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Power transformers –
Part 16: Transformers for wind turbine applications

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FOREWORD

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International Standard IEC/IEEE 60076-16 has been prepared by IEC technical committee 14: Power transformers, in cooperation with Performance Characteristics Subcommittee of the IEEE Power and Energy Society [1], under the IEC/IEEE Dual Logo Agreement between IEC and IEEE.

This second edition of IEC/IEEE 60076-16 cancels and replaces IEC 60076-16:2011, and constitutes a technical revision.

The main changes with respect to the previous edition are as follows:

1) relationship between transformer rated power and the output current from the associated generator is introduced;
2) thermal correction of the effective cooling medium has been introduced;
3) testing regime has been strengthened to ensure transformers are suitable for the harsh electrical environment to which they are subjected.

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
14/959/FDIS	14/965/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 all parts in the IEC/IEEE 60076 series, published under the general title *Power transformers*, can be found on the IEC website.

1 A list of IEEE participants can be found at the following URL: https://standards.ieee.org/project/60076-16.html

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- withdrawn,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.

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INTRODUCTION

This part of IEC 60076 is intended to specify the additional requirements for the transformers for installation in wind turbine applications.

Wind turbines use generator step-up transformers to connect the turbines to a network. These transformers can be installed in the nacelle or in the tower or outside close to the wind turbine.

This standard covers transformers for wind turbine applications or wind farms where the constraints on transformers exceed the requirement of the present IEC 60076 series. The constraints are not often known or recognized by the transformer manufacturers, wind turbine manufacturers and operators and as a result the level of reliability of these transformers can be lower than those used for conventional applications.

The transformers for wind turbine applications are not included in the present list of IEC 60076 standard series.

The purpose of this standard is help to obtain the same level of reliability as transformers for more common applications.

This standard deals particularly with the effects of repeated high frequency transient over-voltages, electrical, environmental, thermal, loading, installation and maintenance conditions that are specific for wind turbines or wind farms.

On site measurements, investigations and observations in wind turbines have detected risks for some different kind of installations:

- repeated high frequency transient over or under voltages in the range of kHz;
- over and under frequency due to turbine control;
- values of over voltage;
- over voltage or under voltage coming from LV side;
- high level of transient over voltages due to switching;
- presence of partial discharge around the transformer;
- harmonic contents current and voltage;
- overloading under ambient conditions;
- fast transient overload;
- clearances not in compliance with the minimum prescribed;
- installation conditions and connections;
- restricted conditions of cooling;
- water droplets;
- humidity levels that exceed the maximum permissible values;
- salt and dust pollution and extreme climatic conditions;
- high levels of vibration;
- mechanical stresses.

Therefore it is necessary to take into account in the design of the transformer the constraints of this application, or to define some protective devices to protect the transformer. Additional or improved routine, type or special tests for these transformers have to be specified to be in compliance with the constraints on the network.

POWER TRANSFORMERS –

Part 16: Transformers for wind turbine applications

1 Scope

This part of IEC 60076 applies to dry-type and liquid-immersed transformers for ~~rated power 100 kVA up to 10 000 kVA for~~ wind turbine step-up applications having a winding with highest voltage for equipment up to and including ~~36~~ 72,5 kV ~~and at least one winding operating at a voltage greater than 1,1 kV~~. This document applies to the transformer used to connect the wind turbine generator to the wind farm power collection system or adjacent distribution network and not the transformer used to connect several wind turbines to a distribution or transmission network.

Transformers covered by this document comply with the relevant requirements prescribed in the IEC 60076 standards or IEEE C57 standards.

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

IEC 60076-7~~:2005~~, *Power transformers – Part 7: Loading guide for mineral-oil-immersed power transformers*

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

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

IEC 60076-12~~:2008~~, *Power transformers – Part 12: Loading guide for dry-type power transformers*

~~IEC 60076-13:2006, *Power transformers – Part 13: Self-protected liquid-filled transformers*~~

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

~~IEC 61100, *Classification of insulating liquids according to fire-point and net calorific value*~~

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

~~IEC 61378-3:2006, *Converter transformers – Part 3: Application guide*~~

~~IEC 61400-1:2005, *Wind turbines – Part 1: Design requirements*~~

2.2 IEEE references

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

IEEE Std C57.12.01™, *IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers*

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

IEEE Std C57.91™, *IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators*

IEEE Std C57.96™, *IEEE Guide for Loading Dry-Type Distribution and Power Transformers*

IEEE Std C57.110™, *IEEE Recommended Practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Nonsinusoidal Load Currents*

IEEE Std C57.154™, *IEEE Standard for the Design, Testing, and Application of Liquid-Immersed Distribution, Power, and Regulating Transformers Using High-Temperature Insulation Systems and Operating at Elevated Temperatures*

ANSI C84.1, *Electric Power Systems and Equipment – Voltage Ratings (60 Hz)*

2.3 ISO references

ISO 12944 (all parts), *Paints and varnishes – Corrosion protection of steel structures by protective paint systems*

ISO 12944-4, *Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 4: Types of surface and surface preparation*

2.4 CENELEC references

EN 50588-1:2015, *Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV – Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC 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

3.1
wind turbine transformer
generator step up transformer connecting the wind turbine to the power collection ~~network~~ system of the wind farm or the adjacent distribution network for single turbine installations

3.2
tower
~~part of the~~ supporting structure of the wind turbine on top of which the nacelle with generator and other equipment~~s are~~ is located

3.3
nacelle
housing that contains the drive-train and other elements on top of a horizontal-axis wind turbine tower

[SOURCE: IEC 60050-415:1999, 415-01-07]

3.4
effective cooling medium
ambient air, either internal or external to the tower or nacelle, or cooling water that comes into contact with the cooling surface of the transformer

3.5
compartmentalized type transformer
transformer with integral enclosure comprised of multiple independent compartments, usually with separate entrances into the HV and LV termination compartments

3.6
sealed transformer
transformer which is so constructed that the external atmosphere is not intended to gain access to the interior

3.7
routine sample test
test which is usually defined as a type test or special test but carried out as an additional routine test on a random sample of transformers

4 Use of normative references

This standard 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 wind turbine transformers intended for installation in North America where IEEE standards shall be used.

5 Rating

The transformer rating specified by the purchaser shall take into account the maximum current delivered to the transformer by the associated wind turbine generator system irrespective of the operating voltage and power factor.

6 Service conditions

6.1 Normal service conditions

6.1.1 General

~~Unless otherwise stated in this standard, the service conditions in IEC 60076-11 and IEC 60076-1 apply.~~

The normal service conditions detailed in IEC 60076-1 or IEEE Std C57.12.00 for liquid-immersed transformers or the normal service conditions in IEC 60076-11 or IEEE Std C57.12.01 for dry-type transformers shall apply unless otherwise stated in this document or specified by the purchaser.

~~**4.2 Altitude**~~

~~IEC 60076 series applies.~~

6.1.2 Temperature of external cooling ~~air~~ medium

~~The installation of transformers inside an enclosure without active cooling systems increases the transformer temperature.~~

~~The purchaser shall specify the maximum cooling air temperatures if they are different from those stated in IEC 60076-2.~~

~~The transformer shall be designed according to real ambient temperatures and installation real conditions as described by the purchaser at enquiry stage.~~

~~Clause A.1 provides considerations for transformers installed in a naturally ventilated area like at the rear of the nacelle or in a separate enclosure installed outside the tower and equipped with air inlet and outlet.~~

~~In case of transformer installed in the tower or in an enclosure where natural ventilation is not provided the formula in A.1 is not applicable. For transformers operating under these conditions, the effects of air inlet and outlet, cooling conditions, efficiency of air cooling and ventilation shall be considered.~~

~~The purchaser shall prescribe the air ambient temperature and air flow inside the tower at the enquiry stage. If no temperature or air flow is specified, an internal ambient temperature inside the tower of 10 K higher than external temperature shall be assumed and not limited air circulation around the transformers.~~

~~The effect of external direct solar radiation is not taken into account at the design stage. This can increase the temperature of transformers parts and therefore information should be given by purchaser at enquiry time.~~

If the transformer is installed external to the tower or nacelle, the normal conditions specified in IEC 60076-1 or IEEE Std C57.12.00 for liquid-immersed transformers and IEC 60076-11 or IEEE Std C57.12.01 for dry-type transformers shall apply, unless otherwise specified. If the transformer is installed within the tower or nacelle then particular conditions apply as shown in 6.2.

6.2 Particular service conditions for transformers installed in a tower or nacelle

6.2.1 General

Where the transformer is installed in a tower or nacelle then higher temperatures of the cooling medium local to the transformer may be expected.

6.2.2 Temperature rise correction

Based on the ambient conditions of the installation, the purchaser shall specify the yearly average and maximum temperature of the effective cooling medium (e.g. air or water). If the yearly average or maximum temperature of the cooling medium exceeds the relevant value in the respective standard, the difference between the values and the "normal service conditions" values shall be subtracted from the temperature rise limits specified in IEC 60076-2, IEC 60076-11 or IEEE Std C57.12.00 as follows:

$$K_{\text{max}} = T_{\text{max ecm}} - T_{\text{max std}}$$

$$K_{\text{av}} = T_{\text{av ecm}} - T_{\text{av std}}$$

where

K_{max} is the temperature correction for the maximum ambient temperature;

K_{av} is the temperature correction for the yearly average ambient temperature;

$T_{\text{max ecm}}$ is the maximum temperature of the effective cooling medium;

$T_{\text{max std}}$ is the maximum ambient temperature of the effective cooling medium according to the relevant standard;

$T_{\text{av ecm}}$ is the average temperature of the effective cooling medium;

$T_{\text{av std}}$ is the yearly average ambient temperature of the effective cooling medium according to the relevant standard.

K_{av} can be used in determining the temperature rise limit of average winding and winding hot-spot temperatures in all transformers. In liquid-immersed transformers K_{max} can be used in determining the temperature rise limit for the top liquid temperature.

If the only available information is the maximum ambient temperature, the increase of the yearly average ambient temperature can be assumed to be the same as the increase of the maximum ambient temperature, making K_{av} and K_{max} equal.

For example, for a transformer using insulation material of thermal class 105 (regular kraft paper immersed in mineral oil) installed in an environment where the average temperature is 32 °C and the maximum ambient temperature is 48 °C, the corrected temperature rise limits based on IEC 60076-2 would be:

$$K_{\text{av}} = (32 - 20) = 12 \text{ K}$$

$$\Delta\theta_{\text{w}} = 65 - K_{\text{av}} = 65 - 12 = 53 \text{ K}$$

$$\Delta\theta_{\text{h}} = 78 - K_{\text{av}} = 78 - 12 = 66 \text{ K}$$

For liquid-immersed transformers K_{max} can be applied:

$$K_{\text{max}} = (48 - 40) = 8 \text{ K}$$

$$\Delta\theta_{\text{o}} = 60 - K_{\text{max}} = 60 - 8 = 52 \text{ K}$$

Another example, for a transformer using thermally upgraded insulation material (thermally upgraded kraft paper immersed in mineral oil) with similar conditions to the previous example, the corrected temperature rise limits based on IEEE Std C57.12.00 would be: