SLOVENSKI STANDARD
SIST EN 61378-1:2002

01-oktober-2002

Convertor transformers - Part 1: Transformers for industrial applications (IEC 61378-1:1997)

Convertor transformers -- Part 1: Transformers for industrial applications

Stromrichtertransformatoren -- Teil 1: Transformatoren für industrielle Anwendungen

Transformateurs de conversion -- Partie 1: Transformateurs pour applications industrielles

Ta slovenski standard je istoveten z: EN 61378-1:1998

ICS:

29.180	Transformatorji. Dušilke	Transformers. Reactors

SIST EN 61378-1:2002 **en**

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 61378-1

November 1998

ICS 29.180

English version

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Ref. No. EN 61378-1:1998 E

Foreword

The text of document 14/261/FDIS, future edition 1 of IEC 61378-1, prepared by IEC TC 14, Power transformers, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61378-1 on 1997-07-01.

The following dates were fixed:

- latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 1999-08-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 1999-08-01

Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annex ZA is normative and annexes A and B are informative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61378-1:1997 was approved by CENELEC as a European Standard without any modification.

CONTENTS

CONVERTOR TRANSFORMERS –

Part 1: Transformers for industrial applications

1 General

1.1 *Scope*

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

The scope of this standard is limited to applications of power convertors, of any power rating, for local distribution, at moderate rated convertor voltage, generally for industrial applications and typically with a highest voltage for equipment not exceeding 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.

The standards for the complete convertor plant (IEC 60146, or other publications dedicated to particular fields of application) may contain requirements of guarantees and tests (such as insulation, power loss) for the whole plant, including the convertor 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 convertor transformer itself as a separate component before being assembled with the remainder of the convertor plant.

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

The convertor 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 are required to comply with IEC 60076 for oil-immersed transformers, and with IEC 60726 for dry-type transformers.

NOTES

1 For some convertor applications, it is possible to use common distribution transformers of standard design. The use of such standard transformers in the special convertor 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.

2 Where dry-type transformers are used, special care should be taken in considering the short time constants applicable and the increased eddy currents flowing in the larger cross-section conductors or foil windings.

3 EN 61378-1 is not applicable for railway applications.

This standard only deals with transformers with one active part and one interphase transformer. For several active parts in the same tank, an agreement between the purchaser and manufacturer is necessary regarding the determination and the measurement of the total losses.

This standard deals only with transformer star Y and delta Δ connections. For other connections an agreement between purchaser and manufacturer is necessary.

1.2 *Classification*

Classification of convertors and convertor applications are given in 1.3 of IEC 60146-1-1 and in 1.2 of IEC 60146-1-2. 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 convertor 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.

It is required that information about the convertor application be supplied in the transformer specification. This is detailed further in following subclauses of this standard.

1.3 *Normal service conditions*

Normal service conditions for the transformer shall be in accordance with IEC 60076-1, IEC 60076-2, IEC 60726 and IEC 60146-1-1.

It is required that any deviation of the a.c. voltage from the rated voltage value or tapping voltage value, sinusoidal wave shape or three-phase symmetry be within the limits of immunity class B, according to 2.5 of IEC 60146-1-1. If the convertor transformer is supplied with non-sinusoidal voltage, invertor or frequency convertor application, it is necessary that information on the range of variation of service voltage shape and frequency variation be submitted in the specification. It is also important that information be given regarding the d.c. component of the applied voltage cycle.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61378. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 61378 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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

IEC 60076-1:1993, *Power transformers – Part 1: General*

IEC 60076-2:1993, *Power transformers – Part 2: Temperature rise*

IEC 60076-3:1980, *Power transformers – Part 3: Insulation levels and dielectric tests*

IEC 60076-5 :1976, *Power transformers – Part 5: Ability to withstand short circuit*

IEC 60146-1-1:1991, *Semiconductor convertors – General requirements and line commutated convertors – Part 1-1: Specifications of basic requirements*

IEC 60146-1-2:1992, *Semiconductor convertors – General requirements and line commutated convertors – Part 1-2: Application guide*

IEC 60289:1988, *Reactors*

IEC 60354:1991, *Loading guide for oil-immersed power transformers*

IEC 60076-8:1997, *Application guide for power transformers*

IEC 60726:1982, *Dry-type power transformers*

IEC 60905:1987, *Loading guide for dry-type power transformers*

3 Definitions

For the purpose of this International Standard, the definitions in IEC 60050(421) (IEV) apply. Additional definitions of more specific transformer and convertor terms are given in IEC 60076-1, and IEC 60146-1-1, respectively. Where some of these terms are at variance with earlier general definitions of the same terms, found in the IEV, the terms specified in IEC 60076-1 and IEC 60146-1-1 will take precedence. Particular attention is drawn to the terms defined in 1.5.17, 1.5.18, 1.5.19, and 1.5.22 to 1.5.26 inclusive, of IEC 60146-1-1.

4 Ratings

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

Transformers for convertor 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.

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

4.1 *Rated power at rated frequency and load capability*

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

$$S_R = \sqrt{3} \times U_1 \times I_1$$

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 current.

The temperature rise and cooling requirements of the transformers shall be determined after allowance is made for the increased losses due to harmonics (see clause 5).

The load capability of a transformer is essentially a matter of temperature rise within the windings. If load variations are rapid, with peaks having a duration of 5 min or less, then the power rating of the transformer is based on the long-term average value of the load losses.

If the load variations are of longer duration than those defined above, a more detailed study can be made of the maximum temperature peaks during the load pulse or cycle. Guidance for determination of an equivalent constant loading with respect to the rate of thermal aging of the insulation system can be obtained from IEC 60354 for oil-immersed transformers, and IEC 60905 for dry-type transformers. The equivalent constant load so determined may be taken as the rated power of the transformer.

NOTE – The rules above are justified by the considerable thermal time constants of power transformers. In table 2 of IEC 60146-1-1, a number of conventional load cycle patterns are given, representing different convertor duties. These load cycles should be verified in accordance with the rules given above.

The load variation pattern shall be included by the purchaser in the transformer specification in order to determine a suitable value of rated power.

4.2 *Rated and service voltages*

4.2.1 *Transformer energized from an a.c. power system*

For a convertor transformer connected to an a.c. power system, the rated voltage shall be as specified in 4.4 of IEC 60076-1 and in IEC 60076-8.

4.2.2 *Transformer energized from a convertor/invertor with or without variable frequency*

For a convertor 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 spectrum 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 1 – 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.

No-load core losses in transformers are relatively low. Therefore, no correction is necessary for the measured no-load loss with regard to voltage harmonics.

NOTE 2 – The corresponding flux ripple, being a time-integral, is relatively smaller than the short time voltage peaks.

4.3 *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 4.1.

5 Load loss and voltage drop in transformers and reactors

The measurement of load loss shall be carried out with the rated current. The load loss guarantee shall be based on this measurement.

The actual load loss in service includes additional loss due to distorted current. This value shall be calculated in accordance with the procedure of 5.1. It is not guaranteed, but shall be provided by the transformer manufacturer for the purchaser.

The actual load loss, calculated as above, shall be used as the base for determining the oil and winding temperature rises, and to verify that they do not exceed the values permitted in IEC 60076-2 for oil-immersed transformers and IEC 60726 for dry-type transformers.

The temperature-rise type test on the transformer, when specified, shall be conducted with allowance for service load loss (see 5.1 and 6.4).

5.1 *Determination of transformer load loss under distorted current loading*

The load loss in a transformer is conventionally subdivided into loss as measured with d.c. (I^2R loss) and, in addition, eddy loss in windings and connections, and stray losses in conductive structural parts of the transformer.

For transformers with low-voltage high-current windings, in the range of a few kiloamperes, the internal high current connections require a separate analysis of the additional eddy loss. The following principles are used in this standard:

a) winding connections and metallic shields of high conductivity such as copper or aluminium are linear elements. Their losses are proportional to the square of the current:

$$P(I) = \text{constant} \times I^2$$

b) a similar relationship is also valid for shields of magnetic core steel, when used in unsaturated conditions:

$$P(B) = \text{constant} \times B^2$$

where B is the flux density in the magnetic shield;

c) for the stray losses in structural steel parts, a square law relationship may also be used with reasonable accuracy:

$$P(B) = \text{constant} \times B^2$$

where $B^2 = \text{constant} \times I^2$.

In normal service, the convertor transformer load current is non-sinusoidal hence, when transformed into a Fourier series, it shows a considerable amount of harmonics. This non-sinusoidal current raises the eddy loss and stray flux loss, and significantly increases the total loss calculated or measured with purely sinusoidal current.

A correction to the higher loss value at rated, non-sinusoidal convertor load is required for the thermal dimensioning of the transformer, and for the correct calculation of the loss and efficiency of the complete convertor installation. The harmonic spectrum shall be specified by the purchaser prior to the time of placing the order.

It is necessary that the harmonic spectrum of current at rated load be specified by the purchaser prior to the time of placing the order. In the absence of specific information, a harmonic spectrum can be derived according to 3.6.2 and/or 3.6.4 of IEC 60146-1-2. The load losses in convertor application shall be calculated from the harmonic spectrum defined above and the following formulae given in this clause.

The following rules are given for the recalculation of the measured loss under test to the loss value valid under the specified convertor loading.

List of variables and relationships between them

I_L	is the r.m.s. value of non-sinusoidal line current of the transformer
I_{LN}	is the r.m.s. value of current I_L at rated convertor load
I_{PN}	is the r.m.s. value of the non-sinusoidal primary phase current at rated load
I_{SN}	is the r.m.s. value of the non-sinusoidal secondary phase current at rated load
I_{PT}	is the r.m.s. value of the primary phase current during load loss tests (first approximation for the injection of the total load loss)
I_{ST}	is the r.m.s. value of the secondary phase current (six phases) during load loss tests
I_{WN}	is the r.m.s. value of the rated current in the winding under test
I_h	is the r.m.s. value of harmonic current, having order number h
I_P	is a sinusoidal primary phase current having an r.m.s. value equal to I_{PN}
I_S	is a sinusoidal secondary phase current having an r.m.s. value equal to I_{SN}
I_1	is the r.m.s. value of the fundamental current, at rated load (that is equal to transformer rated current)
I_{1P}	is the r.m.s. value of the transformer fundamental primary phase current
I_{1S}	is the r.m.s. value of the transformer fundamental secondary phase current
I_{eq}	is the r.m.s. value of the equivalent sinusoidal test current for the determination of winding temperature rise
I_{dN}	is the rated direct current
U_{d0}	is the conventional no-load direct voltage
h	is the harmonic order number

P_0 is the no-load loss at rated voltage

P_N is the transformer load loss with current I_{LN}

P_1 is the transformer load loss with current I_1

P_W is the winding loss with current I_L

P_{Wh} is the winding loss with current I_h

P_{W1} is the winding loss with current I_1

P_{WP} is the primary winding loss with I_{LN}

P_{WS} is the total secondary winding and associated busbar loss with I_{LN}

P_{WE} is the winding eddy loss with current I_L

P_{WEh} is the winding eddy loss with current I_h

P_{WE1} is the winding eddy loss with current I_1

P_C is the connection loss with current I_L

P_{Ch} is the connection loss with current I_h

P_{C1} is the connection loss with current I_1

P_{CE} is the connection eddy loss with current I_L

P_{CEh} is the connection eddy loss with current I_h

P_{CE1} is the connection eddy loss with current I_1

P_{SE} is the structural parts stray loss with current I_L

P_{SE1} is the structural parts stray loss with current I_1

R_W is the d.c. resistance of windings

R_C is the d.c. resistance of connections

F_{WE} is the eddy loss enhancement factor for windings (see annex A)

F_{CE} is the eddy loss enhancement factor for connections (see annex A)

F_{SE} is the stray loss enhancement factor for structural parts (see annex A)

K_{WE} is the eddy loss enhancement loss for windings at fundamental frequency (see annex A)

x is the exponent to be applied on the frequency harmonic order in calculations of eddy and stray loss enhancement

$$I_L^2 = \sum_1^n I_h^2$$

$$P_{WE} = \sum_1^n P_{WEh} = F_{WE} \times P_{WE1} = P_W - R_W \times I_L^2$$

where R_W is seen from the line side.