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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Power transformers –
Part 16: Transformers for wind turbine applications

Transformateurs de puissance –
Partie 16: Transformateurs pour applications éoliennes

IEC 60076-16:2011

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FOREWORD

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International Standard IEC 60076-16 has been prepared by IEC technical committee 14: Power transformers.

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

FDIS	Report on voting
14/690/FDIS	14/698/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 of the IEC 60076 series can be found, under the general title *Power transformers*, 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

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- withdrawn,
- replaced by a revised edition, or
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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 applications having a winding with highest voltage for equipment up to and including 36 kV and at least one winding operating at a voltage greater than 1,1 kV.

Transformers covered by this standard comply with the relevant requirements prescribed in the IEC 60076 standards.

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 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 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 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*

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

3 Terms and definitions

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

3.1
wind turbine transformer
generator step up transformer connecting the wind turbine to the power collection network of the wind farm

3.2
tower
part of the supporting structure of wind turbine on top of which the nacelle with generator and other equipments are located

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

4 Service conditions

4.1 Normal service conditions

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

4.2 Altitude

IEC 60076 series applies.

4.3 Temperature of cooling air

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.

4.4 Content of harmonic currents in the transformer

At the enquiry stage the purchaser shall specify the magnitude and frequency of all harmonic currents supplied to the transformer. The manufacturer shall take the losses caused by these harmonic currents into account in the transformer design to prevent that the winding and liquid temperature rises exceed the permissible limits.

A method to calculate the impact of the harmonic currents on the design of the transformer is given in A.2.

The transformer shall be designed to take into account the increased rating required due to the harmonic currents. The temperature rise test shall be carried out with the equivalent rated power due to the harmonics defined in A.2. The result of the test shall be in compliance with temperature limits guaranteed for the transformer and related to the transformer insulation thermal class.

4.5 Wave-shape of supply voltage

Within the prescribed value of U_m a transformer shall be capable of continuous service at full load without damage under conditions of 'overfluxing' where the ratio of voltage over frequency exceeds the corresponding ratio at rated voltage and rated frequency according to IEC 60076-1.

The wind turbine manufacturer shall state at enquiry stage the maximum ratio between the voltage and the frequency. The transformer manufacturer shall take into account this value in the design of the transformer.

The purchaser shall specify in the inquiry the magnitude and frequency of any harmonic voltages present in the supply. A method to calculate the impact of the voltage harmonics on the design of the transformer is given in A.3.

4.6 Transient over and under voltages

The risk of failures of a wind turbine transformer is higher due to the fact of repeated transient over and under voltages on each side on transformer.

Several solutions are available to increase the reliability of the transformer against these fast transient interactions:

– to evaluate the insulation level of the transformer and if necessary apply one or more of the following solutions. This can be done by modeling or measuring the system by high frequency resonance analysis. The resonance frequency test is a special test. The test method shall be agreed between manufacturer and purchaser. One method is described in A.4;
– to install standard protection technique such as surge arresters (HV, LV), or RC circuit or surge capacitor.

The choice of the lists 2 or 3 in Table 1 shall be the responsibility of the system engineer based on specific insulation co-ordination (IEC 60071-1 and -2) and risk assessment.

The list 3 covers transformers with increased ability to withstand repeated transient over voltages and increases the reliability of the transformer.

Table 1 – Insulation levels

Highest voltage for equipment U_m (rms) kV	Rated short duration separated source AC withstand voltage (RMS) kV	Rated lightning impulse withstand voltage (peak value) in kV	
		List 2	List 3
≤ 1,1	3	-	20
3,6	10	40	50
7,2	20	60	75
12	28	75	95
17,5	38	95	125
24	50	125	150
36	70	170	200

High frequency steep surges can be generated by switching operation on LV or HV side. These surges are transferred by cables to the terminals of the transformer. Transformers have different values of resonance frequency. See A.4.

If the high frequency steep surges generated by switching operation on LV and HV side coincide with the internal frequency of the winding, the result of these surges can resonate with the winding internal frequencies and cause higher electric stresses than the dielectric withstand strength of the windings

NOTE For U_m ≤ 1,1 kV a.c. withstand voltage should have higher value as 10 kV.

4.7 Humidity and salinity

An abnormal level of humidity and salinity can lead to failures of dry type transformers and problems on open type bushings of liquid-immersed transformers or dry type transformers in enclosures.

The standard pollution levels for open type bushing for liquid-immersed transformers are defined in IEC 60815 series. There are also simulated rain tests defined in IEC 60137.

According to IEC 60076-11, the relative humidity in the test chamber shall be maintained above 93 % for environmental class E2 transformers. Salinity shall be such as the conductivity of the water in E2 test shall be in the range of 0,5 to1,5 S/m.

If a dry type transformer shall operate under more severe conditions than corresponding to class E2 without a protective enclosure against humidity and salinity, the capability of the transformer design shall be demonstrated by the test according to class E3 described in 7.4.5 in this standard.

IEC 61400-1 states that relative humidity up to 95 % shall be taken into account as a normal environmental condition.

Higher values of humidity and salinity shall be given at enquiry stage.

4.8 Special electrical and environmental conditions around the transformer

IEC 60076-3 recommends general minimum clearances between transformer live parts and conductive parts of the wind turbine.

Any part of the wind turbine made of insulation material becomes conductive when moistened with rain water, salt water or other conductive liquids. Partial discharges in the surroundings of the transformer can decrease the dielectric strength of the air.

Therefore the clearances between these wind turbine parts and the live parts of the transformer shall not be less than the clearances recommended in IEC 60076-3.

The transformer manufacturer shall indicate the required minimum clearances on the outline drawing of the transformer and it is the responsibility of the purchaser to follow up that these requirements will be met.

4.9 Level of vibration

Vibrations of the structure where the transformer is to be installed shall be taken into account when designing the transformer and special consideration shall be given in the stress transferred to connection terminals.

The purchaser shall specify vibration spectrum at the enquiry stage. The procedure of vibration test if any should be agreed at enquiry stage between purchaser and manufacturer.

4.10 Provision for unusual service conditions for transformers for wind turbine applications

Provision for unusual service conditions are indicated in IEC 60076-1 for liquid-immersed transformers and IEC 60076-11 for dry type transformers.

4.11 Transportation and storage conditions

Transportation and storage conditions are indicated in IEC 60076-1 for liquid-immersed transformers and IEC 60076-11 for dry type transformers.

Storage conditions shall be included in maintenance and operation manuals and shall be taken into account by the purchaser.

4.12 Corrosion protection

Depending on the kind of the installation, the purchaser should choose a protection class defined in ISO 12944 or otherwise agreed between purchaser and manufacturer.

5 Electrical characteristics

5.1 Rated power

The rated power shall be in accordance with 5.1 of IEC 60076-1.

The rated power S_r of the transformer is based on the fundamental frequency of the voltage U_1 and of the current I_1. The rated power of a three phase transformer is therefore:

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

The temperature rise and the cooling requirements of the transformer shall be determined after allowance is made for any increased losses due to harmonics.

5.2 Highest voltage for equipment

The highest voltage for equipment shall be chosen in accordance with Clause 5 of IEC 60076-3:2000.

The wind turbine designer shall inform the transformer manufacturer of peak voltages, frequencies and durations of any transient and repeated over voltages (see also Table 1 of this standard).

Information about insulation coordination is described in IEC 60071-1 and IEC 60071-2.

5.3 Tappings

The requirements in Clause 5 of IEC 60076-1:2011 apply.

The preferred tapping range if any is either:

- +5 % to –5 % in steps of 2,5 %,

or

- +5 % to –5 % in steps of 5 %.

Tapping selection shall be made by means of off-circuit bolted links or an off-circuit tap changer.

5.4 Connection group

Unless otherwise specified by the purchaser, transformer connections shall be Dyn with clock hour figure 5 or 11 in accordance with Clause 7 of IEC 60076-1:2011.

5.5 Dimensioning of neutral terminal

The neutral terminal shall be capable of carrying full phase rated current unless otherwise specified by the purchaser.

5.6 Short circuit impedance

For general purpose the impedance voltage shall be in accordance with IEC 60076-5.

For auxiliary windings when the combined impedance voltage of the tertiary winding and the system result in short circuit current levels for which the transformer cannot feasibly or economically be designed to withstand, the manufacturer and the purchaser shall mutually agree on the maximum allowed over current. In this case, provision should be made by the purchaser to limit the over current to the maximum value determined by the manufacturer and stated on the rating plate.

5.7 Insulation levels for high voltage and low voltage windings

The selected insulation level for the high voltage and low voltage windings shall be in accordance with Table 1 of this standard.

5.8 Temperature rise guaranteed at rated conditions

The design of the transformer shall be in accordance with the operating conditions (harmonic contents, ambient temperature) stated by the purchaser at the enquiry stage.

The guaranteed temperature rise shall take into account the additional losses due to harmonics if specified, which increase eddy losses and stray losses in the windings and structural/frame parts.

If no harmonics are specified at the design stage but the actual real load current in service contains harmonics, the load on the transformer may need to be reduced to prevent the transformer temperature rises exceed the guaranteed limits.

Examples of calculations of the impact of harmonic currents are given in A.2.

5.9 Overload capability

The loading guides for liquid-immersed transformers in IEC 60076-7 and for dry type transformers in IEC 60076-12 shall apply.

5.10 Inrush current

Due to frequent energizing of the transformers during wind farm operation, transformers are frequently exposed to mechanical and thermal effects of inrush currents.

Frequency of energisation (number of energisation per year) shall be given at enquiry stage. Unless otherwise specified, switching is done on the HV (grid) side. The method of switching and synchronization shall be described in case of generator side energisation.

System inrush current limitations (maximum value, duration) shall be given at enquiry stage by the purchaser.

5.11 Ability to withstand short circuit

Transformers shall fulfill the requirements in IEC 60076-5. If the purchaser requires a test to demonstrate this fulfillment, this test shall be stated in the contract.

5.12 Operation with forced cooling

When additional cooling by means of fans or pumps is provided, the nominal power rating with and without forced cooling shall be subject to agreement between purchaser and manufacturer.

The rating plate shall indicate both the power rating without forced cooling and the maximum power rating with forced cooling.

NOTE In case of forced cooling, the back-to-back method to carry out the temperature rise test for the transformer is preferred and is subject to agreement between manufacturer and purchaser at enquiry stage. Temperatures measured by the back-to-back tests correspond more closely to those obtained in practice during normal operation.

6 Rating plate

See IEC 60076-1 and IEC 60076-11.

7 Tests

7.1 List and classification of tests (routine, type and special tests)

See IEC 60076-1 and IEC 60076-11.

7.2 Routine tests

Tests described in IEC 60076-1 for liquid-immersed transformers and IEC 60076-11 for dry type transformers apply.

NOTE Impulse test for all transformers type and partial discharge tests for liquid-immersed transformers can be justified on each unit by agreement between purchaser and manufacturer at enquiry stage. See IEC 60076-13 for this kind of test cycle for partial discharge test on liquid-immersed transformers.