INTERNATIONAL STANDARD

IEC 60354

Second edition
1991-09

The contents of the corrigendum of March 1992 has been included in this reprint

Loading guide for oil-immersed power ttransformers

*This **English-language** version is derived from the original **bilingual** publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.*

Reference number
IEC 60354:1991(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE XC

For price, see current catalogue

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

LOADING GUIDE FOR OIL-IMMERSED POWER TRANSFORMERS

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

This guide has been prepared by IEC Technical Committee No. 14: Power transformers.

It forms the second edition of IEC 354 and replaces the first edition (1972).

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

Six Months' Rule	Reports on Voting
14(CO)71	14(CO)72 and 72A

Full information on the voting for the approval of this guide can be found in the Voting Reports indicated in the above table.

The following IEC Publications are quoted in this guide:

Publications Nos. 76: Power transformers.
76-1 (1976): Part 1: General.
76-2 (1976): Part 2: Temperature rise.
76-4 (1976): Part 4: Tappings and connections.
76-5 (1976): Part 5: Ability to withstand short circuit.

LOADING GUIDE FOR OIL-IMMERSED POWER TRANSFORMERS

Section 1: General

1.1 Scope

This guide is applicable to oil-immersed transformers complying with IEC 76. It indicates how, within limits, transformers may be loaded above rated conditions. For furnace transformers, the manufacturer should be consulted in view of the peculiar loading profile.

1.2 Object

This guide 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 76-2 contains the requirements and tests relating to temperature rise figures for oil-immersed transformers during continuous rated loading. It should be noted that IEC 76-2 refers to the average winding temperature rise while the present guide refers mainly to the hot-spot temperature and the stated values are provided only for guidance.

The guide 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.

The guide further presents recommendations for limitations of permissible loading according to the results of the temperature calculations. These recommendations refer to different categories of transformers by size and importance, and also to different types of loading duty – *continuous loading, normal cyclic undisturbed loading* or *temporary, emergency loading.*

For small transformers, here called *distribution transformers*, the guide provides curves which make it possible to evaluate cyclic loading at specific ambient temperatures in comparison with conditions at rated loading under normal ambient temperature, for a transformer which fulfils the requirements of IEC 76-2.

For large transformers there are differences in the temperature calculations for different methods of cooling. The category of *medium power transformers* extends up to about 100 MVA three-phase two-winding transformers or equivalent, while transformers with higher rated power are referred to as *large power transformers.* For the latter it is advisable to perform calculations using individual parameters obtained from the acceptance type test. For reasons explained in the guide, the recommended limitations for these two categories of transformers are formulated somewhat differently.

Section 1, General, contains definitions, common background information and specific recommendations for the operation of different categories of transformers.

Section 2, Temperature calculation, presents the mathematical models used.

Section 3 gives calculated results as graphs and tables for standardized conditions.

1.3 Definitions

For the purpose of this guide the following definitions apply.

1.3.1 *Distribution transformer*

A transformer with a maximum rating of 2 500 kVA three-phase or 833 kVA per limb single-phase and a high-voltage rating limited to 33 kV, i.e. a transformer with separate windings that steps down to consumer voltage, with ON cooling and without on-load tap-changing.

1.3.2 *Medium power transformer*

A transformer with separate windings having a rating not exceeding 100 MVA for three-phase transformers or 33,3 MVA per wound limb and, due to the leakage flux density restrictions, a rated short-circuit impedance z_r not exceeding the value:

$$z_r = \left(25 - 0{,}1 \frac{3\,S_r}{W} \right) \%$$

where W is the number of wound limbs and S_r the rated power in MVA.

For auto-transformers, the equivalent rating is defined in annex A.

1.3.3 *Large power transformer*

A transformer exceeding a rating of 100 MVA (three-phase) or the impedance limitation specified above.

1.3.4 *Cyclic loading*

Loading with cyclic variations (the duration of the cycle usually being one day) which is regarded in terms of the average amount of ageing that occurs during the cycle. The cyclic loading may either be a normal loading, or a long-time emergency loading.

a) Normal cyclic loading

A higher ambient temperature or a higher than rated load current is applied during part of the cycle, but, from the point of view of thermal ageing (according to the mathematical model), this loading is equivalent to the rated load at normal ambient temperature. 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 ageing rates greater than unity are compensated for by cycles with ageing rate less than unity.

b) Long-time emergency cyclic loading

Loading resulting from the prolonged outage of some system elements that will not be reconnected before a steady state temperature rise is reached in the transformer. This is not a normal operating condition and its occurrence is expected to be rare, but it may persist for weeks or even months and can lead to considerable ageing. However, it should not be the cause of breakdown due to thermal destruction or reduction of dielectric strength.

1.3.5 *Short-time emergency loading*

Unusually heavy loading due to the occurrence of one or more unlikely events which seriously disturb normal system loading, causing the conductor hot spots to reach dangerous levels and, possibly, a temporary reduction in the dielectric strength. However, acceptance of this condition for a short time may be preferable to other alternatives. This type of loading is expected to occur rarely and it must be rapidly reduced or the transformer disconnected within a short time in order to avoid its failure. The permissible duration of this load is shorter than the thermal time constant of the transformer and depends on the operating temperature before the increase in the loading; typically, it would be less than half an hour.

1.4 General limitations and effects of loading beyond nameplate rating

1.4.1 *Effect of loading beyond nameplate rating*

1.4.1.1 *Factors influencing life duration*

The actual life duration of a transformer depends to a high degree on extraordinary events, such as overvoltages, short-circuits in the system, and emergency overloading.

Decisive for the chance of survival after such events, which can occur either separately or in combination, are:

a) the severity (amplitude and duration) of the event;

b) the transformer design;

c) the temperatures of the various parts of the transformer;

d) the concentration of moisture in the insulation and in the oil;

e) the concentration of oxygen and other gases in the insulation and in the oil;

f) the number, size and type of impurity particles.

The normal life expectancy is a conventional reference basis for continuous duty under normal ambient temperature and rated operating conditions. The application of a load in excess of nameplate rating and/or an ambient temperature higher than rated involves a degree of risk and accelerated ageing. It is the purpose of this guide to identify such risks and to indicate how, within limitations, transformers may be loaded in excess of the nameplate rating.

The consequences of loading a transformer beyond its nameplate rating are as follows:

a) the temperatures of windings, cleats, leads, insulation and oil increase and can reach unacceptable levels;

b) the leakage flux density outside the core increases, causing additional eddy-current heating in metallic parts linked by the flux;

c) the combination of the main flux and increased leakage flux imposes restrictions on possible core overexcitation;

d) as the temperature changes, the moisture and gas content in the insulation and in the oil will change;

e) bushings, tap-changers, cable-end connections and current transformers will also be exposed to higher stresses which encroach upon their design and application margins.

As a consequence there will be a risk of premature failure associated with the increased currents and temperatures. This risk may be of an immediate short-term character or come from the cumulative deterioration of the transformer over many years.

1.4.1.2 *Short-term risks*

a) The main risk, for short-time failures, is the reduction in dielectric strength due to the possible presence of gas bubbles in a region of high electrical stress, i.e. the windings and leads. These bubbles may develop in the paper insulation when the hot-spot temperature rises suddenly above a critical temperature, which is about 140 °C to 160 °C for a transformer with a normal moisture content. This critical temperature decreases somewhat as the moisture concentration increases.

Gas bubbles can also develop (either in oil or in solid insulation) at the surfaces of heavy metallic parts heated by the leakage flux or be produced by supersaturation of the oil. However, such bubbles usually develop in regions of low electric stress and have to circulate in regions where the stress is higher before any significant reduction in the dielectric strength occurs.

Bare metal parts which are not in direct thermal contact with major organic insulation, but are in contact with the oil in the transformer, may rapidly rise to high temperature. 180 °C should not be exceeded.

b) Temporary deterioration of the mechanical properties at higher temperatures could reduce the short-circuit strength.

c) Pressure build-up in the bushings may result in a failure due to oil leakage. Gassing in the bushings may also occur if the temperature of the insulation exceeds about 140 °C.

d) The expansion of the oil could cause overflow of the oil in the conservator.

e) Breaking of excessively high currents in the tap-changer could be hazardous.

1.4.1.3 *Long-term risks*

a) Cumulative thermal deterioration of the mechanical properties of the conductor insulation will accelerate at higher temperatures. If this deterioration proceeds far enough, it may reduce the effective life of the transformer, particularly if the latter is subjected to system short circuits.

b) Other insulation materials, as well as structural parts and the conductors, could also suffer ageing at higher temperature.

c) The contact-resistance of the tap-changers could increase at elevated currents and temperatures and, in severe cases, thermal runaway could take place.

d) The gasket materials in the transformer may become more brittle at elevated temperatures.

The short-term risk normally disappears after the load is reduced to normal level but, from the point of view of reliability, it may have a more significant impact than long term effects.

This guide recognizes that the loading capability could be restricted both by the short-time and the long-time effects. The tables and diagrams are calculated according to the traditional methods of determining the life expectancy of the mechanical properties of the paper insulation as affected by time and temperature, while the limitations on the maximum hot-spot temperatures are based on considerations of the risk of immediate failure.

1.4.2 *Transformer size*

The sensitivity of transformers to loading beyond nameplate rating usually depends on their size. As the size increases, the tendency is that:

a) the leakage flux density will increase;
b) the short-circuit forces increase;
c) the volumes of dielectrically-stressed insulation increase;
d) the hot-spot temperatures are more difficult to determine correctly.

IEC 60354 Ed. 2.0 (English 1991) Loading guide for oil-immersed power transformers