



IEC 60076-7

Edition 2.0 2018-01

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 transformers	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 exponents	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 all 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, access to 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://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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

IMPORTANT – The 'colour inside' 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 cyclical 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*