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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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POWER TRANSFORMERS –

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

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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.

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– 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- withdrawn,
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- amended.

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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.

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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

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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.

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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.

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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

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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.

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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

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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.

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Table 1 – Requirements and tests for different categories of windings

	$U_m \leq 72{,}5$ kV	72,5 kV < $U_m \leq 170$ kV		$U_m > 170$ kV
Insulation	**Uniform**	**Uniform**	**Non-uniform**	**Uniform and non-uniform**
Full wave lightning impulse test for the line terminals (LI)	Type	Routine	Routine	Not applicable (included in LIC)
Chopped wave lightning impulse test for the line terminals (LIC)	Special	Special	Special	Routine
Lightning impulse test for the neutral terminals (LIN)	Special	Special	Special	Special
Switching impulse test for the line terminal (SI)	Not applicable	Special	Special	Routine
Applied voltage test (AV)	Routine	Routine	Routine	Routine
Induced voltage withstand test (IVW)	Routine	Routine	Routine	Not applicable
Induced voltage test with PD measurement (IVPD)	Special[a]	Routine[a]	Routine[a]	Routine
Line terminal AC withstand voltage test (LTAC)	Not applicable	Special	Routine[b]	Special
Auxiliary wiring insulation test (AuxW)	Routine	Routine	Routine	Routine

[a] The requirements of the IVW test can be incorporated in the IVPD test so that only one test is required.

[b] The LTAC test for this category of transformers can be replaced by a switching impulse test by agreement between manufacturer and purchaser.

7.2.2 Test voltage levels

Levels of standard test voltages, identified by the highest voltage for equipment U_m of a winding are given in Table 2. The choice between the different levels of test voltages in these tables depends on the severity of overvoltage conditions to be expected in the system and on the importance of the particular installation. Guidance may be obtained from IEC 60071-1.

All test voltages are phase to earth.

The lowest values given in Table 2 for a particular value of U_m represent the minimum test voltage levels and shall be used if nothing else is specified. In general the values given in each row in Table 2 are co-ordinated. If only a lightning impulse voltage level is specified then the other values on the same row shall be used. The purchaser may specify any value higher than the minimum for the particular U_m for each test, preferably standard values for coordination, but not necessarily the values from a single row in Table 2. If higher levels are specified this shall be stated in the enquiry and order.

If, under special circumstances, the minimum levels given in Table 2 are considered too high by the purchaser then the values in Table 3 may be used. The values in Table 3 may only be used if special precautions have been taken to avoid overvoltage conditions beyond the capability of the transformer and either extensive studies have been completed or the values used represent proven existing practice applicable to the installation.

NOTE Certain installation conditions, particularly where energisation of the transformer is from the remote end of a cable or a long overhead line, can lead to severe exposure to overvoltages which might be frequent and repetitive. In such cases, higher test voltages, lightning impulse, switching impulse and other tests on individual units could be agreed between manufacturer and purchaser. For example a winding with a $U_m < 1{,}1$ kV might be tested at the values appropriate to a winding with a U_m of 3,6 kV. The specific voltage-time characteristic of the overvoltage is an important consideration when deciding the type and level of the test required to assure satisfactory operation.

In particular, failures have been reported at U_m = 36 kV and below where the transformer is energised or de-energised by a vacuum type circuit breaker from the remote end of a cable because a resonant condition might exist causing

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re-ignitions and repetitive transients. In certain cases increasing the insulation level might not be sufficient and other methods such as the installation of a snubber circuit could be considered. Further information is contained in IEEE C57.142:2010 and CIGRE report 12-14.

Table 2 – Test voltage levels *(1 of 2)*

Highest Voltage for equipment winding U_m kV	Full Wave Lightning Impulse (LI) kV	Chopped Wave Lightning Impulse (LIC) kV	Switching impulse (SI) kV	Applied voltage or line terminal AC withstand (AV) (LTAC) kV
<1,1	–	–	–	3
3,6	20	22	–	10
	40	44	–	10
7,2	60	66	–	20
	75[a]	83[a]	–	20
12	75	83	–	28
	95	105	–	28
	110[a]	121[a]	–	34[a]
17,5	95	105	–	38
	125[a]	138[a]	–	38
24	125	138	–	50
	145	160	–	50
	150[a]	165[a]	–	50
36	170	187	–	70
	200[a]	220[a]	–	70
52	250	275	–	95
72,5	325	358	–	140
	350[a]	385[a]	–	140
100	450	495	375[a]	185
123	550	605	460[a]	230
145	550	605	460[a]	230
	650	715	540[a]	275
170	650	715	540[a]	275
	750	825	620[a]	325
245	850	935	700[a]	360
	950	1 045	750[a]	395
	1 050	1 155	850[a]	460
300	950	1 045	750	395
	1 050	1 155	850	460
362	1 050	1 155	850	460
	1 175	1 290	950	510
420	1 175	1 290	950	510
	1 300	1 430	1 050	570
	1 425	1 570	1 175[a]	630

Table 2 *(2 of 2)*

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Highest Voltage for equipment winding U_m kV	Full Wave Lightning Impulse (LI) kV	Chopped Wave Lightning Impulse (LIC) kV	Switching impulse (SI) kV	Applied voltage or line terminal AC withstand (AV) (LTAC) kV
550	1 300	1 430	1 050	570
	1 425	1 570	1 175	630
	1 550	1 705	1 300[a]	680
	1 675[a]	1 845[a]	1 390[a]	–
800	1 800	1 980	1 425	–
	1 950	2 145	1 550	–
	2 050[a]	2 255[a]	1 700[a]	–
	2 100	2 310	1 675[a]	–
1 100	1 950	2 145	1 425	–
	2 250	2 475	1 800	–
1 200	2 250	2 475	1 800	–

[a] These values are not given in IEC 60071-1:2011 for the particular value of U_m but are included either because they represent common practice in some parts of the world or for some switching impulse levels, because they represent a co-ordinated value for a particular value of lightning impulse level.

Table 3 – Test voltage levels used in special cases

Highest Voltage for equipment winding U_m kV	Full Wave Lightning Impulse (LI) kV	Chopped Wave Lightning Impulse (LIC) kV	Switching impulse (SI) kV	Applied voltage or line terminal AC withstand (AV) (LTAC) kV
7,2	40	44	-	20
12	60	66	-	28
17,5	75	83	-	38
24	95	105	-	50
36	145	160	-	70
60[a]	280[a]	308[a]	230[a]	115[a]
123[b]	450[b]	495[b]	375[a]	185[b]
170 [b]	550[b]	605[b]	460[a]	230[b]
245	650[b]	715[b]	550[a]	275[b]
	750[b]	825[b]	620[a]	325[b]
300	850	935	750	395
362	950	1 045	850	395
420	1 050	1 155	850	460
550	1 175	1 290	950	510

[a] These values are not given in IEC 60071-1:2011 for the particular value of U_m but are included because they represent existing practice in some parts of the world.

[b] these values require special consideration, refer to IEC 60071-1:2011

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7.2.3 Test sequence

The tests shall be performed in the sequence given below:

a) lightning impulse tests (LI, LIC, LIN, LIMT);
b) switching impulse (SI);
c) applied voltage test (AV);
d) line terminal AC withstand test (LTAC);
e) induced voltage withstand test (IVW);
f) induced voltage test with partial discharge measurement (IVPD).

NOTE This is a comprehensive list, not all these tests will be applicable to a particular transformer.

By agreement between the manufacturer and purchaser, the switching impulse test may be performed before the lightning impulse test.

If an IVPD test is to be performed then by agreement between the manufacturer and purchaser, the test sequence may be varied except that the IVPD test shall be the last dielectric test.

7.3 Test requirements for specific transformers

7.3.1 Tests for transformers with $U_m \leq 72{,}5$ kV

7.3.1.1 Routine tests

a) Applied voltage test (AV)

An applied voltage test shall be performed according to the method given in Clause 10 on each separate winding of the transformer. Test voltages are given in Table 2.

NOTE Transformers with $U_m \leq 72{,}5$ kV are expected to have uniform winding insulation to satisfy this test.

b) Induced voltage withstand test (IVW)

An induced voltage withstand test shall be performed according to the method given in 11.2 with a (phase to earth) test voltage of $(2 \times U_r)/\sqrt{3}$. If agreed by the purchaser this test may be substituted by an IVPD test with an enhancement voltage of $(2 \times U_r)/\sqrt{3}$ see 7.3.1.3 a).

7.3.1.2 Type tests

Full wave lightning impulse test (LI)

A full wave lightning impulse test shall be carried out on the line terminals using the method given in 13.1 and 13.2. Test voltages are given in Table 2.

7.3.1.3 Special tests

a) Induced voltage test with partial discharge measurement (IVPD)

If specified by the purchaser, a test shall be carried out according to the method given in 11.3, with an enhancement (phase to earth) voltage level of $(1{,}8 \times U_r)/\sqrt{3}$ and a PD measurement voltage of $(1{,}58 \times U_r)/\sqrt{3}$. Alternative higher voltage levels may be used if specified by the purchaser. In particular an enhancement voltage of $(\sqrt{3} \times U_m)/\sqrt{3}$ and a PD measurement voltage of $(1{,}5 \times U_m)/\sqrt{3}$ may be used if higher.

If an enhancement voltage level of $(2 \times U_r)/\sqrt{3}$ is used this test can substitute for the routine induced voltage withstand test.

A shorter duration at the PD measurement voltage may be agreed between manufacturer and purchaser, a duration of 5 min is recommended.

b) Chopped wave lightning impulse test (LIC)

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If specified by the purchaser the full wave lightning impulse test shall be substituted by a chopped wave lightning impulse test according to the method given in 13.1 and 13.3.

The extension of the lightning impulse test to include impulses chopped on the tail as a special test is recommended in cases where the transformer is directly connected to GIS by means of liquid to SF6 bushings or when the transformer is protected by rod gaps.

c) Lightning impulse test on the neutral terminal (LIN)

If specified by the purchaser a full wave lightning impulse test shall be carried out on the neutral terminal according to the method given in 13.1 and 13.4. This normally applies if the neutral is not directly connected to earth in service.

d) Lightning impulses applied to multiple line terminals simultaneously (LIMT)

If specified by the purchaser an additional lightning impulse test on two or more terminals connected together shall be performed according to the method given in 13.1 with the test connections given in 13.1.4.3. If not otherwise specified the type of test is LI.

7.3.2 Tests on transformers with 72,5 kV < U_m ≤ 170 kV

7.3.2.1 Routine tests

a) Full wave lightning impulse test (LI)

A full wave lightning impulse test shall be carried out on the line terminals using the method given in Clause 13 Test voltages are given in Table 2.

b) Applied voltage test (AV)

An applied voltage test in accordance with the method given in Clause 10 shall be performed on each separate winding of the transformer. Test voltages are given in Table 2 for transformers with uniform insulation. For transformers with non-uniform insulation the test shall be carried out at the test voltage for the neutral terminal see 7.4.2.

c) Induced voltage withstand test (IVW)

An induced voltage withstand test shall be performed according to the method given in 11.2 with a (phase to earth) test voltage of $(2 \times U_r)/\sqrt{3}$. If agreed by the purchaser this test may be substituted by an IVPD test with an enhancement voltage $(2 \times U_r)/\sqrt{3}$, see e) below.

d) Line terminal AC withstand voltage test for non-uniformly insulated transformers (LTAC)

For windings with non-uniform insulation this test shall be performed at the test level given for the applied voltage test applicable to the line terminal in Table 2 using the method given in Clause 12. This test may be omitted if a switching impulse test is performed by agreement between manufacturer and purchaser.

e) Induced voltage test with partial discharge measurement (IVPD)

A test shall be carried out according to the method given in 11.3, with and enhancement (phase to earth) voltage level of $(1{,}8 \times U_r)/\sqrt{3}$ and a PD measurement voltage of $(1{,}58 \times U_r)/\sqrt{3}$. Alternative higher voltage levels may be used if specified by the purchaser. In particular an enhancement voltage of $(\sqrt{3} \times U_m)/\sqrt{3}$ and a PD measurement voltage of $(1{,}5 \times U_m)/\sqrt{3}$ may be used if higher.

If an enhancement voltage level of $(2 \times U_r)/\sqrt{3}$ is used this test can substitute for the routine induced voltage withstand test.

7.3.2.2 Special tests

a) Switching impulse test (SI)

If specified by the purchaser a switching impulse test using the method given in Clause 14 shall be performed on the line terminals. The test voltage is given in Table 2. If this test is carried out, then the Line Terminal AC Withstand Test (LTAC) may be omitted by agreement.

b) Chopped wave lightning impulse test (LIC)

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If specified by the purchaser the full wave lightning impulse test shall be substituted by a chopped wave lightning impulse test according to the method given in 13.1 and 13.3.

The extension of the lightning impulse test to include impulses chopped on the tail as a special test is recommended in cases where the transformer is directly connected to GIS by means of liquid to SF6 bushings or when the transformer is protected by rod gaps.

c) Line terminal AC withstand voltage test (LTAC)

If specified by the purchaser for windings with uniform insulation, this test shall be performed at the test level given for the applied voltage test applicable to the line terminal in Table 2 using the method given in Clause 12.

d) Lightning impulse test on the neutral terminal (LIN)

If specified by the purchaser a full wave lightning impulse test shall be carried out on the neutral terminal. This normally applies if the neutral is not directly connected to earth in service.

e) Lightning impulses applied to multiple line terminals simultaneously (LIMT)

If specified by the purchaser an additional lightning impulse test on two or more terminals connected together shall be performed according to the method given in 13.1 with the test connections given in 13.1.4.3. If not otherwise specified the type of test is LI.

7.3.3 Tests on Transformers with U_m > 170 kV

7.3.3.1 Routine tests

a) Chopped wave lightning impulse test (LIC)

A chopped wave lightning impulse test shall be carried out on the line terminals using the method given in Clause 13. Test voltages are given in Table 2.

b) Switching impulse test (SI)

A switching impulse test using the method given in Clause 14 shall be performed on the line terminals. The test voltage is given in Table 2.

c) Applied voltage test (AV)

An applied voltage test shall be performed in accordance with the method given in Clause 10 on each separate winding of the transformer. Test voltages are given in Table 2 for transformers with uniform insulation. For transformers with non-uniform insulation the test shall be carried out at the test voltage for the neutral terminal see 7.4.2.

d) Induced voltage test with partial discharge measurement (IVPD)

A test shall be carried out using the method given in 11.3, with an enhancement (phase to earth) voltage level of $(1{,}8 \times U_r)/\sqrt{3}$ and a one hour PD measurement voltage of $(1{,}58 \times U_r)/\sqrt{3}$. Alternative higher voltage levels may be used if specified by the purchaser. In particular an enhancement voltage of $(\sqrt{3} \times U_m)/\sqrt{3}$ and a one hour PD measurement voltage of $(1{,}5 \times U_m)/\sqrt{3}$ may be used if higher.

NOTE For three phase transformers, the voltage between the phases at the IVPD-enhancement level can be higher than the phase to earth AC withstand voltages given in Table 2 – Test voltage levels.

7.3.3.2 Special tests

a) Lightning impulse test on the neutral terminal (LIN)

If specified by the purchaser a full wave lightning impulse test shall be carried out on the neutral terminal. This normally applies if the neutral is not directly connected to earth in service.

b) Line terminal AC withstand voltage test for non-uniformly insulated windings (LTAC)

If specified by the purchaser this test shall be performed at the test level given for the applied voltage test applicable to the line terminal in Table 2 using the method given in Clause 12.

c) Lightning impulses applied to multiple line terminals simultaneously (LIMT)

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If specified by the purchaser an additional lightning impulse test on two or more terminals connected together shall be performed according to the method given in 13.1 with the test connections given in 13.1.4.3. If not otherwise specified the type of test is LIC.

7.4 Assigning U_m and test voltages to the neutral terminal of a winding

7.4.1 Transformers with $U_m \leq 72{,}5$ kV

The neutral shall be tested at the applied voltage test level for the line terminals. If a lightning impulse test on the neutral terminal is specified then the test level shall be given in the enquiry and order.

NOTE Transformers with $U_m \leq 72{,}5$ kV need to be designed with uniform winding insulation to satisfy the test requirements.

7.4.2 Transformers with $U_m > 72{,}5$ kV

7.4.2.1 Directly earthed neutral terminal

If the neutral terminal is to be permanently connected to earth in service, either directly or through a current transformer, but without any intentionally added impedance in the connection then the applied voltage test voltage shall be at least 38 kV ($U_m \geq 17{,}5$ kV). Higher test levels may be specified.

No impulse test on the neutral terminal is recommended but it may be specified.

7.4.2.2 Neutral terminal not directly earthed

The U_m and test voltages for the neutral terminal shall be given by the purchaser at the time of enquiry and order. The U_m of the neutral depends on whether the neutral terminal is intended to be left open or earthed via an impedance (see Annex D). The value of U_m and the test voltages shall preferably be selected from Table 2. U_m shall in no case be less than 17,5 kV.

If a lightning impulse test on the neutral terminal is specified, then the test level shall be given in the enquiry and order, and the rated impulse withstand voltage of the neutral terminal shall be verified by the test described in 13.4. A chopped wave lightning impulse test on the neutral is not applicable.

8 Dielectric tests on transformers that have been in service

Any transformer that is to be regarded as complying with this standard in the same way as a new transformer (for example following a warranty repair or complete rewind and refurbishment intended to restore the transformer to the ‘as new’ condition) shall be subject to all the routine tests required by this standard for the transformer at 100 % of the required test voltage level after the repair or refurbishment is complete.

Any transformer that is repaired to restore its functionality (for example after a breakdown following many years in service) but is still to be regarded as compliant with this standard shall be subject to the tests described in this standard necessary to verify the repair at a test voltage of between 80 % and 100 % of the original test voltage level. As a general guide any new part of a repaired transformer should be tested at 100 %, but 80 % of the original test voltage level may be regarded as an adequate test voltage level for verifying that used parts or components are suitable for continued use. Where both old and new parts are tested at the same time then an agreement on the test voltage level shall be reached. The IVPD test shall be performed at 100 % of the original test voltage level. The partial discharge criteria may need to be modified depending on the circumstances of the test and this shall be subject to agreement.

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9 Insulation of auxiliary wiring (AuxW)

The wiring for auxiliary power, and control circuitry shall be subjected to a 1 min AC separate source test of 2 kV to earth. The test is passed if no voltage collapse or other sign of breakdown occurs. The test shall be carried out at the manufacturer's works, unless the transformer is to be installed on-site by the manufacturer in which case the test may be performed on-site instead of in the factory. Wiring disconnected or removed for transport which has been subject to a 2 kV test at the factory shall be tested at site following erection using either a repeat of the 2 kV AC test or a 1 kV DC insulation resistance measurement with a minimum measured resistance of 1 MΩ.

The wiring for current transformer secondary windings shall be tested at 2,5 kV AC to earth for 1 min. The test shall be carried out at the manufacturer's works. If the current transformer knee-point voltage exceeds 2 kV AC the test shall be performed at 4 kV AC. The test is passed if no voltage collapse or other sign of breakdown occurs.

Motors and other apparatus for auxiliary equipment shall fulfil insulation requirements according to the relevant IEC standard (which are generally lower than the value specified for the wiring alone, and which may sometimes make it necessary to disconnect them in order to test the circuits). All solid state and microprocessor based devices shall be excluded from the test circuit. All three phase undervoltage relays and withdrawable type devices shall be removed from the test circuit.

NOTE It is normal practice for all the auxiliary wiring to be checked on-site at 1 kV DC for 1 min before energisation.

10 Applied voltage test (AV)

The test shall be carried out on each separate winding of the transformer in turn.

The full test voltage shall be applied for 60 s between all accessible terminals of the winding under test connected together and all accessible terminals of the remaining windings, core, frame and tank or casing of the transformer, connected to earth.

The test shall be made with an approximately sinusoidal single-phase alternating voltage at not less than 80 % of the rated frequency. The peak value of voltage shall be measured. The peak value divided by $\sqrt{2}$ shall be equal to the test value.

NOTE Approximately sinusoidal can be taken to mean that the peak value divided by $\sqrt{2}$ does not differ from the r.m.s value of the waveform by more than about 5 % (see IEC 60060-1), but wider deviations may be accepted.

The test shall commence at a voltage not greater than one-third of the specified test value, and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off.

The test is successful if no collapse of the test voltage occurs.

For windings with non-uniform insulation, the test is carried out with the test voltage specified for the neutral terminal.

In transformers where windings having different U_m values are connected together within the transformer (usually auto-transformers), the test voltages shall be determined by the insulation of the common neutral and its assigned U_m.

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11 Induced voltage tests (IVW and IVPD)

11.1 General

The test shall be carried out with any accessible neutral terminals and any other terminals that are normally at earth potential in service earthed. For three phase transformers a symmetrical three phase test voltage shall be used. Any line terminals not connected to the test supply shall be left open.

NOTE 1 When voltage is induced in a winding with no neutral connection, the voltages with respect to earth at each terminal of this winding will depend on the capacitances to earth and other windings. Any flashover from one of the line terminals to earth during the test can result in voltages exceeding the applied voltage test level appearing at the other terminals of the winding. Suitable precautions can be required to take account of this possibility.

During the test, the test voltage appropriate to a winding without voltage variation shall appear at the terminals of that winding so that the voltages between turns and between phases will have the same ratio between test voltage and rated voltage. The voltage shall either be measured on the highest voltage terminals, or if this is not practical the voltage shall be measured at the terminals of the transformer connected to the supply.

For transformers with tappings, the test shall be carried out with the transformer on principal tap unless otherwise specified or agreed by the purchaser.

If the purchaser requires a specific test voltage for lower voltage windings higher than the voltage determined in this clause then this shall be clearly stated in the enquiry and tender and an agreement reached on the method of test and the test voltages that will appear on the higher voltage windings which may consequently exceed the specified test voltages.

The test shall be performed with the transformer excited exactly as it will be for service. The voltage may be induced from any winding or from a special winding or taps provided for test purposes.

An alternating voltage shall be applied to the terminals of one winding of the transformer. The form of the voltage shall be as nearly as possible sinusoidal and its frequency shall be sufficiently above the rated frequency to avoid excessive magnetizing current during the test.

The peak value, as defined in IEC 60060-1 divided by $\sqrt{2}$ and the r.m.s. value of the induced test voltage shall be measured and the lower of the peak value divided by $\sqrt{2}$ and the r.m.s. value shall be taken as the test value.

11.2 Induced voltage withstand test (IVW)

The test time at full test voltage shall be 60 s for any test frequency up to and including twice the rated frequency, unless otherwise specified. When the test frequency exceeds twice the rated frequency, the test time in seconds of the test shall be:

$$120 \times \frac{\text{rated frequency}}{\text{test frequency}}\text{, but not less than 15 s}$$

The test shall commence at a voltage not greater than one-third of the specified test value, and the voltage shall be increased to the test value as rapidly as is consistent with measurement. At the end of the test, the voltage shall be reduced rapidly to less than one-third of the test value before switching off.

The test is successful if no collapse of the test voltage occurs.

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11.3 Induced voltage test with partial discharge measurement (IVPD)

11.3.1 General

When a particular type of bushing is specified by the purchaser that is expected to have a partial discharge level that will prevent accurate partial discharge measurements of the transformer on test it is permitted to exchange the bushings for a partial discharge free type during the testing of the transformer.

11.3.2 Test duration and frequency

The test time at the enhancement voltage shall be 60 s in case $U_m \leq 800$ kV and 300 s in case $U_m > 800$ kV for any test frequency up to and including twice the rated frequency, unless otherwise specified. When the test frequency exceeds twice the rated frequency, the test time in seconds of the test shall be:

$$120 \times \frac{\text{rated frequency}}{\text{test frequency}}\text{, but not less than 15 s for } U_m \leq 800 \text{ kV}$$

or

$$600 \times \frac{\text{rated frequency}}{\text{test frequency}}\text{, but not less than 75 s for } U_m > 800 \text{ kV}$$

The duration of the test, except for the enhancement level, shall be independent of the test frequency

11.3.3 Test sequence

The test sequence shall be as follows:

a) The voltage shall be switched on at a voltage not higher than $(0{,}4 \times U_r)/\sqrt{3}$.

b) The voltage shall be raised to $(0{,}4 \times U_r)/\sqrt{3}$ and a background PD measurement shall be made and recorded.

c) The voltage shall be raised to $(1{,}2 \times U_r)/\sqrt{3}$ and held there for a minimum duration of 1 min and only long enough to make a stable PD measurement.

d) The PD level shall be measured and recorded.

e) The voltage shall be raised to the one hour PD measurement voltage and held there for a minimum duration of 5 min and only long enough to make a stable PD measurement.

f) The PD level shall be measured and recorded.

g) The voltage shall be raised to the enhancement voltage and held there for the test time in 11.3.2.

h) Immediately after the test time, the voltage shall be reduced without interruption to the one hour PD measurement voltage.

i) The PD level shall be measured and recorded.

j) The voltage shall be held at the one hour PD measurement voltage for a duration of at least one hour following the PD measurement.

k) The PD level shall be measured and recorded every 5 min during the one hour period.

l) After the last PD measurement in the one hour period the voltage shall be reduced to $(1{,}2 \times U_r)/\sqrt{3}$ and held there for a minimum duration of 1 min and only long enough to make a stable PD measurement.

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m) The PD level shall be measured and recorded.

n) The voltage shall be reduced to $(0{,}4 \times U_r)/\sqrt{3}$ and the background PD level shall be measured and recorded.

o) The voltage shall be reduced to a value below $(0{,}4 \times U_r)/\sqrt{3}$.

p) The voltage shall be switched off.

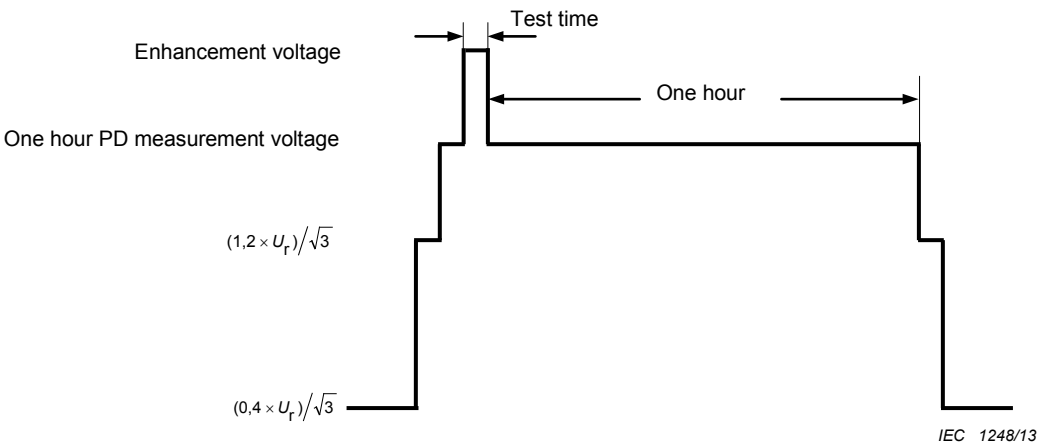
The partial discharge level shall be continuously observed on at least one measuring channel for the entire duration of the test.

During the test sequence the inception and extinction voltages of any significant PD activity should be noted to aid the evaluation of the test result if the test criteria are not met.

NOTE It can also be helpful to record the PD pattern (phase angle, apparent charge and number) of any significant PD activity to aid evaluation.

Enhancement voltage level and one hour PD measurement voltage are given in 7.3.1.3, 7.3.2.1 and 7.3.3.1 depending on the U_m of the transformer.

The main features of the test sequence are illustrated in Figure 1.



NOTE Enhancement voltage level and one hour PD measurement voltage are given in 7.3.1.3, 7.3.2.1 and 7.3.3.1

Figure 1 – Time sequence for the application of test voltage for induced voltage test with partial discharge measurement (IVPD)

11.3.4 Partial discharge (PD) measurement

Partial discharges shall be measured by a method according to IEC 60270.

Each PD measurement channel including the associated bushing or coupling capacitor shall be calibrated in terms of apparent charge (pC) according to the method given in IEC 60270.

The PD measurement shall be given in pC and shall refer to the highest steady-state repetitive impulses indicated by the measuring instrument.

Occasional bursts of high partial discharge level may be disregarded.

For each required PD measurement step in the test sequence, PD measurements shall be made and recorded on all the line terminals equipped with bushings with a $U_m \geq 72{,}5$ kV, during the test, however if there are more than six such terminals then only six measurements need to be made (one on each of the highest voltage terminals) unless otherwise specified.

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NOTE Bushings with $U_m \geq 72{,}5$ kV are equipped with test taps according to IEC 60137 which can be used for the measurement, if this test is specified as a special test for transformers with a $U_m < 72{,}5$ kV then the method of measurement will have to be agreed between the manufacturer and purchaser.

11.3.5 Test acceptance criteria

The test can only be considered valid if the measured background PD level does not exceed 50 pC at both the beginning and the end of the test. For tests on shunt reactors a background PD level of up to 100pC may be accepted.

NOTE The higher background level for shunt reactors is because filtering of the test supply might not be possible where high current and high voltage is required.

The test is successful if all the following criteria are fulfilled:

a) no collapse of the test voltage occurs;

b) none of the PD levels recorded during the one hour period exceed 250 pC;

c) the PD levels measured during the one hour period do not exhibit any rising trend and no sudden sustained increase in the levels occur during the last 20 min of the test;

d) the measured PD levels during the one hour period do not increase by more than 50 pC;

e) the PD level measured at a voltage level of $(1{,}2 \times U_r)/\sqrt{3}$ after the one hour period does not exceed 100 pC.

If the criteria c) or d) are not met, the one hour period may be extended and these criteria will be considered to have been met if they are fulfilled for a continuous period of one hour.

As long as no breakdown occurs, and unless very high partial discharges are sustained for a long time, the test is regarded as non-destructive. A failure to meet the partial discharge acceptance criteria shall therefore not warrant immediate rejection, but lead to consultation between purchaser and manufacturer about further investigations. Suggestions for such procedures are given in Annex A.

12 Line terminal AC withstand test (LTAC)

The test shall be arranged so that the test voltage appears between the tested terminal and earth. Each phase terminal of the tested winding shall be tested in turn. The test time, frequency and voltage application shall be as given for the induced voltage withstand test see 11.2.

For transformers with taps and a non-uniformly insulated lower voltage winding, the tap position for test shall be selected so that when the required test voltage appears on the highest voltage winding terminals, the voltage appearing on the lower voltage winding terminals shall be as close as possible to the required test value. For transformers with a uniformly insulated lower voltage winding subject to an applied voltage test, the tap position may be chosen by the manufacturer.

The test is successful if no collapse of the test voltage occurs.

NOTE This test is intended only as a withstand test for each line terminal of a non-uniformly insulated transformer to earth, it is not intended to test the phase to phase or turn to turn insulation so the test arrangement can be made in any convenient way, for example with voltage at the neutral to reduce the turn to turn voltage and the test will normally be carried out as three single phase tests. Under normal circumstances the switching impulse test fully covers the intent of this test. If required by the purchaser partial discharge measurements can be made during this test.

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13 Lightning impulse tests (LI, LIC, LIN, LIMT)

13.1 Requirements for all lightning impulse tests

13.1.1 General

General definitions of terms related to impulse tests and requirements for test circuits are given in IEC 60060-1. General definitions of terms related to performance tests and routine checks on approved measuring devices are given in IEC 60060-2. Further information is given in IEC 60076-4.

For liquid-immersed transformers, the test voltage is normally of negative polarity, because this reduces the risk of erratic external flashovers in the test circuit. One, more or all of the impulses may be specified by the purchaser to be of positive polarity. If positive impulses are required by the purchaser this shall be stated in the enquiry and order. If a mixture of impulse polarities are used then additional reference impulses will be required and the test sequence shall be agreed between the manufacturer and purchaser.

Before an impulse of opposite polarity is applied, sufficient time should be allowed for any residual charge to dissipate.

13.1.2 Tap positions

If the tapping range is ± 5 % or less and the rated power of the transformer is ≤ 2 500 kVA then, the lightning impulse tests shall be made with the transformer connected on the principal tapping.

If the tapping range is larger than ± 5 % or the rated power of the transformer is > 2 500 kVA then, unless otherwise agreed, the two extreme tappings and the principal tapping shall be used, one tapping for each of the three individual phases of a three-phase transformer or the three single-phase transformers designed to form a three-phase bank.

Alternatively if specified by the purchaser and in special cases such as one single phase transformer, or multiple tap-changers, or when the tapping-range is not symmetrical, the tap-position which gives the highest internal voltages (determined either by calculation or by performing low voltage impulse measurements) shall be used. If different tap-positions give highest internal voltages in different parts of the insulation then by agreement those different tap positions may be tested, one on each phase of a three phase transformer.

NOTE Particular attention is drawn to the difference between the raise and lower positions at the change-over tap position(s) of a reversing type tapping winding or of a coarse-fine type tapping winding as these give different internal voltages.

In the case of a coarse-fine type tapping winding, if the tap-changer diverter is provided with a non-linear element or arcing gap, which might operate if the transformer is tested on a particular tap-position, then an alternative tap-position may be chosen. Guidance is given in IEC 60076-4.

13.1.3 Records of tests

The applied test voltage shall be recorded using a measurement system according to IEC 60060-2. The records obtained shall clearly show the applied voltage impulse shape (front time, time-to-half value and amplitude).

The recorded curve and the extreme value of the recorded curve (as defined in IEC 60060-1) shall be presented in the test record.

The value of the test voltage (after the application of any filtering or correction for overshoot, U_t see IEC 60060-1) shall be reported in the test record.

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At least one more measurement channel shall be used. In most cases an oscillogram of the current flowing to earth from the tested winding (neutral current) or the capacitive probe current, i.e. the current transferred to the non-tested and shorted winding, will represent the best sensitivity for fault indication. The current flowing from tank to earth, or the transferred voltage in a non-tested winding, are examples of alternative suitable measuring quantities. The detection method chosen shall be agreed between manufacturer and purchaser.

Further recommendations about failure detection, suitable time-base durations, etc. are given in IEC 60076-4.

13.1.4 Test connections

13.1.4.1 Test connections during tests on line terminals

The impulse test sequence is applied to each of the line terminals of the tested winding in succession. The other line terminals of the transformer shall be earthed directly or, if needed to achieve the required waveshape, through an impedance. The impedance shall not exceed the surge impedance of the connected line (if a value is supplied by the purchaser) or 400 Ω whichever is lower. In all circumstances, the voltage appearing during the impulse test at the other line terminals shall not be more than 75 % of their rated lightning impulse withstand voltage for star-connected windings, or 50 % for delta-connected windings. The lowest value of impedance at each terminal needed to achieve the required waveshape shall be used.

If the winding has a neutral terminal, the neutral shall be earthed directly or through a low impedance such as a current measuring shunt. The tank shall be earthed. If the required waveshape cannot be obtained without the use of a resistor between neutral and earth, then an additional complete impulse test sequence shall be applied. In this case the first impulse test sequence tests the winding at the full voltage without the resistor but the required waveshape may not be achieved and the second sequence with the resistor achieves the waveshape. Chopped waves, if required, would not be repeated in the second sequence.

When a transformer is fitted with internal non-linear elements such as surge arresters which will limit the voltage on internal parts during the impulse test then the provisions of 13.2.3 apply. Any such internal non-linear elements which are present in the service condition shall be present during the tests. External non-linear elements and other external voltage control elements such as capacitors shall be disconnected for test.

The impulse circuit and measuring connections shall remain unchanged during reference and full voltage tests.

Exceptions from this main procedure are given in 13.3.2 and 13.3.3.

NOTE If an impulse test is required by the purchaser on an LV winding with $U_m \leq 1{,}1$ kV then this is normally applied to all the LV terminals (including the LV neutral) connected together with the higher voltage terminals earthed.

13.1.4.2 Test connections for lightning impulse on the neutral

Lightning impulses are applied directly to the neutral with all other terminals earthed.

When a transformer is fitted with internal non-linear elements such as surge arresters which will limit the voltage on internal parts during the impulse test then the provisions of 13.2.3 apply. Any such internal non-linear elements which are present in the service condition shall be present during the tests. External non-linear elements shall be disconnected for test.

For transformers having a tapped winding near the neutral end of the winding, the tapping connection with the maximum turns ratio shall be chosen for the impulse test, if not otherwise agreed between purchaser and manufacturer.

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The impulse circuit and measuring connections shall remain unchanged during reference and full voltage tests.

13.1.4.3 Test connections for lightning impulses applied to multiple line terminals simultaneously (LIMT)

The purchaser shall specify the terminals which are to be connected together for this test.

Lightning impulses shall be applied simultaneously to the specified line terminals connected together with the other terminals earthed. The test levels and details of the test arrangement shall be agreed. The test shall be carried out on each phase in turn.

NOTE The voltages appearing within the winding during this test can significantly exceed the terminal voltages during this test.

13.2 Full wave lightning impulse test (LI)

13.2.1 Wave shape, determination of test voltage value and tolerances

The test impulse shall be a full standard lightning impulse: 1,2 ± 30 % / 50 μs ± 20 %..

The test voltage value shall be the test voltage value as defined in IEC 60060-1 (after the test voltage function is applied). If the maximum relative overshoot magnitude is 5 % or less, the test voltage value may be taken as the extreme value as defined in IEC 60060-1.

The tolerance on the test voltage value is ± 3 %.

It is important that the manufacturer assesses the adequacy of the test equipment to achieve a waveshape within the tolerances for the particular combination of transformer and test equipment at the bid stage and has a reasonable expectation of meeting the requirements. In circumstances where the manufacturer believes that it is not reasonably possible to meet the waveshape because of the transformer characteristics and the variations to the waveshape allowed in the following paragraphs will need to be applied then this shall be clearly stated in the tender. The value of the effective energy of the impulse generator shall be made available to the purchaser on request.

NOTE 1 The minimum impulse generator energy required to meet the tail time (50 μs) during an impulse test on a transformer can be estimated by using the following equation (this equation is only a guide and might underestimate the energy required. Information from previous experience of testing similar transformers can be used if available):

$$E_{min} = \frac{100 \times 2\pi \times f \times (t_2)^2}{z \times U^2} \times \left(\frac{U_{LI}}{\eta}\right)^2 \times S_r$$

where

- E_{min} is the minimum energy required from the impulse generator in joules;
- f is the rated frequency of the transformer in hertz;
- t_2 is the tail time in seconds; t_2 equal 50×10^{-6} s;
- z is the short circuit impedance in % seen from the impulse terminal see IEC 60076-1;
- U is the winding rated voltage in volts, phase-to-phase;
- U_{LI} is the full wave lightning impulse test voltage of the tested winding in volts;
- η is the impulse generator efficiency per unit; η = 1,0;
- S_r is the three-phase power rating in volt-amperes for which the impedance 'z' is defined.

If the standard impulse shape cannot reasonably be obtained because of low winding inductance or high capacitance to earth and the resulting impulse shape is oscillatory so that the relative overshoot magnitude exceeds 5 % then for windings that will receive a chopped wave lightning impulse test, the front time may be increased to reduce the overshoot. In all cases with $U_m \leq 800$ kV the front time shall not exceed 2,5 μs. If the relative overshoot magnitude exceeds 5 % at the full wave voltage level, then a test voltage function shall be

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applied in accordance with IEC 60060-1 to determine the test voltage value. It is permissible to apply the requirements of IEC 60060-1 Annex B to the evaluation of the parameters of the lightning impulse irrespective of the overshoot value.

NOTE 2 This clause gives two methods of dealing with an overshoot of more than 5 %. The front time can be increased, but if 1,2 μs + 30 % is exceeded then chopped waves are required to provide a high frequency test. Alternatively or in addition, the peak voltage of the impulse (maximum value of the recorded curve) is increased if the overshoot exceeds 5 % and the frequency of oscillation is higher than about 100 kHz by the application of the test voltage function in accordance with IEC 60060-1.

For transformers with a U_m > 800 kV there may be cases where a front time of less than 2,5 μs cannot be reasonably achieved because of a very high capacitance to earth. In these cases a longer front time may be accepted by agreement between purchaser and manufacturer.

If the minimum tail time is not achieved then by agreement between manufacturer and purchaser a shorter tail time may be accepted but the test voltage shall be increased by 1 % for each 2 μs by which the tail time is less than 40 μs. The minimum allowable tail time is 20 μs. In the case of the low voltage winding of generator step-up transformers where the connection is arranged so that a direct lightning impulse cannot occur in service then this requirement may be varied by agreement.

Further guidance may be obtained from IEC 60076-4.

13.2.2 Tests on transformers without non-linear elements

13.2.2.1 Test sequence

The test sequence shall consist of:

a) one reference impulse of a voltage between 50 % and 70 % of the full test voltage

b) three subsequent impulses at full voltage.

If, during any of these applications, an external flashover in the circuit or across a bushing spark gap occurs, or if the recording fails on any of the specified measuring channels, that application shall be disregarded and a further application made.

NOTE Additional impulses at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report.

13.2.2.2 Test acceptance criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the reference impulse and those recorded at the full test voltage.

NOTE The detailed interpretation of the test records and the discrimination between marginal differences and differences indicating failure requires a great deal of skill and experience. Further information is given in IEC 60076-4.

If there is a voltage collapse or deviation and it is agreed between the manufacturer and purchaser that the test is not immediately failed, the test sequence shall be completed and then the full test sequence repeated using the original reference impulse. If any further voltage collapse or deviation is observed then the test is failed.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

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13.2.3 Tests on transformers with non-linear elements

13.2.3.1 Test sequence

If non-linear elements or surge arresters are built into the transformer for the limitation of transferred overvoltage transients, they may operate during the test procedure and this may cause differences between impulse records made at different voltages. There will be a threshold voltage at which the differences caused by the non-linear elements start to appear and the test sequence shall include at least one record below this threshold.

The test sequence shall consist of:

a) one reference impulse at between 50 % and 60 % of the full test voltage;

b) one reference impulse at between 60 % and 75 % of the full test voltage;

c) one reference impulse at between 75 % and 90 % of the full test voltage;

d) three consecutive 100 % full wave impulses;

e) a comparison impulse at as nearly as possible the same voltage as c) above;

f) a comparison impulse at as nearly as possible the same voltage as b) above;

g) a comparison impulse at as nearly as possible the same voltage as a) above.

The reference impulse voltages shall be at least 10 % (of the 100 % level) different from each other.

If none of the 100 % full wave records differ from the lowest voltage record of the reference impulse records, then impulses e), f) and g) above may be omitted.

NOTE Additional impulses at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report.

If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

13.2.3.2 Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the lowest voltage reference impulse and those recorded at the full test voltage.

If this is not the case then the records of current and voltage from the following impulses shall be compared:

– a) and g)

– b) and f)

– c) and e)

– all the 100 % level impulse records.

The test is successful if there is no significant difference between the compared records (beyond that which can reasonably be explained by small differences in the test voltage) and any changes between successive records are progressive and smooth, consistent with the proper operation of the non-linear element.

NOTE Further information is given in IEC 60076-4.

If there is a voltage collapse or deviation and it is agreed between the manufacturer and purchaser that the test is not immediately failed, the test sequence shall be completed and then the full test sequence repeated using the original reference impulse. If any further voltage collapse or deviation is observed then the test is failed.

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Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

13.3 Chopped wave lightning impulse test (LIC)

13.3.1 Wave shape

The wave shape of the full wave impulses shall be as given in 13.2.1. The chopped wave lightning impulse shall have a time to chopping between 3 μs and 6 μs. The time to first voltage zero after the instant of chopping shall be as short as possible. The test shall be made without the deliberate addition of impedance in the chopping circuit, but if the overswing observed during a reduced voltage application is more than 30 % then the minimum impedance required to bring the overswing below 30 % may be added to the chopping circuit.

A time to chopping of between 2 μs and 3 μs can be accepted by agreement provided that the peak value of the lightning impulse wave is achieved before the chop.

NOTE Transformers are normally designed to withstand an overswing to the opposite polarity of 30 % of the amplitude of the chopped wave lightning impulse. If the transformer is to be tested by a third party the overswing is to be limited to this value.

Usually, the same settings of the impulse generator and measuring equipment are used, and only the chopping gap equipment is added.

Different time bases may be used to record the chopped wave lightning impulses.

It is recommended to use a triggered-type chopping gap with adjustable timing, although a plain rod-rod gap is allowed.

The peak value of the chopped wave lightning impulse shall be as given in Table 2.

13.3.2 Tests on transformers without non-linear elements

13.3.2.1 Test sequence

The test is combined with the full impulse test in a single sequence. Unless otherwise specified the order of the different impulse applications shall be:

a) one full wave reference impulse at between 50 % and 70 % of the full wave lightning impulse test voltage;

b) one full wave impulse at the full wave lightning impulse test voltage;

c) two chopped impulses at the chopped wave lightning impulse test voltage;

d) two full wave impulses at the full wave lightning impulse test voltage.

The same types of measuring channels and oscillographic records are specified as for the full-wave impulse test.

NOTE Additional impulses (full or chopped) at amplitudes not higher than the reference impulse voltage level can be used, these do not need to be shown in the test report

If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

As far as possible the same time to chop shall be used for all chopped wave lightning impulses in the sequence.

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13.3.2.2 Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the reference reduced level full impulse and those recorded at the full test voltage including the chopped impulses up to the time of chop. In the case of the chopped impulses differences after the chopping time may be due to minor variations in the performance and timing of the chopping gap.

NOTE The detailed interpretation of the test records and the discrimination between marginal differences and differences indicating failure requires a great deal of skill and experience. Further information is given in IEC 60076-4.

If there is a voltage collapse or deviation and it is agreed between the manufacturer and purchaser that the test is not immediately failed the test sequence shall be completed and then the full test sequence repeated using the original reference impulse. If any further voltage collapse or deviation is observed then the test is failed.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

13.3.3 Tests on transformers with non-linear elements

13.3.3.1 Test sequence

The test is combined with the full impulse test in a single sequence.

If non-linear elements or surge diverters are built into the transformer for the limitation of transferred overvoltage transients, they may operate during the test procedure and this may cause differences between impulse records made at different voltages. There will be a threshold voltage at which the differences caused by the non-linear elements start to appear and the test sequence shall include at least one record below this threshold.

The test sequence shall consist of:

a) one full wave reference impulse at between 50 % and 60 % of the full wave lightning impulse test voltage;

b) one full wave reference impulse at between 60 % and 75 % of the full wave lightning impulse test voltage;

c) one full wave reference impulse at between 75 % and 90 % of the full wave lightning impulse test voltage;

d) one full wave impulse at the full wave lightning impulse test voltage;

e) two chopped impulses at the chopped wave lightning impulse test voltage;

f) two full wave impulses at the full wave lightning impulse test voltage;

g) a comparison impulse at as nearly as possible the same voltage as c) above;

h) a comparison impulse at as nearly as possible the same voltage as b) above;

i) a comparison impulse at as nearly as possible the same voltage as a) above.

The reference impulse voltages shall be at least 10 % (of the 100 % level) different from each other.

If none of the 100 % full wave records differ from the lowest voltage of the reference impulse record then impulses g), h) and i) above may be omitted.

The time interval between the application of the last chopped wave and the first full wave after the chop waves shall be as short as practicable.

NOTE Additional impulses (full or chopped) at amplitudes not higher than 75 % of the full level can be used; these do not need to be shown in the test report.

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If, during any of these applications, an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

The same types of measuring channels and oscillographic records are specified as for the full-wave impulse test.

As far as possible the same time to chop shall be used for all chopped impulses in the sequence.

13.3.3.2 Test criteria

The test is successful if there are no significant differences between voltage and current transients recorded from the lowest voltage reference impulse and those recorded at the full test voltage including the chopped wave impulses up to the time of chop. In the case of the chopped impulses differences after the chopping time may be due to minor variations in the performance and timing of the chopping gap.

If this is not the case then the records of current and voltage from the following impulses shall be compared:

– a) and i);
– b) and h);
– c) and g);
– all the 100 % level impulse records;
– both the chopped wave records up to the time of chop.

The test is successful if there is no significant difference between the compared records (beyond that which can reasonably be explained by small differences in the test voltage) and any changes between successive records should be progressive and smooth, consistent with the proper operation of the non-linear element.

NOTE 1 Further information is given in IEC 60076-4.

If there is a voltage collapse or deviation and it is agreed between the manufacturer and purchaser that the test is not immediately failed, the test sequence shall be completed and then the full test sequence repeated using the original reference impulse. If any further voltage collapse or deviation is observed then the test is failed.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the interpretation of the records, but they do not constitute evidence in themselves.

NOTE 2 The information given in IEC 60076-4 with reference to waveshape evaluation is based on the visual observation of oscillographic records. Under certain circumstances it might be appropriate to evaluate the waveshape parameters of non-standard waveshapes and perform the interpretation of deviations manually rather than relying completely on software tools.

13.4 Lightning impulse test on a neutral terminal (LIN)

13.4.1 General

Full wave lightning impulses at the impulse voltage level specified for the neutral are applied directly to the neutral with all other terminals earthed.

13.4.2 Waveshape

The wave shape of the full wave impulses shall be as given in 13.2.1 except that the duration of the front may be up to a maximum of 13 μs.

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13.4.3 Test sequence

The test sequence shall be as given in 13.2.2.1 for transformers without a non-linear element and 13.2.3.1 for transformers with a non-linear element.

13.4.4 Test criteria

The test criteria shall be as given in 13.2.2.2 for transformers without a non-linear element and 13.2.3.2 for transformers with a non-linear element.

14 Switching impulse test (SI)

14.1 General

During switching impulse tests, the voltages developed across different windings are approximately proportional to the ratio of numbers of turns.

The switching impulse test voltage shall be as specified for the winding with the highest U_m value. If the ratio between the windings is variable by tappings, the tappings shall be used to bring the test voltage for the winding with lower U_m as close as possible to the corresponding test value given in Table 2. The windings with lower U_m values may not receive their full test voltage; this shall be accepted. If lower voltage windings do not have a switching impulse level given in Table 2 then the manufacturer may choose the tap position for test unless otherwise specified by the purchaser.

In a three-phase transformer, the voltage developed between line terminals during the test shall be approximately 1,5 times the voltage between line and neutral terminals.

14.2 Test connections

The impulses are applied either directly from the impulse voltage source to a line terminal of the highest voltage winding, or to a lower voltage winding so that the test voltage is inductively transferred to the highest voltage winding. The specified test voltage shall appear between the line terminal of the highest voltage winding and earth. The voltage shall be measured at the line terminal of the highest voltage winding.

A three-phase transformer shall be tested phase by phase.

Star connected windings with the neutral brought out shall be earthed at the neutral terminal either directly or through a low impedance such as a current measuring shunt. A voltage of opposite polarity and about half amplitude appears on the two remaining line terminals which may be connected together but not connected to earth. To limit the voltage of opposite polarity to approximately 50 % of the applied level, it is permissible to connect high resistance damping resistors (5 kΩ to 20 kΩ) to earth at the non-tested phase terminals.

For delta connected windings the terminal corresponding to the end of the phase under test shall be earthed either directly or through a small measuring impedance, the other terminals shall be open circuit. Tests on a three-phase transformer shall be arranged so that a different terminal of the delta is earthed for each phase test. Delta connected windings with more than three terminals brought out shall have the delta closed for the test.

For a single phase transformer with one or more windings which will have both ends connected to a line in service and with a switching impulse test specified, then the switching impulse test shall be applied to both ends of the winding.

For a star connected winding with a neutral connection not brought out and not connected to earth internally, it is not always possible to achieve the appropriate test voltages by earthing

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one or more line terminals, in this case the test connection shall be agreed between manufacturer and purchaser.

Bushing spark gaps may be removed or their spacing increased to prevent sparkover during the test.

14.3 Waveshape

The test voltage is normally of negative polarity to reduce the risk of erratic external flashover in the test circuit.

The voltage impulse shall have a time to peak (T_p as defined in IEC 60060-1) of at least 100 μs, a time above 90 % (T_d as defined in IEC 60060-1) of the specified amplitude of at least 200 μs, and a time to zero (T_z as defined in IEC 60060-1) of a minimum of 1 000 μs.

NOTE 1 The impulse wave shape is purposely different from the standard waveshape of 250 / 2 500 μs recommended in IEC 60060-1, since IEC 60060-1 is intended for equipment without a saturable magnetic circuit. The time to peak is chosen to be long enough to give an essentially linear voltage distribution along the winding.

The time to zero can be increased by inducing a remnant flux into the core of opposite direction to that induced during the test before each full-voltage test impulse. This is normally accomplished by applying impulses of similar shape but opposite polarity at a voltage not exceeding 70 % of the full test level, but other methods may be used. A time to zero of less than 1 000 μs is permissible if as far as practicable full reverse saturation of the core is achieved.

NOTE 2 During the test considerable flux is developed in the magnetic circuit. The impulse voltage can be sustained up to the instant when the core reaches saturation and the magnetizing impedance of the transformer becomes drastically reduced.

For test objects without a magnetic core or with a gapped core design, it is permissible to have a time to zero of less than 1 000 μs. See IEC 60076-4.

14.4 Test sequence

The test sequence shall consist of one reference impulse of a voltage between 50 % and 70 % of the full test voltage and three impulses at full voltage. Sufficient reverse polarity applications shall be made before each full impulse to ensure the magnetization of the core is similar before each full wave impulse in order to make the time to first zero as uniform as possible.

NOTE If the core does not saturate during the full voltage applications then reverse polarity applications might not be required.

Oscillographic records shall be made of the impulse wave-shape on the line terminal under test and the current between the tested winding and earth. If during any of these applications an external flashover in the circuit or across a bushing spark gap should occur, or if the recording should fail on any of the specified measuring channels, that application shall be disregarded and a further application made.

14.5 Test criteria

The test is successful if there is no sudden collapse of voltage or discontinuity in the voltage or current indicated on the oscillographic records.

Additional observations during the test (abnormal sounds, etc.) may be used to confirm the oscillographic records, but they do not constitute evidence in themselves.

NOTE Successive oscillograms might differ because of the influence of magnetic saturation on impulse duration.

Documents
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