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

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CONTENTS

FOREWORD 6
INTRODUCTION 8
1 Scope 10
2 Normative references 10
3 Terms and definitions 10
4 Symbols and abbreviations 13
5 Effect of loading beyond nameplate rating 14
5.1 ~~Introduction~~ General 14
5.2 General consequences 14
5.3 Effects and hazards of short-time emergency loading 15
5.4 Effects of long-time emergency loading 16
5.5 Transformer size 16
~~Non-thermally and thermally upgraded insulation paper~~ .....
6 Relative ageing rate and transformer insulation life 18
6.1 General 18
6.2 Insulation life 19
6.3 Relative ageing rate 23
6.4 Loss-of-life calculation 24
7 Limitations 25
7.1 ~~Current and~~ Temperature limitations 25
7.2 Current limitations 26
7.3 Specific limitations for ~~distribution~~ small transformers 27
7.3.1 Current and temperature limitations 27
7.3.2 Accessory and other considerations 27
7.3.3 Indoor transformers 27
7.3.4 Outdoor ambient conditions 27
7.4 Specific limitations for medium power transformers 27
7.4.1 Current and temperature limitations 27
7.4.2 Accessory, associated equipment and other considerations 27
7.4.3 Short-circuit withstand requirements 28
7.4.4 Voltage limitations 28
7.5 Specific limitations for large power transformers 28
7.5.1 General 28
7.5.2 Current and temperature limitations 28
7.5.3 Accessory, equipment and other considerations 28
7.5.4 Short-circuit withstand requirements 29
7.5.5 Voltage limitations 29
8 Determination of temperatures 29
8.1 Hot-spot temperature rise in steady state 29
8.1.1 General 29
8.1.2 Calculation of hot-spot temperature rise from normal heat-run test data 29
8.1.3 Direct measurement of hot-spot temperature rise 30
8.1.4 Hot-spot factor 35
8.2 Top-oil and hot-spot temperatures at varying ambient temperature and load conditions 37

SIST Preview
(https://ecommerce.sist.si)
IEC 60076-7:2018
https://ecommerce.sist.si/catalog/standards/iec/0e204ec0-4cfd-4090-84c6-6dbb71e398a1/iec-60076-7-2018

8.2.1 General 37
8.2.2 Exponential equations solution 39
8.2.3 ~~Differential~~ Difference equations solution 44
8.3 Ambient temperature 46
8.3.1 Outdoor air-cooled transformers 46
8.3.2 Correction of ambient temperature for transformer enclosure 47
8.3.3 Water-cooled transformers 48
9 Influence of tap-changers 48
9.1 General 48
9.2 ~~Short-circuit losses~~ Load loss 48
9.3 Ratio of losses 48
9.4 Load factor 49
Annex A (informative) Insulation life expectancy and relative ageing rate considering oxygen and water effect 50
A.1 Insulation life expectancy 50
A.2 Relative ageing rate considering oxygen and water effect 52
Annex B (informative) Core temperature 55
B.1 General 55
B.2 Core hot-spot locations 55
Annex C (informative) Specification of loading beyond rated power 56
Annex D (informative) Description of Q, S and H factors 58
Annex E (informative) Calculation of winding and oil time constant 61
Annex F (informative) Thermal model parameters 63
F.1 General 63
F.2 Thermal constant estimation: experimental approach 63
F.3 Dynamic thermal modelling: further development 65
Annex G (informative) Oil and winding exponents 66
G.1 General 66
G.2 Historical background 66
G.3 Theoretical approach 68
G.4 Extended temperature rise test approach 70
Annex H (informative) Practical example of the exponential equations method 72
H.1 ~~Introduction~~ General 72
H.2 Time period 0 min to 190 min 73
H.3 Time period 190 min to 365 min 74
H.4 Time period 365 min to 500 min 74
H.5 Time period 500 min to ~~710~~ 705 min 75
H.6 Time period ~~710~~ 705 min to ~~735~~ 730 min 76
H.7 Time period ~~735~~ 730 min to ~~750~~ 745 min 77
H.8 Comparison with measured values 77
Annex I (informative) ~~Illustration~~ Application of the ~~differential~~ difference equation solution method 79
I.1 General 82
I.2 Example 82
I.3 Use of measured top-oil temperature 87
Annex J (informative) Flowchart, based on the example in Annex H 88
Annex K (informative) Example of calculating and presenting overload data 90

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(https://ecommerce.sist.si)
IEC 60076-7:2018
https://ecommerce.sist.si/standards/sist/1ec0e204-c7e-4e1d-4090-84e0-6db871e398a1/iec-60076-7-2018

Annex L (informative) Geomagnetic induced currents 94
L.1 Background 94
L.2 GIC capability of power transformers [54], [55] 94
Annex M (informative) Alternative oils 96
Bibliography 97

~~Figure – Sealed tube accelerated ageing in mineral oil at 150 °C ..... ~~
~~Figure – Local temperature rises above air temperature in a 120 kV winding at a load factor of 1,6 ..... ~~
~~Figure – Local temperature rises above air temperature in a 410 kV winding at a load factor of 1,6 ..... ~~
~~Figure – Two fibre optic sensors installed in a spacer before the spacer was installed in the 120 kV winding ..... ~~
Figure 1 – Structural formula of cellulose 18
Figure 2 – Correlation between tensile strength and DP value 20
Figure 3 – Accelerated ageing in mineral oil at 140 °C, oxygen and moisture contents maintained at < 6 000 ppm and 0,5 %, respectively 21
Figure 4 – Expected life for non-thermally upgraded paper and its dependence upon moisture, oxygen and temperature 22
Figure 5 – Expected life for thermally upgraded paper and its dependence upon moisture, oxygen and temperature 23
Figure 6 – Thermal diagram 30
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 (-) 33
Figure 8 – Coil edges, where the sensors should be located in the edge with the higher calculated temperature rise 34
Figure 9 – Temperature rises above top-oil temperature at the end of an 8 h thermal no-load test at 110 % supply voltage 35
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 36
Figure 11 – Top view section of a rectangular winding with “collapsed cooling duct arrangement” under the yokes 37
Figure 12 – Block diagram representation of the differential equations 38
Figure 13 – Temperature responses to step changes in the load current 40
Figure 14 – The function ~~$f_2(t)$~~ $f_2(t)$ $\Delta\theta_h(t)/\Delta\theta_{hr}$ generated by the values given in Table 4 44
Figure 15 – Principle of losses as a function of the tap position 48
Figure A.1 – Arrhenius plot for an ageing process 51
Figure F.1 – Hot-spot and top-oil overall model 65
Figure G.1 – Extended temperature rise test 70
Figure G.2 – Transformer exponent estimation plots 71
Figure H.1 – Hot-spot temperature response to step changes in the load current 77
Figure H.2 – Top-oil temperature response to step changes in the load current 78
Figure I.1 – Plotted input data for the example 84
Figure I.2 – Plotted output data for the example 87
Figure K.1 – OF large power transformers: permissible duties for normal loss of life 93
Figure L.1 – GIC flow into a power transformer 94

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(https://standards.iteh.ai)
IEC 60076-7:2018
https://standards.iteh.ai/catalog/standards/iec/0e204cc0-4cfd-4090-84c6-6dbb71e398a1/iec-60076-7-2018

~~Table – Life of paper under various conditions~~ .....

~~Table – Normal insulation life of a well-dried, oxygen-free thermally upgraded insulation system at the reference temperature of 110 °C~~ .....

~~Table – Current and temperature limits applicable to loading beyond nameplate rating~~ .....

Table 1 – Relative ageing rates due to hot-spot temperature 24

Table 2 – Maximum permissible temperature limits applicable to loading beyond nameplate rating 26

Table 3 – Recommended current limits applicable to loading beyond nameplate rating 27

Table 4 – Recommended thermal characteristics for exponential equations 43

Table 5 – Correction for increase in ambient temperature due to enclosure 47

Table A.1 – Activation energy (E_A) and environment factor (A) for oxidation, hydrolysis 51

Table A.2 – Expected life of paper under various conditions 52

Table A.3 – Relative ageing rates due to hot-spot temperature, oxygen and moisture for non-upgraded paper insulation 53

Table A.4 – Relative ageing rates due to hot-spot temperature, oxygen and moisture for upgraded paper insulation 54

Table H.1 – Load steps of the 250 MVA transformer 72

Table H.2 – Temperatures at the end of each load step 78

Table I.1 – Input data for example 83

Table I.2 – Output data for the example 86

Table K.1 – Example characteristics related to the loadability of transformers 90

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 92

SIST Preview
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IEC 60076-7:2018
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POWER TRANSFORMERS –

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

FOREWORD

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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

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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.

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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.

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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. ~~It should be noted that IEC 60076-2 refers to the average winding temperature rise while this part of IEC 60076 refers mainly to the hot-spot temperature and the stated values are provided only for guidance.~~

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 IEC 60354:1991 is the increased use of fibre optic temperature sensors in transformers. This has radically increased the possibilities of obtaining a proper thermal modelling of power transformers, especially at step changes in the load current. These possibilities have also yielded some differences between the "oil exponent x" and the "winding exponent y" used in this part of IEC 60076 and in IEC 60076-2:1993, for power transformers:~~

- ~~x = 0,9 in IEC 60076-2, and x = 0,8 in this part of IEC 60076 at ON cooling.~~
- ~~y = 1,6 in IEC 60076-2, and y = 1,3 in this part of IEC 60076 at ON and OF cooling.~~

~~For distribution transformers, the same x and y values are used in this part of IEC 60076 as in IEC 60076-2.~~

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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.

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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 ~~should be~~ 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~~:1993~~, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

~~IEC 60076-4:2002, *Power transformers – Part 4: Guide to the lightning impulse and switching impulse testing – Power transformers and reactors*~~

~~IEC 60076-5:2000, *power transformers – Part 5: Ability to withstand short circuit*~~

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

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3 Terms and definitions

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

~~**3.1**~~
~~**distribution transformer**~~
~~power transformer with a maximum rating of 2 500 kVA three-phase or 833 kVA single-phase~~

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 ~~exceeding the limits specified in 3.2~~ 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.

3.5
normal cyclic loading
loading in which a higher ambient temperature or a higher-than-rated load current is applied during part of the cycle, but which, from the point of view of relative thermal ageing rate (according to the mathematical model), is equivalent to the rated load at normal ambient temperature

Note 1 to entry: This is achieved by taking advantage of low ambient temperatures or low load currents during the rest of the load cycle. For planning purposes, this principle can be extended to provide for long periods of time whereby cycles with relative thermal ageing rates greater than unity are compensated for by cycles with thermal ageing rates less than unity.

3.6
long-time emergency loading
loading resulting from the prolonged outage of some system elements that will not be reconnected before the transformer reaches a new and higher steady-state temperature

3.7
short-time emergency loading
unusually heavy loading of a transient nature (less than 30 min) due to the occurrence of one or more unlikely events which seriously disturb normal system loading

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3.8
hot-spot
if not specially defined, hottest spot of the windings

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3.9
relative thermal ageing rate
for a given hot-spot temperature, rate at which transformer insulation ageing is reduced or accelerated compared with the ageing rate at a reference hot-spot temperature

3.10
transformer insulation life
total time between the initial state for which the insulation is considered new and the final state ~~when~~ for which the insulation is considered deteriorated due to thermal ageing, dielectric stress, short-circuit stress, or mechanical movement (which could occur in normal service), and ~~result in~~ at which a high risk of electrical failure exists

3.11
per cent loss of life
equivalent ageing in hours over a time period (usually 24 h) times 100 divided by the expected transformer insulation life

Note 1 to entry: The equivalent ageing in hours is obtained by multiplying the relative ageing rate with the number of hours.

3.12
non-thermally upgraded paper
kraft paper produced from unbleached softwood pulp under the sulphate process without addition of stabilizers

3.13
thermally upgraded paper
cellulose-based paper which has been chemically modified to reduce the rate at which the paper decomposes

Note 1 to entry: Ageing effects are reduced either by partial elimination of water forming agents (as in cyanoethylation) or by inhibiting the formation of water through the use of stabilizing agents (as in amine addition, dicyandiamide). A paper is considered as thermally upgraded if it meets the life criteria defined in ANSI/IEEE C57.100 [1][1]; 50 % retention in tensile strength after 65 000 h in a sealed tube at 110 °C or any other time/temperature combination given by the equation:

$$\text{Time (h)} = e^{\left(\frac{15\,000}{(\theta_h + 273)} - 28{,}082\right)} \approx 65\,000 \times e^{\left(\frac{15\,000}{(\theta_h + 273)} - \frac{15\,000}{(110 + 273)}\right)} \quad (1)$$

Because the thermal upgrading chemicals used today contain nitrogen, which is not present in kraft pulp, the degree of chemical modification is determined by testing for the amount of nitrogen present in the treated paper. Typical values for nitrogen content of thermally upgraded papers are between 1 % and 4 % when measured in accordance with ASTM D-982 [2], but after the sealed tube test.

~~NOTE This definition was approved by the IEEE Transformers Committee Task Force for the Definition of Thermally Upgraded Paper on 7 October 2003.~~

3.14
non-directed oil flow
OF
flow indicating that the pumped oil from heat exchangers or radiators flows freely inside the tank, and is not forced to flow through the windings

Note 1 to entry: The oil flow inside the windings can be either axial in vertical cooling ducts or radial in horizontal cooling ducts with or without zigzag flow.

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3.15
non-directed oil flow
ON
flow indicating that the oil from the heat exchangers or radiators flows freely inside the tank and is not forced to flow through the windings

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Note 1 to entry: The oil flow inside the windings can be either axial in vertical cooling ducts or radial in horizontal cooling ducts with or without zigzag flow.

3.16
directed oil flow
OD
flow indicating that the principal part of the pumped oil from heat exchangers or radiators is forced to flow through the windings

Note 1 to entry: The oil flow inside the windings can be either axial in vertical cooling ducts or zigzag in horizontal cooling ducts.

3.17
design ambient temperature
temperature at which the permissible average winding and top-oil and hot-spot temperature over ambient temperature are defined

[1] Numbers in square brackets refer to the bibliography.