IEEE Std C57.12.01-1998
(Revision of
IEEE Std C57.12.01-1989)

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

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

Approved 16 September 1998

IEEE-SA Standards Board

Abstract: Electrical, mechanical, and safety requirements of ventilated, nonventilated, 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. Information that can be used 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, is given.
Keywords: autotransformer connection, basic lightning impulse insulation level (BIL), dielectric strength, distribution transformer, nonventilated dry-type transformer, power transformer, resin encapsulated, short circuit, single-phase, solid cast, temperature rise, three phase, ventilated dry-type transformer, winding

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Introduction

(This introduction is not part of IEEE Std C57.12.01-1998, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid-Cast and/or Resin-Encapsulated Windings.)

This standard, together with its companion standards documents, represents a new milestone in standards for dry-type transformers, which are becoming increasingly more important with the elimination of askarel insulating fluids in new transformers.

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

This revision was developed to recognize dry-type transformers with solid-cast and resin-encapsulated windings. The Working Group that developed the revision identified requirements for IEEE Std C57.12.01-1989, incorporating dry-type transformers with solid-cast and resin-encapsulated windings in 3.1 through 5.10, 5.12, and 6.52 of this standard. In addition, new materials and coil design techniques necessitated a revision that recognizes factors that differ from conventional design of dry-type transformers.

Previous editions of this standard used a constant 30 °C difference between hottest-spot and average winding temperature rises for a kVA range from 1–20 000 kVA. Since the last revision of this standard, a Working Group reviewed hottest-spot and average temperature-rise data. Several manufacturers of different transformer designs conducted extensive test programs. The Working Group concluded that the difference between the hottest-spot and average temperature rise was dependent on the size and design of the transformer. For some large transformer designs the difference may exceed 30 °C, however, for small units, the difference is considerably below 30 °C. The Working Group recommended a constant ratio of hottest-spot to average winding temperature rise for the various insulation temperature classes. This approach improves harmonization with international standards such as IEC 60050-726:1982. The revision of this standard clarifies the requirement that hottest-spot temperature rise is a performance criteria to be met by the manufacturer. Calculation of hottest-spot temperature rise is required by this revision; however, future study is planned to develop test procedures to verify hottest-spot temperature rise.

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.

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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. Scope

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.

Electrical, mechanical, and safety requirements of ventilated, nonventilated, 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.

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 transformers;
f) Mine transformers.

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. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI/ASME, Boiler and Pressure Vessel Code (BPV) 1995, Section VIII, Division 1—Pressure Vessels, or Division 2—Alternative Rules.[1]

ANSI C57.12.50-1981 (Reaff 1989), American National Standard Requirements for Ventilated Dry-Type Distribution Transformers, 1 to 500 kVA, Single-Phase, and 15 to 500 kVA, Three-Phase with High-Voltage 601 to 34 500 Volts, Low-Voltage 120 to 600 Volts.

ANSI C57.12.51-1981 (Reaff 1989), American National Standard Requirements for Ventilated Dry-Type Power Transformers, 501 kVA and Larger, Three-Phase with High-Voltage 601 to 34 500 Volts, Low-Voltage 208Y/120 to 4160 Volts.

ANSI C57.12.52-1981 (Reaff 1989), American National Standard Requirements for Sealed Dry-Type Power Transformers, 501 kVA and Larger, Three-Phase with High-Voltage 601 to 34 500 Volts, Low-Voltage 208Y/120 to 4160 Volts.

ANSI C57.12.55-1987, American National Standard Dry-Type Transformers in Unit Installations, Including Unit Substations—Conformance Standard.

ANSI C57.12.57-1986, American National Standard Requirements for Ventilated Dry-Type Network Transformers 2500 kVA and Below, Three-Phase, High-Voltage 34 500 Volts and Below, Low-Voltage 216Y/125 and 480Y/277 Volts.

ANSI C57.12.70-1978 (Reaff 1993), American National Standard Terminal Markings and Connections for Distribution and Power Transformers.

ANSI C84.1-1995, American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz).

IEEE Std 99-1980 (Reaff 1992), IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment.[2]

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms.

IEEE Std 315-1975 (Reaff 1993), IEEE Graphic Symbols for Electrical and Electronics Diagrams. (DoD)

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.56-1986 (Reaff 1993), IEEE Standard Test Procedure for Thermal Evaluation of Insulation Systems for Ventilated Dry-Type Power and Distribution Transformers.

IEEE Std C57.12.60-1998, IEEE Guide for Test Procedures for Thermal Evaluation of Insulation Systems for Solid-Cast and Resin-Encapsulated Power and Distribution Transformers.

[1]ANSI and ANSI/ASME publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[2]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/).

IEEE Std C57.12.80-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.91-1995, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.

IEEE Std C57.94-1982 (Reaff 1987), IEEE Recommended Practice for the Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers.

IEEE Std C57.96-1989, IEEE Guide for Loading Dry-Type Distribution and Power Transformers.

IEEE Std C57.98-1993, IEEE Guide for Transformer Impulse Tests.

IEEE Std C57.124-1991 (Reaff 1996), IEEE Recommended Practice for the Detection of Partial Discharge and the Measurement of Apparent Charge in Dry-Type Transformers.

IEEE Std C62.2-1987 (Reaff 1994), IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems.

3. Definitions

Standard transformer terminology, available in IEEE Std C57.12.80-1978, shall apply. Other electrical terms are defined in IEEE Std 100-1996.

4. Service conditions

4.1 Usual service conditions

4.1.1 General

Transformers conforming to this standard shall be suitable for operation at rated kVA 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.

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 C57.12.80-1978.[3]

4.1.6 Operation above rated voltage

Transformers shall be capable of

a) Delivering rated output in kVA at 5% above rated secondary voltage, without exceeding the limiting temperature rise, when the power factor of the load is 80% or higher;

b) Operating at 10% above rated secondary voltage at no load without exceeding the limiting temperature rise;

c) Fulfilling the foregoing requirements for rated voltage, rated frequency, and rated kVA for any tap.

The maximum continuous transformer operating voltage should not exceed the levels specified in ANSI C84.1-1995.

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 nonventilated 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 only.

4.1.8 Step-down operation

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

NOTE—See also Note 9 of Table 11.

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.

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

4.2.2 Unusual loading

IEEE Std C57.96-1989 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 kVA with normal life expectancy;

c) Loading that results in reduced life expectancy.

NOTE—IEEE Std C57.96-1989 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 upon 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. 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. This guide does not cover solid-cast and/or resin-encapsulated windings.

4.2.3 Unusual altitude service conditions

Annex A provides guidance concerning operation above 1000 m (3300 ft), including the effects of altitude on temperature rise, operation at rated kVA and reduced ambient temperature, and operation at less than rated kVA.

4.2.4 Insulation at high altitude

The dielectric strength of transformers that depend in whole or in part upon 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.

4.2.5 Other unusual service conditions

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 upon the design of dry-type transformer involved. While such conditions may have little or no effect on sealed, solid-cast and/or resin-encapsulated or nonventilated dry-type transformers, they may have serious effects 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 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 kVA 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—While parallel operation is not unusual, it is desirable that users advise manufacturers if paralleling with other transformers is planned and identify the transformers involved.

Table 1—Dielectric strength correction factors for altitudes 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

NOTE—An altitude of 4 500 m (15 000 ft) is considered a maximum for transformers conforming to this standard.

5. Rating data

5.1 Cooling classes of transformers

a) Ventilated self-cooled: class AA;

b) Ventilated forced-air-cooled: class AFA;

c) Ventilated self-cooled/forced-air-cooled: class AA/FA;

d) Nonventilated self-cooled: class ANV;

e) Sealed self-cooled: class GA.

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 C57.12.70-1978.

5.4 Rated kVA

5.4.1 General

The rated kVA 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 kVA

Preferred continuous kVA of single-phase and three-phase distribution and power transformers shall be as shown in Table 2.

5.5 Voltage ratings and taps

5.5.1 General

Standard nominal system voltages are listed in ANSI C84.1-1995. Voltages available on standard transformers are included in the product standards for particular types of transformers.

Table 2—Preferred continuous kVA ratings

Single-phase transformers	Three-phase transformer
1	15
3	30
7.5	45
10	75
15	112.5
25	150
37.5	225
50	300
75	500
100	750
167	1 000
250	1 500
333	2 000
500	2 500
833	3 750
1 250	5 000
1 667	7 500
2 500	10 000
3 333	12 000
5 000	15 000
6 667	20 000
8 333	
10 000	

5.5.2 Voltage ratings

The voltage ratings 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 together, 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).

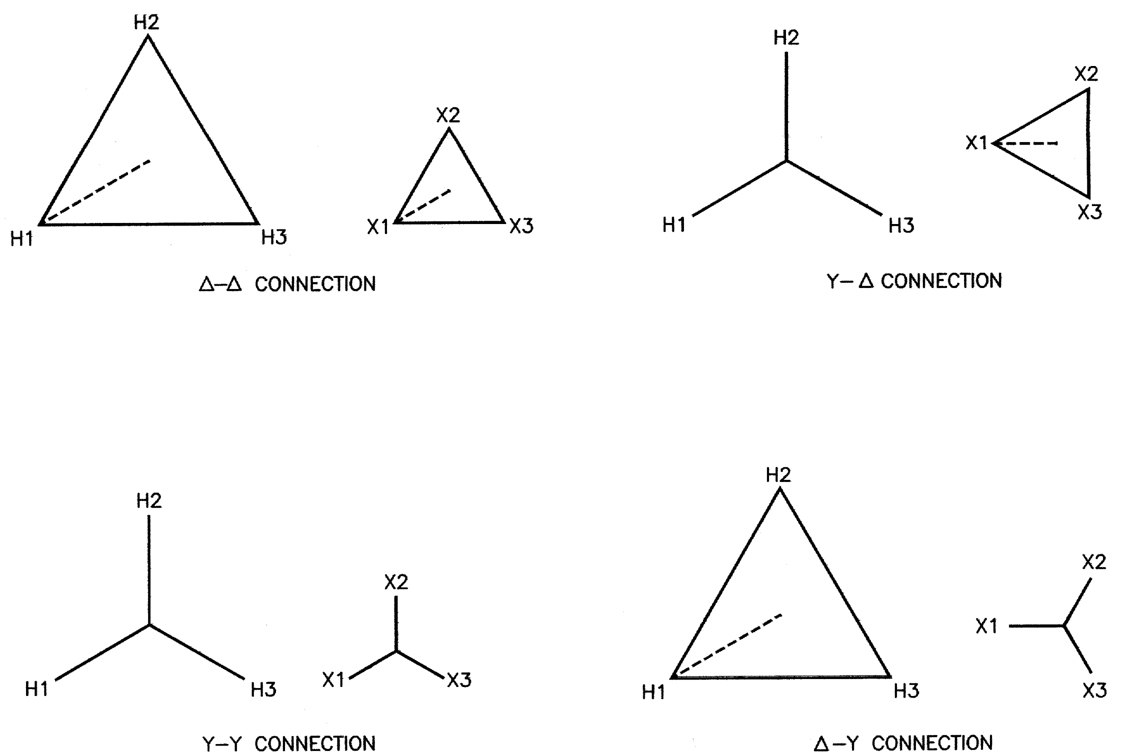


Figure 1—Phase relation of terminal designations for three-phase transformers

5.7.3 Terminal marking

Terminal marking shall be in accordance with ANSI C57.12.70-1978.

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. The load losses shall be based on the reference temperature equal to the rated winding temperature rise plus 20 °C. (See Table 9 for winding temperature-rise values.)

5.9.1 Accuracy required for measuring 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 Clauses 5, 8, and 9 of IEEE Std C57.12.91-1995, are required.
b) The test equipment utilized for measuring losses of power and distribution transformers shall meet the requirements of Clauses 5, 8, and 9 of IEEE Std C57.12.91-1995.
c) The test-system accuracy for each quantity measured shall fall within the limits specified in Table 3.

Table 3—Test-system accuracy requirements

Quantity measured	Test-system accuracy
Losses	±3.0%
Voltage	±0.5%
Current	±0.5%
Resistance	±0.5%
Temperature	±1.0 °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.

The BILs are given in Table 4. The lowest BIL is 10 kV and applies down to, and including, 120 V ratings. Table 5 lists low-frequency insulation levels corresponding to line-terminal BILs for both fully-insulated windings and windings with reduced neutral insulation.

Enhanced BILs, similar to Table 3 in IEEE Std C57.12.00-1993, may be utilized for power transformers.

Table 4—Relationships of nominal system voltage and BILs for systems 34.5 kV and below

Nominal system voltage (kV)	BILs in common use (kV crest)									
	10	20	30	45	60	95	110	125	150	200
1.2	S	1	1							
2.5		S	1	1						
5.0			S	1	1					
8.7				S	1	1				
15.0					S	1	1			
25.0						2	S	1	1	
34.5								2	S	1

NOTES:
S = Standard value.
1 = Optional higher levels where exposure to overvoltage occurs and improved protective margins are required.
2 = Lower levels where protective characteristics of applied surge arresters have been evaluated and found to provide appropriate surge protection.

Table 5—Interrelationships of dielectric insulation levels for dry-type transformers used on systems with BILs 200 kV and below

BIL (kV)[a]	Low-frequency voltage insulation levels (kV rms)[b]	Impulse levels[c]		
		Full wave 1.2 x 50 μs (kV crest)	Chopped wave	
			kV crest	Minimum time to flashover (μs)
10	4	10	10	1.0
20	10	20	20	1.0
30	12	30	30	1.0
45	19	45	45	1.25
60	31	60	60	1.5
95	34	95	95	1.6
110	37	110	110	1.8
125	40	125	125	2.0
150	50	150	150	2.25
200	70	200	200	2.70

[a]The latest edition of IEEE Std C62.2-1987 should be consulted for information concerning coordination with available surge-arrester protection levels.

[b]Low-frequency voltage-insulation levels apply to the standard "S" levels in Table 4. The low-frequency voltage-test level for grounded-Y windings shall be 10 kV (except for windings 1.2 kV and less, which shall be 4 kV).

[c]A positive polarity impulse wave form shall be used.

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

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 of 1200 V or less shall have the neutral insulated for a 4 kV low-frequency applied voltage test.
b) Windings with line-to-line voltages higher than 1200 V shall have the neutral insulated for a 10 kV low-frequency applied voltage test.
c) 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 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 C57.12.91-1995.

NOTE—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, recognizing the construction of windings with “graded insulation.”

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 in order to meet the requirements of the others, or such that no winding need be tested above its specified level in order 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 shall be performed as required by Table 15 or when specified and agreed upon by the user and manufacturer. The tests shall be conducted as part of the induced-voltage test. The partial-discharge inception voltage shall be measured and recorded at the beginning of the induced-voltage test, and the partial-discharge extinction voltage shall be measured at the end of the induced-voltage test. The partial discharge shall be measured in picocolumbs (pC) using techniques described in IEEE Std C57.124-1991.

Acceptance criteria for the test shall be inception and extinction voltages 10% above the maximum operating voltage of the transformer.

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 Tables 6, 7, or 8, measured according to IEEE Std C57.12.91–1995.

Table 6—Average sound level, decibels three-phase primary 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 7—Average sound level, decibels three-phase primary voltages above 1.2 kV

Equivalent two-winding (kVA)	Self cooled		Ventilated forced air cooled[a]	
	Ventilated (class AA rating)	Sealed (class AA rating)	kVA	Class FA and AFA rating
0–9	40	45	0–1167	67
10–50	45	50	1168–1667	68
51–150	50	55	1668–2000	69
151–300	55	57	2001–3333	71
301–500	60	59	3334–5000	73
501–700	62	61	5001–6667	74
701–1000	64	63	6668–8333	75
1001–1500	65	64		
1501–2000	66	65		
2001–3000	68	66		
3001–4000	70	68		
4001–5000	71	69		
5001-6000	72	70		
6001-7500	75	71		

[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.

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 upon the temperatures to which they are subjected and the duration of such temperatures. Since 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.

Table 8—Average sound level, decibels single-phase primary voltages 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
1256	68	66	70
1667	70	68	71
2500	71	70	72
3333	72	71	74
5000	73	72	76

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

Other factors upon which the life of insulating materials depends are

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 and emergency loading are discussed in 4.2.2.

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 C57.12.60-1998.

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 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 C57.12.91-1995, 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[a]

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

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

[b]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 utilizes 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 is the case, 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 10, 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 9, 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 9.

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.

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	Polymide resins
Cast epoxy	Polyester-imides
Cast silicone	
Polymide 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, 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 that follows.

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 (6.5 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 kVA output at rated secondary voltage if there are no taps;
b) Rated kVA output at the rated secondary voltage for that connection if it is a rated kVA tap connection;
c) At the rated secondary voltage of that connection, the kVA output corresponding to the current of the tap if the connection is a reduced kVA 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 nonremovable part.

5.12.2 Nameplate information for ventilated and nonventilated transformers

Unless otherwise specified, the minimum information shown on the nameplate shall be that specified in Table 11 and the associated notes.

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 (cubic feet) 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 Note 7 of Table 11, the "untanking" weight (heaviest piece) shall also be listed.

Table 11—Nameplate information

Serial number (see Note 1)
Class (AA, AA/FA, etc.) (see Note 2)
Number of phases
Frequency
kVA ratings (see Notes 1 and 2)
Voltage ratings (see Notes 1 and 3)
Tap voltages (see Note 4)
Temperature rise in °C, by individual winding if different
Polarity (single-phase transformers)
Phasor diagram (polyphase transformers)
Percent impedance (see Note 5)
Basic lightning impulse insulation levels (BILs) (see Note 6)
Approximate weight in pounds (see Note 7)
Connection diagram (see Note 8)
Name of manufacturer
Installation and operating instruction reference
The words "dry-type transformer"
Conductor material
Step-up transformer suitability, if involved (see Note 9)

Table 11 notes:

1—The letters and numerals showing kVA, serial number, and voltage ratings shall have a minimum height of 3.18 mm (0.125 in), whether engraved or stamped. The weight of other letters and numerals shall be optional for the manufacturer.

2—Where the class of transformer involves more than 1 kVA rating, all ratings shall be shown. Provisions for future forced-cooling equipment shall be indicated.

3—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 designed as specified in Tables 12 and 13.

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.

4—The tap voltages of a winding shall be designed 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 C57.12.80-1978.) 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, 2R, etc. The lower range positions shall be designated by numerals in ascending order, corresponding to decreasing output voltage, followed by the suffix I, such as 1I, 2I, etc.

The rated currents of all windings at the highest kVA rating, and on all tap connections, shall be shown for transformers 501 kVA and larger.

5—The percent tested impedance over 500 kVA of two-winding transformers shall be given on the tested rated voltage connection and at rated self-cooled kVA.

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 1 kVA rating, the kVA base shall be given.

6—Full-wave BIL, 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, it shall be similarly described.

7—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

Table 11 notes continued:

8—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, winding temperature devices, etc., 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 315-1975. Any winding grounds shall be indicated.

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

6. Construction

6.1 Tank-pressure requirements

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

6.2 Finish

The finish for transformer cases on tanks shall consist of a nonmetallic pigment coating.

NOTE—This 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 upon the use of a pigment coating finish.

6.3 Transformer accessories

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

6.4 Terminals

Transformers shall be equipped with suitable insulated cable or bar arrangements of bushings. The BILs of terminals shall be at least equal to that of the windings to which they are connected, unless otherwise specified. See Tables 4 and 5 for BILs of terminals.

Table 12—Designation of voltage ratings of single-phase windings (schematic representation)

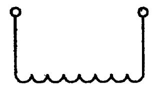
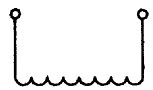
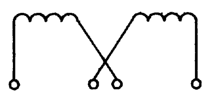
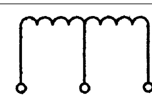
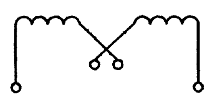
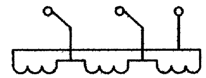
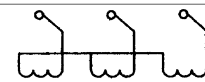
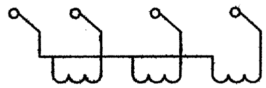
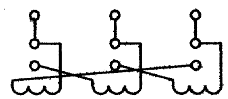
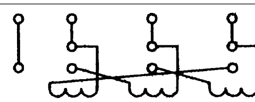
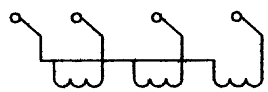
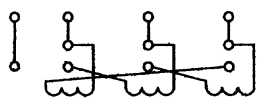
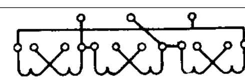
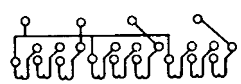
ID	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(1)(a)	E	2400		E shall indicate a winding of E volts that is suitable for Δ connection on an E volt system.
(1)(b)	E/E_1 Y	2400/4160 Y		E/E_1 Y shall indicate a winding of E volts that is suitable for Δ connection on an E volt system or for Y connection on an E_1 volt system.
(1)(c)	E/E_1 Grd Y	2400/4160 Grd Y		E/E_1 Grd Y shall indicate a winding of E_1 volts with reduced insulation that 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_1 Grd Y/E	12 470 Grd Y/7200		E_1 Grd Y/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 1/2 kVA available only from midpoint to each extreme terminal.
(1)(g)	$V \times V_1$	240 × 480 2400/4160 Y × 4800/8320 Y		$V \times V_1$ shall indicate a winding for parallel or series operation only, but not suitable for three-wire service.
Key: $E_1 = \sqrt{3}E$				

Table 13—Designation of voltage ratings of three-phase windings (schematic representation)

ID	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(2)(a)	E	2400		E shall indicate a winding of E volts that is permanently Δ connected for an E volt system.
(2)(b)	E_1 Y	4160 Y		E_1 Y shall indicate a winding that is permanently Y connected without a neutral brought out (isolated) for operation on an E_1 volt system.
(2)(c)	E_1 Y/E	4160 Y/2400		E_1 Y/E shall indicate a winding that 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_1 Y	2400/4160 Y		E/E_1 Y shall indicate a winding that 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_1 Y/E	2400/4160 Y/2400		E/E_1 Y/E shall indicate a winding that 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_1 Grd Y/E	34 500 Grd Y/ 19 920		E_1 Grd Y/E shall indicate a winding with reduced insulation and permanently Y connected with a neutral brought out and effectively grounded, or operation on an E_1 volt system with E volts available from line to neutral.
(2)(g)	E/E_1 Grd Y/E	7200/12 470 Grd Y/7200		E/E_1 Grd Y/E shall indicate a winding with 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 × 14 400 4160 Y/2400 × 12 470 Y/7200	 	$V \times V_1$ shall indicate a winding, the section of which may be connected in parallel to obtain one of the voltage ratings (as defined in rows 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 rows a, b, c, d, e, f, and g) of V_1. Windings are permanently Δ or Y connected.

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

6.5 Grounding

6.5.1 Transformer grounding

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

6.5.2 Grounding of core

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

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. Since means are not available to continuously monitor and quantitatively evaluate the degrading effects of such duty, short-circuit tests, when required, should be performed prior to 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 C57.12.91-1995.

7.2 Transformer categories

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

Category	Single-phase (kVA)	Three-phase (kVA)
I	1–500	15–500
II	501–1667	501–5000
III	1668–10 000	5001–30 000

a) Autotransformers of 500 kVA or less (equivalent two-winding) shall be included in Category I even though their nameplate kVA may exceed 500 kVA.
b) All kVA ratings are minimum nameplate kVA 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

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 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 kVA base) specified by the user. Alternatively, the user may specify the system MVA available 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 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 kVA, 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

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

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

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

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:

$$I_{SC}\text{ (pk asym.)} = KI_{SC} \tag{3}$$

where

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

$\varnothing$ = arc tan (x/r) (in radians),

e is the base of natural logarithm,

x/r (ratio of effective ac reactance to resistance, both in ohms) is 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.

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.

Table 14—Values of K

r/*x*	*x*/*r*	*K*
0.001	1000	2.824
0.002	500	2.82
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	1.99
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	1	1.509

7.4 System zero-sequence data

For Category III transformers with solidly grounded neutral, the user should specify the ratio of system X_0/X_1. In lieu of 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 kVA and base currents

7.7.1 Base kVA of a winding

This is the self-cooled rating of the winding, as specified by the nameplate.

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 kVA of the winding by the rated kV 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 kVA 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 kVA per phase 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 following:

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.

$$T_f = m\,(T_k + T_S)(1 + E + 0.6m) + T_S \qquad (4)$$

where

E is the per-unit eddy-current loss, based on resistance loss W_s, at the starting temperature,

T_k = 234.5 °C for copper,

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

$$m = \frac{W_S t}{C(T_K + T_S)}$$

where

t is the duration of short circuit (in seconds),

$C = 174 + (0.0225)(T_k + T_s) + (110)(A_i/A_c)$ for copper,

$= 405 + (0.1)(T_k + T_s) + (360)(A_i/A_c)$ for aluminum,

A_i is the cross-sectional area of turn insulation (in inches),

A_C is the cross-sectional area of the conductor (in inches),

W_S is the short-circuit resistance loss of the winding at the starting temperature, in watts per pound of conductor material,

with

$$W_S = \frac{W_r N^2}{M} \times [(T_k + T_S)/(T_k + T_r)] \qquad (5)$$

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 pounds);

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 $m \le 0.6$. For values of $m > 0.6$, the following more nearly exact formula should be used:

$$T_f = (T_k + T_S)[\sqrt{e^{2m} + E(e^{2m} - 1)} - 1] + T_S \qquad (6)$$

where

e is the base of natural logarithm = 2.718,

with

$$E = E_r\,[(T_k + T_r)/(T_k + T_s)]^2 \qquad (7)$$

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 C57.12.91-1995. Unless otherwise specified, tests shall be made at the factory only.

8.2 Test classifications

Test classifications are defined in IEEE Std C57.12.80-1978.

8.3 Routine, design, and other tests for transformers

Routine tests shall be made on all transformers. These are listed in Table 15. When specified (as individual tests), "other" tests shall be made on transformers as listed in Table 15.

8.4 Calculations

When specified, transformer regulation shall be determined for the rated voltage, kVA, and frequency by means of calculations based on the tested impedance, in accordance with the procedure given in IEEE Std C57.12.91-1995. 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 9, plus 20 ºC.

NOTE—When a transformer has windings of different insulation system temperatures, only one reference temperature is to be used, i.e., the one relating to the winding having the higher system temperature.

Table 15—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		●		●		
Ratio tests on the rated voltage connection	●			●		
Polarity and phase relation tests on the rated voltage connection	●			●		
No-load losses and excitation current at rated voltage on the rated voltage connection	●[a]			●		
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		●	●	●		
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		●			●	●
Dielectric tests						
applied voltage	●			●		
induced voltage	●			●		
impulse		●[b]	●[b]		●[b]	●[b]
insulation power factor			●			●
insulation resistance			●			●
partial discharge	●[c]	●	●[c]	●[c]		●[c]
Audible sound level		●			●	●
Short-circuit capability			●			●
Mechanical (for sealed transformers)						
pressure		●			●	
leak	●			●		

[a]Statistical sampling may be used for this test. (This does not apply to ≥ 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 are considered routine tests for transformers above 1.2 kV having solid-cast and/or resin-encapsulated windings as part of the insulation systems.

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 autotranformer 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 items a) through 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 16.

Table 16—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 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)

Unusual temperature and altitude

A.1 Service conditions

Transformers may be applied at higher ambient temperatures or at higher altitudes than specified in this standard, but performance may be affected, and special consideration should be given to these applications.

A.2 Effect of altitude on temperature rise

The effect of the decreased air density due to high altitude is to increase the temperature rise of transformers, since they are dependent upon air for the dissipation of heat losses.

A.3 Operation at rated kVA

Transformers may be operated at rated kVA at altitudes greater than 1000 m (3300 ft) without exceeding temperature limits, provided the average temperature-cooling air does not exceed the values of Table A.1 for the respective altitudes.

NOTE—See 4.2.4, for transformer insulation capability at altitudes about 1000 m (3300 ft).

A.4 Operation at less than rated kVA

Transformers may be operated at altitudes greater than 1000 m (3300 ft) without exceeding temperature limits, provided the load to be carried is reduced below rating by the percentages given in Table A.2 for each 100 m (330 ft) that the altitude is above 1000 m (3300 ft).

Table A.1—Maximum 24 hour average temperature of cooling air

Type of apparatus	Average temperature for specified altitude (°C) 1000 m (3300 ft)	2000 m (6600 ft)	3000 m (9900 ft)	4000 m (13 200 ft)
Dry-Type, class AA				
75 °C	30	27	24	20
90 °C	30	26	22	18
115 °C	30	25	20	15
130 °C	30	24	18	12
150 °C	30	23	17	10
Dry-Type, class AA/FA and AFA				
75 °C	30	24	18	12
90 °C	30	22	14	6
115 °C	30	20	10	0
130 °C	30	18	7	–5
150 °C	30	17	5	–8

NOTES:

1—The data included in this table apply to ventilated dry-type transformers and include solid-cast and/or resin-encapsulated windings. These data are not applicable to sealed and nonventilated dry-type transformers. Data for sealed transformers will be included, when available.

2—It is recommended that the average temperature of the cooling air be calculated by averaging 24 consecutive hourly readings. When the outdoor air is the cooling medium, the average of the maximum and minimum daily temperatures may be used. The value obtained in this manner is usually slightly higher, by not more than 0.3 °C, than the true daily average.

Table A.2—Rated kVA derating factors for altitudes greater than 1000 m (3300 ft)

Type of cooling	Derating factor (%)
Dry-type, self cooled	0.3
Dry-type, forced-air cooled	0.5