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TECHNICAL SPECIFICATION

colour inside

Power transformers –
Part 20: Energy efficiency

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Part 20: Energy efficiency

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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POWER TRANSFORMERS –

Part 20: Energy efficiency

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 60076-20, which is a technical specification, has been prepared by IEC technical committee 14: Power transformers.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
14/852/DTS	14/884/RVDTS

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

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

The reader's attention is drawn to the fact that Annex C lists all of the “in-some-country” clauses on differing practices of a less permanent nature relating to the subject of this standard.

A list of all the parts in 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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

The contents of the corrigendum of January 2018 have been included in this copy.

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

The reason prompting the preparation of this document is the need to save energy and to reduce the emission of greenhouse gases. The objective of this document is to promote a higher average level of energy performance for transformers.

It provides a basic model for national standards and, alternatively, a supplement to national standards that do not cover the whole range of transformers.

This part of IEC 60076 gives methods of specifying a transformer with an appropriate level of energy efficiency according to the loading and operating conditions applicable. It also gives minimum efficiency and maximum losses which lead to a generally acceptable balance between losses and use of other resources.

This document proposes two methods (A and B) of defining an energy efficiency index and introduces three methods of evaluating the energy performance of a transformer.

These are based on existing regional practices:

a) the Peak Efficiency Index (PEI) which should be used in conjunction with either a total cost of ownership (TCO) approach or any other mean of specifying the load factor.
b) the no-load and load losses at rated power for rationalization of transformer cores and coils for transformers generally produced in large volumes;
c) the efficiency at a defined power factor and particular load factor (typically at 50 %).

The appropriate method is chosen by agreement between purchasers and manufacturers or according to local regulations.

A transformer that does not comply with this document can still comply with the requirements of other standards in the IEC 60076 series.

Formulae for the calculation of efficiency are given to reflect different regional practices and purposes. The definition of rated power is given in IEC 60076-1.

Energy efficiency is not the sole basis for choosing a transformer. The total capital and estimated lifetime operating and maintenance costs (TCO) are also significant considerations in determining the most suitable transformer for the intended application, and may lead to the selection of more economical solutions when taking into account the lifetime of the transformers.

This document provides a standard method for evaluating the energy performance of power transformers through the use of the PEI, gives benchmark figures and the reasons why certain transformers may have efficiencies which are higher or lower than the benchmark.

Setting a reasonable value of minimum PEI will be effective in improving the overall energy performance of the installed transformer population by eliminating transformers with low efficiency, with the exception for some specific network limitations.

The use of a minimum value of PEI sets a floor for transformer energy performance, but the use of TCO evaluation for purchasing transformers is essential to select a transformer with the optimal economically justified level of efficiency.

POWER TRANSFORMERS –

Part 20: Energy efficiency

1 Scope

This part of IEC 60076 is applicable to transformers in the scope of IEC 60076-1.

The energy performance levels given in Clause 6 are not applicable to the following transformers:

- transformers for high current rectifiers as described in the IEC 61378 (all parts) and in the IEC 60146 (all parts);
- transformers for furnace applications;
- transformers for offshore applications;

NOTE 1 Transformer to be installed on fixed or floating offshore platforms, offshore wind turbines or on board of ships and all kind of vessels).

- transformers for emergency or temporary mobile installations;

NOTE 2 Transformers designed only to provide cover for a specific time limited situation when the normal power supply is interrupted either due to an unplanned occurrence such as failure or a station refurbishment, but not to permanently upgrade an existing substation.

- traction transformers;
- earthing transformers as described in 3.1.10 of IEC 60076-6:2007.
- phase shifting transformers;
- instrument transformers (IEC 61869-1);
- transformers and auto-transformers specifically designed for railway feeding systems, as defined in EN 50329;
- traction catenary supply transformer for 16,67 Hz;
- transformer for high current rectifiers (IEC 61869-1);

NOTE 3 These are transformers specifically designed and intended to supply power electronic or rectifier loads specified according to IEC 61378-1.

NOTE 4 This exclusion does not apply to transformers intended to provide AC power from DC sources such as transformers for wind turbine and photo voltaic applications as well as transformers designed for DC transmission and distribution applications."

- transformers for railway feeding systems (EN 50329);
- subsea transformers;
- starting-, testing- and welding transformers;
- starting transformers, specifically designed for starting three-phase induction motors so as to eliminate supply voltage dips;

NOTE 5 Examples are transformers that are de-energised during normal operation, used for the purpose of starting a rotating machine).

- transformers specifically designed for explosion-proof and underground mining applications;
- transformers which cannot fulfil the energy performance requirements due to unavoidable size and weight limitations.

NOTE 6 Due to the unavoidable weight and size limitation for a rolling stock application, this definition includes all traction transformers for rolling stock, irrespective of the frequency (e.g. 16,7 Hz, 25 Hz, 50 Hz, 60 Hz).

In this document, "transformers" includes both separate winding transformers and autotransformers.

NOTE 7 Transformers intended to provide AC power from DC sources such as transformers for wind turbine and photo voltaic applications as well as transformers designed for DC transmission and distribution applications are included in the Scope of this document.

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 60076-1, *Power transformers – Part 1: General*

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

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
efficiency
ratio of output active power to input active power

Note 1 to entry: This is an apparent power

3.2
electrical losses
electrical power consumed by the transformer at a particular value of transmitted apparent power excluding the power consumed by the cooling system

3.3
efficiency index method A
EI_A
ratio of the transmitted apparent power of a transformer minus electrical losses including the power consumed by the cooling to the transmitted apparent power of the transformer for a given load factor

3.4
efficiency index method B
EI_B
ratio of the transmitted apparent power of a transformer to the transmitted apparent power of the transformer plus electrical losses for a given load factor

Note 1 to entry: This method is only applicable for naturally cooled transformers.

3.5
peak efficiency index
PEI
highest value of efficiency index method A that can be achieved at the optimum value of load factor

Note 1 to entry: To characterize the energy performance of power transformers, it is useful to define an index that is relevant to the transformer design applicable to a wide range of uses rather than a figure that varies from second to second depending on system conditions. For this reason, a metric, the peak efficiency index, has been developed and used, which is based on active power losses and total apparent power transmitted and is independent of load phase angle, load factor and rated power.

3.6
input apparent power
$S_{\mathbf{input}}$
input voltage multiplied by the input current

Note 1 to entry: This is an apparent power.

Note 2 to entry: For three phase transformers, a factor √3 shall be added.

3.7
output apparent power
$S_{\mathbf{output}}$
output voltage multiplied by the output current

Note 1 to entry: This is an apparent power.

Note 2 to entry: For three phase transformers, a factor √3 shall be added.

3.8
transformer load factor
k
ratio of the actual input current to the rated current of the transformer

3.9
load factor of peak efficiency index
$k_{\mathbf{PEI}}$
load factor at which the peak efficiency index (3.5) occurs

3.10
transmitted apparent power
$kS_{\mathbf{r}}$
product of the load factor and the rated power

4 Efficiency and efficiency index calculation

4.1 General

Transformer efficiency is based on the apparent power, this is equivalent to assuming that the power factor is one. For transformers, the efficiency is expressed as follows:

$$\text{Efficiency} = \frac{S_{\text{input}} - L}{S_{\text{input}}} = \frac{S_{\text{output}}}{S_{\text{output}} + L} \qquad (1)$$

The defined power can be either input apparent power or output apparent power resulting in two methods for the calculation of efficiency (Method A and Method B), and historically both methods have been used.

Method A Efficiency = $\frac{S-L}{S}$ (2)

Method B Efficiency = $\frac{S}{S+L}$ (3)

where

S is the defined power;

L is the sum of no-load loss and load loss including loss for cooling equipment.

NOTE S is defined as input apparent power in method A and S is defined as output apparent power in method B.

The formula for calculating efficiency index with method B is limited to transformers without cooling losses.

For the scope of this document and for the sake of simplicity, it is conventionally assumed that:

- the voltage and load current systems are symmetrical and sinusoidal;
- the line voltage is equal to the rated voltage.

4.2 Methods of evaluating energy performance

For the purposes of this document, to consider energy efficiency in a practical manner, the power factor is assumed to be unity, and efficiency can be defined in terms of an efficiency index at a specific power.

This document defines two methods of calculating the efficiency index, method A and method B.

This document introduces three methods of evaluating the energy performance of a transformer:

a) the peak efficiency index (PEI);

b) the no-load and load losses at rated power or at a particular reference power;

c) the efficiency at a defined power factor and particular load factor (typically at 50 %).

The appropriate method shall be chosen by agreement between purchasers and manufacturers or according to local regulations.

The general definition of efficiency raises some complications, such as whether the electrical consumption of the cooling equipment of the transformer at no-load or at a particular load shall be included in the calculation.

The PEI includes the losses associated with only that part of the cooling system that is in service at k_{PEI}.

At k_{PEI} loading, sufficient cooling shall be in service to ensure that the rise in temperature of the transformer does not exceed the requirements of IEC 60076-2 or the customer's specification.

NOTE 1 The advantage of the PEI is that it does not impose a particular load factor that can vary greatly depending on the application, and because it does not depend explicitly on the rated power of the transformer. The PEI is an intrinsic parameter that does not depend on whether the transformer has alternative ratings depending on cooling modes.

NOTE 2 If the loss capitalisation method is used in the transformer procurement process, then it can be expected that the PEI will occur at approximately the loading where the ratio between load and no-load losses is equal to the ratio between the capitalisation rates for load and no-load loss, except where this has been modified by the relative cost of reducing load and no-load losses.

It can be advantageous to switch on the cooling at a lower temperature than is required by the maximum temperature rise requirement to increase the life span of the transformer insulation and reduce total losses, because of the effect of winding temperature on losses.

4.3 Method A

4.3.1 Efficiency index general formula

The efficiency index according to method A is calculated according to the following formula expressed per unit:

$$\mathrm{EI_A} = \frac{kS_\mathrm{r} - (P_0 + P_\mathrm{c0}) - (k^2 P_\mathrm{k} + P_\mathrm{ck}(k))}{kS_\mathrm{r}} \quad \text{(p.u.)} \qquad (4)$$

where

P_0 is the no-load loss measured at rated voltage in W, rated frequency and on rated tap;

P_{c0} is the electrical power in W required by the cooling system for no-load operation derived from the type test measurement of the power taken by the fan and pump motors;

P_k is the measured load loss in W at rated current and rated frequency on the rated tap corrected to reference temperature according to the requirement below;

$P_{ck}(k)$ is the additional electrical power in W required (in addition to P_{c0}) by the cooling system for operation at load factor k, derived from the type test measurement of the power taken by the fan and pump motors;

S_r is the rated power in VA of the transformer or autotransformer as defined in IEC 60076-1 on which P_k is based;

k is the load factor.

This approach respects the philosophy of the IEC 60076 series, which refers the rated power to the rated voltage and current of one of the transformer windings.

For the calculation, the following shall be considered:

a) for liquid-immersed transformers with a rated average winding temperature rise less than or equal to 65 K for OF or ON, or 70 K for OD, the reference temperature is 75 °C;

b) for transformers with other rated average winding temperature rises, the reference temperature is equal to the rated average winding temperature rise +20 °C, or rated winding temperature rise + the yearly external cooling medium average temperature, whichever is higher.

If a purchaser needs to compare a transformer with different insulation systems and different average winding temperature rises, the reference temperature should be according to b) above.

The reference temperature at the rated power chosen for the losses shall be in accordance with IEC 60076-1.

4.3.2 Peak efficiency index

The peak efficiency index (PEI) is obtained when no-load loss equals load loss and is given by substituting k in Equation (4) with k_PEI as in the expression below:

$$k_\mathrm{PEI} = \sqrt{\frac{P_0 + P_\mathrm{c0} + P_{\mathrm{ck}_\mathrm{PEI}}}{P_\mathrm{k}}} \quad \text{(p.u.)} \qquad (5)$$

$P_{\mathrm{ck}_\mathrm{PEI}}$ is the additional electrical power required (in addition to P_{c0}) by the cooling system for operation at k_PEI.