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IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers

IEEE Power and Energy Society

Sponsored by the
Transformers Committee

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USA

IEEE Std C57.12.01™-2015
(Revision of
IEEE Std C57.12.01-2005)

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IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers

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Transformers Committee
of the
IEEE Power and Energy Society

Approved 16 February 2015

IEEE-SA Standards Board

Abstract: Electrical and mechanical 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, distribution, dry-type, IEEE C57.12.01™, power transformer, voltage, winding

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Introduction

This introduction is not part of IEEE Std C57.12.01-2015, IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers.

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 standard was first published in 1979, and was revised and updated in 1989, 1998, and 2005. In the current version of the standard, the title has been revised to reflect the standard's inclusion of all types of dry-type transformers, without specific reference to newer types. In addition, the dielectric insulation table has been expanded to include 46.0 kV and 69.0 kV system voltages, and the references have been updated. Further, informative Annex A, Bibliography, and informative Annex B, Insulation at high altitude, have been added, and the standard has again been updated to match current style guide requirements.

Moreover, as part of ongoing efforts, the clause on partial discharge testing was revised to improve harmonization of this standard with international standards such as IEC 60076-11. This revision included removing the table on partial discharge limits and pre-stress limits, and replacing it with discussion and a figure describing the IEC partial discharge testing methodology.

The dielectric tests discussed in this standard consist of low-frequency and high-frequency testing. 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 to 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.

It is important to reference NEMA ST-20[a] and the National Electrical Code® (NEC®) (NFPA 70)[b, c] as these standards refer to this standard. NEMA 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 is referenced in this introduction for information on voltages 600 V and below applications only.

This revision was developed by the Working Group of the Dry-Type Transformers Subcommittee of the IEEE Transformers Committee of the IEEE Power and Energy 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.

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[a] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http://global.ihs.com/).

[b] 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/).

[c] The NEC is published by the National Fire Protection Association (http://www.nfpa.org/). Copies are also available from The Institute of Electrical and Electronics Engineers at http://shop.ieee.org/.

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1. Overview

1.1 Scope

This standard describes electrical and mechanical requirements of single and polyphase ventilated, non-ventilated, and sealed dry-type distribution and power transformers or autotransformers, with a voltage of 601 V or higher in the highest voltage winding. This standard applies to all dry-type transformers, including those with solid cast and/or resin-encapsulated windings 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

NOTE—Where IEEE standards do not exist for the transformers mentioned above or for other special transformers, this standard may be applicable as a whole or in parts subject to agreement between the parties responsible for the application and for the design of the transformer.[1]

1.2 Purpose

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

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.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

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

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

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.[3]

IEEE Std C57.12.70™, IEEE Standard for Terminal Markings and Connections for Distribution and Power 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.

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[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/).

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[4] Standard transformer terminology, which is available in IEEE Std C57.12.80™ [5], shall apply.

reference temperature for no-load losses: The no-load losses of power and distribution transformers shall be determined based on a reference temperature of 20 °C. [6]

reference temperature: unless otherwise stated, the reference temperature shall be defined as 20 °C plus the rated average winding rise. For multiple winding transformers that have more than one base rated average winding rise, the highest average winding rise shall be used to determine the reference temperature.

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 °C, and the average temperature of the cooling air for any 24-hour period shall not exceed 30 °C.

The minimum ambient temperature shall not be lower than −30 °C.

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] *IEEE Standards Dictionary Online* subscription is available at:
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.
[5] Information on references can be found in Clause 2.
[6] Correction of no-load losses will be required when the top yoke temperature of the core is greater than 40 ºC.

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.
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 nor 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.[7]

4.1.9 Tank or enclosure finish

Temperature limits and tests shall be based on the use of a non-metallic 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.

[7] See footnote i of Table 12.

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
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

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.

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

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. Standard dielectric insulation test levels are found in Table 5.

When specified for installation and/or testing above 1000 m (3300 ft), transformers shall be designed with appropriate insulation system to meet the required dielectric insulation test level. To determine this insulation test level, use the altitude correction factor found in Table 1.

4.2.5.1 Insulation test levels

When performing dielectric insulation tests, multiply the standard dielectric insulation test level found in Table 5 by the test correction factor, T_{CF}.

$$T_{CF} = \frac{\text{correction factor at tested altitute}}{\text{correction factor at installed altitude}}$$

For altitudes not listed, the correction factor can be defined by interpolation of the data in Table 1.

NOTE—If the transformer is tested at the same altitude as it is to be installed, there is no correction to the dielectric insulation test levels.

Table 1—Dielectric insulation level correction factors

Altitude		Altitude correction factor for dielectric strength
Meters (m)	Feet (ft)	
≤ 1000	≤ 3300	1.00
1200	4000	0.98
1500	5000	0.95
1800	6000	0.92
2100	7000	0.89
2400	8000	0.86
2700	9000	0.83
3000	10 000	0.80
3600	12 000	0.75
4200	14 000	0.70
4500	15 000	0.67

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

Examples in Annex B illustrate how to determine the test correction factor, T_{CF}.

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 the dry-type transformer involved. Although such conditions may have little or no effect on sealed or non-ventilated dry-type transformers, they may have serious effects on ventilated dry-type transformers. Contact the manufacturer to determine potential impacts, if any, on ventilated dry-type transformers.

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

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 non-sinusoidal waveform.

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) Multi-winding transformers with a specified combination of power outputs and power factors for each winding.

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

l) Over-excitation 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 (IEEE Std C57.142™ [B2]).

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
Non-ventilated 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	1000.0
167.0	1500.0
250.0	2000.0
333.0	2500.0
500.0	3750.0
833.0	5000.0
1250.0	7500.0
1667.0	10 000.0
2500.0	12 000.0
3333.0	15 000.0
5000.0	20 000.0
6667.0	25 000.0
8333.0	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 markings

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°.

Unless otherwise specified, 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).

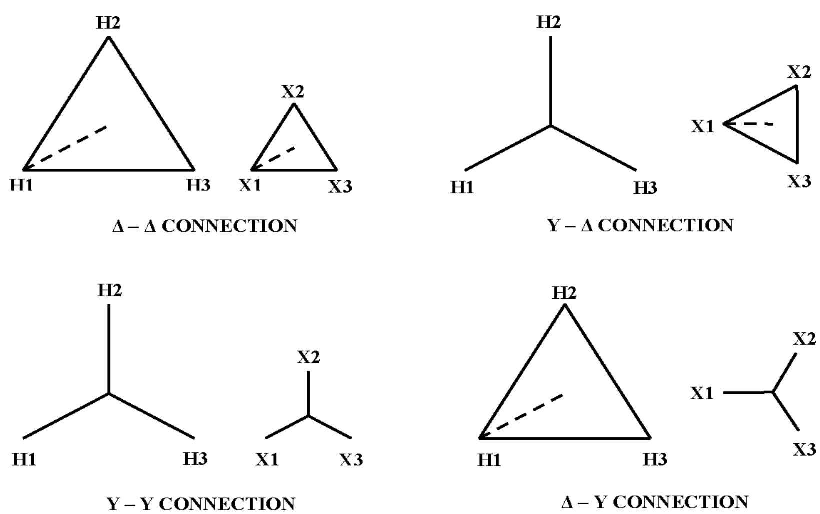

Figure 1—Phase relation of terminal designation for three-phase transformers

5.7.3 Terminal markings

Terminal markings 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 Clause 3 for the reference temperature definitions.

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 help ensure sufficient accuracy in the measured and calculated data, the following requirements shall be met:

a) The test procedures, in accordance with Clause 5, Clause 8, and Clause 9 of IEEE Std C57.12.91™-2011 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 C57.12.91-2011.

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 °C

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.

Standard and optional 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 nominal line-to-line system voltages for fully insulated windings. For windings with reduced neutral insulation, see 5.10.2, 5.10.3.2, and 5.10.3.3. Consideration for higher BIL rating should 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 system with BIL ratings 350 kV BIL and below

Nominal L-L system voltages	Low-frequency voltage insulation level	Basic lightning impulse insulation levels (BIL ratings) in common use kV crest[a,b] (1.2 × 50 μs)												
(kV)	**(kV rms)**	**10**	**20**	**30**	**45**	**60**	**95**	**110**	**125**	**150**	**200**	**250**	**300**	**350**
0.25	2.5	None												
0.6	3	S	1	1										
1.2	4	S	1	1										
2.5	10		S	1	1									
5.0	12			S	1	1								
8.7	20				S	1	1							
15.0	34					S	1	1						
18.0	40						S	1	1					
25.0	50						2	S	1	1				
34.5	70								2	S	1			
46.0	95										S	1	1	
69.0	140											S	1	1
Chopped wave[c,d] 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	3.0	3.0	3.0

CAUTION

When performing an impulse test on the low voltage windings, the high voltage windings may experience higher test voltages than the rated BIL level.

NOTE—The latest edition of IEEE Std C62.22™ [B3] should be consulted for information coordination with available surge arrester protection levels.

S = Standard values

1 = Optional higher levels where exposure to overvoltages occurs and improved protective margins are required

2 = Optional lower levels where protective characteristics of applied surge arresters have been evaluated and found to provide appropriate surge protection

[a] 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.
[b] A positive impulse wave shall be used.
[c] The voltage crest of the chopped wave should be approximately the same as the full wave magnitude.
[d] 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 connected 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 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

<u>Applied voltage test:</u>

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.

[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.”

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.

<u>Induced voltage test:</u>

Twice the rated turn-to-turn voltages shall be developed in each winding in accordance to Clause 10.4 of IEEE Std C57.12.91.

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 16. The transformers under this standard shall be designed to have a minimum extinction voltage of 1.3 times the rated voltage. For high-to-low-voltage solid insulated transformers, the tests for partial discharge shall be conducted during both the induced and applied tests. The preferred arrangement for partial discharge tests is to have the transformer fully assembled before conducting the partial discharge tests; however, testing of coils separately is acceptable if approved by the user. As stated in the foreword 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, 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, 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 of 1.8 times rated voltage, held for a minimum of 30 s, and is then reduced to the voltage level equivalent to 1.3 times rated voltage of the winding under test. After maintaining the 1.3 times rated voltage for 3 minutes, make the partial discharge measurement (see Figure 2). 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. This test procedure is used for all dry-type transformers. The maximum acceptable level of partial discharge for solid cast windings is 10 pC. The maximum acceptable level of partial discharge for resin-encapsulated windings is 50 pC.

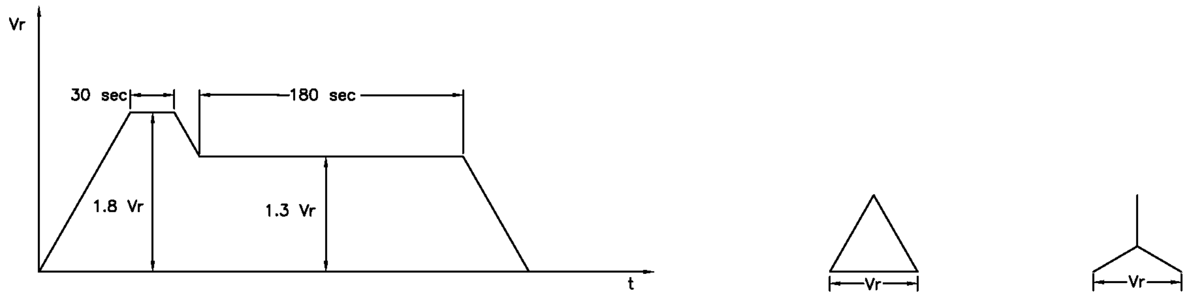

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Figure 2—Voltage application for routine partial discharge test

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 6, Table 7, and Table 8, measured according to IEEE Std C57.12.91.

Table 6—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 to 9	40
10 to 50	45
51 to 150	50
151 to 300	55
301 to 500	60
501 to 700	62
701 to 1000	64
1001 to 1500	65
1501 to 2000	66
2001 to 3000	68

Table 7—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 GA rating)**	**Equivalent two-winding (kVA)**	**Class FA and AFA rating**
0 to 9	40	45	0 to 1167	67
10 to 50	45	50	1168 to 1667	68
51 to 150	50	55	1668 to 2000	69
151 to 300	55	57	2001 to 3333	71
301 to 500	60	59	3334 to 5000	73
501 to 700	62	61	5001 to 6667	74
701 to 1000	64	63	6668 to 8333	75
1001 to 1500	65	64	8334 to 10 000	78
1501 to 2000	66	65	10 001 to 13 333	82
2001 to 3000	68	66	—	—
3001 to 4000	70	68	—	—
4001 to 5000	71	69	—	—
5001 to 6000	72	70	—	—
6001 to 7500	75	71	—	—
7501 to 10 000	79	72	—	—
10 001 to 15 000	82	73	—	—

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

Table 8—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 GA rating)**	
0 to 50	50	50	67
51 to 167	55	55	67
168 to 333	60	60	67
500	64	63	67
833	65	64	68
1256	68	66	70
1667	70	68	71
2500	71	70	72
3333	72	71	74
5000	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

a) Vibration or varying mechanical stress

b) Repeated expansions and contractions

c) Exposure to moisture, contaminating environments, and radiation

d) Incompatible materials

These factors, in combination with time and temperature, may increase the rate of 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

The duration of the service life of a transformer is predominately defined by the thermal aging of the insulation system. Experience has shown that the thermal aging characteristics of a complete insulation system can be different than thermal aging characteristics of each component in the system. For example, some components have ratings lower than the temperature rating of the complete insulation system. To assure satisfactory service life, insulation systems need to be evaluated by service experience or accelerated-life tests on representative coils or models. Accelerated-life tests are used to shorten the evaluation period required before insulation systems using new or a combination of new and existing insulating materials 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 C57.12.60.

5.11.2.2 Insulating materials

Insulating materials are the variety of the dielectric materials that are used in the manufacturing of dry-type transformers. These materials include products in sheet form (papers, boards, or films), products applied in liquid form (impregnating resins, casting resins, wire enamels, or adhesives) as well as other components produced to perform a specific function in the transformer (tapes, sleeving, etc.). Each of these materials have unique characteristics (thermal index, electrical and mechanical properties) which make them appropriate for the specific location used in the transformer design.

5.11.2.3 Insulation system

A transformer insulation system is a combination of insulating materials and insulation components manufactured from these insulating materials arranged to create the structure of the transformer. The major functions of the transformer insulation system are to prevent dielectric breakdown from an electric stress and to provide a mechanical support to the transformer elements (windings, core, frame, etc.) which maintains the ability of the transformer to withstand these stresses over the life of the transformer when subjected to thermal, mechanical, and environmental forces.

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 9. 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 9. The hottest-spot temperature rise shall be determined by calculation or from temperature test data.

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

Insulation system temperature class (°C)	Winding hottest-spot temperature rise (°C)	Average winding temperature rise by resistance (°C)[a]
130	90	75
155	115	95
180	140	115
200	160	135
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 insulation materials, provided that the insulation system has been evaluated in accordance with 5.11.2. Table 10 shows examples of materials used in insulation systems of dry-type transformers.

The individual windings of the transformer may have different insulation system temperature limits. When this case occurs, the individual windings and their corresponding average temperature rises shall be listed on the transformer nameplate. The nameplate listings for the insulation system temperature class for each of the individual windings should be as listed in Table 9.

Table 10—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 Table 11.

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

Table 11 —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, as defined in Clause 3, shall be used for efficiency, losses, impedance, and regulation.

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 12 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 gauge 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 g of Table 12 the "untanking" weight (heaviest piece) shall also be listed.

Table 12—Nameplate information

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

[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] 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 3 and Figure 4. 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.

[d] 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 2½% 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.

[e] 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.

[f] 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.

[g] 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:

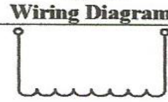
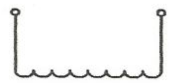
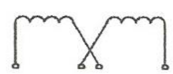
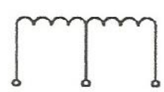
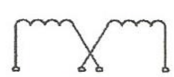
Core and windings
Total

[h] 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.)

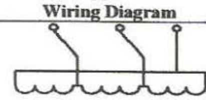
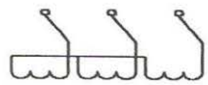
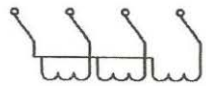
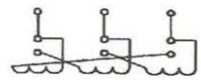
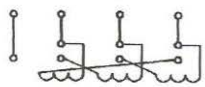
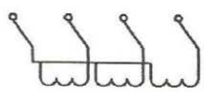
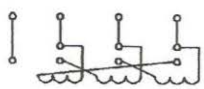
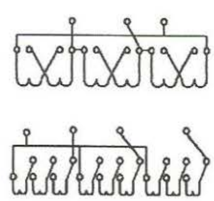
All internal leads and terminals that are not permanently connected shall be designated or marked with numerals or letters in a manner that will permit convenient reference and will obviate confusion with terminal and polarity markings. Winding-development diagrams shall use symbols as described in IEEE Std 315™. Any winding grounds shall be indicated.

[i] If the transformer is larger than 500 kVA and is suitable for step-up operation, the nameplate shall so state.

ID	Nomen-clature	Nameplate Marking	Typical Wiring 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 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 3—Designation of voltage ratings of single-phase windings (schematic representation)

ID	Nomen-clature	Nameplate Marking	Typical Wiring Diagram	Condensed Usage Guide
(2)(a)	E	2400		E shall indicate a winding of 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 the line neutral.
(2)(h)	V X V_1	7200 X 14 400 4160Y/2400 X 12 470Y/7200		V X 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 4—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) 2013 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 three-phase transformers, 300 kVA 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. Multi-winding 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 C57.12.91-2011.

7.2 Transformer categories

Three categories for the rating of dry-type transformers shall be recognized in Table 13.

Table 13—Dry-type transformer rating[10] categories

Category[a]	Single-phase (kVA)	Three-phase (kVA)
I	1 to 500	15 to500
II	501 to 1667	501 to 5000
III	1668 to 10 000	5001 to 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.

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

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.

7.3.2 Duration of short-circuit tests

When short-circuit tests are performed, 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 should be specified at purchase. When making consecutive tests without allowing time for winding cooling, care should be exercised to avoid excessive temperatures limits (specified in 7.9) for transformers under short-circuit conditions.

7.3.3 Short-circuit current magnitude

7.3.3.1 Category I and II

The symmetrical short-circuit current shall be calculated using transformer impedance only, but it shall not exceed 25 times base current.

7.3.3.2 Category III

The symmetrical short-circuit current shall be calculated as follows:

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 69 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

It should be noted that for multi-winding transformers and autotransformers, the required rms value of symmetrical current in each winding shall be determined by calculation as shown in Equation (1) and Equation (2), based on applicable system conditions and fault types.

$$I_{\mathrm{SC}} = \frac{I_{\mathrm{R}}}{Z_{\mathrm{T}} + Z_{\mathrm{S}}} \tag{1}$$

$$I = \frac{I_{\mathrm{SC}}}{I_{\mathrm{R}}} \tag{2}$$

where

- I is the symmetrical short circuit current in multiple of normal base
- I_{SC} symmetrical short circuit current (A, rms)
- I_{R} is the rated current on the given tap connection (A, rms)
- 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}

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

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

ϕ 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 14.

Table 14—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 14 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 kilovolt-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 decrease 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 typical dry-type transformers under the short-circuit conditions described in 7.8 shall not exceed the values given in Table 15.

Table 15—Temperature limits of transformers under short-circuit conditions

Average winding temperature rise by resistance (°C)	Assumed initial average temperatures of winding (°C)	Final conductors temperatures (°C)
75	115	300
95	135	350
115	155	400
135	175	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 + (0.0496) (T_k + T_s) + (110) (A_i/A_c) for copper
- C is the 405 + (0.220) (T_k + T_s) + (360)(A_i/A_c) for aluminum
- A_i is the cross-sectional area of turn insulation in mm^2
- A_c is the cross-sectional area of the conductor in mm^2
- W_S is the short-circuit resistance loss of the winding at the starting temperature, in watts per kilogram of conductor material

with

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

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

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:

$$T_{\mathrm{f}} = \left(T_{\mathrm{k}} + T_{\mathrm{s}}\right)\left[\sqrt{e^{2m} + E\left(e^{2m} - 1\right)} - 1\right] + T_{\mathrm{s}} \tag{7}$$

where

e is the base of natural logarithm = 2.718

with

$$E = E_{\mathrm{r}}\left[\left(T_{\mathrm{k}} + T_{\mathrm{r}}\right)/\left(T_{\mathrm{k}} + T_{\mathrm{s}}\right)\right]^2 \tag{8}$$

where

E_{r} is the per-unit eddy-current loss at the 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 or other approved testing facilities.

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 16. When specified (as individual tests), "other" tests shall be made on transformers as listed in Table 16.

Table 16 —Dry-type transformer tests

Tests	Test classification		
	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[a]	—	—
Ratio tests on the rated voltage connection	X	—	—
Polarity and phase relation tests on the rated voltage connection	X	—	—
No-load losses and excitation current at rated voltage on the rated voltage connection	X[b]	—	—
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[c]	—	—
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
Dielectric tests			
Applied voltage	X	—	—
Induced voltage	X	—	—
Impulse	—	X[d]	X[d]
Insulation power factor	—	—	X
Insulation resistance	X[f]	—	—
Partial discharge	X[e]	—	X[e]
Audible sound level	—	X	X
Short-circuit capability	—	—	X
Mechanical (for sealed transformers)			
Pressure	—	X	—
Leak	X	—	—

[a] To be a *design* test for transformers below 300 kVA.
[b] Statistical sampling may be used for this test. (This does not apply to transformers ≥ 501 kVA.)
[c] To be a *design* and *other* test for transformers below 300 kVA.
[d] When an impulse test is required, it shall precede the applied and induced voltage test.
[e] 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 windings as part of the insulation systems.
[f] To be an *other* test for transformers below 300 kVA.

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 as defined in Clause 3.

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.

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 17.

Table 17 —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.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] IEEE Std 315™, IEEE Graphic Symbols for Electrical and Electronics Diagrams.[11, 12]

[B2] IEEE Std C57.142™, IEEE Guide to Describe the Occurrence and Mitigation of Switching Transients Induced by Transformers, Switching Device, and System Interaction.

[B3] IEEE Std C62.22™, IEEE Guide for Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

[B4] IEC 60076-11, Power Transformers—Part 11: Dry-Type Transformers.[13]

[11] 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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Annex B

(informative)

Insulation at high altitude

Example 1:

A 15 kV, 95 kV basic impulse level (BIL) transformer is designed to operate at 1800 meters (6000 feet) but will be tested at 1000 meters (3300 feet) or less.

The required impulse test level = 95 kV × T_{CF}

$$T_{CF} = \text{test correction factor} = \frac{\text{correction factor at tested altitute}}{\text{correction factor at installed altitude}} = \frac{1.00}{0.92} = 1.087$$

The required applied potential test level = 34 kV (from Table 5) × T_{CF}

The required impulse test level = 95 × 1.087 = 103.27 kV

The required applied potential test level = 34 × 1.087 = 36.96 kV

Example 2:

A 15 kV, 95 kV BIL transformer is designed to operate at 1000 meters (3300 feet) and be tested at 1800 meters (6000 feet).

The required impulse test level = 95 kV × T_{CF}

$$T_{CF} = \text{test correction factor} = \frac{\text{correction factor at tested altitute}}{\text{correction factor at installed altitude}} = \frac{0.92}{1.00} = 0.92$$

The required impulse test level = 95 × 0.92 = 87.4 kV

The required applied potential test level = 34 × 0.92 = 31.28 kV

NOTE—The correction factors, 0.92 and 1.00, come from Table 1.

Consensus

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