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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Converter transformers –
Part 3: Application guide

Transformateurs de conversion –
Partie 3: Guide d'application

IEC 61378-3:2015-02(en-fr)

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Part 3: Application guide

FOREWORD

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International Standard IEC 61378-3 has been prepared by IEC technical committee 14: Power transformers.

This second edition cancels and replaces the first edition published in 2006 and constitutes a technical revision.

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

a) revision of clause on losses to reflect the changes introduced by the second edition of IEC 61378-1;

b) addition of a new clause about design review of converter transformer for both industrial and HVDC applications;

c) addition of content for transformer connected to voltage source converters;

d) reference to the work of CIGRE JWG A2/B4.28 on HVDC transformers.

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

FDIS	Report on voting
14/803/FDIS	14/808/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.

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

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

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

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- withdrawn,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

INTRODUCTION

0.1 General

IEC 61378 series is written in three parts:

– Part 1 applies to transformers associated with general "Industrial" converter uses. (Copper making, aluminium smelting and the electrolysis of certain gases).

– Part 2 applies to transformers required for HVDC applications.

– Part 3 is this application guide which contains the topic headings described in 0.2 to 0.13.

The scope of IEC 61378-1 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.

IEC 61378-2 covers converter transformers used in “HVDC Applications”. There are two types of HVDC power transmission systems known generically as “back to back” and “transmission” schemes. The operation and evaluation of transformers operating within these two systems are covered by Part 2 and the present part of IEC 61378.

Neither IEC 61378-1:2011 nor IEC 61378-2:2001 explicitly include in their scope transformers connected to voltage source converters (VSC). Because VSC applications are becoming more and more common, some guidance is provided in this standard.

0.2 Rating data (Clause 5)

In both IEC 61378-1 and IEC 61378-2, the method of rating converter transformers is different to that used historically. In the traditional method, the r.m.s. value of current was used in defining the nameplate rating of the transformer. IEC 61378 has introduced a fundamental change in the method of defining the rating of transformers. The concept of using the fundamental components of voltage and current as the basis for the transformer nameplate rating is explained. The nameplate rating derived from these fundamental components becomes the basis for the guaranteed impedances and losses.

0.3 Winding configurations (Clause 6)

There are a large number of winding connections and configurations that are specific to converter transformers for both industrial and HVDC applications. They have been developed over many years. The operating characteristics of the various rectifier connections are mostly covered in IEC 60146 series. In the present part of IEC 61378, the connections are discussed in so far as they affect the construction and some operational aspects of the transformer.

The use of regulating schemes is common in industrial applications. The present part of IEC 61378 covers the principles for a number of these schemes.

0.4 Tappings and impedances (Clause 7)

The impedance of transformers for HVDC applications requires special attention and design solutions. The requirements primarily concern the limitation of the impedance variability over the whole tapping range, the limitation of the impedance difference between transformers and in some applications, the impedance difference between star and delta windings. This standard discusses these requirements and their practical aspects.

In general, the tapping range in converter transformers is wider than in conventional transformers. The impact of the wider tapping range on the transformer and the tap-changer is discussed in this standard.

0.5 Insulation aspects and dielectric tests (Clause 8)

Two aspects are covered in Clause 8. First, the increasing use of "hybrid" insulation systems in transformers for industrial applications. Secondly, the ability of transformer insulation structures of HVDC transformers when tested with d.c. voltage and in service.

The basic principles, the methods of testing and the test voltage levels used for both a.c. and d.c. testing are discussed. The safety margins associated with the proposed testing regime are also reviewed.

0.6 Losses (Clause 9)

The present part of IEC 61378 details the derivation of the principles, testing and calculation methods used that take into account the effects of non-sinusoidal load currents on converter transformers of all types.

The principles of testing at two frequencies for HVDC applications are detailed along with a worked example of the calculation. The losses derived from these tests and calculations are used as the base for specifying the test losses and currents to be used in establishing the oil and winding gradients during the thermal testing.

0.7 Core and sound aspects (Clause 10)

The effects of voltage harmonics and a d.c.-bias circulating-current on the performance and construction of the core are discussed and summarized.

The causes of sound and the differences that may be expected between conventional factory sound measurements and those to be expected and experienced at site are reviewed.

The latest methods of assessment of sound associated with converter transformers are discussed.

0.8 Transformer specification (Clause 11)

Transformers for converters differ significantly from power transformers with respect to the transformer specification. An outline of the details required in any specification is included as part of the guide for both technical and functional types of specification.

Some guidance as to what should be specified by the purchaser and what should be expected from the manufacturer during the tender and order process is given.

0.9 Short circuit considerations (Clause 12)

In conventional power transformers, the calculation of the short circuit currents within the windings are dependent solely on the impedance and resistance components of the transformer and supply to which it is connected.

In the case of transformers used to supply converter applications, there are fault conditions within the converter that need to be considered where the peak value of the fault currents may be higher than those derived for conventional power transformers. These conditions are detailed in the present part of IEC 61378.

0.10 Components (Clause 13)

In the design of transformers for both industrial and HVDC converter applications, the choice and operation of the on-load tap-changer is crucial. The present part of IEC 61378 outlines some of the principles governing the use of tap-changers in these applications.

In the HVDC application, the choice and integration of the valve-side bushings into the overall design is of vital importance.

The general requirements and recommendations for the construction, integration of the bushings with the transformer and testing are detailed. An IEC standard specifically for HVDC bushing is in preparation and the recommendations in the present part of IEC 61378 draws upon the requirements of the new standard.

0.11 Maintenance (Clause 14)

Statistics suggest that the HVDC transformers require maintenance to a high standard. Those items that require particular attention are on-load tap-changers and valve-side bushings. Attention is drawn in this standard to maintenance requirements.

0.12 Monitoring and on-site investigations (Clause 15)

Transformer monitoring is recommended if on-site problems are to be minimized and in this respect, condition monitoring is discussed. The present part of IEC 61378 also presents recommendations for the procedure and practices to be followed in the event of a failure at site. These recommendations are made so that vital evidence and data are not destroyed or contaminated at the initial stages of the investigation.

The use of condition monitoring for this application is also discussed in Clause 15.

0.13 Additional sources of information

The preparation of the present part of IEC 61378, specifically for IEC 61378-2 HVDC converter applications, was significantly influenced by the working papers on various topics of CIGRE Joint Working Group 12/14.10.

CONVERTER TRANSFORMERS –

Part 3: Application guide

1 Scope

This part of IEC 61378 provides information to users about specific topics related to industrial and HVDC converter transformers with design, construction, testing and operating conditions differing from conventional transformers used in power systems. In addition, it is the aim of the present part of IEC 61378 to provide manufacturers with the technical background that forms the basis for the principles used within IEC 61378-1 and IEC 61378-2.

It is intended that this part of IEC 61378 is used to supplement and not replace or supersede the application guide for power transformers, IEC 60076-8, since many of the general principles contained within it are equally applicable to converter transformers.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 60076-5:2006, *Power transformers – Part 5: Ability to withstand short circuit*

IEC 60076-14:2013 *Power transformers – Part 14: Liquid-immersed power transformers using high-temperature insulation materials*

IEC 60296, *Fluids for electrotechnical applications – Unused mineral insulating oils for transformers and switchgear*

IEC 60422, *Mineral insulating oils in electrical equipment – Supervision and maintenance guidance*

IEC 61378-1:2011, *Converter transformers – Part 1: Transformers for industrial applications*

IEC 61378-2:2001, *Convertor transformers – Part 2: Transformers for HVDC applications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61378-1 and IEC 61378-2 apply.

4 Symbols and abbreviations

Symbol	Meaning	Units
I_1	r.m.s. value of the fundamental component of the rated line side current	A
I_x	r.m.s. value of the load loss test current at frequency f_x	A

Symbol	Meaning	Units
I_{LN}	r.m.s. value of the non-sinusoidal in-service load current in the winding under consideration at rated converter load	A
I_h	r.m.s. value of harmonic current having order number h	A
I_{eq}	r.m.s. value of the equivalent sinusoidal test current giving the winding in-service load loss	A
h	harmonic order number	
U_1	r.m.s. value of the fundamental component of the line-to-line rated voltage	V
S_r	Rated power of the transformer	VA
P_1	Transformer load losses measured at current I_1	W
P_x	Transformer load loss measured at current I_x	W
I_1^2R	Ohmic losses at rated current I_1	W
R	d.c. resistance of windings including internal leads	Ω
P_{WE1}	Eddy losses in windings with current I_1	W
P_{SE1}	Stray losses in structural parts (excluding windings) with current I_1	W
P_N	Transformer load loss in service with current I_N	W
f_1	Rated frequency and also the fundamental frequency (50 Hz or 60 Hz)	Hz
f_X	Frequency ≥ 150 Hz used to determine the distribution of eddy losses (HVDC transformer applications only, not applicable for industrial transformer applications)	Hz
f_h	Frequency at harmonic order number h	Hz
F_{WE}	Enhancement factor for winding eddy losses	
F_{SE}	Enhancement factor for stray losses in structural parts	
K_h	Ratio of the current I_h to the rated current I_1	
U_{ac}	a.c. separate source test voltage for the valve windings (r.m.s. value)	V
U_m	Highest system voltage of the line winding	V
U_{dm}	Highest d.c. voltage per valve bridge	V
U_{dc}	d.c. separate source test voltage for the valve windings	V
U_{pr}	Polarity reversal test voltage for the valve windings (d.c. voltage)	V
U_{vm}	Maximum phase to phase a.c. operating voltage of the valve windings of the converter transformer	V
N	Number of six-pulse bridges in series from the neutral of the d.c. line to the rectifier bridge connected to the transformer	
NOTE "Valve side" and "line side" define the external connections of the transformer windings. Line side refers to the winding connected to the a.c. network and valve side to the winding connected to the converter.		

5 Rating data

IEC 61378-1 and IEC 61378-2 state that the rating characteristics of the transformer are expressed in steady state sinusoidal quantities of current and voltage at the rated fundamental frequency. The guaranteed losses, impedances and sound level shall correspond to these values. The rated voltage and current refer to the fundamental quantities, line-to-line voltage and line current.

Fundamental components are selected to establish a common platform for guaranteed quantities such as losses and impedances independent of the operating conditions and thus the spectrum of harmonic content. It should be noted that the tests in establishing the operating characteristics can only be carried out with sinusoidal quantities.

When industrial transformer units are provided with transductors (saturable reactors) in their tank, transductor cores make the test challenging because of the distortion of current and voltage wave shapes they cause. An agreement on the test modalities needs to be reached between the supplier and the purchaser before signing of the contract. No method has been commonly accepted. Some are presented in Annex G of IEC 61378-1:2011.

Guaranteed temperature rise values are relevant for a specific loading condition as defined by agreement between purchaser and manufacturer. As a converter transformer is exposed to a current with a certain harmonic content, the actual losses will deviate from the losses developed with a true sinusoidal current. In general, harmonics in the current will give rise to an enhancement in load losses as compared to operation with true sinusoidal current.

From the aspect of transformer design, it is important to distinguish between

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

Information about the converter application should be supplied in the transformer specification.

The no-load loss guaranteed value is defined by the rated sinusoidal voltage.

The actual load loss in converter operation is estimated with sufficient accuracy by the calculation procedure presented in IEC 61378-1:2011, 6.2 and in IEC 61378-2. From this set of formulae the corresponding test current for establishing the corresponding temperature rise can be deduced (see IEC 61378-1:2011, 7.6 or IEC 61378-2:2001, 10.5).

It should also be noted that the actual load current in operation may be higher than the rated current, when measured by an instrument reading r.m.s. values of current, since the rated current on the nameplate refers to the fundamental component of the load current.

6 Winding configurations

6.1 General

This clause describes the different versions of arrangement of windings that can exist in both industrial and HVDC applications.

In general, the windings will be arranged to provide a six-pulse converter bridge from a balanced three-phase system. The converter will carry current twice from each phase for a maximum duration of 120 electrical degrees or one third of a cycle, once in positive and once in negative direction. See Figure 1.

Two or more six-pulse bridges may be connected in series or parallel. When supplying the individual bridges with line-side, three-phase voltages displaced in time, the harmonic content in line-side currents and valve-side voltages and currents will be reduced. With two six-pulse bridges connected in a so-called twelve-pulse arrangement, the two three-phase supplies shall be separated by 30 electrical degrees. Still higher pulse numbers on the converters require less separation between the systems. See Figures 2 and 3.