



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

IEEE Power Engineering Society

Sponsored by the
Transformers Committee

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

Sponsor

Transformers Committee

of the

IEEE Power Engineering Society

Approved 15 September 2006

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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Introduction

This introduction is not part of IEEE Std C57.12.00-2006, IEEE Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

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

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.

When applicable, editorial changes have been incorporated into this revision. Sentence structure and punctuation has been edited to improve clarity and conciseness. Also, editorial changes have been made to conform to the *IEEE Standards Style Manual*. Some changes have also been made to correct errors in previous revisions.

When applicable, references to other standards have been updated.

Changes of major importance to the revision of this standard are listed in sequential order and reference by their clause number or table number:

In Clause 2, the designation and title for IEEE Std C57.131TM-1995 has been corrected. IEEE Std C62.1TM-1989 (Reaff 1994) and IEEE Std C62.2TM-1987 (Reaff 1994) have been removed. Also, ANSI C92.2-1987 has been added.^a

In 4.3.3, item g) has been revised to read: “Unusual duty or frequency of operation, or high current short duration loading.”

In 5.1, the word “power” has been replaced with “kVA” in the paragraph preceding the examples.

In 5.10.3.1, IEEE Std C62.11TM-1999 [B46] has been added as surge arrester information.^b

In Table 2, row 5 has been revised from ONAN/ODAF to ONAN/OFAF, and previous designation is revised to OA/FOA without reference to footnote a).

In 5.4.2, the entire second paragraph has been removed after a lengthy debate by the PCS working group. The position of the working group is that this information belongs in product-specific standards and not in standard for general requirements.

In 5.5.3, words referring to the capacity of taps for windings with load tap-changing equipment have been revised.

In Table 5, 250 kV BIL (corresponding to 69 kV nominal system voltage) has been added.

In 5.11.1, the determination of maximum (hottest spot) temperature rise by calculation or testing was added. Prior editions of this standard required the hottest spot temperature rise not to exceed 80 °C. However, there was no approved test or calculation method for this required performance parameter. Many transformer users rely on this parameter for loading calculations. Therefore, an IEEE task force was

^a Additional information on references can be found in Clause 2.

^b Numbers in brackets refer to sources in the bibliography found in Annex A.

formed to propose a revision of 5.11.1.1. Fiber optic temperature sensors now permit direct measurement of specific points. Prior winding analysis permits sensor placement for reading maximum winding temperature. Also, modern computer technology permits heat transfer programs to calculate the temperature distribution within transformer windings. At the time this revision was approved, an IEEE working group had developed IEEE Std 1538™ [B15], IEEE Guide for Determination of Maximum Winding Temperature Rise in Liquid Filled Transformer. This guide provides additional guidance for compliance with 5.11.1.1.

Subclause 5.12 of this standard recognizes the use of metric and/or empirical units for data appearing on transformer nameplates. In this revision of IEEE Std C57.12.00, all units of dimension, volume, weight, and pressure are listed in metric and empirical (U.S. customary) units. Subclause 5.12.1 has been modified to accommodate either system of units for nameplate information. Numerous equations throughout this standard have also been revised to reflect the use of metric and empirical units.

In 5.12.1, the requirement for an LTC nameplate per IEEE Std C57.131 has been added.

In Table 10, dual system of units for weight or mass has been incorporated. Additional text preceding the table was added to clarify the intent of allowing either SI system of units (metric) or the U.S. customary units (in, lbs) on the nameplate, but does not require both. Additional editorial changes have been made to the entire table for greater clarity. The requirement for “location (country)” has been added to “name of manufacturer”.

Also in Table 10, changes have been made to the table notes. The changes are as follows:

- Note 1, the minimum height requirement for engraved letters and numerals (denoting kVA, serial number, and voltage ratings) has been changed to 4.00 mm (0.157 in).
- Note 9, the following statement has been added: “Any non-linear devices, capacitors, or resistors installed on the winding assembly or on any tap changer shall be indicated on the nameplate.”
- Note 11 (b) has been amended to include the statement: “The manufacturer shall identify any portion of the transformer that cannot withstand the stated vacuum level (i.e., conservator, LTC boards, radiators, etc.)”

Table 11(a) and Table 11(b) have been renumbered to Table 11 and Table 12 respectively.

Table number 15 has been assigned to the existing table on category of transformer rating (previously without a table number). Subsequent table numbers have been updated in sequential order. All references to table numbers in the text of the document have also been updated.

In 6.6, a reference to “Askarel” has been removed and replaced with references to “less flammable hydrocarbon fluid” and “silicone fluid”.

Table 20, (Base current calculation factors), previously Table 18, has been modified with new cooling class designations.

Throughout the document, equation numbers have been assigned to be consistent with latest *IEEE Standards Style Manual*.

In 7.4, Equation (7) through Equation (11) have been updated to correct previous errors.

In 8.2, the previous title, “Routine and other tests for transformers” has been revised to “Routine, design, and other tests for transformers.”

Subclause 8.5 (Determination of thermal duplicate temperature-rise data) has been added to replace a note in Table 21 and to clarify specifically when the design test may be omitted.

Subclause 8.6 has been added to address the requirements of the certified test report. The text came verbatim from Clause 15 of existing IEEE Std C57.12.90™-1999. Clause 15 will be removed from the next revision of IEEE Std C57.12.90 that coincides with this revision.

An area not considered or covered in this revision is a clause requiring an “Instruction manual” including criteria for minimum information content. This will be developed by a working group in a future revision.

Revisions of individual sections (now modified) were prepared by separate groups within the Transformers Committee. Those sections were balloted independently according to applicable rules and procedures of the IEEE for the preparation and approval of voluntary consensus standards. This process 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). Applicable rules and procedures; specifically procedures for voting, review, and attempted reconciliation of dissenting viewpoints; a 60-day public review period; and final review and approval by the ANSI Board of Standards Review, were followed.

Suggestions for improvement resulting from use of this standard will be welcomed.

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IEEE Standard for 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 introduction of this voluntary consensus standard describes the circumstances under which the standard *may* be used on a mandatory basis.

2. Normative references

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

ANSI C92.2, American National Standard for power systems—Alternating-current electrical systems and equipment operating at voltages above 230 kV nominal—Preferred voltage ratings.¹

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

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

ASME Boiler and Pressure Vessel Code (BPV).²

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

ASTM D92, Standard Test Methods for Flash and Fire Points by Cleveland Open Cup.³

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

ASTM D2225, Standard Test Methods for Silicone Fluids Used for Electrical Insulation.

ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.

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

IEEE Std 315TM, IEEE Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters).^{4, 5}

IEEE Std 315ATM, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (Supplement to IEEE Std 315-1975).

IEEE Std 469TM, IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers.

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

IEEE Std C57.12.90TM, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

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IEEE Std C57.19.01TM, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

IEEE Std C57.131TM, IEEE Standard Requirements for Load Tap Changers.

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

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

3. Definitions

Standard transformer terminology available in IEEE Std C57.12.80⁶ shall apply. Other electrical terms are defined in *The Authoritative Dictionary of IEEE Standards Terms* and Definitions, Seventh Edition [B14].⁷

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).

⁶ Information on references can be found in Clause 2.

⁷ The numbers in brackets correspond to those of the bibliography in Annex A.

4.1.4 Supply voltage

The supply-voltage wave shape shall be approximately sinusoidal. 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.

4.1.6 Operation above rated voltage or below rated frequency

4.1.6.1 Capability

Transformers shall be capable of the following:

- 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 5.11.1.1 when all of the following conditions prevail:
 - 1) Secondary voltage and volts per Hertz do not exceed 105% of rated values.
 - 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.

For multiwinding transformers or autotransformers, 4.1.6.1 applies only to 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. 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 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 [B28] 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.

IEEE Std C57.91-1995 [B28] is not standard. It provides the best known general information for loading of transformers under various conditions based on typical winding insulation systems. It is based upon the best engineering information available at the time of preparation. The guide discusses limitations of ancillary components other than windings that may limit the capability of transformers. When specified, ancillary components and other construction features (cables, bushings, tap changers, oil expansion space, etc.) shall be supplied in a manner that 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 4.3.3.

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 [B28] provides information on recommended practices.

4.3.2 Insulation at high altitude

The dielectric strength of transformers that depend in whole or partly upon air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, transformers shall be designed with larger air spacing 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/(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/(10000)	0.80
3600/(12000)	0.75
4200/(14000)	0.70
4500/(15000)	0.67

NOTE—An altitude of 4500 m (15000 ft) is considered a maximum for transformers conforming to this standard.⁸

4.3.2.2 Bushings

Bushings with additional length or arcing 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, or high current short duration loading.
- h) Unbalanced ac voltages, or departure of ac system voltages from a substantially sinusoidal wave form.

⁸ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

- 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 (transient overvoltages, resonance, switching surges, etc.,) 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 strong magnetic fields may cause unanticipated circulating currents in transformer tanks and covers, and in bus ducts. 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 [B11].

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

- O mineral oil or synthetic insulating liquid with fire point⁹ ≤ 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 non-directed 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)]

⁹ Fire point—The lowest temperature at which a specimen will sustain burning for 5 s. (ASTM D92-1998, “Cleveland Open Cup” test method.)

NOTE 1—In a transformer with forced, non-directed 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.

NOTE 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 non-directed coolant circulation.

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

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/OFAF	OA/FOA
ONAN/ODAF/ODAF	OA/FOA ^a /FOA ^a
OFAF	FOA
OFWF	FOW
ODAF	FOA ^a
ODWF	FOW ^a

^aIndicates directed oil flow per Table 9, Note 2 above.

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 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. Common arrangements used 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.

5.3.2.3 Three-legged core

Another arrangement uses a three-legged core with main and teaser coil assemblies located on the two outer legs, and a center leg that has no coil assembly. This 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. 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 (used here, mean 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 limits 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
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

5.5 Voltage ratings and taps

5.5.1 General

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

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

Application	Nominal system voltage, rms (kV)	Maximum system voltage, rms (from ANSI C84.1) (kV)	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	—	—	

NOTE 1—BIL values in bold typeface are listed as standard in one or more of ANSI C57.12.10 [B1], ANSI C57.12.20 [B3], ANSI C57.12.22 [B6], IEEE Std C57.12.23 [B16], ANSI C57.12.24 [B6], ANSI C57.12.25 [B7], and IEEE Std C57.12.26 [B17].

NOTE 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.

NOTE 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.

NOTE 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.

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 for de-energized operation, they shall be full-capacity taps. Transformers with load tap-changing equipment may have reduced capacity taps, unless specified otherwise, for taps below rated winding voltage. When specified, other capacity taps may be provided. In all cases, the capacity shall be stated on the nameplate.

5.6 Connections

Standard connection arrangements are included in the standards for particular types of transformers and in IEEE Std C57.12.70 [B18].

5.7 Polarity, angular displacement, and terminal marking

5.7.1 Polarity of single-phase transformers

Single-phase transformers 200 kVA and below with 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 30°, 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 H_1 and the line-to-neutral voltage of the corresponding identified low-voltage terminal X_1 .

NOTE—Additional phasor diagrams are described in IEEE Std C57.12.70 [B18].

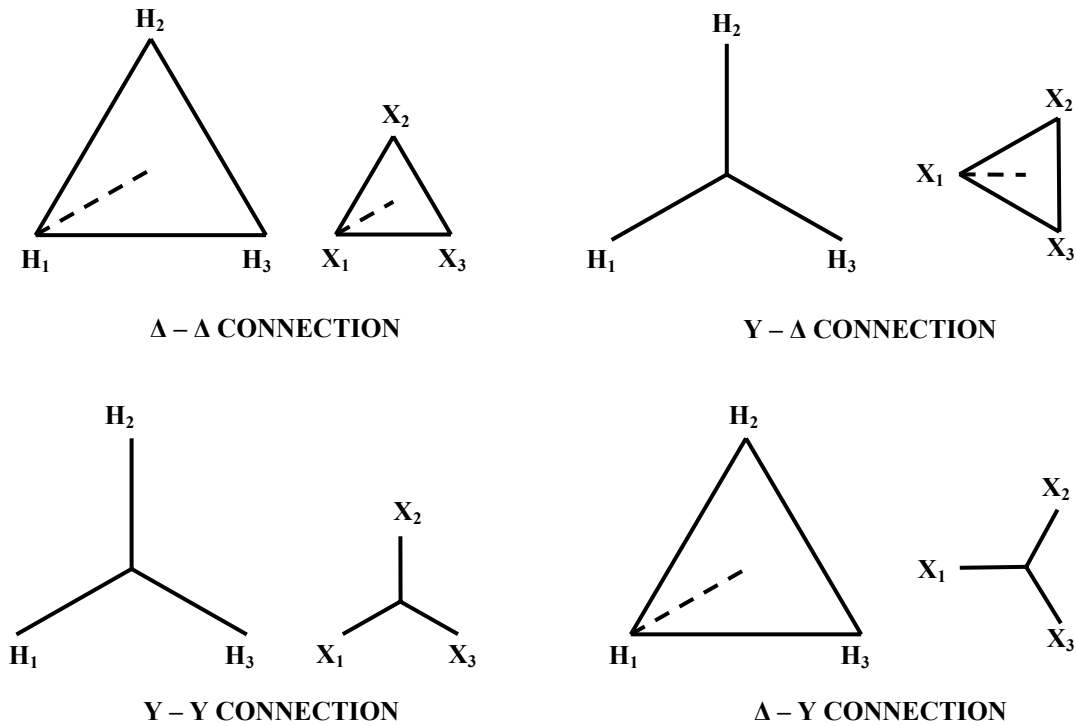


Figure 1—Phase relation of terminal designation for three-phase transformers

5.7.3 Terminal markings

Terminal markings shall be in accordance with IEEE Std C57.12.70 [B18].

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.

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. Therefore, 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, any BIL choice requires careful attention to proper insulation coordination and to accurate assessment of the coefficient of grounding as outlined in 5.10.3.

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

Application	Basic lightning impulse insulation level (BIL) (kV crest)	Chopped-wave impulse levels		Front-of-wave impulse levels		Low-frequency test level (kV rms)
		Minimum voltage (kV crest)	Minimum time to flashover (μs)	Minimum voltage (kV crest)	Specific time to sparkover (μs)	
	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
Power	350	400	3.0	—	—	140
	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

Table 5—Dielectric insulation levels for distribution transformers and Class I power transformers (continued)

Application	Basic lightning impulse insulation level (BIL) (kV crest)	Chopped-wave impulse levels		Front-of-wave impulse levels		Low-frequency test level (kV rms)
		Minimum voltage (kV crest)	Minimum time to flashover (μs)	Minimum voltage (kV crest)	Specific time to sparkover (μs)	
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
	200	220	3.0	345	0.5	70
	250	275	3.0	435	0.5	95
	350	385	3.0	580	0.58	140

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

NOTE 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.

NOTE 3—Internal and external phase-to-phase low-frequency insulation test levels shall not be reduced below the levels listed in Table Minimum phase-to-phase insulation test levels for three-phase distribution transformers.

NOTE 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.

NOTE 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.

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)		Applied-voltage test level (kV rms)
				One hour level (kV rms)	Enhancement 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

Table 6—Dielectric insulation levels for Class II power transformers^a (continued)

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)		Applied-voltage test level (kV rms)
				One hour level (kV rms)	Enhancement level (kV rms)	
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
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	1300	1430	1080	475	550	—
	1425	1570	1180	475	550	—
	1550	1705	1290	475	550	—
	1675	1845	1390	475	550	—
765	1925	2120	1600	690	800	—
	2050	2255	1700	690	800	—

^aSee 5.10 for a description of Class II power transformers.

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

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

NOTE 3—Column 5 and Column 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 and Column 6 must be multiplied by 1.732 to obtain the required phase-to-phase induced-voltage test level.

NOTE 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.

NOTE 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.

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, rms (kV)	Minimum low-frequency phase-to-phase test voltage level, rms (kV)
	Column 1	Column 2
Distribution	25.0	50
	34.5	69
	46.0	92
	69.0	138
Power	46.0	76
	69.0	115

NOTE 1—For nominal system voltages not in the table, use a test level no less than 2.0 times the nominal system voltage for distribution transformers and no less than 1.65 times the nominal system voltage for Class I power transformers.

NOTE 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 for Class I power transformers.

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

^aFor 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.

5.10.1 Line terminals

5.10.1.1 Basic lightning impulse insulation level (BIL)

A basic lightning impulse insulation level (BIL) from Table 4 shall be assigned to each line terminal of a winding. 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 from switching impulse tests on high-voltage windings 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 shall be specified when desired; 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 an accessible neutral external to the tank

A transformer winding designed for wye connection only and with an accessible neutral 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 line terminals.

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 [B13] 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.

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, unless specified otherwise.

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 [B44], IEEE Std C62.2 [B45], IEEE Std C62.11 [B46], and IEEE Std C62.22 [B47]. 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 C62.22 [B47], except 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 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, low-frequency test levels and low-frequency test coefficients in Table 9 are not applicable unless the winding is specified as suitable for application on

ungrounded systems. However, when the neutral is solidly grounded to the tank, the neutral end of the winding cannot shift with respect to the tank. Therefore no significant increase in line-terminal-to-ground (tank) voltage during single or double line-to-ground faults should occur provided that proper system grounding practices are employed.

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

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

NOTE 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 where Table 9 does not apply and neutral grounding devices significantly affect the coefficient of grounding of the transformer, alternate tests shall be specified to provide the necessary verification.

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

5.10.4.1 General

Low-frequency test requirements for distribution and Class I power transformers shall use applied-voltage and induced-voltage tests.

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

5.10.4.3 Exceptions

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, 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.

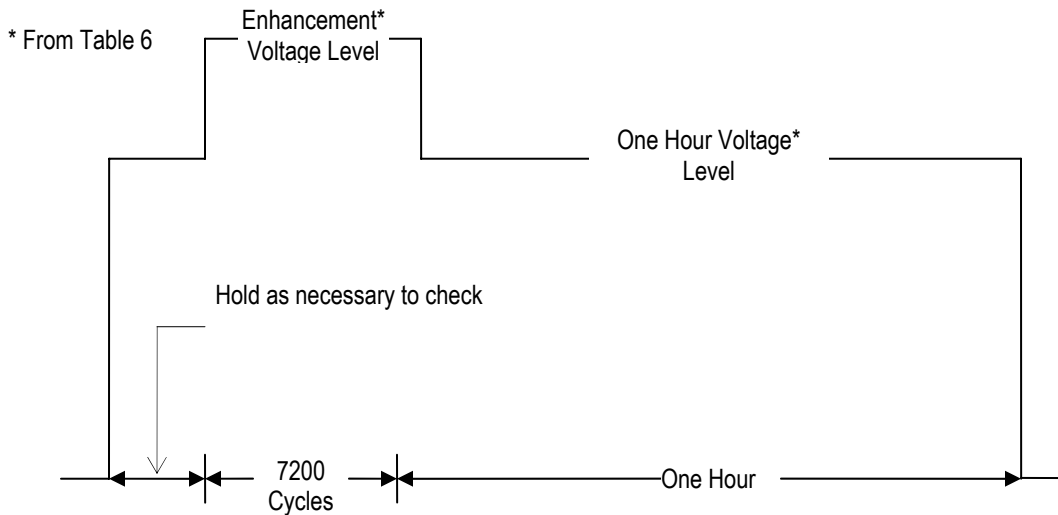


Figure 2—Induced voltage test for Class II transformer

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 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 able to withstand voltages resulting from the required switching impulse tests to the high-voltage terminals, even though such voltages on the other windings may exceed their designated BSL listed in Table 6, when applicable.

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

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 IEEE Std C57.12.90 using the 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.

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. 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 item 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 multiwinding transformers.
- e) Rated kVA output at rated V/Hz.

NOTE—As used here, the term rated secondary voltage or rated current means the value assigned by the manufacturer and shown on the nameplate.

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. This standard recognizes the use of metric (SI) and empirical (U.S. customary) units for data appearing on transformer nameplates. It should be noted that although this standard recognizes the possibility of using SI units as an alternative to the U.S. customary units used in the past, it is not intended that both appear on the specific nameplate. However, units used *shall* be explicitly shown.

In accordance with the requirement of IEEE Std C57.131, LTC transformers shall also contain a tap changer nameplate, permanently attached to the LTC compartment.

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

Row	Nameplate A	Nameplate B	Nameplate C
1	Serial number (1) ¹⁰	Serial number (1)	Serial number (1)
2	Month/year of manufacture	Month/year of manufacture	Month/year of manufacture
3	Class (ONAN, ONAF, etc.)(2)	Class (ONAN, ONAF, etc.)(2)	Class (ONAN, ONAF, etc.)(2)
4	Number of phases	Number of phases	Number of phases
5	Frequency	Frequency	Frequency
6	kVA rating (1)(2)	kVA rating (1)(2)	kVA (or MVA) rating (1)(2)
7	Voltage ratings (1)(3)	Voltage ratings(1)(3)	Voltage ratings (1)(3)
8	Tap voltages (4)	Tap voltages (4)	Tap voltages (4)
9	Temperature rise, °C	Temperature rise, °C	Temperature rise, °C
10	Polarity (single-phase transformers)	Polarity (single-phase transformers)	Polarity (single-phase transformers)
11	Phasor diagram (polyphase transformers)	Phasor diagram (polyphase transformers)	Phasor diagram (polyphase transformers)
13	Percent impedance (5)	Percent impedance (5)	Percent impedance (5)

¹⁰Numbers in parentheses refer to the notes at the end of the table.

Table 10—Nameplate information (continued)

Row	Nameplate A	Nameplate B	Nameplate C
14	—	Basic lightning impulse insulation levels (BIL) (6)	Basic lightning impulse insulation levels (BIL) (6)
15	Approximate total mass in kg or weight in lbs (7)	Approximate total mass in kg or weight in lbs (8)	Approximate total mass in kg or weight in lbs (8)
16	Connection diagram (9)	Connection diagram (9)	Connection diagram (9)
17	Name and location (country) of manufacturer	Name and location (country) of manufacture	Name and location (country) of manufacture
18	Installation and operating instructions reference	Installation and operating instructions reference	Installation and operating instructions reference
19	The word transformer or autotransformer	The word transformer or autotransformer	The word transformer or autotransformer
20	Type of insulating liquid (generic name preferred) (12)	Type of insulating liquid (generic name preferred) (12)	Type of insulating liquid (generic name preferred) (12)
21	Conductor material (of each winding)	Conductor material (of each winding)	Conductor material (of each winding)
22	—	—	Step-up operation suitability (10)
23	—	—	Tank, pressure, and liquid data (11)

NOTE 1—The letters and numerals showing kVA, serial number, and voltage ratings shall have a minimum height of 4.00 mm (0.157 in) whether engraved or stamped. The height of other letters and numerals shall be optional with the manufacturer.

NOTE 2—When 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. When 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.

NOTE 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 and Table 12.

When the transformer is suitable for Y connection, the nameplate shall be so marked. The nameplate on two-winding single-phase transformer insulated for Y connection on both windings, shall show the Y voltage on the high-voltage side only for transformers that have a high-voltage ratings above 600 V.

NOTE 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.

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 transformation¹¹ with tap changers for de-energized operation.

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 positions shall be designated by Arabic numerals in ascending order corresponding to increasing output voltage, followed by the suffix “R,” such as 1R, 2R, etc. The lower positions shall be designated by Arabic 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 specified by the user. This applies to two-winding transformers only.

¹¹ The ratio of transformation is defined as the high-voltage volts divided by the low-voltage volts.

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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.

NOTE 5—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. When the transformer has more than one kVA rating, the kVA base shall be given.

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

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

NOTE 7—Weight may be omitted from the nameplate for transformers rated below 37.5 kVA single-phase or below 30 kVA polyphase. In this case, supplemental data shall be available showing the required volume of insulating liquid and the approximate weight of the transformer.

NOTE 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)

NOTE 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 voltage transformers, potential devices, current transformers, winding temperature devices, etc., when used, shall be shown.

Any nonlinear devices, capacitors, or resistors installed on the winding assembly or on any tap changer shall be indicated on the nameplate.

Polarity and location of current transformers shall be identified 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 not permanently connected shall be identified with numbers or letters in a manner that permits convenient reference will prevent confusion with terminal and polarity markings.

The scallop symbol shall be used in accordance with IEEE Std 315 and IEEE Std 315A for the development of windings.

NOTE 10—The nameplate shall state when the transformer is suitable for step-up operation.

NOTE 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/in²) positive and _____ kPa (lbf/in²) negative.
- b) Tank designed for ___ kPa (lbf/in²) vacuum filling. The manufacturer shall identify any portion of the transformer that can not withstand the stated vacuum level (i.e., conservator, LTC boards, radiators, etc.).
- 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 liters (gallons), and type of insulating liquid shall be shown for the main tank and for each liquid-filled compartment.
It is suggested that liters be used for volumes less than 1000 liters, and cubic meters for volumes 1000 liters and larger.

NOTE 12—The nameplate shall state: “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 and Table 12.

**Table 11—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 <i>shall</i> indicate a winding of E volts that is suitable for Δ connection on an E volt system.
(1)(b)	E/E ₁ Y	2400/4160Y		E/E ₁ Y <i>shall</i> indicate a winding of E volts that is suitable for Δ connection on an E volt system, or for Y connection on an E ₁ volt system.
(1)(c)	E/E ₁ GrdY	39 840/69 000GrdY		E/E ₁ GrdY <i>shall</i> 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 <i>shall</i> indicate a winding of E volts with reduced insulation at the neutral end. The neutral end <i>may</i> 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.

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

Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(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.
(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)	$V \bullet V_1$	240 × 480 2400/4160Y × 4800/8320Y		$V \bullet V_1$ 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.

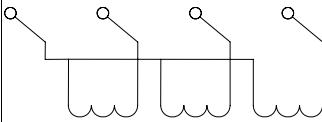
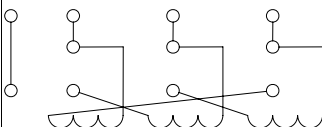
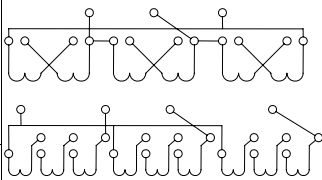
NOTE 2—E1 is $\sqrt{3}$ E.

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

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

Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(2)(a)	E	2400		<i>E shall</i> 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.
(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.

**Table 12—Designation of voltage ratings of three-phase windings
(schematic representation) (continued)**

Identification	Nomenclature	Nameplate marking	Typical winding diagram	Condensed usage guide
(2)(f)	$E_1\text{GrdY}/E$	60 000GrdY/ 39 840		$E_1\text{GrdY}/E$ 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)	$E/E_1\text{GrdY}/E$	39 840/ 69 000GrdY/ 39 840		$E/E_1\text{GrdY}/E$ shall indicate a winding having reduced insulation, which may be Δ connected for operation on an E volt system; or may be connected Y with a neutral brought out and effectively grounded for operation on an E_1 volt system with E volts available from line to neutral.
(2)(h)	$V \bullet V_1$	7200 \times 14 400 4160Y/2400 \times 12 470Y/7200		$V \bullet V_1$ 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.

6. Construction

6.1 Bushings

Transformers shall be equipped with bushings with an insulation level no 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 13 and IEEE Std C57.19.01.

Transformers using bushings that have dimensions in accordance with IEEE Std C57.19.01 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 shall have an inside diameter to accommodate the maximum D dimensions for those bushings, as shown in the applicable tables.

**Table 13—Electrical insulation characteristics of transformer bushings
(applies only to bushings 34.5 kV and below not listed in IEEE Std C57.19.01)**

Outdoor bushing								Indoor bushings ^a	
Power transformer ^b				Distribution transformers ^b					
System voltage	Minimum creepage distance	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)
		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

^aIndoor 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.

^bPower transformers indicate transformers rated above 500 kVA and distribution transformers indicate transformer rated 500 kVA and below.

^cNominal system voltage values given above are used merely as reference numbers and do not necessarily imply a relation to specific operating voltages.

^dSmall indoor transformers *may* be supplied with bushing for a dry withstand test of 38 kV and an impulse test of 95 kV.

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.

The thermometer well shall be positioned in such a way that it is at least 25.4 mm below the liquid level at minimum operating temperature (either $-20\text{ }^{\circ}\text{C}$, or as specified by the user).

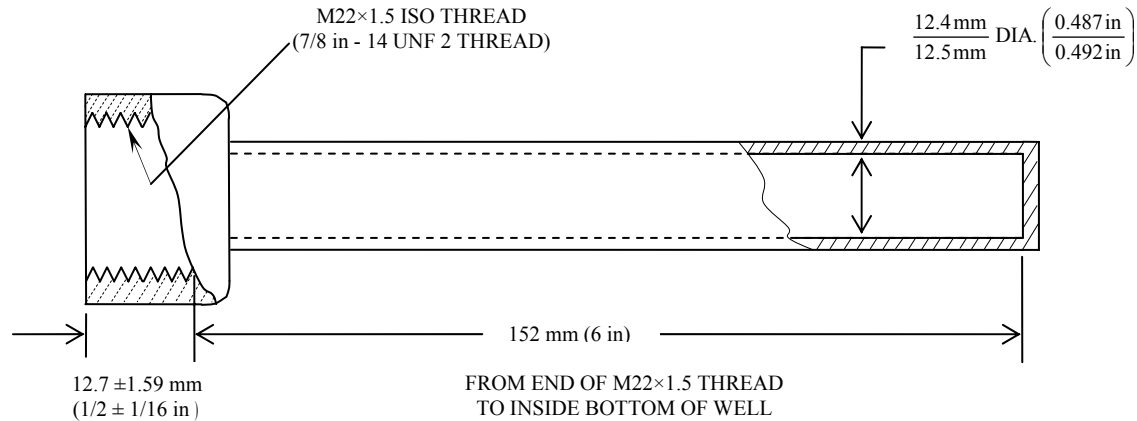


Figure 3—Dimension of thermometer well

6.5 Tank pressure requirements

6.5.1 Maximum under rated conditions

Tank pressure under rated conditions for sealed transformers shall not exceed two atmospheres (203 kPa) absolute pressure¹² unless 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.

¹² Two atmosphere absolute pressure = 203 kPa or 14.7 psig

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.
NOTE—IEEE Std C57.106 [B35] 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 Std C57.121 [B43] 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 [B38] 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, neither ASTM specifications nor IEEE guides for use in transformers exist.

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

NOTE—Various insulating liquid (oil) preservation systems are described and defined in IEEE Std C57.12.80.

6.6.3 Nitrogen inert-gas pressure system

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

Nitrogen shall be supplied in 5.66 m³ (200 ft³) cylinders equipped with Connection No. 580 of ANSI/CGA-V-1. The filling pressure shall be 15.2 MPa (2200 lbf/in²) 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 to the transformer tank for electrostatic purposes.

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

Table 14 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 is 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 unusually not 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 14.

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 14. For phase-to-phase voltages other than 3.8 per unit, refer to footnote b) of Table 14.

Minimum external clearances shall comply with Table 14 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. Normal manufacturing tolerances should not significantly increase the likelihood of a flashover because the clearances listed in Table 14 are conservative.

Table 14—Minimum external clearances between transformer live parts of different phases of the same voltage

Nominal system voltage, rms	Maximum system voltage, rms (from ANSI C84.1, ANSI C92.2)	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)	mm (in)	mm (in)	mm (in)	mm (in)
1.2	—	25 (1)	51 (2)	25 (1)	25 (1)
2.5	—	51 (2)	76 (3)	25 (1)	38 (1.5)
5.0	—	64 (2.5)	102 (4)	38 (1.5)	51 (2)
8.7	—	102 (4)	127 (5)	51 (2)	64 (2.5)
15	—	140 (5.5)	165 (6.5)	76 (3)	89 (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)

Table 14—Minimum external clearances between transformer live parts of different phases of the same voltage (continued)

Nominal system voltage, rms	Maximum system voltage, rms (from ANSI C84.1, ANSI C92.2)	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)	mm (in)	mm (in)	mm (in)	mm (in)
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)
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 —

^aIt should be noted that ANSI C57.12.22 [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.

^bFor 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:

$$X = 3.0734(Y) - 1143; \quad \text{or} \quad (X = 0.121(Y) - 45)$$

where

X is the minimum clearance between live parts of different phases in mm (in)

Y is the switching impulse voltage from phase to phase (peak kV) (applicable only from 1000 kV to 1800 kV)

^cPower transformers, at nominal system voltages of 765 kV and 1100 kV, are usually single phase so that clearances between live parts of different phases are not an issue.

NOTE 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, 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).

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

CAUTION

If there is 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 lower system voltages where clearances between bushings are small. In the case where bushings terminate in a closed junction box for connection to cables, intrusion by birds and animals is not possible; therefore the above minimum clearances will be adequate.

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 rated greater 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.

Short-circuit withstand capability can be adversely affected by the cumulative effects of repeated mechanical and thermal overstressing produced by short circuits and loads above the nameplate rating. It is not feasible 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.

7.1.2 Transformer categories

Four categories for the rating of transformers are recognized.

Table 15—Category of transformer ratings

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

^aCategory I shall include distribution transformers manufactured in accordance with ANSI C57.12.20 [B3] up through 500 kVA, single phase or three phase. In addition, autotransformers with equivalent two-winding kVA of 500 or less, which are manufactured as distribution transformers in accordance with ANSI C57.12.20 [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 Equation (1).

$$t = \frac{1250}{I^2} \quad (1)$$

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 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 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 shown in Equation (2).

Category I:

$$t = \frac{1250}{I^2} \quad (2)$$

where

- t is duration (s)

Category II:

- t is 1.0 s

Category III:

- t is 0.5 s

For special applications when 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 temperature limits (specified in 7.3.5) for transformers under short-circuit conditions.

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 16.

Table 16—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

^aThis 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 [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. 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.

$$I_{SC} = \frac{I_R}{Z_T + Z_S} \quad (3)$$

$$I = \frac{I_{SC}}{I_R} \quad (4)$$

where

- I is the symmetrical short circuit current in multiple of normal base
- I_{SC} symmetrical short circuit current, (A, rms)
- I_R is the rated current on the given tap connection, (A, rms)
- Z_T is the transformer impedance on the given tap connection, in per unit on the same apparent power base as I_R
- Z_S is the impedance of the system or permanently connected apparatus, in per unit on the same apparent power base as I_R

7.1.5.2 Asymmetrical current

The first-cycle asymmetrical peak current that the transformer is required to withstand *shall* be determined as shown in Equation (5) and Equation (6).

$$I_{SC(pk\ asym)} = K I_{SC} \quad (5)$$

$$K = \left\{ 1 + \left[\varepsilon^{-\left(\phi + \frac{\pi}{2}\right)\frac{r}{x}} \right] \sin \phi \right\} \sqrt{2} \quad (6)$$

where

- ϕ is arc tan (x/r), (radians)
- e is the base of natural logarithm
- x/r is 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 17—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
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 17 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 X_0/X_1) 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 18 and Table 19. In lieu of a specified X_0/X_1 ratio, a value of 2.0 shall be used.

Table 18—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

Table 19—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

^aAssumptions 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 with 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 identified on the transformer nameplate.

For distribution transformers, the short-circuit withstand capability limits of Table 16 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 and 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).

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.

- f) 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 7.1.3 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 20.

For a transformer without a self-cooled rating, the applicable multiplying factor from Table 20 *shall* be applied to the maximum nameplate kVA rating to obtain the equivalent base kVA rating.

Table 20—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 and OFWF, ODWF)	0.60

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).

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 7.1.4, *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.

$$T_f = (T_k + T_s) m (1 + E + 0.6m) + T_s \quad (7)$$

where

$$m = \frac{W_s t}{C(T_k + T_s)} \quad (8)$$

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:

$$T_f = (T_k + T_s) \left[\sqrt{\epsilon^{2m} + E(\epsilon^{2m} - 1)} - 1 \right] + T_s \quad (9)$$

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

ϵ 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

$$E = E_r \left[\frac{T_k + T_r}{T_k + T_s} \right]^2 \quad (10)$$

where

E_r is the per-unit eddy-current loss at the 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/kg) of conductor material

$$W_s = \frac{W_r N^2}{M} \left(\frac{T_k + T_s}{T_k + T_r} \right) \quad (11)$$

where

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 mass of winding conductor (kg)

C is the average thermal capacitance per kg of conductor material and its associated turn insulation, (W 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 in mm²

A_c is the cross-sectional area of conductor in mm²

CAUTION

When applying the above formulas for calculation, care must be taken ensure consistent application of units for mass, weights, and cross sectional areas. This will involve the variables W_s , M , C , A_i , and A_c . Mixing of units between SI system and the U.S. customary units (in, lbs) will yield incorrect results.

8. Testing and calculations

8.1 General

Unless otherwise specified, all tests *shall* be made in accordance with IEEE Std C57.12.90. Unless otherwise specified, tests *shall* be made at the factory or other approved testing facilities.

8.2 Routine, design, and other tests for transformers

Routine, design, and other tests *shall* be made in accordance with the requirements of Table 21.

8.2.1 Routine tests

Routine tests *shall* be made on every transformer to verify that the product meets the design specifications.

8.2.2 Design tests

Design tests *shall* be made to determine the adequacy of the design of a particular type, style, or model of transformer or its component parts. Design adequacy includes but is not limited to: meeting assigned ratings, operating satisfactorily under normal service condition or under special condition if specified, and compliance with appropriate standards of the industry. Design tests are made on representative transformers to substantiate the ratings assigned to all other transformers of basically the same design. Design tests are not intended to be used as a part of normal production. The applicable portion of these design tests *may* also be used to evaluate modifications of a previous design and to assure that performance has not been adversely affected. Test data from previous similar designs *may* be used for current designs, where appropriate. Once made, the tests need not be repeated unless the design is changed to modify performance.

8.2.3 Other tests

Other tests are identified in individual product standards and *may* be specified by the purchaser in addition to routine tests. (Examples: impulse, insulation power factor, audible sound, temperature rise, short circuit).

Table 21 — 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)			•			•

Table 21 — 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
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 (See NOTE 1 and NOTE 2. For LTC units, see 8.3.2)		•	•	•		
Zero-phase sequence impedance voltage						•
Temperature rise At minimum and maximum ratings of the first unit of a new design		•			•	
At minimum and maximum ratings when temperature-rise tests are specified			•			•
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)						•
Partial discharge test (see NOTE 14 and NOTE 17)			•	•		•
Audible sound level (see NOTE 4)		•	•		•	•
Short-circuit capability (see NOTE 5)		•				•

**Table 21 — 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
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)			•			

NOTE 1—Resistance is a design test for distribution transformers rated 2500 kVA and smaller. Resistance, impedance, and load-loss tests *may* be omitted on transformers rated 500 kVA and smaller, 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.

NOTE 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.

NOTE 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.

NOTE 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 [B48], Table 0-1.

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

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

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

NOTE 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.

NOTE 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.

NOTE 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.

NOTE 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 other transformers.

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

NOTE 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.

NOTE 14—This test shall be a routine test for Class II power transformers and an “other test” for other transformers.

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

NOTE 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.

NOTE 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.

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

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

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.

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

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

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

8.3.1 Ratio tests on load tap changing transformers 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 22, shall be made on one unit of a given rating when multiple units are produced by one manufacturer at the same time.

Table 22—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 Impedance voltage and load-loss tests on load tap changing transformers or Impedance testing of regulating transformers 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 IEEE Std C57.12.90. Regulation calculations shall be based on a reference temperature equal to the rated average winding temperature rise, plus 20 °C.

8.5 Determination of thermal duplicate temperature-rise data

When specifications state that a thermal test may be omitted if there are thermal test data available for a thermal duplicate transformer, then calculated data based upon the thermal test data may be submitted as thermal duplicate test data. A thermal duplicate is a transformer whose thermal design characteristics are identical to a design previously tested, or whose differences in thermal characteristics are within agreed upon variations, such that the thermal performance of the thermal duplicate transformer shall comply with performance guarantees established by standards or specifications.

8.6 Certified test data

The minimum information listed in this subclause shall be included in certified test data.

- a) Order data
 - 1) Purchaser.
 - 2) Purchaser's order number.
 - 3) Manufacturer's production order number and serial number.
- b) Rating data
 - 1) Type (power, auto, grounding, etc.).
 - 2) Type of construction (core form or shell form) *.
 - 3) Cooling Class.
 - 4) Number of phases.
 - 5) Connections (delta, wye, zigzag, etc.).
 - 6) Polarity for single phase transformers.
 - 7) Frequency *.
 - 8) Insulation medium (oil, silicone, etc.) *.
 - 9) Temperature rise *.
 - 10) Winding ratings: voltage, voltampere, BIL, all temperature rise ratings specified, including future ratings *.
 - 11) Harmonic factor if other than standard *.
- c) Test and calculated data (by individual serial number; if the results are from another transformer "design" tested, provide serial number, kV and kVA ratings, and date of the test.)
 - 1) Date of test.
 - 2) Winding resistances (when required).
 - 3) Losses: no-load, load, auxiliary and total.
 - 4) Impedance(s) in %.
 - 5) Excitation current in %.
 - 6) Thermal performance data **.
 - i) Ambient temperature.
 - ii) Tap position, total loss, and line currents for total loss runs.
 - iii) Oil flow in winding (directed or nondirected).

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- iv) Final bottom and top oil temperature rise over ambient for total loss run for each test.
 - v) Average winding temperature rise over ambient for each winding for each test.
 - vi) Calculated winding hottest spot temperature rise over ambient for maximum rating.
- 7) Zero-sequence impedance (when specified) *.
 - 8) Regulation (calculated when specified).
 - 9) Applied voltage test values for each winding *.
 - 10) Induced voltage test value, including measured PD values when required *.
 - 11) Impulse test data per IEEE Std C57.98 [B31] (when required or specified) *.
 - 12) Switching impulse test data (when specified) *.
 - 13) Sound level test results (when specified) *.
 - 14) Short-circuit test results (when specified) *.
 - 15) Ratio test results *.
 - 16) Phase relation or polarity test results *.
 - 17) Other special test results (when specified) *.
- d) Certification statement and approval

NOTE 1— Items identified with * are not required for distribution transformers unless specified by the user.

NOTE 2— Number of significant figures of reported data should reflect the level of the data accuracy.

NOTE 3— All temperature sensitive data should be reported after correcting to reference temperature (defined in 14.1 of IEEE Std C57.12.90) except no-load losses (see 8.4 of IEEE Std C57.12.90).

NOTE 4— Other significant information, such as tap position during induced potential test, test connection used, and any particular method used when alternatives are allowed in the test code, should be included.

NOTE 5— Other drawings, such as nameplate and outline, may be made a part of certified test data in place of duplicating the same information.

NOTE 6— Items identified with ** are not required for distribution transformers 2500 kVA and smaller, unless specified by the user.

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 $\sqrt{3}$.

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 greater than 2.5% shall have a tolerance of $\pm 7.5\%$ of the specified value and those with an impedance voltage of 2.5% or less shall have a tolerance of $\pm 10\%$ 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 $\pm 10\%$ 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 $\pm 10\%$ 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 regarding the further investigation of possible causes and the consequences of the higher losses.

It is important to note that this clause is only an acceptance criterion 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 Std C57.12.90, 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 Std C57.12.90, Clauses 5, 8, and 9.
- c) The test system accuracy for each quantity measured shall fall within the limits specified in Table 23.

Table 23—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

- d) Frequency of the test source shall be within ±0.5% of the rated frequency of the transformer under test.

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.

Annex A

(informative)

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¹³ Although this document has been withdrawn by IEEE in March 2000, it nevertheless provides relevant information that the user may find helpful. This document is still available for purchase as archive document from Global Engineering, Phone: 1-800-854-7179, Fax: 303-397-2740. Outside the U.S. call 303-792-2181.

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