IEC TS 60076-20

Edition 1.0 2017-01

TECHNICAL SPECIFICATION

Power transformers –
Part 20: Energy efficiency

IEC TS 60076-20:2017-01(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

IEC TS 60076-20

Edition 1.0 2017-01

TECHNICAL SPECIFICATION

Power transformers – Part 20: Energy efficiency

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 29.180

ISBN 978-2-8322-3870-7

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

POWER TRANSFORMERS –

Part 20: Energy efficiency

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.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- 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.

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:

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

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 $$\text{Efficiency} = \frac{S-L}{S} \quad (2)$$

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

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:

$$EI_A = \frac{kS_r - (P_0 + P_{c0}) - (k^2 P_k + P_{ck}(k))}{kS_r} \quad \text{(p.u.)} \tag{4}$$

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:

$$k_{PEI} = \sqrt{\frac{P_0 + P_{c0} + P_{ck_{PEI}}}{P_k}} \quad \text{(p.u.)} \tag{5}$$

$P_{ck_{PEI}}$ is the additional electrical power required (in addition to P_{c0}) by the cooling system for operation at k_{PEI}.

The formula for calculating the PEI is therefore given by Equation (6):

$$PEI = 1 - \frac{2(P_0 + P_{c0} + P_{ck_{PEI}})}{S_r \sqrt{\frac{P_0 + P_{ck_{PEI}} + P_{c0}}{P_k}}} \quad \text{(p.u.)} \tag{6}$$

The losses shall be measured in accordance with the methods specified in the IEC 60076 series.

NOTE The value of Equation (6) depends on the ratio $S_r / \sqrt{P_K}$ which does not vary significantly if S_r is changed (for example by changing the cooling mode) provided that P_K is measured at S_r.

4.4 Method B

4.4.1 Efficiency index general formula (EI_B)

This formula is only applicable to transformers with natural cooling AN, ONAN, KNAN, GNAN and LNAN. For forced cooled transformers, method A shall apply.

The general way to calculate the efficiency index is given by Equation (7). This is different from the usual definition of rated power as per IEC 60076-1 as shown by this method. This method is named method B.

$$EI_B = \frac{k S_u}{k S_u + P_0 + k^2 T_f P_k} \quad \text{(p.u.)} \tag{7}$$

where

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

P_k is the measured load loss in W at the rated current and the rated frequency on the rated tap corrected to the reference temperature of 85 °C;

S_u is the rated power in VA of the transformer or autotransformer as defined in IEEE C57.12.80 on which P_k is based. S_u is used for distinction from S_r;

k is the load factor;

T_f is the temperature correction factor used to correct the losses from the standard reference temperature to the reference temperature used for calculation of the EI at a load factor lower than 1.

This method should be applied when an efficiency value is not specified by the purchaser or in local regulation.

4.4.2 Efficiency index at 50 % loading (EI_{B50})

In some countries, regulations are based on an efficiency index calculated according to method B (Equation (7)) at a load factor k of 50 %.

The efficiency index when the load factor k = 50 % is calculated with Equation (8):

$$EI_{B50} = \frac{0{,}5\, S_u}{0{,}5\, S_u + P_0 + 0{,}25 \times T_f \times P_k} \quad \text{(p.u.)} \tag{8}$$

where

T_f shall be taken as unity.

The exact correction factor T_f depends at least on the type of winding conductor (copper or aluminum) and the reference temperature at full load and ratio of eddy to I^2R losses.

In some countries, for transformers with an assumed average winding temperature (yearly average ambient plus reduced temperature rise due to under-loading conditions) at 50 % load factor, of 55 °C for liquid immersed transformers, and 75 °C for dry type transformers, T_f is approximated to an arbitrary value of 0,91.

Other values of T_f are based on the temperature correction of losses given in IEC 60076-1 and IEC 60076-2.

If T_f is not equal to 1, the value of T_f shall be given when EI_{B50} is stated.

S_u is the rated power of the transformer or autotransformer as defined in IEEE 57.12.80.

NOTE There is no provision for cooling losses in the formula, and different ratings for different cooling modes are not accounted for.

5 Specification of energy performance

The energy performance of a transformer may be specified in one of the following ways:

a) minimum PEI (method A, see 4.3) with load and no load loss capitalisation values;

b) maximum load losses and maximum no load losses;

c) minimum efficiency index at a load factor of 50 % EI_{B50} (method B, see 4.4).

To minimize the total cost of ownership (TCO) of the transformer, a loss capitalisation method should be used with all methods in addition to the minimum requirement. See Annex A.

Additional requirements may be added, for example, by specifying the level of total losses or the level of individual losses or the efficiency at another load factor and/or power factor.

NOTE Specifying a k_{PEI} with PEI will achieve the same goal as far as compliance with this standard is concerned, nevertheless this may not produce the optimum economical design.

6 Energy performance levels

6.1 General

This document provides two levels of recommended minimum PEIs, two levels of recommended losses and two levels of recommended efficiency indexes at a load factor of 50 %:

- level 1 is for basic energy performance;
- level 2 is for high energy performance.

The level chosen should be economically validated for the intended application.

For transformers having a rated power not included in these tables, the value of efficiency shall be linearly interpolated between the figures given for the nearest higher and lower rated powers:

a) 6.2.1 and 6.3.1 can be applied to all sizes and types of transformers in the scope;

b) 6.2.3 and 6.3.2 are included for the rationalization of transformer cores and coils for transformers generally produced in mass production;

c) 6.2.3 and 6.3.3 are applicable to particular sizes and types of transformers and are included because they reflect practices in some countries.

NOTE 1 In addition, Annex A provides a general method to compare energy performances and Annex C provides Japanese practices.

NOTE 2 Tables 5, 11 and 12 are derived from US Federal regulation. 10 CRF 431.196.

6.2 Liquid immersed transformers

6.2.1 Minimum PEI method A

6.2.1.1 PEI values for single-phase transformers with U_m ≤ 12 kV and S_r ≤ 100 kVA

For single-phase two winding transformers with

- U_m ≤ 12 kV,
- S_r ≤ 100 kVA,
- a second winding maximum voltage ≤ 1,1 kV,
- a de-energised tapping range ≤ ± 5 %,

Table 1 applies.

Table 1 – PEI values for single-phase transformers with U_m ≤ 12 kV and S_r ≤ 100 kVA

Rated power kVA	PEI level 1 %	PEI level 2 %
15	98,38	98,48
25	98,50	98,65
33	98,61	98,80
50	98,73	98,89
100	98,90	99,08

6.2.1.2 PEI values for transformers with U_m ≤ 36 kV and S_r ≤ 3 150 kVA

For two winding transformers, single or three phase with vector group Dyn or Yzn

- with U_m ≤ 36 kV,
- S_r ≤ 3 150 kVA,
- with a second winding maximum voltage ≤ 1,1 kV,
- with a de-energised tapping range ≤ ± 5 %,
- not within the applicability of 6.2.1.1, Table 2 applies.

Conditions for the application of the PEI are given in Clause 5.

Three-phase or single-phase transformers shall be evaluated against the rated power of the individual transformer.

Table 2 – PEI values for transformers with U_m ≤ 36 kV and S_r ≤ 3 150 kVA

	U_m ≤ 24 kV		24 kV < U_m ≤ 36 kV	
Rated power	**PEI level 1**	**PEI level 2**	**PEI level 1**	**PEI level 2**
kVA	%	%	%	%
≤25	97,992	98,445	97,742	98,251
50	98,741	99,014	98,584	98,891
100	98,993	99,194	98,867	99,093
160	99,122	99,281	99,012	99,191
250	99,210	99,363	99,112	99,283
315	99,248	99,395	99,154	99,320
400	99,297	99,439	99,209	99,369
500	99,330	99,465	99,247	99,398
630	99,373	99,500	99,295	99,437
800	99,416	99,532	99,343	99,473
1 000	99,431	99,541	99,360	99,484
1 250	99,483	99,544	99,418	99,487
1 600	99,488	99,550	99,424	99,494
2 000	99,495	99,558	99,432	99,502
2 500	99,504	99,568	99,442	99,514
3 150	99,506	99,572	99,445	99,518
NOTE Although the values in this table have been developed from 50 Hz transformer data, they are also applicable to 60 Hz transformers.				

National practices may require the use of the highest voltages for equipment up to (but not including) 52 kV (such as U_m = 38,5 kV or U_m = 40,5 kV), when the rated voltage is less than 36 kV. This is considered to be an unusual case and, for these transformers, the requirements for power transformers with U_m = 36 kV in the Table 2 apply.

6.2.1.3 PEI values for transformers with U_m > 36 kV or S_r > 3 150 kVA

For transformers not covered by Table 1 or Table 2, Table 3 applies.

Conditions for the application of PEI are given in Clause 5.

Three-phase or single-phase transformers shall be evaluated against the rated power of the individual transformer.

Table 3 – PEI values for transformers with U_m > 36 kV or S_r >3 150 kVA

Rated power kVA	PEI level 1 %	PEI level 2 %
> 3 150 and ≤ 4 000	99,465	99,532
5 000	99,483	99,548
6 300	99,510	99,571
8 000	99,535	99,593
10 000	99,560	99,615
12 500	99,588	99,640
16 000	99,615	99,663
20 000	99,639	99,684
25 000	99,657	99,700
31 500	99,671	99,712
40 000	99,684	99,724
50 000	99,696	99,734
63 000	99,709	99,745
80 000	99,723	99,758
≥ 100 000	99,737	99,770
NOTE Although the values in this table have been developed from 50 Hz transformer data, they are also applicable to 60 Hz transformers.		

6.2.2 Maximum load losses and maximum no load losses for transformers with rated frequency equal to 50 Hz

For two-winding transformers

- with a rated frequency of 50 Hz,
- with U_m ≤ 24 kV,
- S_r ≤ 3 150 kVA,
- with a second winding maximum voltage ≤ 1,1 kV,
- with a de-energised tapping range ≤ ± 5 %,

Table 4 applies.

Table 4 – Maximum load losses and maximum no load losses for transformers with rated frequency equal to 50 Hz

	Level 1		Level 2	
Rated power kVA	**Maximum load losses** (in W)	**Maximum no-load losses** (in W)	**Maximum load losses** (in W)	**Maximum no-load losses** (in W)
≤ 25	900	70	600	63
50	1 100	90	750	81
100	1 750	145	1 250	130
160	2 350	210	1 750	189
250	3 250	300	2 350	270
315	3 900	360	2 800	324
400	4 600	430	3 250	387
500	5 500	510	3 900	459
630	6 500	600	4 600	540
800	8 400	650	6 000	585
1 000	10 500	770	7 600	693
1 250	11 000	950	9 500	855
1 600	14 000	1 200	12 000	1 080
2 000	18 000	1 450	15 000	1 305
2 500	22 000	1 750	18 500	1 575
3 150	27 500	2 200	23 000	1 980
NOTE In some countries, higher losses are allowed in regulations for transformers outside the scope of this table, for example with a wider tapping range, dual LV windings or higher voltage.				

If economically justified, compliant with local regulation and agreed between the manufacturer and the purchaser, for transformers outside the scope of this table, the loss values in this table can be increased by not more than 20 %.

6.2.3 Efficiency index method B

6.2.3.1 60 Hz transformers

For two-winding transformers:

- with S_r ≤ 2 500 kVA three-phase or ≤ 833 kVA single-phase,
- with a rated frequency of 60 Hz,

Table 5 applies.

For transformers not covered by Table 5 and when an efficiency value is not specified by the purchaser or in local regulation, the values in Table 2 or Table 3 shall be applied preferably using a method A efficiency calculation. For these transformers, calculation using method B with values from Table 2 or Table 3 is possible. In this case, for forced cooling transformers, the cooling losses shall be taken into account.

For applications where the load factor is not close to 50 %, the load factor or capitalization values shall be provided by the purchaser.

This table is based on rated frequency 60 Hz transformers using a winding temperature of 55 °C.

Table 5 – EI_{B50} value for liquid-immersed 60 Hz transformers

Single phase			Three phase		
Rated power kVA	**EI_{B50}** % Level 1	**EI_{B50}** % Level 2	**Rated power** kVA	**EI_{B50}** % Level 1	**EI_{B50}** % Level 2
≤ 10	98,62	98,70	≤15	98,36	98,65
15	98,76	98,82	30	98,62	98,83
25	98,91	98,95	45	98,76	98,92
37,5	99,01	99,05	75	98,91	99,03
50	99,08	99,11	112,5	99,01	99,11
75	99,17	99,19	150	99,08	99,16
100	99,23	99,25	225	99,17	99,23
167	99,25	99,33	300	99,23	99,27
250	99,32	99,39	500	99,25	99,35
333	99,36	99,43	750	99,32	99,40
500	99,42	99,49	1 000	99,36	99,43
667	99,46	99,52	1 500	99,42	99,48
833	99,49	99,55	2 000	99,46	99,51
			2 500	99,49	99,53
NOTE Level 1 values are in compliance with the United States of America Department of Energy (DOE) ruling 2010 and level 2 values are in compliance with the amended ruling 2016.					

6.2.3.2 50 Hz transformers

For two-winding transformers

- with S_r ≤ 3 150 kVA,
- with a rated frequency of 50 Hz,

Table 6 applies.

For transformers not covered by Table 6 and when an efficiency value is not specified by the purchaser or in local regulation, the values in Table 2 or Table 3 shall be applied preferably using a method A efficiency calculation. For these transformers, calculation using method B with values from Table 2 or Table 3 is possible. In this case, for forced cooling transformers, the cooling losses shall be taken into account.

For applications where the load factor is not close to 50 %, the load factor or capitalization values shall be provided by the purchaser.

This table is based on 50 Hz transformers using T_f equal to 0,91, calculated from the maximum loss values given in Table 4.