IEC 61378-1

Edition 2.0 2011-07

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Converter transformers –
Part 1: Transformers for industrial applications

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Transformateurs de conversion -
Partie 1: Transformateurs pour applications industrielles

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IEC 61378-1:2011-07(en-fr)

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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

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INTERNATIONAL
ELECTROTECHNICAL
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COMMISSION
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PRICE CODE
CODE PRIX XC

ICS 29.180

ISBN 978-2-8322-1698-9

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CONVERTER TRANSFORMERS –

Part 1: Transformers for industrial applications

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International Standard IEC 61378-1 has been prepared by IEC technical committee 14: Power transformers.

This bilingual version (2014-07) corresponds to the English version, published in 2011-07.

This second edition cancels and replaces the first edition published in 1997. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- addition of winding connections (zig-zag, extended delta, etc.) with phase displacement (< 30 º);
- addition of transformers with more than one active part in the same tank;
- change of reference power definition (it is now based on fundamental component of the current);

- addition of considerations for guidelines for OLTC selection;
- addition of regulating transformer feeding converter transformer;
- addition of considerations about current sharing and hot spot temperature in high current windings for various winding arrangements;
- addition of transductors used for d.c. voltage regulation together with diode rectifiers;
- improved old annexes with several calculation examples;
- addition of new annexes for special measurements setups.

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

FDIS	Report on voting
14/686/FDIS	14/695/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.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61378 series can be found, under the general title *Converter transformers*, on the IEC website.

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The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

The contents of the corrigendum of January 2012 have been included in this copy.

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CONVERTER TRANSFORMERS –

Part 1: Transformers for industrial applications

1 Scope

This Part of IEC 61378 deals with the specification, design and testing of power transformers and reactors which are intended for integration within semiconductor converter plants; it is not applicable to transformers designed for industrial or public distribution of a.c. power in general.

The scope of this International Standard is limited to application of power converters of any power rating. Typical applications are: thyristor rectifiers for electrolysis; diode rectifiers for electrolysis; thyristor rectifiers for large drives; thyristor rectifiers for scrap melting furnaces, and diode rectifiers feeding inverters for variable speed drives. The standard also covers the regulating unit utilized in such application as step down regulating transformers or autotransformers. The valve winding highest voltage for equipment is limited to 36 kV.

This standard is not applicable to transformers for HVDC power transmission. These are high-voltage transformers, and they are subjected to d.c. voltage tests.

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The standards for the complete converter plant (IEC 60146 series, or other publications dedicated to particular fields of application) may contain requirements of guarantees and tests (such as insulation and power loss) for the whole plant, including the converter transformer and possibly auxiliary transformers and reactor equipment. This does not relieve the application of the requirements of this standard concerning the guarantees and tests applicable to the converter transformer itself as a separate component before being assembled with the remainder of the converter plant.

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The guarantees, service and type tests defined in this standard apply equally to transformers supplied as part of an overall converter package, or to those transformers ordered separately but for use with converter equipment. Any supplementary guarantee or special verification has to be specifically agreed in the transformer contract.

The converter transformers covered by this standard may be of the oil-immersed or dry-type design. Unless specific exceptions are stated in this standard, the transformers comply with IEC 60076 series for oil-immersed transformers, and with IEC 60076-11 for dry-type transformers.

NOTE For some converter applications, it is possible to use common distribution transformers of standard design. The use of such standard transformers in the special converter applications may require a certain derating. This matter is not specifically covered in this standard, which deals with the requirements to be placed on specially designed units. It is possible to estimate this derating from the formulae given in 5.1, and also from Clause 9 of IEC 60076-8:1997.

This standard deals with transformers with one or more active parts installed in the same tank like regulating (auto)transformer and one or two rectifier transformers. It also covers transformers with transductors and/or one or more interphase transformers.

For any combination not listed above an agreement between the purchaser and manufacturer is necessary regarding the determination and the measurement of the total losses.

This standard deals with transformers star Y and delta D and any other phase shifting connections (like zig-zag, extended delta, polygon etc.). Phase shifting windings can be placed on either the regulating or rectifier transformer.

2 Normative references

The following referenced documents are indispensable for the application 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.

IEC 60050-421:1990, *International Electrotechnical Vocabulary (IEV) – Chapter 421: Power transformers and reactors*

IEC 60076 (all parts), *Power transformers*

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

IEC 60076-2:2011, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-3:2000, *Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air*

IEC 60076-6:2007, *Power transformers – Part 6: Reactors*

IEC 60076-8:1997, *Power transformers – Part 8: Application guide*

IEC 60076-11:2004, *Power transformers – Part 11: Dry-type transformers*

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IEC 60146 (all parts), *Semiconductor converters – General requirements and line commutated converters*

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IEC 60146-1-1:2009, *Semiconductor converters – General requirements and line commutated converters – Part 1-1: Specifications of basic requirements*

IEC/TR 60146-1-2:2011, *Semiconductor converters – General requirements and line commutated converters – Part 1-2: Application guide*

IEC/TR 60616:1978, *Terminal and tapping markings for power transformers*

3 Terms, definitions and acronyms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-421, IEC 60076-1 and IEC 60146-1-1, as well as the following apply.

3.1.1
polygon connection
P
the winding connection in which each phase winding consists of two parts in which phase displaced voltages are induced. One part of each phase is connected in series to the other part of a different phase and then closed in a delta (see Annex I)

3.1.2
extended delta connection
E
the winding connection in which each phase winding consists of two parts in which phase displaced voltages are induced. One part of each phase is delta connected and it is then connected to its appropriate line terminal through the other part (see Annex I)

3.1.3
phase shifting angle
Γ
the angle with sign, expressed in degrees and decimal of degrees, which needs to be added to the nearest clock number to obtain the phase displacement

3.1.4
transductor
device consisting of one or more ferromagnetic cores with windings, by means of which an a.c. or d.c. current or voltage can be varied by an independent voltage or current, utilizing saturation phenomena in the magnetic circuit

NOTE The French term transducteur magnétique (English: transductor) should not be confused with the more general French term transducteur (English: transducer). The use of the term transducteur in the sense of transducteur magnétique is permissible when no ambiguity is possible.

[IEC 60050-431:1980, 431-01-01]

3.1.5
interphase transformer
an electromagnetic device enabling the operation in parallel of two or more phase displaced commutating groups through inductive coupling between the windings placed on the same core
[IEC 60050-551:1998, 551-14-16]

3.1.6
line side
transformer winding connected to the a.c. network

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3.1.7
valve side
transformer winding connected to the converter

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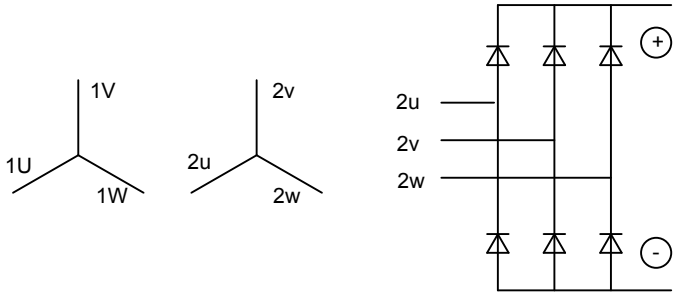
3.2 Acronyms

B6U 6-pulse double bridge connection (see Figure 1 below)

DB double bridge connection (see Figure 1 below)

NOTE The transformer windings can be star or delta connected.



IEC 1720/11

Figure 1 – B6U or DB 6 pulse double bridge connection

DSS double star with interphase transformer (see Figure 2 below)

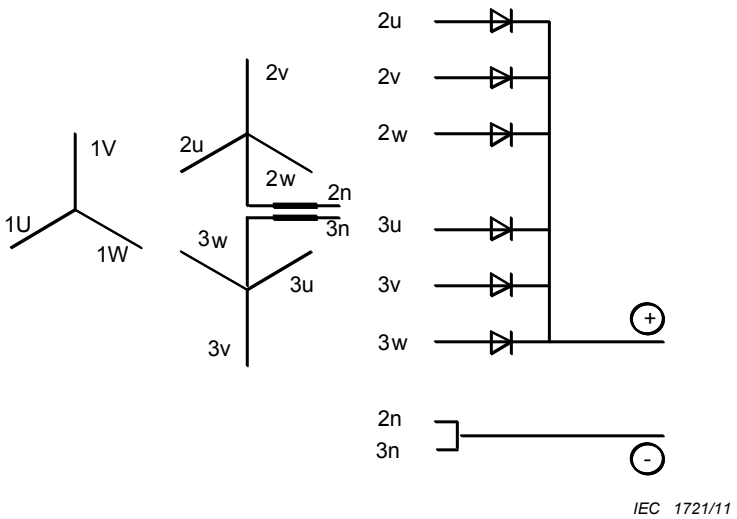


Figure 2 – DSS 6 pulse connection

IPT see definition 3.1.5

SR see definition 3.1.4

FFT fast fourier transformation

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4 Classification

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4.1 General

Classification of converters and converter applications are given in 4.1 of IEC 60146-1-1:2009 and in 4.1 of IEC/TR 60146-1-2:2011. From the aspect of transformer design, it is important to distinguish between

– applications with essentially sinusoidal voltage across the transformer, and

– applications with non-sinusoidal voltage where the transformer primary is energized from a converter circuit for a.c. power control or variable frequency conversion.

It is also important to distinguish between

– applications characterized by a continuous load, such as electrolysis, d.c. arc furnace etc., and

– applications with short-time cyclic or irregular load variation, such as reversible mill-motor drives, etc.

Information about the converter application should be supplied in the transformer specification. This is detailed further in following subclauses of this standard.

4.2 Normal service conditions

Normal service conditions for the transformer are in accordance with IEC 60076-1, IEC 60076-2, IEC 60076-11 and IEC 60146-1-1.

Any deviation of the a.c. voltage from the rated voltage value or tapping voltage value, sinusoidal wave shape or three-phase symmetry should be within the limits of immunity class B, according to 5.4 of IEC 60146-1-1:2009. If the converter transformer is supplied with non-sinusoidal voltage, inverter or frequency converter application, it is necessary that information on the range of variation of service voltage shape and frequency variation shall be submitted in

the specification. It is also important that information is given regarding the d.c. component of the applied voltage cycle.

4.3 Provision for unusual service conditions

In addition to the unusual service conditions to be specified for power transformers, in case of transformers with more than two windings, each loading combination of the windings is to be clearly specified. Each loading combination shall include the respective current harmonic components.

Examples of this type of unusual service conditions are no or reduced load on tertiary compensation winding or on one valve winding.

5 Ratings

5.1 General

IEC 60076-1 applies, with the following additions and explanations.

Transformers for converter application are loaded with non-sinusoidal current, and sometimes work with non-sinusoidal voltage. Even the frequency may vary considerably in certain applications.

The rating of the transformers on which the tests will be conducted and to which the corresponding guarantees are related is expressed in sinusoidal quantities of fundamental frequency in steady state.

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The following subclauses provide guidance as to how to determine the transformer rating when the details of the converter and other information about the loading are available.

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5.2 Rated power at rated frequency and load capability

The rated power of the converter transformer line side winding is based on the fundamental frequency components of voltage and current, hence the rated three-phase power is:

$$S_R = \sqrt{3} \times U_1 \times I_1 \quad (1)$$

where

U_1 is the r.m.s. value of the fundamental component of the line-to-line voltage;

I_1 is the r.m.s. value of the fundamental component of the rated line side current. This fundamental component is calculated from an ideal rectangular waveshape current (see Table 1).

The rated power S_R and line current I_1 shall be used for guaranteed load losses and short circuit impedance.

The rated power of the valve windings S_V is equal to the rated power of the line winding multiplied by a factor which is a function of number of valve windings and type of rectifier (single or double way). This factor is defined in Table 1.

The thermal design and cooling system of the transformers shall be determined after allowance is made for the increased losses due to harmonics (including d.c. components) by means of an equivalent thermal current to be used in temperature rise test (see Clause 6).

In case of cyclic loading, the load variation pattern shall be included by the purchaser in the transformer specification.

5.3 Rated and service voltages

5.3.1 Transformer energized from an a.c. power system

For a converter transformer connected to an a.c. power system, the rated voltage shall be as specified in 5.4 of IEC 60076-1:2011 and in IEC 60076-8.

5.3.2 Transformer energized from a converter/inverter with or without variable frequency

For a converter application with a considerably distorted transformer voltage, the rated voltage shall be the r.m.s value of the sinusoidal fundamental component derived from the Fourier series analysis of the maximum continuous service voltage.

For applications with such a distorted transformer voltage, or with variable frequency, information shall be given in the specification concerning the applied voltage under various service conditions.

NOTE For the above applications, the amplitude of flux density in the magnetic circuit is the determining parameter, and not the amplitude of a non-sinusoidal voltage. The value of flux is determined by the voltage-time integral over a half-cycle. This value will be the maximum value in continuous service. If short-time higher values of the voltage-time integral exist, they should also be included in the specification, to permit checking against possible overfluxing.

5.4 Rated current

The rated current of the transformer is the r.m.s. value of the fundamental component of current corresponding to rated power according to 5.2.

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5.5 Phase displacement and terminal identification for three-phase transformer

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The definition of phase displacement is described in 3.10.6 of IEC 60076-1:2011.

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Whenever the ‘clock number’ notation outlined in the Clause 7 of IEC 60076-1:2011 is not sufficient to identify the phase displacement; the nearest clock number shall be used followed by the value with sign of the angle Γ which has to be added to obtain the exact phase displacement. The indication of the sign of the Γ has to follow the definition of the leading and lagging displacement included in 3.10.6 of IEC 60076-1:2011 (see Annex I).

The terminal identification of a converter transformer shall also include the information regarding the sequence of the commutating valve. Therefore the terminals are expressed by a code of three symbols as described below.

First symbol: Number, that refers the different winding systems (with 1 for line side winding).

Second symbol: Letter, that refers the sequence of the phases according to the IEC 60616.

Third symbol (optional): “+” or “–“ that refers to which polarity of the rectifier the terminal is connected to.

Examples of different type of connections, phase displacement and terminal indications are included in the Annex I.

If the phase displacement changes with tap position, the one on the nominal tap shall be indicated and the range of variation shall be agreed at the tender stage.