IEC/IEEE 60076-57-129

Edition 1.0 2017-11

INTERNATIONAL STANDARD

Power transformers –
Part 57-129: Transformers for HVDC applications

IEC/IEEE 60076-57-129:2017-11(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue
New York, NY 10016-5997
United States of America
stds.ipr@ieee.org
www.ieee.org

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IEC/IEEE 60076-57-129

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.180 ISBN 978-2-8322-4447-0

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POWER TRANSFORMERS –

Part 57-129: Transformers for HVDC applications

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International Standard IEC/IEEE 60076-57-129 has been prepared by IEC technical committee 14: Power transformers, in cooperation with the Transformers Committee of the IEEE Power & Energy Society[1], under the IEC/IEEE Dual Logo Agreement.

This publication cancels and replaces the first edition of IEC 61378-2 published in 2001 and IEEE Std C57.129™ published in 2007.

This publication is published as an IEC/IEEE Dual Logo standard.

The text of this standard is based on the following IEC documents:

FDIS	Report on voting
14/904/FDIS	14/907/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

International standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

A list of parts of the 60076 International Standard, published under the general title *Power transformers*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

1 A list of IEEE participants can be found at the following URL: http://standards.ieee.org/downloads/60076/60076-57-129-2017/60076-57-129-2017_wg-participants.pdf

POWER TRANSFORMERS –

Part 57-129: Transformers for HVDC applications

1 Scope

This part of 60076 International Standard specifies requirements of liquid-immersed three-phase and single-phase converter transformers for use in high voltage direct current (HVDC) power transmission systems including back-to-back applications. It applies to transformers having two, three or multiple windings.

This document does not apply to

– converter transformers for industrial applications (see IEC 61378-1 or IEEE Std C57.18.10);

– converter transformers for traction applications (see IEC 60310).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

2.1 IEC references

IEC 60050-421, *International Electrotechnical Vocabulary – Chapter 421: Power transformers and reactors* (available at http://www.electropedia.org)

IEC 60076-1:2011, *Power transformers – Part 1: General*

IEC 60076-2, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-3:2013, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-5, *Power transformers – Part 5: Ability to withstand short-circuit*

IEC 60076-18, *Power transformers – Part 18: Measurement of frequency response*

IEC 60076-10, *Power transformers – Part 10: Determination of sound levels*

IEC 60137, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60214-1, *Tap-changers – Part 1: Performance requirements and test methods*

IEC 60270, *High voltage test techniques – Partial discharge measurements*

IEC/IEEE 65700-19-03, *Bushings for DC application*

2.2 IEEE references

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

IEEE Std C57.12.10™, *IEEE Standard Requirements for Liquid-Immersed Power Transformers*

IEEE Std C57.12.80™, *IEEE Standard Terminology for Power and Distribution Transformers*

IEEE Std C57.12.90™, *IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers*

IEEE Std C57.19.00™, *IEEE Standard General Requirements and Test Procedures for Power Apparatus Bushings*

IEEE Std C57.113™, *IEEE Recommended Practice for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors*

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

IEEE Std C57.149™, *IEEE Guide for the Application and Interpretation of Frequency Response Analysis for Oil-Immersed Transformers*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in IEC 60050-421 and IEC 60076-1 apply to IEC specified transformers for HVDC applications. For IEEE specified transformers for HVDC applications, the terms and definitions given in IEEE Std C57.12.80 apply. For all transformers for HVDC applications, the following apply and take precedence.

NOTE Where the term oil is used in the text, it is understood to be the insulating liquid in the transformer.

ISO, IEC and IEEE maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp
- IEEE Standards Dictionary Online: available at http://ieeexplore.ieee.org/xpls/dictionary.jsp

3.1 Terms and definitions

3.1.1
valve side winding
winding connected to the converter

3.1.2
line side winding
winding connected to the AC network

Note 1 to entry: In other standards, valve side can be denoted as DC side and line side can be denoted as AC side.

3.2 Symbols

f_1 rated frequency and also the fundamental frequency

f_h frequency at harmonic order number h

F_h loss adjustment factor at harmonic h

f_x frequency ≥ 150 Hz used to determine the distribution of eddy current losses

F_{SE} enhancement factor for stray losses in structural parts

F_{WE} enhancement factor for winding eddy losses

h harmonic order number

I_{eq} equivalent sinusoidal r.m.s. current of rated frequency, giving the winding losses, used in temperature rise test

I_h magnitude of the h^{th} harmonic current in the transformer

I_{LN} square root of the sum of the square of the fundamental and harmonic currents up to the 49th harmonic for a particular loading condition and associated harmonic current spectra. $I_{LN}=\sqrt{\sum_{h=1}^{49} I_h^2}$ (49 is the highest harmonic to be evaluated).

NOTE I_{LN} equals I_r for the nominal load condition but it can also be used for other load conditions (e.g. overload).

I_r rated current, r.m.s. value of the nominal in-service load current, including harmonics, in the winding under consideration calculated in the same way as I_{LN} above. Used as a basis for the definition of rated impedance.

$I_r^2 R$ ohmic losses at rated current

I_x load loss test current at frequency f_x

k_h ratio of the current I_h to the rated current I_r

K_{WE} windings enhancement loss p.u. at fundamental frequency due to eddy losses

N number of six-pulse bridges in series from the neutral of the DC line to the rectifier bridge connected to the transformer

P_{1r} total load losses at fundamental frequency (50 Hz or 60 Hz) and rated current

P_{LLG} load loss used in determining guaranteed total losses

P_{LLT} calculated total load loss under service conditions

P_N total service load loss

P_{NL} total no-load loss

P_{SE1r} stray losses in structural parts (excluding windings) at fundamental frequency and rated current

P_{TL} total loss under service conditions (used for temperature rise test)

P_{WE1r} eddy losses in windings at fundamental frequency and rated current

P_x load loss measured at frequency f_x

R DC resistance of windings including internal leads

S_R rated power

U_{AC} AC separate source test voltage for the valve windings (r.m.s. value)

U_{DC} DC withstand test voltage for the valve windings

U_{dm} highest DC voltage per valve bridge

U_m highest system voltage of the line winding

U_{pr} polarity reversal test voltage (DC voltage) for the valve windings

U_r rated voltage

U_{vm} maximum phase-to-phase AC operating voltage of the valve windings of the converter transformer

4 Use of normative references

This document can be used with either the IEC or IEEE normative references, but the references shall not be mixed. The purchaser shall include in the enquiry and order which normative references are to be used. If the choice of normative references is not specified, then IEC standards shall be used except for HVDC converter transformers intended for installation in North America where IEEE standards shall be used.

5 General requirements

5.1 General

All the requirements in IEC 60076-1 or IEEE Std C57.12.00 and IEEE Std C57.12.10 are valid unless specific requirements are given in this document. In case of conflicting requirements, this document shall prevail.

5.2 Service conditions

5.2.1 General

Converter transformers in this document shall comply with the service conditions stated in IEC 60076-1 or IEEE Std C57.12.00, except where it is clearly not applicable to converter transformers or when other requirements are specified herein. It is assumed that the transformer operates in an approximately symmetrical three-phase system, unless otherwise stated.

5.2.2 Temperature

If any part of the transformer (for example, the valve bushings) protrudes into the valve hall, the maximum temperature in the valve hall shall be specified in addition to the normal ambient temperature.

NOTE The maximum air temperature in the valve hall is normally between 40 °C and 60 °C depending on the technology used

5.2.3 Load current

The currents flowing through the transformers contain harmonics. Residual DC currents may also flow through the windings. The purchaser shall provide the manufacturer with the harmonic content and the magnitude of the residual DC currents in the enquiry.

The harmonic content should preferably be given by listing a number of typical operating conditions.

5.2.4 AC voltage

The voltage applied to the line side winding shall be approximately sinusoidal (e.g., maximum total harmonic distortion of 5 % with no individual harmonic exceeding 1 %), and the phase voltages supplying a poly-phase transformer shall be approximately equal in magnitude and time displacement.

5.2.5 Direction of power flow

Unless otherwise specified, the transformer shall be designed for both rectifier and inverter operation.

5.3 Unusual service conditions

Conditions other than those described in 5.2 are considered unusual and shall be specified by the purchaser. Special attention on sources of DC current also needs to be considered.

NOTE Sources of DC current could be currents induced by geomagnetic storms and by fundamental frequency currents in DC lines.

5.4 Loading of transformer above rating

Any requirements for loading beyond rated power or at other than rated conditions shall be specified by the purchaser. The loading of HVDC transformers above nameplate rating shall not be made without consultation with the supplier.

NOTE Converter transformers are normally designed for a specific installation and are coordinated with the capabilities of the valves and other DC components. If the station is to be operated above its rated capacity, a detailed thermal study would be 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 would be part of the study.

6 Rating data

6.1 General

The rating characteristics of the transformer are expressed in steady-state sinusoidal quantities of current and voltages at rated fundamental frequency. The guaranteed losses, impedances and sound level shall correspond to these values. For a general list of rating data see IEC 60076-1 or IEEE Std C57.12.00.

6.2 Rated voltage

The rated voltage is the r.m.s. value of the fundamental component of the phase-to-phase (line-to-line) voltage.

NOTE For single-phase transformers intended to be connected in star to form a three-phase bank or to be connected between the line and the neutral of a three phase system, the rated voltage is indicated as the phase-to-phase voltage, divided by √3 , for example 400 / √3 kV.

6.3 Rated current

The rated current is the square root of the sum of the square of the fundamental and harmonic currents up to the 49th harmonic for the nominal loading condition

$$I_r = \sqrt{\sum_{h=1}^{49} I_h^2} \quad (1)$$

(49 is the highest harmonic to be evaluated).

6.4 Rated frequency

The rated frequency is the fundamental frequency of either 50 Hz or 60 Hz for which the transformer is designed.

6.5 Rated power

The rated three-phase power is the product of $\sqrt{3}$, the rated voltage and the rated current.

$$S_R = \sqrt{3} \times U_r \times I_r \quad (2)$$

7 Losses

7.1 General

The total losses of a converter transformer shall be the sum of the no-load loss and the load loss at a specific service condition. The guaranteed losses shall be within the tolerances of IEC 60076-1:2011, Table 1 or IEEE Std C57.12.00.

The standard reference temperatures for the losses of converter transformers shall be the ones given in IEC 60076-1 or IEEE Std C57.12.00.

7.2 No-load loss

No-load loss and no-load current are measured in the same way as for conventional AC transformers according to IEC 60076-1 or IEEE Std C57.12.90. This shall be the guaranteed no-load loss.

NOTE The harmonic voltages and DC bias currents have an effect on no-load loss and no-load current. However, in practice the differences due to this effect can be disregarded in comparison to the total losses of the transformer.

7.3 Load loss under rated frequency conditions

The load loss shall be measured in accordance with IEC 60076-1 or IEEE Std C57.12.90.

7.4 Load loss under service conditions

The currents flowing through the windings of converter transformers contain certain harmonics whose magnitudes depend on the parameters of the converter station. The determination of actual load loss in service cannot be deduced from one single load loss measurement. The procedure to determine the load loss in accordance with this document includes two load loss measurements and certain assumptions on loss distribution and a specific calculation scheme (see 9.2).

The determination of actual load loss in service is more complicated due to harmonic effects. The harmonic spectrum for the temperature rise test and the harmonic spectrum to be used for load loss evaluation shall be clearly defined by the purchaser. The spectrum for load loss evaluation may be different from the one specified for temperature rise tests; the latter representing a worst case operating condition.

To determine the losses under service conditions, the following assumptions are made:

– eddy and stray losses are proportional to the square of the current;
– winding eddy losses depend on the frequency with the exponent 2, and stray losses in structural parts depend on the frequency with the exponent 0,8.

Eddy loss and stray loss:

$$\Delta P \propto I^2 \times f^k \qquad (3)$$

where

$$k = \begin{cases} 2 & \text{for winding eddy losses,} \\ 0{,}8 & \text{for stray losses.} \end{cases}$$

Based on a given harmonic spectrum, the total service load loss can be calculated as follows:

$$P_{\mathrm{N}} = I_{\mathrm{LN}}^2 R + P_{\mathrm{WE1r}} \times F_{\mathrm{WE}} + P_{\mathrm{SE1r}} \times F_{\mathrm{SE}} \qquad (4)$$

where