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Power transformers - Part 3: Insulation levels and dielectric tests



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# Transformateurs de puissance

## Troisième partie: Niveaux d'isolement et essais diélectriques



# Power transformers



## Part 3: Insulation levels and dielectric tests



**Mots clés:** transformateurs de puissance; exigences; essais; propriétés; définitions; niveaux d'isolement; essais diélectriques.

**Key words:** power transformers; requirements; testing; properties; definitions; insulation levels; dielectric tests.



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE



This standard has been prepared by IEC Technical Committee No. 14, Power Transformers.



A first draft was discussed at the meeting held in Athens in 1972 and a second draft was discussed at the meeting held in Bucharest in 1974. As a result of this meeting, a draft, Document 14(Central Office)39, was submitted to the National Committees for approval under the Six Months' Rule in January 1977.

An amended draft, Document 14(Central Office)45, was submitted to the National Committees for approval under the Two Months' Procedure in December 1978.

The National Committees of the following countries voted explicitly in favour of publication:

| | |
|---|---|
| Australia | Israel |
| Austria | Italy |
| Belgium | Japan |
| Canada | Norway |
| China | Poland |
| Czechoslovakia | Romania |
| Denmark | South Africa (Republic of) |
| Egypt | Spain |
| Finland | Sweden |
| France | Switzerland |
| Germany | Turkey |
| Hungary | United States of America |
| Indonesia | Yugoslavia |

The National Committees of the Netherlands, the United Kingdom and the Union of Soviet Socialist Republics voted against publication for the following reasons:

The Netherlands National Committee voted against publication because it could not accept the minimum duration of the induced overvoltage withstand test specified in Sub-clause 11.1, nor Sub-clause 11.2, because the test specified should be carried out on all three-phase transformers, including those mentioned in Sub-clause 11.3, nor the values of the test voltages $U_1$ and $U_2$ in Sub-clause 11.4.

The British National Committee voted against publication because it could not accept Sub-clause 13.3. It considers that when a chopped-wave impulse test is combined with a full-wave impulse test the full-wave records should constitute a quality criterion just as much as do the chopped-wave impulse records.

The U.S.S.R. National Committee voted against publication because the requirements for routine tests on transformers with $U_m \geqslant 300$ kV, and the impulse levels for the chopped wave lightning impulse test differ from U.S.S.R. practice.

Publication 76 has been divided into the following five parts which are published as separate booklets:

Publication 76-1, Part 1: General
Publication 76-2, Part 2: Temperature Rise
Publication 76-3, Part 3: Insulation Levels and Dielectric Tests
Publication 76-4, Part 4: Tappings and Connections
Publication 76-5, Part 5: Ability to Withstand Short Circuit

The publication of Part 3 completes the revision of Publication 76 (1967), which now no longer applies to power transformers. It is, however, being retained pending the revision of IEC Publication 289: Reactors, which makes reference to Publication 76 (1967).



*Other IEC publications quoted in this standard:*

Publications Nos. 50: International Electrotechnical Vocabulary.
60: High-voltage Test Techniques.
60-2: Part 2: Test Procedures.
71: Insulation Co-ordination.
71-1: Part 1: Terms, Definitions, Principles and Rules.
71-2: Part 2: Application Guide.
76: Power Transformers.
76-1: Part 1: General.
137: Bushings for Alternating Voltages above 1 000 V.
270: Partial Discharge Measurements.

# POWER TRANSFORMERS

## Part 3: Insulation levels and dielectric tests

### 1. Definitions

For the purposes of this part of the standard the following definitions apply. Other terms used have the meanings ascribed to them in Publication 76-1: Power Transformers, Part 1: General, or in the International Electrotechnical Vocabulary (I.E.V.)*.

1.1 *Highest voltage for equipment applicable to a transformer winding $U_m$*

The highest r.m.s. phase-to-phase voltage for which a transformer winding is designed in respect of its insulation.

*Note.* — $U_m$ is the maximum value of the highest voltage of a system to which the winding may be connected, in respect of its insulation.



1.2 *Rated insulation level*

Two alternative definitions are used:

*a)* The rated lightning impulse and short duration power frequency withstand voltages.



*Note.* — Definition *a)* applies for all windings with highest voltage for equipment $U_m$ lower than 300 kV, and for windings with $U_m$ equal to or greater than 300 kV that are specified according to Method 1 — see Clause 5.

*b)* The rated lightning and switching impulse withstand voltages (phase-to-earth).

*Note.* — Definition *b)* applies for windings with $U_m$ equal to or greater than 300 kV that are specified according to Method 2 — see Clause 5.

1.3 *Uniform insulation of a transformer winding*

The insulation of a transformer winding when all its ends connected to terminals have the same power frequency withstand voltage to earth.

1.4 *Non-uniform insulation of a transformer winding*

The insulation of a transformer winding when it has an end intended for direct or indirect connection to earth, and is designed with a lower insulation level assigned to this earth or neutral winding end.

* Note concerns French text only.

## 2. General

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

For oil-immersed 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.

*Note.* — Where appropriate these tests can be type tests on a suitable model of the configuration.

If the user intends to make the connections to the transformer in a way which may reduce the clearances provided by the transformer alone, this should be brought to attention in the enquiry.

When an oil-immersed 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 those specified for the internal insulation of the transformer windings (see Clause 42 of IEC Publication 137, Bushings for Alternating Voltages above 1 000 V).

Bushings are subject to separate type and routine tests according to IEC Publication 137, which verify their phase-to-earth insulation, external as well as internal.



It is presupposed that bushings and tap-changers are specified, designed and tested in accordance with relevant IEC standards. The insulation tests on the complete transformer, however, constitute a check on the correct application and installation of these components.



The insulation tests shall generally be made at the manufacturer's works with the transformer approximately at ambient temperature.

The transformer shall be completely assembled as in service, except that for oil-immersed transformers the fitting of external cooling and supervisory equipment is not necessary.

If a transformer fails to meet its test requirements and the fault is in a bushing, it is permissible to replace this bushing temporarily with another bushing and continue the tests on the transformer to completion without delay. A particular case arises for tests with partial discharge measurements, where certain types of commonly used high-voltage bushings create difficulty because of their relatively high level of partial discharge in the dielectric. When such bushings are specified for the transformer, it is permitted to exchange them for bushings of a partial discharge free type during the testing of the transformer (see Appendix A).

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 insulation tests, using temporary bushings if necessary.

When the manufacturer intends to use non-linear elements or surge arresters—built into the transformer or externally fitted—for the limitation of transferred overvoltage transients, this shall be brought to the user's attention.

## 3. Highest voltage for equipment and insulation level

To each winding of a transformer is assigned a value of "highest voltage for equipment" $U_m$ (Sub-clause 1.1). The rules for co-ordination of transformer insulation with respect to transient overvoltages are formulated differently depending on the value of $U_m$. When rules about specific tests for different windings in a transformer are in conflict, the rule for the winding with the highest $U_m$ value shall apply.

Rules for a number of special cases are given in Clause 4.

Standardized values of $U_m$ are listed in Tables II to V. The value to be used for a transformer winding is the one equal to, or nearest above, the rated voltage of the winding.

*Notes 1.* — Single-phase transformers intended for connection in star to form a three-phase bank are designated by phase-to-earth rated voltage—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.

2\. — It may happen that certain tapping voltages are chosen slightly higher than a standardized value of $U_m$, but that 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 co-ordinated with actual system conditions, and therefore this standard value should be accepted as $U_m$ for the transformer, and not the nearest higher value.

The rated withstand voltages for the winding which constitute its insulation level are verified by a set of dielectric tests, and the set of tests is different depending on the value of $U_m$ (Clause 5).



The value $U_m$ and the 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 insulation level of the neutral terminal shall also be specified by the purchaser (Sub-clause 5.5.3). If there is a winding with non-uniform insulation and $U_m \geqslant 300$ kV, it shall be tested according to Method 1 or Method 2 (Clause 5, Table I), and in the case of Method 2 further information shall be given about the choice of certain alternative procedures in the induced overvoltage withstand test (Sub-clause 11.4).



The rated withstand voltages for all windings shall appear on the rating plate. The principles of the standard abbreviated notation are shown by the following examples:

*Note.* — The abbreviations used in examples 1 to 3 have the following meanings:
LI = lightning impulse withstand voltage.
SI = switching impulse withstand voltage.
AC = power frequency withstand voltage.

*Example 1:*

A transformer having windings with $U_m = 72.5$ and 12 kV, both uniformly insulated.

| INSULATION LEVELS: LI 325 AC 140/LI 60 AC 28 |
|---|

Data for different windings are separated by a stroke, and the impulse level is put first.

*Example 2:*

A transformer having:

— a non-uniformly insulated star-connected high-voltage winding with $U_m = 245$ kV and neutral to be non-directly earthed;

— a uniformly insulated, star-connected winding with $U_m = 72.5$ kV;

— a tertiary, delta-connected winding with $U_m = 24$ kV.

| | |
|---|---|
| INSULATION LEVELS: | LI 850 AC 360 – LI 250 AC 95/<br>LI 325 AC 140/LI 125 AC 50 |

For a non-uniformly insulated winding, line terminal data are given first, and then, after a separating dash, neutral terminal data.

*Example 3:*

An auto-transformer with $U_m = 420$ and 145 kV, specified according to Method 2 (Sub-clause 5.4) and with neutral for direct connection to earth. The tertiary has $U_m$ = 24 kV.



| | |
|---|---|
| INSULATION LEVELS: | SI 1 050 LI 1 300 – AC 38/<br>LI 550 – AC 38/<br>LI 125 AC 50 |



In this example the specification of Method 2 determines the testing of the 145 kV winding as well, and this means that there is no separately specified power frequency withstand voltage for the line terminals of this winding. The induced overvoltage withstand test according to Sub-clause 11.4 applies to both auto-connected windings.

## 4. Rules for some special classes of transformers

In transformers where uniformly insulated windings having different $U_m$ values are connected together within the transformer (usually auto-transformers), the separate-source power-frequency withstand test voltage shall be determined by the winding with the highest $U_m$ value.

In transformers which have one or more non-uniformly insulated windings, the test voltages for the induced overvoltage withstand test, and for the switching impulse test if used, are determined by the winding with the highest $U_m$ value, and the windings with lower $U_m$ values may not receive their appropriate test voltages. This discrepancy should normally be accepted. If the ratio between the windings is variable by tappings, this should be used to bring the test voltage for the winding with lower $U_m$ voltage as close as possible to the appropriate value.

During switching impulse tests, the voltages developed across different windings are approximately proportional to the turns ratios. If rated switching impulse withstand voltages are assigned to several windings, the problem should be solved as indicated in the preceding paragraph. A tapped winding of lower $U_m$ without assigned switching impulse withstand voltage should preferably be connected on its principal tapping during the switching impulse test.

Series windings in booster regulating transformers, phase shifting transformers etc., where the rated voltage of the winding is only a small fraction of the voltage of the system, shall have a value of $U_m$ corresponding to the system voltage. It is often impracticable to test such transformers in formal compliance with this specification, and it should be agreed between the manufacturer and the purchaser as to which tests have to be omitted or modified.

## 5. Insulation requirements and dielectric tests — Basic rules

### 5.1 *General*

The basic rules for insulation requirements and dielectric withstand tests are as follows. They are summarized in Table I.

TABLE I

*Guide to requirements and tests for different categories of windings*

| Category of winding | Withstand voltages constituting insulation level, relevant sub-clauses and tables | Tests and test clauses |
|---|---|---|
| $U_m < 300$ kV<br>uniform insulation | – Power frequency 5.2, II or III<br>– Lightning impulse 5.2, II or III (optional for dry-type transformers)<br>– Lightning impulse for neutral, if specified 5.5.3 | – Separate source A.C. (routine) 10<br>– Lightning impulse (type) 12 on line terminals (Modified impulse test on neutral, special, 12.3.2)<br>– Induced overvoltage (routine) 11.2 |
| $U_m < 300$ kV<br>non-uniform insulation | – Power frequency for line terminal 5.3, II or III<br>– Lightning impulse for line terminals 5.3, II or III<br>– Power frequency for neutral 5.5<br>– Lightning impulse for neutral, if specified 5.5.3 | – Separate source A.C. (routine) 10 corresponding to insulation level of neutral<br>– Lightning impulse (type) 12 on line terminals (Modified impulse test on neutral, special, 12.3.2)<br>– Induced overvoltage (routine) 11.3 |
| $U_m \geq 300$ kV<br>non-uniform insulation<br>Specified according to Method 1, Sub-clause 5.4.1 | – Power frequency for line terminals 5.4.1, IV<br>– Lightning impulse for line terminals 5.4.1, IV<br>– Power frequency for neutral 5.5<br>– Lightning impulse for neutral, if specified 5.5.3 | – Separate source A.C. (routine) 10 corresponding to insulation level of neutral<br>– Lightning impulse (routine) 12 on line terminals (Modified impulse test on neutral, special 12.3.2)<br>– Induced overvoltage (routine) 11.3 |
| $U_m \geq 300$ kV<br>non-uniform insulation<br>Specified according to Method 2, Sub-clause 5.4.2 | – Lightning impulse for line terminals 5.4.2, V<br>– Switching impulse for line terminals 5.4.2, V<br>– Power frequency for neutral 5.5<br>– Lightning impulse for neutral, if specified 5.5.3 | – Separate source A.C. (routine) 10 corresponding to insulation level of neutral<br>– Lightning impulse (routine) 12 on line terminals (Modified impulse test on neutral, special, 12.3.2)<br>– Switching impulse (routine) on line terminals 14<br>– Induced overvoltage (routine) 11.4 with partial discharge measurement |

Information about transformer insulation requirements and dielectric tests shall be supplied with an enquiry and with an order (see Appendix C).

*Note.* — The extension of the lightning impulse test to include impulses chopped on the tail is sometimes specified, particularly for cases where the transformer is not protected by surge arresters. This modification is dealt with in Clause 13.

5.2 *Insulation requirements and dielectric tests for windings with $U_m < 300$ kV, uniform insulation*

The rated withstand voltages of the winding are:

— A rated short-duration power-frequency withstand voltage according to Table II or III.

— A rated lightning impulse withstand voltage for the line terminals according to Table II or III.

— If specified, a rated impulse withstand voltage for the neutral terminal, with the same peak value as for the line terminals.

For values of $U_m$ lower than 52 kV there are two lists of alternative impulse withstand voltages in Table II.

For $U_m = 123$, 145, 170 and 245 kV there are different alternatives of power frequency and impulse withstand voltages in Tables II and III.

The choice between list 1 and list 2 for $U_m < 52$ kV and the choice between alternative rated withstand voltages for $U_m \geq 123$ kV 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 Publication 71-1, Insulation Co-ordination: Part 1: Terms, Definitions, Principles and Rules. The values chosen should be clearly stated in the enquiry.



The rated withstand voltages are verified by the following dielectric tests.

— A separate-source power-frequency voltage withstand test, Clause 10 (routine test).

This test is intended to verify the power-frequency withstand strength of the winding under test to earth and other windings.

— An induced overvoltage withstand test, Sub-clause 11.2 (routine test).
This test is intended to verify the power-frequency withstand strength along the winding under test and between its phases.

— A full-wave lightning impulse test for the line terminals, Clause 12 (type test).
This test is intended to verify the impulse withstand strength of each line terminal to earth and other windings, and along the winding under test.

— An impulse test for the neutral terminal, Sub-clause 12.3.2 (special test), if a rated impulse withstand voltage for the neutral terminal has been specified.
This test is intended to verify the impulse withstand strength of the neutral terminal to earth and other windings.

*Note.* — Distribution transformers for suburban or rural installations are in some countries severely exposed to overvoltages. In such cases, higher test voltages or additional tests, which are not mentioned here, may be agreed between manufacturer and purchaser.