# SLOVENSKI STANDARD

# SIST EN 60076-4:2004

februar 2004

Power transformers - Part 4: Guide to the lightning impulse and switching impulse testing - Power transformers and reactors (IEC 60076-4:2002)

# iTeh STANDARD PREVIEW (standards.iteh.ai)

<u>SIST EN 60076-4:2004</u> https://standards.iteh.ai/catalog/standards/sist/e9666639b-2724-4db0-8fd2-46b18da7ce15/sist-en-60076-4-2004

ICS 29.180

Referenčna številka SIST EN 60076-4:2004(en)

© Standard je založil in izdal Slovenski inštitut za standardizacijo. Razmnoževanje ali kopiranje celote ali delov tega dokumenta ni dovoljeno

# iTeh STANDARD PREVIEW (standards.iteh.ai)

### EUROPEAN STANDARD

## EN 60076-4

### NORME EUROPÉENNE

### **EUROPÄISCHE NORM**

September 2002

ICS 29,180

English version

### Power transformers Part 4: Guide to the lightning impulse and switching impulse testing -Power transformers and reactors (IEC 60076-4:2002)

Transformateurs de puissance Partie 4: Guide pour les essais au choc de foudre et au choc de manoeuvre -Transformateurs de puissance et bobines d'inductance (CEI 60076-4:2002) iTeh STANDARD PREVIEW

Leistungstransformatoren Teil 4: Leitfaden zur Blitzund Schaltstoßspannungsprüfung von Leistungstransformatoren und Drosselspulen

# (standards.iteh.ai)

SIST EN 60076-4:2004

https://standards.iteh.ai/catalog/standards/sist/e966639b-2724-4db0-8fd2-

46b18da7ce15/sist-en-60076-4-2004 This European Standard was approved by CENELEC on 2002-09-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and United Kingdom.

# CENELEC

European Committee for Electrotechnical Standardization Comité Européen de Normalisation Electrotechnique Europäisches Komitee für Elektrotechnische Normung

#### Central Secretariat: rue de Stassart 35, B - 1050 Brussels

© 2002 CENELEC - All rights of exploitation in any form and by any means reserved worldwide for CENELEC members.

#### Foreword

The text of document 14/413/FDIS, future edition 1 of IEC 60076-4, prepared by IEC TC 14, Power transformers, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60076-4 on 2002-09-01.

The following dates were fixed:

<ul> <li>latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement</li> </ul>	(dop)	2003-06-01
<ul> <li>latest date by which the national standards conflicting with the EN have to be withdrawn</li> </ul>	(dow)	2005-09-01

Annexes designated "normative" are part of the body of the standard. Annexes designated "informative" are given for information only. In this standard, annex ZA is normative and annexes A and B are informative. Annex ZA has been added by CENELEC.

#### **Endorsement notice**

The text of the International Standard IEC 60076-4:2002 was approved by CENELEC as a European Standard without any modification STANDARD PREVIEW

## (standards.iteh.ai)

#### Annex ZA

#### (normative)

# Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60060-1	_ 1)	High-voltage test techniques Part 1: General definitions and test requirements	HD 588.1 S1	1991 <sup>2)</sup>
IEC 60060-2	_ 1)	Part 2: Measuring systems	EN 60060-2	1994 <sup>2)</sup>
IEC 60076-3	- <sup>1)</sup> iT(	Power transformers RD PREVIE Part 3: Insulation levels, dielectric tests and external clearances in air 1.21	<b>EN</b> /60076-3	2001 <sup>2)</sup>
IEC 60289	_ 1)	Reactors SIST EN 60076-4:2004	EN 60289	1994 <sup>2)</sup>
IEC 61083-1	https://star	Instruments and software used for measurement in high-voltage impulse tests Part 1: Requirements for instruments	EN 61083-1	2001 <sup>2)</sup>
IEC 61083-2	_ 1)	Digital recorders for measurements in high-voltage impulse tests Part 2: Evaluation of software used for the determination of the parameters of impulse waveforms	EN 61083-2	1997 <sup>2)</sup>

<sup>&</sup>lt;sup>1)</sup> Undated reference.

<sup>&</sup>lt;sup>2)</sup> Valid edition at date of issue.

# iTeh STANDARD PREVIEW (standards.iteh.ai)

# NORME INTERNATIONALE INTERNATIONAL STANDARD

CEI **IEC** 60076-4

Première édition First edition 2002-06

Transformateurs de puissance -

Partie 4: Guide pour les essais au choc de foudre et au choc de manoeuvre – i Transformateurs de puissance et bobines d'inductance

(standards.iteh.ai)

Power transformers/2004 https://standards.iteh.avcatalog/standard/sist/e966639b-2724-4db0-8fd2-46b18da7ce15/sist-en-60076-4-2004 Part 4:

Guide to the lightning impulse and switching impulse testing – Power transformers and reactors

© IEC 2002 Droits de reproduction réservés — Copyright - all rights reserved

Aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'éditeur. No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from the publisher.

International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch



Commission Electrotechnique Internationale International Electrotechnical Commission Международная Электротехническая Комиссия



Pour prix, voir catalogue en vigueur For price, see current catalogue

XB

### CONTENTS

FO	DREWORD	7
1	Scope	11
2	Normative references	11
3	General	13
4	Specified waveshapes	13
5	Test circuit	13
6	Calibration	17
7	′Lightning impulse tests	17
	7.1 Waveshapes	17
	7.2 Impulses chopped on the tail	19
	7.3 Terminal connections and applicable methods of failure detection	21
	7.4 Test procedures	23
	7.5 Recording of tests	25
8	Switching impulse tests	31
	8.1 Special requirements	31
	8.2 TransformersTeh.STANDARD PREVIEW	
~	8.3 Reactors	
9	Interpretation of oscillograms or digital recordings. II. 4.I.	
	9.1 Lightning impulse	
10	9.2 Switching impulse	
10	Digital processing, including transfer function analysis 2004	
11	Impulse test reports	53
Anr	nnex A (informative) Principles of waveshape control	63
Anr	nex B (informative) Typical oscillograms and digital recordings	77
Fig	gure 1 – Typical impulse test circuit	55
Fig	gure 2 – Lightning impulse test terminal connections and applicable methods	
of f	failure detection	57
Fig	gure 3 – Transformer and reactor switching impulse waveshapes	59
Fig	gure 4 – Switching impulse test terminal connections and methods	61
Eia	Tallure detection	
Fig	gure A.1 – Waveshape control for low impedance windings	03
Fig	gure A.2 – Wavetan control for low impedance windings	
Fig	gure A.4 Effects due to short length of wayotail	
Fig	gure $A.5$ Winding earthed through a resistor	75
Fig	gure $A.6 = \text{Resistance earthing of low-impedance windings}$	
Fig	gure $A.0 = A$ indicating include full-wave failure $-1$ into to neutral breakdown	
acr	ross high-voltage winding of 400 kV generator transformer	81
Fig	gure B.2 – Lightning impulse, full-wave failure – Breakdown between discs	
ate	entrance to high-voltage winding of 115 kV transformer	83

Figure B.3 – Lightning impulse, interlayer breakdown in coarse-step tapping winding of a 400/220 kV transformer	85
Figure B.4 – Lightning impulse, full-wave failure – Breakdown between leads of two 1,1 % sections of outside tapping winding of 400 kV generator transformer	87
Figure B.5 – Lightning impulse, full-wave failure – Breakdown short-circuiting one section of the fine-step tapping winding of a 220 kV transformer	89
Figure B.6 – Lightning impulse, full-wave failure – Breakdown between parallel conductors in a multi-conductor main high-voltage winding of a 220/110 kV transformer	91
Figure B.7 – Lightning impulse, full-wave failure – Breakdown between foils of 66 kV bushing on tested winding	93
Figure B.8 – Lightning impulse, chopped-wave failure – Breakdown between turns in the main high-voltage winding of a 115 kV transformer	95
Figure B.9 – Lightning impulse, chopped-wave failure – Breakdown between turns in a fine-step tapping winding of a 220 kV transformer	97
Figure B.10 – Chopped lightning impulse – Impulses at different voltage levels with identical times to chopping when testing a 115 kV transformer	99
Figure B.11 – Chopped lightning impulse – Effects of differences in times to chopping when testing a 220 kV transformer	101
Figure B.12 – Full lightning impulse – Effect of non-linear resistors embodied in neutral end on-load tap-changer of a transformer with separate windings	103
Figure B.13 – Full lightning impulse – Effect of generator firing differences at different voltage levels when testing a 400 kV transformer	105
Figure B.14 – Switching impulse – Satisfactory test on a 400 kV three-phase generator transformer	107
Figure B.15 – Switching impulse – Breakdown by axial flashover of the main high- voltage winding of a 525 kV single-phase, generator transformer	109
Figure B.16 – Switchingsimpulsect Satisfactory test on a 33 Myar4-525 kV12- single-phase shunt reactor	111
Figure B.17 – Lightning impulse – Comparison of the transfer function of a full wave and a chopped wave	113
Figure B.18 – Full lightning impulse – Evaluation of a non-standard waveshape – Influence of in-built smoothing algorithms in digitizers	115
Figure B.19 – Full lightning impulse – Non-standard waveshape, superimposed oscillations with >50 % amplitude and frequency <0,5 MHz	115
Figure B.20 – Chopped lightning impulse – Non-standard chopped wave on a layer type winding	117
Figure B.21 – Full lightning impulse – Non-standard waveshape, comparison of non-standard waveshapes by digitizers of different make from the same recording	119
Figure B.22 – Full lightning impulse – Test-circuit problem caused by a sparkover to earth from a measuring cable	121
Figure B.23 – Full lightning impulse – Failure digital recordings of a flashover between tap leads of a tap changer and of a flashover between coarse and fine tapping winding	123

Table B.1 – Summary of examples illustrated in oscillograms and digital recordings ......77

#### INTERNATIONAL ELECTROTECHNICAL COMMISSION

#### **POWER TRANSFORMERS –**

#### Part 4: Guide to the lightning impulse and switching impulse testing – Power transformers and reactors

#### FOREWORD

- 1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
- 3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
- 4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter. <u>SIST EN 60076-4:2004</u>
- 5) The IEC provides not marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.4-2004
- 6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. The IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60076-4 has been prepared by IEC technical committee 14: Power transformers.

This International Standard cancels and replaces IEC 60722 published in 1982 and constitutes a technical revision of that document.

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

FDIS	Report on voting
14/413/FDIS	14/446/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 3.

Annexes A and B are for information only.

IEC 60076 consists of the following parts, under the general title Power transformers:

- Part 1: General
- Part 2: Temperature rise
- Part 3: Insulation levels, dielectric tests and external clearances in air
- Part 4: Guide to lightning impulse and switching impulse testing Power transformers and reactors
- Part 5: Ability to withstand short-circuit
- Part 8: Application guide
- Part 10: Determination of sound levels

The committee has decided that the contents of this publication will remain unchanged until 2007. At this date, the publication will be

- reconfirmed;
- withdrawn;
- · replaced by a revised edition, or
- amended.

## iTeh STANDARD PREVIEW (standards.iteh.ai)

#### POWER TRANSFORMERS –

#### Part 4: Guide to the lightning impulse and switching impulse testing – Power transformers and reactors

#### 1 Scope

This part of IEC 60076 gives guidance and explanatory comments on the existing procedures for lightning and switching impulse testing of power transformers to supplement the requirements of IEC 60076-3. It is also generally applicable to the testing of reactors (see IEC 60289), modifications to power transformer procedures being indicated where required.

Information is given on waveshapes, test circuits including test connections, earthing practices, failure detection methods, test procedures, measuring techniques and interpretation of results.

Where applicable, the test techniques are as recommended in IEC 60060-1 and IEC 60060-2.

### 2 Normative references

### iTeh STANDARD PREVIEW

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

#### SIST EN 60076-4:2004

IEC 60060-1, High-voltage test techniques ter Parts/Jist Generals definitions and test requirements 46b18da7ce15/sist-en-60076-4-2004

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

IEC 60076-3, Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air

IEC 60289, Reactors

IEC 61083-1, Instruments and software used for measurement in high-voltage impulse tests – *Part 1: Requirements for instruments* 

IEC 61083-2, Digital recorders for measurements in high-voltage impulse tests – Part 2: Evaluation of software used for the determination of the parameters of impulse waveforms

#### 3 General

This standard is primarily based on the use of conventional impulse generators for both lightning and switching impulse testing of transformers and reactors. The practice of switching impulse generation with discharge of a separate capacitor into an intermediate or low-voltage winding is also applicable. However, the method which employs an additional inductance in series with the capacitor to provide slightly damped oscillations transferred into the high-voltage winding is not applicable.

Alternative means of switching impulse generation or simulation such as d.c. current interruption on an intermediate or low-voltage winding or the application of a part-period of power frequency voltage are not discussed since these methods are not as generally applicable.

Different considerations in the choice of test circuits (terminal connections) for lightning and switching impulse tests apply for transformers and reactors. On transformers, all terminals and windings can be lightning impulse tested to specific and independent levels. In switching impulse testing, however, because of the magnetically transferred voltage, a specified test level may only be obtained on one winding (see IEC 60076-3).

Whilst, on reactors, lightning impulse testing is similar to that on transformers, i.e., all terminals can be tested separately, different considerations apply and different problems arise in switching impulse testing. Hence, in this standard, lightning impulse testing is covered by a common text for both transformers and reactors whilst switching impulse testing is dealt with separately for the two types of equipment.

### (standards.iteh.ai)

#### 4 Specified waveshapes

#### SIST EN 60076-4:2004

https://standards.iteh.ai/catalog/standards/sist/e966639b-2724-4db0-8fd2-The voltage waveshapes to be used normally during lightning and switching impulse testing of transformers and reactors are given in IEC 60076-3 and the methods for their determination are given in IEC 60060-1.

#### 5 Test circuit

The physical arrangement of test equipment, test object and measuring circuits can be divided into three major circuits:

- the main circuit including the impulse generator, additional waveshaping components and the test object;
- the voltage measuring circuit;
- the chopping circuit where applicable.

This basic arrangement is shown in figure 1.

The following parameters influence the impulse waveshape;

- a) the effective capacitance  $C_t$ , and inductance of the test object,  $L_t$ ;  $C_t$  is constant for any given design and any given waveshape,  $L_t$  is also a constant for any given design. The effective  $L_t$ , however, may be influenced by the terminal treatment. It varies between the leakage inductance  $L_s$  for short-circuited terminals and  $L_o$  for open-circuited terminals. More details in this respect are given in 7.1 and 7.3 and in annex A;
- b) the generator capacitance  $C_q$ ;
- c) waveshaping components, both internal and external to the generator,  $R_{si}$ ,  $R_{se}$ ,  $R_p$ ,  $C_L$  (plus, where applicable, the impedance of a voltage divider  $Z_1$ );
- d) the stray inductance and capacitance of the generator and the complete test circuit;
- e) chopping equipment, where applicable.

The front time  $T_1$  is determined mainly by combination of the effective surge capacitance of the test object, including  $C_L$ , and the generator internal and external series resistances.

The time to half-value  $T_2$  is, for lightning impulses, primarily determined by the generator capacitance, the inductance of the test object and the generator discharge resistance or any other parallel resistance. However, there are cases, for example, windings of extremely low inductance, where the series resistance will have a significant effect also on the wavetail. For switching impulses, other parameters apply; these are dealt with in clause 8.

The test equipment used in lightning and switching impulse applications is basically the same. Differences are in details only, such as values of resistors and capacitors (and the terminal connections of the test object). (standards.iteh.ai)

To meet the different requirements of the waveshape for lightning and switching impulses, due consideration has to be given to the selection of the impulse generator parameters, such as capacitance and series and discharge (parallel) resistances. For switching impulses, large values of series resistors and/or load capacitors may be necessary, which will result in significant reduction of the efficiency.

While the output voltage of the impulse generator is determined by the test levels of the windings with respect to their highest voltage for equipment  $U_m$  for the test object, the required energy storage capability is essentially dependent on the inherent impedances of the test object.

A brief explanation of the principles of waveshape control is given in annex A.

The arrangement of the test plant, test object and the interconnecting cables, earthing strips, and other equipment is limited by the space in the test room and, particularly, the proximity effect of any structures. During impulse testing, zero potential cannot be assumed throughout the earthing systems due to the high values and rates of change of impulse currents and voltages and the finite impedances involved. Therefore, the selection of a proper reference earth is important.

The current return path between the test object and the impulse generator should be of low impedance. It is good practice to firmly connect this current return path to the general earth system of the test room, preferably close to the test object. This point of connection should be used as reference earth and to attain good earthing of the test object it should be connected to the reference earth by one or several conductors of low impedance (see IEC 60060-2).

The voltage measuring circuit, which is a separate loop of the test object carrying only the measuring current and not any major portion of the impulse current flowing through the windings under test, should also be effectively connected to the same reference earth.

In switching impulse testing, since the rates of change of the impulse voltages and currents are much reduced compared with those in a lightning impulse test and no chopping circuit is involved, the problems of potential gradients around the test circuit and with respect to the reference earth are less critical. Nevertheless, it is suggested that, as a precaution, the same earthing practices should be followed as used for lightning impulse testing.

#### 6 Calibration

It is not the intention of this standard to give any recommendation on measuring systems or their calibration but, of course, the apparatus which is used should be approved in accordance with IEC 60060. Before a test, an overall check of the test circuit and the measuring system may be performed at a voltage lower than the reduced voltage level. In this check, voltage may be determined by means of a sphere gap or by comparative measurement with another approved device. When using a sphere gap, it should be recognized that this is only a check and does not replace the periodically performed calibration of the approved measuring system. After any check has been made, it is essential that neither the measuring nor the test circuit is altered except for the removal of any devices for checking.

#### SIST EN 60076-4:2004

Information on types of voltage dividers their applications accuracy, calibration and checking is given in IEC 60060-2. 46b18da7ce15/sist-en-60076-4-2004

#### 7 Lightning impulse tests

#### 7.1 Waveshapes

The values of waveshape specified may not always be obtainable. In the impulse testing of large power transformers and reactors, of low winding inductance and/or high surge capacitance, wider tolerances may have to be accepted.

The surge capacitance of the transformer under test being constant, the series resistance may have to be reduced in an attempt to obtain the correct front time  $T_1$  or rate of rise, but the reduction should not be to the extent that oscillations on the crest of the voltage wave become excessive. If it is considered desirable to have a short front time (preferably within the specified limits) then oscillations and/or overshoots greater than ±5 % of the peak voltage, allowed in IEC 60060-1, may have to be accepted. In such an event, a compromise between the extent of allowable oscillations and the obtainable front time is necessary. In general, oscillations not greater than ±10 % should be aimed at, even with extensions to the front time as necessary and as agreed between manufacturer and purchaser. The value of the test voltage is determined according to the principles of IEC 60060-1.