IEEE Std C57.12.00-2000
(Revision of
IEEE Std C57.12.00-1993)

IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

Approved 21 June 2000

IEEE-SA Standards Board

Abstract: Electrical, mechanical, and safety requirements are set forth for liquid-immersed distribution and power transformers, and autotransformers and regulating transformers; single and polyphase, with voltages of 601 V or higher in the highest voltage winding. This standard is a basis for the establishment of performance, limited electrical and mechanical interchangeability, and safety requirements of equipment described; and for assistance in the proper selection of such equipment. The requirements in this standard apply to all liquid-immersed distribution, power, and regulating transformers except the following: instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, mobile transformers, and mine transformers.
Keywords: autotransformers, distribution transformers, electrical requirements, mechanical requirements, power transformers, regulating transformers, safety requirements

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Print: ISBN 0-7381-1980-6 SH94832
PDF: ISBN 0-7381-1981-4 SS94832

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Introduction

(This introduction is not part of IEEE Std C57.12.00-2000, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.)

In this revision of IEEE Std C57.12.00-1993, metric units are interchanged with English units where applicable throughout the standard (i.e., values with English units are now shown in parentheses). Clause 5, which covers rating data, has been completely revised. Table 5, which outlines coordinated insulation levels for Class II power transformers, has been revised for typographical errors. In 5.11, which covers temperature rise and loading conditions, heading 5.11.1.1, Winding rise, has been replaced by Winding temperature rises.

This revision requires that the maximum (hottest spot) temperature rise be determined by calculation or testing. Prior editions of this standard required that the hottest spot temperature rise not exceed 80 ˚C, however, there was no approved test or calculation method for this required performance parameter. Many users of transformers rely on this parameter for their loading calculations. Because of this need, an IEEE Task Force was formed, which proposed a revision of 5.11.1.1. Fiber optic temperature sensors now permit direct measurement of a specific point. By prior analysis of the winding, the sensor can be placed to read the maximum winding temperature. Modern computer technology also permits development of heat transfer programs to calculate the temperature distribution within the transformer windings. At the time this revision was approved, an IEEE Working Group was developing a *Guide for Hottest Spot Temperature Rise Determination in Liquid-Filled Transformers*. This guide, when completed, will give additional guidance for compliance with subclause 5.11.1.1. In Table 6, which covers dielectric insulation levels, test levels corresponding to 69 kV, nominal system voltage, for 250 kV BIL have been added.

In Table 10, several changes have been made to cover new cooling class designations, and month/year of manufacture. Note 12 and the footnotes related to limit of PCB in the insulating liquid have been added to the table. In footnote 2 (last sentence) and items 2(a) and 2(b), references to the definition of directed and nondirected flow have been deleted.

References to other standards have been updated, where applicable, for year of revision, reaffirmation, etc.

Table 18, which covers base current calculation factors, has been modified with new cooling class designations.

Table 19 has been revised, and new tests, such as Core insulation resistance; Single-phase excitation; Low-frequency test on auxiliary devices, control, and current transformer circuits; Operation test of all devices; and Dissolved gasses in oil analysis have been added. Radio influence voltage has been replaced by Partial discharge test. Footnotes for the new tests, and for switching impulse have been added. Footnotes 4 and 11 have been modified whereas footnotes 16 and 17 have been added to this table.

A reference to *Askarel* in 6.6.1 was removed and replaced with references to *less flammable hydrocarbon fluid* and *silicone fluid*.

Table 19, which covered tolerances for single-phase and three-phase transformer losses, has been eliminated. Subclause 9.3 has been expanded to include the definition of these tolerances. The previous Table 20 of IEEE Std C57.12.00-1993, which covers test system accuracy requirements, now becomes Table 21.

One area that has not been previously covered and still is not covered is a definition of *thermal duplicate*, as referenced in Table 19. This is being developed by a working group and will include the fundamental definition and an annex to establish limits and provide calculations for determining thermal performance.

A second area that has not been covered is a requirement of an instruction manual along with the minimum information that should be included in the instruction manuals. This will be developed by the working group for future revision.

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

Suggestions for improvement gained in the use of this standard will be welcomed.

Revisions of the individual clauses that have been modified were prepared by separate groups within the IEEE Transformers Committee and were balloted independently according to the applicable rules and procedures of IEEE for the preparation and approval of voluntary consensus standards. This standard was approved by the IEEE Transformers Committee, the IEEE-SA Standards Board, and the Accredited Standards Committee for Distribution and Power Transformers and Regulators (C57). The applicable rules and procedures were followed.

The working group that coordinated the compilation of this standard had the following membership:

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IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

1. Overview

1.1 Scope

This standard is a basis for the establishment of performance, limited electrical and mechanical interchangeability, and safety requirements of equipment described. It is also a basis for assistance in the proper selection of such equipment.

This standard describes electrical, mechanical, and safety requirements of liquid-immersed distribution and power transformers, and autotransformers and regulating transformers, single-phase and polyphase, with voltages of 601 V or higher in the highest voltage winding.

This standard applies to all liquid-immersed distribution, power, and regulating transformers that do not belong to the following types of apparatus:

a) Instrument transformers
b) Step voltage and induction voltage regulators
c) Arc furnace transformers
d) Rectifier transformers
e) Specialty transformers
f) Grounding transformers
g) Mobile transformers
h) Mine transformers

1.2 Word usage

When this standard is used on a mandatory basis, the words *shall* and *must* indicate mandatory requirements. The words *should* and *may* refer to matters that are recommended or permissive, but not mandatory. The foreword of this voluntary consensus standard describes the circumstances under which the standard may be used on a mandatory basis.

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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 C57.12.20-1997, American National Standard for Overhead-Type Distribution Transformers, 500 kVA and Smaller: High Voltage, 34 500 Volts and Below; Low Voltage, 7970/13 800Y Volts and Below—Requirements.[1]

ANSI C57.12.70-1978 (Reaff 1992), 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).

ANSI/CGA V-1-1994, Compressed Gas Cylinder Valve Outlet and Inlet Connections.[2]

ASME Boiler and Pressure Vessel Code (BPV), 1984 Edition.[3]

ASME B1.1-1989, American National Standard for Unified Inch Screw Threads (UN and UNR Thread Form).

ASTM D92-1998, Standard Test Methods for Flash and Fire Points by Cleveland Open Cup.[4]

ASTM D117-1996, Standard Guide for Sampling, Test Methods, Specifications, and Guide for Electrical Insulating Oils of Petroleum Origin.

ASTM D1933-1997, Standard Specification for Nitrogen Gas as an Electrical Insulating Material.

ASTM D2225-1992 (1997), Standard Test Methods for Silicone Fluids Used for Electrical Insulation.

ASTM D3487-1988 (Reaff 1993), Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.

ASTM D5222-1998, Standard Guide for High Fire-Point Mineral Electrical Insulating Oils.

IEC 60076-2: 1993, Power transformers—Part 2: Temperature rise.[5]

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.[6]

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[2]ANSI 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/), or from the Compressed Gas Association, Inc., Crystal Gateway 1, Suite 501, 1235 Jefferson Davis Highway, Arlington, VA 22202, USA.

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[5]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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IEEE Std 32-1972 (Reaff 1997), IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices.

IEEE Std 315-1975 (Reaff 1993), IEEE Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters).

IEEE Std 315A-1986 (Reaff 1994), IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (Supplement to IEEE Std 315-1975).

IEEE Std 469-1988 (Reaff 1994), IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers.

IEEE Std 799-1987 (Reaff 1992), IEEE Guide for Handling and Disposal of Transformer Grade Insulating Liquids Containing PCBs.

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

IEEE Std C57.12.90-1999, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.

IEEE Std C57.19.01-1991 (Reaff 1997), IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

IEEE Std C57.91-1995, IEEE Guide for Loading Mineral-Oil-Immersed Transformers.

IEEE Std C57.131-1995, IEEE Guide for the Application of Metal Oxide Surge Arresters for AC Systems.

IEEE Std C62.1-1989 (Reaff 1994), IEEE Standard for Gapped Silicone-Carbide Surge Arresters for AC Power Circuits.

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

IEEE Std C62.11-1999, IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits (>1 kV).

IEEE Std C62.22-1997, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

3. Definitions

Standard transformer terminology available in IEEE C57.12.80-1978 shall apply. Other electrical terms are defined in the *IEEE Standard Dictionary of Electrical and Electronics Terms,* Sixth Edition [B11].

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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 following usual service conditions.

4.1.2 Temperature

4.1.2.1 Cooling air temperature limit

When air-cooled, the temperature of the cooling air (ambient temperature) shall not exceed 40 ˚C, and the average temperature of the cooling air for any 24 h period shall not exceed 30 ˚C.

4.1.2.2 Liquid temperature limit

The top liquid temperature of the transformer (when operating) shall not be lower than –20 ˚C. Liquid temperatures below –20 ˚C are not considered as usual service conditions.

4.1.2.3 Cooling water temperature limit

When water-cooled, the temperature of the cooling water (ambient temperature) shall not exceed 30 ˚C, and the average temperature of the cooling water for any 24 h period shall not exceed 25 ˚C. Minimum water temperature shall not be lower than 1 ˚C, unless the cooling water includes antifreeze suitable for –20 ˚C operation.

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 voltages supplying a polyphase transformer shall be approximately equal in magnitude and time displacement.

4.1.5 Load current

The load current shall be approximately sinusoidal. The harmonic factor shall not exceed 0.05 per unit. Harmonic factor is defined in IEEE Std C57.12.80-1978.

4.1.6 Operation above rated voltage or below rated frequency

4.1.6.1 Capability

Transformers shall be capable of:

a) Operating continuously above rated voltage or below rated frequency, at maximum rated kVA for any tap, without exceeding the limits of observable temperature rise in accordance with 5.11.1 when all of the following conditions prevail:
    1) Secondary voltage and volts per hertz do not exceed 105% of rated values.

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2) Load power factor is 80% or higher.

3) 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 in accordance with 5.11.1, when neither the voltage nor volts per hertz exceed 110% of rated values.

In the case of multiwinding transformers or autotransformers, 4.1.6.1 applies only to the specific loading conditions used as the basis of design. These loading conditions involve simultaneous coordination of kVA input and output, load power factors, and winding voltage combinations [see item j) of 4.3.3]. Differences in loading and voltage regulation for various output windings may prevent simultaneous achievement of 105% voltage on all output terminals. In no case shall the kVA outputs specified for any loading condition require continuous loading of any input winding in excess of its rating.

4.1.6.2 Maximum continuous transformer operating voltage

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

Unless otherwise specified, transformers shall be suitable for outdoor operation.

4.1.8 Step-down operation

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

4.1.8.1 Generator step-up transformers

Transformers identified as generator step-up transformers shall be designed for step-up operation.

4.1.8.2 System tie autotransformers

Transformers identified as system tie transformers or autotransformers shall be designed for either step-down operation or step-up operation, or both, as specified by the user.

4.1.9 Tank or enclosure finish

Temperature limits and tests shall be based on the use of a nonmetallic pigment surface paint finish. It should be noted that metallic-flake paints, such as aluminum and zinc, have properties that increase the temperature rise of transformers, except in direct sunlight.

4.2 Loading at other than rated conditions

IEEE Std C57.91-1995 provides guidance for loading at other than rated 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

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The guides are not standards. They provide the best known general information for loading of transformers under various conditions based on typical winding insulation systems and are based upon the best engineering information available at the time of preparation. The guides discuss limitations of ancillary components other than windings that may limit the capability of transformers. When specified, ancillary components and other construction features (cables, bushing, tap changers, oil expansion space, etc.) shall be supplied so that they in themselves will not limit the loading to less than the capability of the windings.

4.3 Unusual service conditions

Conditions other than those described in 4.1 are considered unusual service conditions and, when prevalent, should be brought to the attention of those responsible for the design and application of the apparatus. Examples of some of these conditions are listed in 4.3.1.

4.3.1 Unusual temperature and altitude conditions

Transformers may be used at higher or lower ambient temperatures or at higher altitudes than those specified in 4.1.3, but special consideration should be given to these applications. IEEE Std C57.91-1995 provides information on recommended practices.

4.3.2 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 spacings between terminals using the correction factors of Table 1 to obtain adequate air dielectric strength at altitudes above 1000 m (3300 ft).

4.3.2.1 Insulation level

The minimum insulation necessary at the required altitude can be obtained by dividing the standard insulation level at 1000 m (3300 ft) by the appropriate correction factor from Table 1.

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

Altitude (m)	Altitude (ft)	Altitude correction factor for dielectric strength
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

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

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4.3.2.2 Bushings

Bushings with additional length or creep distance shall be furnished when necessary for operation above 1000 m (3300 ft).

4.3.3 Other unusual service conditions

Other unusual service conditions include the following:

a) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture, or dripping water, etc.
b) Abnormal vibration, tilting, shock, or seismic conditions.
c) Ambient temperatures outside of 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 substantially sinusoidal wave form.
i) Loads involving abnormal harmonic currents such as those that may result where appreciable load currents are controlled by solid-state or similar devices. Such harmonic currents may cause excessive losses and abnormal heating.
j) Specified loading conditions (kVA outputs, winding load power factors, and winding voltages) associated with multiwinding transformers or autotransformers.
k) Excitation exceeding either 110% rated voltage or 110% rated volts per hertz.
l) Planned short circuits as a part of regular operating or relaying practice.
m) Unusual short-circuit application conditions differing from those described as usual in Clause 7.
n) Unusual voltage conditions including transient overvoltages, resonance, switching surges, etc., which may require special consideration in insulation design.
o) Unusually strong magnetic fields. It should be noted that solar magnetic disturbances may result in the flow of telluric currents in transformer neutrals.
p) Large transformers with high-current isolated-phase bus ducts. It should be noted that high-current isolated-phase bus ducts with accompanying strong magnetic fields may cause unanticipated circulating currents in transformer tanks and covers, and in the bus ducts. The losses resulting from these unanticipated currents may result in excessive temperatures when corrective measures are not included in the design.
q) Parallel operation. It should be noted that while parallel operation is not unusual, it is desirable that users advise the manufacturer when paralleling with other transformers is planned and identify the transformers involved.

5. Rating data

5.1 Cooling classes of transformers

Transformers shall be identified according to the cooling method employed. For liquid-immersed transformers, this identification is expressed by a four-letter code as described below. These designations are consistent with IEC 60076-2: 1993.

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First letter: Internal cooling medium in contact with the windings:

O mineral oil or synthetic insulating liquid with fire point[7] ≤ 300 °C
K insulating liquid with fire point > 300 °C
L insulating liquid with no measurable fire point

Second letter: Circulation mechanism for internal cooling medium:

N *natural* convection flow through cooling equipment and in windings
F *forced* circulation through cooling equipment (i.e., coolant pumps), natural convection flow in windings (also called nondirected flow)
D forced circulation through cooling equipment, *directed* from the cooling equipment into at least the main windings

Third letter: External cooling medium:

A air
W water

Fourth letter: Circulation mechanism for external cooling medium:

N natural convection
F forced circulation [fans (air cooling), pumps (water cooling)]

NOTES:

1—In a transformer with forced, nondirected cooling, (second code letter F), the rates of coolant flow through all the windings vary with the loading, and are not directly controlled by the pumps. The pumped oil flows freely inside the tank and is not forced to flow through the windings.

2—In a transformer designated as having forced directed coolant circulation (second code letter D), the rate of coolant flow through the main windings is determined by the pumps and not by the loading. A minor fraction of the coolant flow through the cooling equipment may be directed outside the main windings to provide cooling for core and other parts. Regulating windings and/or other windings having relatively low power may also have nondirected coolant circulation.

A transformer may be specified with more than one power rating (also referred to as cooling stages). The transformer nameplate shall list the rated power and cooling class designation for each rating. The ratings shall be listed in order of increasing power. The cooling class designations are normally listed in order with a diagonal slash separating each one.

Examples:

ONAN/ONAF. The transformer has a set of fans which may be put in service as desired at high loading. The coolant circulation is by natural convection only.

ONAN/OFAF. The coolant circulation is by natural convection only at base loading. However, the transformer has cooling equipment with pumps and fans to increase the power-carrying capacity at high loading.

Examples of the cooling class designations used in IEEE Std C57.12.00-1993 and in previous revisions, and the corresponding new designations, are provided in Table 2.

[7]Fire point—The lowest temperature at which a specimen will sustain burning for 5 s. (ASTM D92-1998, “Cleveland Open Cup” test method.)

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Table 2—Cooling class designation

Present designations	Previous designations
ONAN	OA
ONAF	FA
ONAN/ONAF/ONAF	OA/FA/FA
ONAN/ONAF/OFAF	OA/FA/FOA
ONAN/ODAF	OA/FOA[a]
ONAN/ODAF/ODAF	OA/FOA[a]/FOA[a]
OFAF	FOA
OFWF	FOW
ODAF	FOA[a]
ODWF	FOW[a]

[a]Indicates directed oil flow per Table 9, NOTE 2 of IEEE Std C57.12.00-1993.

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-connected or T-connected transformers

5.3.2.1 Phase transformation

These may be provided to accomplish three-phase to two-phase transformation, or vice versa; or to accomplish three-phase to three-phase transformation. Several arrangements commonly utilized to accomplish such transformations are described here.

5.3.2.2 Dissimilar single-phase transformers

Two single-phase transformers are assembled in an enclosure, and permanently interconnected, with the following characteristics:

a) Performance characteristics shall be based on bank operation of three-phase to two-phase transformation or vice versa.
b) The single-phase transformers may not be identical or interchangeable.

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5.3.2.3 Three-legged core

Another possible arrangement is an assembly utilizing a three-legged core with main and teaser coil assemblies located on the two outer legs, and with a center leg that has no coil assembly and provides a common magnetic circuit for the two outer legs.

5.3.2.4 Identical single-phase transformers

When specified, two identical single-phase transformers shall be furnished.

a) The kVA rating of each transformer shall be half the bank output required, and the rating of the individual units shall agree with the ratings established for single-phase transformers.
b) Performance characteristics, except heating, shall be based on single-phase operation.
c) The temperature rise shall be based on delivering the required bank capacity when transforming from three-phase to two-phase or from two-phase to three-phase, as specified.
d) Transformers shall be interchangeable as main and teaser.
e) Regulating taps are not usually supplied on transformers for three-phase to two-phase or from two-phase to three-phase service. When taps are required, the teaser tap shall be 86.6% of the mean regulating taps (mean, as used here, refers to the midpoint of the range of regulating taps).

5.4 Rated kilovoltamperes

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 kilovoltampere ratings

Preferred continuous kVA ratings of single-phase and three-phase distribution and power transformers are based on an average winding rise by resistance of 65 °C, in accordance with 5.11.1.1, and are listed in Table 3.

Table 3—Preferred continuous kilovoltampere ratings

Single-phase transformers	Three-phase transformers
5	15
10	30
15	45
25	75
37.5	112.5
50	150
75	225
100	300
167	500
250	750

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Table 3—Preferred continuous kilovoltampere ratings (continued)

Single-phase transformers	Three-phase transformers
333	1000
500	1500
—	2000
833	2500
1250	3750
1667	5000
2500	7500
3333	10 000
—	12 000
5000	15 000
6667	20 000
8333	25 000
10 000	30 000
12 500	37 500
16 667	50 000
20 000	60 000
25 000	75 000
33 333	100 000

For multiple rated transformers, the preferred kVA rating for the ONAN rating is according to Table 3. For transformers rated over 10 000 kVA, the preferred increase for the first stage of cooling (ONAF) is 33%, and the preferred increase for the second stage of cooling (ONAF/ONAF or OFAF) is 66% of the ONAN rating.

5.5 Voltage ratings and taps

5.5.1 General

Standard nominal system voltages and maximum system voltages are included in ANSI C84.1-1995 and are listed in Table 4.

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Table 4—Relationships of nominal system voltage to maximum system voltage and basic lightning impulse insulation levels (BIL) for systems 765 kV and below

Application	Nominal system voltage (kV rms)	Maximum system voltage (from ANSI C84-1-1995) (kV rms)	Basic lightning impulse insulation levels (BIL) in common use (kV crest)			
Distribution	1.2	—	**30**	—	—	—
	2.5	—	**45**	—	—	—
	5.0	—	**60**	—	—	—
	8.7	—	**75**	—	—	—
	15.0	—	**95**	—	—	—
	25.0	—	**150**	**125**	—	—
	34.5	—	**200**	**150**	125	—
	46.0	48.3	**250**	200	—	—
	69.0	72.5	**350**	250	—	—
Power	1.2	—	**45**	**30**	—	—
	2.5	—	**60**	**45**	—	—
	5.0	—	**75**	**60**	—	—
	8.7	—	**95**	**75**	—	—
	15.0	—	**110**	**95**	—	—
	25.0	—	**150**	—	—	—
	34.5	—	**200**	—	—	—
	46.0	48.3	**250**	200	—	—
	69.0	72.5	**350**	250	—	—
	115.0	121.0	550	**450**	350	—
	138.0	145.0	650	**550**	450	—
	161.0	169.0	750	**650**	550	—
	230.0	242.0	900	825	**750**	650
	345.0	362.0	1175	1050	900	—
	500.0	550.0	1675	1550	1425	1300
	765.0	800.0	2050	1925	1800	—

NOTES

1—BIL values in **bold** typeface are listed as standard in one or more of ANSI C57.12.10-1988 [B1], ANSI C57.12.20-1997 [B3], ANSI C57.12.22-1989 [B5], IEEE Std C57.12.23-1992 [B12], ANSI C57.12.24-1992 [B6], ANSI C57.12.25-1990 [B7], and IEEE Std C57.12.26-1992 [B13].

2—Single-phase distribution and power transformers and regulating transformers for voltage ratings between terminals of 8.7 kV and below are designed for both Y and Δ connection, and are insulated for the test voltages corresponding to the Y connection so that a single line of transformers serves for the Y and Δ applications. The test voltages for such transformers, when operated and connected, are therefore higher than needed for their voltage rating.

3—For series windings in transformers, such as regulating transformers, the test values to ground shall be determined by the BIL of the series windings rather than by the rated voltage between terminals.

4—Values listed as nominal system voltage in some cases (particularly voltages 34.5 kV and below) are applicable to other lesser voltages of approximately the same value. For example, 15 kV encompasses nominal system voltages of 14 440 V, 13 800 V, 13 200 V, 13 090 V, 12 600 V, 12 470 V, 12 000 V, 11 950 V, etc.

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5.5.2 Voltage ratings

The voltage ratings shall be at no load and shall be based on the turn ratio.

5.5.3 Ratings of transformer taps

Whenever a transformer is provided with taps from a winding, they shall be full-capacity taps. When specified, other than full-capacity taps may be provided, and this shall be stated on the nameplate. It should be noted that transformers with load tap changing equipment commonly have reduced capacity taps for taps below rated winding voltage.

5.6 Connections

Standard connection arrangements are included in the standards for particular types of transformers and in ANSI C57.12.70-1978

Relationships of nominal system voltage to maximum system voltage and basic lightning impulse insulation levels (BIL) for systems 765 kv and below

5.7 Polarity, angular displacement, and terminal markings

5.7.1 Polarity of single-phase transformers

Single-phase transformers in sizes 200 kVA and below and having high-voltage ratings of 8660 V and below (winding voltage) shall have additive polarity. All other single-phase transformers shall have subtractive polarity.

5.7.2 Angular displacement (nominal) 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 zero degrees.

The angular displacement between high-voltage and low-voltage phase voltages of three-phase transformers with Y-Δ or Δ-Y connections shall be 30º, with the low voltage lagging the high voltage as shown in Figure 1. The angular displacement of a polyphase transformer is the time angle expressed in degrees between the line-to-neutral voltage of the reference identified high-voltage terminal H1 and the line-to-neutral voltage of the corresponding identified low-voltage terminal X1.

NOTE—Additional phasor diagrams are described in ANSI C57.12.70-1978.

5.7.3 Terminal markings

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

5.8 Impedance

The impedance shall be referred to a temperature equal to the sum of the rated average winding temperature rise by resistance, plus 20 ˚C. Preferred standard values of impedance are included in the product standards for particular types of transformers.

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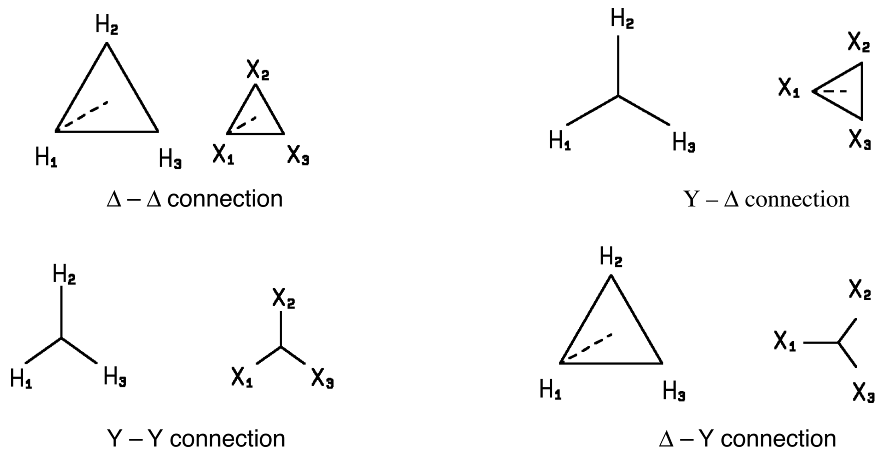

Figure 1—Phase relation of terminal designations for three-phase transformers

5.9 Total losses

The total losses of a transformer shall be the sum of the no-load losses and the load losses.

The losses of cooling fans, oil pumps, space heaters, and other ancillary equipment are not included in the total losses. When specified, power loss data on such ancillary equipment shall be furnished.

The standard reference temperature for the load losses of power and distribution transformers shall be 85 ˚C. The standard reference temperature for the no-load losses of power and distribution transformers shall be 20 ˚C.

For Class II transformers, control/auxiliary (cooling) losses shall be measured and recorded. All stages of cooling, pumps, heaters, and all associated control equipment shall be energized, provided these components are integral parts of the transformer.

5.10 Insulation levels

Transformers shall be designed to provide coordinated low-frequency and impulse insulation levels on line terminals and low-frequency insulation levels on neutral terminals. The primary identity of a set of coordinated levels shall be its basic lightning impulse insulation level (BIL).

The system voltage and the type of transformer may also influence insulation levels and test procedures. In this regard, power transformers are separated into two different classes as follows:

a) Class I power transformers shall include power transformers with high-voltage windings of 69 kV and below.
b) Class II power transformers shall include power transformers with high-voltage windings from 115 kV through 765 kV.

Table 4 lists BIL levels in current use at various system voltages; however, the use of any given BIL choice requires careful attention to proper insulation coordination and to accurate assessment of the coefficient of grounding as outlined in 5.10.3.

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Table 5 outlines coordinated insulation levels for distribution transformers and for Class I power transformers.

Table 5—Dielectric insulation levels for distribution transformers and Class I power transformers[a]

Application	Basic lightning impulse insulation level (BIl) (kV crest)	Chopped-wave impulse levels		Front-of-wave impulse levels		
		Minimum voltage (kV crest)	Minimum time to flashover (μs)	Minimum voltage (kV crest)	Specific time to sparkover (μs)	Low-frequency test level (kV rms)
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Distribution	30	36	1.0	—	—	10
	45	54	1.5	—	—	15
	60	69	1.5	—	—	19
	75	88	1.6	—	—	26
	95	110	1.8	—	—	34
	125	145	2.25	—	—	40
	150	175	3.0	—	—	50
	200	230	3.0	—	—	70
	250	290	3.0	—	—	95
	350	400	3.0	—	—	140
Power	45	50	1.5	—	—	10
	60	66	1.5	—	—	15
	75	83	1.5	—	—	19
	95	105	1.8	165	0.5	26
	110	120	2.0	195	0.5	34
	150	165	3.0	260	0.5	50
	200	220	3.0	345	0.5	70
	250	275	3.0	435	0.5	95
	350	385	3.0	580	0.58	140

[a]See 5.10 for a description of Class I power transformers.

NOTES

1—Front-of-wave impulse levels must be specified prior to design of the transformer.

2—Front-of-wave tests are not recommended on low-voltage or tertiary windings that will not be exposed to lightning and that are connected directly to user equipment having low impulse strengths. This includes low-voltage windings of generator transformers and transformer windings that operate at 5000 V or less.

3—Internal and external phase-to-phase low-frequency insulation test levels shall not be reduced below the levels listed in Table 7.

4—The insulation levels for distribution transformers and for Class I power transformers shall be selected from this table for both the high-voltage and the low-voltage windings.

5—The BIL serves both as a test level for the full-wave lightning impulse tests and as the primary identity of a set of coordinated insulation levels.

Table 6 outlines coordinated insulation levels for Class II power transformers.

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Table 6—Dielectric insulation levels for Class II power transformers[a]

Nominal system voltage (kV)	Basic lightning impulse insulation level (BIL) (kV crest)	Chopped wave level (kV crest)	Switching impulse level (BSL) (kV crest)	Low frequency test levels: Induced-voltage test (phase to ground): One hour level (kV rms)	Low frequency test levels: Induced-voltage test (phase to ground): Enhancement level kV rms)	Low frequency test levels: Applied-voltage test level (kV rms)
Column 1	**Column 2**	**Column 3**	**Column 4**	**Column 5**	**Column 6**	**Column 7**
15 and below	110	120	—	—	—	34
25	150	165	—	—	—	50
34.5	200	220	—	—	—	70
46	250	275	—	—	—	95
69	250	275	—	—	—	95
	350	385	—	—	—	140
115	350	385	280	105	120	140
	450	495	375	105	120	185
	550	605	460	105	120	230
138	450	495	375	125	145	185
	550	605	460	125	145	230
	650	715	540	125	145	275
161	550	605	460	145	170	230
	650	715	540	145	170	275
	750	825	620	145	170	325
230	650	715	540	210	240	275
	750	825	620	210	240	325
	825	905	685	210	240	360
	900	990	745	210	240	395
345	900	990	745	315	360	395
	1050	1155	870	315	360	460
	1175	1290	975	315	360	520
500	1130	1430	1080	475	550	—
	1425	1570	1180	475	550	—
	1550	1705	1290	475	550	—
	1675	1845	1390	475	550	—
765	1800	1980	1500	690	800	—
	1925	2120	1600	690	800	—
	2050	2255	1700	690	800	—

[a]See 5.10 for a description of Class II power transformers.

NOTES

1—For chopped-wave tests, the minimum time to flashover shall be 3.0 µs except for 110 kV BIL, in which case the minimum time to flashover shall be 2.0 µs.

2—Although Column 4 establishes phase-to-ground switching impulse levels, it is not always possible to test these levels on low-voltage windings.

3—Columns 5 and 6 provide phase-to-ground test levels that would normally be applicable to wye windings. When the test voltage level is to be measured phase-to-phase, as is normally the case with delta windings, then the levels in Column 5 must be multiplied by 1.732 to obtain the required phase-to-phase induced-voltage test level.

4—The applied-voltage test is not applicable to wye-winding line terminals unless they have been specified to be suitable for application on ungrounded systems.

5—The insulation levels for Class II power transformers shall be selected from this table for both the high-voltage and the low-voltage windings.

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Table 7 outlines minimum phase-to-phase insulation test levels for distribution transformers and for Class I power transformers.

Table 7—Minimum phase-to-phase insulation test levels for three-phase distribution transformers and for three-phase Class I power transformers

Application	Nominal system voltage (kV)	Minimum low-frequency phase-to-phase test level (kV rms)
Distribution	25.0	50
	34.5	69
	46.0	92
	69.0	138
Power	46.0	76
	69.0	115

NOTES

1—For nominal system voltages not in the table, use a test level not less than 2.0 times the nominal system voltage for distribution transformers and not less than 1.65 times the nominal system voltage for Class I power transformers.

2—The low-frequency test level between phases shall not be lower than the low-frequency test level from line to ground.

Table 8 outlines minimum low frequency insulation levels for neutral terminals.

Table 8—Minimum low frequency insulation test levels at neutral for Class I power transformers

Minimum low-frequency insulation level (kV rms)			
Application	Nominal system voltage (kV)[a]	Grounded solidly or through a current transformer or through a regulating transformer	Grounded through a ground-fault neutralizer, or isolated but impulse protected
	Column 1	Column 2	Column 3
Distribution or power	1.2	10	10
	2.5	15	15
	5.0	19	19
	8.7	26	26
	15.0	26	26
	25.0	26	34
	34.5	26	50
	46.0	34	70
	69.0	34	95

[a]For higher line terminal system voltages than shown above, the low frequency insulation level at the neutral shall be specified to conform with service requirements, but in no case shall be less than 34 kV.

NOTE—When specified, Y-Y connected transformers using a common, solidly grounded neutral may use a neutral bushing selected in accordance with the requirements of the low-voltage winding.

For test procedures, see IEEE Std C57.12.90-1999.

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5.10.1 Line terminals

5.10.1.1 Basic lightning impulse insulation level (BIL)

Each line terminal of a winding shall be assigned a basic lightning impulse insulation level (BIL) from Table 4. The associated insulation levels shall be provided regardless of whether tests are or can be performed.

5.10.1.2 Switching impulse insulation level

Windings for system voltages 115 kV and above shall be designed for the switching impulse insulation levels (BSL) associated with the assigned BIL. In addition, low-voltage windings shall be designed to withstand stresses resulting from switching impulse tests on the high-voltage winding regardless of whether or not such tests are specified.

5.10.1.3 Front-of-wave insulation level

Front-of-wave insulation levels and tests, when desired, shall be specified; otherwise, withstand insulation capability is not required.

5.10.1.4 Wye-winding line terminal

Each wye-winding line terminal shall be specified as suitable or unsuitable for ungrounded neutral operation.

5.10.1.5 Windings that have no terminals brought out

Windings that have no terminals brought out shall be capable of withstanding voltages resulting from the various tests that may be applied to other terminals corresponding to their respective BIL.

5.10.2 Neutral terminals

5.10.2.1 Wye connection with the neutral end accessible external to the tank

A transformer winding designed for wye connection only and with the neutral end accessible external to the tank shall be assigned a low-frequency test level for the neutral terminal. This assigned low-frequency test level may be lower than that for the line terminal.

5.10.2.2 Neutral terminals that are solidly grounded

The assigned low-frequency test level for neutral terminals that are solidly grounded directly or through a current transformer shall be not less than that specified in Column 2 of Table 8.

The assigned low-frequency test level for other cases shall be coordinated with voltages that can occur between the neutral and ground during normal operation or during fault conditions, but shall be not less than those specified in Column 2 and Column 3 of Table 8.

It should be noted that IEEE Std 32-1972 includes additional information on neutral insulation, application, etc.

5.10.2.3 Specific BIL

When specified, neutral terminals shall be designed for a specific BIL instead of a low-frequency test level.

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5.10.2.4 Insulation level of the neutral bushing

The insulation level of the neutral end of a winding may differ from the insulation level of the neutral bushing being furnished or of the bushing for which provision for future installation is made. In this case, the dielectric tests on the neutral shall be determined by whichever is lower: the insulation of the neutral end of the winding or the insulation level of the neutral bushing shipped with the transformer.

5.10.2.5 Neutral not brought out of the tank

Insulation levels shall not be assigned where the neutral end of the winding is not brought out of the tank through a bushing. In such cases, the neutral end of the winding shall be directly connected to the tank and the tank shall be solidly grounded.

5.10.3 Coordination of insulation levels

5.10.3.1 BIL levels

The BIL chosen for each line terminal shall be such that the lightning impulse, chopped-wave impulse, and switching impulse insulation levels include a suitable margin in excess of the dielectric stresses to which the terminal will be subjected in actual service. For information on surge arrester characteristics and application, see IEEE Std C62.1-1989 [B37], IEEE Std C62.2-1987 [B39], and IEEE Std C62.22-1997 [B41]. It should be noted that it is recommended that surge-arrester protection be provided for tertiary windings that have terminals brought out.

5.10.3.2 BSL levels

A switching surge impulse occurring at one terminal during test or in actual service will be transferred to other winding terminals with a magnitude approximately proportional to the turns ratio involved. This interaction should be considered when evaluating surge arrester application, evaluating expected magnitude of surges, and establishing coordinated insulation levels.

5.10.3.3 Grounding considerations

It is necessary to verify the ability of a transformer to withstand temporary overvoltage on unfaulted terminals during single or double line-to-ground faults. In most cases, the low-frequency test is used to provide this verification. The applicable low-frequency test levels are shown in Column 6 of Table 5 or Column 7 of Table 6. An adequate margin is provided when the low-frequency test coefficient from Table 9 is approximately 1.5 times the coefficient of grounding. The coefficient of grounding is defined in IEEE Std C62.1-1989 [B38], except that, in this case, a decimal fraction should be used as opposed to a percentage; for example, 0.8 instead of 80%. Caution should be exercised to ensure that the coefficient of grounding has been accurately determined and can be maintained, especially in the case of maximum BIL reductions on delta windings, such as 650 kV BIL at 230 kV or 350 kV BIL at 115 kV. Consideration should be given to such possibilities as backfeed in determining if the coefficient of grounding can be maintained. Backfeed would involve energization from the low side of the transformer together with clearing on the high side so that the fault remains on one phase and the system grounding is lost. Under these conditions, a full neutral shift could result on the high-voltage delta winding.

In the case of wye windings for Class II transformers, the low-frequency test levels and low-frequency test coefficients in Table 9 are not applicable unless the winding has been specified to be suitable for application on ungrounded systems. However, when the neutral is solidly grounded to the tank, there should be no problem because the neutral end of the winding cannot shift with respect to the tank, and there should be no significant increase in line-terminal-to-ground (tank) voltage during single or double line-to-ground faults, providing that proper overall system grounding practices are employed.

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Table 9—Low-frequency test coefficients

Nominal system voltage (kV)	Basic lightning impulse insulation level (BIL) (kV crest)	Low-frequency test level (kV rms)	Low-frequency test coefficient
Column 1	**Column 2**	**Column 3**	**Column 4**
46	200	70	1.449
	250	95	1.697
69	250	95	1.310
	350	140	1.931
115	350	140	1.157
	450	185	1.529
	550	230	1.901
138	450	185	1.276
	550	230	1.586
	650	275	1.897
161	550	230	1.361
	650	275	1.627
	750	325	1.923
230	650	275	1.136
	750	325	1.343
	825	360	1.488
	900	395	1.632
345	900	395	1.091
	1050	460	1.271
	1175	520	1.436

NOTES

1—The application of this table is covered in 5.10.3.3. In particular, the caution regarding application of maximum BIL reductions should be considered.

2—The low-frequency test coefficient is the ratio between the low-frequency test level and the *maximum* line-to-line system voltage.

For wye windings in which Table 9 does not apply and in which neutral grounding devices are involved that significantly affect the coefficient of grounding of the transformer, alternate tests shall be specified to provide the necessary verification.

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5.10.4 Low-frequency voltage tests on line terminals for distribution transformers and Class I power transformers

5.10.4.1 General

The low-frequency test requirements for distribution and Class I power transformers shall be accomplished by utilizing applied-voltage and induced-voltage tests or combinations thereof.

5.10.4.2 Requirements

The low-frequency test requirements are as follows:

a) A voltage to ground (not necessarily to neutral) shall be developed at each terminal in accordance with Column 6 of Table 5. For ungraded windings, this voltage shall be maintained throughout the winding.

b) A phase-to-phase voltage shall be developed between line terminals of each three-phase winding in accordance with Column 6 of Table 5 or Column 2 of Table 7, where applicable.

c) Two times rated turn-to-turn voltage shall be developed in each winding.

5.10.4.3 Exceptions

The exceptions to the low-frequency test requirements are as follows:

a) Subject to the limitation that the voltage-to-ground test shall be performed as specified in item a) of 5.10.4.2 on the line terminals of the winding with the lowest ratio of test voltage to minimum turns, the test levels may otherwise be reduced so that none of the three test levels required in 5.10.4.2 need be exceeded to meet the requirements of the other two, or so that no winding need be tested above its specified level to meet the test requirements of another winding.

b) For delta windings, the voltage-to-ground developed at each terminal shall be in accordance with Table 5 for the BIL specified; however, the voltage within the winding may be reduced to 87% of the voltage developed at the terminals.

5.10.5 Low-frequency voltage tests on line terminals for Class II power transformers

5.10.5.1 Induced-voltage test

With the transformer connected and excited as it will be in service, an induced-voltage test shall be performed as indicated in Figure 2, at voltage levels indicated in Column 5 and Column 6 of Table 6.

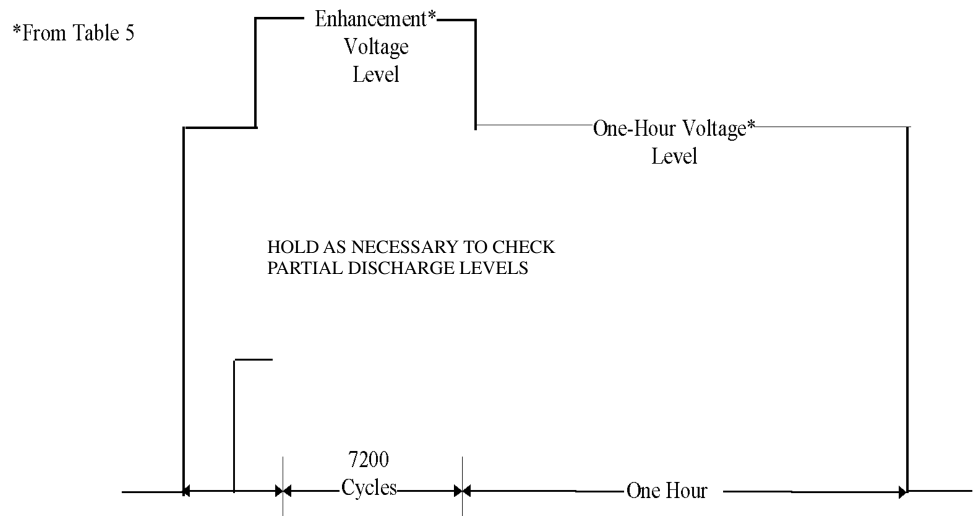

Figure 2—Induced voltage test for Class II transformer

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5.10.5.2 Applied-voltage test

Line terminals of delta windings and all terminals of wye windings for application on ungrounded systems shall receive an applied-voltage test at the levels indicated in Column 7 of Table 6.

5.10.6 Low-frequency voltage test on neutral terminals for all transformers

Each neutral terminal shall receive an applied-voltage test at its assigned low-frequency insulation level.

5.10.7 Impulse tests

5.10.7.1 Lightning impulse tests

The lightning impulse test shall include reduced-full-wave, chopped-wave, and full-wave tests for Class II power transformers. Lightning impulse tests shall not be made on windings that do not have terminals brought out through the tank or cover. When lightning impulse tests are required on line terminals, the neutral terminals rated 200 kV BIL and above shall be lightning impulse tested. Lightning impulse tests are not required on terminals brought out from buried windings in the following cases:

a) When a single terminal is brought out for the purpose of grounding the buried winding
b) When two terminals are brought out so that the delta connection may be opened for the purpose of testing the buried winding
c) When temporary connections to terminals of a buried winding are brought out only for the purpose of factory tests

5.10.7.2 Switching impulse tests

When required, switching impulse tests shall be performed. Switching impulse tests on the high-voltage line terminals may overtest or undertest other line terminals depending upon the relative BSL levels, the turns ratios between windings, and the test connections. Regardless of this fact, tests on the high-voltage terminals shall be controlling, and a switching impulse test at the level specified in Table 6 shall be applied to the high-voltage terminals.

The switching surge insulation of other windings shall be capable of withstanding the voltages resulting from application of the required switching impulse level to the high-voltage terminal even though such voltages on the other windings may exceed their designated BSL, where applicable, in Table 6.

Where the application of the switching impulse to the high-voltage terminals results in a voltage on another winding less than the BSL requirement for that winding in Table 6, no additional test is necessary to demonstrate switching surge insulation withstand capability.

5.11 Temperature rise and loading conditions

5.11.1 Limits of observable temperature rise

5.11.1.1 Winding temperature rises

The average winding temperature rise above ambient temperature shall not exceed 65 °C at rated kVA when tested in accordance with C57.12.90-1999 using the particular combination of connections and taps that give the highest average winding temperature rise. This will generally involve those connections and taps resulting in the highest losses.

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The maximum (hottest-spot) winding temperature rise above ambient temperature shall not exceed 80 ˚C at rated kVA for the particular combination of connections and taps that give the highest maximum (hottest-spot) winding temperature rise. This will generally involve those connections and taps resulting in the highest losses. The maximum (hottest-spot) winding temperature rise above ambient shall be determined by one of the following conditions:

a) Direct measurement during a thermal test in accordance with IEEE Std C57.12.90-1999. A sufficient number of direct reading sensors should be used at expected locations of the maximum temperature rise as indicated by prior testing or loss and heat transfer calculations.
b) Direct measurement on an exact duplicate transformer design per a).
c) Calculations of the temperatures throughout each active winding and all leads. The calculation method shall be based on fundamental loss and heat transfer principles and substantiated by tests on production or prototype transformers or windings.

The maximum (hottest-spot) winding temperature rise above ambient temperature shall be included in the test report with the other temperature rise data. A note shall indicate which of the above methods was used to determine the value.

5.11.1.2 Other winding rises

Other winding rises may be recognized for unusual ambient conditions or for special applications. These are specified in appropriate applications or in certain product standards.

5.11.1.3 Rises of metallic parts other than windings

Metallic parts in contact with current-carrying conductor insulation shall not attain a temperature rise in excess of the winding hottest-spot temperature rise.

Metallic parts other than those described above shall not attain excessive temperature rises at maximum rated load.

5.11.1.4 Liquid temperature rise

The temperature rise of the insulating liquid shall not exceed 65 ˚C when measured near the top of the main tank.

5.11.2 Conditions under which temperature rise 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 when there are no taps.
b) Rated kVA output at the rated secondary voltage for that connection when it is a rated kVA tap connection.
c) At the rated secondary voltage of that connection, the kVA output corresponding to the rated current of the tap when the connection is a reduced kVA tap connection.
d) A specified combination of kVA outputs at specified power factors (for each winding) for multi-winding transformers.
e) Rated kVA output at rated V/Hz.

It should be noted that, as used here, the term *rated secondary voltage* or *rated current* means the value assigned by the manufacturer and shown on the nameplate.

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5.12 Nameplates

5.12.1 General

A durable metal nameplate shall be affixed to each transformer by the manufacturer. Unless otherwise specified, it shall be made of corrosion-resistant material. It shall bear the rating and other essential operating data as specified in 5.12.2. It should be noted that although this standard recognizes the possibility of using SI units as an alternative to the system of units used in the past, it is not intended that both appear on the specific nameplate.

5.12.2 Nameplate information

Unless otherwise specified, the minimum information shown on the nameplate shall be that specified in Table 10 and its associated notes, and shall be in accordance with the following categories:

a) Nameplate A shall be used on transformers rated 500 kVA or below with a high-voltage basic impulse insulation level (BIL) less than 150 kV.

b) Nameplate B shall be used on transformers rated 500 kVA or below, which are not covered above.

c) Nameplate C shall be used on transformers rated above 500 kVA.

Table 10—Nameplate information

Nameplate A	Nameplate B	Nameplate C
Serial number (1)[a]	Serial number (1)	Serial number (1)
Month/year of manufacture	Month/year of manufacture	Month/year of manufacture
Class (ONAN, ONAF, etc.)(2)	Class (ONAN, ONAF, etc.)(2)	Class (ONAN, ONAF, etc.)(2)
Number of phases	Number of phases	Number of phases
Frequency	Frequency	Frequency
kVA rating (1)(2)	kVA rating (1)(2)	kVA (or MVA) rating (1)(2)
Voltage ratings (1)(3)	Voltage ratings(l)(3)	Voltage ratings (1)(3)
Tap voltages (4)	Tap voltages (4)	Tap voltages (4)
Temperature rise, ˚C	Temperature rise, ˚C	Temperature rise, ˚C
Polarity (single-phase transformers)	Polarity (single-phase transformers)	Polarity (single-phase transformers)
Phasor diagram (polyphase transformers)	Phasor diagram (polyphase transformers)	Phasor diagram (polyphase transformers)
Percent impedance (5)	Percent impedance (5)	Percent impedance (5)
Approximate total mass in kg (pounds) (7)	Basic lightning impulse insulation levels (BIL) (6)	Basic lightning impulse insulation levels (BIL) (6)
Connection diagram (9)	Approximate masses in kg (pounds) (8)	Approximate masses in kg (pounds) (8)
Name of manufacturer	Connection diagram (9)	Connection diagram (9)
Installation and operating instructions reference	Name of manufacturer	Name of manufacturer
The word transformer or autotransformer	Installation and operating instructions reference	Installation and operating instructions reference
Type of insulating liquid (generic name preferred) (12)	The word transformer or autotransformer	The word transformer or autotransformer

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Table 10—Nameplate information (continued)

Nameplate A	Nameplate B	Nameplate C
Serial number (1)[a]	Serial number (1)	Serial number (1)
Conductor material (of each winding)	Type of insulating liquid (generic name preferred) (12)	Step-up operation suitability (10)
	Conductor material (of each winding)	Tank, pressure, and liquid data (11)
		Type of insulating liquid (generic name preferred) (12)
		Conductor material (of each winding)

[a]Numbers in parentheses refer to the following notes.

NOTES

1—The letters and numerals showing kVA, serial number, and voltage ratings shall have a minimum height of 3.97 mm (0.156 in.) whether engraved or stamped. The height of other letters and numerals shall be optional with the manufacturer.

2—Where the class of transformer involves more than one kVA (or MVA) rating, all ratings shall be shown. Any winding, such as a tertiary winding, that has a different rating shall have its kVA (or MVA) suitably described. Where the transformer has more than one temperature rating, the additional rating shall be shown on the nameplate. Provision for future forced-cooling equipment shall be indicated.

3—The voltage ratings of a transformer or autotransformer shall be designated by the voltage rating of each winding separated by a dash (-) or voltages may be listed in tables. The winding voltage ratings shall be designated as specified in Table 11(a) and 11(b).

When 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 transformers that have high-voltage ratings above 600 V.

4—The tap voltages of a winding shall be designated by listing the winding voltage of each tap, separated by a solidus (/), or shall be listed in tabular form. The rated voltage of each tap shall be shown in volts, except that for transformers rated 500 kVA and smaller with taps in uniform 2.5% or 5% steps, they 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 letter “A” shall be assigned to the voltage rating providing the *maximum* ratio of transformation with tap changers for de-energized operation.

Note that the ratio of transformation is defined as the high-voltage volts divided by low-voltage volts.

The neutral position (the position in which the LTC circuit has no effect on the output voltage) shall be designated by the letter “N” for load tap changers. The raise 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 “L,” such as 1L, 2L, etc. (this applies to the relationship between two windings of a transformer only, such as the H and X windings). In the event of system requirements, such as reversal of power flow, regulation of input voltage (LTC in the primary winding), or any unusual conditions, nameplates shall have raise-lower designations as specified by the user. This applies to two-winding transformers only.

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

Any reduced capacity taps shall be identified.

5—The percent impedance shall be given between each pair of windings and shall be the tested value for transformers rated 501 kVA and larger. The voltage connection shall be stated following each percent impedance and, when the transformer has more than one kVA rating, the kVA base shall be given.

6—Full-wave BIL in kV of line terminals shall be designated as in the following example:

High-voltage winding	450 BIL
High-voltage winding neutral	110 BIL
High-voltage winding neutral bushing	95 BIL
Low-voltage winding	95 BIL

7—For transformers rated below 37.5 kVA single-phase or below 30 kVA polyphase, the weight may be omitted from the nameplate. Supplemental data shall be available that show the volume of oil required and the approximate weight of the transformer for ratings that are smaller than those for which the data are shown on the nameplate.

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8—The approximate weights shall be shown as follows:

a) Core and coils
b) Tank and fittings
c) Liquid
d) Total weight
e) Untanking weight (heaviest piece)

9—All winding terminations shall be identified on the nameplate or on the connection diagram. A schematic plan view shall be included, preferably indicating orientation by locating a fixed accessory such as the de-energized tap changer handle, the load tap changer, instruments, or other prominent items. 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 H, high-voltage terminal, at the top left. (This arrangement may be modified in particular cases, such as multiwinding transformers that are equipped with terminal locations that do not conform to the suggested arrangement.)

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 when used for metering, relaying, or line drop compensation. Polarity need not be shown when current transformers are used for winding temperature equipment or cooling control.

All internal leads and terminals that are not permanently connected shall be designated or marked with numbers or letters in a manner that will permit convenient reference and will obviate confusion with terminal and polarity markings.

Where development of windings is shown, the scallop symbol shall be used in accordance with IEEE Std 315-1975 and IEEE Std 315A-1986.

10—When the transformer is suitable for step-up operation, the nameplate shall so state.

11—The following tank, pressure, and liquid data for transformers larger than 500 kVA shall be provided:

a) Maximum operating pressures of liquid preservation system_______ kPa (lbf/in^2) positive and_______ kPa (lbf/in^2) negative.
b) Tank designed for _______ kPa (lbf/in^2) vacuum filling.
c) Liquid level below top surface of the highest point of the highest manhole flange at 25 °C_______ mm (in). Liquid level changes _______ mm (in) per 10 °C change in liquid temperature. (This applies only to transformers that have a gas cushion above the liquid in the transformer.) The volume of insulating liquid, in cubic meters (gallons), and type shall be shown for the main tank and for each liquid-filled compartment.

It is suggested that when SI units are used, that liters be used for volumes less than 1000 liters, and cubic meters for volumes 1000 liters and large.

12—The nameplate shall have the following note:
"Contains no detectable level of PCB (less than 2 PPM) at the time of manufacture."

5.12.3 Schematic representation.

Windings shall be represented as shown in Table 11(a) and Table 11(b).

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Table 11(a)—Designation of voltage ratings of single-phase windings (schematic representation)

Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(1)(a)	E	34 500		E shall indicate a winding of E volts that 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 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_1GrdY	39 840/69 000GrdY		E/E_1GrdY shall indicate a winding of E volts having 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 GrdY/E	12 470GrdY/7200		E_1 GrdY/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, 240/480		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.

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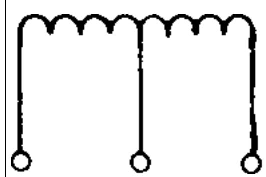
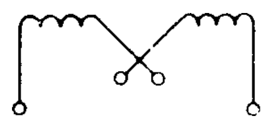
Table 11(a)—Designation of voltage ratings of single-phase windings (schematic representation) (continued)

Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(1)(f)	2E/E	240/120		2E/E shall indicate a winding for 2E volts, two-wire full kilovoltamperes between extreme terminals, or for 2E/E volts three-wire service with 1/2 kVA available only, from midpoint to each extreme terminal.
(1)(g)	V • V_1	240 × 480 2400/4160Y × 4800/8320Y		V • V_1 shall indicate a winding for parallel or series operation only but not suitable for three-wire service.

NOTE

1—E is line-to-neutral voltage of a Y winding, or line-to-line voltage of a Δ winding.

2—E_1 is $\sqrt{3}$ E

3—Additional subscripts, H, X and Y (when used) identify high-voltage, low-voltage, and tertiary-voltage windings.

Table 11(b)—Designation of voltage ratings of three-phase windings (schematic representation)

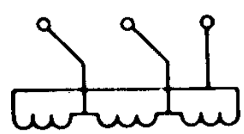
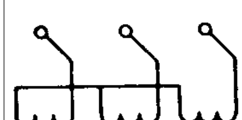
Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(2)(a)	E	2400		E shall indicate a winding that is permanently Δ connected for operation on an E volt system.
(2)(b)	E_1Y	4160Y		E_1Y shall indicate a winding that is permanently Y connected without a neutral brought out (isolated) for operation on an E_1 volt system.

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Table 11(b)—Designation of voltage ratings of three-phase windings (schematic representation) (continued)

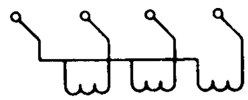
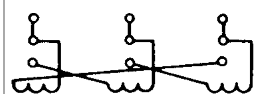
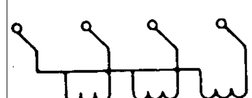
Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(2)(c)	E_1Y/E	4160Y/2400		E_1Y/E shall indicate a winding that is permanently Y connected with a fully insulated neutral brought out for operation on an E_1 volt system, with E volts available from line to neutral.
(2)(d)	E/E_1Y	2400/4160Y		E/E_1Y 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_1Y/E	2400/4160Y/ 2400		E/E_1Y/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_1GrdY/E	60 000GrdY/ 39 840		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	39 840/ 69 000GrdY/ 39 840		E/E_1GrdY/E shall indicate a winding, having reduced insulation, which may be Δ connected for operation on an E volt system or may be connected Y with a neutral brought out and effectively grounded for operation on an E_1 volt system with E volts available from line to neutral.

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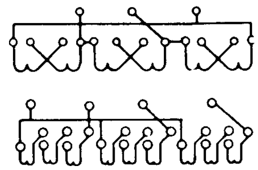
Table 11(b)—Designation of voltage ratings of three-phase windings (schematic representation) (continued)

Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(2)(h)		7200 × 14 400		V • 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–g) of V, or may be connected in series to obtain one of the voltage ratings (as defined in a–g) of V_1. Winding are permanently Δ or Y connected.
	V • V_1	4160Y/2400 × 12 470Y/ 7200		

6. Construction

6.1 Bushings

Transformers shall be equipped with bushings with an insulation level not less than that of the winding terminal to which they are connected, unless otherwise specified.

Bushings for use in transformers shall have impulse and low-frequency insulation levels as listed in Table 12 and IEEE Std C57.19.01-1991.

Transformers using bushings that have dimensions in accordance with IEEE Std C57.19.01-1991 shall have bushing mounting holes that are adequate to accommodate the maximum *P* dimensions for those bushings, as shown in the applicable tables.

6.2 Transformer accessories

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

6.3 Bushing current transformers

Bushing current transformers used with bushings having dimensions in accordance with IEEE Std C57.19.01-1991 shall have an inside diameter that is adequate to accommodate the maximum *D* dimensions for those bushings, as shown in the applicable tables.

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Table 12—Electrical insulation characteristics of transformer bushings (applies only to bushings 34.5 kV and below not listed in IEEE Std C57.19.01-1991

Outdoor bushing									Indoor bushings[a]	
Power transformer[b]						Distribution transformers[b]				
			60 Hz withstand		Impulse full wave dry withstand (kV)	60 Hz withstand		Impulse full wave dry withstand (kV)	60 Hz withstand 1 min dry	Impulse full wave dry withstand (kV)
System voltage	Minimum creepage distance		1 min dry	10 s wet		1 min dry	10 s wet			
(kV)[c]	(mm)	(in)	(kV)	(kV)	(1.2/50 μs)	(kV)	(kV)	(1.2/50 μs)	(kV)	(1.2/50 μs)
1.2	—	—	—	—	—	10	6	30	—	—
2.5	—	—	21	20	60	15	13	45	20	45
5.0	—	—	27	24	75	21	20	60	24	60
8.7	—	—	—	—	—	27	24	75	30	75
8.7	178	7	35	30	95	—	—	—	—	—
15.0	—	—	—	—	—	35	30	95	50[d]	110[d]
18.0	—	—	—	—	—	42	36	125	—	—
25.0	—	—	—	—	—	—	—	—	60	150
34.5	—	—	—	—	—	—	—	—	80	200

[a]Indoor bushings are those intended for use on indoor transformers. Indoor bushing test values do not apply to bushings used primarily for mechanical protection of insulated cable leads. Wet test values are not assigned to indoor bushings.
[b]Power transformers indicate transformers rated above 500 kVA and distribution transformers indicate transformer rated 500 kVA and below.
[c]The nominal system voltage values given above are used merely as reference numbers and do not necessarily imply a relation to specific operating voltages.
[d]Small indoor transformers may be supplied with bushing for a dry withstand test of 38 kV and an impulse test of 95 kV.

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6.4 Thermometer wells

Unless otherwise specified in the standard applying to the particular type of transformer, dimensions for thermometer wells shall be as shown in Figure 3.

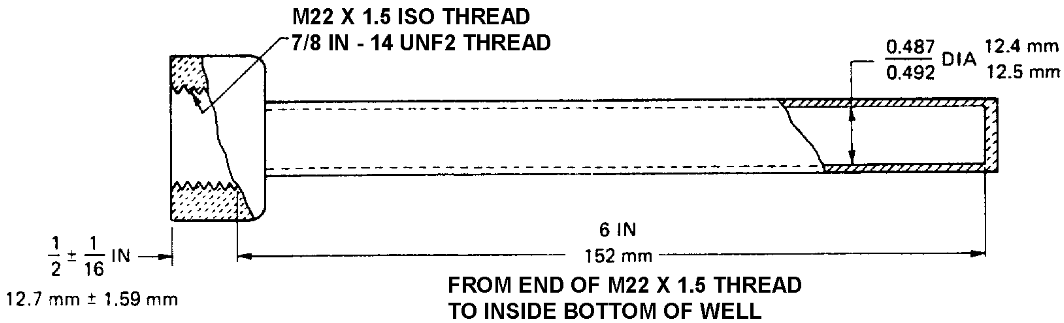

Figure 3—Dimensions of thermometer well

The thermometer well shall be positioned in such a way that it is at least 25.4 mm (1 in) below the liquid level at minimum operating temperature (either –20 °C, or as specified by the user).

6.5 Tank pressure requirements

6.5.1 Maximum under rated conditions

Tank pressure under rated conditions of sealed transformers shall not exceed two atmospheres (203 kPa, 14.74 psig) absolute pressure unless the requirements of applicable sections of the ASME Boiler and Pressure Vessel Code (BPV) are met.

6.5.2 Limits and tests

Specific pressure limits and tests are included in standards applying to particular types of transformers.

6.6 Liquid insulation system

6.6.1 Insulating liquids

Transformers shall be filled with a suitable insulating liquid such as

a) *Mineral oil*. New, unused mineral oil shall meet the requirements of ASTM D3487-1988.

   NOTE—IEEE Std C57.106-1991 [B29] provides information concerning the acceptance and maintenance of mineral oil, including dielectric test breakdown criteria according to oil application, age, and test method.

b) *Less flammable hydrocarbon fluid*. New, unused less flammable hydrocarbon fluid shall meet the requirements of ASTM D5222-92.

   NOTE—IEEE C57.121-1998 provides information concerning the acceptance and maintenance of less-flammable fluid in transformers.

c) *Silicone fluid*. New, unused silicone fluid shall meet the requirements of ASTM D2225-92.

   NOTE—IEEE Std C57.111-1989 [B42] provides information concerning the acceptance and maintenance of silicone insulating fluid in transformers.

There are other insulating fluids that may be suitable and are commercially available. At the time of this revision, they do not have ASTM specifications nor IEEE guides for use in transformers.

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6.6.2 Insulating liquid preservation

Transformers shall be equipped with an insulating liquid preservation system such as

a) Sealed tank
b) Gas-oil seal
c) Conservator
d) Conservator/diaphragm

It should be noted that the various insulating liquid (oil) preservation systems are described and defined in IEEE Std C57.12.80-1978.

6.6.3 Nitrogen inert-gas pressure system

The nitrogen for use with inert-gas-protected transformers shall be in accordance with ASTM D1933-1997, Type III.

The nitrogen shall be supplied in 5.66 m^3 (200 ft^3) cylinders equipped with Connection No. 580 of ANSI/CGA-V-1-1994. The filling pressure shall be 15.2 MPa (2200 $lbf/in.^2$) at 21.1 ˚C (70 ˚F).

6.7 Grounding

6.7.1 Transformer grounding

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

6.7.2 Grounding of core

The transformer core shall be grounded for electrostatic purposes to the transformer tank.

6.8 Minimum external clearances between transformer live parts of different phases of the same voltage

Table 13 describes the minimum external clearances between transformer live parts of different phases. In the establishment of these clearances, it was recognized that bushing ends normally have rounded electrode shapes. It was also assumed that conductor clamps would be suitably shaped so that they would not reduce the withstand strengths, and the arrangement of the incoming conductors would not reduce the effective clearances provided by the transformer bushing. In other words, the clearances were established based upon electrostatic fields that are not unusually divergent.

Where adequate, previous experience has indicated that smaller clearances are acceptable, the smaller clearances may be applied. Factory dielectric test conditions may require larger clearances than those defined here.

The clearances indicated for 345 kV and 500 kV nominal system voltages are based upon a maximum phase-to-phase switching impulse voltage equal to 3.8 per unit times the maximum peak line-to-ground voltage for each nominal system voltage addressed. The 3.8 per unit value is based on the use of closing resistors in the circuit breaker. The switching of EHV shunt capacitor banks could result in higher voltages up to 4.2 per unit of peak line-to-ground voltage and may require greater spacing than those stated in Table 13.

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The application of metal oxide surge arresters connected in close proximity to EHV line bushings can reduce the phase-to-phase switching impulse voltages to a level less than 3.8 per unit, thereby permitting smaller clearances than those given in Table 13. For phase-to-phase voltages other than 3.8 per unit, refer to Note 1 of Table 13.

Minimum external clearances shall meet Table 13 except where suitable grading of local stresses may allow smaller clearances. Any such reduction in clearances should be on the basis of agreement between user and manufacturer.

The nominal clearance values indicated are subject to normal manufacturing tolerances. With the conservatism established in the clearances listed, normal manufacturing tolerances should not significantly increase the likelihood of a flashover.

Table 13—Minimum external clearances between transformer live parts of different phases of the same voltage

Nominal system voltage	Maximum system voltage kV (from ANSI C84.1-1995, ANSI C92.2-1987	Minimum clearance between live parts of different phases				Minimum clearance between top shed of insulator of bushings of different phases			
		Distribution transformers		Power transformers		Distribution transformers		Power transformers	
(kV)	(kV rms)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
1.2	_	25.4	(1)	50.8	(2)	25.4	(1)	25.4	(1)
2.5	_	50.8	(2)	76.2	(3)	25.4	(1)	38.1	(1.5)
5.0	_	63.5	(2.5)	102	(4)	38.1	(1.5)	50.8	(2)
8.7	_	102	(4)	127	(5)	50.8	(2)	63.5	(2.5)
15	_	140	(5.5)	165	(6.5)	76.2	(3)	88.9	(3.5)
25	_	178[a]	(7)	229	(9)	114	(4.5)	152	(6)
34.5	_	330[a]	(13)	330	(13)	203	(8)	203	(8)
46	48.3	432	(17)	432	(17)	305	(12)	305	(12)
69	72.5	635	(25)	635	(25)	483	(19)	483	(19)
115	121.0			1041	(41)			914	(36)
138	145.0			1245	(49)			1118	(44)
161	169.0			1448	(57)			1321	(52)
230	242.0			1778	(70)			1651	(65)

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Table 13—Minimum external clearances between transformer live parts of different phases of the same voltage (continued)

Nominal system voltage	Maximum system voltage kV (from ANSI C84.1-1995, ANSI C92.2-1987	Minimum clearance between live parts of different phases				Minimum clearance between top shed of insulator of bushings of different phases			
		Distribution transformers		Power transformers		Distribution transformers		Power transformers	
(kV)	(kV rms)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
345	362.0			2286[b]	(90)			2159	(85)
500	550.0			4064[b]	(160)			3937	(155)
765	800.0			[c]				[c]	
1100	1200.0			[c]				[c]	

[a]It should be noted that ANSI C57.12.22-1989 [B5] specifies a phase-to-phase clearance of 165 mm (6.25 in) for 25 kV and 229 mm (9 in) for 34.5 kV nominal system voltage. The smaller clearances are acceptable since the bushings are always located within a metal enclosure and are not subject to the same conditions that occur with bushings exposed to the elements.

[b]For phase-to-phase switching impulse voltages other than 3.8 per unit, the following formula may be used to establish the minimum external clearance for peak switching impulse voltages between 1000 kV and 1800 kV only:

$X = .121(Y) - 45$

where

X is the minimum clearance between live parts of different phases (in)
Y is the switching impulse voltage from phase to phase (peak kV) (applicable only from 1000 kV to 1800 kV)

[c]Power transformers, at nominal system voltages of 765 kV and 1100 kV, are usually single phase so that clearances between live parts of different phases is not an issue.

NOTES

1—The external clearances given are for transformers intended for operation at altitudes of 1000 m (3300 ft) or less. For operation at altitudes in excess of 1000 m (3300 ft), the external clearances shall be increased to compensate for the decrease in sparkover voltage at the rate of 1% (0.01) per 100 m (330 ft) increase in altitude in excess of 1000 m (3300 ft).

2—The above clearances are the minimum required to ensure satisfactory operation considering only the effects of the electrical stress between bushings.

CAUTION—If the user considers that there is a risk that these clearances will be effectively reduced by the intrusion of birds or animals, the user should specify increased clearances between bushings. This is most important at the lower system voltages where clearances between bushings are small. Where bushings terminate in a closed junction box for connection to cables, intrusion by birds or animals is not possible, therefore, the above minimum clearances will be accurate.

7. Short-circuit characteristics

7.1 Requirements

7.1.1 General

Liquid-filled transformers shall be designed and constructed to withstand the mechanical and thermal stresses produced by external short circuits under the conditions specified in 7.1.3, 7.1.4, and 7.1.5. 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

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than 35% of the terminal kVA 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 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 IEEE Std C57.12.90-1999.

7.1.2 Transformer categories

Four categories for the rating of transformers are recognized.

Category	Single phase (kVA)	Three phase (kVA)
I[a]	5 to 500	15 to 500
II	501 to 1667	501 to 5000
III	1668 to 10 000	5001 to 30 000
IV	Above 10 000	Above 30 000

[a]Category I shall include distribution transformers manufactured in accordance with ANSI C57.12.20-1997 [B3] up through 500 kVA, single phase or three phase. In addition, autotransformers of 500 equivalent two-winding kVA or less, which are manufactured as distribution transformers in accordance with ANSI C57.12.20-1997 [B3], shall be included in Category I, even though their nameplate kVA may exceed 500.

NOTE—All kVA ratings listed are minimum nameplate kVA for the principal windings.

7.1.3 Short-circuit current duration

7.1.3.1 General

For Category I distribution transformers, the duration of the short circuit shall be determined by the formula

$$t = \frac{1250}{I^2}$$

where

t is duration (s)
I is symmetrical short-circuit current in multiples of normal base current (see 7.1.5.1)

For Category II, III, and IV units, the duration of the short-circuit current as defined in 7.1.4 is limited to 2 s, unless otherwise specified by the user.

When used on circuits having reclosing features, transformers in all categories shall be capable of withstanding the resulting successive short circuits without cooling to normal operating temperatures

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between successive occurrence of the short circuit, provided that the accumulated duration of short circuit does not exceed the maximum duration permitted for single short circuits as defined in 7.1.3.1.

For currents between rated current and maximum short-circuit current, the allowable time duration should be obtained by consulting the manufacturer.

IEEE Std C57.12.90-1999 defines a procedure by which the mechanical capability of a transformer to withstand short-circuit stresses may be demonstrated. The prescribed tests are not designed to verify thermal performance. Conformance to short-circuit thermal requirements shall be by calculation in accordance with 7.4.

7.1.3.2 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 requirement shall be made for a longer duration on Category I, II, and III transformers. The duration of the long test in each case shall be as follows:

Category I:

$$t = \frac{1250}{I^2}$$

where

t is duration (s)

Category II:

t is 1.0 s

Category III:

t is 0.5 s

For special applications where longer fault durations are 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 exceeding the temperature limits for transformers under short-circuit conditions, which are specified in 7.3.5.

7.1.4 Short-circuit current magnitude

7.1.4.1 Category I

The symmetrical short-circuit current shall be calculated using transformer impedance only except that the maximum symmetrical current magnitudes shall not exceed the values listed in Table 14.

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Table 14—Distribution transformer short-circuit withstand capability

Single phase (kVA)	Three phase (kVA)	Withstand capability[a] per unit of base current (symmetrical)
5–25	15–75	40
37.5–110	112.5–300	35
167–500	500	25

[a]This table applies to all distribution transformers with secondaries rated 600 V and below and to distribution autotransformers with secondaries rated above 600 V. Two winding distribution transformers with secondaries rated above 600 V should be designed to withstand short circuits limited only by the transformer's impedance. Autotransformers having nameplate kVA greater than 500 that are built as distribution transformers in accordance with ANSI C57.12.20-1997 [B3] shall have withstand capabilities of 25 per unit of base current (symmetrical).

7.1.4.2 Category II

The symmetrical short-circuit current shall be calculated using transformer impedance only.

7.1.4.3 Categories III and IV

The symmetrical short-circuit current shall be calculated using transformer impedance plus system impedance, as specified by the transformer user. When system impedance is not specified, data from 7.1.5.3 shall be used.

7.1.4.4 Stabilizing windings

Stabilizing windings in three-phase transformers (Δ-connected windings with no external terminals) shall be capable of withstanding the current resulting from any of the system faults specified in 7.1.1, recognizing the system grounding conditions. An appropriate stabilizing winding kVA, voltage, and impedance shall be provided.

7.1.5 Short-circuit current calculations

7.1.5.1 Symmetrical current (two-winding transformers)

It should be noted that for multiwinding transformers and autotransformers, the required rms value of symmetrical current in each winding shall be determined by calculation based on applicable system conditions and fault types.

$$I_{SC} = \frac{I_r}{Z_T + Z_s} = \text{symmetrical short-circuit current, rms A}$$

where

I_R is the rated current on the given tap connection, rms A
Z_T is the transformer impedance on the given tap connection, in per unit on the same apparent power base as I_R

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Z_s is the impedance of the system or permanently connected apparatus, in per unit on the same apparent power base as I_R

$$I = \frac{I_{SC}}{I_R}$$ = symmetrical short-circuit current, in multiples of normal base current

7.1.5.2 Asymmetrical current

The first-cycle asymmetrical peak current that the transformer is required to withstand shall be determined as follows:

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

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

x/r = the ratio of effective ac reactance to resistance, both in ohms, in the total impedance that 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, when not specified.

Values of K are given in Table 15.

Table 15—Values of K

r/*x*	*x*/*r*	*K*
0.001	1000.00	2.824
0.002	500.00	2.820
0.003	333.00	2.815
0.004	250.00	2.811
0.005	200.00	2.806
0.006	167.00	2.802
0.007	143.00	2.798
0.008	125.00	2.793
0.009	111.00	2.789
0.010	100.00	2.785
0.020	50.00	2.743
0.030	33.30	2.702
0.040	25.00	2.662
0.050	20.00	2.624
0.060	16.70	2.588
0.070	14.30	2.552
0.080	12.50	2.518

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Table 15—Values of K (continued)

r/x	*x/r*	*K*
0.090	11.10	2.484
0.100	10.00	2.452
0.200	5.00	2.184
0.300	3.33	1.990
0.400	2.50	1.849
0.500	2.00	1.746
0.600	1.67	1.669
0.700	1.43	1.611
0.800	1.25	1.568
0.900	1.11	1.534
1.000	1.00	1.509

NOTE—The expression of *K* is an approximation. The tabulated 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.

7.1.5.3 System characteristics

For Categories III and IV, the characteristics of the system on each set of terminals of the transformer (system fault capacity and the ratio of X0/X1) should be specified. For terminals connected to rotating machines, the impedance of the connected equipment should be specified. In lieu of specified system fault capacities and rotating machine impedances, values shall be selected for each source from Table 16 and Table 17. In lieu of a specified X0/X1 ratio, a value of 2.0 shall be used.

Table 16—Short-circuit apparent power of the system to be used unless otherwise specified

Maximum system voltage (kV)	System fault capacity	
	(kA rms)	(MVA)
Below 48.3	—	4300
48.3	54	4300
72.5	82	9800
121.0	126	25 100
145.0	160	38 200
169.0	100	27 900
242.0	126	50 200
362.0	84	50 200
550.0	80	69 300
800.0	80	97 000

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Table 17—Subtransient reactance of three-phase synchronous machines[a]

Type of machine	Most common reactance per unit	Subtransient reactance range per unit
Two-pole turbine generator	0.10	0.07–0.20
Four-pole turbine generator	0.14	0.12–0.21
Salient pole generators and motors with dampers	0.20	0.13–0.32
Salient pole generators without dampers	0.30	0.20–0.50
Condensers-air cooled	0.27	0.19–0.30
Condensers-hydrogen cooled	0.32	0.23–0.36

[a]Assumptions of rotating machine impedances should be defined by the transformer manufacturer.

7.1.5.4 Present limitations

Conventional transformer materials and constructions have inherent short-circuit withstand capability limitations. An example is the tensile withstand capability of annealed copper, which places a limit on the permissible hoop tensile stress in the outer winding of a core form transformer. New materials and construction techniques have been, and will continue to be, developed to extend the withstand capability limitations.

However, in certain circumstances it may not be possible to provide the requisite strength in the transformer. In such situations, it would become necessary to limit the fault current by means of additional impedance external to the transformer windings. For example, it may not be possible to design a reduced-capacity auxiliary winding to withstand a fault directly on its terminals. When the current requirements of 7.1.4 cannot be met, limits of fault-current capability of the transformer shall be specified by the manufacturer in the proposal and shall be incorporated on the transformer nameplate.

For distribution transformers, the short-circuit withstand capability limits of Table 14 have been accepted as being representative for conventional materials and constructions.

7.1.5.5 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) Regulating transformers with extremely low impedance that depend on the impedance of directly connected apparatus to limit fault currents.
b) Generator transformers susceptible to excessive overcurrents produced by connection of the generator to the system out of synchronism.
c) Transformer terminals connected to rotating machines (such as motors or synchronous condensers) that can act as generators to feed current into the transformer under system fault conditions.
d) Operating voltage that is higher than rated maintained at the unfaulted terminal(s) during a fault condition.
e) Frequent overcurrents arising from the method of operation or the particular application (for example, furnace transformers, starting taps, applications using grounding switches for relay purposes, and traction feeding transformers).

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f) Station auxiliary transformers or main generator step-up transformers directly connected to a generator that may be subjected to prolonged duration terminal faults as a result of the inability to remove the voltage source quickly.

g) Faults initiated by circuit breakers that may, under certain conditions, cause fault current in excess of those calculated in accordance with this section.

7.2 Components

Transformer components such as leads, bushings, load tap changers (LTC), de-energized tap changers, and current transformers that carry current continuously shall comply with all the requirements of and 7.1.4. However, when not explicitly specified, load tap changers are not required to change taps successfully under short-circuit conditions.

7.3 Base kilovoltamperes

7.3.1 Base kilovoltamperes of a winding

This is the self-cooled rating of a winding as specified by the nameplate, or as determined in accordance with Table 18.

Table 18—Base current calculation factors

Type of transformer	Multiplying factor
Water-cooled (ONWF)	1.0
Natural or forced liquid-cooled with either forced-air cooled or forced-water cooled (ONAF, ODAF or OFWF, ODWF)	0.60

For a transformer without a self-cooled rating, the applicable multiplying factor from Table 18 shall be applied to the maximum nameplate kVA rating to obtain the equivalent base kVA rating.

7.3.2 Base current of windings 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.

7.3.3 Base current of windings with autotransformer connections

For transformers with two or more windings, including one or more autotransformer connections, the base current and base kVA of any winding other than the series and common windings are determined as described in 7.3.2.

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 kV 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 the maximum phasor difference. All conditions of simultaneous loading authorized by the nameplate should be considered to obtain the maximum value. Base currents are calculated based on self-cooled loading conditions or equivalent (use multiplying factors).

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7.3.4 Base current in windings of a regulating transformer

The base current for each winding of a regulating transformer is the maximum current that can occur in that winding for any loading condition authorized by the nameplate. Base currents are calculated based on self-cooled loading conditions or equivalent (use multiplying factors). It should be noted that these base current definitions are applicable only to windings designed for connection to load.

7.3.5 Temperature limits of transformers for short-circuit conditions

The temperature of the conductor material in the windings of transformers under the short-circuit conditions specified in 7.1.1 through 7.1.4, as calculated by methods described in 7.4, shall not exceed 250 ˚C for copper conductor or 200 ˚C for EC aluminum conductor. A maximum temperature of 250 ˚C shall be allowed for aluminum alloys that have resistance to annealing properties at 250 ˚C equivalent to EC aluminum at 200 ˚C, or for applications of EC aluminum where the characteristics of the fully annealed material satisfy the mechanical requirements. In setting these temperature limits, the following factors were considered:

a) Gas generation from oil or solid insulation
b) Conductor annealing
c) Insulation aging

7.4 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.

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

where

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

These equations are approximate formulas, and their use should be restricted to values of $m = 0.6$ or less.

For values of m in excess of 0.6, the following more nearly exact formula should be used:

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

where

T_k is 234.5 for copper, and
is 225 for EC grade aluminum

The appropriate values for other grades may be used

T_s is the starting temperature.
It is equal to:
a) A 30 ˚C ambient temperature plus the average winding rise plus the manufacturer's recommended hottest-spot allowance, or

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b) A 30 ˚C ambient temperature plus the limiting winding hottest-spot temperature rise specified for the appropriate type of transformer.

e is the base of natural logarithm, 2.718

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

$$E_r\left[\frac{T_k + T_r}{T_k + T_s}\right]^2$$

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

T_r is the reference temperature

is 20 ˚C ambient temperature plus rated average winding rise

W_s is the short-circuit resistance loss of the winding at the starting temperature (W/lb of conductor material

$$W_S = \frac{W_r N^2}{M}\left(\frac{T_k + T_s}{T_k + T_r}\right)$$

W_r is the resistance loss of winding at rated current and reference temperature (W)

N is the ratio of symmetric short-circuit current magnitude to normal rated current

M is the weight of winding conductor (lbs)

C is the average thermal capacitance per pound of conductor material and its associated turn insulation, (*W o s*)/˚C. It shall be determined by iteration from either of the following empirical equations:

is $174 + 0.0225\,(T_s + T_f) + 110\,A_i/A_c$ for copper

is $405 + 0.1(T_s + T_f) + 360A_i/A_c$ for aluminum

A_i is the cross-sectional area of turn insulation

A_c is the cross-sectional area of conductor

8. Testing and calculations

8.1 General

Unless otherwise specified, all tests are defined and shall be made in accordance with IEEE Std C57.12.90-1999. Unless otherwise specified, tests shall be made at the factory only.

8.2 Routine, design, and other tests for transformers

These are listed in Table 19. Definitions of these various tests are included in IEEE Std C57.12.80-1978.

8.2.1 Routine tests.

Routine tests shall be made on all transformers in accordance with the requirements of Table 19.

8.2.2 Other tests

When specified (as individual tests), other tests shall be made on transformers as listed in Table 19.

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Table 19—Routine, design, and other tests for liquid-immersed transformers

Tests	500 kVA and smaller			501 kVA and larger		
	Routine	Design	Other	Routine	Design	Other
Resistance measurements of all windings on the rated voltage tap and at the tap extremes of the first unit made on a new design (see NOTE 1)		●		●		
Winding insulation resistance (see NOTE 14 and NOTE 17)			●	●		●
Core insulation resistance (see NOTE 11 and NOTE 17)			●	●		●
Ratio tests on the rated voltage connection and on all tap connections (for LTC units, see 8.3.1)	●			●		
Polarity and phase relation tests on the rated voltage connection	●			●		
Insulation power factor (see NOTE 14 and NOTE 17)			●	●		●
Control (auxiliary) cooling losses (see NOTE 9 and NOTE 17)			●			●
Single phase excitation tests on the rated voltage connection (see NOTE 8 and NOTE 17)			●			●
No-load losses and excitation current at 100 and 110% of rated voltage and at rated power frequency on the rated voltage tap connection(s) (see NOTE 16 and NOTE 17)	●		●	●		●
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 (for LTC units, see 8.3.2 and NOTE 1 and NOTE 2)		●	●	●		
Zero-phase sequence impedance voltage						●
Temperature rise at minimum and maximum ratings of the first unit on a new design—may be omitted if test of a thermally duplicate or essentially duplicate unit is available.		●			●	●
Dielectric tests						
Low frequency	●			●		
Low frequency on auxiliary devices, control, and current transformer circuits (see NOTE 10 and NOTE 14)			●	●		●
Lightning impulse (see NOTE 3)		●	●		●	●
Front of wave impulse						●
Switching impulse, phase-to-ground (see NOTE 12)						●

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Table 19—Routine, design, and other tests for liquid-immersed transformers (continued)

Tests	500 kVA and smaller			501 kVA and larger		
	Routine	Design	Other	Routine	Design	Other
Partial discharge test (see NOTE 14 and NOTE 17)			●	●		●
Audible sound level (see NOTE 4)		●	●		●	●
Short-circuit capability (see NOTE 5)		●				●
Operation test of all devices (see NOTE 13)				●		
Dissolved gasses in oil analysis (see NOTE 14 and NOTE 17)				●		●
Mechanical						
Lifting and moving devices (see NOTE 15)		●			●	
Pressure		●			●	
Leak	●			●		
Telephone influence factor (TIF) (see NOTE 6 and NOTE 7)			●			

NOTES

1—Resistance is a design test for distribution transformers rated 2500 kVA and smaller. Resistance, impedance, and load-loss tests shall be omitted on transformers rated 500 kVA and smaller. These tests shall be omitted when a record of such tests made on a duplicate or essentially duplicate unit in accordance with this standard is available. The tested load loss of duplicate transformers shall be corrected to reference temperature by assuming the same stray and eddy loss as the design test transformer.

2—For duplicate units, these measurements shall be taken only at the rated voltage connection for a two-winding unit, and for three or more rated voltage connections for the case of a three or more winding unit.

3—Lightning impulse tests are routine for Class II power transformers. A special routine impulse test for distribution transformers is required for overhead-type, pad-mounted type, and underground-type liquid-immersed distribution transformers. This test is specified in 10.4 of IEEE Std C57.12.90-1999.

4—The transformer shall be connected for, and energized at, rated voltage, frequency, and at no load, Noise-contributing elements of the transformer, such as pumps and fans, shall be operated as appropriate for the rating being tested. When it is impractical or undesirable to include the appropriate cooling equipment, the self-cooled sound level may be corrected for cooling noise contribution, if suitable corrections are available and it is mutually agreeable to those concerned. Transformers shall meet standard audible sound levels as listed in NEMA Standard TR1, Table 0-1.

5—Testing of large transformers may not be practical because of test facility limitations.

6—A test method for measuring TIF may be found in IEEE Std 469-1988.

7—This test is not practical because of test facility limitations for transformers larger than 50 kVA.

8—This test is a single-phase test and shall be performed on all phases of any winding only when terminals are brought out and accessible for suitable connections. Only line-to-ground, low-frequency voltage suitable for the winding shall be applied during this measurement.

9—Power consumption (auxiliary/cooling) Losses associated with fans, pumps, coolers, heaters, LTC drive motor, lamps, and all other devices operated from the fan control box shall be measured on all Class II transformers.

10—Control and voltage transformer secondary circuits shall be tested at 1500 V AC 60 Hz, and current transformer circuits shall be tested at 2.5 kV AC 60 Hz for a maximum of 1 min duration.

11—The insulation resistance between the core(s) and ground shall be measured after complete assembly of the transformer at a level of at least 500 V DC, for a duration of 1 min. This test shall be routine test for Class II power transformers and other test for Class I transformers.

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12—Switching impulse tests are routine for transformers with high voltage windings operating at 345 kV and above.

13—All electrical and electro-mechanical devices such as fans, pumps, motors, LTC, etc. shall be operated both in auto and manual mode for proper sequence/staging and function.

14—This test shall be a routine test for Class II power transformers and an other test for less than Class II transformers.

15—The mechanical adequacy of the lifting and moving devices may be determined either by test or mathematical analysis.

16—No-load losses and excitation test at 110% of rated voltage is an other test for 500 kVA and smaller transformers, except it is a routine test for Class II transformers.

17—Winding insulation resistance (Megger), core insulation resistance (Megger), insulation power factor, control (auxiliary) cooling losses, single phase excitation, no-load losses, and excitation current test at 110% voltage, partial discharge and dissolved gas in oil analysis tests are not applicable to distribution class transformers.

8.2.3 Dielectric test for low voltage control wiring, associated auxiliary control equipment, and current transformer secondary circuits, on Class II power transformers.

Dielectric withstand test (Hipot) shall be performed for a maximum of 1 min, either on each terminal or all terminals grouped together, on low-voltage control wiring, circuits, including motor, and LTC control wiring when terminated in the control box of a fully assembled transformer for Class II power transformers.

1500 V AC shall be applied to all control wiring circuits, excluding current transformer secondary circuits.

NOTES:

1—All solid state and microprocessor based devices shall be excluded from the test circuit.

2—All 3 phase undervoltage relays and withdrawal type devices shall be removed from the test circuits.

2500 V AC shall be applied to the entire current transformer secondary circuits at the location of each tap(s) termination in the control box.

8.3 Additional routine tests on transformers with load tap changing or regulating transformers

8.3.1 Ratio tests on load tap changing transformers ratio tests shall be made

a) At all connection positions of the tap changer for de-energized operation with the load tap changer on the rated voltage position.

b) At all load tap changer positions with the tap changer for de-energized operation on the rated-voltage position.

8.3.2 Impedance voltage and load-loss tests on load tap changing transformers

Impedance voltage and load-loss tests, as listed in Table 20, shall be made on one unit of a given rating when multiple units are produced by one manufacturer at the same time.

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Table 20—Additional tests

Test number	Voltages for which tap changers are set	
	Tap changer for de-energized operation	Load tap changer
1	Rated voltage tap position	Max voltage tap position
2[a]	Rated voltage tap position	Min voltage tap position
3	Max voltage tap position	Max voltage tap position
4[a]	Max voltage tap position	Min voltage tap position
5	Min voltage tap position	Max voltage tap position
6[a]	Min voltage tap position	Min voltage tap position

[a]For tests 2, 4, and 6, the current held may be such that the current in the winding corresponds to the rated kVA and the rated winding voltage, when the transformer has been so designed with the load tap changer. All other tests shall be made at currents corresponding to the rated kVA and the voltage of the tap position being tested.

8.3.2.1 Impedance testing of regulating transformers

The impedance of regulating transformers shall be tested at the maximum and minimum rated voltage positions and at the neutral position of the load tap changer.

8.3.2.2 Test report

When a test report is specified, the impedance values of 8.3.2 or 8.3.2.1 shall be included in the report.

8.4 Determination of transformer regulation

When specified, transformer regulation shall be determined for the rated voltage, kVA, and frequency by means of calculations based on the tested impedance and load losses in accordance with the procedure given in IEEE C57.12.90-1999. Regulation calculations shall be based on a reference temperature equal to the rated average winding temperature rise, plus 20 °C.

9. Tolerances

9.1 Tolerances for ratio

The turns ratios between windings shall be such that, with the transformer at no load and with rated voltage on the winding with the least number of turns, the voltages of all other windings and all tap connections shall be within 0.5% of the nameplate voltages. However, when the volts per turn of the winding exceeds 0.5% of the nameplate voltage, the turns ratio of the winding on all tap connections shall be to the nearest turn.

For three-phase Y-connected windings, this tolerance applies to the phase-to-neutral voltage. When the phase-to-neutral voltage is not explicitly marked on the nameplate, the rated phase-to-neutral voltage shall be calculated by dividing the phase-to-phase voltage markings by $\sqrt{3}$.

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9.2 Tolerances for impedance

The tolerances for impedance shall be as follows:

a) The impedance of a two-winding transformer with an impedance voltage larger than 2.5% shall have a tolerance of ±7.5% of the specified value and those with an impedance voltage of 2.5% or less shall have a tolerance of ±10% of the specified value.

   Differences of impedance between 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 a transformer 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 when reactances come within the limitations of the foregoing paragraphs, provided that turns ratios and other controlling characteristics are suitable for such operation.

9.3 Tolerances for losses

Unless otherwise specified, the losses represented by a test of a transformer shall be subject to the following tolerances: The no-load losses of a transformer shall not exceed the specified no-load losses by more than 10%, and the total losses of a transformer shall not exceed the specified total losses by more than 6%. Failure to meet the loss tolerances shall not warrant immediate rejection but shall lead to consultation between purchaser and manufacturer about further investigation of possible causes and the consequences of the higher losses.

It is important to note that this clause is only an acceptance criteria and is not intended to replace a manufacturer's guarantee of losses for economic loss evaluation purposes.

9.4 Accuracies required for measuring losses

Measured values of electric power, voltages, currents, resistances, 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 IEEE C57.12.90-1999, Clauses 5, 8, and 9, are required.
b) The test equipment utilized for measuring losses of power and distribution transformers shall meet the requirements of IEEE C57.12.90-1999, Clauses 5, 8, and 9.
c) The test system accuracy for each quantity measured shall fall within the limits specified in Table 21.
d) The frequency of the test source shall be within ±0.5% of the rated frequency of the transformer under test.

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Table 21—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

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. Unless otherwise specified, 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 operation only shall be shipped connected in series.

Unless otherwise specified, three-phase transformers designed for both Δ and Y operation shall be shipped connected for the Y voltage.

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Annex A

(informative)

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