

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

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

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Abstract: The electrical, mechanical, and physical requirements of oil-immersed single-phase and three-phase converter transformers are specified. 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, tests, test code

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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Introduction

(This introduction is not part of IEEE Std C57.129-1999, IEEE Standard 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 20 years, prior to this standard there were only two papers available that presented suggested dielectric tests for the HVDC equipment: IEEE Paper 85 mentioned above, and a CIGRÉ paper published in 1976. Clearly, with the increased activity in HVDC transmission, there was a significant need for a standard covering the requirements and testing of inductive equipment for HVDC stations, and the first responsibility of the new subcommittee was to create a proposed standard for HVDC stressed equipment. Two separate standards have been developed—one for oil-immersed transformers and one for both dry-type and oil-immersed smoothing reactors.

Significant accomplishments of this standard include:

- Establishment of dielectric tests on HVDC transformers. In addition to the polarity reversal test and long-term dc tests recommended by the previous papers, a special 1 h ac applied voltage test on the dc-side winding has been included to demonstrate insulation integrity for service conditions. The duration of the long-term dc test has been increased, and the polarity reversal test has been modified to include two reversals instead of one.
- Establishment of a procedure for measuring load losses at higher harmonics.

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Lars-Erik Juhlin
Klaus Papp
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Einar Purpa
Pierre Riffon
Georges H. Vaillancourt
Joe D. Watson

Other individuals who contributed to the development of the document are:

Frank David
Donald A. Gillies

Peter Iijima
Jack W. McGill
E. T. Norton

V. Q. Pham
W. W. Stein

The following members of the balloting committee voted on this standard:

R. K. Ahuja
George Allen
Glenn Andersen
Jacques Aubin
Mike Barnes
A. Bartek
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Wallace B. Binder
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Contents

1.	Scope.....	1
2.	References.....	1
3.	Definitions.....	3
4.	Letter symbols.....	3
5.	General requirements—systems and environmental data.....	4
	5.1 Usual service conditions	4
	5.2 Loading at other than rated conditions.....	5
	5.3 Unusual service conditions	5
6.	Rating data	5
	6.1 Cooling classes of converter transformers	5
	6.2 Frequency.....	5
	6.3 Phases.....	6
	6.4 Rated kilovoltamperes	6
	6.5 Rated current.....	6
	6.6 Voltage ratings and taps for converter transformers.....	6
	6.7 Connections.....	6
	6.8 Polarity, angular displacement, and terminal markings for converter transformers.....	6
	6.9 Impedance	6
	6.10 Total losses.....	6
	6.11 Insulation levels	10
	6.12 Temperature rise and loading conditions	12
	6.13 Loss capitalization rates.....	12
	6.14 Sound level limits	12
	6.15 Auxiliary power supply voltage.....	12
7.	Construction.....	13
	7.1 General.....	13
	7.2 Tank and component design	13
	7.3 Oil preservation.....	13
	7.4 Auxiliary equipment	13
8.	Tests.....	15
	8.1 General.....	15
	8.2 Routine, design, and other tests	15
	8.3 Additional routine tests for converter transformers with load tap changing or regulating transformers	17
9.	Test code	17
	9.1 General.....	17
	9.2 Resistance measurements.....	17
	9.3 Polarity and phase-relation tests	17

9.4	Ratio tests.....	17
9.5	No-load losses and excitation current.....	17
9.6	Impedance and load losses.....	18
9.7	Dielectric tests.....	19
9.8	Temperature rise	24
9.9	Short circuit test.....	25
9.10	Audible sound test.....	25
10.	Tolerances.....	25
10.1	Tolerance on ratio	25
10.2	Tolerance on impedance	25
10.3	Tolerance on losses.....	25
	Annex C (informative) Determination of loss adjustment factors.....	27
	Annex B (informative) Power testing concepts and methodologies under consideration.....	31
	Annex C (informative) Bibliography.....	33

IEEE Standard 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. References

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

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

ANSI C57.12.10-1988, American National Standard for Transformers—230 kV and Below 833/958 through 8333/10 417 kVA, Single-Phase, and 750/862 through 60 000/80 000/100 000 kVA, Three-Phase without Load Tap Changing; and 3750/4687 through 60 000/80 000/100 000 kVA with Load Tap Changing—Safety Requirements.

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

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/>).

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

ANSI C92.1-1982, American National Standard for Power Systems—Insulation Coordination

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 4-1995, IEEE Standard Techniques for High-Voltage Testing.³

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

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

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

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

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

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

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 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, IEEE Standard Requirements, Terminology, and Test Coding 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 C57.92-1981 (Reaff 1991), IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers (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, IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits.

IEEE Std C62.22-1991, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

3. Definitions

Standard transformer terminology available in IEEE Std C57.12.80-1978⁷ shall apply. Other electrical terms are defined in The IEEE Standard Dictionary of Electrical and Electronics Terms [B8].⁸

4. 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

⁶IEEE 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/>).

⁷Information on references can be found in Clause 2.

⁸The numbers in brackets correspond to those of the bibliography in Annex C.

h	harmonic number
I	root-mean-square (rms) value of the actual nonsinusoidal full load current
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)

5. General requirements—systems and environmental data

5.1 Usual service conditions

5.1.1 General

Converter transformers conforming to this standard shall be suitable for operation at rated kilovoltamperes under the usual service conditions defined in IEEE Std C57.12.00-1993 except where clearly not applicable to converter transformers, or when otherwise specified in this standard.

5.1.2 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.

5.1.3 AC system voltage

The voltage applied to the ac-side winding shall be approximately sinusoidal (e.g., maximum total harmonic distortion of 3–5% 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 C84.1-1995.

5.1.4 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).

5.1.5 Direction of power flow

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

5.2 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.

5.3 Unusual service conditions

Conditions other than those described in 5.1 are considered unusual and should be brought to the attention of those responsible for the design and application of the apparatus.

5.3.1 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).

5.3.2 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 C57.12.00-1993 to obtain adequate air dielectric strength at altitudes above 1000 m (3300 ft).

5.3.3 Other unusual service conditions

Unusual service conditions are described in 4.3.3 of IEEE Std C57.12.00-1993. 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 C57.12.00-1993, dc currents caused by geomagnetic storms are considered as unusual service conditions.

6. Rating data

6.1 Cooling classes of converter transformers

Cooling classes of converter transformers are defined in 5.1 of IEEE Std C57.12.00-1993.

6.2 Frequency

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

6.3 Phases

Converter transformers are either single phase or three phase.

6.4 Rated kilovoltamperes

The rated kilovoltamperes 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.

6.5 Rated current

The rated current is the rms equivalent of the actual operating current waveshape based on the dc rated load commutated with a zero commutating angle. In a document published by CIGRÉ JWG 12/14.10 [B3], 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.”

6.6 Voltage ratings and taps for converter transformers

The voltage ratings and taps for converter transformers are defined in 5.5 of IEEE Std C57.12.00-1993.

6.7 Connections

Standard connections for converter transformers are presented in Figure 1.

NOTE—Converter transformers are not recommended for parallel operation.

6.8 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 C57.12.00-1993.

6.9 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.

6.10 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.

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 9.6.2.2).