

# INTERNATIONAL STANDARD



---

**Power transformers –  
Part 7: Loading guide for mineral-oil-immersed power transformers**



## THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2018 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, 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 either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office  
3, rue de Varembe  
CH-1211 Geneva 20  
Switzerland

Tel.: +41 22 919 02 11  
[info@iec.ch](mailto:info@iec.ch)  
[www.iec.ch](http://www.iec.ch)

### About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

### About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

#### IEC Catalogue - [webstore.iec.ch/catalogue](http://webstore.iec.ch/catalogue)

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

#### IEC publications search - [webstore.iec.ch/advsearchform](http://webstore.iec.ch/advsearchform)

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

#### IEC Just Published - [webstore.iec.ch/justpublished](http://webstore.iec.ch/justpublished)

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

#### Electropedia - [www.electropedia.org](http://www.electropedia.org)

The world's leading online dictionary of electronic and electrical terms containing 21 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

#### IEC Glossary - [webstore.iec.ch/glossary](http://webstore.iec.ch/glossary)

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

#### IEC Customer Service Centre - [webstore.iec.ch/csc](http://webstore.iec.ch/csc)

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: [sales@iec.ch](mailto:sales@iec.ch).

# INTERNATIONAL STANDARD



---

**Power transformers –  
Part 7: Loading guide for mineral-oil-immersed power transformers**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 29.180

ISBN 978-2-8322-5082-2

**Warning! Make sure that you obtained this publication from an authorized distributor.**

## CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	9
2 Normative references .....	9
3 Terms and definitions .....	9
4 Symbols and abbreviations.....	11
5 Effect of loading beyond nameplate rating .....	13
5.1 General.....	13
5.2 General consequences .....	13
5.3 Effects and hazards of short-time emergency loading .....	14
5.4 Effects of long-time emergency loading.....	15
5.5 Transformer size.....	15
6 Relative ageing rate and transformer insulation life .....	15
6.1 General.....	15
6.2 Insulation life .....	16
6.3 Relative ageing rate.....	20
6.4 Loss-of-life calculation .....	21
7 Limitations.....	21
7.1 Temperature limitations .....	21
7.2 Current limitations.....	22
7.3 Specific limitations for small transformer.....	23
7.3.1 Current and temperature limitations.....	23
7.3.2 Accessory and other considerations .....	23
7.3.3 Indoor transformers .....	23
7.3.4 Outdoor ambient conditions .....	23
7.4 Specific limitations for medium power transformers.....	23
7.4.1 Current and temperature limitations.....	23
7.4.2 Accessory, associated equipment and other considerations.....	23
7.4.3 Short-circuit withstand requirements .....	24
7.4.4 Voltage limitations .....	24
7.5 Specific limitations for large power transformers .....	24
7.5.1 General .....	24
7.5.2 Current and temperature limitations .....	24
7.5.3 Accessory, equipment and other considerations .....	24
7.5.4 Short-circuit withstand requirements .....	25
7.5.5 Voltage limitations .....	25
8 Determination of temperatures.....	25
8.1 Hot-spot temperature rise in steady state.....	25
8.1.1 General .....	25
8.1.2 Calculation of hot-spot temperature rise from normal heat-run test data .....	25
8.1.3 Direct measurement of hot-spot temperature rise .....	26
8.1.4 Hot-spot factor.....	29
8.2 Top-oil and hot-spot temperatures at varying ambient temperature and load conditions .....	31
8.2.1 General .....	31

8.2.2	Exponential equations solution .....	33
8.2.3	Difference equations solution.....	37
8.3	Ambient temperature.....	39
8.3.1	Outdoor air-cooled transformers .....	39
8.3.2	Correction of ambient temperature for transformer enclosure.....	39
8.3.3	Water-cooled transformers .....	40
9	Influence of tap-changers .....	40
9.1	General.....	40
9.2	Load loss .....	41
9.3	Ratio of losses .....	41
9.4	Load factor .....	41
Annex A	(informative) Insulation life expectancy and relative ageing rate considering oxygen and water effect.....	42
A.1	Insulation life expectancy .....	42
A.2	Relative ageing rate considering oxygen and water effect .....	44
Annex B	(informative) Core temperature .....	47
B.1	General.....	47
B.2	Core hot-spot locations .....	47
Annex C	(informative) Specification of loading beyond rated power .....	48
Annex D	(informative) Description of $Q$ , $S$ and $H$ factors .....	50
Annex E	(informative) Calculation of winding and oil time constant .....	53
Annex F	(informative) Thermal model parameters .....	55
F.1	General.....	55
F.2	Thermal constant estimation: experimental approach .....	55
F.3	Dynamic thermal modelling: further development .....	57
Annex G	(informative) Oil and winding experiments .....	58
G.1	General.....	58
G.2	Historical background .....	58
G.3	Theoretical approach .....	60
G.4	Extended temperature rise test approach.....	62
Annex H	(informative) Practical example of the exponential equations method .....	64
H.1	General.....	64
H.2	Time period 0 min to 190 min .....	65
H.3	Time period 190 min to 365 min .....	65
H.4	Time period 365 min to 500 min .....	66
H.5	Time period 500 min to 705 min .....	66
H.6	Time period 705 min to 730 min .....	67
H.7	Time period 730 min to 745 min .....	67
H.8	Comparison with measured values.....	68
Annex I	(informative) Application of the difference equation solution method .....	70
I.1	General.....	70
I.2	Example.....	70
I.3	Use of measured top-oil temperature .....	75
Annex J	(informative) Flowchart, based on the example in Annex H.....	76
Annex K	(informative) Example of calculating and presenting overload data .....	78
Annex L	(informative) Geomagnetic induced currents .....	82
L.1	Background.....	82

L.2 GIC capability of power transformers [54], [55].....	82
Annex M (informative) Alternative oils .....	84
Bibliography.....	85
Figure 1 – Structural formula of cellulose .....	16
Figure 2 – Correlation between tensile strength and DP value .....	17
Figure 3 – Accelerated ageing in mineral oil at 140 °C, oxygen and moisture contents maintained at < 6 000 ppm and 0,5 %, respectively .....	18
Figure 4 – Expected life for non-thermally upgraded paper and its dependence upon moisture, oxygen and temperature .....	19
Figure 5 – Expected life for thermally upgraded paper and its dependence upon moisture, oxygen and temperature .....	20
Figure 6 – Thermal diagram .....	26
Figure 7 – Temperature rises above top-oil temperature (in tank) 65,8 °C of the zig-zag cooled HV-winding of a 400 MVA ONAF cooled 3-phase transformer, load current 1,0 p.u., tap position (-) .....	27
Figure 8 – Coil edges, where the sensors should be located in the edge with the higher calculated temperature rise.....	28
Figure 9 – Temperature rises above top-oil temperature at the end of an 8 h thermal no-load test at 110 % supply voltage.....	29
Figure 10 – Zigzag-cooled winding where the distance between coil sections is the same and the flow-directing washer is installed in the space between sections .....	30
Figure 11 – Top view section of a rectangular winding with “collapsed cooling duct arrangement” under the yokes .....	31
Figure 12 – Block diagram representation of the differential equations.....	32
Figure 13 – Temperature responses to step changes in the load current.....	34
Figure 14 – The function $\Delta\theta_h(t)/\Delta\theta_{hr}$ generated by the values given in Table 4 .....	37
Figure 15 – Principle of losses as a function of the tap position .....	41
Figure A.1 – Arrhenius plot for an ageing process.....	43
Figure F.1 – Hot-spot and top-oil overall model.....	57
Figure G.1 – Extended temperature rise test.....	62
Figure G.2 – Transformer exponent estimation plots .....	63
Figure H.1 – Hot-spot temperature response to step changes in the load current .....	68
Figure H.2 – Top-oil temperature response to step changes in the load current .....	68
Figure I.1 – Plotted input data for the example.....	72
Figure I.2 – Plotted output data for the example.....	75
Figure K.1 – OF large power transformers: permissible duties for normal loss of life.....	81
Figure L.1 – GIC flow into a power transformer .....	82
Table 1 – Relative ageing rates due to hot-spot temperature .....	21
Table 2 – Maximum permissible temperature limits applicable to loading beyond nameplate rating.....	22
Table 3 – Recommended current limits applicable to loading beyond nameplate rating.....	23
Table 4 – Recommended thermal characteristics for exponential equations .....	36
Table 5 – Correction for increase in ambient temperature due to enclosure .....	40
Table A.1 – Activation energy ( $E_A$ ) and environment factor ( $A$ ) for oxidation, hydrolysis.....	43

Table A.2 – Expected life of paper under various conditions .....	44
Table A.3 – Relative ageing rates due to hot-spot temperature, oxygen and moisture for non-upgraded paper insulation .....	45
Table A.4 – Relative ageing rates due to hot-spot temperature, oxygen and moisture for upgraded paper insulation .....	46
Table H.1 – Load steps of the 250 MVA transformer .....	64
Table H.2 – Temperatures at the end of each load step .....	69
Table I.1 – Input data for example.....	71
Table I.2 – Output data for the example .....	74
Table K.1 – Example characteristics related to the loadability of transformers .....	78
Table K.2 – An example table with the permissible duties and corresponding daily loss of life (in “normal” days), and maximum hot-spot temperature rise during the load cycle.....	80

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## POWER TRANSFORMERS –

Part 7: Loading guide for mineral-oil-immersed  
power transformers

## FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of 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, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). 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. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of 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 IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, accept IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 60076-7 has been prepared by IEC technical committee 14: Power transformers.

This second edition cancels and replaces the first edition published in 2005. It constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

- a) title has been updated from "oil-immersed power transformers" to "mineral-oil-immersed power transformers";
- b) insulation life is updated by considering latest research findings;
- c) temperature limits have been reviewed and maximum core temperature is recommended;
- d) number of fibre optic sensors is recommended for temperature rise test;
- e) Q, S and H factors are considered;
- f) thermal models are revised and rewritten in generally applicable mathematical form;

- g) geomagnetic induced currents are briefly discussed and corresponding temperature limits are suggested;
- h) extensive literature review has been performed and a number of references added to bibliography.

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

FDIS	Report on voting
14/933/FDIS	14/942/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60076 series, 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 website under "<http://www.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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

A bilingual version of this publication may be issued at a later date.

**IMPORTANT – The 'colour in use' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.**

## INTRODUCTION

This part of IEC 60076 provides guidance for the specification and loading of power transformers from the point of view of operating temperatures and thermal ageing. It provides recommendations for loading above the nameplate rating and guidance for the planner to choose appropriate rated quantities and loading conditions for new installations.

IEC 60076-2 is the basis for contractual agreements and it contains the requirements and tests relating to temperature-rise figures for oil-immersed transformers during continuous rated loading.

This part of IEC 60076 gives mathematical models for judging the consequence of different loadings, with different temperatures of the cooling medium, and with transient or cyclic variation with time. The models provide for the calculation of operating temperatures in the transformer, particularly the temperature of the hottest part of the winding. This hot-spot temperature is, in turn, used for evaluation of a relative value for the rate of thermal ageing and the percentage of life consumed in a particular time period. The modelling refers to small transformers, here called distribution transformers, and to power transformers.

A major change from the previous edition is the extensive work on the paper degradation that has been carried out indicating that the ageing may be described by combination of the oxidation, hydrolysis and pyrolysis. Also, providing possibility to estimate the expected insulation life considering different ageing factors, i.e. moisture, oxygen and temperature, and more realistic service scenarios. The title has been updated from "oil-immersed power transformers" to "mineral-oil-immersed power transformers". The temperature and current limits are reviewed and the maximum core temperature is recommended. The use of fibre optic temperature sensors has become a standard practice, however, the number of installed sensors per transformer highly varies. This issue and the description of Q, S and H factors are now considered as well. The thermal models are revised and rewritten in generally applicable mathematical form. The geomagnetic induced currents are briefly discussed and corresponding temperature limits are suggested.

This part of IEC 60076 further presents recommendations for limitations of permissible loading according to the results of temperature calculations or measurements. These recommendations refer to different types of loading duty – continuous loading, normal cyclic undisturbed loading or temporary emergency loading. The recommendations refer to distribution transformers, to medium power transformers and to large power transformers. Clauses 1 to 7 contain definitions, common background information and specific limitations for the operation of different categories of transformers.

Clause 8 contains the determination of temperatures, presents the mathematical models used to estimate the hot-spot temperature in steady state and transient conditions.

Clause 9 contains a short description of the influence of the tap position.

Application examples are given in Annexes A, B, C, D, E, F, G, H, I and K.

## POWER TRANSFORMERS –

### Part 7: Loading guide for mineral-oil-immersed power transformers

#### 1 Scope

This part of IEC 60076 is applicable to mineral-oil-immersed transformers. It describes the effect of operation under various ambient temperatures and load conditions on transformer life.

NOTE For furnace transformers, the manufacturer is consulted in view of the peculiar loading profile.

#### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60076-2, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60076-14, *Power transformers – Part 14: Liquid-immersed power transformers using high-temperature insulation materials*

#### 3 Terms and definitions

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

##### 3.1

###### **small power transformer**

power transformer without attached radiators, coolers or tubes including corrugated tank irrespective of rating

##### 3.2

###### **medium power transformer**

power transformer with a maximum rating of 100 MVA three-phase or 33,3 MVA single-phase

##### 3.3

###### **large power transformer**

power transformer with a maximum rating of greater than 100 MVA three-phase or greater than 33,3 MVA single-phase

##### 3.4

###### **cyclic loading**

loading with cyclic variations (the duration of the cycle usually being 24 h) which is regarded in terms of the accumulated amount of ageing that occurs during the cycle

Note 1 to entry: The cyclic loading may either be a normal loading or a long-time emergency loading.