



**Asia-Pacific  
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## **Overview of IEC/TS 60076-20 Ed. 1.0: Power Transformers - Part 20: Energy Efficiency**

Submitted by: Bergamo University



**Workshop on Reducing Losses in Power  
Distribution Through Improved Efficiency of  
Distribution Transformers**

**Jeju, Korea  
28 March 2017**



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## Reducing Losses in Power Distribution through Improved Efficiency of Distribution Transformers (EWG 05 2015A)

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# Overview of IEC/TS 60076-20 Ed. 1.0 Power transformers - Part 20: Energy efficiency

28 March 2017 | Jeju, Republic of Korea

Angelo Baggini

Bergamo University - Engineering Department

ORGANISERS:



International Copper  
Association Southeast Asia  
Copper Alliance



# Introduction

“[...] The objective of the **technical specification** 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 which do not cover the whole range of transformers**. [...] It also gives minimum efficiency and maximum losses which lead to a **generally acceptable balance between losses and use of other resources.**”

It is “based on existing **regional practices**:

- the Peak Efficiency Index (PEI) incorporating a Total Cost of Ownership(TCO) approach
- the no-load and load losses at rated power for rationalization of transformer cores and coils for transformers generally produced in large volumes
- the efficiency at a defined power factor and particular load factor (typically at 50%)

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

Energy efficiency is not the sole basis for choosing a transformer. The total capital and estimated lifetime operating and maintenance costs (TCO=Total Cost of Ownership) are also significant considerations in determining the most suitable transformer for the intended application and may offer more economical solutions over the lifetime of the transformers.”

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Annex C (informative) Efficiency based on a survey of world practice

Annex D (informative) Japanese practice

# 1. Scope

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

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

- Transformers for high current rectifiers following IEC61378 series and IEC 60146 series.
- Transformers for furnace applications
- Transformers for offshore applications
- Transformers for emergency or temporary mobile installations
- Traction transformers for 16.7 Hz
- Earthing transformers following IEC60076-6
- Transformers which cannot fulfil the energy performance requirements due to unavoidable size and weight limitations

In this standard 'transformers' includes both **separate winding transformers and autotransformers**.

# 3. Definitions

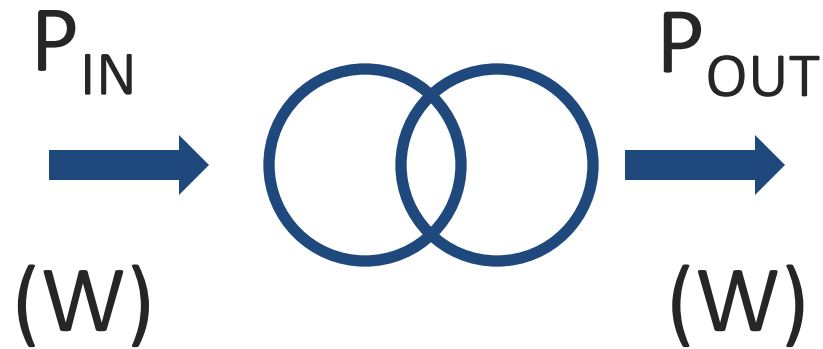
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- 3.1 Efficiency
- 3.2 Electrical losses
- 3.3 Efficiency Index (EIA) method A
- 3.4 Efficiency Index (EIB) method B
- 3.5 Peak Efficiency Index (PEI)
- 3.6 Input power ( $P_{input}$ )
- 3.7 Output power ( $P_{output}$ )
- 3.8 Transformer load factor ( $k$ )
- 3.9 Load factor of Peak Efficiency Index ( $k_{PEI}$ )
- 3.10 Transmitted apparent power ( $k_{Sr}$ )

## Definitions

# Energy efficiency

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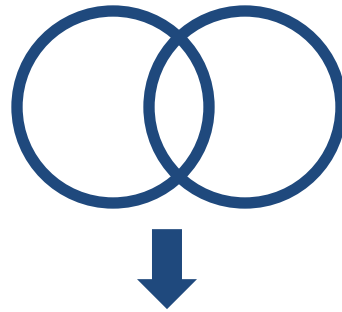


$$\eta = \frac{P_{OUT}}{P_{IN}}$$

(IEV 151-15-25 modified)

# Electrical losses

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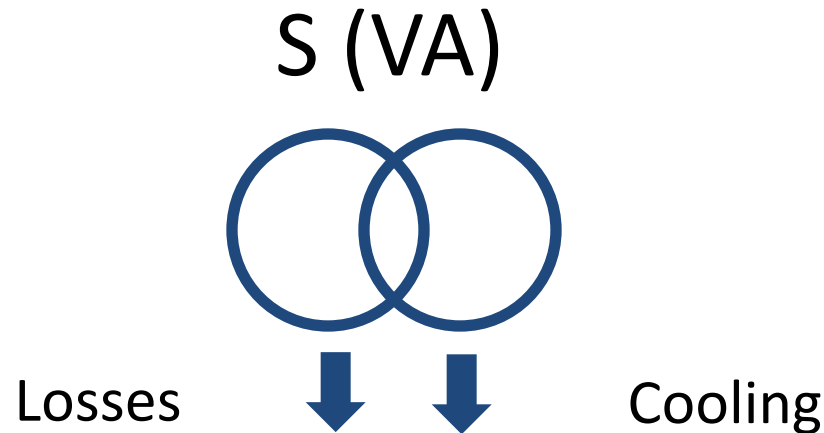
Electrical Losses

the electrical power consumed by the transformer at particular value of transmitted apparent power **excluding the power consumed by the cooling system**



## Definitions

# Energy Efficiency Index Method A



$$\eta = \frac{S - (Losses + Cooling)}{S}$$

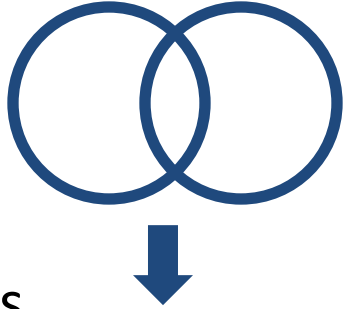
the ratio of the transmitted **apparent power** of a transformer minus **electrical losses including the power consumed by the cooling** to the transmitted apparent power of the transformer **for a given load factor**

## Definitions

# Energy efficiency index Method B

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$S$  (VA)



Losses

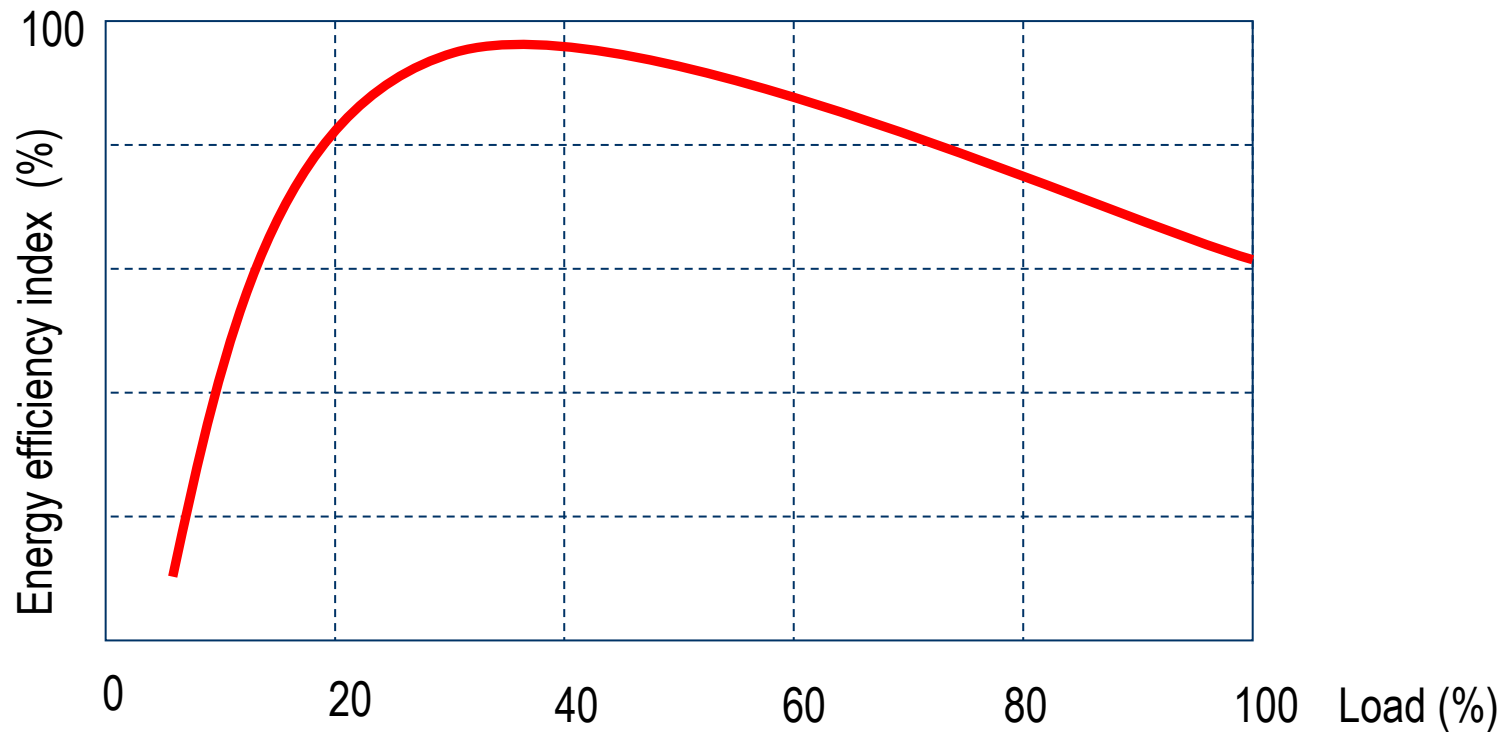
$$\eta = \frac{S}{S + \textit{Losses}}$$

the 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 to entry: This method is only applicable for naturally cooled transformers

## Definitions

# Peak efficiency index



\* Usually 40–50%

# 4. Efficiency and Efficiency Index calculation

## 4.1 General

## 4.2 Methods of evaluating energy performance

## 4.3 Method A

4.3.1 Efficiency Index general formula

4.3.2 Peak Efficiency Index

## 4.4 Method B

4.4.1 Efficiency Index general formula

4.4.2 Efficiency Index at 50% loading  
("EIB50" )

- 3 methods of evaluating the **energy performance**:
  - the Peak Efficiency Index (PEI)
  - the no-load and load losses at rated power or at a particular reference power
  - the efficiency at a defined power factor and particular load factor (typically at 50%)
- 2 methods of calculating **efficiency index** (method A and B)
- the voltage and load current systems are symmetrical and sinusoidal
- the line voltage is equal to the rated voltage
- the power factor is assumed to be unity and efficiency can be defined in terms of an efficiency index at a specific power.

## Definitions


# Efficiency Index method A and B

## IEC 60076-01 2011 Power transformers

**IN**  
RATED POWER  
PRIMARY


$$\eta = \frac{IN - \text{losses}}{IN}$$

## ANSI C57.12.01-2005



**OUT**  
RATED POWER  
SECONDARY

$$\eta = \frac{OUT}{OUT + \text{losses}}$$

# Efficiency Index Method A

$$EI_A = \frac{kS_r - (P_0 + P_{c0}) - (k^2P_k + P_{ck}(k))}{kS_r} \quad (\text{pu})$$

- $P_0$  NLL measured at rated voltage, rated frequency and on rated tap
- $P_{c0}$  electrical power required by the cooling system for NL operation derived from the type test measurement of the power taken by the fan and pump motors.
- $P_k$  measured LL at rated current and rated frequency on the rated tap corrected to reference temperature according to IEC 60076-1.
- $P_{ck}(k)$  is the additional electrical power required (in addition of  $P_{c0}$ ) by the cooling system for operation at load factor  $k$ , derived from the type test measurement of the power taken by the fan and pumps motors
- $S_r$  is the rated power of the transformer or autotransformer as defined in IEC60076-1 on which  $P_k$  is based
- $k$  is the load factor

**This approach respects the philosophy of IEC60076 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:

- For liquid immersed transformers with 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.
- For transformers with other rated average winding temperature rise, the reference temperature is equal to the rated average winding temperature rise + 20 °C, or rated winding temperature rise + yearly external cooling medium average temperature, whichever is higher.

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

The reference temperature at rated power chosen for the losses shall be in accordance with IEC60076-1

# Peak Efficiency Index

$$PEI = 1 - \frac{2(P_0 + P_{c0} + P_{ck}(k_{PEI}))}{S_r \sqrt{\frac{P_0 + P_{c0} + P_{ck}(k_{PEI})}{P_k}}}$$

- $P_0$  = no load losses\*
- $P_{c0}$  = electrical power required by the cooling system for no load operation
- $P_k$  = load losses\* corrected to reference temperature\*\*
- $S_r$  = rated power of the transformer on which  $P_k$  is based

\* measured at rated voltage and rated frequency, on the rated tap

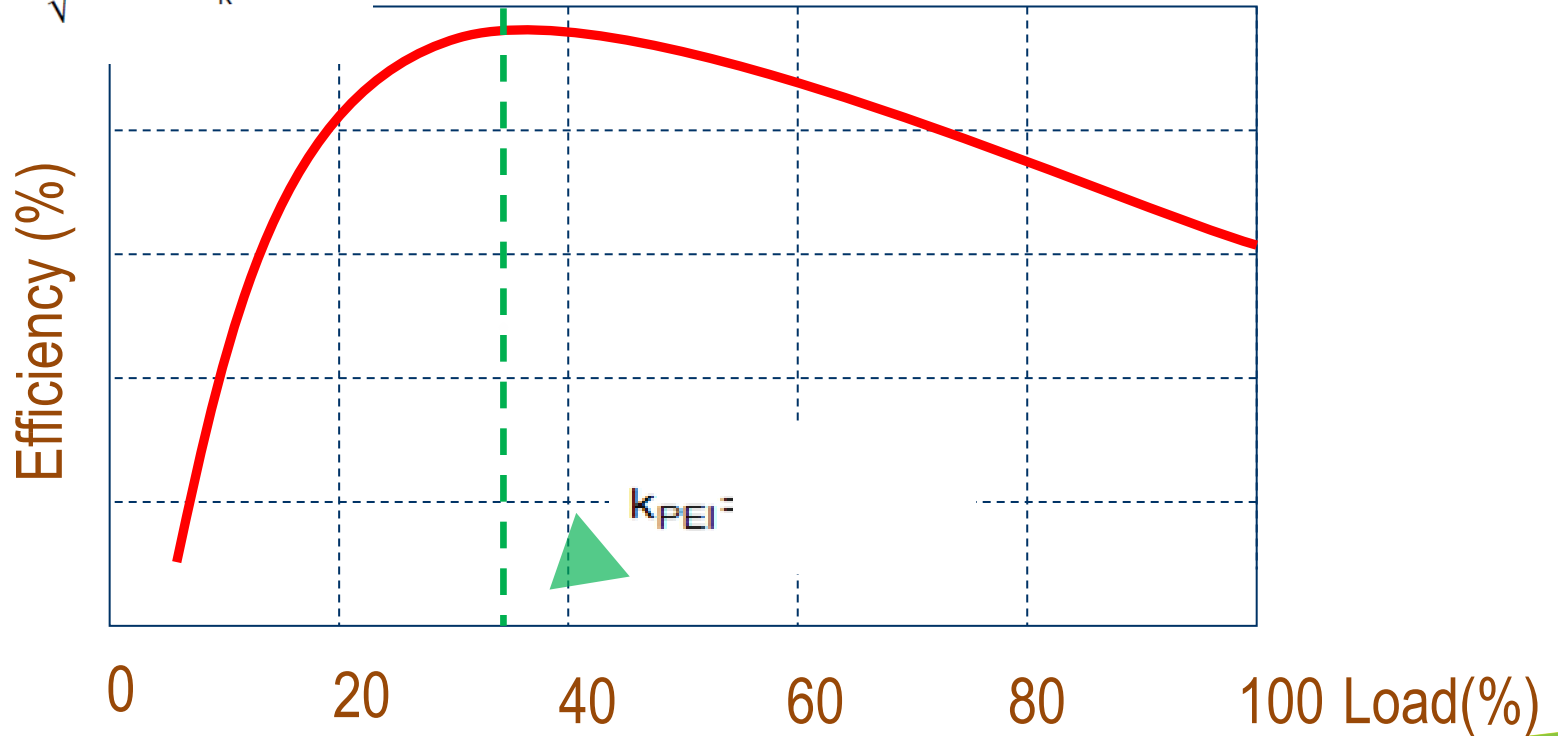
\*\* 20 °C + Average winding rise (i.e. 90 °C for OD cooled transformers, 85 °C for ON or OF cooled transformers)

The Peak Efficiency Index includes the losses associated with only that part of the cooling system that is in service at kPEI.

At kPEI loading sufficient cooling shall be in service to ensure the transformer temperature rise does not exceed the requirements of IEC60076-2 or the customer specification.

# Peak Efficiency Index

$$PEI = 1 - \frac{2(P_0 + P_{c0} + P_{ck}(k_{PEI}))}{S_r \sqrt{\frac{P_0 + P_{c0} + P_{ck}(k_{PEI})}{P_k}}}$$





# Efficiency Index Method B

$$EI_B = \frac{kS_u}{kS_u + P_0 + k^2 T_f P_k} \quad (\text{pu})$$

- $P_0$  is the no-load loss measured at rated voltage, rated frequency and on rated tap
- $P_k$  is the measured load loss at rated current and rated frequency on the rated tap corrected to reference temperature according to IEC 60076-1.
- $S_u$  is the rated power of the transformer or autotransformer as defined in IEEE C57.12.80 on which  $P_k$  is based.  $S_u$  is used to distinguish 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 EI<sub>r</sub>

## **This is different from usual practice of IEC.**

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

# Efficiency Index at 50% loading

$$EI_{B50} = \frac{0,5 S_u}{0,5 S_u + P_0 + 0,25 \times T_f \times P_k} \quad (\text{pu})$$

$T_f$  shall be taken as 1

$S_u$  is the rated power of the transformer or autotransformer as defined in IEEE57.12.80

The exact correction factor  $T_f$  depends at least on the type of 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 at 50% load factor of 55°C for liquid immersed transformers and 75°C for dry type transformers,  $T_f$  is approximated as 0,91.

Other values of  $T_f$  are based on the temperature correction of losses given in IEC60076-1 and 60076-2

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

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

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

1. Minimum Peak Efficiency Index *with load and no load loss capitalisation values*
2. Maximum load losses and maximum no load losses
3. Minimum efficiency index at a load factor of 50%  
EIB50

# 6. Energy performance levels

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## 6.1 General

- Level 1 is for basic energy performance
- Level 2 is for high energy performance

## 6.2 Liquid immersed transformers

6.2.1 Minimum Peak Efficiency Index method A

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

6.2.3 Efficiency Index Method B

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

## 6.3 Dry type transformers

6.3.1 Minimum Peak Efficiency Index value Method A

6.3.2 Maximum load loss and maximum no load loss for transformers with rated frequency equal to 50Hz.

6.3.3 Efficiency Index Method B at 50% load factor



# Thank you

For more information please contact

**Angelo Baggini**

Università di Bergamo

Dipartimento di Ingegneria

Viale Marconi 5,

24044 Dalmine (BG) Italy

email: [angelo.baggini@unibg.it](mailto:angelo.baggini@unibg.it)

**ECD Engineering Consulting and Design**

Via Maffi 21 27100 PAVIA Italy

**Engineering  
Consulting and  
Design**

