



IEEE Standard for General Requirements and Test Code for Oil-Immersed HVDC Converter Transformers

IEEE Power Engineering Society

Sponsored by the
Transformers Committee



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IEEE Standard for General Requirements and Test Code for Oil-Immersed HVDC Converter Transformers

Sponsor

**Transformers Committee
of the
IEEE Power Engineering Society**

Approved 27 September 2007

IEEE-SA Standards Board

Abstract: The electrical, mechanical, and physical requirements of oil-immersed single-phase and three-phase converter transformers are specified in this standard. Tests are described and test code defined. Devices such as arc furnace transformers and rectifier transformers for industrial or locomotive applications are not covered.

Keywords: construction, converter transformers, HVDC, oil-immersed, rating, requirements, test code, tests

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Introduction

This introduction is not part of IEEE Std C57.129-2007, IEEE Standard for General Requirements and Test Code for Oil-Immersed HVDC Converter Transformers.

In 1986, the Transformers Committee of the IEEE Power Engineering Society created the HVDC Converter Transformers and Smoothing Reactors Subcommittee. This subcommittee developed from the working group that prepared Paper 85 SM 375-1, “Recommended Dielectric Tests and Test Procedures for Converter Transformers and Smoothing Reactors.” Although HVDC transformers and smoothing reactors were being built and operated for over 30 years, prior to the initial release of this standard in 1999, there was only a small quantity of papers available that presented suggested test code for HVDC equipment. Two separate standards were developed by the subcommittee—one for oil-immersed transformers and one for both dry-type and oil-immersed smoothing reactors. (The bibliography in Annex C of IEEE Std C57.129™-1999 contains a list of the available papers, which are included in the bibliography of this revision.) This revised standard utilizes feedback from manufacturers and end users based on applying the 1999 document. The net result is modification to the test code and the addition of annexes covering overload testing, converter transformers used with voltage source converters, and design review.

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IEEE Standard for General Requirements and Test Code for Oil-Immersed HVDC Converter Transformers

1. Scope

This standard specifies the electrical, mechanical, and physical requirements of oil-immersed single-phase and three-phase converter transformers.

This standard does not apply to other devices, such as the following:

- Arc furnace transformers
- Rectifier transformers for industrial or locomotive applications

2. Normative references

~~This standard shall be used in conjunction with the following publications:~~ 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 ~~B4C84.1-1989~~ 2006, American National Standard for Electric Power Systems and Equipment—Voltage Ratings (60 Hertz).¹

IEEE Std C57.12.00™-2006, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.^{2,3}

IEEE Std C57.12.80™-2002, IEEE Standard Terminology for Power and Distribution Transformers.¹

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~~ANSI C92.2-1987, American National Standard Preferred Voltage Ratings for Alternating Current Electrical Systems and Equipment Operating at Voltages above 230 kV Nominal.~~²

~~IEEE Std 315-1975 (Reaff 1993), IEEE Standard Graphic Symbols for Diagrams (Including Reference Designation Letters).~~

~~IEEE Std 315A-1986 (Reaff 1993), IEEE Standard Supplement to Graphic Symbols for Electrical and~~

~~IEEE Std 1158-1991 (Reaff 1996), IEEE Recommended Practice for Determination of Power Losses in High Voltage Direct Current (HVDC) Converter Stations.~~

IEEE Std C57.12., IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

~~IEEE Std C57.12.11-1980, IEEE Guide for Installation of Oil-Immersed (10 MVA and Larger, 69 kV to 287 kV Rating).⁴~~

~~IEEE Std C57.18.10TM-1998 (Reaff 2003), IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers~~

~~IEEE Std C57.12.12-1980, IEEE Guide for Installation of Oil-Immersed Extra-High Voltage Transformers 345 kV and Above.⁵~~

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

~~IEEE Std C57.12.90-1993, 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 C57.19.00-1991 (Reaff 1997), IEEE Standard General Requirements and Test Procedures for Outdoor Power~~

~~IEEE Std C57.19.00TM-2004, IEEE Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings.~~

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

IEEE Std C57.19.03-~~1996~~TM-2005, IEEE Standard Requirements, Terminology, and Test Code for Bushings for DC Applications.

²ANSI C92.2-1987 has been superseded by IEEE Std 1312-1993 (Reaff 1999), IEEE Standard Preferred Voltage Ratings for Alternating-Current Electrical Systems and Equipment Operating at Voltages Above 230 kV Nominal. Footnote 3 provides information on obtaining IEEE publications.

³IEEE 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/>).

⁴IEEE Std C57.12.11-1980 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. +1 303 792 2181 (<http://global.ihs.com/>).

⁵IEEE Std C57.12.12-1980 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. +1 303 792 2181 (<http://global.ihs.com/>).

~~IEEE Std C57.113TM-1991, IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers~~

~~IEEE Std C57.92-1981 (Reaff 1991), IEEE Guide for Loading Mineral Oil-Immersed Power (up to and including 100 MVA with 55 °C or 65 °C Winding Rise).⁶~~

~~IEEE Std C57.98-1993 (Reaff 1999), IEEE Guide for Transformer Impulse Tests.~~

~~IEEE Std C57.104-1991, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.~~

~~IEEE Std C57.106-1991 (Reaff 1998), IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.~~

~~IEEE Std C57.109-1993, IEEE Guide for Liquid Immersed Transformer Through Fault Current Duration.~~

~~IEEE Std C57.110-1986 (Reaff 1992), IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents.~~

~~IEEE Std C57.113-1991, IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.~~

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

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

IEEE Std C62.11-~~1993~~™-2005, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits-
(>1 kV). IEEE Std C62.22-~~1991~~™-1997, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

3. Definitions and letter symbols

3.1 Definitions

Standard transformer terminology available in IEEE Std C57.12.80-2002⁴ shall apply. ~~Other electrical terms are defined in~~, and *The Authoritative Dictionary of ~~Electrical and Electronics~~ IEEE Standards Terms* [B16]⁵ should be referenced for terms not defined in this standard.

3.2 Letter symbols

$E_{ACapplied}$	AC applied voltage for transformer test [dc-side winding(s)]
E_d	Maximum dc rated voltage per valve bridge ($= E_{DCSystem} / N_{tot}$)
E_{DC}	Applied voltage for transformer test
$E_{DCSystem}$	Maximum dc rated voltage of system
E_{PR}	Polarity reversal voltage for transformer test
E_{VO}	Maximum phase-to-phase ac operating voltage of valve winding of converter transformer
F_h	Loss adjustment factor at harmonic h
h	Harmonic number
I	Root-sum-square (RSS) equivalent value of the actual nonsinusoidal full load current

⁴ Information on references can be found in Clause 2.

⁵ The numbers in brackets correspond to those of the bibliography in Annex F.

⁶ ~~IEEE Std C57.92-1981 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. +1 303 792 2181 (<http://global.ihs.com/>).~~

I_h	Magnitude of harmonic current, per unit of rated nameplate current
R	DC resistance
N	Number of six-pulse bridges in series from the dc neutral of the converter station to the converter bridge connected to the subject transformer
N_{tot}	Total number of six-pulse bridges in series from the dc neutral of the converter station to the dc line terminal (usually $N_{\text{tot}} = 2$)
P_0	I^2R (ohmic) losses at rated current
P_h	Total load loss at harmonic h
P_{CL}	Total no-load loss
P_{LLG}	Load loss used in determining guaranteed total losses
P_{LLT}	Calculated total load loss under service conditions
P_{TL}	Total loss under service conditions (used for temperature rise test)
P_{we}	Eddy losses in winding at fundamental frequency
P_{se}	Stray losses in structural parts at fundamental frequency
w	Per unit eddy losses in windings divided by total stray and eddy losses (all losses at fundamental frequency)

4. General requirements—Systems and environmental data

4.1 Usual service conditions

4.1.1 General

Converter transformers conforming to this standard shall be suitable for operation at rated kilovolt-amperes under the usual service conditions defined in IEEE Std C57.12.00-2006 except where clearly not applicable to converter transformers, or when otherwise specified in this standard.

4.1.2 Temperature

For parts such as the dc-side bushings that project into a valve hall, ambient temperatures exceeding 40 °C shall not be regarded as a usual service condition.

4.1.3 AC system voltage

The voltage applied to the ac-side winding shall be approximately sinusoidal (e.g., maximum total harmonic distortion of 3% to 5% with no individual harmonic exceeding 1%), and the phase voltages supplying a polyphase transformer shall be approximately equal in magnitude and time displacement. In addition, the maximum continuous ac operating voltage for the ac-side windings of converter transformers shall not exceed the levels specified in ANSI C84.1-2006.

4.1.4 Load current

The currents flowing into converter transformers are rich in harmonics. The system designer shall provide the harmonic content in the winding(s) to the manufacturer, and also provide the magnitude of the residual dc current in the dc-side winding(s). When there is more than one valve winding on a core leg, the amplitude of each harmonic in each winding shall be specified. In addition, the vector sum of the harmonics in the valve windings shall be given. If there is an axial split of the valve windings, the

current waveforms for all valve windings shall be specified.

One should also be aware that the specified harmonics, to some extent, are an “umbrella” case, covering many different modes of operation.

More information on this subject can be found in A.2, “Three-winding transformer loss calculations,” of IEEE Std C57.18.10-1998 and 9.1.3, “Transformers with three or more windings wound on the same core limb,” of IEC 61378-3:2006 [B15].

4.1.5 Direction of power flow

Unless otherwise specified, converter transformers shall be designed for both rectifier and inverter operation.

4.2 Loading at other than rated conditions

Loading above the nameplate is not a normal part of converter transformer loading. Converter transformers are normally designed for a specific dc terminal and are coordinated with the capabilities of the valves and other dc components.

If the terminal is to be operated above rated capacity, a detailed thermal study is needed to determine the capability of all the affected terminal equipment. Detailed information about the transformer design and capabilities at both fundamental and harmonic currents should be part of the study.

4.3 Unusual service conditions

4.3.1 General

Conditions other than those described in 4.1 are considered unusual and should be brought to the attention of those responsible for the design and application of the apparatus.

4.3.2 Unusual temperature conditions

Loading over the full range of ambient temperatures at a given terminal should be part of the transformer design study. Standard tables should not be used for converter transformers because of the effects of harmonic currents and the dc bias on the valve winding(s). [The length of time that a transformer is required to be energized before picking up load shall be provided by the manufacturer for cold weather ambient conditions.](#)

4.3.3 Unusual altitude conditions

The dielectric strength, which depends in whole or in part on air for insulation, decreases as the altitude increases due to the effect of decreased air density. When specified, converter transformers shall be designed with larger air spacings using the correction factors presented in Table 1 of IEEE Std C57.12.00-2006 to obtain adequate air dielectric strength at altitudes above 1000 m (3300 ft).

4.3.4 Other unusual service conditions

Unusual service conditions are described in 4.3.3 of IEEE Std C57.12.00-2006. Note that for converter transformers pollution aspects are extremely important and shall be accurately defined so that proper external insulation (particularly bushings) may be provided. In addition to the factors listed in IEEE Std C57.12.00-2006, dc currents caused by geomagnetic storms are considered as unusual service conditions.

4.4 Environmental impact

The impact on the environment shall be considered in the use of materials contained within the transformer. A “cradle to grave” approach is required, which includes handling and final disposal. Gasket materials shall be chosen and accelerated age tested to ensure a long life and minimize oil leaks.

4.5 Synthetic materials

The use of synthetic materials such as plastics is increasing. Compatibility with oil, high temperatures, and other material is required. Accelerated aging tests are required to prove the materials will last the specified life of the transformer.

4.6 Transformer oil

4.6.1 Non-corrosive oil

The transformer oil used in HVDC converter transformers shall fulfill the criteria for non-corrosive oil in accordance with the extended ASTM test in ASTM D 1275-2006 Method B [B7].

NOTE—CIGRÉ WG A2-32 is, among other tasks, developing tests for transformer oil.⁶

4.6.2 Synthetic insulating oils

Synthetic and non-mineral insulating oils are now available or are being developed. Little information is available regarding their applicability/usage in converter transformers.

5. Rating data

5.1 Cooling classes of converter transformers

Cooling classes of converter transformers are defined in 5.1 of IEEE Std C57.12.00-2006.

5.2 Frequency

Unless otherwise specified, converter transformers shall be designed for operation at a primary frequency (first harmonic) of either 50 Hz or 60 Hz.

5.3 Phases

Converter transformers are either single phase or three phase.

5.4 Rated kilovolt-amperes

The rated kilovolt-amperes shall be the output that can be delivered continuously or for the time to be specified by the end user at rated secondary voltage and at rated frequency for the converter transformer.

⁶ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

5.5 Rated current

The rated current is the rms equivalent of the actual operating current wave shape based on the dc rated load commutated with a zero commutating angle. In a document published by CIGRÉ Joint Working Group 12/14.10 [B11], it was noted “that in power transformers terminology the fundamental ratings are rated power and rated voltage, while rated current is derived from the other two quantities, so as to prevent numerical discrepancy. Rated power is frequently a rounded figure, while rated current is not.”

5.6 Voltage ratings and taps for converter transformers

The voltage ratings and taps for converter transformers are defined in 5.5 of IEEE Std C57.12.00-2006.

5.7 Connections

Standard connections for converter transformers are presented in Figure 1.

NOTE—Converter transformers are not recommended for parallel operation.

5.8 Polarity, angular displacement, and terminal markings for converter transformers

Polarity, angular displacement, and transformer connections used with 12-pulse bridge converter terminal markings for converter transformers are described in 5.7 of IEEE Std C57.12.00-2006.

5.9 Impedance

The impedance for converter transformers shall be referred to a temperature equal to the sum of the rated average winding temperature rise by resistance, plus 20 °C. The resistance shall be given for the rated winding temperature rise plus 20 °C.

5.10 Total losses

The total losses of converter transformers shall be the sum of the no-load losses and the load losses. No-load losses are measured separately in a manner similar to conventional ac transformers.

The determination of actual load losses in service is more complicated due to harmonic effects. ~~Guaranteed losses are normally measured using the sinusoidal rated transformer current.~~ The user shall clearly indicate in the enquiry the method to be used for evaluating guaranteed load losses. These may include a harmonic spectrum and for such cases the harmonic spectrum to be used for load loss evaluation shall be clearly defined. This spectrum may be different from the one specified for temperature rise tests; the latter representing a worst case operating condition.

A harmonic correction is added to the measured sinusoidal load losses as part of the calculation of the appropriate total loss value for the temperature rise test (see 8.6.2.2).

Power required for cooling fans, oil pumps, space heaters, and other ancillary equipment is not included in the total loss. When specified, loss data on such ancillary equipment shall be furnished.

The standard reference temperature for the load loss of converter transformers shall be 85 °C.

Figure 1a—Transformer connections used with six-pulse bridge converter

