



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

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.12.00™-2021
(Revision of IEEE Std C57.12.00-2015)



STANDARDS

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

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Approved 9 November 2021

IEEE SA Standards Board

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Abstract: Electrical and mechanical requirements for 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, are set forth. This standard is a basis for the establishment of performance, and limited electrical and mechanical interchangeability requirements of equipment are described; it is also a basis 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, IEEE C57.12.00™, mechanical requirements, power transformers, regulating transformers

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Participants

At the time this IEEE standard was completed, the Continuous Revision of C57.12.00 Working Group had the following membership:

Steven Snyder, *Chair*

Tauhid Ansari
Stephen Antosz
Eric Davis

Ramsis Girgis
William Griesacker
Philip Hopkinson
Stephen Shull

Ajith Varghese
Rogerio Verdolin
David Walker

The following members of the individual Standards Association balloting group voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Samuel Aguirre
Gregory Anderson
Tauhid Haque Ansari
Stephen Antosz
I. Antweiler
Javier Arteaga
Donald Ayers
Robert Ballard
Peter Balma
Radoslav Barac
Gilles Bargone
Thomas Barnes
Paul Barnhart
Christopher Baumgartner
Barry Beaster
Jeffrey Benach
W. J. (Bill) Bergman
Steven Bezner
Wallace Binder
Thomas Bishop
Thomas Blackburn
Daniel Blaydon
William Bloethe
W. Boettger
Jeffrey Britton
Darren Brown
Steven Brown
Koti Reddy Butukuri
Thomas Callsen
Paul Cardinal
Richard Carter
Michael Chirico
Craig Colopy
John Crouse
Thomas Dautat
Scott Digby
Gary Donner
Jeffrey Door
Thomas Dunmore II
Donald Dunn
Jorge Fernandez Daher

Joseph Foldi
Bruce Forsyth
Carl Fredericks
Fredric Friend
Jose Gamboa
Shubhankar Garg
Saurabh Ghosh
David Gilmer
Ramsis Girgis
Jalal Gohari
James Graham
William Griesacker
Said Hachichi
John Harley
J. Harlow
Roger Hayes
Kyle Heiden
Jeffrey Helzer
Sergio Hernandez
Werner Hoelzl
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Gary Hoffman
Philip Hopkinson
John Houdek
Mohammad Iman
Ramadan Issack
Richard Jackson
John John
Laszlo Kadar
John Kay
Gael Kennedy
Sheldon Kennedy
Irfan Khan
Gary King
James Kinney
Zan Kiparizoski
William Knapke
Boris Kogan
Axel Kraemer
Jim Kulchisky
John Lackey

Chung-Yiu Lam
Benjamin Lanz
An Le
Moonhee Lee
Giancarlo Leone
Aleksandr Levin
Ting Li
Weijun Li
Mario Locarno
Thomas Lundquist
Tapan Manna
Richard Marek
J. Dennis Marlow
Timothy Marrinan
Lee Matthews
James McBride
Jeffrey McElray
Mark McNally
Susan McNelly
Vinay Mehrotra
Reza Mirza Hessabi
Daniel Mulkey
Jerry Murphy
Ali Naderian Jahromi
K. R. M. Nair
Dennis Neitzel
Arthur Neubauer
James Niemira
Joe Nims
Sivaraman P.
Lorraine Padden
Dwight Parkinson
Dhiru Patel
Brian Penny
Harry Pepe
Mark Perkins
Branimir Petosic
Christopher Petrola
Sylvain Plante
Alvaro Portillo
Bertrand Poulin

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Scott Reed	Steve Snyder	David Wallace
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Eric Schleismann	Joshua Verdell	Shibao Zhang
Stephen Schroeder	Rogério Verdolin	Peter Zhao
Devki Sharma	John Vergis	Kris Zibert
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Introduction

This introduction is not part of IEEE Std C57.12.00-2021, IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

Where applicable, editorial changes have been incorporated into this revision. Sentence structure and punctuation have been edited to improve clarity and conciseness. Also, editorial changes have been made to conform to the *2021 IEEE SA Standards Style Manual*.¹ Some changes have also been made to correct errors in previous revisions. When applicable, references to other standards have been updated.

A summary of the major changes is listed in sequential order, as follows:

- a) IEEE Std 1427™ added to Clause 2, Normative references.
- b) Clause 5.7.2, Angular displacement between voltages of windings for three-phase transformers, has been restructured for clarity.
- c) Note f to Table 6, Nameplate information, was revised to more clearly state which basic lightning impulse insulation levels (BIL) are to be shown on the nameplate.
- d) Figure 4 was revised to remove the metric M22 thread alternative because it is not interchangeable with the imperial thread 7/8 in-14, the prevalent usage in North America.
- e) Subclause 6.7.2.1, Grounding of wound cores, was added to emphasize proper core grounding for certain types of transformers utilizing wound cores. A corresponding note was added in Table 17 to specify a special partial discharge test to confirm the adequacy of the core grounding.
- f) Subclause 6.8, Minimum external clearances of transformer live parts, has been completely rewritten and a new Table 10 introduced.
- g) The equations and list of variables in 7.4 have been rearranged to improve clarity.
- h) Equation (14) and Equation (15), for calculating the temperature of windings during a short circuit in 7.4, have been revised due to an earlier metrification conversion error.
- i) An additional test requirement for measuring load loss at the minimum and maximum kVA has been added in Table 17.
- j) The note which describes audible sound level requirements in Table 17 has been moved to a new 8.2.5 for better clarity. Similarly, Annex C has been completely rewritten to incorporate no-load sound pressure levels from NEMA TR1, and to add reference sound pressure levels for load noise.
- k) Annex C, Audible sound pressure levels, has been changed to normative material.
- l) Annex D, Bibliography, has been updated.

Revisions of individual clauses (now modified) were prepared by separate groups within the Transformers Committee. Those clauses were balloted independently in the Working Groups, according to applicable rules and procedures of the Transformers Committee P&P Manual.

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

¹ Available at <https://development.standards.ieee.org/myproject/Public/mytools/draft/styleman.pdf>.

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

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1. Overview

1.1 Scope

This standard describes electrical and mechanical 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 Purpose

This standard is a basis for the establishment of performance⁷ and limited electrical and mechanical interchangeability requirements of the equipment are described. It is also a basis for assistance in the proper selection of such equipment.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{2, 3}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

² The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

³ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

~~In this document, the word *shall* is used to indicate a mandatory requirement. The word *should* is used to indicate a recommendation. The word *may* is used to indicate a permissible action.~~ The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

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

ANSI C84.1, American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hz). ^{4 2}

ASME Boiler and Pressure Vessel Code (BPVC). ^{5 3}

ASTM D92, Standard Test Methods for Flash and Fire Points by Cleveland Open Cup Tester. ^{6 4}

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 Specification for High Fire-Point Mineral Electrical Insulating Oils.

^{4 2} ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

^{5 3} ASME publications are available from the American Society of Mechanical Engineers (<http://www.asme.org/>).

^{6 4} ASTM publications are available from the American Society for Testing and Materials (<http://www.astm.org/>).

ASTM D6871, Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus.

CGA V-1, Compressed Gas Cylinder Valve Outlet and Inlet Connections. ^{2 5}

IEEE Std 315TM, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters). ^{8,9 6,7}

IEEE Std 315ATM, American National Standard/IEEE Standard Supplement to 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 1427TM, IEEE Guide for Recommended Electrical Clearances and Insulation Levels in Air Insulated Electrical Power Substations.

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

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

^{2 5} CGA publications are available at: <https://portal.cganet.com/Publication/index.aspx> ~~from Global Engineering Documents (http://global.ihs.com/).~~

^{8 6} IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

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[IEEE Std C57.19.04™, IEEE Standard for Performance Characteristics and Dimensions for High Current Power Transformer Bushings with Rated Continuous Current in Excess of 5000 A in Bus Enclosures.](#)

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

3. Definitions

Standard transformer terminology available in IEEE Std C57.12.80 shall apply.⁸ The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause. [10](#)⁹

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.

¹⁰[IEEE Standards Dictionary Online](http://dictionary.ieee.org) is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

⁸~~Information on references can be found in Clause 2.~~

⁹~~The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://dictionary.ieee.org/>.~~

4.1.2.2 Liquid temperature limit

The top liquid temperature of the transformer (when operating) shall not be lower than $-20\text{ }^{\circ}\text{C}$. Liquid temperatures below $-20\text{ }^{\circ}\text{C}$ 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 $30\text{ }^{\circ}\text{C}$, and the average temperature of the cooling water for any 24 h period shall not exceed $25\text{ }^{\circ}\text{C}$. Minimum water temperature shall not be lower than $1\text{ }^{\circ}\text{C}$, unless the cooling water includes antifreeze, which is suitable for $-20\text{ }^{\circ}\text{C}$ operation.

4.1.3 Altitude

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

4.1.4 Supply voltage

The supply-voltage wave shape shall be approximately sinusoidal. 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. Refer to IEEE Std C57.110™ [B20 B21] ¹¹ for information on establishing transformer capability when supplying nonsinusoidal load currents. ¹⁰

4.1.6 Operation above rated voltage or below rated frequency

4.1.6.1 Capability

Transformers shall be capable of the following:

^{11,10} The numbers in brackets correspond to those of the bibliography in Annex D.

a) Operating continuously above rated voltage or below rated frequency, at maximum rated kVA for any tap, without exceeding the limits of observable temperature rise in accordance with 5.11.1 when all of the following conditions prevail:

- 1) Secondary voltage and volts per hertz do not exceed 105% of rated values
- 2) Load power factor is 80% or higher
- 3) Frequency is at least 95% of rated value

NOTE—For generator step-up transformers, the maximum value of the primary voltage would be limited by the magnitude of the highest voltage the generator can supply at full load. For all other step-up transformers, the maximum value of the primary voltage would be limited by the highest system voltage at the primary of the transformer. In either case, these levels should be provided by the user and must be indicated on the nameplate of the transformer. If not provided by user, for generator step-up transformers assume 105% of rated voltage, and for all other step-up transformers, use the maximum system voltage as listed in Table 3 Column 1 for distribution and Class I power transformers, and Table 4 Column 1 for Class II power transformers, for the applicable nominal system voltage. ¹²††

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 multi-winding 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.

¹²†† Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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 transformers

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™ [B11 B12] provides guidance for loading at other-than-rated conditions including the following:

- 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 [B11 B12] is an IEEE guide, and as such, it does not specify mandatory requirements. It provides the best-known general information for loading of transformers under various conditions based on typical winding insulation systems. It is based ~~on~~ ~~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 (such as cables, bushings, tap-changers, insulating liquid expansion space, etc.) shall be supplied in a manner that will not limit the loading to less than the specified 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 ambient 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 [B11 B12] provides information on recommended practices.

4.3.2 Insulation at high altitude

The dielectric strength of transformers that depend in whole or partly ~~upon~~ on air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, transformers shall be designed with larger air spacing 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.

4.3.2.2 Bushings

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

Table 1 — Dielectric strength correction factor

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 (10 000)	0.80
3600 (12 000)	0.75
4200 (14 000)	0.70
4500 (15 000)	0.67
NOTE—An altitude of 4500 m (15 000 ft) is considered a maximum for transformers conforming to this standard.	

(New)

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/(10 000)	0.80
3600/(12 000)	0.75
4200/(14 000)	0.70
4500/(15 000)	0.67
NOTE—An altitude of 4500 m (15 000 ft) is considered a maximum for transformers conforming to this standard.	

(Deleted)

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.
- 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. See IEEE Std C57.110TM–[B20 B21] for more information.
- j) Specified loading conditions (kVA outputs, winding load power factors, and winding voltages) associated with multi-winding 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 geomagnetically induced current (GIC) 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, described as follows. These designations are consistent with IEC 60076-2:2011 [B4].

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

O₂: Insulating liquid with fire point ≤ 300 °C (see ASTM D92) ^{13 12}

K₂: Insulating liquid with fire point > 300 °C

L₂: Insulating liquid with no measurable fire point

^{13 12} *Fire point:* The lowest temperature at which a specimen will sustain burning for 5 s (ASTM D92, *Cleveland Open Cup* test method).

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 (also called *directed flow*)

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))

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 insulating liquid 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 that 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 C57.12.00-2006 and in previous revisions, with the corresponding new designations, are provided in Annex A.

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 in 5.3.2.2, 5.3.2.3, and 5.3.2.4.

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 kVA ratings

Preferred continuous kVA ratings of single-phase and three-phase distribution and power transformers are based on an average winding rise of 65 °C, in accordance with 5.11.1.1 and are listed in Table 2.

Table 2 — Preferred continuous kilovoltampere ratings

Single-phase transformers (kVA)	Three-phase transformers (kVA)
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

(New)

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

(Deleted)

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 3 and Table 4 ~~in this document~~.

5.5.2 Voltage ratings

The voltage ratings shall be at no load and shall be based on the [turn's](#) ~~turn~~ ratio.

5.5.3 Ratings of transformer taps

Whenever a transformer [winding](#) 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 [ampacity at each tap](#) ~~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.

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. [Transformer polarity is defined and illustrated in IEEE Std C57.12.90.](#)

5.7.2 Angular displacement (nominal) between voltages of windings for three-phase transformers

The angular displacement of a polyphase transformer is the time angle expressed in degrees between the line-to-neutral voltage of the reference identified high-voltage terminal H1 and the line-to-neutral voltage of the corresponding identified low-voltage terminal X1.

Unless specified otherwise and identified on the nameplate, 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.

Additional phasor diagrams are described in IEEE Std C57.12.70.

5.7.3 Terminal markings

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

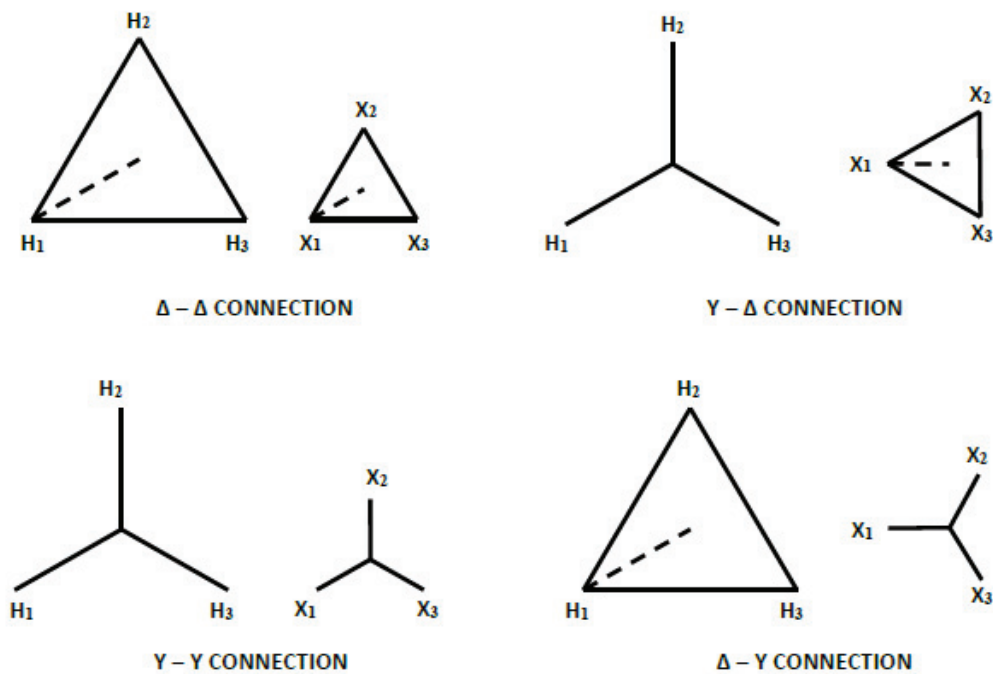


Figure 1 —Phase relation of terminal designation for three-phase transformers

5.8 Impedance

The impedance shall be referred to the reference temperature defined as 20 °C plus the rated average winding rise. 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, insulating liquid 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 defined as 20 °C plus the rated average winding rise. The standard reference temperature for the no-load losses of power and distribution transformers shall be 20 °C.

For Class II transformers (see 5.10), 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 *maximum system voltage* and basic lightning impulse insulation level (BIL). BIL will be selected dependent on the degree of exposure of the transformer and characteristics of the overvoltage protection system.

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 are any that are not categorized as Class II, described in item b).

- b) Class II power transformers shall include power transformers with high-voltage windings rated for 115 kV nominal system voltage and above, and also power transformers with high-voltage windings rated 69 kV through 115 kV nominal system voltage, having a top nameplate rating of at least 15 000 kVA for three-phase transformers or 10 000 kVA for single-phase transformers.

The following tables show various system voltages, insulation, and test levels for various classes of liquid-immersed power transformers:

- Table 3 lists dielectric insulation and low-frequency test levels for distribution and Class I power transformers.
- Table 4 lists dielectric insulation and low-frequency test levels for Class II power transformers.
- Table 5 lists high-frequency test levels.

5.10.1 Front-of-wave insulation level

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

Annex B includes the last published IEEE C57.12.00 front-of-wave test levels for historical reference. See Annex B.

Table 3 — Dielectric insulation levels for distribution and Class I power transformers, voltages in kV

Maximum system voltage (kV rms)	Nominal system voltage ^{a, g} (kV rms)	Applied-voltage test ^f (kV rms)			Induced-voltage test ^{b, f} (phase to ground) (kV rms)	Winding line-end BIL ^{c, f} (kV crest)			Neutral BIL ^{d, e, h} (kV crest)	
		Delta or fully insulated wye	Grounded wye	Impedance grounded wye or grounded wye with higher BIL		Minimum	Alternates		Grounded wye	Impedance grounded wye or grounded wye with higher BIL
Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
Distribution transformers										
1.5	1.2 ^e	10	—	10	1.4	30			30	30
3.5	2.5 ^e	15	—	15	2.9	45			45	45
6.9	5 ^e	19	—	19	5.8	60			60	60
11	8.7 ^e	26	—	26	10	75			75	75
17	15	34	—	34	17	95	110		75	75
26	25	40	—	40	29	125	150		75	95
36	34.5	50	—	50	40	125	150	200	75	125
48	46	95	—	70	53	200	250		95	150
73	69	140	—	95	80	250	350		95	200
Class I power transformers										
1.5	1.2	10	10	10	1.4	30	45		45	45
3.5	2.5	15	15	15	2.9	45	60		60	60
6.9	5	19	19	19	5.8	60	75		75	75
11	8.7	26	26	26	10	75	95		95	95
17	15	34	26	34	17	95	110		95	110
26	25	50	26	40	29	150			95	125
36	34.5	70	26	50	40	200			95	150
48	46	95	34	70	53	200	250		110	200
73	69	140	34	95	80	250	350		110	250

^a For nominal system voltage greater than maximum system voltage, use the next higher voltage class for applied-voltage test levels.

^b Induced-voltage tests shall be conducted at $2.0 \times$ nominal system voltage for 7200 cycles.

^c Bold typeface BILs are the most commonly used standard levels.

^d Y-Y-connected transformers using a common solidly grounded neutral may use neutral BIL selected in accordance with the low-voltage winding rating.

^e 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 connected and operated, are therefore higher than needed for their voltage rating.

^f 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.

^g 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, [and](#) 11 950 V.

^h Neutral BIL shall never exceed winding BIL.

Table 4 — Dielectric insulation levels for all windings of Class II power transformers, voltages in kV

Maximum system voltage (kV rms)	Nominal system voltage ^a (kV rms)	Applied-voltage test ^g (kV rms)			Induced-voltage test ^{b,c} (phase to ground) (kV rms)		Winding line-end BIL ^d (kV crest)				Neutral BIL ^{e,g} (kV crest)	
		Delta and fully insulated wye	Grounded wye	Impedance grounded wye or grounded wye with higher BIL	Enhanced 7200 cycle	One hour	Minimum	Alternates			Grounded wye	Impedance grounded wye or grounded wye with higher BIL
Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 13
≤ 17	≤ 15	34	34	34	16	14	110				110	110
26	25	50	34	40	26	23	150				110	125
36	34.5	70	34	50	36	32	200				110	150
48	46	95	34	70	48	42	200	250			110	200
73	69	140	34	95	72	63	250	350			110	250
121	115	173	34	95	120	105	350	450	550		110	250
145	138	207	34	95	145	125	450	550	650		110	250
169	161	242	34	140	170	145	550	650	750	825	110	350
242	230	345	34	140	240	210	650	750	825	900	110	350
362	345	518	34	140	360	315	900	1050	1175		110	350
550	500	N/A	34	140	550 ^f	475 ^f	1425	1550	1675		110	350
765	735	N/A	34	140	880 ^f	750 ^f	1950 ^f	2050			110	350
800	765	N/A	34	140	885 ^f	795 ^f	1950 ^f	2050			110	350

^a For nominal system voltage greater than maximum system voltage, use the next higher voltage class for applied-voltage test levels.