
Atmospheric Conditions ... 59
Spacings for Dry-Type Transformers Installed Indoors ... 59
Knockouts and Entrance Holes ... 59
Maintenance ... 60

Appendix A LOADING ... 63

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Foreword

In the 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. Inquiries, comments, and proposed or recommended revisions should be submitted to the concerned NEMA product subdivision by contacting the:

Manager, Engineering Department
National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, D.C. 20037

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Scope

This Standards Publication applies to single-phase and polyphase dry-type transformers (including autotransformers and noncurrent-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, machine tool, 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 which may also be known as load center transformers, distribution center transformers, and power center transformers.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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.

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 70-1984 — *National Electrical Code*

American National Standards Institute, Inc.
1430 Broadway
New York, NY 10018

ANSI C2-1984 — *National Electrical Safety Code*

ANSI C57.96-1959 — *Guide for Loading Dry-Type Distribution and Power Transformers*

The American National Standard *Guide for Loading Dry-Type Distribution and Power Transformers* is currently being revised and updated. This document provides the recommended practice and procedures for the loading of dry-type transformers covered in this Standards Publication.

ANSI S1.4-1983 — *Specification for Sound Level Meters*

National Electrical Manufacturers Association
2101 L Street, NW
Washington, DC 20037

NEMA 250-1985 — *Enclosures for Electrical Equipment (1000 Volts Maximum)*

1.2 DEFINITIONS

Accessible. 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.

Accessible, Readily. Readily accessible means 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 11-11-1971.

Accessories. Accessories are devices which perform a minor function as an adjunct or refinement to the major function of a dry-type transformer.
NEMA Standard 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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

NEMA Standard 11-11-1971.

Ampacity. Ampacity is the current-carrying capacity expressed in amperes.

NEMA Standard 11-11-1971.

Circuit.

Single-Phase Circuit. A single-phase circuit is 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 11-11-1971.

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

NEMA Standard 11-11-1971.

Three-Phase Circuit. A three-phase circuit is a combination of circuits energized by alternating electromotive forces which differ in phase approximately one-half of a cycle, i.e., 120 degrees.

NEMA Standard 11-11-1971.

Two-Phase Circuit. A two-phase circuit is 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 11-11-1971.

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

NEMA Standard 11-11-1971.

Contactor. A contactor is an electromagnetic device for repeatedly establishing and interrupting an electric power circuit.

NEMA Standard 11-11-1971.

Cooling Systems.

Dry-Type Self-Cooled Transformer (Class AA). A dry-type self-cooled transformer is a transformer which is cooled by the natural circulation of air.

Dry-Type, Self-Cooled/Forced-Air-Cooled Transformer (Class AA/FA). A dry-type self-cooled/forced-air-cooled transformer is a 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.

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

Dry-Type Self-Cooled/Future-Forced-Air-Cooled Transformer (Class AA/FFA). A dry-type self-cooled/future-forced-air-cooled transformer is a 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 11-11-1971.

Crest.

Crest Value (Peak Value). Crest value is the maximum absolute value of a function when such a maximum exists.

Crest Factor of a Function. The crest factor of a function is the ratio of its crest (peak, maximum) value to its root-mean-square (rms) value.

NEMA Standard 11-11-1971.

Current.

Eddy Currents. Eddy currents are those currents which are induced in the body of a conducting mass by a variation of magnetic flux caused by a varying magnetic field or of a relative motion of the mass with respect to the magnetic field.

NEMA Standard 11-11-1971.

Excitation Current of a Transformer. The excitation current of a transformer is 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 11-11-1971.

Cycle. A cycle is 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 11-11-1971.

Diagrams.

Letter Designations. Letter designations are 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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

C = maximum floor space dimension along a line at right angles to dimension B.

Illustrative Diagram. An illustrative diagram is a diagram whose principal purpose is to show the operating principal of a device or group of devices without necessarily showing the actual connections or circuits. Illustrative diagrams shall be permitted to use pictures or symbols to illustrate or represent devices or their elements.

One-Line Diagram. A one-line (or single-line) diagram is a diagram which indicates by means of single lines and simplified symbols, the route and component devices or parts of an electric circuit or systems of circuits. Physical relationships are usually disregarded.

Schematic Diagram or Elementary Diagram. A schematic or elementary diagram is a diagram which shows all circuits and device elements of an equipment and its associated apparatus, or any clearly defined functional portion thereof. Such a diagram emphasizes the device elements of a circuit and their functions as distinguished from the physical arrangement of the conductors, devices, or device elements of a circuit system.

To emphasize the device elements and show their functional relationships and sequence, physical relationships of devices and device elements are usually disregarded. Circuits are usually drawn in the most direct possible line between and perpendicular to parallel lines representing opposite polarities of voltage sources, and circuits which function inherently in a definite sequence are arranged to indicate that sequence.

Connection Diagram. A connection diagram is a diagram which shows the connections of an installation or its component devices, controllers and equipment. It shall be permitted to cover internal or external connections, or both, and shall contain such detail as is needed to make or trace connections that are involved. It 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 11-11-1971.

Dielectric Testing.

General. Dielectric tests are tests which consist of the application of a voltage higher than the rated voltage, for a specified time, for the purpose of determining the adequacy against breakdown of insulation materials and spacing.

Applied Dielectric Test. An applied dielectric test is one which is intended to test the insulation between windings and between windings and ground.

Induced Dielectric Test. An induced dielectric test is one which is intended to test turn-to-turn insulation and layer-to-layer insulation.

Impulse Tests. Impulse tests are dielectric tests that consist of the application of a high-frequency voltage wave of a specified shape applied between windings and between windings and ground.

NEMA Standard 11-11-1971.

Distance.

Creepage Distance. Creepage distance is the shortest distance, measured on the surface of an insulator, between parts of different electric potential.

Striking Distance. Striking distance is the shortest distance, measured through air, between parts of different electric potential.

NEMA Standard 11-11-1971.

Duty. Duty is a requirement of service which defines the degree of regularity of the load.

Continuous Duty. Continuous duty is a requirement of services which demands operation at a substantially constant load for an indefinitely long time.

Intermittent Duty. Intermittent duty is a requirement of service which demands operation for alternate intervals of (1) load and no load or (2) load and deenergized or (3) load, no load, and deenergized, such alternate intervals being definitely specified.

Periodic Duty. Periodic duty is a type of intermittent duty in which the load conditions are regularly recurrent.

Short-Time Duty. Short-time duty is a requirement of service which demands operation at a substantially constant load, for a short and definitely specified time.

Varying Duty. Varying duty is a requirement of service which demands operation at loads and for intervals of time, both of which may be subject to wide variation.

NEMA Standard 11-11-1971.

Enclosures. An enclosure is a surrounding case constructed to provide a degree of protection to personnel against contact with the enclosed equipment and to provide a degree of protection to the enclosed equipment against specified environmental conditions.

NEMA Standard 11-11-1971.

Equipment. Equipment is 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 11-11-1971.

Frequency. The frequency of a periodic quantity, in

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

which time is the independent variable, is the number of periods occurring in unit time.

NEMA Standard 11-11-1971.

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

Effectively Grounded. Effectively grounded means grounded through a grounding connection or sufficiently low impedance (inherent and/or intentionally added) that fault grounds cannot build up voltages in excess of limits established for apparatus, circuits, or systems so grounded.

An alternating-current system, or portion thereof, is said to be effectively grounded when, for all points on the system, or specified portion thereof, the ratio of zero-sequence reactance to positive-sequence reactance is not greater than three and the ratio of zero-sequence resistance to positive-sequence reactance is not greater than one, for any condition of operation and for any amount of connected generator capacity.

NEMA Standard 11-11-1971.

Hertz. Hertz is the unit of frequency and is cycles per second.

NEMA Standard 11-11-1971.

Impedance.

Impedance Voltage of a Transformer. The impedance voltage of a transformer is the voltage required to circulate rated current through one winding of the transformer when another winding is short circuited, with the respective windings connected as for rated voltage operation.

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

NEMA Standard 11-11-1971.

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

NEMA Standard 11-11-1971.

Insulation.

Insulating Materials. Insulating materials are processed compositions of recognized individual raw materials and simple combination thereof before they are fabricated, processed and placed in position in dry-type transformer coils or other structure identified with specific parts of the transformer.

Insulation System. An insulation system is an assembly of fabricated, processed and in-place combinations of component insulating materials with related structural parts as used in dry-type transformers and/or in a form representative of such use through simulation of operational conditions while portraying the effectiveness of the physical support for the insulation and the severity of forces (including environmental) tending to disrupt it.

Interlock. An interlock is an electrical or mechanical device actuated by the operation of some other device with which it is directly associated, to govern succeeding operations of the same allied devices.

NEMA Standard 11-11-1971.

IR-Drop Compensation. Ir-drop compensation of a transformer is 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, i.e., not interchangeable for step-up and/or step-down transformers hereof.

NEMA Standard 11-11-1971.

Knockout. A knockout is a portion of s sheet-metal wall or partition so fashioned that it may be readily removed at the time of installation in order to provide a hole, for the entrance of wires or the attachment of conduit, cable, etc.

NEMA Standard 11-11-1971.

Load (Output). The load of a transformer is the power in kilovoltamperes, or voltamperes, supplied by the transformer.

NEMA Standard 11-11-1971.

Losses.

Total Losses. The total losses of a transformer shall be the sum of the excitation losses and the load losses, excluding losses due to accessories.

No-Losses (Excitation) Losses. No-load losses are 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.

Load Losses. The load losses of a transformer are those losses which are incident to the carrying of load. Load losses include I^2R loss in the winding due to load current; stray loss due to stray fluxes in the windings, core clamps, etc; and also the loss due to circulating currents if any, in parallel windings.

NEMA Standard 11-11-1971.

Nonenclosed. Nonenclosed means not surrounded by a medium which will prevent accidental contact of a person with live parts.

NEMA Standard 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Overcurrent Protection. Overcurrent protection refers to means provided for the purpose of opening the electric circuit if the current reaches a value which will cause an excessive or dangerous temperature.

NEMA Standard 11-11-1971.

Part.

Dead-Metal Part. A dead-metal part is one, accessible or inaccessible, which is not conductively connected to the power supply circuit under conditions of normal use of the transformer.

Live-Metal Part. A live-metal part is one which consists of electrically conductive material which can be energized under conditions of normal use of the transformer.

NEMA Standard 11-11-1971.

Rating.

Rating of a Transformer. The rating of a transformer consists of a voltampere output together with any other characteristics, such as voltage, current, frequency, and power factor, assigned to it by the manufacturer. The rating of a transformer is a test rating wich defines an output which can be taken from the transformer under prescribed conditions of test and within the limitations of established standards.

Continuous Rating. The continuous rating of a transformer defines the maximum constant load which can be carried continuously without exceeding established termperature rise limitations under prescribed conditions of test and within the limitations of established standards.

kVA Rating of a Transformer. The kVA rating of a transformer is the output which can be delivered for the time specified at rated secondary voltage and rated frequency without exceeding the specified temperature rise limitations under prescribed conditions of test and within the limitations of established standards.

Primary Voltage Rating. The primary voltage rating of a transformer designates the input-circuit voltage for which the primary winding is designed.

Secondary Voltage Rating. The secondary voltage rating of a transformer designates the load-circuit voltage for which the secondary winding is designed.

Short-Time Rating. The short-time rating of a transformer defines the maximum constant load which can be carried for a specified short time, the transformer being approximately at room temperature at the time the load is applied, without exceeding the specified temperature limitation and within the limitations of established standards.

Voltage Rating of a Grounding Transformer. The voltage rating of a grounding transformer is the maximum "line-to-line" voltage at which it is designed to operate continuously.

Winding Voltage Rating. The winding voltage rating of a transformer designates the voltage for which the winding is designed.

Withstand Voltage Rating. The withstand voltage rating of a transformer is the voltage that the transformer is required to withstand without failure or disruptive discharge when tested under specified conditions.

NEMA Standard 11-11-1971.

Ratio.

Turn Ratio of a Transformer. 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.

In the case of a transformer having taps for changing its voltage ratio, the turn ratio is the number of turns corresponding to the normal rated voltage of the respective windings to which operating and performance characteristics are referred.

NEMA Standard 11-11-1971.

Voltage Ratio of a Transformer. The voltage ratio of a transformer is the ratio of the rms primary terminal voltage to the rms secondary terminal voltage under specified conditions of load.

NEMA Standard 11-11-1971.

Reactor. A reactor is a device used for introducing impedance into an electric circuit, the principal element of which is inductive reactance.

Current-Limiting Reactor. A current-limiting reactor is 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 11-11-1971.

Regulation of a Transformer. The regulation of a transformer is 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 in percent, on the base of the rated output (secondary voltage at full load).

NEMA Standard 11-11-1971.

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 injured readily when subjected to the specified material or condition.

NEMA Standard 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Taps.

Tap (In a Transformer). A tap in a transformer is a connection brought out of a winding at some point between its extremities to permit changing the voltage or current ratio.

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

Reduced kVA Tap (In a Transformer). A reduced kVA tap in a transformer is a tap through which the transformer can deliver only load less than rated kVA without exceeding the specified temperature rise.

NEMA Standard 11-11-1971.

Temperatures.

Ambient Temperature. Ambient temperature is the average temperature of the air in the immediate neighborhood of the transformer.

Inside Top Air Temperature. The inside top air temperature is the temperature of the air inside the transformer enclosure, measured in the space above the core and coils.

Hottest-Spot Temperature. The hottest-spot temperature is the highest temperature inside the transformer coil; 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.

Limiting Temperature. The limiting temperature is the temperature at which a component or material can be operated continuously with no sacrifice in life expectancy.

Limiting Insulation System Temperature. Limiting insulation system temperature (limiting hottest-spot temperature) is the 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 11-11-1971.

Transformer. A transformer is an electric device, without continuously moving parts, which by electromagnetic induction transfers electric energy from one or more circuits to one or more other circuits at the same frequency, usually with changed values of voltage and current.

Autotransformer. An autotransformer is a transformer in which part of one winding is common to both the primary and the secondary circuits associated with that winding.

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

Compound-filled Transformer. A compound-filled transformer is a transformer in which the windings or windings and magnetic core(s) are enclosed with an insulation fluid which may be combined with solid inert electrical insulating materials, and becomes solid, or remains slightly plastic, at normal operation 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 or filler or both, before solidification.

Dry-Type Transformers. A dry-type transformer is a transformer in which the windings are immersed in air or some other dry gas. (One that remains in the gaseous state throughout the range of transformer operating temperatures).

The windings shall be permitted to be coated or enclosed with compounds.

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

Grounding Autotransformer. A grounding autotransformer consists of zig-zag or T-connected transformers connected to 3-phase, 3-wire ungrounded systems for the purpose of creating a 3-phase, 4-wire distribution system or to provide a neutral reference for grounding purposes. Such a transformer shall have a continuous per-phase current rating and a continuous neutral current rating. The phase current in a grounding autotransformer is one-third the neutral current.

Grounding Transformer. A grounding transformer is a transformer intended primarily to provide a neutral point for grounding purposes.

Indoor Transformer. An indoor transformer is a transformer which, because of its construction, must be protected from the weather if used outdoors.

Insulating Transformer. An insulating transformer is a transformer used to insulate one circuit from another.

Isolating Transformer. An isolating transformer is a transformer used to separate one section of an electrical system from influences of other sections.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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, or for three-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.

Nonventilated Transformer. A nonventilated transformer is a dry-type transformer which is so constructed as to provide little or no circulation of external air through or around the core(s) and coil(s). Gasketing or the equivalent of sealing the transformer covering is not required.

Outdoor Transformer. An outdoor transformer is a transformer which is so constructed that exposure to the weather will not interfere with its successful operation.

Sealed Transformer. A sealed transformer is an air-or nitrogen-immersed dry-type transformer in which the air or nitrogen surrounding the windings is contained in a sealed tank which prevents the intermingling of outside air.

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 circuits(s).

Step-down Transformer. A step-down transformer is a transformer in which the energy transfer is from a high-voltage circuit to a low-voltage circuit.

Step-up Transformer. A step-up transformer is a transformer in which the energy transfer is from a low-voltage circuit to a high- voltage circuit.

Teaser Transformer. The term "teaser 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, or for three-phase to three-phase operation, designates the transformer which is connected between the midpoint of the main transformer and the third phase wire of the three-phase system.

Ventilated Transformer. A ventilated transformer is a dry-type transformer which is so constructed that ambient air can circulate through its enclosure to cool the transformer core and windings.

NEMA Standard 11-11-1971.

Transformer Distribution Center. A transformer distribution center is an assembly of coordinated equipment consisting of a transformer and protective devices connected to busses, the principal functions of which are subdivision of supply and the control and protection of feeders, subfeeders, or branch circuits, or combinations thereof.

NEMA Standard 11-11-1971.

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.

Windings.

Common, or Shunt, Winding of an Autotransformer. The common or shunt winding of an autotransformer is that part of the autotransformer winding which is common to both the primary and the secondary circuits.

High-Voltage and Low-Voltage Windings. The terms "high-voltage" and "low-voltage" are used to distinguish the windings having the greater from that having the lesser voltage rating.

Primary Winding. The primary winding is the winding on the energy input side.

Series Winding of an Autotransformer. The series winding of an autotransformer is 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.

Stabilizing Winding. A stabilizing winding is an auxiliary winding used particularly in Y-connected transformers for such purposes as the following:

1. To stabilize the neutral point of the fundamental frequency voltages.
2. To minimize third harmonic voltage and the resultant effects on the system.
3. To mitigate electromagnetic influence due to third harmonic current and voltages.

NEMA Standard 11-11-1971.

Wiring or Busing Terminal, Screw and/or Lead. A wiring or busing terminal, screw and/or lead is that terminal, screw or lead to which supply or load conductors will be connected in the field.

NEMA Standard 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 11-11-1971.

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

Voltage Rating of Transformer, Volts	Single-phase kVA Rating																			
	0.250	0.500	0.750	1	1.5	2	3	5	7.5	10	15	25	37.5	50	75	100	167	250	333	500
Transformers																				
120 × 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 × 480 – 120/240	X	X	X	X	X	X	X	X	X	X	X	X	X	X	C	C	E	..	..	..
600 – 120/240	X	X	X	X	X	X	A	A	A	A	A	D	D	D	D	D	E	E	F	F
120 × 240 – 16/32	X	X	X	X	X	X	X	X	..	..	..	..	..	..	..	..	..	..	..	..
120 × 240 – 12 × 24	X	X	X	X	X	X	X	..	..	..	..	..	..	..	..	..	..	..	..	..
Autotransformers																				
240/120	X	X	X	X	X	X	X	X	X	X	X	..	..	..	..	..	..	..	..	..

Voltage Rating of Transformer, Volts	Three-phase kVA Rating														
	3	6	9	15	30	45	75	112.5	150	225	300	500	750	1000	1500
480 – 208Y/120	X	X	A	A	D	D	D	D	D	D	D	E	E	F	F
600 – 208Y/120	X	X	A	A	D	D	D	D	D	D	D	E	E	F	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 2½ percent full-capacity primary taps below rated voltage on the 480-volt winding.

D—designates a transformer having four 2½ percent full-capacity primary taps below rated voltage and two 2½ percent full-capacity primary taps above rated voltage.

E—designates a transformer having two approximately 2½ percent full-capacity primary taps below rated voltage and two approximately 2½ percent full-capacity primary taps above rated voltage.

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

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 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

2.2 VOLTAGE RANGES

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

Authorized Engineering Information 11-11-1971.

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
280Y/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.

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 as defined by its zone values in Table 2-2.

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 SYSTEM VOLTAGE

Nominal System Voltage, Volts	Other Designations for Identical Systems, Volts
120	110, 115 or 125
120/240	110/220 or 115/230
280Y/120	199Y/115
240	220 or 230
480Y/277	440Y/254 or 460Y/265
480	440 or 460
600	550 or 575

Authorized Engineering Information 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 5-19-1986.

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 11-11-1971.

3.3 TRANSFORMER ENCLOSURE

3.3.1 General

A transformer which is intended for use within the enclosure 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 shall satisfy the requirements of NEMA Standards Publication 250 for Types 1, 2, or 3R. This standard shall take precedence in case of conflict, e.g., case openings larger than ½" as permitted in 3.4.

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

1. All factors for judging metals.
2. Physical strength.
3. Resistance to impact.
4. Moisture-absorptive properties.
5. Combustibility.
6. 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.

For unreinforced flat surfaces in general, cast metal shall be not less than $^1/_8$ inch thick; malleable iron shall be not less than $^3/_{32}$ inch thick; and die-case metal shall be:

1. Not less than $^3/_{32}$ inch thick where the area is greater than 24 square inches or any dimension is greater than 6 inches, and
2. Not less than $^1/_{16}$ 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 5-19-1986.

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 5-19-1986.

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 metals 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 5-19-1986.

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 ¼ 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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Table 3-1
THICKNESS OF SHEET METAL

Group	Maximum Dimensions of Enclosure		Minimum Average Thickness of Sheet Metal, Inches			
			Steel		Copper, Brass or Aluminum	
	Length or Width, Inches	Area, Square Inches	Without Supporting Frame	With Supporting Frame or Equivalent Reinforcement	Without Supporting Frame	With Supporting Frame or Equivalent Reinforcement
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.

Note: The figures in parentheses are the Manufacturers' Standard Gage numbers (for uncoated steel) and the American Wire Gage numbers (for copper, brass, or aluminum) which provide the specified minimum average thickness of metal.

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 knockouts 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 11-11-1971.

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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

straight rod having a diameter of more than ½ 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 uninsulated 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 ½ 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.

NEMA Standard 5-19-1986.

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 coables (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 corresonding to the size of the conduit as indicated int 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.

Table 3-2

Nominal Size of Conduit, Inches	Knockout Diameter, Inches			Throat Diameter of Conduit, Inches		Maximum Diameter of
	Nominal	Minimum	Maximum	Maximum	Minimum	Locknut, Inches
½	0.875	0.859	0.906	0.622	0.591	1.152
¾	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
1¼	1.734	1.719	1.766	1.380	1.311	2.309
1½	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
2½	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
3½	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
½ through 3	$+1/32$, $-1/64$
3½ through 6	$+1/32$, $-1/32$

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

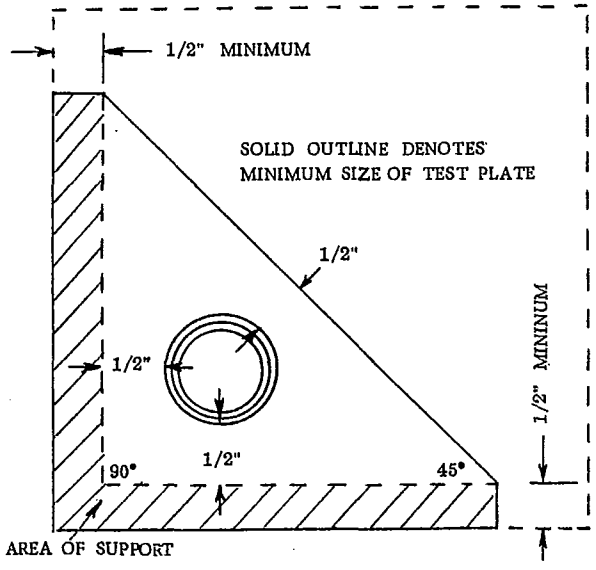


Figure 3-1
DIAGRAM OF TEST PLATE SHOWING AREA OF SUPPORT WITH RESPECT TO LOCATION OF TWISTOUTS

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 requirements does not preclude placing the compartment and its access cover on the bottom surface of a transformer.

NEMA Standard 5-19-1986.

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 3½ 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 corresonding to the nominal size of conduit involved.

NEMA Standard 5-19-1986.

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.

NEMA Standard 5-19-1986.

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 11-11-1971.

3.5 WALL-MOUNTED ENCLOSURES

An enclosure shall be provided with 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 ¼ 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:

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

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

NEMA Standard 11-11-1971.

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, either during the 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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

The following tests shall be applied:

1. 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 ¼ inch-diameter flat end. The mandrel shall be applied at the point most likely to cause movement of the knockout in the direction in which it was originally punched.
2. 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 by following the instructions contained in 5.18 without disturbing the other twistouts or distorting the box.

NEMA Standard 11-11-1971.

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 5-19-1986.

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 5-19-1986.

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, insulation 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 150 °C, 185 °C and 220 °C are approved for 80 °C rise, 115 °C rise and 150 °C rise materials, respectively, only when used in the insulation systems of apparatus within the scope of this standard. Do not confuse these temperatures with the values used for identification and classification of the materials themselves.

NEMA Standard 5-19-1986.

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

Component insulating materials found suitable, from experience or test, for 55 °C rise transformers 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 derivitives of similar properties; (4) varnishes (enamel) as applied to conductors.

Other materials or combinations of materials may be included in this insulation system if by experience or accepted test they can be shown to be capable of operation at 105 °C.

NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 itself 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. (Authorized Engineering Information 5-19-1986.)

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.

Authorized Engineering Information 5-19-1986.

3.9.4 150°C Insulation System for 80°C Rise Transformers

Component insulating materials found suitable, from experience or test, for 80°C rise transformers are mica, asbestos, glass fiber, and similar inorganic materials in built-up form with organic binding substances. A small proportion of 55°C rise materials may be used for structural purposes only. Glass fiber or asbestos magnet-wire insulations are included in this insulation system. These may include supplementary organic materials, such as polyvinylacetal or polyamide films.

Other materials or combinations of materials may be included in this insulation system if by experience or accepted test they can be shown to be capable of operation at 150°C.

Authorized Engineering Information 5-19-1986.

3.9.5 185°C Insulation System for 115°C Rise Transformers

Component insulating materials found suitable, from experience or test, for 115°C rise transformers are materials or combinations of materials such as mica, glass fiber, asbestos, etc., with suitable bonding substances. 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.

Authorized Engineering Information 5-19-1986.

3.9.6 220°C Insulation System for 150°C Rise Transformers

Component insulating materials found suitable, from experience or test, for 150°C rise transformers are materials or combinations of materials such as silicon elastomer, mica, glass fiber, asbestos, etc., with suitable bonding 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.

Authorized Engineering Information 5-19-1986.

3.9.7 Over 220°C Insulation System for Over 150°C Rise Transformers

Component insulating materials found suitable, from experience or test, for over 150°C rise transformers 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 temperatureas over 220°C.

Authorized Engineering Information 11-11-1971.

3.10 COIL INSULATION

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

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

Coil insulation shall be selected so as to be compatible with the hottest temperature that it will encounter in the insulation system under usual service conditions.

NEMA Standard 11-11-1971.

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. 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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 or 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 11-11-1971.

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 11-11-1971.

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 11-11-1971.

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 11-11-1971.

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 transformer 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 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.16 LIMITS OF TEMPERATURE RISE FOR CONTINUOUSLY RATED TRANSFORMERS

The temperature rise of dry-type transformers above the ambient temperature, when measured by the resistance method and tested in accordance with the applicable provisions of 4.2.12, shall not exceed the following:

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

NEMA Standard 5-19-1986.

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

Authorized Engineering Information 5-19-1986.

3.17 MAXIMUM ALLOWABLE TEMPERATURE RISE

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

NEMA Standard 11-11-1971.

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 follows:

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

NEMA Standard 11-11-1971.

3.19 TRANSFORMER SURFACE TEMPERATURES

3.19.1 Transformer Surface Temperature Rise of 65°C or Less

For transformers with a surface temperature rise of 65°C or less, the test outlined in 3.19.2 is omitted.

3.19.2 Transformer Surface Temperature Rise Above 65°C but not Exceeding 80°C

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

1. The temperature test is conducted with the transformer mounted in an alcove as described in 3.20 and Figure 3-2,
2. The temperature rise at any point on the inner surfaces of the alcove does not exceed 65°C (117°F), and
3. The transformer is clearly marked to indicate the minimum separations (the distances X, Y and Z in Figure 3-2) between the enclosure and the adjacent surfaces necessary to prevent temperatures exceeding 90°C (194°F) on the latter. The marking shall be so located that it will be plainly visible after the transformer has been installed as intended.

NEMA Standard 11-11-1971.

3.20 ALCOVE FOR TESTING WHEN TEMPERATURE RISE ON A TRANSFORMER ENCLOSURE IS ABOVE 65°C

The side wall and the top of the test alcove represented in Figure 3-2 are of $^3/_8$ inch thick fit plywood, and the rear wall (on which the transformer is mounted) is of ¾ 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.

Authorized Engineering Information 11-11-1971.

3.21 TEMPERATURE RISE OF TRANSFORMER TERMINATIONS FOR FIELD CONNECTIONS

3.21.1 The transformer terminations used for making field connections to cable shall be limited to a 50°C rise in an ambient of 40°C (90°C maximum total).

3.21.2 In a wiring compartment (including the outlet box on which the transformer is mounted if it is intended

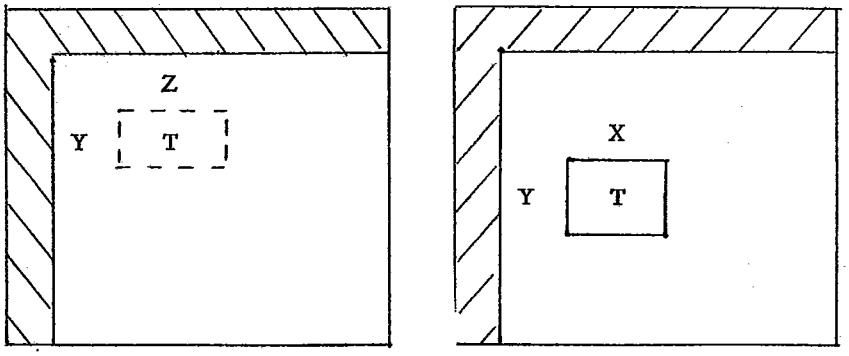
Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Table 3-3
MAXIMUM ALLOWABLE TEMPERATURE RISES BASED ON AN AMBIENT TEMPERATURE OF 30°C

Item	Materials and Component Parts	Allowable Temperature Rise, Degrees C
1	Windings in insulation systems of (see 1.2.22.2)	
	105°C	55
	150°C	80
	180°C	115
	220°C	150
2	Enclosures and exposed cores	65 (except as provided in 3.19)
3	Terminals for external connection	35 (see Note I)
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,TFF 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 3.21.

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.



PLAN ELEVATION

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
TEMPERATURE TEST SET-UP

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS

Not for Resale

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.

3.21.3 Where cables rated above 90 °C and/or bus 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.

3.21.4 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:

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

The temperature value to be used in the preceding statement shall be in accordance with the following table:

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)

NEMA Standard 11-11-1971.

3.22 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 the following table. The dimensions apply only to the immediate terminals.

Winding Voltage Rating, Volts	Insulation Class	BIL kV	Clearance, Inches
0-50	0.25	10	¼
51-250	0.25	10	½
251-600	0.6	10	1
601-1200	1.2	10	1

NEMA Standard 5-19-1986.

3.23 GROUNDING OF CORE

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

NEMA Standard 11-11-1971.

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.

Authorized Engineering Information 11-11-1971.

3.24 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 connection is to be attached.

NEMA Standard 11-11-1971.

3.25 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 11-11-1971.

3.26 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:

1. The identification "transformer."
2. Classes of cooling other than AA shall be specified; e.g., AA/FA, AFA, etc.
3. Number of phases.
4. Frequency(ies).
5. kVA rating(s).
6. Voltage rating(s).
7. Temperature rise(s).
8. Name of manufacturer.

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

1. Vector diagram (for three-phase transformers only).
2. Tap voltage(s).
3. Percent impedance(s) (for ratings over 10 kVA).
4. Connection diagram.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

5. Approximate total weight (if over 100 pounds).

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

NEMA Standard 5-19-1986.

3.27 DESIGNATION OF VOLTAGE RATINGS OF WINDINGS

3.27.1 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.

3.27.2 Single-phase

1. E shall indicate a winding of E volts which is intended for delta connection on an E-volt system. Example: 480.
2. E/E1Y shall indicate a winding of E volts which is intended for delta connection on an E-volt system or for Y connection on an E1-volt system. Example: 120/208Y.
3. E/2E shall indicate a winding, the sections of which can be connected in multiple 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. Example: 12/240.
4. 2E/E shall indicate a winding with a midtap which is intended for three-wire operation at 2E volts between extreme terminals and E volts between the midtap and each of the extreme terminals. Example: 240/120.
5. VxV1 shall indicate a winding, the sections of which may be connected in multiple to obtain one of the voltage ratings (as defined in items 1 and 2) of V, or which may be connected in series to obtain one of the voltage ratings (as defined in items 1 and 2) of V1. Example: 240 × 480.

3.27.3 Three-phase

1. E shall indicate a winding which is delta connected for operation on an E-volt system. Example: 480.
2. EY shall indicate a winding which is Y connected without a neutral brought out for operation on an E-volt system. Example: 208Y.
3. E1Y/E shall indicate a winding which is Y connected with a neutral brought out for operation on an E1-volt system, with E volts available from line to neutral. Example: 208Y/120.
4. E/E1Y shall indicate a winding which shall be delta connected for operation on an E-volt system, or shall be Y connected without a neutral brought out for operation on an E1-volt system. Example: 120/208Y.
5. E/E1Y/E shall indicate a winding which shall be delta connected for operation on an E-volt system or shall be Y connected with a neutral brought out for operation on an E1-volt system with E volts available from line to neutral. Example: 120/208Y/120.
6. E1GrdY/E shall indicate a winding with reduced insulation 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.
7. E/E1GrdY/E shall indicate a winding which shall be delta connected for operation on an E-volt system or shall be Y connected with a neutral brought out and effectively grounded for operation on an E1-volt system with E volts available from line to line neutral. Example: 120/208GrdY/120.
8. VxV1 shall indicate a winding, the sections of which shall be connected in multiple to obtain one of the voltage ratings (as defined in items 1 through 5) of V, or shall be connected in series to obtain one of the voltage ratings (as defined in items 1 through 5) of V1. Examples: 120 × 240 208Y/120 × 416Y/240.

NEMA Standard 5-19-1986.

3.28 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 "HOXO"; "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 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.29 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.

Authorized Engineering Information 5-19-1986.

3.30 TERMINAL MARKINGS

3.30.1 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 of 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.

NEMA Standard 11-11-1971.

3.30.2 Precautions

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

Authorized Engineering Information 11-11-1971.

3.30.3 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.

3.30.4 Markings

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

NEMA Standard 5-19-1986.

3.30.5 Significance of the Terminal Letter

The letter shall indicate the character or function of the winding which is brought to the terminal. The following table gives the terminal letters assigned to the different types of windings and their functions (see 3.30.10):

Winding Identification	Lead Markings	Winding Designation
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.

3.30.6 Significance of the Numeral 0 (Zero)

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

NEMA Standard 5-19-1986.

3.30.7 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, Y3, etc., on the third winding terminals, etc.

Authorized Engineering Information 5-19-1986.

3.30.8 Definition of Phase Sequence

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

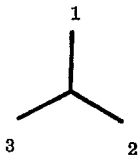
NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.30.9 Direction of Rotation of Vectors

Vector diagrams should be drawn so that an advace in phase of one vector with respect to another is in the counterclockwise direction. In the following figure, vector 1 is 120 degrees in advance of vector 2, and the phase sequence is 1, 2, 3. See 3.30.8.

Authorized Engineering Information 5-19-1986.



3.30.10 Markings of Terminals and Identification of Windings

1. In general, the windings of a transformer shall be distinguished from one another as follows:

   Two-winding transformers shall have their windings designed 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.

2. The sequence of designation is determined as follows:

   The highest voltage winding shall be designated as HV or H, except for transformers designed for three-phase to six-phase transformation. See 3.30.13.

   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 winding shall receive the prior letter designation of the two (or more) letters available, according to the sequence by voltage as explained above.

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

3. 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.
4. 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.
5. 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.

3.30.11 Single-Phase Transformers

1. *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.

   NEMA Standard 5-19-1986.

2. *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.

   NEMA Standard 5-19-1986.

   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.

   Authorized Engineering Information 5-19-1986.

3. *Autotransformers*—Autotransformer terminals shall, so far as practicable, be marked in accordance with the requirements of 3.30.11.1, Figure 3-6 and 3.29.

   NEMA Standard 5-19-1986.

3.30.12 Three-phase Transformers

1. *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.
2. *Relation Between Highest Voltage Winding and Other Windings*—The markings shall be so applied that if the phase sequence of voltage on the highest voltage winding is in the time order H1, H2, H3, it will be in the time order of X1, X2, X3 and Y1,

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 grounds shown in Figure 3-13 to 3-18, inclusive. The angular displacement between the H winding and the X winding is the angle in each of the voltage vector diagrams (see Figure 3-13 to 3-18, inclusive) 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.

3. *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 3-17.

   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 terminal 3; and 6, 9, etc., from terminal 3 toward terminal 1. See Figure 3-17.

   The wye (star) tap terminal numbering shall be as follows: 4, 7, etc., from terminal 1 toward neutral; 5, 8, etc., from terminal 2 toward neutral; and 6, 9, etc., from terminal 3 toward neutral. See Figure 3-17.

   NEMA Standard 5-19-1986.

4. *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.

   Authorized Engineering Information 5-19-1986.

5. *Autotransformers*—Autotransformers terminals shall, as far as practicable, be marked in accordance with the requirements for the corresponding multiwinding transformers. See Figure 3-18 and 3.29.

   NEMA Standard 5-19-1986.

3.30.13 Three-phase to Six-phase Transformers

1. *General*—The markings for three-phase to six-phase transformers shall be based on the three-phase winding always being the H winding.
2. *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 3-7 through Figure 3-10.
3. *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 phses will indicate definite phase relations, they shall be made in accordance with one of the four six-phase groups shown in Figure 3-7 through 3-10. The angular displacement between the three-phase and six-phase windings is the angle in each of the voltage vector diagrams from its neutral through H1 and X1, respectively.
4. *Tap Terminals*—Where tap power connection terminals from the six-phase windings are provided (neutral terminal excepted), they shall be marked as follows:

   The double-wye (diametrical) tap terminals shall be marked from the two ends of each phase winding toward the middle or neutral point in the following order:

   X7, X13, etc., from X1 toward neutral
   X8, X14, etc., from X2 toward neutral
   X9, X15, etc., from X3 toward neutral
   X10, X16, etc., from X4 toward neutral
   X11, X17, etc., from X5 toward neutral
   X12, X18, etc., from X6 toward neutral
   See Figure 3-11.

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 3-12.

NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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

Authorized Engineering Information 5-19-1986.

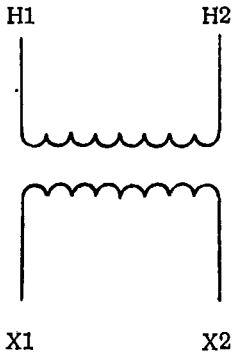


Figure 3-3
SIMPLE H AND X WINDINGS WITHOUT TAPS

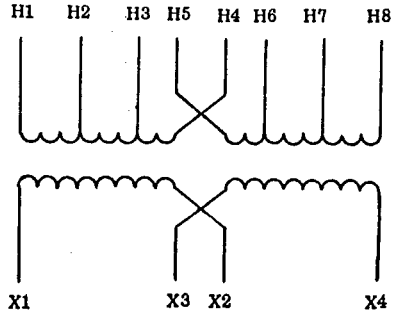


Figure 3-5
SERIES-PARALLEL H WINDING WITH TAPS
SERIES-PARALLEL X WINDING

3.30.14 Terminal Markings—Single-phase Transformers

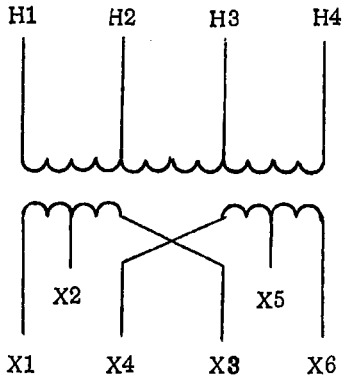


Figure 3-4
SIMPLE H WINDING WITH TAPS
SERIES-PARALLEL X WINDING

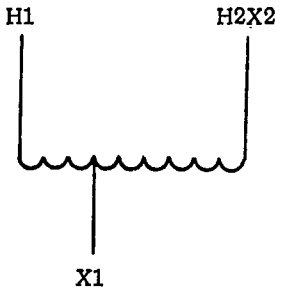


Figure 3-6
AUTOTRANSFORMER

NEMA Standard 5-19-1986.

3.30.15 Terminal Markings and Voltage Vector Diagrams—Usual Six-phase Transformer Connections

The following figures are included to illustrate the method of marking transformer terminals:

SIX-PHASE TRANSFORMERS WITHOUT TAPS

Group 1
Angular
Displacement
0°

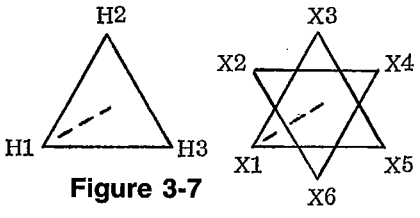


Figure 3-7

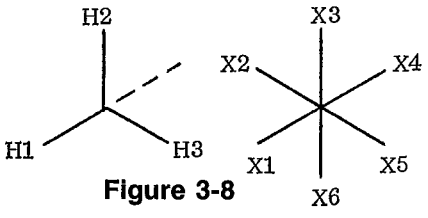


Figure 3-8

Group 2
Angular
Displacement
30°

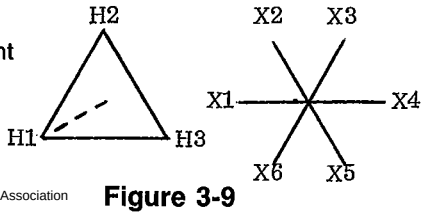


Figure 3-9

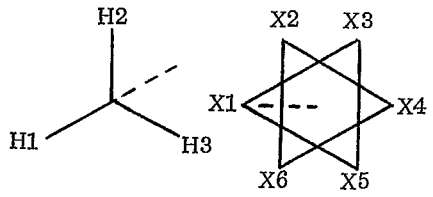


Figure 3-10

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

SIX-PHASE TRANSFORMERS WITH TAPS

Group 3
Angular
Displacement
30°

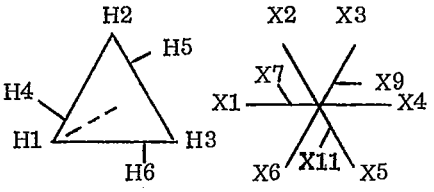


Figure 3-11

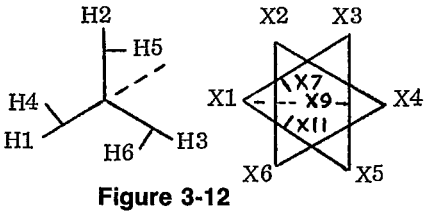


Figure 3-12

Authorized Engineering Information 5-19-1986.

3.30.16 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:

Authorized Engineering Information 5-19-1986.

THREE-PHASE TRANSFORMERS WITHOUT TAPS

Group 1
Angular
Displacement
0°

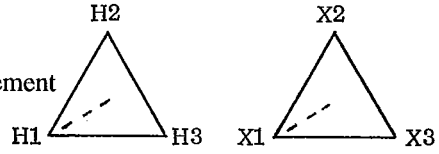


Figure 3-13

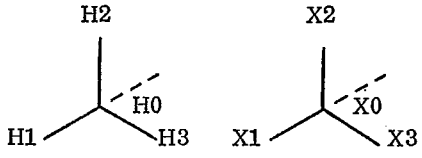


Figure 3-14

Group 2
Angular
Displacement
30°

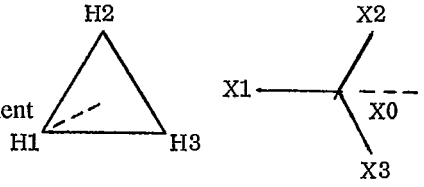


Figure 3-15

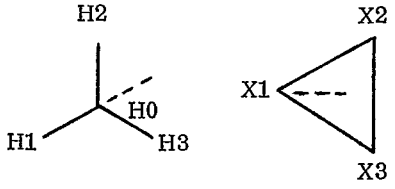


Figure 3-16

THREE-PHASE TRANSFORMERS WITH TAPS

Group 3
Angular
Displacement
30°

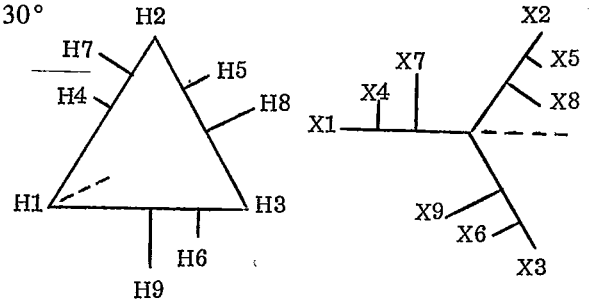


Figure 3-17

Group 4
Autotransformers

(If neutral terminal is brought out)

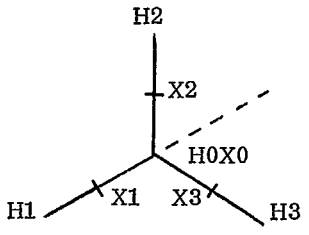


Figure 3-18

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.31 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 voltages should be furnished with each transformer, preferably on the nameplate.

Authorized Engineering Information 5-19-1986.

3.32 CONNECTION OF TRANSFORMERS FOR SHIPMENT

When interconnections are supplied, the following shall be observed:

1. 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.
2. 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.
3. Three-phase transformers designed for both delta and wye operation shall be shipped connected for the wye voltage.

NEMA Standard 11-11-1971.

Section 4

TESTING

4.1 CLASSIFICATION OF TESTS

4.1.1 Routine Tests

Routine tests are 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

Design tests are 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

Prototype tests are tests made 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.

NEMA Standard 11-11-1971.

4.1.4 Tests for Dry-Type Transformers

	Classification of Test			
	Routine	Design	Prototype	See Paragraph
Visual	x	...	...	Section 3
Ratio—tests on the rated voltage connection and on all tap connections	x	...	...	4.2.1
Polarity and Phase Relation—tests on the rated voltage connection	x	...	...	4.22 to 4.2.4
No-load Losses and Excitation Current—at rated voltage on the rated voltage connection. Statistical sampling may be used for this test	x	...	...	4.2.6 and 4.2.7
Impedance Voltage and Load Loss—at rated current on the rated voltage connections	...	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 system	...	...	x	4.9
Weather Classification	...	...	x	4.3

NEMA Standard 5-19-1966.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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.

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

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

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

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.

Authorized Engineering Information 5-19-1986.

4.2.1.2 VOLTAGE TOLERANCES

1. *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.

2. *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 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.

NEMA Standard 5-19-1986.

4.2.1.3 RATIO TEST METHODS

There are three methods of making ratio tests:

1. Voltmeter method (see 4.2.1.4).
2. Comparison method (see 4.2.1.5). (This is the more accurate of the three because the voltmeter or detector indicates the difference in voltage.)
3. Resistance-potentiometer method (see 4.2.1.6).

Authorized Engineering Information 5-19-1986.

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 5-19-1986.

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.

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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.

Authorized Engineering Information 5-19-1986.

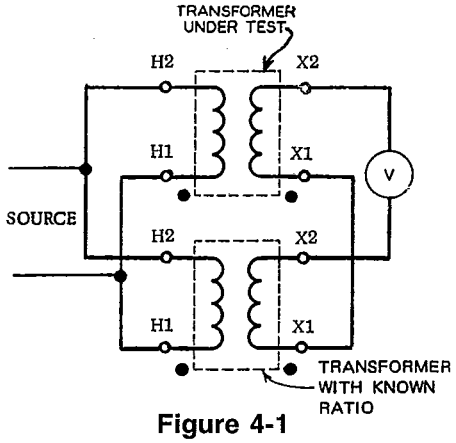


Figure 4-1
VOLTMETER ARRANGED TO READ THE DIFFERENCE BETWEEN THE TWO SECONDARY VOLTAGES

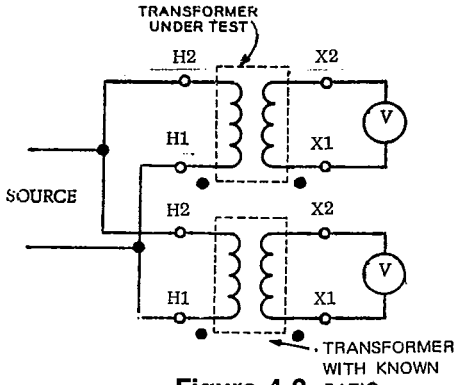


Figure 4-2
VOLTMETERS ARRANGED TO READ THE TWO SECONDARY VOLTAGES
The readings are repeated after interchanging voltmeters.

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.

Authorized Engineering Information 5-19-1986.

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).

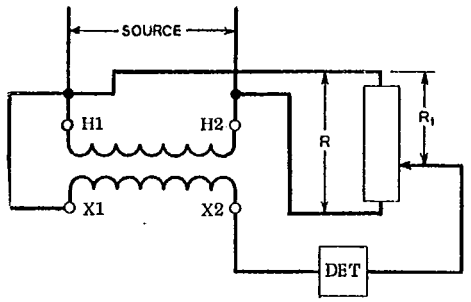
The transformer to be tested shall be excited in parallel with a transformer of a known ratio and the voltmeters arranged to measure the two secondary voltages (Figure 4-2).

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

NEMA Standard 5-19-1986.

4.2.1.6 RATIO BY RESISTANCE POTENTIOMETER

A resistance potentiometer 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.



When balance is shown by detector DET, the transformer ratio = R/R_1.

Figure 4-3
RESISTANCE POTENTIOMETER FOR RATIO TEST

The slide contact on the resistance potentiometer is moved until the detector reads zero. Then the ratio of the potentiometer resistance R/R_1, equals the transformer ratio.

Authorized Engineering Information 5-19-1986.

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.

Authorized Engineering Information 5-19-1986.

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

1. Comparison.
2. Inductive kick.
3. Alternating voltage.
4. Resistance potentiometer.

Each phase of a polyphase transformer shall have the same relative polarity when tested in accordance with one

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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).

1. Test for phasor diagram.
2. Phase-sequence test.

NEMA Standard 11-11-1971.

4.2.3 Method for 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.)

1. Connect the high-voltage windings of both transformers in parallel by connecting similarly marked leads together.
2. Connect also the low-voltage leads, X2, of both transformers together, leaving the X1 leads free.
3. 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.

Authorized Engineering Information 5-19-1986.

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:

1. 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.
2. Transfer the voltmeter lead connected to H1 to X1 and that connected to H2 and X2.
3. Break direct-current excitation, thereby inducing a voltage in the low-voltage winding (inductive kick) which will cause a deflection in the voltmeter.

The pointer should swing in the opposite direction.

Authorized Engineering Information 5-19-1986.

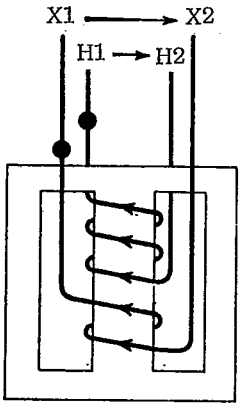


Figure 4-4

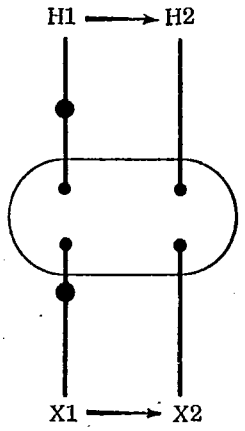


Figure 4-5

Polarity by Inductive Kick Test

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. The latter reading shall be less than the former.

NEMA Standard 5-19-1986.

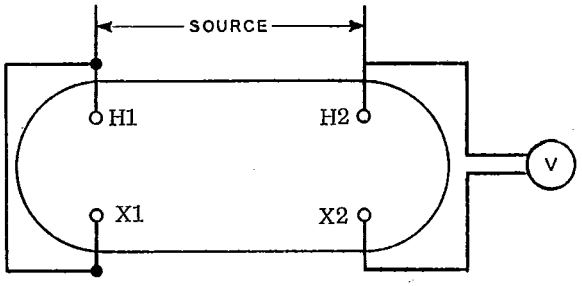


Figure 4-6
POLARITY BY ALTERNATING-VOLTAGE TEST

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

4.2.3.4 POLARITY BY RESISTANCE POTENTIOMETER

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

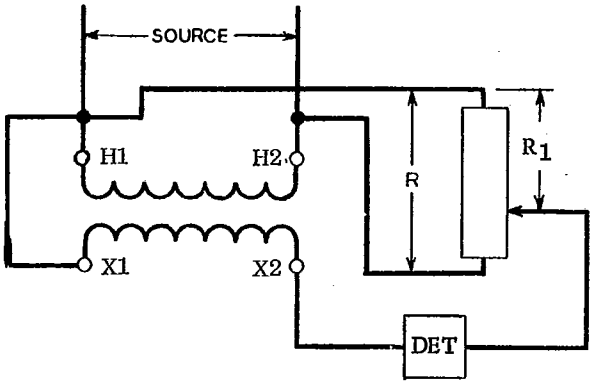


Figure 4-7
RESISTANCE POTENTIOMETER FOR POLARITY TEST

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 windings 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.

NEMA Standard 5-19-1986.

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, in which typical check measurements to be taken in their relative magnitudes are also indicated.

Six-phase windings having no neutral connection should be temporarily connected in delta or wye for the test for phasor diagram.

Authorized Engineering Information 5-19-1986.

4.2.4.2 PHASE-SEQUENCE TEST

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

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

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

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

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

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

4.2.5 Total Losses

Total losses shall be determined for rated voltage, current, and frequency with the load-loss component corrected to the proper reference temperature (see 3.18).

The total losses for individual single- or three-phase transformers shall not exceed the specified values by more than 6 percent. Average losses for two or more transformers on a given order shall not exceed the specified values.

NEMA Standard 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

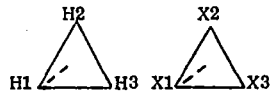
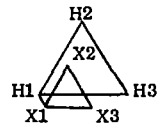
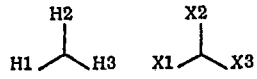
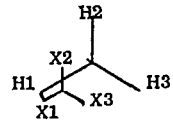
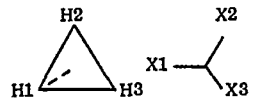
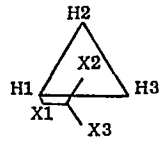
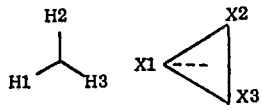
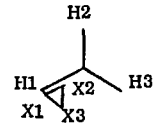
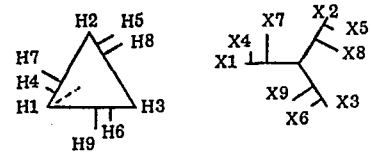
	Angular Displacement	Diagram for Check Measurement	Check Measurements
Group 1 Angular Displacement 0°	 DELTA-DELTA CONNECTION		Connect H1 to X1 Measure H2 − X2, H3 − X2, H1 − H2 H2 − X3 Voltage Relations 1. H2 − X3 = H3 −X2 2. H2 − X2 < H1 − H2 3. H2 − X2 < H2 − H3
	 Y-Y CONNECTION		
Group 2 Angular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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

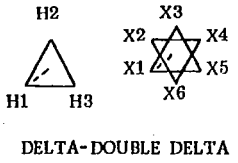
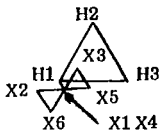
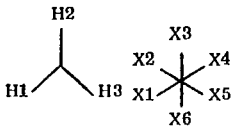
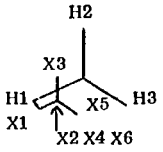
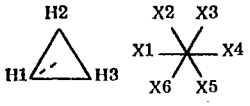
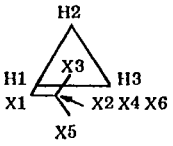
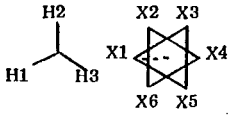
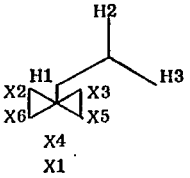
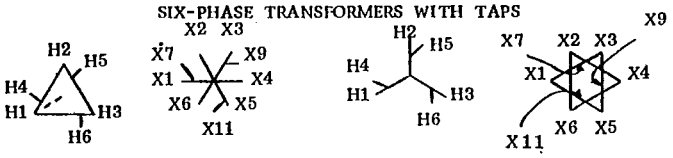
	Angular Displacement	Diagram for Check Measurement	Check Measurements
Group 1 Angular Displacement 0°	 DELTA-DOUBLE DELTA		Connect H1 to X1 to X4 Measure H2 − X3, H1 − H2, H2 − X5, H2 − X6, H3 − X2, H2 − X2, H3 − X3 Voltage Relations 1. H2 − X5 = H3 − X3 2. H2 − X3 < H1 − H2 3. H2 − X3 < H2 − H5 4. H2 − 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 − X5, 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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 for individual single- or three-phase transformers shall not exceed the specified values by more than 10 percent. Average losses for two or more transformers on a given shall not exceed the specified values.

NEMA Standard 5-19-1986.

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 a 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.

Authorized Engineering Information 5-19-1986.

The excitation loss determination shall be based on a sine-wave voltage unless a difference 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.

NEMA Standard 5-19-1986.

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.

NEMA Standard 5-19-1986.

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

*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.

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 4-10, 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.

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.

Authorized Engineering Information 5-19-1986.

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

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

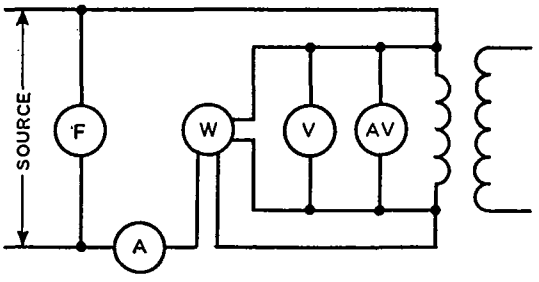


Figure 4-10
CONNECTIONS FOR THE EXCITATION TEST OF A SINGLE-PHASE TRANSFORMER WITHOUT INSTRUMENT TRANSFORMERS

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

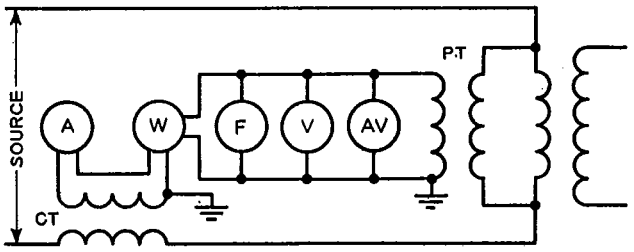


Figure 4-11
CONNECTIONS FOR THE EXCITATION TEST OF A SINGLE-PHASE TRANSFORMER WITH INSTRUMENT TRANSFORMERS

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

NEMA Standard 5-19-1986.

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

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

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)].

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:

$$P = \frac{P_m}{P_1 + kP_2}$$

(Equation 1)

$$k = \left(\frac{E_r^2}{E_a}\right)$$

(Equation 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 following values may be taken as typical:

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

Authorized Engineering Information 5-19-1986.

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:

1. 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.
2. In using the two-wattmeter method, great care should be exercised in reading the wattmeters accurately. Because of the low power factor, the

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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.

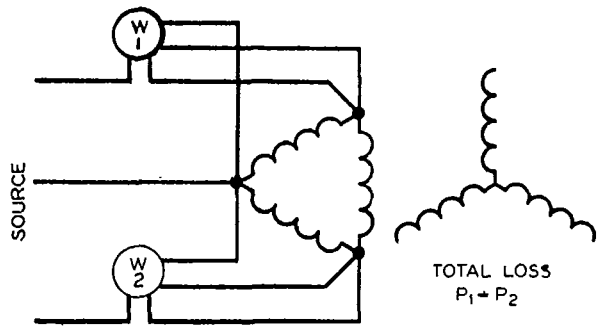


Figure 4-12
TWO-WATTMETER METHOD

3. 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.

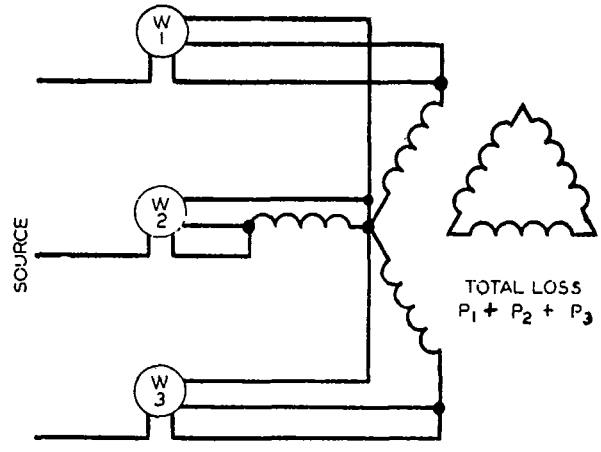


Figure 4-13
THREE-WATTMETER METHOD,
WITH TRANSFORMER NEUTRAL AVAILABLE

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

Authorized Engineering Information 5-19-1986.

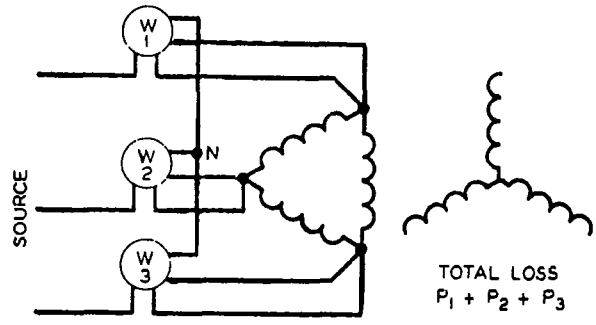


Figure 4-14
THREE-WATTMETER METHOD,
USING ARTIFICIAL WATTMETER NEUTRAL N

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:

NEMA Standard 5-19-1986.

1. *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.

   Authorized Engineering Information 5-19-1986.

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

   NEMA Standard 5-19-1986.

2. *Average-voltage Voltmeter and Rms Ammeter*—When using an average-voltage voltmeter and an rms ammeter, the measured rms value of excitation

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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.

Authorized Engineering Information 5-19-1986.

3. *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:

NEMA Standard 5-19-1986.

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

It is the most accurate method of measurement when waves of sufficiently different form factor to provide effective extrapolation are available (Figure 4-15).

Excitation current is measured with an rms ammeter at two or more applied voltages having different form factors but held at the same value with an average-voltage voltmeter, such as is used for the reduction of excitation loss to a sine-wave basis.

Form factors may be varied conveniently by changing the excitation of the generator field or by inserting an impedance in the test circuit.

Form factors may be determined by taking simultaneous voltage readings with rms and average-voltage voltmeters; their values will be indicated by the ratio of the rms reading to the average-voltage voltmeter reading, provided that the reading indicates the rms value of the equivalent sine-wave voltage.

Authorized Engineering Information 5-19-1986.

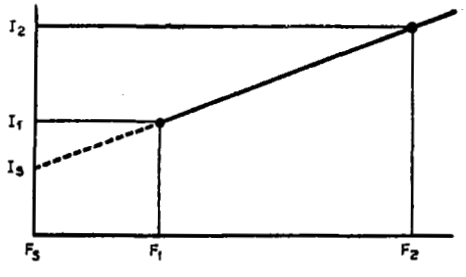


Figure 4-15
FORM-FACTOR PLOT TO REDUCE EXCITATION CURRENT TO SINE-WAVE BASIS (I_s F_s)

I_1, I_2 = exciting currents at form factors F_1, F_2

The excitation current (Is) 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 3)

where I_1 and I_2 are the rms currents corresponding, respectively, to the form factors F_1 and F_2.

NEMA Standard 5-19-1986.

b. *Excitation by Crest-ammeter Method*—In the crest-ammeter method, use is made of an average-voltage voltmeter (the same instrument used for a 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.

Authorized Engineering Information 5-19-1986.

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

$$I_s = \sqrt{\frac{I_1^2}{6} + \frac{I_2^2}{3} + \frac{I_3^2}{3}}$$

(Equation 4)

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.

NEMA Standard 5-19-1986.

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, the 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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 5)

Authorized Engineering Information 5-19-1986.

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 4.2.7.1.1) and too high when an average-voltage voltmeter is used (see 4.2.7.1.2). The procedure is as follows:

1. First, determine the excitation current as in 4.2.7.1.1.
2. Second, determine the excitation current as in 4.2.7.1.2, reading also the rms voltage.
3. 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 4.1.7.1.1 and 4.2.7.1.2.

Authorized Engineering Information 5-19-1986.

4.2.8 Impedance

4.2.8.1 Impedance Voltage

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

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

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

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.

Authorized Engineering Information 5-19-1986.

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.

Authorized Engineering Information 5-19-1986

4.2.8.3 Tolerances for Transformer Impedance

1. 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.
2. 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.
3. 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.
4. 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.

NEMA Standard 5-19-1986.

4.2.8.4 Impedance and Load Loss Tests

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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

$$E_r = \frac{P_z}{I} \qquad \text{(Equation 6a)}$$

$$E_x = \sqrt{E_s^2 - E_r^2} \qquad \text{(Equation 6b)}$$

where—

E_r = resistance voltage, in-phase component
E_x = reactance voltage, quadrature component
E_s = impedance voltage
E_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 impedance loss increases with the temperature, the stray-loss component diminishes with the temperature, and, therefore, when it is desired to convert the impedance losses from one temperature to another, the two components of the impedance loss are converted separately. Thus,

$$P'_r = P_r \frac{K + \Theta'}{K + \Theta} \qquad \text{(Equation 7a)}$$

$$P'_s = P_s \frac{K + \Theta}{K + \Theta'} \qquad \text{(Equation 7b)}$$

where—

P'_r and P'_s = desired resistance and stray losses, respectively, at the specified temperature Θ.
P_r and P_s = measured resistance and stray losses at temperature Θ'.
K = 234.5 for cooper and 2258 for aluminum.

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

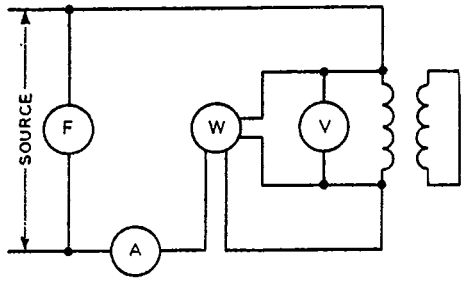


Figure 4-16
SINGLE-PHASE TRANSFORMER CONNECTION FOR IMPEDANCE-LOSS AND IMPEDANCE-VOLTAGE TESTS.
INSTRUMENT TRANSFORMERS TO BE ADDED WHEN NECESSARY.

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 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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

These precautions are of importance 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.

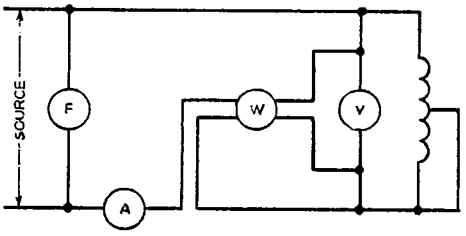


Figure 4-17
CONNECTIONS FOR IMPEDANCE-LOSS AND IMPEDANCE-VOLTAGE TESTS OF AN AUTOTRANSFORMER

2. *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.

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

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

With 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.

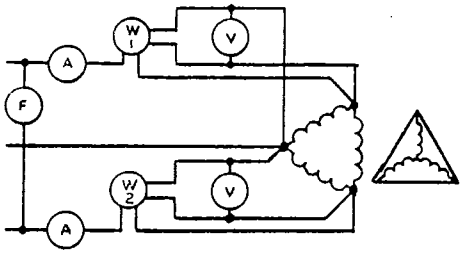


Figure 4-18
THREE-PHASE TRANSFORMER CONNECTIONS FOR IMPEDANCE-LOSS AND IMPEDANCE-VOLTAGE TESTS.
INSTRUMENT TRANSFORMERS TO BE ADDED WHEN NECESSARY

3. *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).

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.

Authorized Engineering Information 5-19-1986.

4. *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 △, and a corner of the △ opened to apply the single-phase voltage. The other winding must be either connected in △ (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 convert-

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

ing the values into percent or per-unit quantities. Use the following formula:

$$\text{Percent impedance volts} = 100 \frac{\text{measured impedance volts}}{3 \times \text{rated voltage of excited windings in } \triangle}$$

(Equation 8)

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 △, 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 △.

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 9a)

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

(Equation 9b)

where—

P and E = individual readings of measured impedance loss and voltage, respectively as 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 R_1 be the resistance measured between two high-voltage terminals and R_2 that between two low-voltage terminals; and let I_1 and I_2 be the respective rated line currents. Then, the total I^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 10)

This formula applies equally well to Y- or △-connected windings.

Temperature correction shall be made as in 4.2.8.4.1.

NEMA Standard 5-19-1986.

5. *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 11a)

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

(Equation 11b)

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

(Equation 11c)

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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

6. *Impedance Bridge Method*—The impedance bridge method may be used as an alternate to the wattmeter-voltmeter-ammeter method for the measurement of impedance and impedance losses.

The impedance bridge method is advantageous for low-power-factor measurements where special wattmeters and techniques are ordinarily required. While many configurations of impedance bridge networks are possible, the choice of a particular network is determined by the measurement problem at hand and the testing facilities available.

a. *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). 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.

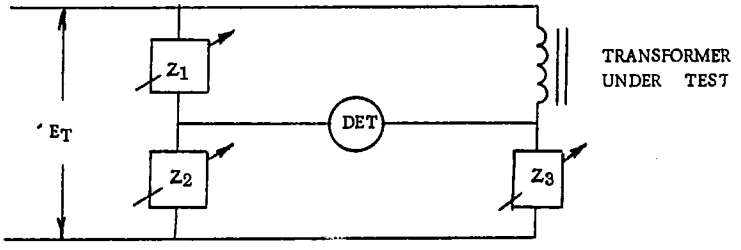


Figure 4-19
GENERAL IMPEDANCE BRIDGE NETWORK

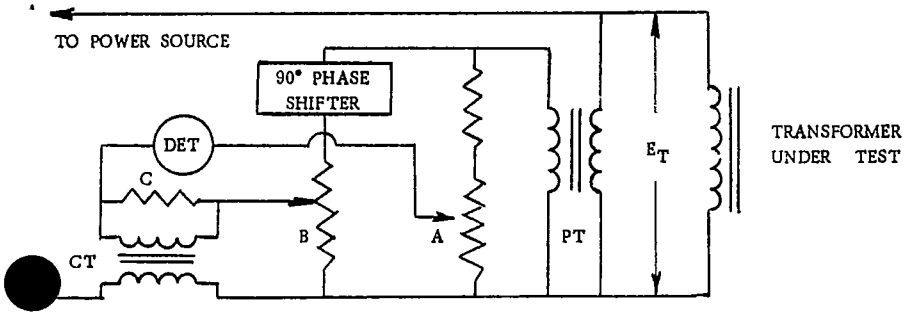


Figure 4-20
POTENTIOMETER-TYPE NETWORK USING A PHASE SHIFTER

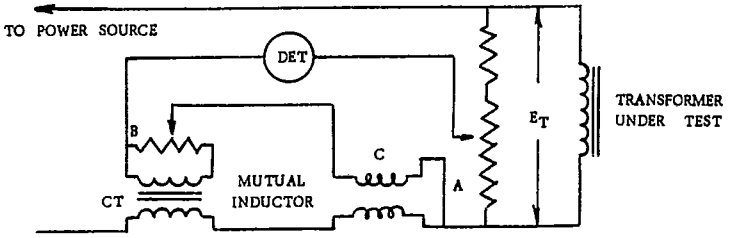


Figure 4-21
POTENTIOMETER-TYPE NETWORK USING A MUTUAL INDUCTOR

b. *Potentiometer-type Networks*—A convenient form of the impedance bridge for transformer testing is a double alternating-current potentiometer-type network using a phase shifter (Figure 4-20). The two potentiometers (A and B) are either connected directly or through a potential transformer (PT) to the terminals of the transformer under test. The phasor sum of the voltage drops (A and B) which are in quadrature, are 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) are 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 positon of potentiometer (B) is directly proportional to the loss in the transformer under test for low power factors.

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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

are advantageously derived from the current portion of the test circuit.

c. *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.

Authorized Engineering Information 5-19-1986.

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 5-19-1986.

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.

Authorized Engineering Information 5-19-1986.

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:

1. Applied potential test.
2. Induced potential test.

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

NEMA Standard 5-19-1986.

4.2.9.2 APPLIED-POTENTIAL TEST

1. 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 4-1.

NEMA Standard 5-19-1986.

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.

Table 4-1
APPLIED POTENTIAL TEST VOLTAGES

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

2. The terminal ends and taps of the winding under test should all be electrically joined together and 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 a good mechanical joint 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.

   Authorized Engineering Information 5-19-1986.

3. The duration of the applied-potential test shall be 1 minute. As an alternative to the 1-minute test, equipment shall be tested for 20 seconds with a voltage 20 percent higher than the 1-minute test voltage where the specified test voltage would be 2500 volts or less.

   NEMA Standard 5-19-1986.

4. 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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 voltamperes should be used for the testing of transformers up through 10kVA. For large or special transformers, a larger capacity testing transformer may be required.

5. 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.

Authorized Engineering Information 5-19-1986.

4.2.9.3 INDUCED-POTENTIAL TESTS

1. 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.

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

NEMA Standard 5-19-1986.

3. 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 4-2.

Table 4-2
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 4-2, it should be reduced slowly (in not more than 5 seconds) to one-quarter of the maximum value or less, and the circuit opened.

4. When transformers have one winding grounded for operation on a grounded-neutral system, special care should be taken to avoid high electrostatic stresses between the other windings and ground.

In the case of transformers having one end of the high-voltage winding grounded, the other windings should be grounded during the induced-potential test. This ground on each winding may be made at a selected point of the winding itself or of the winding of a step-up transformer which is used to supply the voltage or which is 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.

Authorized Engineering Information 5-19-1986.

4.2.10 Audible Sound Level Tests

Transformer shall be so designed that the average sound level will not exceed the values given in Table 4-3 when measured as follows:

NEMA Standard 5-19-1986.

4.2.10.1 TEST CONDITIONS

Measurements shall be made in an ambient having a sound level of at least 4 decibels, and preferably 7 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 4-4.

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

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

NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Table 4-3
AVERAGE SOUND LEVEL

Equivalent Two-winding kVA	Average Sound Level, Decibels: Self-cooled Ventilated, Up to 1.2 kV Line to Line (1)	Self-cooled Ventilated, Above 1.2 kV Line to Line (2)	Self-cooled Sealed (3)	Equivalent Two-winding kVA	Average Sound Level, Decibels: Ventilated Forced-air-cooled* (4)
0-9	40	45	45	0-1107	67
10-50	45	50	50	1168-1667	68
				1668-2000	69
51-150	50	55	55	2001-3333	71
151-300	55	58	57	3334-5000	73
				5001-6667	74
301-500	60	60	50	6668-8333	75
501-700	62	62	61	8334-10000	76
701-1000	64	64	63		
1001-1500	65	65	64		
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		

Columns 1, 2, and 3—Class AA rating.
Column 4—Class FA and AFA rating.

*Does not apply to sealed-type transformers.

4.2.10.2 MEASUREMENTS

1. Sound levels shall be measured with an instrument which is in accordance with ANSI S1.4.
2. The average sound level is defined as the arithmetic means of the sound level readings taken in accordance with 4.2.10.2.4 and 4.2.10.2.5.
3. 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.
4. 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 ⅓ and ⅔ height.
5. 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.

NEMA Standard 11-11-1971.

4.2.11 Resistance Measurements

4.2.11.1 GENERAL

Resistance measurements are of fundamental importance for two purposes:

1. For the calculation of the conductor or I^2R loss.
2. For the calculation of winding temperatures at the end of a temperature test.

NEMA Standard 5-19-1986.

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 following precautions shall be observed:

1. *General*—Cold resistance measurements shall not be taken on a transformer when it is located in drafts or when it is located in a room in which the temperature is fluctuating rapidly.
2. *Transformer Windings*—The temperature of the windings shall be recorded as the average of several thermometers inserted between the coils, with extreme care used to see that their bulbs are as nearly as possible in actual contact with the winding conductor.

NEMA Standard 5-19-1986.

It should not be assumed that the windings are at the same temperature as the surrounding air.

Authorized Engineering Information 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Table 4-4
SOUND LEVEL CORRECTIONS

Difference in Decibels Between the Sound Level of Transformer and Ambient Combined and Sound Level of Ambient	*Corrections in Decibels to be* Applied to Sound Level of Transformer and Ambient Combined to Obtain Sound Level of Transformer
4	−2.2
5	−1.7
6	−1.3
7	−1.0
8	−0.8
9	−0.6
10	−0.4
over 10	−0.0

4.2.11.3 DROP-OF-POTENTIAL METHOD

The drop-of-potential method is generally more convenient than the bridge method for measurements made in the field. It should be employed only if the rated current of the transformer winding is 1 ampere or more.

In all cases, greater accuracy may be obtained by the use of potentiometers for the measurement of both current and potential although the setup may be rather cumbersome.

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.

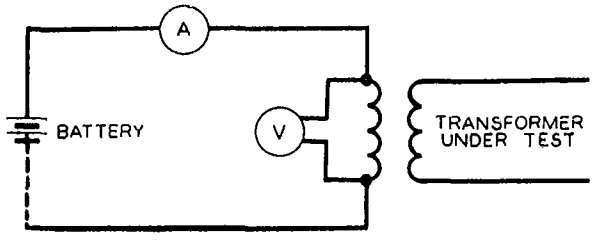


Figure 4-22
CONNECTIONS FOR THE DROP-OF-POTENTIAL METHOD OF RESISTANCE MEASUREMENT

If the direct current is supplied by a commutating machine, the pointer of the voltmeter may vibrate because of the commutator ripple in the voltage. In such cases, some winding of the transformer other than the winding under test should be short-circuited; this will damp the ripple and reduce or eliminate the vibration of the voltmeter.

The current in the winding which is being measured should have become practically constant before short-circuiting the other winding; otherwise, erroneous values of resistance may be obtained. It has been found by experience that the relative time constants under these two conditions are such that steady direct current is reached more quickly under the open-circuit conditions than under the short-circuit conditions.

Authorized Engineering Information 5-19-1986.

In order to minimize errors of observation, the measuring instruments shall have such ranges as will give reasonably large deflections.

The voltmeter leads shall be independent of the current leads and shall be connected as closely as possible to the terminals of 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.

NEMA Standard 5-19-1986.

To protect the voltmeter from injury by off-scale deflections, the voltmeter should be disconnected from the circuit before switching the current on or off.

Authorized Engineering Information 5-19-1986.

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

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

NEMA Standard 5-19-1986.

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 at the termination of the heat run.

If the winding under test has an appreciable time constant, the current can be made to attain its steady-state value more rapidly by first raising the voltage to a value greater than that required under steady-state conditions, to maintain the desired current value, and then decreasing the voltage as the current approaches the desired value.

Authorized Engineering Information 5-19-1986.

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 can cause inaccuracy by heating the winding and thereby changing its temperature and resistance.

If the current is too low to be read on an available ammeter, a shunt and a potentiometer shall be used.

NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

4.2.11.4 BRIDGE METHOD

The bridge methods 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.

Bridge methods are especially recommended for all measurements which are to be used in connection with temperature-rise determinations.

For resistance values of 1 ohm or more, a Wheatstone Bridge may be used; for resistance values of less than 1 ohm, a Kelvin Bridge may be used.

Authorized Engineering Information 5-19-1986.

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 for 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:

1. Rated secondary voltage.
2. 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.

NEMA Standard 5-19-1986.

Temperature testing requires a slight overexcitation. 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:

1. *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.
2. *Simulated Loading*—
   a. *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 particulary suitable for the large size transformers, and is equally satisfactory for small transformers.
   b. *Loading-back (Opposition) Method for Self-cooled and Forced-cooled Transformers*—The loading-back (opposition) method requires a greater amount of testing facilities and auxiliary equipment, and also energy consumption. Because of these requirements, the loading-back method becomes increasingly difficult to perform as the size of the transformers increases.
   c. *Impedance kVA Method*—This is a method for testing a single three-phase transformer or three single-phase transformers having delta windings or connectible to two delta windings. One delta winding should be open so that the impedance kVA can be supplied.

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

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.

Authorized Engineering Information 5-19-1986.

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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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.

NEMA Standard 5-19-1986.

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 should be soldered to a thin metal plate or foil approximately 1 inch square. The plate is to be placed and held firmly and snugly 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.

Authorized Engineering Information 5-19-1986.

The temperature rise of the windings shall be determined by the resistance method, or by thermometer when so specified.

NEMA Standard 5-19-1986.

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 2.5 percent or 1 °C, whichever is greater, during a consecutive 3-hour period.

Authorized Engineering Information 5-19-1986.

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

$$C = \frac{K + 30}{K + \Theta}$$

(Equation 12)

in which Θ = the ambient air temperature.

K = 234.5 for copper
K = 225 for aluminum

NEMA Standard 5-19-1986.

When temperature rise tests by thermometer are required, at least one alcohol thermometer should be placed in each high- and low-voltage group of coils. If the respective coil groups consist of several coils, several thermometers should be placed in each group.

It is important that the coil thermometers be properly placed in the air ducts in such a manner as to indicate the winding temperature and yet not restrict the ventilation. This may be accomplished by means of grooved sticks of insulating material slightly larger than the thermometer bulbs.

Authorized Engineering Information 5-19-1986.

When the thermometers are used, the bulbs shall be covered by pads cemented to the equipment or by grooved sticks.

NEMA Standard 5-19-1986.

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 coil thermometers and any other temperature-indicating devices should be read continually in rotation until the temperature begins to fall. If any of the thermometer temperatures are higher than those observed during the run, the highest temperature should be recorded as the final thermometer temperature.

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

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

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

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

The separate load-loss and excitation-loss test method can be used for nonventilated dry-type transformers. (The test procedure is being investigated and will be made available at a later date.)

Authorized Engineering Information 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 paralled windings (Figure 4-23).

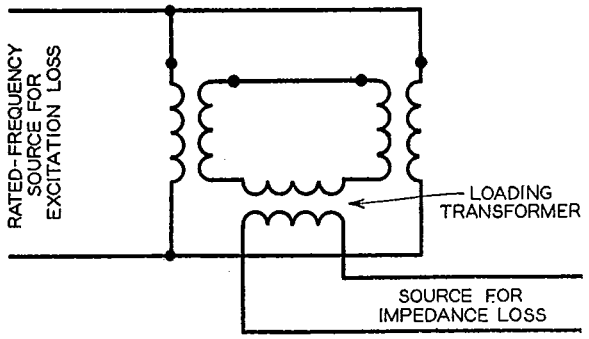


Figure 4-23
TWO SINGLE-PHASE TRANSFORMERS IN OPPOSITION

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.

1. This current should preferably (but not necessarily) be at rated frequency.
2. 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 am bient temperature.

   Correct these rises back to the instant of shutdown.

   Authorized Engineering Information 5-19-1986.

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).

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

Authorized Engineering Information 5-19-1986.

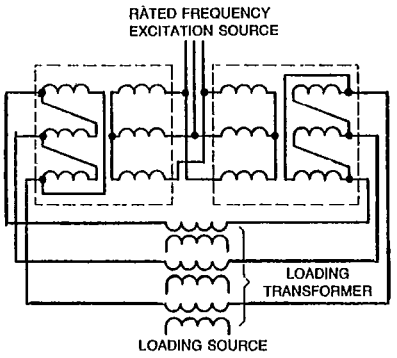


Figure 4-24
TWO Y-△ CONNECTED TRANSFORMERS

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).

NEMA Standard 5-19-1986.

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

Authorized Engineering Information 5-19-1986.

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 shut-down.

NEMA Standard 5-19-1986.

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.

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.

NEMA Standard 5-19-1986.

The circulated current should preferably be at rated frequency.

Authorized Engineering Information 5-19-1986.

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).

NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

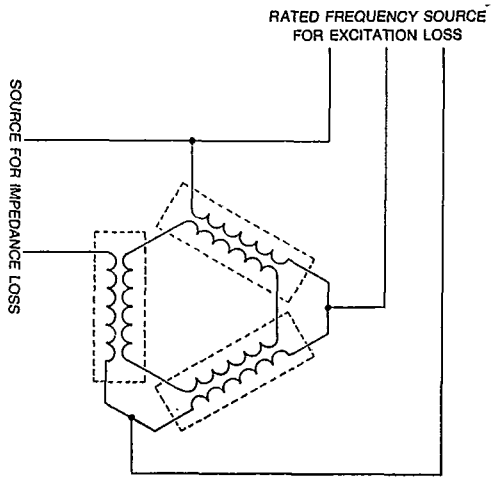


Figure 4-25
DELTA-DELTA CONNECTION
FOR THREE SINGLE-PHASE UNITS
FOR ONE THREE-PHASE UNIT

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 with 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_c', with full load current in the winding and normal excitation on the core can be calculated by the following formula:

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

(Equation 13)

Authorized Engineering Information 5-19-1986.

4.2.12.7 Load Loss Test Plus Additive Factor

The total winding rise, T_c', of a single ventilated dry-type transformer may be calculated by applying an additive factor, $\triangle T_e$, to the rise, T_c, as outlined in the next paragraph.

The additive factor, $\triangle T_e$, 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 only (per 4.2.12.6). It should be established by test data on units of similar construction.

The total winding rise, T_c', is given by:

$$T_c' = T_c + \triangle T_e$$

(Equation 14)

Authorized Engineering Information 5-19-1986.

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:

$$\Theta = \frac{R}{R_o} (K + \Theta_o) - K$$

(Equation 15a)

$$\Theta = \frac{R - R_o}{R_o} (K + \Theta_o) + \Theta_o$$

(Equation 15b)

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

$$\Theta_r = \Theta - \Theta_F$$

(Equation 15c)

where—

Θ = temperature in degrees centigrade corresponding to hot resistance R

Θ_o = temperature in degrees centigrade corresponding to cold resistance R

Θ_r = average temperature rise in degrees C

Θ_F = ambient temperature in degrees C corresponding to hot resistance R

R_o = cold resistance determined in accordance with the rules in this standard

R = hot resistance

K = 234.5 for copper and 225 for 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.

Authorized Engineering Information 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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 330 feet is to be operated at an altitude in excess of 330 feet, it shall be assumed that the observed temperature rise will increase in accordance with the following equation:

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

(Equation 16)

Where F is an empirical factor given in the following table:

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.

NEMA Standard 5-19-1986.

The "observed rise" in Equation 16 is the winding rise over the ambient temperature for dry-type transformers.

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

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:

$$\Theta'_c = \Theta_c \left(\frac{W}{w}\right)^e$$

(Equation 17)

where—

Θ'_c = corrected winding rise

Θ_c = measured winding rise

W = required total loss

w = total loss during temperature tests

e = 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.

Authorized Engineering Information 5-19-1986.

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.

NEMA Standard 5-19-1986.

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 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.

Authorized Engineering Information 5-19-1986.

4.2.13 Short-Circuit Capability

Transformers shall be capable of withstanding without injury the mechanical and thermal stresses caused by short circuits on the external terminals of any winding or windings, with rated voltages maintained across the terminals of all other windings intended for connection to sources of energy, provided:

1. The magnitude of the rms symmetrical current in any winding does not exceed 25 times the rated current of the winding.
2. The duration of the short circuit is limited to the time

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

periods shown in the following table. Intermediate values shall be permitted to be determined by interpolation.

Percent Impedance	RMS Symmetrical Current in Any Winding	Time Period, Seconds
4 or less	25 times rated current	2
5	20 times rated current	3
6	16.6 times rated current	4
7 or more	*	5

NEMA Standard 5-19-1986.

*Intermediate or extended values may be determined by interpolation or extrapolation. (Authorized Engineering Information 5-19-1986.)

EXCEPTIONS:

1. The short-circuit current of transformers that are directly connected to apparatus having inherent impedance may be considered to be limited by the combined impedances of the transformer and the directly connected apparatus if the apparatus is located only a few feet from the transformer and connected to it by buses or cables so arranged that there will be no practical possibility of short circuit occurring between the apparatus and the transformer.
2. Autotransformers having a part of their winding common to both the primary and the secondary circuits may be subjected to exceptionally severe short circuits, unless protected by current-limiting means. Because of the cumulative detrimental effects of successive severe short-circuits, it is practically impossible to determine by test the maximum safe short-circuit current that autotransformers will withstand successfully. It is recommended, therefore, that current-limiting reactors be installed where necessary to limit the short-circuit current to 25 times rated current.

Authorized Engineering Information 5-19-1986.

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

Winding Temperate By Resistance, Degrees C	Assumed Initial Average Temperatures of Winding Degrees C	Final Temperatures, Degrees C
55	95	250
80	120	350
115	155	400
150	190	450

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

$$\Theta = Ft\left(\frac{f}{2\Theta_1} + \frac{618.4K}{f}\right) + \Theta_0$$

(Equation 18a)

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

$$\Theta = Ft\left(\frac{f}{2\Theta_1} + \frac{602\ K}{f}\right) + \Theta_0$$

(Equation 18b)

where—

Θ = final temperature, degrees C
Θ_0 = assumed initial temperature, degrees C
Θ_1 = $(\Theta_0 + 234.5)$ for copper = $(\Theta_0 + 225)$ for aluminum
t = time, in seconds
K* = ratio of eddy current loss to the I^2R loss at 75°C
F* = (for copper) = $\frac{\text{watts per pound (at } \Theta_0)}{180}$ or $(4.6S^2\Theta_1 \times 10^{-11})$ or $\frac{75\Theta_1}{M^2}$ = (for aluminum) $(10.71S^2\Theta_1 \times 10^{-11})$
f = $2\Theta_1 1 + Ft$
S* = amperes per square inch of conductor
M* = circular mils per ampere.

*Based on short-circuit current.

NEMA Standard 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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.

Authorized Engineering Information 5-19-1986.

4.3.1.2 REGULATION COMPUTATION

1. Exact formulae for the calculation of regulation are:
   a. When the load is lagging

$$reg = \sqrt{(r + p)^2 + (x + q)^2} - 1$$

(Equation 19a)

   b. When the load is leading

$$reg = \sqrt{(r + p)^2 + (x - q)^2} - 1$$

(Equation 19b)

2. Approximate formulae generally used for the calculation of regulation are:
   a. When the load is lagging

$$reg = pr + qx + \left(\frac{px - qr}{2}\right)^2$$

(Equation 20a)

   b. When the load is leading

$$reg = pr - qx + \frac{(px + qr)^2}{2}$$

(Equation 20b)

where—

p = power factor of load

$q = +\sqrt{1 - p^2}$

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

x = reactance factor of transformer = $+\sqrt{z^2 - r^2}$

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

The quantities p, q, x and r are on a per-unit basis so the result should be multiplied by 100 to get the regulation in percent. The approximate formulae given 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 the following table:

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

Authorized Engineering Information 5-19-1986.

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 5-19-1986.

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 11-11-1971.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 5

APPLICATION, INSTALLATION AND MAINTENANCE

5.1 SELECTION OF RATED TRANSFORMER kVA

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

1. Connected load currents and possible start-time overload currents of the circuit, including sustained harmonics.
2. Repetitive transient currents of the circuit, such as transformer magnetizing in-rush current, motor starting current, capacitor inrush current and ferroresonance current.
3. Coordination with other circuit components and protective devices.
4. Life expectancy and maintenance requirements of auxiliary equipment such as fans and controls.
5. Multiple thermal ratings.

Authorized Engineering Information 11-11-1971.

5.2 USUAL TEMPERATURE AND ALTITUDE SERVICE CONDITIONS

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

1. The average ambient temperature for any 24-hour period does not exceed 30 °C, and the maximum ambient temperature does not exceed 40 °C.
2. The altitude does not exceed 3300 feet (1000 meters).

NEMA Standard 11-11-1971.

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.

Authorized Engineering Information 5-19-1986.

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 (1000 m).

1. *Temperature.* Dry-type transformers designed for temperature rise in accordance with 5.2 may be used greater than 3300 feet (1000 m) without exceeding the temperature limits provided that either, or a combination of, the following conditions prevails:
   a. 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.
   b. The load to be carried is less than the rating of the transformer by an amount corresponding to the appropriate altitude correction.
2. *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 (1000 m) at any given temperature.
3. *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, or 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 15000 feet is considered to be a practical maximum for dry-type transformers conforming to this standard.

Authorized Engineering Information 5-19-1986.

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:

1. Damaging fumes and vapors, excessive and abrasive dust, steam, salt spray, excessive moisture and dripping water, etc.
2. Abnormal vibration, shocks and tilting.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Table 5-1
ALTITUDE CORRECTION FACTORS

Altitude		Altitude Correction Factor to be applied to			Maximum Temperature of the Cooling Air
		(a)	(b)	(c)	(d)
Feet	Meters	Dielectric Strength	Current Rating	Ambient Temperature	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	33.0
9000	2700	0.83	0.965	0.932	31.5
10000	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

3. Excessively high and low temperatures.
4. Unusual transportation and storage conditions.
5. Unusual space limitations.
6. Difficulty of maintenance, poor wave form, unbalanced voltage or unusual operating duty, frequency of operation, insulation requirements, etc.
7. Areas which may contain hazardous materials in sufficient quantity to cause an explosion.

Authorized Engineering Information 5-19-1986.

5.4 OVERCURRENT CIRCUIT PROTECTION

Overcurrent circuit protection shall conform with the requirements of the *National Electrical Code*. For this application, the word transformer shall mean a transformer or polyphase bank of two or three single-phase transformers operating as a unit.

NEMA Standard 5-19-1986.

5.5 OVERVOLTAGE CIRCUIT PROTECTION

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.

Authorized Engineering Information 5-19-1986.

5.6 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.

Authorized Engineering Information 5-19-1986.

5.7 AUTOTRANSFORMERS

5.7.1 Advantages and Disadvantages

The advantages of an autotransformer are that the size and weight per kVA of output is 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 gound 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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

between the two output terminals may be quite moderate. The fact that the effective percent impedance of an autotransformer connection is lower when compared with its value in transformer connection increases the short-circuit current by the inverse ratio and the short-circuit stresses by the square of the inverse ratio.

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

Authorized Engineering Information 5-19-1986.

5.7.2 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.

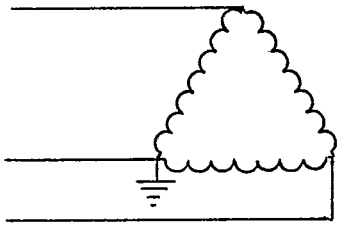


Figure 5-1

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.

5.7.3 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.

Authorized Engineering Information 5-19-1986.

5.7.4 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:

1. Check the supply circuit for grounds.
2. Check the load circuit for grounds.
3. Check for possible other grounded equipment not in the circuit at the time.
4. 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.

Authorized Engineering Information 5-19-1986.

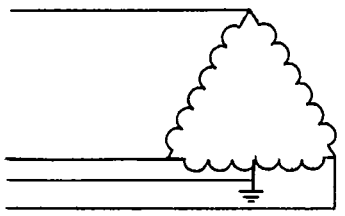


Figure 5-2

5.8 SINGLE-PHASE TRANSFORMER CONNECTIONS FOR THREE-PHASE BANKS

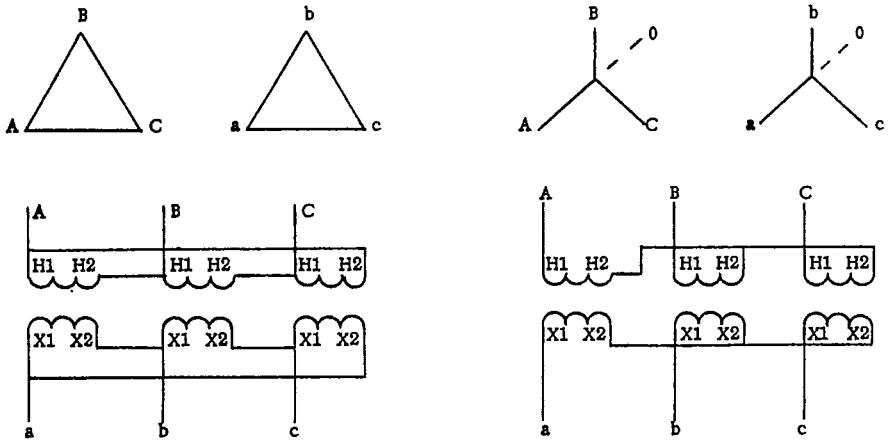


Figure 5-3*

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.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

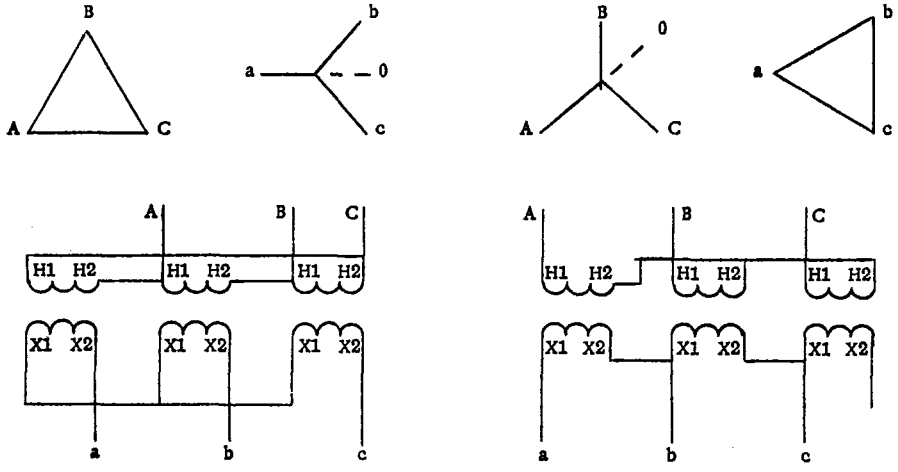


Figure 5-4*
ANGULAR DISPLACEMENT AND CONNECTIONS— SINGLE-PHASE TRANSFORMERS CONNECTED DELTA-Y AND Y-DELTA IN THREE-PHASE BANKS WITH 30-DEGREE ANGULAR DISPLACEMENT.

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

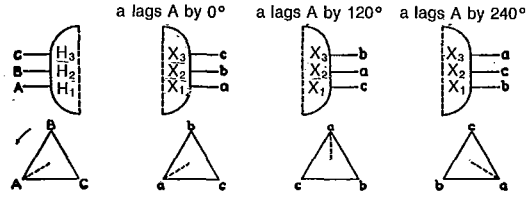
NEMA Standard 5-19-1986.

5.9 USE OF TRANSFORMERS IN CONNECTING SYSTEMS OF VARIOUS PHASE DISPLACEMENTS

Assume two systems, the one with phase terminals arbitrarily designated 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 are shown examples of transformer connections which may be made for any of these displacements.

5.9.1 0-degrees Phase Displacement—Delta-Delta or Y-Y

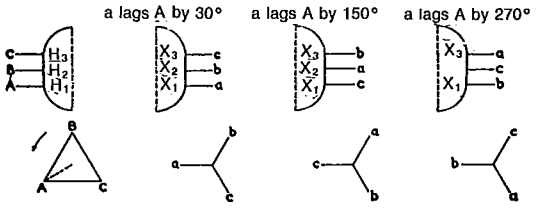
The examples shown are for delta-delta connections with system displacements of 0, 120, and 240 degrees.



Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

5.9.2 30-Degree Phase Displacement—Delta-Y or Y-Delta

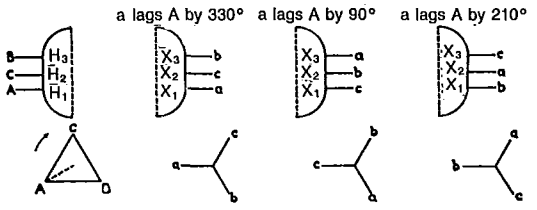
The examples shown are for Delta-Y connections with system displacements of 30, 150 and 270 degrees.



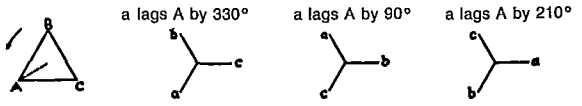
5.9.3 30-Degree Phase Displacement—Delta-Y or Y-Delta

To connect systems with 90-, 210- or 330-degree displacements, the procedure described in 5.9.2 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 counterclockwise rotation, the equivalent diagrams are:



5.9.4 180-Degree Phase Displacement

To connect systems of 60-, 180-, or 300-degree phase displacements, 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 5.9.1 and 5.9.2 can be followed to obtain all three angles.

Summary of Preceding Examples

System Displacement			See
0°	120°	240°	5.9.1
30°	150°	270°	5.9.2
60°	180°	300°	5.9.3
90°	210°	330°	5.9.4

Authorized Engineering Information 5-19-1986.

5.10 GENERAL PRECAUTIONS DURING INSTALLATION

The transformer should be inspected to see that it has not been damaged in shipment.

Work-up instructions and other installation instructions furnished with the transformer should be checked. Examples are:

1. Method of lifting.
2. Removal of bolts or packing materials used in shipment only.
3. On wall-mounted transformers, mounting bolts of sufficient size.
4. Temperature rating of lead insulation required.
5. Grounding of transformer case to the closest ground, using wire or cable or proper current capacity.
6. Voltage rating of transformer and actual voltage of the line to which it is going to be connected and connection of primary leads and/or taps as required for that voltage.
7. Output voltage after installation.

Authorized Engineering Information 5-19-1986.

5.11 GROUNDING OF ENCLOSURE AND CONDUCTOR

The metal enclosure or mounting frame of each transformer, reactor and similar electromagnetic equipment connected to a circuit operating at more than 30 volts to ground shall be effectively grounded. A grounding conductor for a transformer shall have a current-carrying capacity in accordance with the *National Electrical Code* or the *National Electrical Safety Code*, whichever is applicable.

NEMA Standard 5-19-1986.

5.12 SOUND

Audible sound may be a factor, and consideration should be given to the specific location and method of installation of the transformer keeping in mind the following suggestions:

1. Mount the transformer away from corners of walls

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

or ceilings.

2. Provide a solid foundation for mounting and then use vibration dampening mounts if not already provided in the transformer.
3. Provide flexible conduit to make the connection to the transformer.
4. Use sound absorbing material on the walls and ceiling.
5. Locate the transformer as far as practical from areas where high sound levels are undesirable.

Authorized Engineering Information 5-19-1986.

5.13 LOCATION

Factors which should be kept clearly in mind and considered in locating dry-type transformers are accessibility, ventilation, atmospheric conditions, spacings and sound.

A fire-resistant heat-insulating barrier should be installed beneath transformers which are mounted above floor level or on combustible material to catch any molten material which might fall from the transformer under fault conditions.

Authorized Engineering Information 5-19-1986.

5.14 ACCESSIBILITY (WORKING SPACE ABOUT DRY-TYPE TRANSFORMERS)

Dry-type transformers should be located in an area where the transformer can be inspected at any time. The wiring compartment should be easily accessible at all times.

The horizontal dimensions of the working space in the direction of access to live parts which are likely to require examination, adjustment, servicing or maintenance while live parts should be not less than indicated in Table 5-2 for the voltage to ground situations involved. Distances should be measured from the live parts if the parts are exposed or from the enclosure front or opening when the parts are enclosed. Distances associated with switchgear of the removable (draw-out) type should be increased by an amount equivalent to that required for removal.

Table 5-2
MINIMUM WORK SPACE CLEARANCES

Voltage to Ground, Volts	Minimum Clear Distance in Feet for Conditions 1	2	3
0-150	3.0	3.0	3.0
151-600	3.0	3.5	4.0
601-1200	3.0	4.0	5.0

Condition 1—Exposed live part on one side and no live or grounded part on the other side of the working space or exposed live parts on both sides effectively guarded by suitable wood or other insulating materials. Insulated wire or insulated bus bars operating at not more than 300 volts should not be considered live parts.

Condition 2—Exposed live parts on one side and grounded parts on the other side. Concrete, brick or tile walls should be considered as being grounded.

Condition 3—Exposed live parts on both sides of the work space (not guarded as provided in condition 1) with operator between them.

Working space is not required in back of assemblies such as a dead-front switchboard, panelboard or control center when there are no renewable or adjustable parts such as fuses, breakers, or switches on the back and when all connections are accessible from locations other than the back.

Smaller spaces may be permitted by the authority having jurisdiction where it is judged that the particular arrangement of the installation will provide adequate accessibility.

The working space required by this standard should not be used as a passageway or for storage. When normally enclosed live parts are exposed for inspection or servicing, the working space, if adjacent to a passageway or general open space where other work is carried on, should be guarded.

At least one entrance of sufficient area should be provided to give access to the working space about electrical equipment.

The minimum headroom of working spaces about dry-type transformers and associated switchgear where there are live parts exposed at any time should be 6¼ feet for voltages of 600 volts or less.

Adequate illumination should be provided for all working spaces about dry-type transformers and associated switchgear.

In all cases where live parts are normally exposed on the front of dry-type transformers and associated switchgear, the working space in front of the wiring compartment should be not less than 4 feet.

Authorized Engineering Information 5-19-1986.

5.15 VENTILATION

Adequate ventilation is essential for the proper cooling of dry-type transformers and associated switchgear, and clean air is desirable. Filtered air may reduce maintenance if a location presents a particular problem.

When transformers are installed in vaults, stair wells, closets and other restricted spaces, sufficient ventilation should be provided to hold the air temperature within established ambient limits when measured near the transformer air inlets. A maximum ambient of 40°C is normally recommended. Maintaining the ambient so that

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

the maximum of 40 °C is not exceeded will usually require approximately 100 cubic feet of air per minute per kilowatt of transformer loss.

For each 100 kVA of transformer rating, each inlet and outlet opening should have a net area of at least 1 square foot. The actual area of ventilated openings required depends on the configuration of the space, the location of openings, and the maximum loads to be carried by the transformers.

The ventilating screens and openings in the transformers are designed to provide adequate ventilation for the transformer and should not be restricted in any way.

The ventilating screens and openings in the transformers are designed to prevent entrance of most small animals and foreign objects. However, in some locations, it may be necessary to consider additional protection.

Authorized Engineering Information 5-19-1986.

5.16 ATMOSPHERIC CONDITIONS

Exposed core and ventilated dry-type transformers are normally designed for installation indoors in dry locations. When recommended by the manufacturer, they may be installed outdoors if they are suitably protected or they are of outdoor construction.

They will operate successfully where the humidity is high, providing precautions are taken to keep them dry if they are shut down for appreciable periods.

Locations where there is dripping water should be avoided or suitable protection should be provided to prevent water from entering the enclosure. Precautions should be taken to guard against the accidental entrance of water from an open window, skylight or other opening; a break in a water or stream line; flooding; or from the use of water near the transformer.

Transformers should be installed in locations where the ambient atmosphere is free from unusual chemical fumes or dust.

Authorized Engineering Information 11-11-1971.

5.17 SPACINGS FOR DRY-TYPE TRANSFORMERS INSTALLED INDOORS

5.17.1 Nonventilated-type Transformers

Nonventilated-type transformers depend upon the natural circulation of air and convection principles for their cooling with the air coming in contact only with their outer surfaces. An unimpeded air flow should be provided. Equally important is the clearance between the top surface of the transformer and adjacent surfaces so that as the warm air rises around the transformer, and its volume increases, it has an adequate means of egression. Transformers should be mounted in such a manner that one transformer, or another heat source, will not add to the heating of another transformer beyond the allowable temperature limits. Transformers should not be located where walls or other obstructions might prevent the free circulation of air through and around each unit.

5.17.2 Ventilated-type Transformers

Ventilated-type transformers use a construction that envelopes the core and coils in a louvered or otherwise ventilated case which aids the natural draft cooling of the transformer winding. The windings are freely ventilated to the outside air through a chimney effect.

Transformers should be mounted in such a manner that one transformer, or another heat source, will not add to the heating of another transformer beyond the allowable temperature limits. Transformers should not be located where walls or other obstructions might prevent the free circulation of air through and around each unit.

5.17.3 Nonenclosed Transformers

Nonenclosed transformers are intended for installation with other equipment or in other enclosures. Adequate electrical thermal and mechanical clearances should be provided in the installation.

5.17.4 Enclosed Transformers

Enclosed transformers which are to be floor mounted or mounted on a wall or other vertical surface should be mounted as specified by the instructions on the transformer or in accordance with the following:

1. Transformers rated 30 kVA and less should be spaced from the ceiling or adjacent wall by a minimum of 1 inch for each 5 kVA or fraction thereof. The adjacent wall is the wall other than the one on which the transformer is mounted.
2. Transformers rated above 30 kVA, should be at least 6 inches from the ceiling or adjacent wall. The adjacent wall is the wall other than the one on which the transformer is mounted.

5.17.5 Separation from Combustible Materials

Dry-type transformers which are located near combustible materials should have the minimum separation established by the *National Electrical Code*.

Authorized Engineering Information 5-19-1986.

5.18 KNOCKOUTS AND ENTRANCE HOLES

Knockouts should be removed in accordance with the following:

1. Remove knockouts one at a time, alternating inward and outward.
2. Remove center knockout inward. Place screwdriver blade against point farthest from tie and strike inward (Figure 5-5). Bend back and forth to break tie.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3. Remove rings one at a time without straining remaining rings.
   a. Pry first ring outward with screwdriver midway between ties, using pliers flat against box under screwdriver (Figure 5-6). Bend ring sections outward with pliers, then back and forth to break ties (Figure 5-7).
   b. Remove second ring inward by striking screwdriver (with blade against point midway between ties) then bending ring sections inward and back and forth to break ties.

In making other types of entrances holes, care should be exercised so that the transformer will not be damaged and metal particles do not remain in the transformer.

Entrance holes should be placed in the vicinity of terminal used for attaching field conductors in order to prevent locating cable in areas having excessive ambient temperatures.

Authorized Engineering Information 5-19-1986.

5.19 MAINTENANCE

Dry-type transformers are virtually maintenance free. However, they do 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 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.

Some maintenance may be conducted while the transformer is energized. This would include such things as peripheral inspection, external dust removal, external painting of enclosed units when no exposed electrical wiring or terminations exist, recording of service data, etc. Other 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:

1. Be sure that the transformer is disconnected from all electric power sources before servicing (live parts whose potential exceeds 30 volts to ground are considered to present a shock hazard).
2. After power has been disconnected from the transformer, attach ground leads or their equivalent to the input and output terminals of the transformer. Such grounding may be unnecessary in the case of low-voltage transformers that can be visibly isolated from energized conductors by other disconnecting means.
3. 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 pervail. This is necessary to avoid flashover as a result of the accumulation of foreign substance on their surface.
4. 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 any plating is not damaged, smooth down the surface with clean fine sandpaper (not emery) or follow the manufacturer's recommendations.
5. Inspect for moisture conditions which may cause corrosion or harmful lowering of insulation levels.
6. Inspect air ducts for the accumulation of dust and foreign substances; if necessary, blow out the accumulation.
7. See that bolts, nuts, washers, pins, terminal connections, including ground connection, are in place and in good condition.
8. 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.
9. 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.

Authorized Engineering Informatin 5-19-1986.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

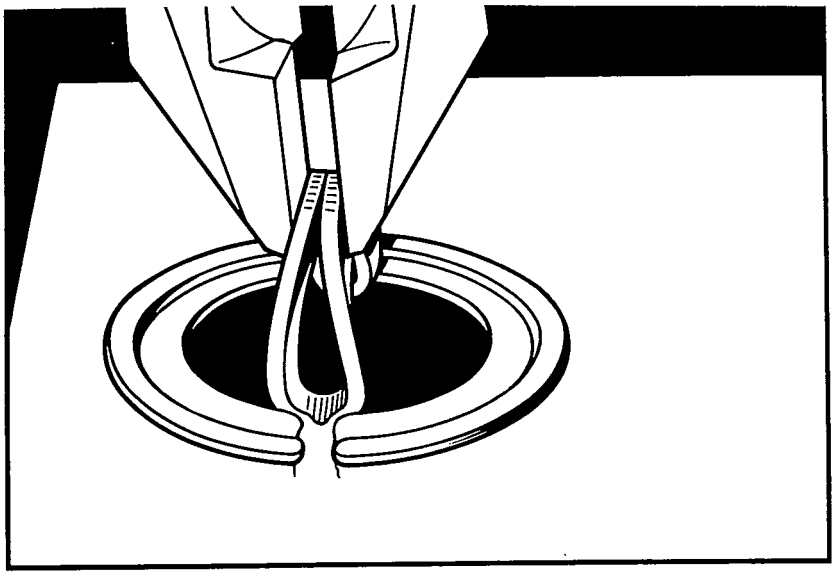


Figure 5-7

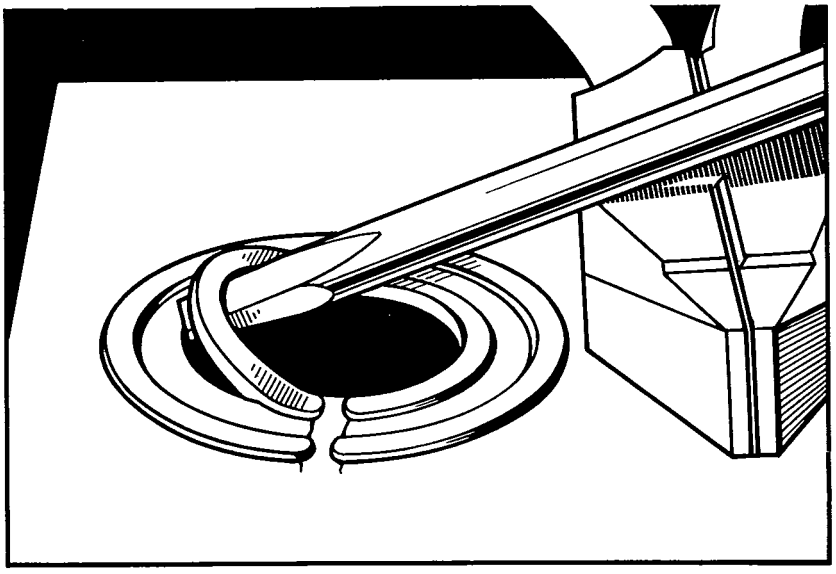


Figure 5-6

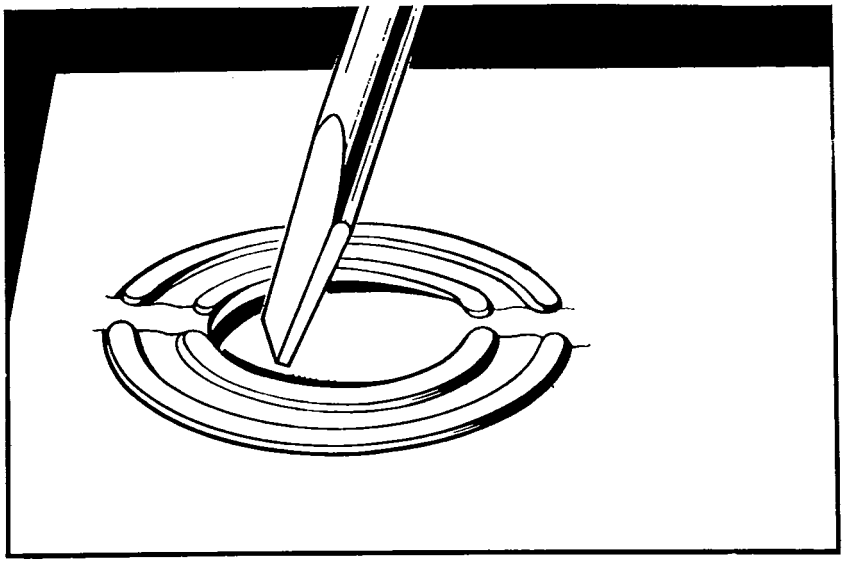


Figure 5-5

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Appendix

LOADING

(Authorized Engineering Information 5-19-1986.)

The American National Standard *Guide for Loading Dry-Type Distribution and Power Transformers* ANSI C57.96, dated November 1959, is currently being revised and updated. The ANSI C57.96 document provides the recommended practice and procedures for the loading of dry-type transformers covered in this Standards Publication.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS

Not for Resale

September 1984

NEMA STANDARDIZATION

The purpose of NEMA Standards, their classification and status are set forth in certain clauses of the NEMA Bylaws, which are quoted 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 its particular need. 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.

(Bylaw—Art. V, Sec. 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, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Bylaw—Art. V, Sec. 2, Subsection A)

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.

(NEMA Policy Memorandum 84-2, dated June 7, 1984)

Classes of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
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, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

(Bylaw—Art. V, Sec. 2, Subsection B)

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.

(Bylaw—Art. V, Sec. 6, 1st Sentence)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment and/or approval.

(Bylaw—Art. V, Sec. 4, Subsection A)

Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

DRY-TYPE AND SPECIALTY TRANSFORMER SECTION OF THE NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

MEMBER COMPANIES

Acme Electric Corporation
Lumberton, NC 28358

BBC Brown-Boveri, Inc.
Spring House, PA 19477

Challenger Electrical Equipment Corporation
Jackson, MS 39205

Federal Pacific Electric Company
(A Subsidiary of Reliance Electric Company)
Raleigh, NC 27607

General Electric Company
Rome, GA 30161

Hevi-Duty Electric
(Unit of General Signal Corporation)
Goldsboro, NC 27530

International Transformer Corporation
Montebello, CA 90604

Matra Electric Corporation
Compton, CA 90224

National Industri Transformers, Inc.
Hampton, VA 23661

NECO Hammond, Inc.
Baraboo, WI 53913

Niagara Transformer Corporation
Buffalo, NY 14225

Southern Transformer Company
East Point, GA 30344

Square D Company
Palatine, IL 60067

R. E. Uptegraff Manufacturing Company
Scottsdale, PA 15683

Walker Power, Inc.
Division of Walker Magnetic Group
Warner, NH 03278

Westinghouse Electric Corporation
Pittsburgh, PA 15220

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale