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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Power transformers –
Part 3: Insulation levels, dielectric tests and external clearances in air

Transformateurs de puissance –
Partie 3: Niveaux d'isolement, essais diélectriques et distances d'isolement dans l'air

IEC 60076-3:2013

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER TRANSFORMERS –

Part 3: Insulation levels, dielectric tests and external clearances in air

FOREWORD

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International Standard IEC 60076-3 has been prepared by IEC technical committee 14: Power transformers.

This third edition of IEC 60076-3 cancels and replaces the second edition published in 2000, and constitutes a technical revision. The main changes from the previous edition are as follows:

– Three categories of transformer are clearly identified together with the relevant test requirements, these are summarised in Table 1.
– Switching impulse levels are defined for all $U_m > 72{,}5$kV.
– The procedure for Induced voltage tests with PD has been revised to ensure adequate phase to phase test voltages.
– The AC withstand test has been redefined (LTAC instead of ACSD).
– Induced voltage tests are now based on U_r rather than U_m.
– New requirements for impulse waveshape (k factor) have been introduced.

– Tables of test levels have been merged and aligned with IEC 60071-1:2010.
– Additional test levels have been introduced for U_m > 800kV.
– A new Annex E has been introduced, which sets out the principles used in assigning the tests, test levels and clearances in air.

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

FDIS	Report on voting
14/745/FDIS	14/749/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 the parts in the IEC 60076 series, under the general title *Power 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- withdrawn,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

This part of IEC 60076 specifies the insulation requirements and the corresponding insulation tests with reference to specific windings and their terminals. It also recommends external clearances in air (Clause 16).

The insulation levels and dielectric tests which are specified in this standard apply to the internal insulation only. Whilst it is reasonable that the rated withstand voltage values which are specified for the internal insulation of the transformer should also be taken as a reference for its external insulation, this may not be true in all cases. A failure of the non-self-restoring internal insulation is catastrophic and normally leads to the transformer being out of service for a long period, while an external flashover may involve only a short interruption of service without causing lasting damage. Therefore, it may be that, for increased safety, higher test voltages are specified by the purchaser for the internal insulation of the transformer than for the external insulation of other components in the system. When such a distinction is made, the external clearances should be adjusted to fully cover the internal insulation test requirements.

Annex E sets out some of the principles used in assigning the tests, test levels and clearances in air to the transformer according to the highest voltage for equipment U_m.

POWER TRANSFORMERS –

Part 3: Insulation levels, dielectric tests and external clearances in air

1 Scope

This International Standard applies to power transformers as defined by and in the scope of IEC 60076-1. It gives details of the applicable dielectric tests and minimum dielectric test levels. Recommended minimum external clearances in air between live parts and between live parts and earth are given for use when these clearances are not specified by the purchaser.

For categories of power transformers and reactors which have their own IEC standards, this standard is applicable only to the extent in which it is specifically called up by cross reference in the other standards.

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

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

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

IEC 60137, *Insulated bushings for alternating voltages above 1 000 V*

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

3 Terms and definitions

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

3.1
highest voltage for equipment applicable to a transformer winding
U_m
highest r.m.s. phase-to-phase voltage in a three-phase system for which a transformer winding is designed in respect of its insulation

3.2
rated voltage of a winding
***U*r**
voltage assigned to be applied, or developed at no-load, between the terminals of an untapped winding, or a tapped winding connected on the principal tapping, for a three-phase winding it is the voltage between line terminals

Note 1 to entry: The rated voltages of all windings appear simultaneously at no-load when the voltage applied to one of them has its rated value.

Note 2 to entry: For single-phase transformers intended to be connected in star to form a three-phase bank or to be connected between the line and the neutral of a three phase system, the rated voltage is indicated as the phase-to-phase voltage, divided by $\sqrt{3}$, for example $400/\sqrt{3}$ kV.

Note 3 to entry: For single phase transformers intended to be connected between phases of a network, the rated voltage is indicated as the phase-to-phase voltage.

Note 4 to entry: For the series winding of a three-phase series transformer, which is designed as an open winding, the rated voltage is indicated as if the windings were connected in star.

[SOURCE: IEC 60076-1:2011, 3.4.3]

3.3
rated insulation level
set of rated withstand voltages which characterise the dielectric strength of the insulation

3.4
rated withstand voltage
value of the assigned test voltage applied in one of the standard dielectric tests that proves that the insulation complies with the assigned test voltage

3.5
uniform insulation of a transformer winding
insulation of a transformer winding that has all its ends connected to terminals with the same rated insulation level

3.6
non-uniform insulation of a transformer winding
insulation of a transformer winding when it has a neutral terminal end for direct or indirect connection to earth, and is designed with a lower insulation level than that assigned to the line terminal

Note 1 to entry: Non-uniform insulation may also be termed graded insulation.

4 General

The insulation requirements for power transformers and the corresponding insulation tests are given with reference to specific windings and their terminals.

For liquid-immersed or gas-filled transformers, the requirements apply to the internal insulation only. Any additional requirements or tests regarding external insulation which are deemed necessary shall be subject to agreement between manufacturer and purchaser. If the purchaser does not specify any particular requirements for external clearances then the provisions of Clause 16 shall apply. If the purchaser intends to make the connections to the transformer in a way which may reduce the clearances provided by the transformer alone, this should be indicated in the enquiry.

Bushings shall be subject to separate type and routine tests according to IEC 60137 (including appropriate bushing test levels for the particular transformer test level), which verify their phase-to-earth insulation, external as well as internal.

When a transformer is specified for operation at an altitude higher than 1 000 m, clearances shall be designed accordingly. It may then be necessary to select bushings designed for higher insulation levels than otherwise required for operation at lower altitudes, see Clause 16 of this standard and IEC 60137.

The manufacturer may shield the bushing terminals if necessary during the dielectric tests but any shielding of the earthed parts closest to the terminals shall form part of the transformer structure in-service except for shielding required only during partial discharge measurement.

Bushings and tap-changers are specified, designed and tested in accordance with the relevant IEC standards. The dielectric tests on the complete transformer constitute a check on the correct application and installation of these components. In the case of tap-changers which according to IEC 60214-1 are not subjected to dielectric routine tests at the tap-changer manufacturer's works then the tests performed according to this standard also serve as the only dielectric tests routinely performed on this component.

The temperature of the insulation system shall not be less than 10 °C during the tests, but temperatures higher than those given in IEC 60076-1 may be used.

The transformer shall be completely assembled as in service in respect of all elements that might influence the dielectric strength of the transformer. It is normally assumed that the insulating liquid or gas is not circulated during the tests and coolers do not need to be assembled. Any equipment designed to collect or detect free gas produced by faults in the insulation shall be installed and monitored during the tests. If free gas is detected during any test, the nature and cause of the gas shall be investigated and any further actions shall be agreed between purchaser and manufacturer.

NOTE 1 External overvoltage protection devices such as surge arresters do not need to be assembled and bushing spark gaps can be removed or their spacing increased to avoid operation during the tests.

NOTE 2 It is common practice for larger transformers for oil samples to be taken for dissolved gas analysis before and after dielectric tests.

Liquid immersed transformers shall be tested with the same type (mineral, ester, silicone, etc.) and specification (with respect to the properties that might affect the test performance) of liquid that it will contain in service.

NOTE 3 Some purchasers can require that the insulating liquid be circulated on OD cooled transformers during an IVPD test to detect the possibility of static electrification, but this is a very specific requirement and is not covered by this standard.

Transformers for cable box connection or direct connection to metal-enclosed SF_6 installations should be designed so that temporary connections can be made for dielectric tests, using temporary bushings, if necessary. By agreement between manufacturer and purchaser, the service liquid to SF_6 bushings may be replaced by appropriate liquid to air bushings for test, in this case the design of the end of the bushing inside the transformer including the positions of the live parts and the clearances of the substitute bushings inside the transformer shall be the same (within the normal variation of dimensions of the bushing associated with manufacturing tolerances) as those of the in-service bushings.

When the manufacturer intends to use non-linear elements (for example surge arresters or spark gaps), built into the transformer or tap-changer or externally fitted, for the limitation of overvoltage transients, this shall be brought to the purchaser's attention by the manufacturer at the tender and order stage and shall be indicated on the transformer rating plate circuit diagram.

If any terminals of the transformer are to be left open when the transformer is energised in service then consideration needs to be given to the possibility of a transferred voltage occurring on the open terminals, see Annex B. During the lightning impulse tests all non-tested line and neutral terminals are normally connected to earth, see Clause 13.

5 Highest voltage for equipment and rated insulation level

A value of highest voltage for equipment U_m (see Clause 3) is assigned to both the line and neutral end of each winding, see IEC 60076-1.

The rules for dielectric testing depend on the value of U_m. When rules about tests for different windings in a transformer are in conflict, the rule for the winding with the highest U_m value shall apply for the whole transformer.

Series windings (for example found in autotransformers and phase shifting transformers) where the rated voltage of the winding is less than the rated voltage of the system, shall be assigned a value of U_m corresponding to the rated voltage of the highest voltage system to which the winding is connected.

Standardized values of U_m are listed in Table 2. Unless otherwise specified, the value to be used for a transformer winding is the one equal to, or nearest above, the value of the rated voltage of the winding.

NOTE 1 Single-phase transformers intended for connection in star to form a three-phase bank are designated by phase-to-phase rated voltage divided by $\sqrt{3}$, for example $400/\sqrt{3}$ kV. The phase-to-phase value determines the choice of U_m in this case, consequently, U_m = 420 kV (see also IEC 60076-1). The same principle applies to single-phase transformers intended for use in a single phase system in that the maximum phase to earth voltage is multiplied by $\sqrt{3}$ to obtain the equivalent U_m in order to define the test voltages.

NOTE 2 For transformer windings intended to be used for example in railway supply applications where two opposite phase to earth voltages are supplied, U_m relates to the phase to phase voltage unless otherwise specified.

NOTE 3 It might happen that certain tapping voltages are chosen slightly higher than a standardized value of U_m, but the system to which the winding will be connected has a system highest voltage which stays within the standard value. The insulation requirements are to be coordinated with actual conditions, and therefore this standard value can be accepted as U_m for the transformer, and not the nearest higher value.

NOTE 4 In certain applications with very special conditions the specification of other combinations of withstand voltages can be justified. In such cases, general guidance should be obtained from IEC 60071-1.

NOTE 5 In certain applications, delta-connected windings are earthed through one of the external terminals. In those applications, a higher withstand voltage with respect to the highest voltage for equipment U_m can be required for this winding and would need to be agreed between manufacturer and purchaser.

The highest voltage for equipment U_m and the rated insulation level (the set of assigned rated withstand voltages) determine the dielectric characteristics of a transformer. These characteristics are verified by a set of dielectric tests, see Clause 7.

The value of U_m and the rated insulation level which are assigned to each winding of a transformer are part of the information to be supplied with an enquiry and with an order. If there is a winding with non-uniform insulation, the assigned U_m and the rated insulation level of the neutral terminal may also be specified by the purchaser, see 7.4.

The rated insulation level shall be characterised as follows:

U_m / SI / LI / LIC / AC with the associated values (see examples below) for the line terminals of each winding

If the winding does not have an assigned SI or LIC withstand level then the abbreviation is omitted from the rating so for terminals without an assigned switching impulse withstand level or chopped wave lightning impulse withstand level and for neutral terminals the abbreviation would be:

U_m / LI / AC together with the associated values

If the neutral terminal of a winding has the same rated insulation level as the line terminal then the rated insulation level of the neutral does not need to be shown separately.

The abbreviations here and in the examples below have the following meaning:

SI is the rated switching impulse withstand voltage level for the line terminals of the winding with the highest U_m;

LI is the rated lightning impulse withstand voltage level for the terminal of each individual winding;

LIC is the rated lightning impulse withstand voltage level for the line terminals of each individual winding if a chopped wave lightning impulse test was performed;

AC is the highest rated AC withstand voltage level to earth designed for the terminals of each winding.

NOTE 6 The AC is the value for which the transformer is designed, this is generally the highest AC voltage required to be achieved on test.

HV high voltage;

LV low voltage;

MV medium voltage (intermediate voltage IEC 60076-1);

N neutral.

The rated withstand voltages for all windings shall appear on the rating plate.

The principles of the standard abbreviated notation are shown in some examples below.

EXAMPLE 1

Transformer with a nominal rated voltage of 66 / 11 kV U_m (HV) = 72,5 kV and U_m (LV) = 12 kV, both uniformly insulated, Y connected, the rating plate would read:

HV U_m 72,5 / LI 325 / AC 140 kV

LV U_m 12 / LI 75 / AC 28 kV

EXAMPLE 2

U_m (HV) line = 245 kV, Y connected (220 kV rated voltage);

U_m (HV) neutral = 52 kV;

U_m (MV) line = 72,5 kV, uniform insulation, Y connected (LIC not specified);

U_m (LV) line = 24 kV, D connected LIC not required.

The rating plate would read:

HV U_m 245 / SI 750 / LI 950 / LIC 1045 / AC 395 kV

HVN U_m 52 / LI 250 / AC 95 kV

MV U_m 72,5 / LI 325 / AC 140 kV

LV U_m 24 / LI 125 / AC 50 kV

6 Transformers with re-connectable windings

Unless otherwise specified, windings which are specified to be capable of being connected in more than one configuration for service shall be tested in each configuration.

7 Dielectric tests

7.1 Overview

The dielectric capability of the transformer insulation is verified by dielectric tests. The following is a general explanation of the different tests.

– **Full wave lightning impulse test for the line terminals (LI)**, see 13.2

The test is intended to verify the capability of the transformer to withstand fast rise time transients in service typically associated with lightning strikes. The test verifies the withstand strength of the transformer under test, when the impulse is applied to its line terminals. The test contains high frequency voltage components and produces non-uniform stresses in the winding under test different to those for an alternating voltage test.

– **Chopped wave lightning impulse test for the line terminals (LIC)**, see 13.3

As well as covering the intention of the LI test, this test is intended to verify the capability of the transformer to withstand some high frequency phenomena that may occur in service. For this test the lightning impulse test includes both full wave impulses and impulses chopped on the tail to produce a very high rate of change of voltage. The chopped wave test voltage impulse has a higher peak value and contains higher frequency components than the full wave impulse.

NOTE 1 According to this standard the LIC test is specified for each winding separately. For example, if a routine LIC test is required by this standard on the highest voltage winding this would not lead automatically to LIC tests being required on other winding(s) with $U_m \leq 170$ kV unless LIC tests are specified specifically for these windings by the purchaser.

– **Lightning impulse test for the neutral terminal (LIN)**, see 13.4

The test is intended to verify the impulse withstand voltage of the neutral terminal and it's connected winding(s) to earth and other windings, and along the winding(s) under test.

– **Switching impulse test for the line terminal (SI)**, see Clause 14

The test is intended to verify the capability of the transformer to withstand slow rise time transient voltages typically associated with switching operations in service. The test verifies the switching impulse withstand strength of the line terminals and the connected winding(s) to earth and other windings. The test also verifies the withstand strength between phases and along the winding(s) under test. This is a single-phase test. The voltage is inductively distributed through all windings of the transformer, line terminals are open circuit for the test and the line terminals of the tested phase experience a voltage during the test approximately determined by the transformer turns ratio.

The voltage distribution in the tested phase is similar to that experienced during an induced voltage withstand test.

– **Applied voltage test (AV)**, see Clause 10

The test is intended to verify the alternating voltage withstand strength of the line and neutral terminals and their connected windings to earth and other windings. The voltage is applied to all the terminals of a winding, including the neutral, simultaneously so there is no turn-to-turn voltage.

– **Line terminal AC withstand voltage test (LTAC)**, see Clause 12

The test is intended to verify the alternating voltage (AC) withstand strength of each line terminal to earth. During the test, voltage appears at one or more of the line terminals. The test allows the line terminals of a transformer with non-uniform insulation to be tested at the applied voltage test level applicable to the line terminals.

– **Induced voltage withstand test (IVW)**, see 11.2

The test is intended to verify the alternating voltage withstand strength of each line terminal and its connected winding(s) to earth and other windings, along the winding(s) under test and the withstand strength between phases. The test is performed with the transformer

connected as for service. During the test, symmetrical voltages appear at all the line terminals and between turns, with no voltage at the neutral. The test is performed with a three phase voltage on three phase transformers.

– **Induced voltage test with PD measurement (IVPD)**, see 11.3

This test is intended to verify that the transformer will be free of harmful partial discharges under normal operating conditions. The test voltage is applied in the same way as the voltage that the transformer will experience in service. During the test, symmetrical voltages appear at all the line terminals and between turns, with no voltage at the neutral. The test is performed with a three phase voltage on three phase transformers.

– **Auxiliary wiring insulation test (AuxW)**, see Clause 9

This test verifies the insulation of the auxiliary wiring of the transformer that is not connected to the windings.

– **Lightning impulses applied to two or more terminals simultaneously (LIMT),** see 13.1.4.3

This test verifies that the transformer can withstand the internal voltage rises that may occur if two or more terminals are subjected to a lightning impulse simultaneously. The test is only applicable to some special types of transformer with either a series winding that may be shorted in service (for example some phase shifting transformers with an on-load bypass) or where impulses on two or more terminals may occur simultaneously in service.

NOTE 2 This test is also referred to as a 'double-ended lightning impulse test'.

7.2 Test requirements

7.2.1 General

The requirements for dielectric tests, both the required tests and the test voltage levels, depend on the highest voltage for equipment U_m for the highest voltage winding of the particular transformer. The required tests are summarised in Table 1 and specific requirements are given in 7.3.

NOTE Lightning impulses applied to two or more line terminals simultaneously is a special test for only a few special types of transformer irrespective of U_m and is not included in the table for clarity.

Any additional tests above the requirements of this standard and the test voltage levels shall be specified by the purchaser at the time of enquiry and order since they may affect the transformer design (see Annex C).

Reference shall be made to IEC 60060-1 for details of the tests. Where tolerances on test parameters and values are not specifically given in this standard then the values given in IEC 60060-1 shall be used.