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# IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers, Including Those with Solid-Cast and/or Resin Encapsulated Windings

## IEEE Power Engineering Society

Sponsored by the
Transformers Committee

IEEE
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(Revision of
IEEE Std C57.12.01-1998)

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Approved 8 December 2005

**IEEE-SA Standards Board**

**Abstract:** Electrical, mechanical, and safety requirements of ventilated, non-ventilated, and sealed dry-type distribution and power transformers or autotransformers (single and polyphase, with a voltage of 601 V or higher in the highest voltage winding) are described.
**Keywords:** autotransformer, dry-type distribution, power transformer, voltage winding

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## Introduction

This introduction is not part of IEEE Std C57.12.01-2005, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers, Including Those with Solid-Cast and/or Resin Encapsulated Windings.

This standard is the result of an effort encompassing the interests of users, manufacturers, and others dedicated to producing voluntary consensus standards for dry-type transformers.

This revision continues to improve harmonization with international standards such as IEC 60076-11:2004.

Table 4 and Table 5 in IEEE Std C57.12.01-1998 implied a dependent relationship between high-frequency test levels and the corresponding low-frequency levels. Such a dependency was not intended. These tables have been combined into one table (Table 5) to clarify the proper relationship.

Dielectric tests consist of low-frequency and high-frequency values. Low-frequency tests include induced voltages up to two times rated volts, which are intended to verify the integrity of turn-to-turn and layer-to-layer insulation systems. Applied potential tests verify the integrity of major insulation systems above ground and between separate windings. High- frequency tests include a 1.2 × 50 μs wave and a chopped wave to verify the integrity of electrical windings to withstand lightning and switching transients.

This revision also adds references to NEMA ST-20[1] and the National Electrical Code® (NEC®) (NFPA 70)[2] as these standards refer to this standard.

NEMA standard ST-20 is a standard for dry-type transformers with primary windings connected to secondary distribution circuits with voltages of 600 V and below usually installed and used in accordance with the National Electric Code. NEMA ST-20 does, in its content, refer to IEEE Std C57.12.01 and it is referenced here for information on voltages 600 V and below applications only.

Annex A from IEEE Std C57.12.01-1998 has been removed from this revision because the material in question, the operation of transformers at altitudes greater than 1000 m (3300 ft), is covered in IEEE Std C57.96.

This revision was developed by the Working Group of the Dry-Type Transformers Subcommittee of the IEEE Transformer Committee of the IEEE Power Engineering Society.

This standard is a voluntary consensus standard. Its use may become mandatory only when required by a duly constituted legal authority, or when specified in a contractual relationship. To meet specialized needs and to allow innovation, specified changes are permissible when mutually determined by the user and the producer, provided such changes do not violate existing laws and are considered technically adequate for the function intended.

[1] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http://global.ihs.com/).
[2] NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (http://www.nfpa.org/).

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# IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers, Including Those with Solid-Cast and/or Resin Encapsulated Windings

## 1. Overview

### 1.1 Scope

Electrical, mechanical, and safety requirements of ventilated, non-ventilated, and sealed dry-type distribution and power transformers or autotransformers (single and polyphase, with a voltage of 601 V or higher in the highest voltage winding) are described.

### 1.2 Purpose

This standard is intended as a basis for the establishment of performance, interchangeability, and safety requirements of equipment described, and for assistance in the proper selection of such equipment.

The information in this standard applies to all dry-type transformers except as follows:

a) Instrument transformers

b) Step- and induction-voltage regulators

c) Arc-furnace transformers

d) Rectifier transformers

e) Specialty and general-purpose transformers

f) Mine transformers

g) Testing transformers

h) Welding transformers

### 1.3 Word usage

When this standard is used on a mandatory basis, the word *shall* indicates mandatory requirements; the words *should* and *may* refer to matters that are recommended or permissive but not mandatory.

NOTE—The introduction of this voluntary consensus standard describes the circumstances under which the standard may be used on a mandatory basis.[1]

## 2. Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI C57.12.55, American National Standard for Dry-Type Transformers in Unit Installations, Including Unit Substations—Conformance Standard.[2]

ANSI C57.12.70, American National Standard for Terminal Markings and Connections for Distribution and Power Transformers.

ANSI C84.1, American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hz).

IEEE Std 315™, IEEE Graphic Symbols for Electrical and Electronics Diagrams.[3, 4]

IEEE Std C57.12.56™, IEEE Standard Test Procedure for Thermal Evaluation of Insulation Systems for Ventilated Dry-Type Power and Distribution Transformers.

IEEE Std C57.12.60™, IEEE Guide for Test Procedures for Thermal Evaluation of Insulation Systems for Solid Cast and Resin-Encapsulated Power and Distribution Transformers.

IEEE Std C57.12.80™, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.91™, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.

IEEE Std C57.96™, IEEE Guide for Loading Dry-Type Distribution and Power Transformers.

IEEE Std C57.124™, IEEE Recommended Practice for the Detection of Partial Discharge and the Measurement of Apparent Charge in Dry-Type Transformers.

IEEE Std C62.22™, IEEE Guide for Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

[1] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.
[2] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).
[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://www.standards.ieee.org/).
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# 3. Definitions

Standard transformer terminology, which is available in IEEE Std C57.12.80[5], shall apply. Other electrical terms are defined in *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

# 4. Service conditions

## 4.1 Usual service conditions

### 4.1.1 General

Transformers conforming to this standard shall be suitable for operation at rated power under the usual service conditions in 4.1.2 through 4.1.9.

### 4.1.2 Temperature

The temperature of the cooling air (ambient temperature) shall not exceed 40 ºC, and the average temperature of the cooling air for any 24-hour period shall not exceed 30 ºC.

The minimum ambient temperature shall not be lower than –30 ºC.

For special ambient temperatures below –30 °C, see 4.2.1 and 4.2.6.

### 4.1.3 Altitude

The altitude shall not exceed 1000 m (3300 ft).

### 4.1.4 Supply voltage

The supply-voltage wave shape shall be approximately sinusoidal, and the phase voltage supplying a polyphase transformer shall be approximately equal in magnitude and of approximate equal time phase in displacement.

### 4.1.5 Load current

The load current shall be approximately sinusoidal. The harmonic factor shall not exceed 0.05 per unit.

NOTE—*Harmonic factor* is defined in IEEE Std C57.12.80.

### 4.1.6 Operation above rated voltage

Transformers shall be capable of

a) Operating continuously above rated voltage or below rated frequency, at maximum rated kilovolt-amperes for any tap, without exceeding limits of observable temperature rise when secondary voltage and volts per hertz does not exceed 105% of rated values, load power factor is 80% or higher, and frequency is at least 95% of rated value.

[5] Information on references can be found in Clause 2.

b) Operating continuously above rated voltage or below rated frequency on any tap at no load, without exceeding limits of observable temperature rise when neither the voltage or volts per hertz exceed 110% of rated values.

The maximum continuous transformer operating voltage should not exceed the levels specified in ANSI C84.1.

NOTE—System conditions may require voltage transformation ratios involving tap voltages higher than the maximum system voltage for regulation purposes. However, the appropriate maximum system voltage should be observed under operating conditions.

#### 4.1.7 Location

Sealed and non-ventilated transformers shall be suitable for indoors, outdoors, or indoor and outdoor operation as specified.

Unless otherwise specified, ventilated transformers shall be suitable for indoor operation or outdoor operation as specified. When used outdoors, the transformer shall be provided with a suitable weather-resistant enclosure that complies with the requirements contained in ANSI C57.12.55 for outdoor enclosures.

#### 4.1.8 Step-down operation

Unless otherwise specified, dry-type transformers shall be designed for step-down operation.[6]

#### 4.1.9 Tank or enclosure finish

Temperature limits and tests shall be based on the use of a nonmetallic pigment-coating finish.

### 4.2 Unusual service conditions

#### 4.2.1 General

Conditions, other than those described in 4.1, are considered unusual service conditions and, when present, should be brought to the attention of those responsible for the design and application of the apparatus.

NOTE—IEEE Std C57.96 is a guide. It provides the best known general information for the loading of transformers under various conditions based on typical winding insulation systems, and it is based on the best engineering information available at the time of preparation. The guide discusses limitations of ancillary components other than windings that may limit the capability of transformers to meet the guide.

#### 4.2.2 Ancillary components

When specified, construction features (cables, leads, tap changers, etc.) shall be supplied so that the ancillary components will not in themselves limit the short-time loading to less than that which will result in no loss in normal life expectancy of the winding insulation system.

#### 4.2.3 Unusual loading

IEEE Std C57.96 provides guidance for loading under unusual conditions, including

a) Ambient temperatures higher or lower than the basis of rating

[6] See Footnote k of Table 13.

b) Short-time loading in excess of nameplate rated power with normal life expectancy

c) Loading that results in reduced life expectancy

d) High-altitude service conditions

### 4.2.4 Unusual altitude service conditions

Information regarding the operation of transformers above 1000 m (3300 ft) is presented in IEEE Std C57.96. The standard provides information that includes the effects of altitude on temperature rise, operation at rated power and reduced ambient temperature, and operation at less than rated power.

### 4.2.5 Insulation at high altitude

The dielectric strength of transformers that depend in whole or in part on air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, transformers shall be designed with larger air spacing, using the correction factors from Table 1 to obtain adequate air dielectric strength at altitudes above 1000 m (3300 ft).

The insulation level at 1000 m (3300 ft) multiplied by the correction factor from Table 1 shall be not less than the required insulation level at the required altitude.

**Table 1— Dielectric strength correction factors for altitudes[7] greater than 1000 m (3300 ft)**

| Altitude | | Altitude correction factor for dielectric strength |
|---|---|---|
| (m) | (ft) | |
| 1 000 | 3 300 | 1.00 |
| 1 200 | 4 000 | 0.98 |
| 1 500 | 5 000 | 0.95 |
| 1 800 | 6 000 | 0.92 |
| 2 100 | 7 000 | 0.89 |
| 2 400 | 8 000 | 0.86 |
| 2 700 | 9 000 | 0.83 |
| 3 000 | 10 000 | 0.80 |
| 3 600 | 12 000 | 0.75 |
| 4 200 | 14 000 | 0.70 |
| 4 500 | 15 000 | 0.67 |

### 4.2.6 Other unusual service conditions

Other unusual service conditions include:

a) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, and excessive moisture or dripping water constitute service conditions for which some dry-type transformers are not intended and, therefore, may have detrimental effects on transformer life.

NOTE—The seriousness of the effects of the unusual conditions listed in item a) varies widely, depending on the design of dry-type transformer involved. Although such conditions may have little or no effect on sealed or nonventilated dry-type transformers, they may have serious effects on ventilated dry-type transformers.

b) Abnormal vibrations, tilting, shock, or seismic conditions.

[7] An altitude of 4500 m (15 000 ft) is considered a maximum for transformers conforming to this standard.

c) Ambient temperatures outside the normal range.

d) Unusual transportation or storage conditions.

e) Unusual space limitations.

f) Unusual maintenance problems.

g) Unusual duty or frequency of operation, impact loading.

h) Unbalanced ac voltages, or departure of ac system voltages from a sinusoidal waveform, as identified in 4.1.4.

i) Loads involving abnormal harmonic currents, such as those that may result where solid-state or similar devices control appreciable load currents. Harmonic currents may cause excessive losses and abnormal heating. Limits for usual service conditions are identified in 4.1.5.

j) Multiwinding transformers with a specified combination of power outputs and power factors for each winding.

k) Unusually high, low, or unbalanced ac system impedance.

l) Overexcitation exceeding 110% rated V/Hz.

m) Planned short circuits as part of a regular operating or relaying practice.

n) Short-circuit application conditions requiring special consideration as described in 7.5.

o) Special insulation requirements or unusual transient voltages present on the ac power supply, including resonant or switching-related disturbances.

p) Unusually strong magnetic radiation.

q) Unusually high nuclear fields.

r) Parallel operation.

NOTE—Although parallel operation is not unusual, it is desirable that users advise manufacturers if paralleling with other transformers is planned and identify the transformers involved.

# 5. Rating data

## 5.1 Cooling classes of transformers

Transformer cooling classes are listed in Table 2.

**Table 2— Cooling classes**

| Description | Class | IEC equivalent |
|---|---|---|
| Ventilated self-cooled | AA | AN |
| Ventilated forced-air-cooled | AFA | AF |
| Ventilated self-cooled/forced-air-cooled | AA/FA | AN/AF |
| Nonventilated self-cooled | ANV | — |
| Sealed self-cooled | GA | — |
| NOTE—In the IEC symbols “N” indicates natural. | | |

## 5.2 Frequency

Unless otherwise specified, transformers shall be designed for operation at a frequency of 60 Hz.

## 5.3 Phases

### 5.3.1 General

Transformers described in this standard are either single phase or three phase. Standard ratings are included in the product standards for particular types of transformers. When specified, other phase arrangements may be provided.

### 5.3.2 Scott or T-connected transformers

For rarely used connections such as Scott or T-connected transformers, see ANSI C57.12.70.

## 5.4 Rated power

### 5.4.1 General

The power rating of a transformer shall be the output that 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.

### 5.4.2 Preferred continuous power rating

Preferred continuous power rating of single-phase and three-phase distribution and power transformers shall be as shown in Table 3.

**Table 3—Preferred continuous power ratings**

| Single-phase transformers (kVA) | Three-phase transformers (kVA) |
|---|---|
| 1.0 | 15.0 |
| 3.0 | 30.0 |
| 5.0 | 45.0 |
| 7.5 | 75.0 |
| 10.0 | 112.5 |
| 15.0 | 150.0 |
| 25.0 | 225.0 |
| 37.5 | 300.0 |
| 50.0 | 500.0 |
| 75.0 | 750.0 |
| 100.0 | 1 000.0 |
| 167.0 | 1 500.0 |
| 250.0 | 2 000.0 |
| 333.0 | 2 500.0 |
| 500.0 | 3 750.0 |
| 833.0 | 5 000.0 |
| 1 250.0 | 7 500.0 |
| 1 667.0 | 10 000.0 |
| 2 500.0 | 12 000.0 |
| 3 333.0 | 15 000.0 |
| 5 000.0 | 20 000.0 |
| 6 667.0 | 25 000.0 |
| 8 333.0 | 30 000.0 |
| 10 000.0 | — |

## 5.5 Voltage rating and taps

### 5.5.1 General

Standard nominal system voltages are listed in ANSI C84.1. Voltages available on standard transformers are included in the product standards for particular types of transformers.

### 5.5.2 Voltage rating

The voltage rating at no load shall be based on the turn ratio. The ratio of voltage is subject to the effect of regulation at various loads and power factors.

### 5.5.3 Rating of transformer taps

Whenever a transformer is provided with taps from a winding, the taps shall be full-capacity taps. When specified, taps other than full-capacity taps may be provided, and this shall be stated on the nameplate.

## 5.6 Connections

Standard connection arrangements are described in the product standards for particular types of transformers.

## 5.7 Polarity, angular displacement, and terminal marks

### 5.7.1 Polarity of single-phase transformers

The numbering of the termination of the *H* winding and the termination of the *X* winding shall be applied so that when the lowest numbered *H* and the lowest numbered *X* termination are connected, and voltage is applied to the transformer, the voltage between the highest numbered *H* termination and the highest numbered *X* termination 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.

NOTE—This arrangement is also known as *subtractive polarity.*

### 5.7.2 Angular displacement between voltages of windings for three-phase transformers

The angular displacement between high-voltage and low-voltage phase voltages of three-phase transformers with Δ–Δ or Y–Y connections shall be 0°.

The angular displacement between high-voltage and low-voltage phase voltages of three-phase transformers with Y–Δ or Δ–Y connections shall be 30°, with the low voltage lagging the high voltage, as shown in Figure 1. The angular displacement of polyphase transformers is the time angle, expressed in degrees, between the line-to-neutral voltage terminal (*H*1) and the line-to-neutral voltage of the corresponding identified low-voltage terminal (*X*1).

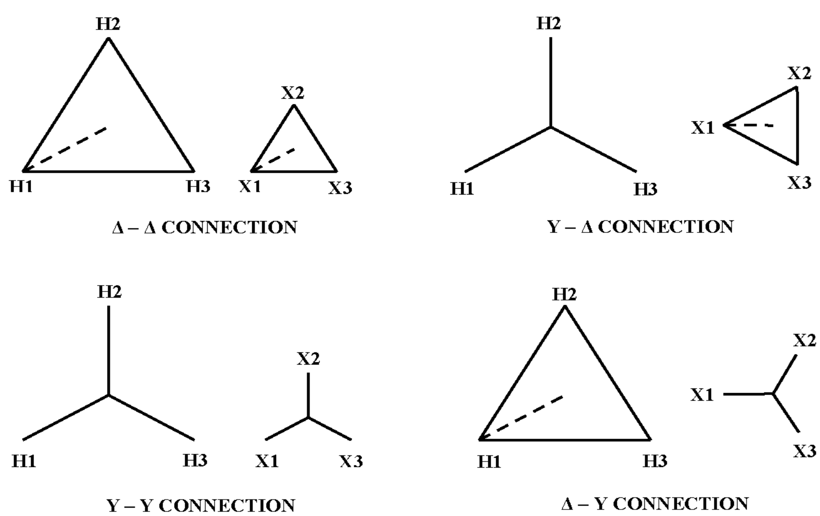


**Figure 1—Phase relation of terminal designation for three-phase transformers**

### 5.7.3 Terminal marking

Terminal marking shall be in accordance with ANSI C57.12.70.

## 5.8 Impedance

Standard values of impedance are included in the product standards for particular types of transformers.

## 5.9 Losses

The total losses of a transformer shall be the sum of the no-load losses and the load losses. Refer to 5.11.5 for the determination of the reference temperature upon which these losses are established. (See Table 10 for winding temperature-rise values.)

### 5.9.1 Accuracy required for measured losses

Measured values of electric power, voltage, current, resistance, and temperatures are used in the calculations of reported data. To ensure sufficient accuracy in the measured and calculated data, the following requirements shall be met:

a) Test procedures, in accordance with Clause 5, Clause 8, and Clause 9 of IEEE Std C57.12.91, are required.

b) The test equipment used for measuring losses of power and distribution transformers shall meet the requirements of Clause 5, Clause 8, and Clause 9 of IEEE Std C57.12.91.

c) The test-system accuracy for each quantity measured shall fall within the limits specified in Table 4.

**Table 4—Test-system accuracy requirements**

| Quantity measured | Test-system accuracy |
|---|---|
| Losses | ±3.0% |
| Voltage | ±0.5% |
| Current | ±0.5% |
| Resistance | ±0.5% |
| Temperature | ±2.0 ºC |

## 5.10 Insulation levels

### 5.10.1 Line terminals

The line terminals of a winding shall be assigned a basic lightning impulse insulation level (BIL) to indicate the factory dielectric tests that these terminals are capable of withstanding.

The BIL ratings are given in Table 5. The lowest BIL rating is 10 kV and applies down to and including 251 V ratings. Table 5 lists low-frequency insulation levels corresponding to line-terminal BIL ratings for both fully insulated windings and windings with reduced neutral insulation. Consideration for the proper insulation to be applied shall be determined by the degree of exposure to lightning and switching overvoltages, the type of system grounding, and the type of over voltage protective devices used in each application.

Transformers designed for Y connection only, with a neutral brought out through a terminal, shall be assigned a BIL rating for line terminals, and neutral terminals shall be insulated in accordance with 5.10.2.

### Table 5— Dielectric insulation levels for dry-type transformers used on systems with BIL ratings 200 kV BIL and below

| Nominal L-L system voltages | Low-frequency voltage insulation level[a] | Basic lightning impulse insulation levels (BIL ratings) in common use kV crest[b,c] (1.2 × 50 μs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (kV) | (kV rms) | 10 | 20 | 30 | 45 | 60 | 95 | 110 | 125 | 150 | 200 |
| 0.25 | 2.5 | None | | | | | | | | | |
| 0.6 | 3 | S[d] | 1[e] | 1 | | | | | | | |
| 1.2 | 4 | S | 1 | 1 | | | | | | | |
| 2.5 | 10 | | S | 1 | 1 | | | | | | |
| 5.0 | 12 | | | S | 1 | 1 | | | | | |
| 8.7 | 19 | | | | S | 1 | 1 | | | | |
| 15.0 | 34 | | | | | S | 1 | 1 | | | |
| 18.0 | 40 | | | | | | S | 1 | 1 | | |
| 25.0 | 50 | | | | | | 2[f] | S | 1 | 1 | |
| 34.5 | 70 | | | | | | | | 2 | S | 1 |
| Chopped wave[g,h] minimum time to flashover μs | | 1.0 | 1.0 | 1.0 | 1.25 | 1.5 | 1.6 | 1.8 | 2.0 | 2.25 | 2.7 |

**CAUTION**

When impulsing the low side windings, the high side may experience relatively higher voltages than BIL levels.

NOTE—The latest edition of IEEE Std C62.22 should be consulted for information coordination with available surge arrester protection levels.

[a]Low-frequency voltage insulation levels apply to the standard "S" levels in the table.
[b]Low-impedance low-side windings may be tested with a much faster 0.5 × 1.5 μs impulse wave on BIL ratings less than or equal to 30 kV.
[c]A positive impulse wave shall be used.
[d]S = Standard values.
[e]1 = Optional higher level where exposure to overvoltages occurs and improved protective margins are required.
[f]2 = Optional lower levels where protective characteristics of applied surge arresters have been evaluated and found to provide appropriate surge protection.
[g]The voltage crest of the chopped wave should be approximately the same as the full wave magnitude.
[h]No chopped waves are required on 0.6 kV systems and below.

## 5.10.2 Neutral terminals

The neutral terminal of a winding, which is designed for grounded-Y connection only, may have an insulation level lower than that for the line terminal. Such neutral terminals shall be bolted to the equipment ground pad on the transformer frame and to the system ground.

Windings of transformers and autotransformers designed for Y connection only, with the neutral brought out and solidly grounded directly or through a current transformer, shall have neutral insulation as follows:

a) Windings with line-to-line voltages less than or equal to 250 V shall have the neutral insulated for a 2.5 kV low-frequency applied voltage test.

b) Windings with line-to-line voltages than 251 V to 600 V shall have the neutral insulated for a 3 kV low-frequency applied voltage test.

c) Windings with line-to-line voltages 601 V to 1200 V shall have the neutral insulated for a 4 kV low-frequency applied voltage test.

d) Windings with line-to-line voltages 1201 V or greater shall have the neutral insulated for a 10 kV low-frequency applied voltage test.

e) When specified, the neutral shall be designed for a higher insulation level.

Y-connected windings with an ungrounded neutral shall be treated the same as a Δ-connected winding having the same phase-to-phase voltage, and a BIL rating shall be assigned to the neutral terminal.

The insulation level of the neutral end of the winding may differ from the insulation level of the highest-voltage neutral terminal for which provision is made in the transformer. In this case, the dielectric tests on the neutral shall be determined by whichever of the following is lower:

a) The insulation level of the neutral end of the winding, or

b) The insulation level of the neutral terminal.

### 5.10.3 Insulation tests

#### 5.10.3.1 General

The following insulation tests shall be performed in accordance with the procedures described in IEEE Std C57.12.91.[8]

#### 5.10.3.2 Low-frequency tests

a) A winding-to-winding and winding-to-ground applied voltage test shall be made in accordance with Table 5 on Δ- and Y-connected windings when the neutral is ungrounded.

b) For internally solidly grounded-Y windings

   1) A line-terminal-to-ground test voltage shall be induced from another winding. This test voltage shall be twice the operating line-terminal-to-neutral voltage, with the neutral grounded.

   2) A phase-to-phase test voltage shall be induced from another winding, which will develop twice the operating phase-to-phase voltage between line terminals.

c) Twice the rated turn-to-turn voltages shall be developed in each winding.

#### 5.10.3.3 Low-frequency test—exceptions

Tests are subject to the limitations that the voltage-to-ground test shall be performed as specified in 5.10.3.2 on the line terminals of the winding with the lowest ratio of test voltage to minimum turns. Then test levels may otherwise be reduced such that none of the tests required in 5.10.3.2 need be exceeded to meet the requirements of the others, or such that no winding need be tested above its specified level to meet the test requirements of another winding.

#### 5.10.3.4 Impulse tests

Impulse tests shall be performed in accordance with Table 5.

#### 5.10.3.5 Partial discharge tests

Partial discharge tests are intended to verify that the internal insulation is free from damaging discharges. Partial discharge tests shall be performed as required by Table 17. The transformers under this standard shall be designed to have a minimum extinction voltage of 110% of the designed rated voltage. The tests for partial discharge shall be conducted during the induced test for high- to low-voltage air insulated transformers, and the induced and applied test shall be made for high- to low-voltage solid insulated transformers. The preferred arrangement for partial discharge tests is to have the transformer fully

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[8] In the test descriptions in 5.10.3.2 through 5.10.3.6, the word "phase" refers to the line terminal of a winding and not to the entire winding, which recognizes the construction of windings with "graded insulation."

assembled before conducting the partial discharge tests; however, testing of coils separately is acceptable if approved by the user. As stated in the forward of IEEE Std C57.124, bus assemblies may be disconnected from the coils when conducting the partial discharge tests.

Partial discharge extinction voltage is the highest voltage at which partial discharge no longer exceeds the intensity specified in Table 6 as the applied voltage is gradually decreased from the inception level. If partial discharge inception does not occur or is less than the intensity listed in Table 6, the transformer is considered partial discharge free. Both winding ends of each phase shall be tested. No test shall be made on a terminal that is intended to be grounded. The general procedure for partial discharge testing is as follows. The voltage is raised to the pre-stress level, held for a minimum of 10 s, and is then reduced to the voltage level equivalent to 110% of rated voltage of the winding under test. Make the partial discharge measurement after holding the applied voltage for 1 min. The ambient level of the instrumentation shall be considered when determining the final value of partial discharge. This value shall be measured in picocoulombs (pC) using techniques described in IEEE Std C57.124 .

**Table 6—Partial discharge limits and pre-stress limits**

| Standard voltage class (kV) | Pre-stress voltage level (kV L-L) | Maximum permissible partial discharge intensity @110% rated voltage in pC |
|---|---|---|
| 0.25 | — | — |
| 0.6 | 0.8 | 50 |
| 1.2 | 1.6 | 50 |
| 2.5 | 3.3 | 50 |
| 5.0 | 6.5 | 50 |
| 8.7 | 11.3 | 100 |
| 15.0 | 19.5 | 100 |
| 18.0 | 23.4 | 100 |
| 25.0 | 32.5 | 100 |
| 34.5 | 44.9 | 100 |

### 5.10.3.6 Audible sound levels

Transformers shall be designed so that the average sound-pressure level does not exceed the values given in Table 7 through Table 9, measured according to IEEE Std C57.12.91.

**Table 7—Average sound level, decibels three-phase high voltage 601 V to 1.2 kV**

| Equivalent two-winding (kVA) | Self-cooled ventilated (class AA rating) |
|---|---|
| 0–9 | 40 |
| 10–50 | 45 |
| 51–150 | 50 |
| 151–300 | 55 |
| 301–500 | 60 |
| 501–700 | 62 |
| 701–1000 | 64 |
| 1001–1500 | 65 |
| 1501–2000 | 66 |
| 2001–3000 | 68 |

**Table 8—Average sound level, decibels three-phase high voltage above 1.2 kV**

| Self cooled | | | Ventilated forced air cooled[a] | |
|---|---|---|---|---|
| Equivalent two-winding (kVA) | Ventilated (class AA rating) | Sealed (class AA rating) | Equivalent two-winding (kVA) | Class FA and AFA rating |
| 0-9 | 40 | 45 | 0–1 167 | 67 |
| 10-50 | 45 | 50 | 1 168–1 667 | 68 |
| 51-150 | 50 | 55 | 1 668–2 000 | 69 |
| 151–300 | 55 | 57 | 2 001–3 333 | 71 |
| 301–500 | 60 | 59 | 3 334–5 000 | 73 |
| 501–700 | 62 | 61 | 5 001–6 667 | 74 |
| 701–1 000 | 64 | 63 | 6 668–8 333 | 75 |
| 1 001–1 500 | 65 | 64 | 8 334–10 000 | 78 |
| 1 501–2 000 | 66 | 65 | 10 001–13 333 | 82 |
| 2 001–3 000 | 68 | 66 | — | — |
| 3 001–4 000 | 70 | 68 | — | — |
| 4 001–5 000 | 71 | 69 | — | — |
| 5 001–6 000 | 72 | 70 | — | — |
| 6 001–7 500 | 75 | 71 | — | — |
| 7 501–10 000 | 79 | 72 | — | — |
| 10 001–15 000 | 82 | 73 | — | — |

[a]Does not apply to sealed dry-type transformers.

**Table 9—Average sound level, decibels single-phase high voltage above 601 V**

| Equivalent two-winding (kVA) | Self cooled | | Ventilated forced air cooled (class FA and AFA rating)[a] |
|---|---|---|---|
| | Ventilated (class AA rating) | Sealed (class AA rating) | |
| 0–50 | 50 | 50 | 67 |
| 51–167 | 55 | 55 | 67 |
| 168–333 | 60 | 60 | 67 |
| 500 | 64 | 63 | 67 |
| 833 | 65 | 64 | 68 |
| 1 256 | 68 | 66 | 70 |
| 1 667 | 70 | 68 | 71 |
| 2 500 | 71 | 70 | 72 |
| 3 333 | 72 | 71 | 74 |
| 5 000 | 73 | 72 | 76 |
| 10 000 | 79 | 72 | 78 |

[a]Does not apply to sealed dry-type transformers.

### 5.10.4 Taps

Transformers may be provided with taps for voltages above rated voltages without increasing the insulation level, provided that the maximum system voltage is not exceeded. The preferred tapping range is 5% in 2.5% steps above and below rated voltage.

## 5.11 Temperature rise and insulation-system capability

### 5.11.1 Life of insulating materials

The life of insulating materials commonly used in transformers depends largely on the temperatures to which they are subjected and the duration of such temperatures. As the actual temperature is the sum of the ambient temperature and the temperature rise, the ambient temperature largely determines the load that can reasonably be carried by transformers in service.

Other factors on which the life of insulating materials depends are as follows:

a) Electric stress and associated effects
b) Vibration or varying mechanical stress
c) Repeated expansions and contractions
d) Exposure to moisture, contaminating environments, and radiation
e) Incompatible materials

These factors, in combination with time and temperature, may increase the rate of thermal degradation of materials and contribute to early failure. The winding temperature-rise limits and insulation-system materials for dry-type transformers are so chosen that the transformers will have a satisfactory life under usual operating conditions based on insulation-system thermal evaluation. Unusual loading conditions are discussed in 4.2.3.

#### 5.11.2 Classification of insulation systems

##### 5.11.2.1 General

Experience has shown that the thermal-life characteristics of composite insulation systems generally cannot be reliably inferred from information concerning component materials when some component materials have ratings lower than the temperature rating of the insulation system. To assure satisfactory service life, insulation systems need to be evaluated by service experience or accelerated-life tests on models. Accelerated-life tests are being used increasingly to evaluate systems using the many new synthetic insulating materials that are available, thus shortening the period 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 IEEE Std C57.12.56 and IEEE Std C57.12.60.

##### 5.11.2.2 Insulating materials

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

##### 5.11.2.3 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 or in a form representative of such use through simulations 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.

##### 5.11.2.4 System limiting temperature

Limiting system hottest-spot temperatures and associated maximum winding-temperature rises are described in 5.11.3 and are approved only when used in the insulation of apparatus within the scope of this standard. These temperatures should not be confused with the values used for the identification and classification of the materials themselves.

The electrical and mechanical properties of the insulated winding shall not be impaired by the application of the hottest-spot temperature permitted for the specific insulation system. The word *impaired* is used here 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.

### 5.11.3 Limits of temperature rise for continuously rated transformers

Hottest-spot temperature rise above the ambient temperature shall not exceed the limits given in Table 10. The average winding-temperature rises above the ambient temperature (when measured by the resistance method and tested in accordance with the applicable provisions of IEEE Std C57.12.91) shall not exceed the values given in Table 10. The hottest-spot temperature rise shall be determined by calculation or from temperature test data.

**Table 10 —Limits of temperature rise for continuously rated dry-type transformer windings[9]**

| Insulation system temperature class (ºC) | Winding hottest-spot temperature rise (ºC) | Average winding-temperature rise by resistance (ºC)[a] |
|---|---|---|
| 130 | 90 | 75 |
| 150 | 110 | 90 |
| 180 | 140 | 115 |
| 200 | 160 | 130 |
| 220 | 180 | 150 |

[a]Higher average winding temperature rises by resistance may apply if the manufacturer provides thermal-design test data substantiating that temperature limits of the insulation are not exceeded.

Transformers with a specified temperature rise may have an insulation system that uses any combination of materials by temperature-rise insulation definitions, provided that the insulation system has been evaluated in accordance with 5.11.2.

Insulation material used in the individual windings of the transformer may have different system temperature limits. When this case occurs, the individual windings and their corresponding average temperature rises shall be listed on the transformer nameplate.

Materials, or combinations of materials, such as those listed in Table 11, may be used in windings and insulation structures involving the various paired combinations of insulation-system temperature and average winding temperature rise by resistance listed in Table 10, provided that such insulating materials (or combinations of materials) have been shown by experience or accepted tests to be adequate for such service application in the type of transformer involved in Table 10.

[9] Based on an average daily ambient temperature of 30 °C, with a maximum ambient temperature of 40 °C.

**Table 11 —Examples of materials used in insulation systems**

| Solid insulating materials | Binding insulating materials |
|---|---|
| Mica | Polyester resins |
| Porcelain | Epoxy resins |
| Glass | Silicone elastomers |
| Glass fibers | Silicone resins |
| Aramid sheets/fibers | Polyimide resins |
| Cast epoxy | Polyester-imides |
| Cast silicone | — |
| Polyimide sheet | — |
| Polyester film | — |
| NOTE—The lists of materials in this table do not purport to be complete. They are only intended to identify generically some typical insulating materials for illustrative purposes. | |

Metallic parts in contact with, or adjacent to, the insulation shall not attain a temperature in excess of that allowed for the hottest spot of the windings adjacent to that insulation.

Metallic parts, other than those described in the previous paragraph, shall not attain temperature rises that would impair the functional capability of the transformer.

Temperature of external parts accessible to operators shall not exceed the temperature rises over ambient temperature at maximum rated load shown in the Table 12.

**Table 12 —Allowable temperature rise of external parts over ambient**

| | |
|---|---|
| Readily accessible | 65 °C |
| Not readily accessible | 80 °C |
| NOTE—*Not readily accessible* is considered to apply to equipment parts located at heights greater than 2.0 m (6 ft) above floor level or otherwise located to make accidental contact unlikely. | |

### 5.11.4 Conditions under which temperature limits apply

Temperature limits shall not be exceeded when the transformer is operating on the connection that will produce the highest winding-temperature rise above ambient temperature and is delivering:

a) Rated kilovolt-ampere output at rated secondary voltage if there are no taps.

b) Rated kilovolt-ampere output at the rated secondary voltage for that connection if it is a rated kilovolt-ampere tap connection.

c) At the rated secondary voltage of that connection, the kilovolt-ampere output corresponding to the current of the tap if the connection is a reduced kilovolt-ampere tap connection.

NOTE—As used here, the terms *rated secondary voltage* and *rated current* mean the values assigned by the manufacturer and shown on the nameplate.

### 5.11.5 Reference temperature for efficiency, losses, impedance, and regulation

The reference temperature for which efficiency, losses, impedance, and regulation are stated shall be the rated average winding temperature rise plus 20 °C.

## 5.12 Nameplates

### 5.12.1 General

The manufacturer shall affix a durable nameplate to each transformer. Unless otherwise specified, it shall be made of corrosion-resistant materials. It shall bear the rating and other essential operating data as specified in 5.12.2 and 5.12.3.

For transformers that have nameplates mounted on a removable part, the manufacturer's name and transformer serial number shall be permanently affixed to a non-removable part.

### 5.12.2 Nameplate information for ventilated and non-ventilated transformers

Unless otherwise specified, the minimum information shown on the nameplate shall be that specified in Table 13 and the associated footnotes.

### 5.12.3 Nameplate information for sealed transformers

Unless otherwise specified, the minimum information shown on the nameplate shall be that required in 5.12.2 plus the following additional data:

a) Insulating gas identification and weight by compartments. If the insulating gas is nitrogen, the cubic meters at 25 °C and 13.8 kPa (2 psi) shall be furnished instead of the weight.

b) Maximum operating gauge pressures:_______ kPa (_____ psi) positive.

c) Tank designed for _____ kPa (_____ psi) negative for vacuum filling.

NOTE—Vacuum filling applies only to insulating gases other than nitrogen.

d) Gas-filling gage pressure at 25 °C.

e) Temperature limitations of gases condensing at temperatures higher than –30 °C.

f) The taps shall be identified on the transformer nameplate and on the tap-changer-position indicating plate by means of letters in sequence or Arabic numerals. The number 1 or letter A shall be assigned to the voltage rating providing the maximum ratio of transformation with tap changers for de-energized operation.

g) In addition to the weights listed in Footnote i of Table 13, the "untanking" weight (heaviest piece) shall also be listed.

### Table 13 —Nameplate information

| |
|---|
| Serial number[a] |
| Class (AA, AA/FA, etc.)[b] |
| Number of phases |
| Frequency |
| Power ratings[c] |
| Voltage ratings[d,e] |
| Tap voltages[f] |
| Temperature rise in °C, by individual winding if different |
| Polarity (single-phase transformers) |
| Phasor diagram (polyphase transformers) |
| Percent impedance[g] |
| Basic lightning impulse insulation levels (BILs)[h] |
| Approximate weight in pounds and kilograms[i] |
| Connection diagram[j] |
| Name of manufacturer |
| Installation and operating instruction reference |
| The words “dry-type transformer” |
| Conductor material |
| Step-up transformer suitability, if involved[k] |

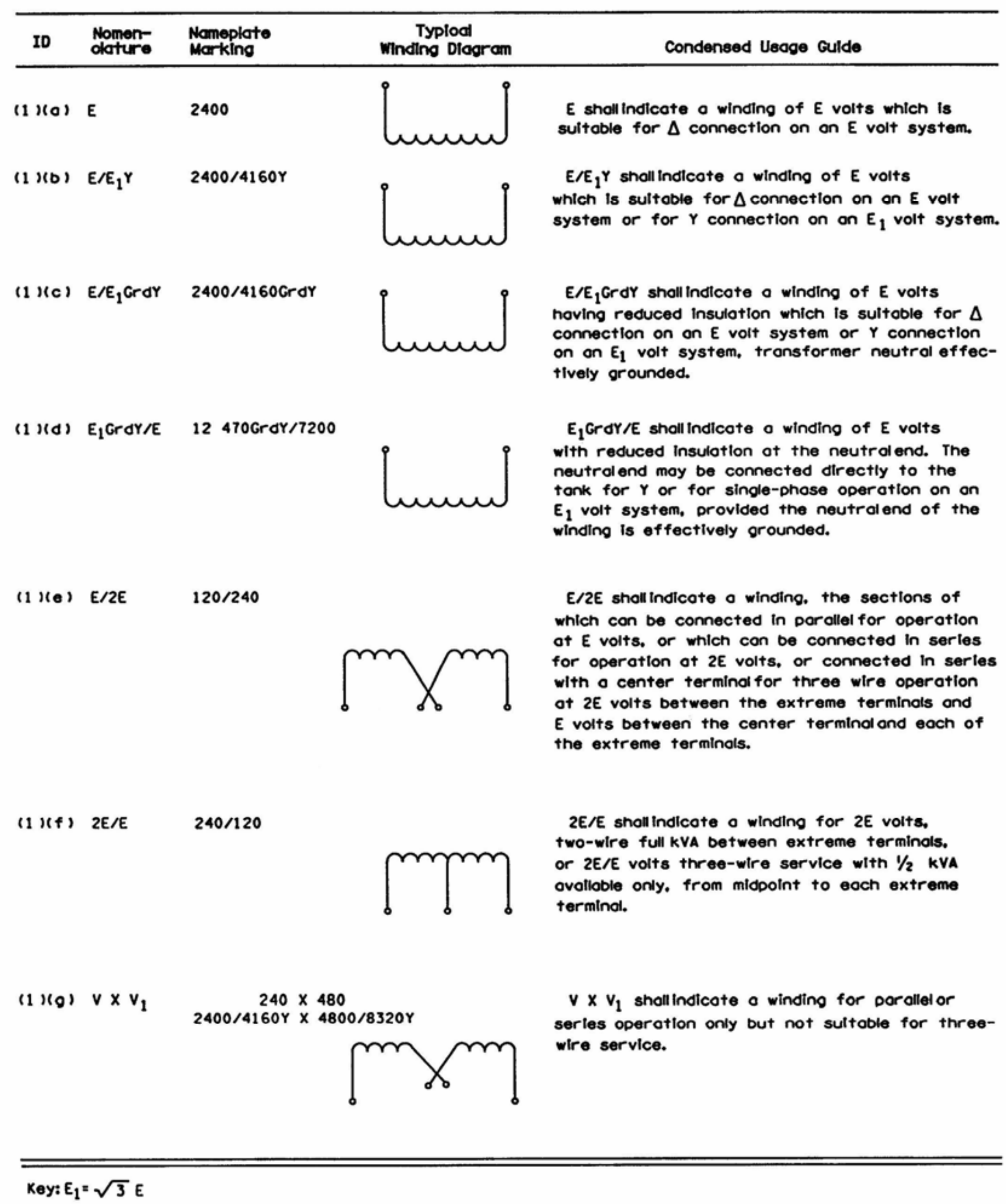
[a]The letters and numerals showing the power rating, serial number, and voltage ratings shall have a minimum height of 3.2 mm (0.125 in), whether engraved or stamped. The height of other letters and numerals shall be optional for the manufacturer.
[b]Where the class of transformer involves more than one kilovolt-ampere rating, all ratings shall be shown. Provisions for future forced-cooling equipment shall be indicated.
[c]See Footnote a and Footnote b.
[d]The voltage ratings of a transformer shall be designated by the voltage ratings of each winding separated by dashes. The winding voltage ratings shall be designated as specified in Figure 2 and Figure 3. If the transformer is suitable for Y connection, the nameplate shall be so marked, except that, on a two-winding single- phase transformer that is insulated for Y connection on both windings, the nameplate shall show the Y voltage on the high-voltage side only for such transformers having high-voltage ratings of above 600 V.
[e]See Footnote a.
[f]The tap voltages of a winding shall be designated by listing the winding voltage of each tap, separated by a slant (/), or shall be listed in tabular form. The rated voltage of each tap shall be shown in volts, except that for transformers 500 kVA and smaller with taps in uniform 2-1/2% or 5% steps that may be shown as percentages of rated voltage. The taps shall be identified on the transformer nameplate by means of letters in sequence or Arabic numerals. The numeral 1 or the letter A shall be assigned to the voltage rating providing the maximum ratio of transformation with tap changers for de-energized operation. The normal position shall be designated by the letter N for load-tap changers. (See IEEE Std C57.12.80.) The raised range positions shall be designated by numerals in ascending order, corresponding to increasing output voltage, followed by the suffix R, such as 1R and 2R. The lower range positions shall be designated by numerals in ascending order, corresponding to decreasing output voltage, followed by the suffix L, such as 1L and 2L. The rated currents of all windings at the highest kilovolt-ampere, and on all tap connections, shall be shown for transformers 501 kVA and larger.
[g]The percent tested impedance of two-winding transformers over 500 kVA shall be given on the tested rated voltage connection and at rated self-cooled power. For transformers with more than two windings, the percent impedance shall be given between each pair of windings. The voltage base shall be stated following each percent impedance figure, and if the transformer has more than one kilovolt-ampere rating, the rated power base shall be given.
[h]Full-wave BIL rating, in kilovolts of line terminals, shall be designated as in the following example:

| | |
|---|---|
| High-voltage winding | 60 kV BIL |
| Low-voltage winding | 10 kV BIL |

If a neutral terminal is assigned a BIL rating, it shall be similarly described.
[i]For transformers rated 30 kVA or less, the weight may be omitted from the nameplate. Supplemental data shall be available showing the approximate weight of the transformer for ratings smaller than those for which data are shown on the nameplate. The total approximate weight shall be shown for transformers larger than 30 kVA up to 500 kVA. The following approximate weights shall be shown for transformers larger than 500 kVA:

Core and windings
Total

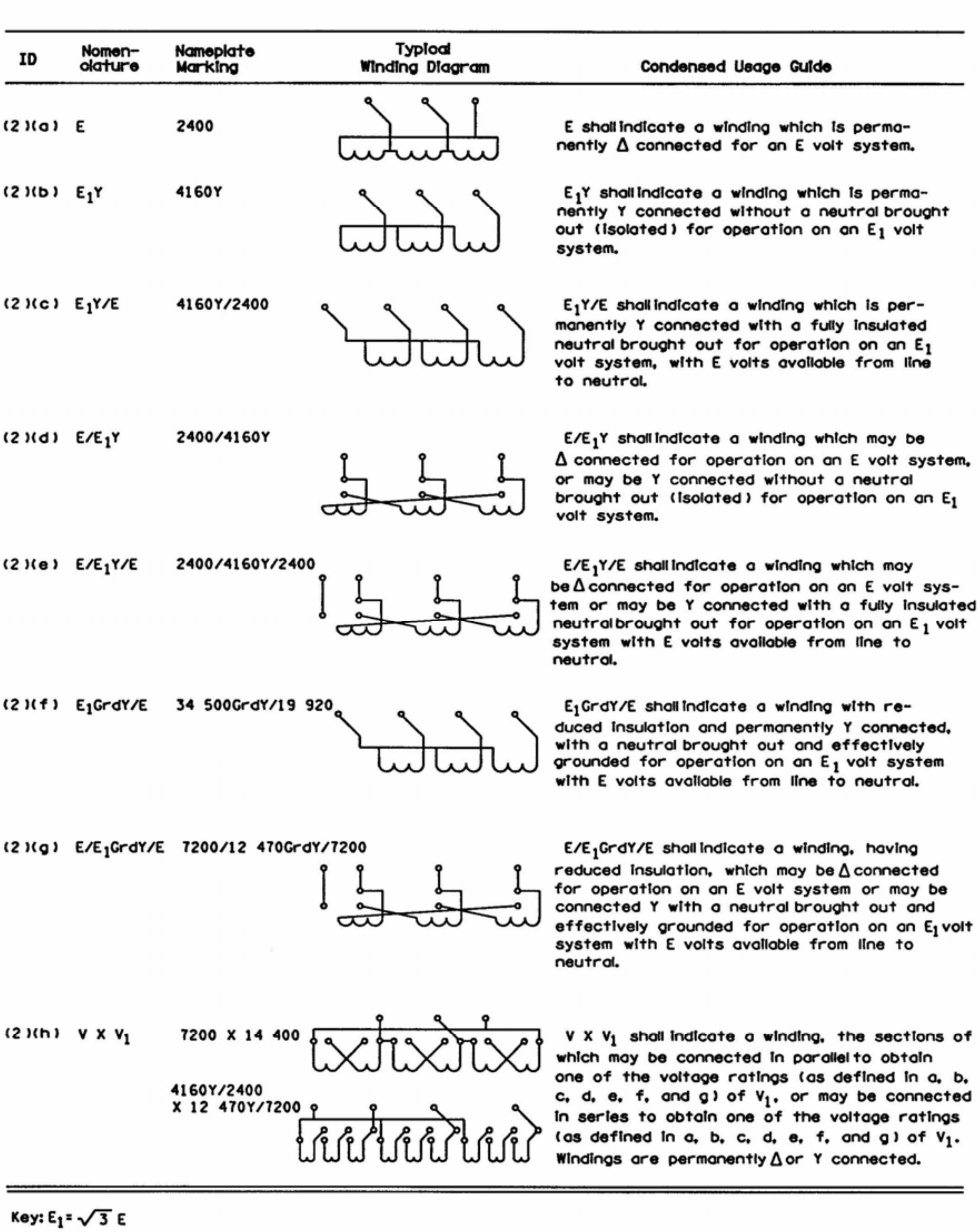
[j]All winding terminations shall be identified on the nameplate or on the connection diagram.
A schematic view shall be included. All termination or connection points shall be permanently marked to agree with the schematic identification. In general, the schematic view should be arranged to show the low-voltage side at the bottom and the H1 high-voltage terminal at the top left. (This arrangement may be modified in particular cases, such as multi-winding transformers equipped with terminal chambers, potheads, or transformers having terminal locations not conforming to the suggested arrangements.) Indication of potential transformers, potential devices, current transformers, and winding temperature devices, when used, shall be shown. Polarity and location identification of current transformers shall be shown if used for metering, relaying, or line-drop compensation. (Polarity need not be shown if current transformers are used for winding-temperature equipment or fan control.)
All internal leads and terminals that are not permanently connected shall be designated or marked with numerals or let¬ters in a manner that will permit convenient reference and will obviate confusion with terminal and polarity markings. Winding-development diagrams shall use symbols as described in IEEE Std 315. Any winding grounds shall be indicated.
[k]If the transformer is larger than 500 kVA and is suitable for step-up operation, the nameplate shall so state.



| ID | Nomenclature | Nameplate Marking | Typical Winding Diagram | Condensed Usage Guide |
|---|---|---|---|---|
| (1)(a) | E | 2400 | | E shall indicate a winding of E volts which is suitable for Δ connection on an E volt system. |
| (1)(b) | $E/E_1Y$ | 2400/4160Y | | $E/E_1Y$ shall indicate a winding of E volts which is suitable for Δ connection on an E volt system or for Y connection on an $E_1$ volt system. |
| (1)(c) | $E/E_1GrdY$ | 2400/4160GrdY | | $E/E_1GrdY$ shall indicate a winding of E volts having reduced insulation which is suitable for Δ connection on an E volt system or Y connection on an $E_1$ volt system, transformer neutral effectively grounded. |
| (1)(d) | $E_1GrdY/E$ | 12 470GrdY/7200 | | $E_1GrdY/E$ shall indicate a winding of E volts with reduced insulation at the neutral end. The neutral end may be connected directly to the tank for Y or for single-phase operation on an $E_1$ volt system, provided the neutral end of the winding is effectively grounded. |
| (1)(e) | E/2E | 120/240 | | E/2E shall indicate a winding, the sections of which can be connected in parallel for operation at E volts, or which can be connected in series for operation at 2E volts, or connected in series with a center terminal for three wire operation at 2E volts between the extreme terminals and E volts between the center terminal and each of the extreme terminals. |
| (1)(f) | 2E/E | 240/120 | | 2E/E shall indicate a winding for 2E volts, two-wire full kVA between extreme terminals, or 2E/E volts three-wire service with ½ kVA available only, from midpoint to each extreme terminal. |
| (1)(g) | $V \times V_1$ | 240 X 480<br>2400/4160Y X 4800/8320Y | | $V \times V_1$ shall indicate a winding for parallel or series operation only but not suitable for three-wire service. |

Key: $E_1 = \sqrt{3}\,E$

**Figure 2—Designation of voltage ratings of single-phase windings (schematic representation)**



| ID | Nomen-clature | Nameplate Marking | Typical Winding Diagram | Condensed Usage Guide |
|---|---|---|---|---|
| (2)(a) | E | 2400 | | E shall indicate a winding which is permanently Δ connected for an E volt system. |
| (2)(b) | $E_1Y$ | 4160Y | | $E_1Y$ shall indicate a winding which is permanently Y connected without a neutral brought out (isolated) for operation on an $E_1$ volt system. |
| (2)(c) | $E_1Y/E$ | 4160Y/2400 | | $E_1Y/E$ shall indicate a winding which is permanently Y connected with a fully insulated neutral brought out for operation on an $E_1$ volt system, with E volts available from line to neutral. |
| (2)(d) | $E/E_1Y$ | 2400/4160Y | | $E/E_1Y$ shall indicate a winding which may be Δ connected for operation on an E volt system, or may be Y connected without a neutral brought out (isolated) for operation on an $E_1$ volt system. |
| (2)(e) | $E/E_1Y/E$ | 2400/4160Y/2400 | | $E/E_1Y/E$ shall indicate a winding which may be Δ connected for operation on an E volt system or may be Y connected with a fully insulated neutral brought out for operation on an $E_1$ volt system with E volts available from line to neutral. |
| (2)(f) | $E_1GrdY/E$ | 34 500GrdY/19 920 | | $E_1GrdY/E$ shall indicate a winding with reduced insulation and permanently Y connected, with a neutral brought out and effectively grounded for operation on an $E_1$ volt system with E volts available from line to neutral. |
| (2)(g) | $E/E_1GrdY/E$ | 7200/12 470GrdY/7200 | | $E/E_1GrdY/E$ shall indicate a winding, having reduced insulation, which may be Δ connected for operation on an E volt system or may be connected Y with a neutral brought out and effectively grounded for operation on an $E_1$ volt system with E volts available from line to neutral. |
| (2)(h) | $V \times V_1$ | 7200 X 14 400<br>4160Y/2400 X 12 470Y/7200 | | $V \times V_1$ shall indicate a winding, the sections of which may be connected in parallel to obtain one of the voltage ratings (as defined in a, b, c, d, e, f, and g) of $V_1$, or may be connected in series to obtain one of the voltage ratings (as defined in a, b, c, d, e, f, and g) of $V_1$. Windings are permanently Δ or Y connected. |

Key: $E_1 = \sqrt{3}\,E$

**Figure 3—Designation of voltage ratings of three-phase windings (schematic representation)**

# 6. Construction

## 6.1 Tank-pressure requirements

The tank pressure under rated conditions of sealed transformers shall not exceed 101 kPa (14.7 psi) gauge unless the requirements of applicable sections of the ANSI/ASME Boiler and Pressure Vessel Code (BPV) 1995 are met.

## 6.2 Finish of tank or enclosure

The finish for transformer enclosures or tanks shall consist of a non-metallic pigment coating.

NOTE—This finish applies to sealed units but not to open ventilated dry-types. Metallic flake coatings, such as aluminum and zinc, have properties that increase the temperature rise of transformers, except in direct sunlight. Temperature limits and tests are based on the use of a pigment coating finish.

## 6.3 Handling provisions

Transformers with a total weight exceeding 45.4 kg (100 lb) shall have provisions for lifting. All transformers 300 kVA –3 phase and above shall have provisions for jacking and skidding.

## 6.4 Transformer accessories

Specific information concerning accessories is contained in the product standards applying to particular types of transformers.

## 6.5 Terminals

Transformers shall be equipped with suitable insulated cable or bar arrangements of terminals. The BIL ratings of terminals shall be at least equal to that of the windings to which they are connected, unless otherwise specified. See Table 5 for BIL ratings of terminals.

## 6.6 Grounding

### 6.6.1 Transformer grounding

Transformer-grounding facilities shall be furnished in accordance with the product standards for particular types of dry-type transformers.

### 6.6.2 Grounding of core

The transformer core shall be grounded, for electrostatic purposes, to the transformer frame and enclosure (if supplied).

### 6.7 Shipping

Transformers shall be shipped from the factory completely assembled unless the size or weight limits this requirement.

## 7. Short-circuit characteristics

### 7.1 General

Transformers shall be designed and constructed to withstand the mechanical and thermal stress produced by external short circuits under the conditions in 7.3.2, 7.3.3, and 7.3.6. The external short circuits shall include three-phase, single line-to-ground, double line-to-ground, and line-to-line faults on any one set of terminals at a time. Multiwinding transformers shall be considered to have system-fault power supplied at no more than two sets of unfaulted terminals, and only at terminals rated more than 35% of the terminal kilovolt-amperes of the highest capacity winding. For other fault conditions, the requirements shall be specified by those responsible for the application of the transformer. It is recognized that short-circuit withstand capability can be adversely affected by the cumulative effects of repeated mechanical and thermal overstressing, as produced by short circuits and loads above the nameplate rating. As the means are not available to continuously monitor and quantitatively evaluate the degrading effects of such duty, short-circuit tests, when required, should be performed before placing the transformer(s) in service. The intention here is not that every transformer be short-circuit tested to demonstrate adequate construction. When specified, short-circuit tests shall be performed as described in Clause 12 of IEEE Std C57.12.91.

### 7.2 Transformer categories

Three categories for the rating of dry-type transformers shall be recognized in Table 14.

**Table 14—Dry-type transformer rating[10] categories**

| Category[a] | Single-phase (kVA) | Three-phase (kVA) |
|---|---|---|
| I | 1–500 | 15–500 |
| II | 501–1 667 | 501–5 000 |
| III | 1 668–10 000 | 5 001–30 000 |

[a]Autotransformers of 500 kVA or less (equivalent two-winding) shall be included in Category I even though their nameplate power rating may exceed 500 kVA.

### 7.3 Short-circuit current duration and magnitude

#### 7.3.1 General

For Categories I, II, and III dry-type transformers, the short-circuit current duration shall be limited to 2 s. When used on circuits having reclosing features, transformers shall be capable of withstanding the resulting successive short circuits without cooling to normal operating temperatures between successive occurrences of the short circuit, provided the accumulated duration of the short circuits does not exceed 2 s.

[10] All power ratings are minimum nameplate power for the principal windings.

### 7.3.2 Duration of short-circuit tests

The duration of each test shall be 0.25 s, except that one test satisfying the symmetrical current requirements shall be made for a longer duration on Categories I, II, and III transformers. The duration of the long test in each case shall be as follows:

- Category I: $t = 2$ s
- Category II: $t = 1$ s
- Category III: $t = 0.5$ s

For special applications where longer fault duration will be common in service, special long-duration tests shall be specified at purchase. When making consecutive tests without allowing time for winding cooling, care shall be exercised to avoid excessive temperatures.

### 7.3.3 Short-circuit current magnitude

#### 7.3.3.1 Category I

The short-circuit-current magnitude will normally be limited only by the transformer impedance, but maximum symmetrical-current magnitudes shall not exceed 25 times base current.

#### 7.3.3.2 Categories II and III

The symmetrical short-circuit current shall be calculated as follows, but it shall not exceed 25 times base current:

a) The symmetrical short-circuit current shall be calculated based on the sum of the transformer impedance plus a value of system impedance (including the appropriate power base) specified by the user. Alternatively, the user may specify the system power available in MVA at the transformer.

b) In the absence of system information from the user, the system symmetrical short-circuit current available at the transformer terminals shall be assumed to be 36 kA for nominal system voltages 34.5 kV and below.

NOTE—This calculation corresponds to a circuit-breaker first-cycle or momentary current of 58 kA (for a 13.8 kV system, which is equivalent to a system with approximately 750 MVA nominal interrupting duty).

c) When specified, or when the system impedance is known to be negligible (e.g., a station service transformer located close to a generator), the symmetrical short-circuit current shall be calculated using the transformer impedance only.

### 7.3.4 Stabilizing winding

Stabilizing winding in three-phase transformers (Δ-connected winding with no external terminals) shall be capable of withstanding the current resulting from any of the system faults specified in 7.1, recognizing the system-grounding conditions. An appropriate stabilizing winding power rating, voltage, and impedance shall be provided.

### 7.3.5 Dry-type autotransformer winding

Dry-type autotransformer winding shall be designed for a maximum withstand capability limit of 25 times base current (symmetrical).

### 7.3.6 Short-circuit current calculations

#### 7.3.6.1 Symmetrical current

The symmetrical short-circuit current $I_{SC}$ (in rms amperes) can be calculated using Equation (1).

$$I_{SC} = \frac{I_R}{Z_T + Z_S} \tag{1}$$

where

- $I_R$ is the rated current on the given tap connection (in rms amperes)
- $Z_T$ is the transformer impedance on the given tap connection, in per unit on the same apparent power base as $I_R$
- $Z_S$ is the impedance of the system or permanently connected apparatus, in per unit on the same apparent power base as $I_R$

The symmetrical short-circuit current *I,* in multiples of normal base current, can be calculated using Equation (2).

$$I = \frac{I_{SC}}{I_R} \tag{2}$$

#### 7.3.6.2 Asymmetrical current

The first-cycle asymmetrical peak current $I_{SC}$ (pk asym.), which the transformer is required to withstand, shall be determined as follows:

$$I_{SC}(\text{pk asym.}) = KI_{SC}$$

where

$$K = \left\{1 + \left[e^{-\left(\phi + \frac{\pi}{2}\right)\frac{r}{x}}\right]\sin\phi\right\}\sqrt{2} \tag{3}$$

- $\phi$ is the arc tan $(x/r)$ (in radians) e is the base of natural logarithm

*x*/*r* is the ratio of effective ac reactance to resistance, both in ohms, of the total impedance, which limits the fault current for the transformer connections when the short circuit occurs

When the system impedance is included in the fault-current calculation, the *x*/*r* ratio of the external impedance shall be assumed equal to that of the transformer, if not specified.

Values of *K* are given in Table 15.

**Table 15—Values of *K***

| *r/x* | *x/r* | *K* |
|---|---|---|
| 0.001 | 1000 | 2.824 |
| 0.002 | 500 | 2.820 |
| 0.003 | 333 | 2.815 |
| 0.004 | 250 | 2.811 |
| 0.005 | 200 | 2.806 |
| 0.006 | 167 | 2.802 |
| 0.007 | 143 | 2.798 |
| 0.008 | 125 | 2.793 |
| 0.009 | 111 | 2.789 |
| 0.01 | 100 | 2.785 |
| 0.02 | 50 | 2.743 |
| 0.03 | 33.3 | 2.702 |
| 0.04 | 25 | 2.662 |
| 0.05 | 20 | 2.624 |
| 0.06 | 16.7 | 2.588 |
| 0.07 | 14.3 | 2.552 |
| 0.08 | 12.5 | 2.518 |
| 0.09 | 11.1 | 2.484 |
| 0.1 | 10 | 2.452 |
| 0.2 | 5 | 2.184 |
| 0.3 | 3.33 | 1.990 |
| 0.4 | 2.5 | 1.849 |
| 0.5 | 2 | 1.746 |
| 0.6 | 1.67 | 1.669 |
| 0.7 | 1.43 | 1.611 |
| 0.8 | 1.25 | 1.568 |
| 0.9 | 1.11 | 1.534 |
| 1.0 | 1 | 1.509 |

NOTE—The expression of *K* is an approximation. The values of *K* given in Table 15 are calculated from this approximation and are accurate to within 0.7% of the values calculated by exact methods.

## 7.4 System zero-sequence data

For Category III transformers with a solidly grounded neutral, the user should specify the ratio of system $X_0/X_1$. In lieu of a specified $X_0/X_1$ ratio, a value of 2.0 shall be used.

## 7.5 Application conditions requiring special consideration

The following situations affecting fault-current magnitude, duration, or frequency of occurrence require special consideration and should be identified in transformer specifications:

a) Transformer terminals connected to rotating machines (such as motors or synchronous condensers), which can act as generators to feed current into the transformer under system-fault conditions. The system impedance for such cases should be derived by the user, considering the subtransient reactance of synchronous machines and the locked-rotor reactance of induction motors, such as those used in calculating first-cycle or momentary duty.

b) Three-winding transformer applications.

c) Operating voltages higher than rated, maintained at the unfaulted terminal(s) during a fault condition.

d) Frequent overcurrents arising from the method of operation or the particular applications (such as furnace transformers starting taps, applications using grounding switches for relay purposes, and traction feeding transformers).

e) Station auxiliary transformers directly connected to a generator that may be subject to prolonged-duration terminal faults as a result of the inability to remove the voltage source quickly.

## 7.6 Components

Transformer components, such as leads, bushings, load-tap changers, de-energized tap changers, and current transformers, which carry current continuously, shall comply with all the requirements of 7.1. However, if not explicitly specified, load-tap changers are not required to change taps successfully under short-circuit conditions.

## 7.7 Base power rating of a winding

### 7.7.1 Base rated power of a winding

Base power is the self-cooled rated power of the winding, as specified by the nameplate in kilvolt-ampere.

### 7.7.2 Base current of winding without autotransformer connections

For transformers with two or more windings without autotransformer connections, the base current of a winding is obtained by dividing the base kilovolt-ampere of the winding by the rated kilovolt of the winding on a per-phase basis.

### 7.7.3 Base current of winding with autotransformer connections

For transformers with two or more windings, including one or more autotransformer connections, the base current and the base power of any winding, other than the series and common windings, are determined as described in 7.7.2. The base current of the series winding is equal to the base power per phase in kilovolt-ampere at the series line terminal (*H*) divided by the minimum full capacity tap voltage at the series line terminal (*H*) in kilovolts line to neutral. The base current of the common winding is equal to the line current at the common winding terminal (*X*) minus the line current at the series winding terminal (*H*) under loading conditions, resulting in maximum phasor difference. All conditions of simultaneous loading authorized by the nameplate shall be considered to obtain the maximum value. Base currents are calculated based on self-cooled loading conditions or the equivalent.

## 7.8 Effects of temperature on transformer windings during short-circuit conditions

The winding temperature will increase during a short circuit, and care shall be exercised in the winding design and the application of the conductor material to avoid a significant loss of yield strength in the period of fault duration. In most applications of dry-type transformers with normal application limits for fuses and circuit breakers, the duration of a short circuit is limited to a few cycles, and the added temperature-rise effects are minimal. Where it is determined that the fault duration is more than a few cycles and a need exists to determine by calculation the temperature rise for a specific application, the temperature rise may be calculated as described in 7.10.

The effect of the calculated temperature increase on a transformer in a specific application may thus be determined, and proper allowance made, to minimize permanent reduction in conductor mechanical strength due to annealing, and to coordinate any temporary reduction in conductor strength with the applied forces at any time.

## 7.9 Temperature limits of transformer for short-circuit conditions

The final temperature of the conductor in the windings of general-purpose transformers, under the short-circuit conditions described in 7.8, shall not exceed the values given in Table 16.

**Table 16—Temperature limits of transformers under short-circuit conditions**

| Winding temperature rise by resistance (°C) | Assumed initial average temperatures of winding (°C) | Final conductors temperatures (°C) |
|---|---|---|
| 75 | 115 | 300 |
| 90 | 130 | 350 |
| 115 | 155 | 400 |
| 130 | 170 | 425 |
| 150 | 190 | 450 |

## 7.10 Calculation of winding temperature during a short circuit

The final winding temperature $T_f$ at the end of a short circuit of duration $t$ shall be calculated on the basis of all heat stored in the conductor material and its associated turn insulation. All temperatures are in degrees Celsius.

$$T_f = m(T_k + T_s)(1 + E + 0.6m) + T_s \tag{4}$$

where

$E$ is the per-unit eddy-current loss, based on resistance loss $W_s$, at the starting temperature
$T_k$ is 234.5 °C for copper
$T_k$ is 225 °C for EC grade aluminum (The appropriate values of $T_k$ for the other grades may be used.)

$T_S$ is the starting temperature. It is equal to

a) 30 °C ambient temperature plus the average winding rise plus the manufacturer's recommended hottest-spot allowance

b) 30 °C ambient temperature plus the limiting winding hottest-spot temperature rise specified for the appropriate type temperature

$$m = 0.454 \frac{W_s t}{C(T_k + T_s)} \tag{5}$$

where

$t$ is the duration of short circuit (in seconds)
$C$ is the 174 + (0.0225) ($T_k + T_s$) + (110) ($A_i/A_c$) for copper
$C$ is the 405 + (0.1) ($T_k + T_s$) + (360)($A_i/A_c$) for aluminum
$A_i$ is the cross-sectional area of turn insulation
$A_c$ is the cross-sectional area of the conductor
$W_S$ is the short-circuit resistance loss of the winding at the starting temperature, in watts per kilogram of conductor material

with

$$W_s = \frac{W_r N^2}{M} x[(T_k + T_s)/(T_k + T_r)] \tag{6}$$

where

$W_r$ is the resistance loss of winding at rated current and reference temperature (in watts)
$N$ is the symmetrical short-circuit magnitude, in times normal rated current
$M$ is the weight of winding conductor (in kilograms)
$T_r$ is the reference temperature, which is 20 °C ambient temperature plus rated average winding rise

These equations are approximate formulas, and their use should be restricted to values of $m \leq 0.6$. For values of $m > 0.6$, the following more nearly exact formula should be used:

$$T_f = (T_k + T_s)\left[\sqrt{e^{2m} + E\left(e^{2m} - 1\right)} - 1\right] + T_s \tag{7}$$

where

$e$ is the base of natural logarithm = 2.718

with

$$E = E_r \left[ (T_k + T_r)/(T_k + T_s) \right]^2 \tag{8}$$

where

$E_r$ is the per-unit eddy-current loss at reference temperature

# 8. Testing and calculations

## 8.1 General

Unless otherwise specified, all tests are defined and shall be made in accordance with IEEE Std C57.12.91. Unless otherwise specified, tests shall be made at the factory only.

## 8.2 Test classifications

Test classifications are defined in IEEE Std C57.12.80.

## 8.3 Routine, design, and other tests for transformers

Routine tests shall be made on all transformers. These are listed in Table 17. When specified (as individual tests), “other” tests shall be made on transformers as listed in Table 17.

**Table 17 —Dry-type transformer tests**

| Tests | Test classification | | | | | |
|---|---|---|---|---|---|---|
| | ≤500 kVA | | | ≥501 kVA | | |
| | Routine | Design | Other | Routine | Design | Other |
| Resistance measurements of all windings on the rated voltage tap, and at tap extremes of the first unit made on a new design | — | x | — | x | — | — |
| Ratio tests on the rated voltage connection | x | — | — | x | — | — |
| Polarity and phase relation tests on the rated voltage connection | x | — | — | x | — | — |
| No-load losses and excitation current at rated voltage on the rated voltage connection | x[a] | — | — | x | — | — |
| Impedance voltage and load loss at rated current and rated frequency on the rated voltage connection and at the tap extremes of the first unit of a new design | — | x | x | x | — | — |
| Temperature rise at minimum and maximum ratings of the first unit on a new design. This test may be omitted if tests of thermally duplicate or essentially duplicate unit are available | — | x | x | — | x | x |
| Dielectric tests | | | | | | |
| Applied voltage | x | — | — | x | — | — |
| Induced voltage | x | — | — | x | — | — |
| Impulse | — | x[b] | x[b] | — | x[b] | x[b] |
| Insulation power factor | — | — | x | — | — | x |
| Insulation resistance | — | — | x | — | — | x |
| Partial discharge | x[c] | — | x[c] | x[c] | — | x[c] |
| Audible sound level | — | x | x | — | x | x |
| Short-circuit capability | — | — | x | — | — | x |
| Mechanical (for sealed transformers) | | | | | | |
| Pressure | — | x | — | — | x | — |
| Leak | x | — | — | x | — | — |

[a]Statistical sampling may be used for this test. (This does not apply to transformers ≥501 kVA.)
[b]When an impulse test is required, it shall precede the applied and induced voltage test.
[c]Partial discharge tests may be performed on the windings of all types of dry-type transformers, but they are considered routine tests for transformers above 1.2 kV having solid-cast and/or resin-encapsulated windings as part of the insulation systems.

### 8.4 Calculations

When specified, transformer regulation shall be determined for the rated voltage, kilovolt-amperes, and frequency by means of calculations based on the tested impedance, in accordance with the procedure given in IEEE Std C57.12.91. The reference temperature to which the load loss, impedance voltage, short-circuit impedance, and regulation are to be corrected shall be the average winding temperature rise, as given in Table 10, plus 20 ºC.

## 9. Tolerances

### 9.1 Ratio

With rated voltage impressed on one winding of a transformer, all other rated voltages at no load shall be correct within 0.5% of the nameplate markings.

Rated tap voltages shall correspond to the voltage of the nearest turn if the voltage per turn exceeds 0.5% of the desired voltages.

### 9.2 Impedance

The tolerances for impedance shall be as follows:

a) The impedance of a two-winding transformer shall have a tolerance of ±7.5% of the specified 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% of the specified value.

b) The impedance of transformers having three or more windings, or having zigzag windings, shall have a tolerance of ± 10% of the specified value. Differences of impedance between duplicate three-winding or zigzag transformers, when two or more units of a given rating are produced by one manufacturer at the same time, shall not exceed 10% of the specified value.

c) The impedance of an autotransformer shall have a tolerance of ± 10% of the specified 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% of the specified value.

d) Transformers shall be considered suitable for operation in parallel if their resistance and reactances come within the limitations of item a) through item c), provided turn ratios and other controlling characteristics are suitable for such operation.

### 9.3 Losses

The losses represented by testing a transformer, or transformers, on a given order shall not exceed the specified losses by more than the percentages given in Table 18.

**Table 18—Tolerances for single-phase and three-phase transformers losses**

| Number of units on one order | Basis determination | No-load losses (%) | Total losses (%) |
|---|---|---|---|
| 1 | 1 unit | 10 | 6 |
| 2 or more | Each unit | 10 | 6 |
| 2 or more | Average of all units | 0 | 0 |

## 10. Connection of transformers for shipment

Single-phase and three-phase transformers shall be shipped with both high-voltage and low-voltage windings connected for their rated voltage.

Single-phase transformers designed for both series-multiple and three-wire operation shall be shipped connected in series with the midpoint brought out for three-wire operation. Single-phase and three-phase transformers, designed for series-multiple operations only, shall be shipped connected in series. Three-phase transformers designed for both Δ and Y operation shall be shipped connected for the Y voltage.