

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

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

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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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3 Park Avenue, New York, NY 10016-5997, USA

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Introduction

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

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 In 5.11, which covers temperature rise and loading conditions, heading 5.11.1.1, Winding rise, has been replaced by Winding temperature rises.

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

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

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

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

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

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

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

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

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

This standard is a voluntary consensus standard. Its use may become mandatory only when required by a duly constituted legal authority or when specified in a contractual relationship. To meet specialized needs and to allow for innovation, specific changes are permissible when mutually determined by the user and the producer, provided that such 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 word *shall* indicates mandatory requirements, and the words *should* or *may* refer to matters that are recommended or permissive, but not mandatory.

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

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

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K. J. Fleming

At the time that Clause 5 of this standard was approved by the IEEE Transformers Committee, the working group had the following membership:

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R. Barker
D. Chu
F. E. Elliott
J. A. Fleeman

M. L. Frazier
P. E. Krause
W. J. McNutt
H. Moore

G. J. Reitter
S. M. A. Rizvi
V. Shenoy
S. C. Tuli
R. A. Veitch

At the time that Table 10 of this standard was approved by the IEEE Transformers Committee, the working group had the following membership:

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J. Antweiler
R. Barker
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C. A. Colopy
J. Corkran
A. Delgado
D. Dohnal
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At the time that 5.11.1.1 of this standard was approved by the IEEE Transformers Committee, the working group to investigate winding temperature rise had the following membership:

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D. J. Allen	K. R. Highton	A. Rizvi
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R. H. Frazer	D. C. Papyne	L. B. Wagenaar
M. Frydman	D. D. Perco	F. Willett
	M. Perkins	

Revision to Table 19 was prepared by

S. C. Tuli

K. J. Fleming

At the time that the expansion of 9.3 and the elimination of the former Table 19 was approved by the IEEE Transformers Committee, the working group on loss tolerance and measurement had the following membership:

Ramsis S. Girgis, *Chair*

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D. E. Ballard
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J. D. Borst
J. Bosiger
J. Crouse
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H. J. Sim
S. Smith
E. So
A. Traut
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IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

1. Overview

1.1 Scope

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

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

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

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

1.2 Word usage

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

2. References

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

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

ANSI C57.12.70-1978 (Reaff 1992), American National Standard Terminal Markings and Connections for Distribution and Power Transformers.

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

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

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

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

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

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

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

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

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

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

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

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

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

²ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>), or from the Compressed Gas Association, Inc., Crystal Gateway 1, Suite 501, 1235 Jefferson Davis Highway, Arlington, VA 22202, USA.

³ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5900, USA (<http://www.asme.org/>).

⁴ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

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

⁶IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3. Definitions

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

4. Service conditions

4.1 Usual service conditions

4.1.1 General

Transformers conforming to this standard shall be suitable for operation at rated kVA under the following usual service conditions.

4.1.2 Temperature

4.1.2.1 Cooling air temperature limit

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

4.1.2.2 Liquid temperature limit

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

4.1.2.3 Cooling water temperature limit

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

4.1.3 Altitude

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

4.1.4 Supply voltage

The supply-voltage wave shape shall be approximately sinusoidal, and the phase voltages supplying a polyphase transformer shall be approximately equal in magnitude and time displacement.

4.1.5 Load current

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

4.1.6 Operation above rated voltage or below rated frequency

4.1.6.1 Capability

Transformers shall be capable of:

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

- 2) Load power factor is 80% or higher.
- 3) Frequency is at least 95% of rated value.
- b) Operating continuously above rated voltage or below rated frequency, on any tap at no load, without exceeding limits of observable temperature rise in accordance with 5.11.1, when neither the voltage nor volts per hertz exceed 110% of rated values.

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

4.1.6.2 Maximum continuous transformer operating voltage

The maximum continuous transformer operating voltage should not exceed the levels specified in ANSI C84.1-1995. System conditions may require voltage transformation ratios involving tap voltages higher than the maximum system voltage for regulation purposes. However, the appropriate maximum system voltage should be observed under operating conditions.

4.1.7 Outdoor operation

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

4.1.8 Step-down operation

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

4.1.8.1 Generator step-up transformers

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

4.1.8.2 System tie autotransformers

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

4.1.9 Tank or enclosure finish

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

4.2 Loading at other than rated conditions

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

- a) Ambient temperatures higher or lower than the basis of rating
- b) Short-time loading in excess of nameplate kVA with normal life expectancy
- c) Loading that results in reduced life expectancy

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

4.3 Unusual service conditions

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

4.3.1 Unusual temperature and altitude conditions

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

4.3.2 Insulation at high altitude

The dielectric strength of transformers that depend in whole or in part upon air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, transformers shall be designed with larger air spacings between terminals using the correction factors of Table 1 to obtain adequate air dielectric strength at altitudes above 1000 m (3300 ft).

4.3.2.1 Insulation level

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

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

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

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

4.3.2.2 Bushings

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

4.3.3 Other unusual service conditions

Other unusual service conditions include the following:

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

5. Rating data

5.1 Cooling classes of transformers

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

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

- O mineral oil or synthetic insulating liquid with fire point⁷ ≤ 300 °C
- K insulating liquid with fire point > 300 °C
- L insulating liquid with no measurable fire point

Second letter: Circulation mechanism for internal cooling medium:

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

Third letter: External cooling medium:

- A air
- W water

Fourth letter: Circulation mechanism for external cooling medium:

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

NOTES:

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

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

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

Examples:

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

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

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

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

Table 2—Cooling class designation

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

^aIndicates directed oil flow per Table 9, NOTE 2 of IEEE Std C57.12.00-1993.

5.2 Frequency

Unless otherwise specified, transformers shall be designed for operation at a frequency of 60 Hz.

5.3 Phases

5.3.1 General

Transformers described in this standard are either single-phase or three-phase. Standard ratings are included in the product standards for particular types of transformers. When specified, other phase arrangements may be provided.

5.3.2 Scott-connected or T-connected transformers

5.3.2.1 Phase transformation

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

5.3.2.2 Dissimilar single-phase transformers

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

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