

© Copyright SEK. Reproduction in any form without permission is prohibited.

Krafttransformatorer – Del 7: Oljeisolerade krafttransformatorer – Belastbarhet

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

Denna svenska standard innehåller den engelska texten i nedan angiven IEC-publikation, utarbetad inom International Electrotechnical Commission, IEC:

- **IEC 60076-7, First edition, 2005 - Power transformers - Part 7: Loading guide for oil-immersed power transformers**

Nationellt förord

Tidigare fastställd svensk standard SS-IEC 354, utgåva 1, 1996, gäller ej fr o m 2013-05-08.

Standarder underlättar utvecklingen och höjer elsäkerheten

Det finns många fördelar med att ha gemensamma tekniska regler för bl a säkerhet, prestanda, dokumentation, utförande och skötsel av elprodukter, elanläggningar och metoder. Genom att utforma sådana standarder blir säkerhetskraven tydliga och utvecklingskostnaderna rimliga samtidigt som marknadens acceptans för produkten eller tjänsten ökar.

Många standarder inom elområdet beskriver tekniska lösningar och metoder som åstadkommer den elsäkerhet som föreskrivs av svenska myndigheter och av EU.

SEK är Sveriges röst i standardiseringsarbetet inom elområdet

SEK Svensk Elstandard svarar för standardiseringen inom elområdet i Sverige och samordnar svensk medverkan i internationell och europeisk standardisering. SEK är en ideell organisation med frivilligt deltagande från svenska myndigheter, företag och organisationer som vill medverka till och påverka utformningen av tekniska regler inom elektrotekniken.

SEK samordnar svenska intressenters medverkan i SEKs tekniska kommittéer och stödjer svenska experters medverkan i internationella och europeiska projekt.

Stora delar av arbetet sker internationellt

Utformningen av standarder sker i allt väsentligt i internationellt och europeiskt samarbete. SEK är svensk nationalkommitté av International Electrotechnical Commission (IEC) och Comité Européen de Normalisation Electrotechnique (CENELEC).

Standardiseringsarbetet inom SEK är organiserat i referensgrupper bestående av ett antal tekniska kommittéer som speglar hur arbetet inom IEC och CENELEC är organiserat.

Arbetet i de tekniska kommittéerna är öppet för alla svenska organisationer, företag, institutioner, myndigheter och statliga verk. Den årliga avgiften för deltagandet och intäkter från försäljning finansierar SEKs standardiseringsverksamhet och medlemsavgift till IEC och CENELEC.

Var med och påverka!

Den som deltar i SEKs tekniska kommittéarbete har möjlighet att påverka framtida standarder och får tidig tillgång till information och dokumentation om utvecklingen inom sitt teknikområde. Arbetet och kontakterna med kollegor, kunder och konkurrenter kan gynnsamt påverka enskilda företags affärsutveckling och bidrar till deltagarnas egen kompetensutveckling.

Du som vill dra nytta av dessa möjligheter är välkommen att kontakta SEKs kansli för mer information.

SEK Svensk Elstandard

Box 1284
164 29 Kista
Tel 08-444 14 00
www.elstandard.se

CONTENTS

INTRODUCTION.....	11
1 Scope.....	13
2 Normative references	13
3 Definitions	13
4 Symbols and abbreviations.....	17
5 Effect of loading beyond nameplate rating	21
5.1 Introduction	21
5.2 General consequences.....	23
5.3 Effects and hazards of short-time emergency loading.....	23
5.4 Effects of long-time emergency loading	25
5.5 Transformer size	27
5.6 Non-thermally and thermally upgraded insulation paper	27
6 Relative ageing rate and transformer insulation life	31
6.1 General.....	31
6.2 Relative ageing rate	31
6.3 Loss-of-life calculation.....	33
6.4 Insulation life.....	33
7 Limitations.....	33
7.1 Current and temperature limitations.....	33
7.2 Specific limitations for distribution transformers.....	35
7.3 Specific limitations for medium-power transformers.....	37
7.4 Specific limitations for large power transformers.....	39
8 Determination of temperatures	41
8.1 Hot-spot temperature rise in steady state	41
8.2 Top-oil and hot-spot temperatures at varying ambient temperature and load conditions.....	53
8.3 Ambient temperature	63
9 Influence of tap changers	65
9.1 General	65
9.2 Short-circuit losses.....	67
9.3 Ratio of losses	67
9.4 Load factor	67
Annex A (informative) Calculation of winding and oil time constant	69
Annex B (informative) Practical example of the exponential equations method.....	73
Annex C (informative) Illustration of the differential equations solution method	83
Annex D (informative) Flowchart, based on the example in annex B	101
Annex E (informative) Example of calculating and presenting overload data	105
Bibliography.....	113

Figure 1 – Sealed tube accelerated ageing in mineral oil at 150 °C	29
Figure 2 – Thermal diagram	43
Figure 3 – Local temperature rises above air temperature in a 120 kV winding at a load factor of 1,6	45
Figure 4 – Local temperature rises above air temperature in a 410 kV winding at a load factor of 1,6	47
Figure 5 – Two fibre optic sensors installed in a spacer before the spacer was installed in the 120 kV winding	47
Figure 6 – Zigzag-cooled winding where the distance between all sections is the same and the flow-directing washer is installed in the space between sections	51
Figure 7 – Top view section of a rectangular winding with "collapsed cooling duct arrangement" under the yokes	51
Figure 8 – Temperature responses to step changes in the load current	55
Figure 9 – The function $f_2(t)$ generated by the values given in Table 5	59
Figure 10 – Block diagram representation of the differential equations	61
Figure 11 – Principle of losses as a function of the tap position	67
Figure B.1 – Hot-spot temperature response to step changes in the load current	79
Figure B.2 – Top-oil temperature response to step changes in the load current	79
Figure C.1 – Plotted input data for the example	93
Figure C.2 – Plotted output data for the example	99
Figure E.1 – OF large power transformers: permissible duties for normal loss of life	111
 Table 1 – Life of paper under various conditions	 29
Table 2 – Relative ageing rates due to hot-spot temperature	31
Table 3 – Normal insulation life of a well-dried, oxygen-free thermally upgraded insulation system at the reference temperature of 110 °C	33
Table 4 – Current and temperature limits applicable to loading beyond nameplate rating	35
Table 5 – Recommended thermal characteristics for exponential equations	59
Table 6 – Correction for increase in ambient temperature due to enclosure	65
Table B.1 – Load steps of the 250 MVA transformer	73
Table B.2 – Temperatures at the end of each load step	81
Table C.1 – Input data for example	91
Table C.2 – Output data for the example	97
Table E.1 – Example characteristics related to the loadability of transformers	105
Table E.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	109

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.

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 B, C and E.

POWER TRANSFORMERS –

Part 7: Loading guide for oil-immersed power transformers

1 Scope

This part of IEC 60076 is applicable to 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 consulted in view of the peculiar loading profile.

2 Normative references

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.

IEC 60076-2:1993, *Power transformers – Part 2: Temperature rise*

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*