

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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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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Foreword

(This foreword is not a part of IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.)

In this revision of IEEE Std C57.12.00-1987, Section 5.9, which covers total losses, has been revised. Section 6.8, which covers external clearances, and Section 9.4, which covers accuracy requirements for measured losses, have been added. Changes have been made to the table of nameplate information and the table of routine design and other tests; and new tables of minimum external clearances and test system accuracy requirements have been added. Tables 11 through 20 have been renumbered. The references in Section 3 have been updated.

One area that has not previously been covered and that is still not covered is a suitable phase-to-phase switching impulse test requirement. Work on developing such a test requirement is underway within the Transformers Committee of the IEEE Power Engineering Society.

This standard is a voluntary consensus standard. Its use may become mandatory only when required by a duly constituted legal authority, or when specified in a contractual relationship. To meet specialized needs and to allow innovation, 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 words *shall* and *must* indicate 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.

For the manufacturer's use, samples of specification forms are given at the end of this standard for power transformer specification and manufacturer's name distribution transformer specification. These forms, or an equivalent, are suggested for use.

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

A special task force was also appointed to coordinate all the approved changes into one complete document and link them together in a logical manner.

The Accredited Standards Committee on Transformers, Regulators, and Reactors, C57, that reviewed and approved this document, had the following members at the time of approval:

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

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 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 except as indicated below:

- 1) Instrument transformers
- 2) Step voltage and induction voltage regulators
- 3) Arc furnace transformers
- 4) Rectifier transformers
- 5) Specialty transformers
- 6) Grounding transformers
- 7) Mobile transformers
- 8) Mine transformers

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.

NOTE — The foreword of this voluntary consensus standard describes the circumstances under which the standard may be used on a mandatory basis.

2. Terminology

Standard transformer terminology available in IEEE C57.12.80-1978 [18]¹ shall apply.

Other electrical terms are defined in IEEE Std 100-1992 [13].

3. References

This standard shall be used in conjunction with the following publications:

- [1] ANSI C57.12.70-1978 (Reaff 1992), American National Standard Terminal Markings and Connections for Distribution and Power Transformers.²
- [2] ANSI C84.1-1989, American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz).
- [3] ANSI C92.1-1982, American National Standard for Insulation Coordination.
- [4] ANSI C92.2-1987, American National Standard Preferred Voltage Ratings for Alternating-Current Electrical Systems and Equipment Operating at Voltages above 230 Kilovolts Nominal.
- [5] ANSI/CGA V-1-1987, Compressed Gas Cylinder Valve Outlet and Inlet Connections.³
- [6] ASME Boiler and Pressure Vessel Code (BPV), 1984 Edition.⁴
- [7] ASME B1.1-1989, American National Standard for Unified Inch Screw Threads (UN and UNR Thread Form).
- [8] ASTM D117-1989, Standard Methods of Testing and Specifications for Electrical Insulating Oils of Petroleum Origin.⁵
- [9] ASTM D1933-1991, Specifications for Nitrogen Gas as an Electrical Insulating Material.
- [10] ASTM D3487-1988, Specifications for Mineral Insulating Oil Used in Electrical Apparatus.
- [11] IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing (ANSI).⁶
- [12] IEEE Std 32-1972 (Reaff 1991), IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices (ANSI).
- [13] IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).

¹The numbers in brackets correspond to those of the references in Section 3.

²ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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⁴ASME publications are available from the American Society of Mechanical Engineers, 22 Law Drive, Fairfield, NJ 07007, USA.

⁵ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

⁶IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

- [14] IEEE Std 315-1975 (Reaff 1989), IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (ANSI).
- [15] IEEE Std 315A-1986, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (Supplement to IEEE Std 315-1975) (ANSI).
- [16] IEEE Std 469-1988, IEEE Recommended Practice for Voice Frequency Electrical-Noise Tests of Distribution Transformers (ANSI).
- [17] IEEE Std 799-1987, IEEE Guide for Handling and Disposal of Transformer Grade Insulating Liquids Containing Polychlorinated Biphenyls (ANSI).
- [18] IEEE C57.12.80-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers (ANSI).
- [19] IEEE C57.12.90-1992, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers; and Guide for Short-Circuit Testing of Distribution and Power Transformers (ANSI).
- [20] IEEE C57.19.01-1991, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

4. Services 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.

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.

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

4.1.2.3.

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 3300 ft (1000 m).

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.

NOTE — Harmonic factor is defined in IEEE C57.12.80-1978 [18].

4.1.6 Operation Above Rated Voltage or Below Related Frequency

4.1.6.1.

Transformers shall be capable of

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

NOTE — 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 put, load power factors, and winding voltage combinations [see 4.3.3(10)]. 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.

The maximum continuous transformer operating voltage should not exceed the levels specified in ANSI C84.1-1989 [2].

NOTE — System conditions may require voltage transformation ratios involving tap voltages higher than the maximum system voltage for regulation purposes. However, the appropriate maximum system voltage should be observed under operating conditions (see ANSI C92.2-1987 [4]).

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.

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

4.1.8.2.

Transformers identified as system tie autotransformers (or transformers) 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.

NOTE — 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 C57.91-1981 [B22], IEEE C57.115-1991 [B34], and IEEE C57.92-1981 [B23] provide guidance for loading at other than rated conditions, including

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

NOTE — 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 (see IEEE C57.115-1991 [B34])

Transformers may be used at higher or lower ambient temperatures or at higher altitudes than those specified in 4.1.3; but special consideration must be given to these applications. IEEE C57.91-1981 [B22] and IEEE C57.92-1981 [B23] provide 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 using the correction factors of Table 1 to obtain adequate air dielectric strength at altitudes above 3300 ft (1000 m).

4.3.2.1.

The insulation level at 3300 ft (1000 m) multiplied by the correction factor from Table 1 must be not less than the required insulation level at the required altitude.

Table 1— Dielectric-Strength Correction Factors for Altitudes Greater Than 3300 ft (1000 m)

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

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

4.3.2.2.

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

4.3.3 Other Unusual Service Conditions

- 1) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture, or dripping water, etc.
- 2) Abnormal vibration, tilting, shock, or seismic conditions.
- 3) Ambient temperatures outside of normal range.
- 4) Unusual transportation or storage conditions.
- 5) Unusual space limitations.
- 6) Unusual maintenance problems.
- 7) Unusual duty or frequency of operation, impact loading.
- 8) Unbalanced ac voltages, or departure of ac system voltages from a substantially sinusoidal wave form.
- 9) 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.
- 10) Specified loading conditions (kVA outputs, winding load power factors, and winding voltages) associated with multiwinding transformers or autotransformers.
- 11) Excitation exceeding either 110% rated voltage or 110% rated volts per hertz.
- 12) Planned short circuits as a part of regular operating or relaying practice.
- 13) Unusual short-circuit application conditions differing from those described as usual in Section 7.
- 14) Unusual voltage conditions including transient overvoltages, resonance, switching surges, etc., which may require special consideration in insulation design.
- 15) Unusually strong magnetic fields.

NOTE — Solar magnetic disturbances may result in the flow of telluric currents in transformer neutrals.

- 16) Large transformers with high-current isolated-phase bus ducts.

NOTE — 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.

- 17) Unusually high nuclear radiation.

- 18) Parallel operation.

NOTE — 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

5.1.1 Liquid-Immersed, Air-Cooled

- 1) Liquid-immersed, self-cooled: class OA
- 2) Liquid-immersed, self-cooled/forced air, cooled class OA/FA
- 3) Liquid-immersed, self-cooled/forced air-cooled/forced air-cooled: class OA/FA/FA

5.1.2 Liquid-Immersed, Air-Cooled/Forced Liquid-Cooled

- 1) Liquid-immersed, self-cooled/forced air-cooled/forced liquid-cooled: class OA/FA/FOA
- 2) Liquid-immersed, self-cooled/forced air—forced liquid-cooled/forced air—forced liquid-cooled: class OA/FOA/FOA

5.1.3 Liquid-Immersed, Water-Cooled

- 1) Liquid-immersed, water-cooled: class OW
- 2) Liquid-immersed, water-cooled/self-cooled: class OW/A

5.1.4 Liquid-Immersed, Forced Liquid-Cooled

- 1) Liquid-immersed, forced liquid-cooled with forced air cooler: class FOA
- 2) Liquid-immersed, forced liquid-cooled, water-cooled: class FOW

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.

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.

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

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

5.3.2.3.

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

5.3.2.4.

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

- 1) The kVA rating of each transformer shall be half the bank output required, and the rating of the individual units shall agree with the ratings established for single-phase transformers.
- 2) Performance characteristics, except heating, shall be based on single-phase operation.
- 3) 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.
- 4) Transformers shall be interchangeable as main and teaser.
- 5) Regulating taps are not usually supplied on transformers for three-phase to two-phase or from two-phase to three-phase service. When taps are required, the teaser tap shall be 86.6% of the mean regulating taps (mean, as used here, refers to the midpoint of the range of regulating taps).

5.4 Rated Kilovoltamperes

5.4.1 General

The rated kVA of a transformer shall be the output that can be delivered for the time specified at rated secondary voltage and rated frequency without exceeding the specified temperature-rise limitations under prescribed conditions of test, and within the limitations of established standards.

5.4.2 Preferred Continuous Kilovoltampere Ratings

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