INTAS

Database and report on EN/IEC/ISO technical standards

Annex A: Power transformers

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Lead author of this document: ECD
Project coordinator: WIP

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Project acronym: INTAS
Project full name:
Industrial and tertiary product Testing and Application of Standard

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About the INTAS project

The aim of the INTAS project is to provide technical and cooperative support, as well as capacity building activities, to Market Surveillance Authorities (MSAs). The need for the INTAS project arises from the difficulty that MSAs and market actors face in establishing and verifying compliance with energy performance requirements for large industrial products subject to requirements of the Ecodesign Directive, specifically transformers and industrial fans. Therefore, the project aims to:

- Support European Member State MSAs deliver compliance for large products (specifically for transformers and large fans);
- Support industry to be sure of what their obligations are under the Ecodesign Directive and to deliver compliance in a manner that will be broadly accepted by MSAs;
- Foster a common European approach to the delivery and verification of compliance for these products.

List of project partners:

WIP Renewable Energies	Europe
European Environmental Citizens' Organisation for Standardisation	Europe
European Copper Institute	Europe
Engineering Consulting and Design	Europe
Waide Strategic Efficiency	Europe
Austrian Energy Agency	Austria
Federal Public Service Health, Foodchain, Safety and Environment	Belgium
SEVEn Energy Efficiency Center	Czech Republic
Danish Technological Institute	Denmark
Finnish Safety and Chemicals Agency	Finland
The Polish Foundation for Energy	Poland
Directorate General of Energy and Geology	Portugal
Romanian Regulatory Authority for Energy	Romania
Foundation for the Promotion of Industrial Innovation	Spain
Italian National Agency for New Technologies, Energy and Sustainable Economic Development	Italy
Food and Economic Safety Authority	Portugal

Annex A:
D2.1.A Power transformer testing worldwide and EU technical standard and legislation framework

A1. Introduction

This document is extracted from Deliverable 2.1 of the INTAS project, published in October 2016. The full document, entitled *Database and report on EN/IEC/ISO technical standards,* includes the present content focusing on technical standards applicable to power transformers, as well as Annex B, focusing on the standards applicable to large electrical fans. An introductory section on the main standardization organizations mentioned in this annex is also provided. The full report, separate annexes and related spreadsheet databases are publically available on the project website at http://intas-testing.eu/project-documents.

The present Annex A reports the results of the research carried out regarding Power transformer (Group A) in Task 2.1 „Worldwide and EU Technical standard and legislative framework into the WP2 - Landscape of testing avenues“ of the INTAS project.

An introductory briefing on power transformers and on their characteristics useful to fully understand the technical content of the report is provided, before all identified standards relevant to the product group are listed and commented on.

A2. Scope

A2.1 Technical boundaries

This study considers three-phase and single-phase power transformers (including auto-transformers) with a minimum power rating of 1 kVA used electricity transmission and distribution networks or for industrial applications with the exception of small and special transformers such as:

- instrument transformers, specifically designed to supply measuring instruments, meters, relays and other similar apparatus
- transformers with low-voltage windings specifically designed for use with rectifiers to provide a DC supply
- transformers specifically designed to be directly connected to a furnace
- transformers specifically designed for offshore applications and floating offshore applications
- single-phase transformers with rated power less than 1 kVA and three-phase transformers less than 5 kVA
- transformers, which have no windings with rated voltage higher than 1 000 V
- traction transformers mounted on rolling stock
- starting transformers
- testing transformers
- welding transformers
- explosion-proof and mining transformers
- transformers for deep water (submerged) applications.

It is to be pointed out that for the INTAS scope and consequently for the this report all the transformers above have been considered large products even if as detailed in section A2.5 the current EN definition of large power transformers is different.

A2.2 Geographical boundaries

In addition to IEC world, this study considers the following region and countries (alphabetical order):

- Australia and New Zealand
- Brazil
- Canada
- China
- European Union
- India
- Israel
- Japan
- Korea

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- Mexico
- United States of America
- Vietnam

A2.3 Power transformer background

This section recalls some backgrounds about power transformers. It is intended to brief non-technical transformer readers.

A2.4 Basics

Transformers are static electrical devices that are used in electrical power systems to transfer electrical power among circuits through the use of electromagnetic induction.

The purpose of a transformer is to convert power from one system voltage to another. This voltage relationship, or voltage ratio, is determined by the ratio of the number of turns on the primary winding to the number of turns on the secondary winding.

As the alternating current in the primary winding changes 50 or 60 times a second (according to the frequency of the network 50 Hz in EU), it induces a voltage in the secondary winding that is proportional to the voltage of the primary winding divided by the turns ratio. As the transformer works, it incurs power (and hence energy) losses in the windings, the magnetic core and in the surrounding transformer tank / housing and fittings in addition to the power required by the cooling system (if any).

A power transformer is a transformer for the purpose of transmitting electrical power.

A2.5 Classification

The definitions of the different types of power transformers are not harmonised around the world and may be different.

Transformers can be classified according to their:

- high voltage winding or winding voltages
  - High voltage transformer (HV): Um of at least one winding is > 36 kV
  - Medium voltage transformer (MV): Um of at least one winding is > 1,1 kV
  - Low voltage transformer (LV): Um of all windings is < 1,1 kV

- function in the network
  - Step up: to convert the MV of the synchronous generator up to adequate long distance HV transmission values (110, 150, 220, 400 and 750 kV)
  - Transmission or large HV/MV: to obtain the reverse effects described above, reducing the HV to a suitable MV distribution values (10 - 15 - 20 kV)

- Distribution MV/LV: to reduce MV down to suitable LV user values (400 - 230 – 110 V)
- Special (industrial) transformer: to be used for a specific application (for example to feed converter, traction systems, furnaces, etc.)

- type with specific reference to the adopted insulation system
  - Liquid immersed
  - Dry type
    - Cast resin
    - Open type
  - Gas insulated

- number of phases
  - 1
  - 3

- number of windings
  - two-winding transformer: used to connect power system having two different voltage levels
  - three-winding transformer: connecting three voltage levels
  - auto-transformer: used to connect different voltage power systems

A formal classification of power transformer has been introduced by CENELEC TC14 and EU Regulation N 348/14:

- Small power transformer: a power transformer with a highest voltage for equipment not exceeding 1,1 kV.
- Medium power transformer: a power transformer with a highest voltage for equipment higher than 1,1 kV, but not exceeding 36 kV and a rated power equal to or higher than 5 kVA but lower than 40 MVA
- Large power transformer: a power transformer with a highest voltage for equipment exceeding 36 kV and a rated power equal or higher than 5 kVA, or a rated power equal to or higher than 40 MVA regardless of the highest voltage for equipment.

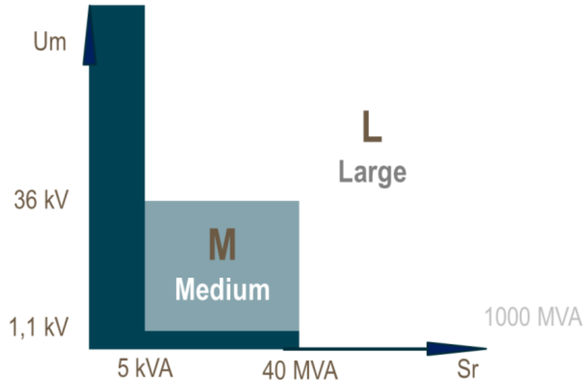

Figure 1 - Classification of power transformer according to EU Regulation N 348/14.

With reference to the type of installation, a pole mounted transformer is a power transformer with a rated power of up to 315 kVA suitable for outdoor service and designed to be mounted on the support structures of overhead power lines.

Liquid-filled transformers, most often used by electric utilities, have several performance advantages over dry-type transformers. Liquid-filled transformers tend to have higher energy performances, have greater overload capability and have a longer service life. This longer service life is due to a greater ability to reduce coil hot-spot temperatures and to have higher dielectric withstand ratings. Liquid-filled transformers are also physically ~~a~~ smaller than dry-type for a given rating, which can be important in areas with restricted space. However, liquid-filled transformers are often filled with mineral oil which has a higher flammability potential than dry-types and local environmental laws may require containment troughs or other facilities to guard against insulating fluid leaks.

Dry-type transformers tend to be used most often by commercial and industrial customers. Generally, the installation location can be a critical consideration here – higher-capacity transformers used outdoors are almost always liquid-filled, while lower-capacity transformers used indoors are often dry-type. Dry-type transformers typically are housed in enclosures, with the windings insulated through varnish, vacuum pressure impregnated (VPI) varnish, epoxy resin or cast resin.

A2.6 Losses

Power transformer losses can be divided into two main components: no-load losses and load losses. These types of losses are common to all types of transformers, regardless of transformer application or power rating. There are, however, two other types of losses; extra losses created by non ideal quality of power and losses which may apply particularly to larger transformers – cooling or auxiliary losses, caused by the use of cooling equipment like fans and pumps.

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A3. No-Load losses

These losses occur in the transformer core whenever the transformer is energised (even when the secondary circuit is open). They are also called iron losses or core losses and are constant.
They are composed of:

- Hysteresis losses, caused by the frictional movement of magnetic domains in the core laminations being magnetized and demagnetized by alternation of the magnetic field. These losses depend on the type of material used to build a core. Silicon steel has much lower hysteresis than normal steel but amorphous metal has much better performance than silicon steel. Hysteresis losses can be reduced by material processing such as cold rolling, laser treatment or grain orientation. Hysteresis losses are usually responsible for more than a half of total no-load losses (~50% to ~80%). This ratio was smaller in the past (due to the higher contribution of eddy current losses).
- Eddy current losses, caused by varying magnetic fields inducing eddy currents in the laminations and thus generating heat. These losses can be reduced by building the core from thin laminated sheets insulated from each other by a thin varnish layer to reduce eddy currents. Eddy current losses usually account for 20% to 50% of total no-load losses

There are also less significant stray and dielectric losses which occur in the transformer core, accounting usually for no more than 1% of total no-load losses.

A3.1 Load losses

These losses are commonly called copper losses or short circuit losses. Load losses vary according to the transformer loading. They are composed of:

- Ohmic heat loss, sometimes referred to as copper loss, since this resistive component of load loss dominates. This loss occurs in transformer windings and is caused by the resistance of the conductor. The magnitude of these losses increases with the square of the load current and is proportional to the resistance of the winding. It can be reduced by increasing the cross sectional area of conductor or by reducing the winding length. Using copper as the conductor maintains the balance between weight, size, cost and resistance; adding an additional amount to increase conductor diameter, consistent with other design constraints, reduces losses.
- Conductor eddy current losses. Eddy currents, due to magnetic fields caused by alternating current, also occur in the windings. Reducing the cross-section of the conductor reduces eddy currents, so stranded conductors with the individual strands insulated against each other are used to achieve the required low resistance while controlling eddy current loss. Effectively, this means that the ‘winding’ is made up of a number of parallel windings. Since each of these windings would experience a slightly different flux, the voltage developed by each would be slightly different and connecting the ends would result in circulating currents which would contribute to loss. This is avoided by transposing the conductors to average the flux differences and equalise the voltage.

A3.2 Auxiliary losses

These losses are caused by using energy to run cooling fans or pumps which help to cool larger transformers.

A3.3 Extra losses due to harmonics and unbalance

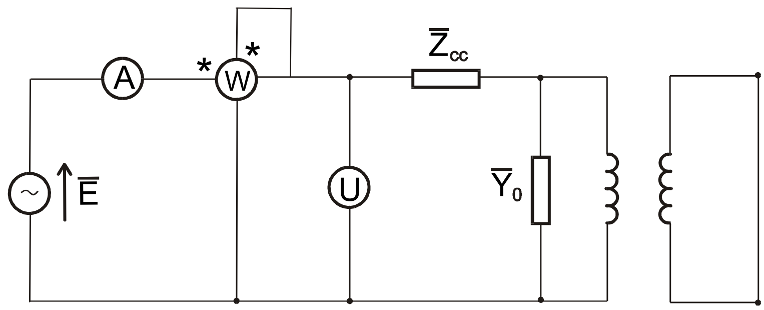
Distorted or unbalanced voltages or currents result in extra losses.
Power losses due to eddy currents depend on the square of frequency so the presence of harmonic frequencies which are higher than rated frequency causes extra losses in the core and windings.
Transformers subject to negative sequence voltages transform them in the same way as positive-sequence voltages. The behaviour with respect to homopolar voltages depends on the primary and secondary connections and, more particularly, the presence of a neutral conductor.

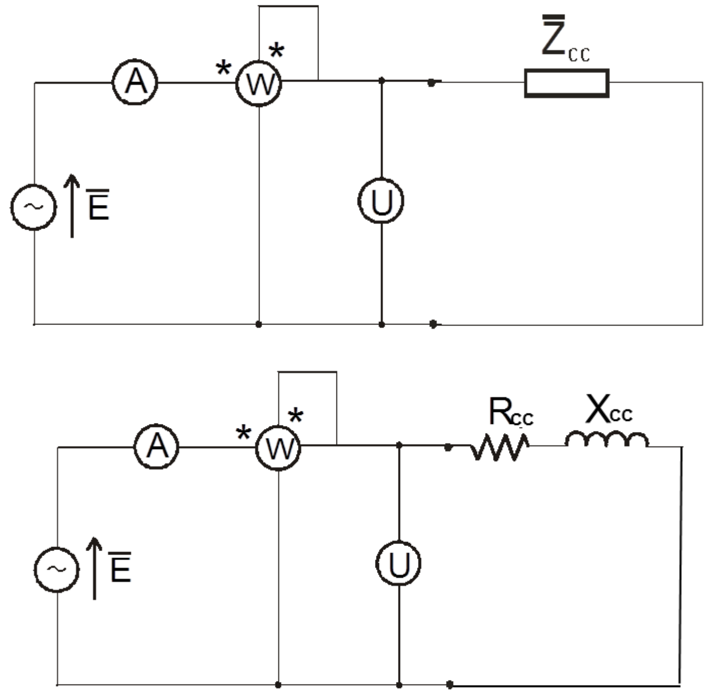
A3.4 Measurement of losses

A3.4.1 Load loss

The measurement of load loss on a large transformer requires considerable care and good measuring equipment because of the low power factor and the often large test currents.

The load loss for a pair of windings is measured at rated frequency with voltage applied to the terminals of one winding, with the terminals of the other winding short-circuited, and with possible other windings open-circuited.
The supplied current should be equal to the relevant rated current. The measurements shall be performed quickly so that temperature rises do not cause significant errors.





$$Z_{CC} = \frac{V}{A} \qquad R_{CC} = \frac{W}{A^2} \qquad X_{CC} = \sqrt{Z_{CC}^2 - R_{CC}^2}$$

Figure 2 – Short circuit test single phase equivalent circuits.

The measured value of load loss (wattmeter reading) shall be multiplied with the square of the ratio of rated current to test current.
The resulting figure shall then be corrected to reference temperature. The ohmic losses are usually and conventionally taken as varying directly with the temperature and all other losses inversely with the temperature.

On a three-winding transformer, measurements are performed on the three different two winding combinations. The results are re-calculated, allocating losses to individual windings. Total losses for specified loading cases involving all these windings are determined accordingly.

Any errors and external circuit losses should be minimized. Correction for measuring transformer errors and for resistance of the test connections should be applied unless they are obviously negligible.

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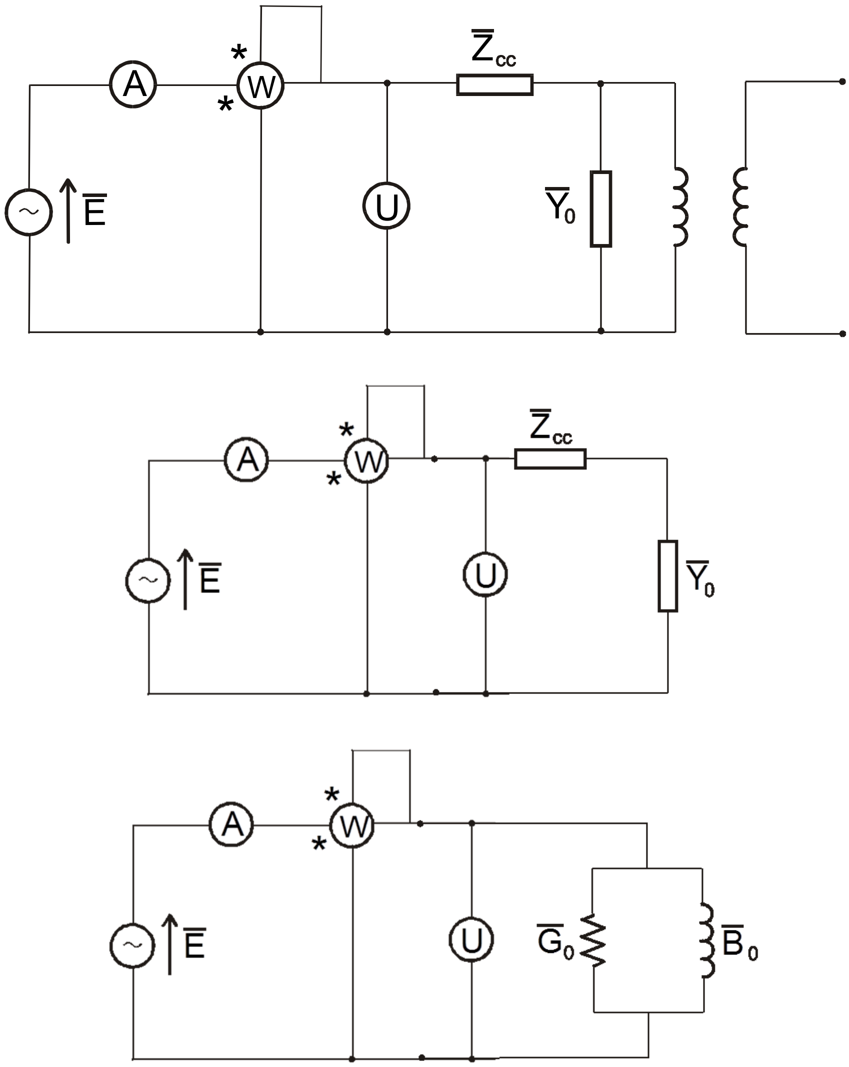
A3.4.2 Measurement of no-load losses

The no-load losses shall be measured on one of the windings at rated frequency and at a voltage corresponding to rated voltage. The remaining winding or windings shall be left open-circuited.



$$Y_0 = \frac{A}{V} \qquad G_0 V^2 = W \qquad B_0 = \sqrt{Y_0^2 - G_0^2}$$

Figure 3 – No load test single phase equivalent circuits.

The transformer shall be approximately at factory ambient temperature. Usually the no load losses are not corrected for any effect of temperature.

A3.4.3 Measurement of auxiliary losses

Measurement of cooling equipment consumption refers to specific product standards and basically consists in electrical energy or power measurement in given conditions.

A3.4.4 Measurement of extra losses due to harmonics and unbalance

Measurement of extra losses due to harmonics and unbalance can be done in different ways. For the scope of this study the conventional and standardized methods described in section A6. are enough.

A3.5 Energy performance metrics

There are different metrics in use for assessing the energy-performance of a power transformer. All of them fundamentally refer to two main categories: maximum losses and minimum efficiency.

Each approach offers certain strengths, but also has some weaknesses. Hereunder the different approaches are shortly discussed in light of the experience built up with the new European Regulation.

Table 1 - Categorization of main metrics used for assessing energy-performance of power transformers.

Maximum losses	Minimum Efficiency
Load and no-load at full load	Efficiency at a defined loading point
Total losses at a specified loading point	Peak efficiency index

A3.5.1 Maximum losses

The benefits of setting the maximum no load and load losses separately in the attempt to either regulate or standardize transformer energy performances can be summarized as follows:

- One of the most important goals of standardization is unification. Unification allows to open a horizontal market, with very important implications for future developments of scale economies, interchangeability, etc...
- No load and load losses are never greater than a certain value regardless of the applied load, which is generally difficult to predict on rms, on a daily, seasonal or life cycle basis across the stock of identically rated transformers. This means that a minimum level of performance is assured whatever the level of loading applied to the transformer.
- Maximum losses are not dependent from the application but only from the product while efficiency is an index depending on the application and this introduces additional uncertainty.

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- In the most situations, the expected load profile is known with a quite high uncertainty. The knowledge of the load profile to be used for optimization ex ante is typically not enough to reach the theoretical optimum promised by efficiency approaches.
- Flexibility related to efficiency approaches is a pro but leaves more space than a loss list to distorted behavior of the market and frauds etc.
- Setting a mandatory maximum level of load and no load losses does not mean that it's not possible to standardize or simply to choose other values optimizing each specific application.
- All these considerations are valid for medium power transformers, which are typically produced in large series and do not allow single special optimization neither by the user nor by the manufacturer.
- For such reasons the European Regulation of energy performances of medium power transformers was based on maximum no load and load losses.
- An alternative to having separate requirements for maximum no-load and load losses is to combine the total losses into one value. Similar to the minimum efficiency set, there will be an implicit least cost point of manufacturer at a given loading point, which may or may not be optimal for a given market. If this loading point does not match the load where the least cost transformer is being installed, the least cost transformer's optimal performance point would not coincide with the installation loading, resulting in lost energy savings.

A3.5.2 Minimum efficiency

Efficiency is a more neutral technological metric, which allows flexibility in designing and manufacturing of transformers. In fact, it allows transformer design engineers to trade-off no-load and load losses while trying to produce an optimized transformer for a specific customer and application. At the same time, it shall be noticed that if a transformer is purchased simply on a least cost basis, its optimal loading point may not coincide with the average loading at all installation sites, resulting in lost energy savings.
Thus, the transformer procurement practice needs to keep all these aspects in mind and minimize the cost of losses over the array of projected load profiles. This is feasible for large power transformers (few very important units specified by expert professionals one by one), but it is practically unfeasible for medium power transformers produced in thousands of units for the general market.

Efficiency is expressed as follows:

$$\text{Efficiency} = \frac{S_{input} - \text{Losses}}{S_{input}} = \frac{S_{output}}{S_{output} + \text{Losses}}$$

The defined power can be either input power (EN) or output power (IEEE) resulting in two methods for calculation of efficiency and historically both methods have been used.

The peak efficiency index is a unit-less metric, which was developed as a regulatory option for the European ecodesign process.

To obtain peak efficiency index, a load factor k_{PEI}, which represent the transformer load conditions in which the efficiency is maximum is calculated as follows:

$$k_{PEI} = \sqrt{\frac{P_0 + P_{c0} + P_{ckPEI}}{P_k}} \quad (pu)$$

Where:

- P0 is the no-load loss measured at rated voltage, rated frequency and on rated tap
- Pc0 is the electrical power 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.
- Pk is the measured load loss at rated current and rated frequency on the rated tap corrected to reference temperature according to IEC 60076-1.
- Pck(k) is the additional electrical power required (in addition of Pc0) 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
- Sr is the rated power of the transformer or autotransformer as defined in IEC60076-1 on which Pk is based
- k is the load factor
- P_{ckPEI} is the additional electrical power required (in addition of Pc0) by the cooling system for operation at kPEI.

In this conditions the Peak Efficiency Index is obtained when no-load loss equals load loss and is given by the equation below:

$$PEI = 1 - \frac{2(P_0 + P_{c0} + P_{ckPEI})}{S_r \sqrt{\frac{P_0 + P_{ckPEI} + P_{c0}}{P_k}}} \quad (pu)$$

The value of equation depends on the ratio Sr /√PK which does not vary significantly if Sr is changed (for example by changing cooling mode) provided that PK is measured at Sr.

The Regulation EU 548/14 neglects formally P_{ckPEI}.

The peak efficiency index (PEI) is defined and set to:

- take into account also energy performances of units required to transform reactive power only
- have an index not depending from the application but related to the product only

Such index includes both no-load and load losses, but the equation is written in such a way that it does not require a specified loading point. Instead, the index finds the point where the no-load loss equals the load loss, and calculates the value. This approach has an advantage over others, because it does not require prescribing or implying a loading point.
At the same time, considering that in a competitive market environment all manufacturers are trying to minimize their costs, prescribing only minimum values for the PEI can be somehow risky. In fact, there may be a mismatch between the no load and load loss ratio which minimizes the transformer cost and the one which optimizes the energy performance during service (provided that in both cases the minimum PEI value is fulfilled). For this reason, it is important that transformer users prescribe suitable capitalization figures or specify minimum efficiency values at certain load factors in order to obtain the highest energy savings. The importance of this issue is higher for smaller units, while larger power transformers tend to be already today state of the art for what concerns efficiency.

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A4. Technical standards

There are a large number of technical standards that are of importance/interest for energy performance and testing energy performance of power transformers:

- Worldwide the most important standards are the international IEC standards
- At regional level the most important are the EN standards for the European region and the IEEE standards for the North American region. Even if containing regional practices and unification values, the EN standards are fully aligned with the IEC standards while the IEEE standards just initiated the alignment with the international standards and still differ in some main assumptions
- at national level some other standards applies repealing partially or totally the contents of IEC, EN or IEEE standards.

A4.1 IEC standards

The set of international standards covering power transformers is published under IEC 60076, Power Transformers and is prepared by IEC Technical Committee 14.

The scope of the IEC TC14 is the standardization in the field of power transformers, tap-changers and reactors for use in power generation, transmission and distribution. Generally these transformers have power ratings above 1 kVA single phase and 5 kVA polyphase with a higher voltage winding of 1 000 V or more, however the scope includes lower voltage transformers and regulators used in power delivery applications. Excluded: - Instrument transformers - Testing transformers - Traction transformers mounted on rolling stock - Welding transformers - Transformers for applications covered by TC 96.

The following table lists the main IEC TC14 published standards documents. The IEC standards addressing specifically power transformer tests (PTT) and power transformer energy performance related tests (EPT) are highlighted in the EPT/PTT column.

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Table 2 - List of Standards for IEC 60076 Power Transformers (May 2016).

Standard	Title	Notes
IEC 60076-1 ed3.0 (2011-04)	Part 1: General	EPT
IEC 60076-2 ed3.0 (2011-02)	Part 2: Temperature rise for liquid-immersed transformers	EPT
IEC 60076-3 ed3.0 (2013-07)	Part 3: Insulation levels, dielectric tests and external clearances in air	PTT
IEC 60076-4 ed1.0 (2002-06)	Part 4: Guide to the lightning impulse and switching impulse testing- Power transformers and reactors	PTT
IEC 60076-5 ed3.0 (2006-02)	Part 5: Ability to withstand short circuit	PTT
IEC 60076-6 ed1.0 (2007-12)	Part 6: Reactors	
IEC 60076-7 ed1.0 (2005-12)	Part 7: Loading guide for oil-immersed power transformers	
IEC 60076-8 ed1.0 (1997-10)	Part 8: Application guide	
IEC 60076-10 ed1.0 (2001-05)	Part 10: Determination of sound levels	PTT
IEC 60076-10-1 ed1.0 (2005-10)	Part 10-1: Determination of sound levels - Application guide	
IEC 60076-11 ed1.0 (2004-05)	Part 11: Dry-type transformers	EPT
IEC 60076-12 ed1.0 (2008-11)	Part 12: Loading guide for dry-type power transformers	
IEC 60076-13 ed1.0 (2006-05)	Part 13: Self-protected liquid-filled transformers	
IEC 60076-14 (2013-09)	Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials	
IEC 60076-15 ed1.0 (2008-02)	Part 15: Gas-filled power transformers	
IEC 60076-16 ed1.0 (2011-08)	Part 16: Transformers for wind turbine applications	
IEC 60076-18 ed1.0 (2012-07)	Part 18: Measurement of frequency response	PTT
IEC/TS 60076-19 ed1.0 (2013-03)	Part 19: Rules for the determination of uncertainties in the measurement of losses in power transformers and reactors	EPT
IEC/TS 60076-20 ed1.0	Energy efficiency	EPT
IEC 60076-21 ed1.0 (2011-12)	Part 21: Standard requirements, terminology, and test code for step-voltage regulators	

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In addition to the above IEC 60076 standards, the Technical Committee 14 (TC 14) on Power Transformers also maintains another international standards. These standards are outside of the scope of this report, although it is understood that IEC 60616 is more applicable to distribution transformers and may become IEC 60076-9 at some point in the future:

- IEC 60214-1 ed1.0 (2003-02) - Tap-changers - Part 1: Performance requirements and test methods
- IEC 60214-2 ed1.0 (2004-10) - Tap-changers - Part 2: Application guide
- IEC/TR 60616 ed1.0 (1978-01) - Terminal and tapping markings for power transformers
- IEC 61378-1 ed2.0 (2011-07) - Converter transformers - Part 1: Transformers for industrial applications
- IEC 61378-2 ed1.0 (2001-02) - Convertor transformers - Part 2: Transformers for HVDC applications
- IEC 61378-3 ed1.0 (2006-04) - Converter transformers - Part 3: Application guide
- IEC 62032 ed2.0 (2012-06) - Guide for the Application, Specification and Testing of Phase-Shifting Transformers

A4.2 EN standards

The set of European EN standards covering power transformers is prepared by CENELEC Technical Committee 14 Power transformer.

The following table lists the main CENELEC TC14 published standards documents. The EN standards addressing specifically power transformer tests (PTT) and power transformer energy performance related tests (EPT) are highlighted in the EPT/PTT column.

The scope of CENELEC TC14 is and has to be identical to the scope of IEC TC14.

Table 3 - List of Standards for CENLEC TC14 (May 2016).

Standard	Title	Tests	MEPS*
EN 60076-1 (2011)	Power transformer - Part 1: General	EPT	NO
EN 60076-2 (2011)	Power transformer - Part 2: Temperature rise for liquid-immersed transformers	PTT	NO
EN 60076-3 (2013)	Power transformer - Part 3: Insulation levels, dielectric tests and external clearances in air	PTT	NO
EN 60076-4 (2002)	Power transformer - Part 4: Guide to the lightning impulse and switching impulse testing- Power transformers and reactors	PTT	NO
EN 60076-5 (2006)	Power transformer - Part 5: Ability to withstand short circuit	PTT	NO
EN 60076-6 (2007)	Power transformer - Part 6: Reactors	NO	NO
EN 60076-10 (2001)	Power transformer - Part 10: Determination of sound levels	PTT	NO
EN 60076-11 (2004)	Power transformer - Part 11: Dry-type transformers	EPT	NO
EN 60076-12 (2008)	Power transformer - Part 12: Loading guide for dry-type power transformers	NO	NO
EN 60076-13 (2006)	Power transformer - Part 13: Self-protected liquid-filled transformers	NO	NO
EN 60076-14 (2013)	Power transformer - Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials	NO	NO
EN 60076-16 (2011)	Power transformer - Part 16: Transformers for wind turbine applications	NO	NO
EN 60076-18 (2012)	Power transformer - Part 18: Measurement of frequency response	PTT	NO
EN 60076-19 (2013)	Power transformer - Part 19: Rules for the determination of uncertainties in the measurement of losses in power transformers and reactors	EPT	NO
EN 60076-21 (2011)	Power transformer - Part 21: Standard requirements, terminology, and test code for step-voltage regulators	NO	NO
EN 50588-1 (2015)	Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV - Part 1: General requirements	EPT	YES
EN 50629 (2015)	Energy performance of large power transformers (Um > 36 kV or Sr ≥ 40 MVA)	EPT	YES

*MEPS: Minimum Energy Performance Standard

A4.3 IEEE standards

The set of US standards covering power transformers is prepared by the IEEE transformers Committee.

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The scope of the IEEE transformers committee is the treatment of all matters in which the dominant factors are the application, design, construction, testing and operation of transformers, reactors and other similar equipment. Included is treatment of the following:

- Transmission and Distribution Transformers
- Voltage Regulators(step and induction regulators)
- Reactors and Grounding Transformers
- HVDC Converter Transformers and Smoothing Reactors
- Power Semiconductor Rectifier Transformers
- Instrument Transformers (voltage and current transformers)
- Insulation and Dielectric Issues Relating to Transformers
- Outdoor Apparatus Bushings
- Insulating Fluids
- Underground Transformers and Network Protectors
- Phase Angle Regulating Transformers

The IEEE transformers committee is organized in some subcommittees :

- Administrative
- Bushing
- Dielectric Test
- Distribution Transformers
- Dry-Type
- Meeting Planning Subcommittee
- HVDC Converter Transformers and Smoothing Reactors
- Instrument Transformers
- Insulating Fluids
- Insulation Life

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- Performance Characteristics
- Power Transformers
- Standards
- Underground Transformers and Network Protectors

The IEEE Power Transformers Subcommittee scope is to

- study and review engineering aspects of liquid filled power transformers, including transmission transformers, primary unit substation transformers, generator step-up transformers, phase angle regulating transformers, and related products
- develop and maintain related standards, recommended practices and guides for such products.
- coordinate with other technical committees, groups, societies and associations as required.

While the Distribution Transformers Subcommittee scope is to:

- Study and review engineering aspects of overhead, pad mounted and certain underground type distribution transformers rated 2500 kVA and smaller, high voltage 38,000 volts and below, low voltage 15,000 volts and below. Evaluation to include enclosure integrity and surface coatings.
- Develop and maintain related standards, recommended practices and guides for such products.
- Coordinate with other technical committees, groups, societies and associations as required.

The following table lists the main IEEE published standard documents on power transformers. The EN standards addressing specifically power transformer tests (PTT) and power transformer energy performance related tests (EPT) are highlighted in the EPT/PTT column.

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Table 4 - List of Standards for IEEE power transformer standards (May 2016).

Standard	Title	EPT	MEPS*
IEEE C57.12.90 (2015)	Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers	EPT	NO
IEEE C57.12.91 (2011)	Standard Test Code for Dry-Type Distribution and Power Transformers		NO
IEEE C57.12.00 (2015)	IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers		NO
ANSI C57.12.10 (2010)	IEEE Standard Requirements for Liquid-Immersed Power Transformers		NO
IEEE C57.12.20 (2011)	IEEE Standard for Overhead-Type Distribution Transformers 500 kVA and Smaller: High Voltage, 34 500 V and Below; Low Voltage, 7970/13 800Y V and Below		NO
IEEE C57.12.40 (2011)	IEEE Standard for Network, Three-Phase Transformers, 2500 kVA and Smaller; High Voltage, 34 500 GrdY/19 920 and Below; Low Voltage, 600 V and Below; Subway and Vault Types (Liquid Immersed)		NO
IEEE C57.12.01 (2015)	IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers		NO

*MEPS: Minimum Energy Performance Standard

A4.4 National standards

The main national standards addressing power transformers in the countries included in the scope of this study are listed in following table.

Table 5 - List of national standards (May 2016).

Country	Ref	Title	Tests	MEPS
Australia / New Zealand	AS 2374.1.2 (2003)	Power Transformers Part 1.2: Minimum Energy Performance Standard (MEPS) requirements for distribution transformers	NO	YES
Australia / New Zealand	AS 2374.1.2 Amdt1 (2005)	Power Transformers Part 1.2: Minimum Energy Performance Standard (MEPS) requirements for distribution transformers	NO	YES
Australia / New Zealand	AS 2374.1. (2003)	Power Transformers Part 1: General	EPT	NO
Australia / New Zealand	AS 2735 (1984)	Dry-type power transformers	NO	NO
Brazil	ABNT NBR 5356-1 (2012)	Power transformers - Part 1: General	EPT	NO
Canada	CSA C802.1-13 (2000)	Minimum efficiency values for liquid-filled distribution transformers	YES	YES

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Country	Ref	Title	Tests	MEPS
Canada	CSA C802.2-12 (2012)	Minimum efficiency values for dry-type transformers	YES	YES
Canada	CSA C802.4-13 (2013)	Guide for kVA sizing of dry-type transformers, 1.2 kV class, single-phase and three-phase	NO	NO
China	JB/T 10317-02 (2014)	Specification and requiremetns for single phase oil immersed distribution transformers	NO	NO
China	GB 20052 (2013)	Minimum Allowable Values of Energy Efficiency and the Evaluating Values of Energy Conservation for Three-Phase Distribution Transformers Program applies to liquid-filled distribution transformers of 30 kVA-1600 kVA and dry type of rated capacity of 30 kVA-2500 kVA.	NO	YES
China	GB 1094.1 (1996)	Power transformers--Part 1:General	EPT	NO
China	GB 1094.2 (1996)	Power transformers--Part 2:Temperature rise	PTT	NO
China	GB 1094.3 (2003)	Power transformers--Part 3: Insulation levels, dielectric tests and external clearances in air	NO	NO
China	GB 1094.5 (2008)	Power transformers - Part 5: Ability to withstand short circuit	NO	NO
China	GB 1094.11 (2007)	Power transformers - Part 11: Dry-type transformers	EPT	NO
China	GB 24790 (2015)		NO	YES
China	GB T28180 (2011)	Eco-design standard of transformers		
China	-- (2015)	Method and Requirement for Evaluating Low-carbon Three-phase Distribution Transformer Products		
China	GB 20052 (2013)	Minimum Allowable Values of Energy Efficiency and the Evaluating Values of Energy Conservation for Three-Phase Distribution Transformers Program applies to liquid-filled distribution transformers of 30 kVA-1600 kVA and dry type of rated capacity of 30 kVA-2500 kVA	YES	YES
India	IS 1180 Part 1 (2015)	Outdoor Type Oil Immersed Distribution Transformers Upto And Including 2 500 KVA, 33kV - Specification Part 1 Mineral Oil Immersed (Fourth Revision)	NO	YES
India	IS I2026: Part 1 (2011)	Power transformers: Part 1 General	EPT	NO
India	IS I2026: Part 2 (2010)	Power transformers Part 2 Temperature-rise	PTT	NO
India	IS I2026: Part 3 (2009)	Power Transformers Part - 3 Insulation Levels, Dielectric Tests and External Clearances in Air	NO	NO
India	IS I2026: Part 4 (1977)	Power transformers: Part 4 Terminal marking, tappings and connections	NO	NO
India	IS I2026: Part 5 (2011)	Power Transformers Part 5 Ability to Withstand Short Circuit	NO	NO

Country	Ref	Title	Tests	MEPS
India	IS I2026: Part 7 (2009)	Power Transformers Part 7 Loading Guide for Oil-Immersed PowerTransformers	NO	NO
India	IS I2026: Part 8 (2009)	Power Transformers : Part 8 Applications guide	NO	NO
India	IS I2026: Part 10 (2009)	Power Transformers : Part 10 Determination of sound levels	PTT	NO
Israel	IS 5484 ()	Distribution transformers - energy efficiency requirements and marking	EPT?!	YES
Japan	JIS C4304 (2013)	6 kV liquid-filled distribution transformers	EPT	NO
Japan	JIS C4306 (2013)	6 kV encapsulated-winding distribution transformers	EPT	NO
Japan	JEC 2200 (2014)	Power transformers	NO	NO
Korea	KS C IEC 60076-1 (2002.10.29)	Power transformers—Part 1 : General	EPT	NO
Korea	KS C IEC 60076-2 (2002.10.29)	Power transformers—Part 2 : Temperature rise	PTT	NO
Korea	KS C IEC 60076-3 (2002.10.29)	Power transformer—Part 3 : Insulation levels, dielectric tests and external clearances in air	PTT	NO
Korea	KS C IEC 60076-4 (2008.03.31)	Power transformers—Part 4 : Guide to the lightning impulse and switching impulse testing—Power transformers and reactors	PTT	NO
Korea	KS C IEC 60076-5 (2008.03.31)	Power transformers—Part 5 : Ability to withstand short circuit	PTT	NO
Korea	KS C IEC 60076-7 (2008.11.20)	Power transformers—Part 7 : Loading guide for oil-immersed power transformers	NO	NO
Korea	KS C IEC 60076-8 (2002.10.29)	Power transformers—Part 8 : Application guide	NO	NO
Korea	KS C IEC 60076-10 (2003.12.29)	Power transformers—Part 10 : Determination of sound levels	PTT	NO
Korea	KS C IEC 60076-10-1 (2008.11.20)	Power transformers—Part 10—1 : Determination of sound levels—Application guide	NO	NO
Korea	KS C IEC 60076-11 (2008.03.31)	Power transformers—Part 11 : Dry-type transformers	EPT	NO
Korea	KS C4306 ()	Single high voltage cover bushing transformers	NO	YES
Korea	KS C4316 ()	Tow bushing type pole transformer for 22.9 kV	NO	YES
Korea	KS C4317 ()	Distribution transformers not more than 3MVA for 22.9kV	NO	YES
Korea	KS C4311 ()	Dry-type transformer	NO	NO
Mexico	NOM 002-SEDE (2010)	Safety requirements and energy efficiency for distribution transformers	NO	YES
Mexico	NMX J169-ANCE (2004)	Electrical Products – Distribution and Power Transformers and Autotransformers – Test Methods	EPT	NO
USA	NEMA TP1 (2002)	Guide for Determining Energy Efficiency for	NO	NO

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Country	Ref	Title	Tests	MEPS
		Distribution Transformers		
USA	NEMA TP2 (2005)	Standard Test Method for Measuring the Energy Consumption of Distribution Transformers		
Vietnam	TCVN 8525 (2015)	Distribution transformers – minimum energy performance and method for determination of energy efficiency.	NO	NO
Vietnam	TCVN 6306-1 (2015)	Power transformers. Part 1: General	EPT	NO
Vietnam	TCVN 6306-2 (2006)	Power transformers. Part 2: Temperature rise	PTT	NO
Vietnam	TCVN 6306-3 (2006)	Power transformers. Part 3: Insulation levels and dielectric tests and external clearances in air	PTT	NO
Vietnam	TCVN 6306-5 (2006)	Power transformers. Part 5: Ability to withstand short circuit	PTT	NO

*MEPS: Minimum Energy Performance Standard

A5. Main standard contents

In the following paragraph the content of the main power transformer standards are shortly analysed and summarized.

Except for Europe and China MEPS for transformers other than distribution transformers, such standards cover distribution transformers.

The scope and other main contents of surveyed standards can be compared using the filter function in the annexed database.

A5.1 IEC standards

A5.1.1 IEC 60076-1

Full title: Power transformers - Part 1: General

This part of IEC 60076 applies to three-phase and single-phase power transformers (including auto-transformers) with the exception of certain categories of small and special transformers.1 When IEC standards do not exist for certain categories of transformers, this part of IEC 60076 may still be applicable either as a whole or in part. For those categories of power transformers and reactors which have their own IEC standards, this part is applicable only to the extent in which it is specifically called up by cross-reference in the other standard. The updated edition of this standard includes the following technical sections that were not in the previous version:

- definition of harmonic content;

- subclause on transport;

- functional method of specification;

- connection symbols for single phase transformers;

- safety and environmental requirements;

- requirements for liquid preservation systems;

- clause on DC currents;

- vacuum, pressure and leak tests on tanks;

- facilities for condition monitoring and environmental and safety considerations.

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The IEC 60076-1 is the most important standard for power transformer energy performance tests. A more detailed analysis of the content of this standard related to this context is given in section A6. .

A5.1.2 IEC 60076-2

Full title: Power transformers - Part 2: Temperature rise for liquid-immersed transformers	

This standard applies to liquid-immersed transformers, identifies power transformers according to their cooling methods, defines temperature rise limits and gives the methods for temperature rise tests. This new edition includes the following significant technical changes with respect to the previous edition:

- the winding hot-spot temperature rise limit was introduced among the prescriptions;
- the procedures for the temperature rise test were improved in relation to the new thermal requirements;
- five informative annexes were added in order to facilitate the implementation of this standard.

A5.1.3 IEC 60076-3

Full title:	Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air

IEC 60076-3:2013 specifies the insulation requirements and the corresponding insulation tests with reference to specific windings and their terminals. This International Standard applies to power transformers as defined by IEC 60076-1. It also recommends external clearances in air. It gives details of the applicable dielectric tests and minimum dielectric test levels. Recommended minimum external clearances in air between live parts and between live parts and earth are given for use when these clearances are not specified by the purchaser. For categories of power transformers and reactors which have their own IEC standards, this standard is applicable only to the extent in which it is specifically called up by cross reference in the other standards. This third edition of IEC 60076-3 cancels and replaces the second edition published in 2000, and constitutes a technical revision.

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A5.1.4 IEC 60076-4

Full title:	Power transformers - Part 4: Guide to the lightning impulse and switching impulse testing - Power transformers and reactors

This standard gives guidance and explanatory comments on the existing procedures for lightning and switching impulse testing of power transformers to evaluate their insulation supplementing the requirements of IEC 60076-3. Also generally applicable to the testing of reactors (see IEC 60289), modifications to power transformer procedures being indicated where required. The standard provides information on waveshapes, test circuits including test connections, earthing practices, failure detection methods, test procedures, measuring techniques and interpretation of results.

A5.1.5 IEC 60076-5

Full title:	Power transformers - Part 5: Ability to withstand short circuit

This standard identifies the requirements for power transformers to sustain without damage the effects of overcurrents originated by external short circuits. It describes the calculation procedures used to demonstrate the thermal ability of a power transformer to withstand such overcurrents and both the special test and the theoretical evaluation method used to demonstrate the ability to withstand the relevant dynamic effects.

A5.1.6 IEC 60076-6

Full title:	Power transformers - Part 6: Reactors

The standard applies to the following types of reactors: shunt reactors; series reactors including current-limiting reactors, neutral-earthing reactors, power flow control reactors, motor starting reactors, arc-furnace series reactors; filter (tuning) reactors; capacitor damping reactors; capacitor discharge reactors; earthing transformers (neutral couplers); arc-suppression reactors; smoothing reactors for HVDC and industrial application.

A5.1.7 IEC 60076-7

Full title:	Power transformers - Part 7: Loading guide for oil-immersed power transformers

This standard is applicable to oil-immersed transformers and describes the effect of operation under various ambient temperatures and load conditions on transformer life.

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A5.1.8 IEC 60076-8

Full title:	Power transformers - Part 8: Application guide

This standard provides information to users about certain fundamental service characteristics of different transformer connections and magnetic circuit designs; system fault currents; parallel operation of transformers, calculation of voltage drop or rise under load; selection of rated quantities and tapping quantities; application of transformers of conventional design to convertor loading; measuring techniques and so on. This standard cancels and replaces IEC 60606.

A5.1.9 IEC 60076-10

Full title:	Power transformers - Part 10: Determination of sound levels

This standard defines sound pressure and sound intensity measurement methods by which sound power levels of transformers, reactors and their associated cooling auxiliaries may be determined. Is applicable to transformers and reactors covered by the IEC 60076 series and the IEC 61378 series, without limitation as regards size or voltage and when fitted with their normal cooling auxiliaries.

A5.1.10 IEC 60076-10-1

Full title:	Power transformers - Part 10-1: Determination of sound levels - Application guide

This standard provides supporting information to help both manufacturers and purchasers apply the measurement techniques described in IEC 60076-10. This standard describes the sources and characteristics of transformer and reactor sound, provides practical guidance on making measurements, and discusses factors that may influence the accuracy of the methods. It applies to transformers and reactors together with their associated cooling auxiliaries.

A5.1.11 IEC 60076-11

Full title:	Power transformers - Part 11: Dry-type transformers

This standard applies to dry-type power transformers (including auto-transformers) having values of highest voltage for equipment up to and including 36 kV and at least one winding operating at greater than 1,1 kV. This standard applies to all construction technologies.

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The IEC 60076-11 is a key standard for dry-type power transformer energy performance tests. A more detailed analysis of the content of this standard related to this context is given in section A6. .

A5.1.12 IEC 60076-12

Full title:	Power transformers - Part 12: Loading guide for dry-type power transformers

This standard applies to dry-type transformers according to the scope of IEC 60076-11. It provides the means to estimate ageing rate and consumption of lifetime of the transformer insulation as a function of the operating temperature, time and the loading of the transformer.

A5.1.13 IEC 60076-13

Full title:	Power transformers - Part 13: Self-protected liquid-filled transformers

The standard applies to high-voltage/low-voltage self-protected liquid-filled and naturally cooled transformers for rated power 50 kVA to 1 000 kVA for indoor or outdoor use having a primary winding (high-voltage) with highest voltage for equipment up to 24 kV; a secondary winding (low-voltage) with highest voltage for equipment of 1,1 kV.

A5.1.14 IEC 60076-14

Full title:	Power transformers - Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials

This standard provides specification, design, testing and loading information for use by both the manufacturer and user of liquid-immersed power transformers employing either high-temperature insulation or combinations of high-temperature and conventional insulation. Is applicable to:

- power transformers designed in accordance with IEC 60076-1;

- convertor transformers designed to IEC 61378 series;

- arc furnace transformers; and

- covers the use of various liquid and solid insulation combinations.

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This new edition includes the following significant technical changes with respect to the previous edition:

- enhancement of insulation system descriptions;

- clarification of temperature rise limits; and

- the addition of overload temperature limits.

A5.1.15 IEC 60076-15

Full title:	Power transformers - Part 15: Gas-filled power transformers

This standard applies to gas-filled power transformers (including auto-transformers) and to all construction technologies. This standard may be applicable as a whole or in parts to other transformers.

A5.1.16 IEC 60076-16

Full title:	Power transformers - Part 16: Transformers for wind turbine applications

This standard applies to dry-type and liquid-immersed transformers for rated power 100 kVA up to 10 000 kVA for wind turbine applications having a winding with highest voltage for equipment up to and including 36 kV and at least one winding operating at a voltage greater than 1,1 kV.

A5.1.17 IEC 60076-18

Full title:	Power transformers - Part 18: Measurement of frequency response

This standard covers the measurement technique and measuring equipment to be used when a frequency response measurement is required either on-site or in the factory either when the test object is new or at a later stage. This standard is applicable to power transformers, reactors, phase shifting transformers and similar equipment.

A5.1.18 IEC 60076-19

Full title:	Power transformers - Part 19: Rules for the determination of uncertainties in the measurement of losses in power transformers and reactors

This document is a Technical Specification (TS), it illustrates the procedures that should be applied to evaluate the uncertainty affecting the measurements of no-load and load losses during the routine tests on power transformers. Even if the attention is especially paid to the transformers, when applicable the specification can be also used for the measurements of reactor losses, except large reactors with very low power factor.

This Technical Specification is now at CDV stage to became a standard identical to EN 60076-19.

The IEC 60076-19 is a key document for power transformer energy performance tests. A more detailed analysis of the content of this standard related to this context is given in section A6. .

A5.1.19 IEC 60076-20

Full title:	prTR Power transformers - Part 20: Energy efficiency

This part of IEC 60076 gives mathematical models to calculate the efficiency of the transformer according to the impedance, resistance and capacity of the load and the level of the rated power. Other matter is also indicated as:

- Levels of losses and no load losses with their efficiency
- Methods of measurement of the no load losses and load losses
- Uncertainties of measurement
- Maximum tolerances on the guaranties

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

The IEC 60076-20 will be a key standard for power transformer energy performances.

A5.1.20 IEC 60076-21

Full title:	Power transformers - Part 21: Standard requirements, terminology, and test code for step-voltage regulators

This standard provides a description of design types, tables of 50 Hz and 60 Hz ratings, supplementary ratings, construction, and available accessories are provided. Methods for performing routine and design tests applicable to liquid-immersed single and three-phase step-voltage regulators are described. Winding resistance measurements, polarity tests, insulation power factor and resistance tests, ratio tests, no load loss and excitation current measurements, impedance and load loss measurements, dielectric tests, temperature tests, routine and design impulse tests, short-circuit tests, control tests, calculated data, and certified test data are covered.

A5.2 EN standards

The EN standard identical to IEC standards are not described in the following paragraph, please refer to the appropriate paragraph in section A5.1 .

Table 6 – List of EN standard identical to IEC standards.

Standard	Title	Tests	MEPS
EN 60076-1 (2011)	Power transformer - Part 1: General	EPT	NO
EN 60076-2 (2011)	Power transformer - Part 2: Temperature rise for liquid-immersed transformers	PTT	NO
EN 60076-3 (2013)	Power transformer - Part 3: Insulation levels, dielectric tests and external clearances in air	PTT	NO
EN 60076-4 (2002)	Power transformer - Part 4: Guide to the lightning impulse and switching impulse testing- Power transformers and reactors	PTT	NO
EN 60076-5 (2006)	Power transformer - Part 5: Ability to withstand short circuit	PTT	NO
EN 60076-6 (2007)	Power transformer - Part 6: Reactors	NO	NO
EN 60076-10 (2001)	Power transformer - Part 10: Determination of sound levels	PTT	NO
EN 60076-11 (2004)	Power transformer - Part 11: Dry-type transformers	EPT	NO
EN 60076-12 (2008)	Power transformer - Part 12: Loading guide for dry-type power transformers	NO	NO
EN 60076-13 (2006)	Power transformer - Part 13: Self-protected liquid-filled transformers	NO	NO
EN 60076-14 (2013)	Power transformer - Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials	NO	NO
EN 60076-16 (2011)	Power transformer - Part 16: Transformers for wind turbine applications	NO	NO
EN 60076-18 (2012)	Power transformer - Part 18: Measurement of frequency response	PTT	NO
EN 60076-19 (2013)	Power transformer - Part 19: Rules for the determination of uncertainties in the measurement of losses in power transformers and reactors	EPT	NO
EN 60076-21 (2011)	Power transformer - Part 21: Standard requirements, terminology, and test code for step-voltage regulators	NO	NO

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A5.2.1 EN 50588-1

Full title:	Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV - Part 1: General requirements

This European Standard covers power transformer with a highest voltage for equipment higher than 1,1 kV, but not exceeding 36 kV and a rated power equal to or higher than 5 kVA but lower than 40 MVA.
National European practices may require the use of highest voltages for equipment up to (but not including) 52 kV, such as Um = 38,5 kV or Um = 40,5 kV when the rated voltage is less than 36 kV. This is considered to be an unusual case of a large power transformer, where the requirements are those for a medium power transformer with Um = 36 kV.

Transformers with tap changer (DETC or OLTC) are included in this European Standard even if they have separate tapping winding.

The object of this European Standard is to set up requirements related to electrical characteristics and design of medium power transformers. The following transformers are excluded from this European Standard:

- instrument transformers, specifically designed to supply measuring instruments, meters, relays and other similar apparatus
- transformers with low-voltage windings specifically designed for use with rectifiers to provide a DC supply
- transformers specifically designed to be directly connected to a furnace
- transformers specifically designed for offshore applications and floating offshore applications
- transformers specially designed for emergency installations
- transformers and auto-transformers specifically designed for railway feeding systems
- earthing or grounding transformers, this is, three-phase transformers intended to provide a neutral point for system grounding purposes
- traction transformers mounted on rolling stock, this is, transformers connected to an AC or DC contact line, directly or through a converter, used in fixed installations of railway applications
- starting transformers, specifically designed for starting three-phase induction motors so as to eliminate supply voltage dips
- testing transformers, specifically designed to be used in a circuit to produce a specific voltage or current for the purpose of testing electrical equipment
- welding transformers, specifically designed for use in arc welding equipment or resistance welding equipment
- transformers specifically designed for explosion-proof and underground mining applications
- transformers specifically designed for deep water (submerged) applications
- medium Voltage (MV) to Medium Voltage (MV) interface transformers up to 5 MVA.

This standard will have to be considered together with the prEN 50588-1:2015/A1:2016 dedicated to the improvement of the definitions of transformers excluded from the EU Regulation No 548/2014 as well as other definitions requiring further clarification.

This standard is a key reference for power transformer energy performances and energy performance testing.

A5.2.2 EN 50629

Full title:	Energy performance of large power transformers (Um > 36 kV or Sr ≥ 40 MVA)

This European Standard applies to new three-phase and single-phase power transformers with a highest voltage for equipment exceeding 36 kV and a rated power equal or higher than 5 kVA, or a rated power equal to or higher than 40 MVA regardless of the highest voltage for equipment. The scope of this European Standard is the following:

- Defining the appropriate energy efficiency criteria
- Setting of benchmark minimum efficiency levels for new transformers based on an assessment of the energy efficiency of the European transformer population installed in the last 10 years
- Proposing higher minimum efficiency levels for improving the energy efficiency of new transformers
- Providing guidance for consideration of Total Cost of Ownership. This European Standard provides also a form for efficiency data collection to inform future efficiency benchmark levels.

This standard covers the transformers under the EU Regulation N. 548/2014 and gives additional specific indications for single phase transformers, auto transformers, multi winding transformers and for transformers with OD and OF cooling systems. Transformers considered to be out of the scope of this document are the following:

- instrument transformers, specifically designed to supply measuring instruments, meters, relays and other similar apparatus
- transformers with low-voltage windings specifically designed for use with rectifiers to provide a DC supply
- transformers specifically designed to be directly connected to a furnace
- transformers specifically designed for offshore applications and floating offshore applications
- transformers specially designed for emergency installations
- transformers and auto-transformers specifically designed for railway feeding systems
- earthing or grounding transformers, this is, three-phase transformers intended to provide a neutral point for system grounding purposes
- traction transformers mounted on rolling stock, this is, transformers connected to an AC or DC contact line, directly or through a converter, used in fixed installations of railway applications

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- starting transformers, specifically designed for starting three-phase induction motors so as to eliminate supply voltage dips
- testing transformers, specifically designed to be used in a circuit to produce a specific voltage or current for the purpose of testing electrical equipment
- welding transformers, specifically designed for use in arc welding equipment or resistance welding equipment
- transformers specifically designed for explosion-proof and underground mining applications
- transformers specifically designed for deep water (submerged) applications
- medium Voltage (MV) to Medium Voltage (MV) interface transformers up to 5 MVA
- large power transformers where it is demonstrated that for a particular application, technically feasible alternatives are not available to meet the minimum efficiency requirements set out by EU Regulation N. 548/2014
- large power transformers which are like for like replacements in the same physical location/installation for existing large power transformers, where this replacement cannot be achieved without entailing disproportionate costs associated to their transportation and/or installation.

For dry type large power transformers Minimum PEI values have been published in European Regulation and these values are included in Annex A.
To retain consistency, the same list of exclusions in the EU Regulation N. 548/2014, has also been reproduced in the standard. Within the above EU exclusion list, some had been excluded simply because no PEI data was available to CENELEC at the time on which to base appropriate PEI levels. Consequently, as such information becomes available in the future, it may be possible to derive suitable PEI Levels. Accordingly these particular categories are listed in Clause 6 as suitable for future consideration.

This standard will have to be considered together with the prEN 50629:2015/A1:2016 dedicated to the improvement of the definitions of transformers excluded from the EU Regulation No 548/2014 as well as other definitions requiring further clarification.

This standard is a key reference for power transformer energy performances and energy performance testing.

A5.2.3 EN 60076-19

Full title:	Power transformers - Part 19: Rules for the determination of uncertainties in the measurement of the losses on power transformers and reactors

This European Standard illustrates the procedures that should be applied to evaluate the uncertainty affecting the measurements of no-load and load losses during the routine tests on power transformers.
The procedures can also be applied to loss measurements on power transformers and reactors as evaluation of the achievable performance of a test facility in the course of prequalification

processes, as estimations of achievable uncertainty in the enquiry stage of an order or prior to beginning final testing at manufacturer´s premises and for evaluations of market surveillance measurements.

A5.3 IEEE standards

A5.3.1 IEEE C57.12.00

Full title: Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

This standard specifies electrical and mechanical requirements for liquid-immersed distribution and power transformers, and autotransformers and regulating transformers; single-phase and polyphase, with voltages of 601 V or higher in the highest voltage winding, are set forth. This standard is a basis for the establishment of performance and limited electrical and mechanical interchangeability requirements of equipment are described; it is also a basis for assistance in the proper selection of such equipment. The requirements in this standard apply to all liquid immersed distribution, power, and regulating transformers except the following: instrument transformers, step voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, mobile transformers, and mine transformers.

A5.3.2 IEEE C57.12.01

Full title: Standard for General Requirements for Dry-Type Distribution and Power Transformers

This standard specifies electrical and mechanical requirements of ventilated, non-ventilated and sealed dry-type distribution, and power transformers or autotransformers (single and polyphase, with a voltage of 601 V or higher in the highest voltage winding) are described.

A5.3.3 IEEE C57.12.20

Full title: Standard for Overhead-Type Distribution Transformers 500 kVA and Smaller: High Voltage, 34 500 V and Below; Low Voltage, 7970/13 800Y V and Below

This standard specifies certain electrical, dimensional, and mechanical characteristics and safety features of single- and three-phase, 60 Hz, mineral-oil-immersed, self-cooled, overhead-type distribution transformers 500 kVA and smaller, high voltages 34 500 V and below, and low voltages 7970/13 800Y V and below are covered in this standard.

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A5.3.4 IEEE C57.12.40

Full title: Standard for Network, Three-Phase Transformers, 2500 kVA and Smaller; High Voltage, 34 500 GrdY/19 920 and Below; Low Voltage, 600 V and Below; Subway and Vault Types (Liquid Immersed)

This standard is intended for use as a basis for establishing the performance, interchangeability, and safety of the equipment covered and to assist in the proper selection of such equipment.

A5.3.5 IEEE C57.12.90

Full title:	Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

The purpose of this standard is to provide test procedure information for tests specified in IEEE Std C57.12.00 and other standards applicable to liquid-immersed distribution, power, and regulating transformers. It is intended for use as a basis for performance and proper testing of such transformers.

Methods for performing tests specified in IEEE Std C57.12.00 and other standards applicable to liquid-immersed distribution, power, and regulating transformers are described. Instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, and mine transformers are excluded. This standard covers resistance measurements, polarity and phase-relation tests, ratio tests, no-load loss and excitation current measurements, impedance and load loss measurements, dielectric tests, temperature tests, short-circuit tests, audible sound level measurements, and calculated data.

It is intended for use as a basis for performance and proper testing of such transformers.This standard applies to all liquid-immersed transformers, except instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, and mine transformers.

Transformer requirements and specific test criteria are not a part of this standard, but they are contained in appropriate standards, such as IEEE Std C57.12.00, ANSI C57.12.10, IEEE Std C57.12.20, and IEEE Std C57.12.40, or in user specifications.

The IEEE C57.12.90 is a key standard for liquid-immersed distribution, power, and regulating transformer energy performance tests. A more detailed analysis of the content of this standard related to this context is given in section A6. .

A5.3.6 IEEE C57.12.91

Full title:	Standard Test Code for Dry-Type Distribution and Power Transformers

This revision addresses substantive changes to Clause 5, 10 and 11 This revision addresses substantive changes to Clause 5, Clause 10, and Clause 11 of IEEE Std C57.12.91-2001 to reflect current practice in the testing procedures of dry-type transformers. This revision does not address transformer requirements and specific test criteria; rather they are contained in appropriate standards such as IEEE Std C57.12.01 or in user specifications.

The IEEE C57.12.91 is a key standard for dry type transformer energy performance tests. A more detailed analysis of the content of this standard related to this context is given in section A6. .

A5.4 National standards

In this section national standard relevant for the scope of this study are listed in alphabetical order by country name.

A5.4.1 Australia and New Zealand AS 2374.1

Full title: Power Transformers Part 1: General

This standard specifies the technical requirements for single and three-phase power transformers, including auto transformers, but excludes single-phase transformers rated at less than 1 kVA, three-phase transformers rated at less than 5 kVA, and certain special transformers such as instrument, starting, testing and welding transformers, transformers for static converters and those mounted on rolling stock. Based on but not equivalent to and has been reproduced from IEC 60076-1:1993. Includes Australian variations such as commonly used power ratings and preferred methods of cooling, connections in general use, and details regarding connection designation.

A5.4.2 Australia and New Zealand AS 2735

Full title: Dry-type power transformers

This standard specifies requirements for dry-type power transformers (including autotransformers) having highest voltage for equipment values up to and including 36 kV. This Standard should be read in conjunction with AS 2374, Power transformers. Where Australian Standards do not exist for other particular power transformers, this Standard may be applicable as a whole or in parts.

The following small and special dry-type transformers are not covered by this standard:

(a) Single-phase transformers rated at less than 1 kVA and polyphase transformers rated at less than 5 kVA

(b) Instrument transformers (covered by AS 1243 and AS 1675)

(c) Transformers for semiconductor converters (AS 1955)

(d) Starting transformers

(e) Testing transformers

(f) Traction transformers mounted on rolling stock

(g) Flameproof transformers

(h) Welding transformers

(i) Voltage regulating transformers

(j) Small power transformers in which safety is a special consideration

A5.4.3 Australia and New Zealand AS 2374.1.2 + AMD 1

Full title: Power Transformers Part 1.2: Minimum Energy Performance Standard (MEPS) requirements for distribution transformers

This standard applies to dry-type and oil-immersed type, three-phase and single-phase power transformers with power ratings from 10 kVA to 2500 kVA and system highest voltage up to 24 kV. This standard does not apply to certain categories of special transformers such as:

(a) transformers other than those on 11 or 22 kv networks;

(b) instrument transformers;

(c) auto transformers;

(d) traction transformers mounted on rolling stock;

(e) starting transformers;

(f) testing transformers;

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(g) welding transformers;

(h) three phase transformers with three or more windings per phase;

(i) arc-furnace transformers;

(j) earthing transformers;

(k) rectifier or converter transformers;

(l) uninterruptible power supply (ups) transformers;

(m) transformers with an impedance less than 3% or more than 8%;

(n) voltage regulating transformers;

(o) transformers designed for frequencies other than 50 hertz;

(p) gas-filled dry-type transformers; or

(q) flameproof transformers.

The scope of this Standard is to permit the calculation of transformer efficiency, and to specify the permissible minimum power efficiency of distribution transformers under certain defined load conditions. This Standard is intended to be used as an instrument for regulation by State and Territory authorities of the Commonwealth of Australia responsible for energy efficiency regulation.

A5.4.4 Brazil ABNT NBR 5356-1

Full title: Power Transformers Part 1: General

The Brazilian test standard for power transformers NBR 5356-1:2007 Version: 2010 “Power Transformers Part 1: General” has published by the Brazilian Association of Technical Standards (ABNT).

The standard was issued in 2007, corrected in 2010 and re-affirmed in November 2012. This part of ABNT NBR 5356, together with the ABNT NBR 5356-2, 3, 4 and 5, applies to single-phase and three-phase transformers (including autotransformers), except for certain categories of small transformers and special transformers.

The standard states that it lays down the required measurement conditions for power transformers, and does not apply to single-phase power transformers that are less than 1 kVA or three-phase power transformers that are less than 5 kVA. It also excludes instrument transformers, static converter transformers, motor starter transformers, testing transformers, electric traction transformers, welding transformers, medical device transformers, electric arc transformers and grounded three-phase reactors. The standard would not be applicable to these special type of transformers, but it should be applied as appropriate.

The test method appears to be consistent with the approach followed in IEC 60076.1.

A5.4.5 Canada CSA C802.1-13

Full title: Minimum efficiency values for liquid-filled distribution transformers

CSA C802.1-13 specifies energy efficiencies for liquid-filled distribution transformers. The total ownership cost (TOC) methodology is recommended as the means for achieving these energy efficiencies, particularly for use by electric utilities. This Standard also specifies an optimal method for nonutility users, based on a modified TOC methodology that meets the conditions of energy cost.
The transformers to which this Standard applies are single-phase and three-phase, 60 Hz, liquid-filled distribution transformers, rated at 10–833 kVA for single-phase and at 15–3000 kVA for three-phase, insulation class 34.5 kV and less.
This Standard describes special features that influence efficiency, and provides for the necessary modifications to the tabulated efficiency values.
This Standard addresses the test methods and procedures for determining the transformer efficiencies.
This Standard does not apply to autotransformers, testing transformers, welding transformers, furnace transformers, rectifier transformers, network transformers, or grounding transformers. Also excluded are transformers with special core/coil designs required by dimensional constraints, transformers with tap ranges greater than 15%, transformers with frequencies other than 60 Hz, and step-voltage regulators.

A5.4.6 Canada CSA C802.2-12

Full title: Minimum efficiency values for dry-type transformers

CSA C802.2-12 establishes minimum efficiency values for dry-type distribution transformers that were made mandatory by the Canadian government. This regulation includes the following types: “dry-type transformer" means a transformer, including a transformer that is incorporated into any another product, in which the core and coils are in a gaseous or dry compound insulating medium and that (a) is either single-phase with a capacity from 15 to 833 kVA or three-phase with a capacity from 15 to 7500 kVA, (b) has a nominal frequency of 60 Hz, and (c) has a primary voltage of 35 kV or less and a secondary voltage of 600 volts or less.
Canada defines a dry-type transformer as one in which the core and windings are in a gaseous or dry compound and that is either single-phase and nominal power of 15 to 833 kVA, or three-phase and nominal power of 15 to 7500 kVA and operates at 60 Hz. The transformer has a high voltage winding rated at 35 kV or less, and does not include several special types transformers, including

auto transformers; drive (isolation) transformers with two or more output windings or a nominal low-voltage line current greater than 1500 A; grounding transformers; rectifier transformers; sealed transformers; non-ventilated transformers, including encapsulated; testing transformers; furnace transformers; welding transformers; special impedance transformers; transformers with a nominal low-voltage line current of 4000 A or more; on-load regulating transformers and resistance grounding transformers.

A5.4.7 Canada C802.4-13

Full title: Guide for kVA sizing of dry-type transformers, 1.2 kV class, single-phase and three-phase

The Guide applies to all 1.2 kV class dry –type transformers covered under CSA C22.2 No. 47 and CSA C9 for commercial and industrial applications.
The Guide is not intended to apply to transformers applying specialty loads such as drive transformers, rectifier transformers, grounding transformers, and mining transformers.
Not included in this Guide is the treatment of harmonics, it being recognized that the forecasting and treatment of load harmonics and voltage harmonics is a significant concern in itself.
The Guide is to be considered for both new installations and the replacement of existing installations.

A5.4.8 China GB 1094 Series

Full title: Power transformers - Series

In China, there are four levels of Chinese standards. The most widely implemented are the National Standards, followed by Professional Standards, then Local Standards, and finally Enterprise Standards. The standards are hierarchical, so that Local Standards supersede Enterprise Standards, Professional Standards supersede Local Standards, and so on. For any given product or service, only one standard will apply, with national standards taking precedence over all.

National Standards are often referred to as “GB standards”. They are consistent across all of China and are developed for technical requirements. As of 2006, there were over 20,000 national GB standards, of which approximately 15% were mandatory, and 85% voluntary. GB standards can be identified as mandatory or voluntary according to their prefix code:

- GB Mandatory National Standards
- GB/T Voluntary National Standards
- GB/Z National Guiding Technical Documents

Many Chinese national GB standards are adopted from ISO, IEC or other international standards developers, and distribution transformers are no exception. For distribution transformers, China covers and regulates both liquid-filled and dry-type.

GB 1094 series is consistent with IEC 60076 series.

A5.4.9 China GB 20052-2013

Full title: Minimum Allowable Values of Energy Efficiency and the Evaluating Values of Energy Conservation for Three-Phase Distribution Transformers Program applies to liquid-filled distribution transformers of 30 kVA-1600 kVA and dry type of rated capacity of 30 kVA-2500 kVA.

This standard specifies energy efficiency grades, minimum allowable values, evaluating values and test method for energy efficiencies of three-phase distribution transformers.

This standard applies to 10kV three-phase oil-immersed distribution transformers with a rated capacity of 30kVA-1600kVA and an off-circuit tap changer and 10kV three-phase dry-type distribution transformers with a rated capacity of 30kVA-2500kVA.

This standard does not apply to gas-filled transformers.

A5.4.10 China GB 24790-2009

Full title: Minimum allowable values of energy efficiency and the energy efficiency grades for power transformers.

This standards provides minimum allowable values of energy efficiency and the energy efficiency grades for power transformers for power transformers of three-phase oil-filled type, with rated working frequency of 50 Hz, voltage level ranges from 35 kV to 220 kV, rated power 3150 kVA and above.

A5.4.11 China JB/T 10317-02

Full title: Specification and requirements for single phase oil immersed distribution transformers.

This standard specifies the technical parameter and requirement of Single-phase Oil-immersed Distribution Transformer; it applies to 5 to 160kVA single-phase liquid-filled distribution transformers.

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A5.4.12 European Union

European Union Standards are EN standards.

A5.4.13 India IS 1180 (part I)

Full title: Outdoor Type Oil Immersed Distribution Transformers Upto And Including 2 500 KVA, 33kV - Specification Part 1 Mineral Oil Immersed (Fourth Revision)

Indian Standard IS 1180 (part I) covers oil filled distribution transformers ratings up to and including 2500kVA, up to 33 kV. This standard is mandated as per gazette notification 'Electrical Transformers (Quality Control) Order, 2015' dated 7th May 2015 issued by Ministry Of Industries & Public Enterprises, Department of heavy industries.

Also the standard ratings covered under the energy labelling scheme are 16, 25, 63, 100, 160, 200 kVA under Energy Conservation Act 2003.

A5.4.14 Israel IS 5484

Full title: Distribution transformers - energy efficiency requirements and marking.

The national standard IS 5484 applies to liquid-filled and dry-type distribution transformers with nominal input voltage of 22kV or 33kV and a nominal output voltage of 400V, with power ratings up to 2500 kVA. The Israeli standards follow the IEC standards, so the kVA ratings are complaint with IEC and the transformers are designed to operate in Israel's 50Hz distribution system.

A5.4.15 Japan JIS C4304

Full title: 6 kV Oil-immersed distribution transformers

JIS C4304 (liquid-filled distribution transformers) is based on the IEC 60076 family of standards, however there were some minor modifications that have been made to the Japanese national standards.

Rated voltage: 6 kV for high voltage side
Rated capacity: two windings transformers having, both 50 and 60 Hz, single-phase, from 5 to 500 kVA and three-phase from 10 to 2000 kVA

A5.4.16 Japan JIS C4306

Full title: 6 kV Encapsulated-winding distribution transformers

JIS C4306 (dry type distribution transformers) is based on IEC 60076, however it was adopted in 2005, at the same time that the IEC was completing its development of IEC 60076-11:2004 for dry-type power transformers. For this reason, JIS C4306 makes reference to IEC 60726: 1982 for dry-type transformers, in addition to the IEC 60076 standard series.

Rated voltage: 6 kV for high voltage side
Rated capacity: two windings transformers having, both 50 and 60 Hz, single-phase, from 5 to 500 kVA and three-phase from 10 to 2000 kVA

A5.4.17 Mexico NOM-002-SEDE

Full title: Safety requirements and energy efficiency for distribution transformers

This Mexican Official Standard establishes the minimum safety requirements and energy efficiency of distribution transformers . It also establishes the test methods to be used to assess these requirements.
This Standard applies to distribution transformers domestic and imported construction, type : post, substation , pedestal and submersible (according to the definitions set out in chapter 3 of Standard) , naturally cooled immersed in insulating liquid for final users , when they are marketed in the United Mexican States .
Also, this Mexican Official Standard applies when the distribution transformer is subject to repair, rebuild or re-installation in order to be marketed in national territory.

A5.4.18 Mexico NMX-J-169-ANCE

Full title: Electrical Products – Distribution and Power Transformers and Autotransformers – Test Methods.

Transformers and autotransformers power distribution and test methods.

A5.4.19 USA: NEMA TP1

Full title: Guide for Determining Energy Efficiency for Distribution Transformers

This Guide specifies minimum efficiency levels for qualifying products to NEMA Premium Efficiency Transformer Program and has been adopted by the U.S. Department of Energy (DOE) as the national energy-efficiency rule for low-voltage dry-type distribution transformers. The manufacturer shall determine the energy efficiency in accordance with 10 C.F.R. Part 431 (Test Procedures for Distribution Transformers).

A5.4.20 USA: NEMA TP2

Full title: Standard Test Method for Measuring the Energy Consumption of Distribution Transformers

This standard has been withdrawn.

A5.4.21 USA: ANSI C57.12.10

Full title: Standard Requirements for Liquid-Immersed Power Transformers

This standard sets forth the requirements for power transformer application. This standard is intended to be used as a basis for performance, interchangeability, and safety of the equipment covered and to assist in the proper selection of such equipment. This document is a product standard that covers certain electrical, dimensional, and mechanical characteristics of 50 Hz and 60 Hz, liquid-immersed power transformers and autotransformers. Such power transformers may be remotely or integrally associated with either primary switchgear or substations, or both, for step-down or step-up purposes and base rated as follows: 833 kVA and above single-phase, 750 kVA and above three-phase. This standard applies to all liquid-immersed power transformers and autotransformers that do not belong to the following types of apparatus: instrument transformers, step voltage and induction voltage regulators, arc-furnace transformers, rectifier transformers, specialty transformers, grounding transformers, mobile transformers, and mine transformers.

A5.4.22 Vietnam TCVN 8525

Full title: Distribution transformers – minimum energy performance and method for determination of energy efficiency.

This standard cross-references the IEC Standards.
The Vietnam national standard TCVN 8525: 2010 has been revised for new version TCVN 8525:2015 since 2015 Dec. 31 .
The 2015 version regulated the MEPs for 3-phases dry and oil transformers as mentioned in table 1 (oil) and table 2 (dry).

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A6. Standardized measurement methods

For the measurement of losses of power transformers, most countries and economies active on distribution transformers use a test standard based on IEC 60076. In some cases, there are slight (local) modifications that have been made due to specific or unique requirements, however for the most part, the standards are consistent and based on IEC 60076.

Of the given standards identified in section **Fehler! Verweisquelle konnte nicht gefunden werden.** above, the procedure to follow on the measurement of losses of a distribution transformer are given in IEC 60076-1.

This is true of both liquid-filled and dry-type transformers. For dry-type transformers, the applicable standard is IEC 60076-11, however in sections 15 (“Measurement of Winding Resistance”), 17 (“Measurement of short-circuit impedance and load loss (routine test)”), and 18 (“Measurement of no-load loss and current (routine test)”), all of these sections cross-reference parts of IEC 60076-1.

Thus, in addition to all the sections that specify the general requirements for tests, the two key sections from IEC 60076-1 that are the focus of quantifying the energy performance metric for distribution transformers:

- IEC 60076-1 Section 11.4 for measurement of load loss
- IEC 60076-1 Section 11.5 for measurement of no-load loss

The following subsections look at critical parts of the IEC test standards, providing also a comparison between IEC test standards and other main test standards.

The measurement of losses is critical for any energy performance metric as losses underpin a policy requirement such as maximum loss levels as well as minimum efficiency level at a specified loading point or some other metric that can be calculated. Therefore, this comparison between the IEC and the other standards focuses only on those aspects directly related to the loss measurement sections.

The two other main IEC documents dealing with the measurement of losses of power transformers are:

- TS 60076-19 for the procedures that should be applied to evaluate the uncertainty affecting the measurements of no-load and load losses during the routine tests on power transformers.
- prTS IEC 60076-20 for the mathematical models to calculate the efficiency of the transformer according to the impedance, resistance and capacity of the load and the level of the rated power

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The countries and economies reviewed for this study that have standards referencing or based on IEC 60076 are: Australia, Brazil, China, Europe, India, Israel, Japan, Korea, Mexico, New Zealand and Vietnam.
The United States and Canada, on the other hand, rely on test standards that are based on IEEE. The US uses a test standard that was developed by the Department of Energy (DOE) and the National Institute of Standards and Testing (NIST) in close consultation with manufacturers and other stakeholders. The US test standard is largely based on IEEE standards.
The Canadian standard references the voluntary industry association standard NEMA4 TP 2-2005 as their test standard, which is also based on the IEEE test methodology.

A6.1 IEC test methods

A6.1.1 General Test Conditions

The general test conditions for conducting loss measurements provide specifications for the test equipment and the reference temperatures at which losses are measured.
In IEC 60076-1:2011, section 11.1.1 specifies that the performance of the test source that supplies the power for the test. The standard specifies that the voltage supply waveshape shall not have a total harmonic content exceeding 5% and the supply frequency shall be within 1% of the rated frequency of the transformer. If a three-phase supply is used, then the supply voltage must be symmetrical, and the maximum voltage across each phase winding shall not differ from the minimum voltage by more than 3%.

A6.1.2 Measurement of load losses

During the load loss and impedance test, a voltage is applied to the terminals of one of winding(s) (typically the high voltage side) of the transformer while the terminals of the windings on the other side (typically the low voltage side) are shorted together. This is called the transformer “short circuit test”. An applied voltage is increased until the current supplied matches the rated current. Losses supplied to the transformer under these conditions are equivalent to the load losses that are incurred during full load operation. Because the applied voltages are much lower than rated voltage in the short circuit test the magnetic field generated in the core is also much lower and thus loss in the core is insignificant in this test.

In many cases, because of possible supply voltage limitations, such as can occur in field testing, it is usual to excite from the low voltage side of the transformer and to short circuit the high voltage side terminals.

Load losses are the sum of the DC resistive losses in the windings plus eddy losses due to circulating currents in the winding conductors plus stray losses in the tank, core clamps and other metal parts. The load losses are sensitive to temperature, due to the fact that the winding resistance increases with temperature while stray and eddy losses decrease with temperature. On the test report, the losses are corrected to the reference temperatures, which are given in section

11.1 of the standard. In the United States, this is 75°C for 55°C rise units or 85°C for 65°C rise units.

Part of section 11.4, the measurement of short-circuit impedance and load loss is given below.

11.4 Measurement of short-circuit impedance and load loss
The short-circuit impedance and load loss for a pair of windings shall be measured at rated frequency with voltage applied to the terminals of one winding, with the terminals of the other winding short-circuited, and with possible other windings open-circuited. (For selection of tapping for the test, see 6.5 and 6.6). The supplied current should be equal to the relevant rated current (tapping current) but shall not be less than 50 % thereof. The measurements shall be performed quickly so that temperature rises do not cause significant errors. The difference in temperature between the top liquid and the bottom liquid shall be small enough to enable the mean temperature to be determined accurately. The difference in temperature between the top and bottom liquid shall not exceed 5 K. To obtain this result more rapidly, the liquid may be circulated by a pump.
The measured value of the short-circuit resistance shall be multiplied with the square of the ratio of rated current (tapping current) to obtain the load loss at rated conditions. The resulting figure shall then be corrected to reference temperature (11.1). The I2R loss (R being d.c. resistance) is taken as varying directly with the temperature and all other losses inversely with the temperature. The measurement of winding resistance shall be made according to 11.2 of IEC 60076-1. The temperature correction procedure is detailed in Annex E.
[…deleted text relating to impedance measurement…]
NOTE 2 The measurement of load loss on a large transformer requires considerable care and good measuring equipment because of the low power factor and the often large test currents. Any errors and external circuit losses should be minimized. Correction for measuring transformer errors and for resistance of the test connections should be applied unless they are obviously negligible (see IEC 60076-8).

A6.1.3 Measurement of No-Load Losses

The no-load loss is measured using the standard “open-circuit test” on the transformer.
By applying an alternating voltage to one side of the transformer, a magnetic flux is established in the core, which induces a voltage across the terminals of the other side. The exciting current and no load loss or core loss is the energy required to establish (or excite) the magnetic flux in the core. Because the exciting current is much lower than rated current there are no significant winding (I2R) losses in the open circuit test. To obtain accurate values of no load losses, the wave shape of the applied voltage must be a close as possible to a sine wave. A correction for the waveshape variation is made to the measured results.
These tests are performed to ensure that the electrical performance of the core is comparable to the calculated values. They verify that the core has been designed and built correctly, that the quality of the core materials is satisfactory and the core is operating in the correct range of flux density.
It also enables the transformer to operate in accordance with certain over voltage conditions as specified in the IEEE Standards without exceeding its rated temperature rating. A transformer can have its no load loss and magnetizing currents measured at 90%, 100% and 110% rated voltage. These tests verify that the core will not operate in the saturation level of the core magnetic field during an over voltage condition.

Section 11.4 from IEC 60076-1, the measurement no-load loss and current is given below:

11.5 Measurement of no-load loss and current

The no-load loss and the no-load current shall be measured on one of the windings at rated frequency and at a voltage corresponding to rated voltage if the test is performed on the principal tapping, or to the appropriate tapping voltage if the test is performed on another tapping. The remaining winding or windings shall be left open-circuited and any windings which can be connected in open delta shall have the delta closed. Where indicated in 11.1.2 and 11.1.3, the measurement shall also be made at 90 % and 110 % of rated voltage (or appropriate tapping voltage).

The transformer shall be approximately at factory ambient temperature.

For a three-phase transformer, the selection of the winding and the connection to the test power source shall be made to provide, as far as possible, symmetrical and sinusoidal voltages across the three phases.

The test voltage shall be adjusted according to a voltmeter responsive to the mean value of voltage but scaled to read the r.m.s. voltage of a sinusoidal wave having the same mean value. The reading of this voltmeter is U'.

At the same time, a voltmeter responsive to the r.m.s. value of voltage shall be connected in parallel with the mean-value voltmeter and its indicated voltage U shall be recorded.

When a three-phase transformer is tested, the voltages shall be measured between line terminals, if a delta-connected winding is energized, and between phase and neutral terminals if a YN or ZN connected winding is energized.

Phase to phase voltages may be derived from phase to ground measurements, but phase to neutral voltages shall not be derived from phase to phase measurements.

The test voltage wave shape is satisfactory if the readings U' and U are equal within 3%. If the difference between voltmeter readings is larger than 3%, the validity of the test is subject to agreement. A larger difference may be acceptable at higher than rated voltage unless this measurement is subject to guarantee.

NOTE 1 It is recognized that the most severe loading conditions for test voltage source accuracy are usually imposed by large single-phase transformers.

The measured no-load loss is Pm, and the corrected no load loss is taken as:

$$P_o = P_m (1 + d)$$

$$d = (U' - U)/U' \quad \text{(usually negative)}$$

The r.m.s. value of no-load current is measured at the same time as the loss. For a three-phase transformer, the mean value of readings in the three phases is taken.

The no load losses shall not be corrected for any effect of temperature.

NOTE 2 In deciding the place of the no-load test in the complete test sequence, it should be borne in mind that no-load loss measurements performed before impulse tests and/or resistance measurements are, in general, representative of the average loss level over long time in service, assuming, that the core is not pre-magnetized. That means, if no-load tests are carried out after resistance measurements and/or lightning impulse tests, *the core of the transformer should be demagnetized by over-excitation before the no-load test is carried out.*

A6.1.4 Measurement uncertainty evaluation

Measurement uncertainty evaluation method described in the IEC 60076-19 assumes that:

- the uncertainty adopted to qualify loss measurement of power transformers is the standard uncertainty (ISO/IEC 13005)
- the transformer losses are measured in the conditions prescribed by IEC 60076-1 by means of digital instruments
- for three-phase transformers, losses are intended to be measured using three independent single-phase measuring systems. These systems may be made by separate instruments or a combined in a three-phase instrument
- in general, losses are measured using current and voltage transformers in conjunction with a power meter (power analyser)
- the measuring system usually has a known systematic deviation (error) that can be corrected for, or not, and the two cases ask for different approach in the uncertainty analysis
- systematic deviations related to measuring equipment can be characterized by calibration
- if not negligible, systematic deviations introduced by the measuring system should be
- corrected before the uncertainty estimate.

The uncertainty estimation includes uncertainties in the measuring system as well as in the tested object (transformer or reactor).
It's to be noted that special care should be mad to secure good calibration for low cos phi values.

A6.1.4.1 No-load loss measurement uncertainty

The no-load loss measurement shall be referred to rated voltage and frequency and to voltage with sinusoidal wave shape.
The current drawn by the test object is non-sinusoidal, and this may cause a distortion in the voltage that leads to erroneous values for the losses. A correction for the transformer losses is the one prescribed in IEC 60076-1, as well as a limit for the permissible distortion.

When the uncertainty estimate is sufficiently accurate as in the determination of the standard uncertainty the following contributions can be disregarded:

- the uncertainty related to the phase displacement when the power factor is greater than 0,2
- the uncertainty on the correction to sinusoidal waveform when the indications of the voltmeters responsive of the r.m.s. and mean voltages are equal within 3 %.

The uncertainty estimate of no-load loss power can be obtained as given in the following table (taken from IEC 60076-19).

Table 7 - Measured no-load loss uncertainties

Quantity	Component	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution	See subclause
CT ratio error	ε_C	u_C	1	u_C	10.2
VT ratio error	ε_V	u_V	n-1	$(n-1)u_V$	10.2
Power meter	P_W	u_{PW}	1	u_{PW}	10.5
Phase displacement	$\frac{1}{1-(\Delta\varphi_V-\Delta\varphi_C)\tan\varphi}$	$u_{\Delta\varphi}\approx 0$	1	≈ 0	10.3
Voltage	U_N	u_{UM}	n	nu_{UM}	10.4
Correction to sinusoidal waveform	$1+\frac{U_{avg}-U_{rms}}{U_{avg}}$	u_{WF}	1	u_{WF}	10.6
Combined standard uncertainty calculated as: $u_{NLL}=\sqrt{u_C^2+(n-1)^2u_V^2+u_{PW}^2+n^2u_{UM}^2+u_{WF}^2}$					
The expanded relative uncertainty is $U_{NLL}=2u_{NLL}$, which corresponds to a level of confidence of approximately 95 %.					

A6.1.4.2 Load loss measurement uncertainty

In load loss measurements the measured loss shall be referred to rated current or to be reported at this current if performed at a reduced current. Moreover, the results of load loss measurements shall be reported to the reference temperature.

The uncertainty estimate of no-load loss power can be obtained as given in the following tables (taken from IEC 60076-19).
For large power transformers, the complete reference procedure described in IEC 60076-19 art. 10.3.2 should be applied.

Table 8 - Measured load loss uncertainties

Quantity	Component	Standard uncertainty	Sensitivity coefficient	Uncertainty contribution [%]	See subclause
CT ratio error	ε_C	u_C	1	u_C	10.2
VT ratio error	ε_V	u_V	1	u_V	10.2
Power meter	P_W	u_{PW}	1	u_{PW}	10.5
Phase displacement	$\frac{1}{1-(\Delta\varphi_V-\Delta\varphi_C)\tan\varphi}$	u_{FD}	1	u_{FD}	10.3
Ampere meter	I_{IM}	u_{IM}	2	$2u_{IM}$	10.4
Combined standard uncertainty calculated as: $u_{P2}=\sqrt{u_C^2+u_V^2+u_{PW}^2+u_{FD}^2+4u_{IM}^2}$					
The expanded uncertainty is $U_{P2}=2u_{P2}$ which corresponds to a level of confidence of approximately 95 %.					

Table 9 - Absolute uncertainty of the additional losses at temperature θ2

Quantity	Component	Absolute measurement	Sensitivity	Contribution
Measured loss	P_2	$\dot{u}_{P2}$	1	$\dot{u}_{P2}$
$I_N^2R_2$ loss	$I_N^2R_2$	$\dot{u}_{R2}$	I^2	$I^2R\times u_{R2}$
The absolute uncertainty of the additional loss as: $\dot{u}_{Pa2}=\sqrt{\dot{u}_{P2}{}^2+(I_N^2R_2\times u_{R2})^2}$				
The expanded absolute uncertainty is $\dot{U}_{Pa2}=2\dot{u}_{Pa2}$ which corresponds to a coverage probability of approximately 95 %.				

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Table 10 - Absolute uncertainty of load losses PLL reported at reference temperature

Quantity	Component	Absolute uncertainty	Sensitivity	Absolute uncertainty contribution
$I_N^2 R_r$ loss	R_r	$\dot{u}_{R2}$	$I_N^2 \frac{t+\theta_r}{t+\theta_2}$	$\frac{t+\theta_r}{t+\theta_2} I_N^2 R_2 u_{R2}$
Additional loss	P_{ar}	$\dot{u}_{Pa2}$	$\frac{t+\theta_2}{t+\theta_r}$	$\frac{t+\theta_2}{t+\theta_r} \dot{u}_{Pa2}$
Mean winding temperature	θ_2	$\dot{u}_{\theta 2}$	$\approx I_N^2 R_r \frac{t+\theta_r}{(t+\theta_2)^2}$	$\frac{t+\theta_r}{(t+\theta_2)^2} I_N^2 R_r \dot{u}_{\theta 2}$
The total standard absolute uncertainty is calculated as: $\dot{u}_{LL} = \sqrt{(\frac{t+\theta_r}{t+\theta_2} I_N^2 R_2 u_{R2})^2 + (\frac{t+\theta_2}{t+\theta_r} \dot{u}_{Pa2})^2 + (\frac{t+\theta_r}{(t+\theta_2)^2} I_N^2 R_2 \dot{u}_{\theta 2})^2}$				
The expanded absolute uncertainty is $\dot{U}_{LL} = 2\dot{u}_{LL}$ which corresponds to a coverage probability of approximately 95 %.				
The expanded relative uncertainty is obtained as: $U_{LL} = \frac{\dot{U}_{LL}}{P_{LL}}$				

A6.2 EN test methods

EN test methods including measurement uncertainty evaluation methods are identical to the IEC ones (Section A6.1) except for the following additional prescriptions (taken from EN 50588-1 and EN 50629).

7. Tolerances

7.1. Tolerances for factories acceptances tests

Tolerances during factory acceptance are subject to agreement between manufacturers and customers provided that requirement in 7.1.1 and 7.12 are met.

Any transformer exceeding one or the other of the limits indicated in 7.1.1 and 7.1.2 shall be considered non compliant with the COMMISSION REGULATION (EU) No 548/2014 of 21 May 2014

7.1.1. Transformers subject to maximum losses

During factory acceptance tests, the measured values of no load and load losses shall not exceed the respective maximum values specified in chapter 6.

7.1.2. Transformers subject to minimum PEI

During factory acceptance tests the PEI value calculated from the losses measurement shall be equal or higher than given in the tables.

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7.2. Tolerances for Market surveillance

7.2.1. Acceptance criteria

Any transformer exceeding one or the other of the limits indicated in 7.2.2 and 7.2.3 shall be considered non compliant with the COMMISSION REGULATION (EU) No 548/2014 of 21 May 2014

7.2.2. Transformers subjected to max losses

During market surveillance measurements, the measured values of no load and load losses can be up to 5% higher than the respective maximum values specified in chapter 6.

7.2.3. Transformers subjected to PEI

During the market surveillance, with reference to annex III of the Regulation 548, market surveillance authority will measure no load and load loss. PEI value shall then be calculated by the market surveillance authority by this formula:

$$PEI = 1 - \frac{2(P_{A0}+P_{Ac0})}{1.05 \cdot S_r \sqrt{\frac{P_{A0}+P_{Ac0}}{P_{Ak}}}} \text{ (pu)}$$

Where:

- *PA0 is the no load loss measured at rated voltage and rated frequency, on the rated tap by the market surveillance authority;*
- *PAc0 is the electrical power required by the cooling system for no load operation derived from the type test measurements of the power taken by the fan and liquid pump motors by the market surveillance authority;*
- *PAk is the measured load loss at rated current and rated frequency on the rated tap corrected to reference temperature according to EN 60076-1 by the market surveillance authority;*
- *Sr is the rated power of the transformer or autotransformer on which Pk is based;*

NOTE: the factor 1.05 represents the verification tolerance on loss components which is allowed to market authority during surveillance checks according to Annex III of EU Regulation 548.

7.3. Uncertainties for market surveillance verification

7.3.1. General purpose

The test results of the loss measurements are expressed as a numerical quantity which is not an exact number but suffers from uncertainty. How wide this margin of uncertainty is depends on the quality of the test installation, particularly its measuring system, on the skill of the staff and on measurement difficulties presented by the test object. The submitted test result shall contain the most correct estimate that is possible, based on the measurements that have been carried out.
This value shall be accepted as it stands. The uncertainty margin shall not be involved in the judgement of compliance for guarantees with no positive tolerance or tolerance ranges for performance data of the test object. However, a condition for acceptance of the whole test is that the measurements themselves have to fulfil certain requirements of quality. Statements of limits or uncertainty shall be available and these statements shall be supported by a documented traceability (see EN ISO 9001).

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Note
When a specific product is subjected to market surveillance check:

- *The measurement uncertainty should be the expanded uncertainty, as defined in IEC /TS 60076 - 19 and referring to a coverage factor k = 2 (i.e. to a confidence level of about 95 % assuming a normal distribution).*
- *the uncertainty defined in this way should not exceed 5 %.*

A6.3 IEEE test methods

With reference to the international standard method for measurement of transformer losses described in the section A6.1 , the IEEE method differs in many aspects.
The following paragraphs describes and comments the main differences.

A6.3.1 General Test Conditions

In IEEE C57.12.00-2010, the general test conditions are presented in section 9.4, establishing the 'accuracies required for measuring losses'. The standard states that measured values of various parameters must be met, including the test equipment used for measuring losses. The frequency of the test source has to be within 0.5% of the rated frequency of the transformer under test (more stringent than IEC), and the test system accuracy for each quantity measured must fall within the limits specified – for example, losses must be measured within 3% accuracy and voltage, current and resistance must all be measured within 0.5%.

Table 11 - Comparison IEC and IEEE for General Test Conditions

Test Source	IEC 60076-1 (2011)	IEEE C57.12.00-2010
Voltage Waveshape	Total harmonic content of waveshape shall not exceed 5% (Section 11.1.1)	Not specified.
Supply Frequency	Shall be within 1% of the rated frequency of the transformer (Section 11.1.1)	Shall be within 0.5% of the rated frequency of the transformer (Section 9.4)
Three-Phase Symmetry	Maximum voltage across each phase winding shall not differ from the minimum voltage by more than 3% (Section 11.1.1)	Not specified

A6.3.2 Measurement of Load Losses

Between the IEC and the IEEE standards about measurement of load losses there are some important differences.

The reference temperature at which load losses are measured differs between the two standards. The IEC calls for a reference temperature dependent on the transformer insulation whereas the IEEE standard is 85°C.

It is important to note that while the current version of the IEEE standard calls for a reference temperature of 85°C, the US DOE adopted its Test Procedure Final Rule in April 2006 for Distribution Transformers prior to the new IEEE reference temperature being adopted. Therefore, the national testing standard in the US for measuring load losses in liquid-filled distribution transformers uses the earlier reference temperature of 55°C.

Due to the fact that load losses vary with temperature, this difference in the reference temperature would result in a difference in reported loss of approximately 3% more losses for the same transformer tested under IEEE.

Load losses are most often measured at ambient temperature in the test laboratory. For this reason, there is a need to correct the measured losses to the reference temperature so the results can be compared to other transformers. Resistive losses in the wire will increase at higher temperatures, but eddy-currents in the wire and stray losses will decrease with rising temperature. For this reason, to get a clear understanding of how losses vary with temperature, the resistive (i2R) losses must be separated from the eddy current and stray losses.

To determine the resistive losses of a transformer requires conducting a resistance test on the windings. The IEEE considers the resistance test to be a “design test” for distribution transformers of 2500 kVA and below, so it does not have to be performed on every unit. The IEEE provides several methods for conducting the resistance test. IEC, on the other hand, requires the resistance test to be a “routine test” (i.e., conducted on all units), but it does not offer a methodology to follow to conduct it. Both standards offer equations for correcting the losses measured at ambient to the reference temperature, and these equations are consistent – each separating out the resistive losses from the ‘other’ losses and applying temperature-based ratios based on the metals used for the windings.

The tolerances associated with the measurement of load losses differ between the two standards. IEC allows for slightly greater variance, up to +15% of the load loss or no-load loss as long as the variance of the total losses does not exceed more than +10 %. IEEE, on the other hand, has no limit for load loss measurement, except to say that the total losses (i.e., combined no-load and load losses) must not exceed the specified values by more than 6%. Thus, the IEEE tolerance is tighter than IEC.

Finally, when measuring the load losses, the transformer should be tested at the rated current. However, some laboratories may not have the necessary equipment to maintain the rated current for the duration of the test, therefore the IEC permits the load losses to be measured at a lower level than the rated current. The minimum allowable test current for the load loss measurement in IEC is 50% of the rated capacity, to allow for measurement when very large rated powers or high impedances create problems with obtaining rated current in a test measurement. The IEEE does not specify whether partial current can be used when measuring load loss, therefore losses must always be measured at full load.

Table 12 - Comparison IEC and IEEE for Measurement Load Losses

Aspect	IEC 60076-1 (2011)	IEEE C57.12.00-2010
Reference Temperature	Reference temperature is 75°C (section 11.1.1); IEC has an equation for correcting to this temperature in Annex E (normative)	Load loss reference temperature is 85°C[8] (section 5.9); and IEEE offers an equation to correct measured losses to this reference temperature (Section 9.4.2 of C57.12.90:2006)
Temperature Correction Equations	$P_r = \Sigma I^2 R_r + P_{ar}$ Where P_r is load loss corrected for temperature; I is the specified load current; R_r is the winding resistance at the reference temperature; and P_{ar} is the temperature corrected additional losses (see Annex E)	$P(T_m) = P_r(T_m) + P_S(T_m)$ Where $P(T_m)$ is the load loss at the reference temperature, $P_r(T_m)$ is the calculated I^2R loss at the reference temperature and $P_s(T_m)$ is the calculated stray loss at the reference temperature (see Section 9.4.2 of C57.12.90:2006)
Loss Tolerances	+15 % for load loss, provided that the total losses does not exceed +10 % (section 10)	No limit for load loss measurement, but total losses must not exceed specified by more than 6% (Section 9.3)
Test Current	Allows less than full-rated current to be used for load loss measurement, down to a minimum of 50% of the rated current (section 11.4). Direct current must be used for the measurement (Section 11.2.1)	Does not specify whether partial current can be used when measuring load loss. Various methods are offered for measuring
Resistance Measurement Method	No methodology specified.	Bridge method or Voltmeter-ammeter method (Section 5.3 of C57.12.90:2006)
Winding Temperature Guidelines	Cold resistance after 3 hour minimum with no excitation. Temperature rise. When determining temperature rise, the difference between top and bottom liquid shall not exceed 5 degrees, and a pump may be used (Section 11.2.3)	No excitation and no current in the windings from 3 to 8 hours depending on size of transformer. The top & bottom temperature difference shall not exceed 5degrees (Section 5.1.2 of C57.12.90:2006)

On the issue of load-loss, it should be noted that the US DOE Test Procedure Final Rule was adopted in April 2006 and was based on an earlier draft of the IEEE test standard, which used 55°C as the reference temperature for the measurement of load losses in liquid-filled distribution transformers. This can be seen in the following excerpt from the US DOE Test Procedure[9]:

3.5 *Conversion of Resistance Measurements.*

(a) Resistance measurements must be corrected, from the temperature at which the winding resistance measurements were made, to the reference temperature. As specified in these test procedures, the reference temperature for liquid-immersed transformers loaded at 50 percent of the rated load is 55 °C. For medium-voltage, dry-type transformers loaded at 50 percent of the rated load, and for low-voltage, dry-type transformers loaded at 35 percent of the rated load, the reference temperature is 75 °C.

Figure 4 - Excerpt from US DOE Test Procedure for Distribution Transformers

Here, the reference temperature for the load losses on dry-type are aligned with IEC (both are 75°C); however for the liquid-filled, 55°C must be corrected to 75°C for comparison with the other regulatory requirements. The method used to develop a temperature correction factor for the load losses is presented in Annex section A.4 of the Part 1 report in this series.

A6.3.3 Measurement of No-Load Losses

Between the IEC and the IEEE standards about measurement of no-load losses there are some important differences.

First and foremost, the reference temperature at which no-load losses are measured is different. The IEC standard calls for the measurement of no load loss at factor temperature and is not corrected for temperature. Therefore, the measurement temperature will be somewhere between 10°C and 30°C, see IEC 60076-1 clause 11.5. The IEEE standard reference temperature for no-load losses is 20°C. The IEEE standard offers a formula for correcting the measured no-load losses to the reference temperature, but the IEC standard does not.

Both standards have waveform correction, so laboratories that do not have a true sine wave generator can correct test results so they report what the losses would have been under a true sine wave generator. However, the formulae used by the two standards are different, and could result in different reported losses. Both standards also set a limit on the waveform correction that can be applied, however they describe those limits differently (see table below).

The tolerances associated with the measurement of no-load losses differ between the two standards. IEC allows for slightly greater variance, up to +15% of the no-load loss or load loss as long as the variance of the total losses does not exceed more than +10 %.5 IEEE, on the other hand, states that the measured no load loss shall not exceed specified values by more than 10%, and total losses must not exceed the specified values by more than 6%. Thus, the IEEE tolerance is tighter than IEC.

Finally, IEC establishes a maximum of +30% of the design value for the no-load current (i.e., excitation current) when making the no-load loss measurement. IEEE does not specify a limit on this current. The table below presents these comparisons and gives the citations.

Table 13 - Comparison IEC and IEEE for Measurement of No-Load Losses

Aspect	IEC 60076-1 (2011)	IEEE C57.12.00-2010
Reference Temperature	Reference temperature is 75°C (section 11.1.1); IEC does not have an equation for correcting measured losses to this reference temperature[6]	Core loss reference temperature is 20°C (section 5.9); offers an equation to correct measured losses to this reference temperature.IEEE C57.12.90 section 8.4 states that average oil temperature should be within 10% of the reference temperature (20°C), the difference between top and bottom oil temp shall not exceed 5°C and provides an equation for temperature correction.
Waveform Correction	Section 11.5 sets out an equation: $P_0 = P_m (1+d)$ where the measured no-load loss is P_m and $d=(U'-U)/U'$ where U is the measured average voltage and U' is the measured r.m.s. voltage.	$P_c (T_m) = P_m /(P_1+kP_2)$ $k = (\text{r.m.s. voltage / average voltage})^2$ Tm is average oil temp P_m is measured no-load loss P_1 is per unit hysteresis loss and P_2 is per unit eddy-current loss P_c is the waveform-corrected losses at T_m (Section 8.3 of C57.12.90:2006)
Maximum Waveform Correction	The maximum difference between U' and U shall be 3%. (Section 11.5)	The above equation should only be used where the correction is 5% or less. If greater than 5% then the voltage waveform for the measurement must be improved. (Section 8.3 of C57.12.90:2006)
Loss Tolerances	+15 % for no-load loss, provided that the total losses does not exceed +10 % (section 10)	No load losses shall not exceed specified valuesby more than 10%, and total losses must not exceed specified by more than 6% (Section 9.3)
Excitation current	+30 % of the design value (section 10)	Not specified.

A6.4 National test methods

A6.4.1 Australia and New Zealand

The test methods for the current minimum energy performance standards are designated in AS2374.1.2:2003/Amdt1-2005. Although there is no designated test procedure developed specifically for the efficiency requirements, the test method is based on the power loss measurement techniques specified in the Australian/New Zealand power transformer Standard AS/NZS 60076.1, which is adapted from the IEC Standard IEC 60076 – Power Transformers, Part 1: General.
Power loss measurements are performed at specified load conditions and the losses are adjusted to standard temperatures and the efficiency is calculated from the loss

measurements by the standard equations. The specified load conditions are 50% of rating and unity power factor.
The method uses a testing temperature of 75°C for both liquid filled and dry-type transformers. This is a deviation from the method in IEC 60076.1 where 75°C is used for liquid filled units and a higher value for dry-types (specified in IEC 60076-11).
The testing standard is based on, but not equivalent to, IEC 60076-1:1993. The standard AS/NZS 60076.1 incorporates some appropriate national variations such as commonly used power ratings and preferred methods of cooling, connections in general use, and details regarding connection designation.
One other important difference is the equation for efficiency – this is based on the IEEE equation rather than the IEC equation. The Australian equation for efficiency is:

$$EP = PL / [PL + PC + PW]$$

Where:
PL = the real power delivered to the load in Watts
PC = the watts of losses in the core material (no-load losses)
PW = the watts of losses in the transformer windings (load losses) at the specified loading point (e.g., 50% RMS load)

A6.4.2 Brazil

The test method appears to be consistent with the approach followed in IEC 60076.1.

A6.4.3 Canada

The test method in Chapter 6 discusses the accuracy, resistance measurement, loss measurement and calculation method for the measured efficiency. However the methods themselves are not contained in C802.2-12, instead they are cross-references to the National Electrical Manufacturers Association (NEMA) TP 2-2005, “Standard Test Method for Measuring the Energy Consumption of Distribution Transformers”. C802.2-12 states the following:

6. Test methods
6.1 Accuracy
Test system accuracy requirements shall be as specified in NEMA TP 2, Section 2.

6.2 Resistance measurement
Test methods for resistance measurement shall be in accordance with NEMA TP 2, Section 3.

6.3 Loss measurement
Test methods for loss measurement shall be in accordance with NEMA TP 2, Section 4.

6.4 Calculation of tested efficiency
The efficiency percentage is determined using the output kVA, divided by output kVA plus losses, and multiplied by 100, as follows:

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$$\% \text{ efficiency} = \frac{\left[(100)(p)(\text{kVa})(1000)\right]}{\left[\left[(p)(\text{kVa})(1000)\right] + NL + \left[(P_{L75})(p^2)\right]\right]}$$

where

- *p = per unit load in accordance with Table 1*
- *kVA = nameplate kVA rating*
- *NL = no-load loss in watts at 100% of the rated voltage and ambient temperature*
- *PL75 = load loss in watts at 75°C (see Annex A for basic loss calculation steps)*

A6.4.4 China

The test standard for measuring the efficiency of the transformer is the family of GB 1094 national standards, which are harmonized with IEC 60076, but it is noted as being “modified” when it was adapted to the Chinese context, however it will be consistent with the IEC approach.

A6.4.5 European countries

The European Countries adopt the measurement method stated in the EN documents.

A6.4.6 India

The testing code and procedure for the distribution transformers would be as per the Indian Standard (IS) 1180 (part 1): 2014 with all amendments to date. One exception is the conditions on temperature rise limits. For the labelling scheme, the temperature rise of the top liquid and transformer winding in IS 1180 (part 1):2015 is 35°C and 40°C.
The testing standard IS 1180 (part 1) defines the separate measurement of load losses and no load losses. For the Bureau of Energy Efficiency (BEE) labelling programme total losses are measured at 50% and 100% load.
In India, the standard IS 1180 (Part 1): 2015 specifies the requirements and tests for oil-immersed, naturally air-cooled, three-phase, double-wound, non-sealed type outdoor distribution transformers of ratings up to and including 100 kVA. These transformers are designed for use on systems with nominal system voltages up to and including 11 kV. The standard IS 1180 (Part 2): 1989 “Outdoor Type Three-Phase Distribution Transformers up to and including 100 kVA 11 kV” specifies the requirements and tests for oil immersed, naturally air-cooled, three-phase, double-wound, outdoor distribution transformers with sealed tank construction up to and including 100 kVA. These transformers are designed for use on systems with nominal system voltages up to and including 11 kV.
For testing transformers, India is harmonised with IEC 60076. Both Parts of IS cross-reference a series of Indian Standards (IS) based around the IEC 60076 standard. This set of standards are under the reference IS 2026, and are all listed in the following table. All of these standards were developed by the BIS Technical Committee, ET 16.

A6.4.7 Israel

Contained in the standard IS 5484 are cross-references to IEC 60076 and the appropriate standards within that group for liquid-filled and dry-type. Therefore, Israel is harmonised with IEC standards.

A6.4.8 Japan

The Top Runner transformer efficiency levels are not given as specific efficiency values or maximum watts of loss, but are determined from aggregate core and coil losses derived from an empirical equation based on the transformer rating at a specific loading point.
The methods used for measuring actual losses are those given in the Japanese Standards JIS C4304 and JIS C4306 which are based on the IEC 60076 family of standards, however there were some minor modifications that have been made to the Japanese national standards.

The methods for measuring and calculation losses are a following equation:

$$Ea = Wi + (m/100)2 * Wc$$

where

- Ea Total loss in Watts
- Wi No-load loss in watts
- m Load factor in %
- The load factor is 40 % for 500 kVA or below and 50 % for above 500kVA
- Wc Load loss in watts

A6.4.9 Korea

Within KS standards, the regulations cross-reference the measurement methodologies that are published in the IEC 60076 standards, which have been adopted without modification (i.e., “identical”) as national Korean Standards (KS). KS C IEC 60076-1, Power transformers – Part 1: General, corresponds to IEC 60076-1:1993 and is identical to that standard. KS C IEC 60076-11, Power transformers – Part 11: Dry-type transformers, corresponds to IEC 60076-11:2004 and is identical to that standard.
These standards have been adopted by KATS (The Korea Laboratory Accreditation Scheme (KOLAS) and the Korea Accreditation System (KAS) represent Korea in the International Laboratory Accreditation Cooperation (ILAC) and the International Accreditation Forum (IAF), and other international and regional conformity assessment meetings.).

A6.4.10 Mexico

The section 6.2 of the NOM-002-SEDE cross-references the Mexican testing standard that should be used for measuring the core and coil losses.

6.2 Test methods applicable to energy efficiency

To check the energy efficient features set forth in subsection 5.2 shall comply with the following:

a) For testing no-load loss, distribution transformers shall comply with the set out in Chapter 7 on "No load losses and excitation current" of the Standard NMX-J-169-ANCE-2004.

b) For testing due to the load losses, distribution transformers shall comply with the provisions of Chapter 8 on "Losses due to load and impedance" of the Standard NMX-J-169-ANCE-2004.

The regulation, NMX-J-169-ANCE-2004 is titled “Transformadores y Autotransformadores de Distribución y Potencia - Métodos de Prueba”, which translates as “Electrical Products – Distribution and Power Transformers and Autotransformers – Test Methods.” In that standard, Chapter 7 provides a methodology for measuring no load losses and Chapter 8 provides a methodology for measuring load losses.

The calculation of the percentage efficiency for the Mexican regulations is published in the Official Gazette of the Federation (“Diario Oficial de la Federacion”), 17 June 2009. 23

In this section, 6.2.1 Calculation of the efficiency, it states that the equation to be used for calculating efficiency should be calculated taking into account the no load and the load losses, corrected to 75°C or 85°C, as appropriate and a unity power factor.

6.2.1 Cálculo de la eficiencia

Para la determinación de la eficiencia se deben considerar las pérdidas nominales en vacío y debidas a la carga (corregidas a 75°C u 85°C, según corresponda su diseño) y un factor de potencia unitario.

$$\text{Eficiencia}\ (\eta) = \frac{Ps}{Pe} \times 100$$

y

$$Pe = (Ps + pc + pv)$$

Donde:

Ps = es la potencia de salida en W (capacidad nominal);

Pe = es la potencia de entrada en W;

pc = son las pérdidas debidas a la carga en W, y

pv = son las pérdidas en vacío en W.

NOTA - La capacidad nominal (voltamperes) debe estar en función de los valores de tensión, frecuencia y corriente eléctricas nominales que se utilizaron para el cálculo de las pérdidas y considerando un factor de potencia unitario.

The equation shown is that efficiency is equal to Ps, the output power of the transformer in Watts (nominal capacity), divided by Pe, which is the input power to the transformer. Pe is

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equal to Ps plus the core and coil losses, all expressed in Watts. This equation construction is consistent with the IEEE equation approach.

A6.4.11 United States of America

The USA adopt the measurement method stated in the NEMA, CFR and IEEE documents.

A6.4.12 Vietnam

The measurement methods are based on IEC 60076. The old version as TCVN 6306-1:2006 is replaced by TCVN 6306-1:2015 from 2015 Dec.31

A6.5 Standardisation needs

There is a need of development in the area of loss measurements on power transformers at very low power factors. In the specific description of the three subjects can be mentioned:

- Need for the development of new measuring systems for more accurate measurement of losses of power transformers with high energy performance and for the measurement of losses of large reactors (where the power factor is very low).
- Calibration facilities are required to calibrate and verify the performance of these new measuring systems.
- Guidance is needed on the evaluation of uncertainty in loss measurements of high-energy performance power transformers and of large reactors in order to ensure a common and correct approach in the quite complicated uncertainty analysis.

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A7. Legislative documents and programs

There are a certain number of legislative documents dealing with energy performance and testing energy performance of power transformers at:

- European Union level
- USA level
- other country level

Legislative documents are more to support principal targets like energy efficiency. They may include the following:

- Voluntary or mandatory minimum energy efficiency standard (MEPS)
- Labelling
- Incentives from obligations or certificate schemes
- Other financial or fiscal incentives
- Information and motivation
- Tool-kits for buyers
- Energy Advice / Audits
- Co-operative procurement
- Support to R&D and pilot or demonstration projects.

Regulations usually referred to MEPS - Minimum Energy Performance Standards - for transformers have evolved in many countries during last decade.
Such regulations cover distribution transformers only, both liquid immersed and dry type transformers except for Europe and China.

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Table 14 – Comparison among legislative documents (May 2016).

Country	Transformers	Indicative Requirements	Mandatory	Standard / Regulation
Australia / New Zealand	1 phase: 10-50 kVA 3 phase: 25-2500 kVA Voltage: 11 and 22 kV	Efficiency at 50% load	Yes, since April 2004	AS2374.1.2-2003
Brazil	1 phase: 5 to 100 kVA 3 phase: 15 to 300 kVA Voltage: 15, 24.2 & 36.2kV	Max watts core and coil losses at 100% load	Yes, current regulation	ABNT NBR 5356
Canada	1 phase: 10-833 kVA 3 phase: 15-3000 kVA	Efficiency at 50% load	No, voluntary since 2000	CSA C802.1
China	1 phase: 5-160 kVA 3 phase: 30-1600 kVA	Maximum core and coil losses at 100% load	Yes	JB/T 10317-02 GB 20052-2013
European Union	3 phase: 50-2500 kVA; Voltage: 24 and 36kV (draft: 3 phase: 25-3150 kVA)	Maximum core and coil losses at 100% load	No (draft MEPS in review)	EN50464-1:2007
India	3 phase: 16-200 kVA for labelling	Maximum W losses at 50% and 100% loading	No, but utility required to purchase 3-Star	IS 1180
Israel	100-2500 kVA Voltage: 22kV or 33kV	Maximum W losses 100%	Yes, 2011	IS 5484
Japan	1 phase: 5-500 kVA 3 phase: 10-2000 kVA both 50 and 60 Hz	<500 kVA: 40% >500 kVA: 50%	Yes, March 2008; updated 2013	Top Runner
Korea	1 phase 10-100 kVA; 1 and 3 phase; 3.3-6.6kV, 100-3000 kVA 1 and 3 phase; 22.9kV, 100-3000 kVA & 10-3000 kVA	Efficiency at 50% load	Yes, July 2012	KS C4306; C4316and C4317
Mexico	1 phase: 5-167 kVA 3 phase: 15-500 kVA Voltage: 15, 25 and 34.5 kV	Efficiency at 50% load	Yes, 1999	NOM-002-SEDE-1997
USA	1 phase: 10-833 kVA 3 phase: 15-2500	Efficiency at 50% load	Yes, Jan 2010; new Jan 2016	10 CFR 431
Vietnam	25-2500 kVA, 0.4-35kV	Efficiency	Yes, Jan 2013	TCVN 8525:2010

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A7.1 Legislation at European Union level

There are several EU Directives and one EU Regulation that have an impact on the large power transformers considered in this document and their subassemblies like cooling and control systems.

A7.1.1 EU Ecodesign Directive 2009/125/EC

The European Union's Ecodesign Directive (Directive 2009/125/EC) establishes a framework to set mandatory ecological requirements for energy-using and energy-related products sold in all 28 Member States. Its scope currently covers more than 30 product groups (such as boilers, lightbulbs, TVs and fridges and also power transformers, which are responsible for around 40% of all EU greenhouse gas emissions).
The 2009 revision of the Directive extended its scope to energy-related products such as windows, insulation materials and certain water-using products.
The ultimate aim of the Ecodesign Directive is that manufacturers of energy-using products will, at the design stage, be obliged to reduce the energy consumption and other negative environmental impacts of products. While the Directive's primary aim is to reduce energy use, it is also aimed at enforcing other environmental considerations including: materials use; water use; polluting emissions; waste issues and recyclability.
The Ecodesign Directive is a framework directive, meaning that it does not directly set minimum ecological requirements. These are adopted through specific implementing measures for each group of products in the scope of the Directive. The implementing measures are adopted through the so-called comitology procedure. Implementing measures are based on EU internal market rules governing which products may be placed on the market. Manufacturers who begin marketing an energy using product covered by an implementing measure in the EU area have to ensure that it conforms to the energy and environmental standards set out by the measure.
In practice, the introduction of a new minimum requirement results in effectively banning all non-compliant products from being sold in the EU.

The 2005 Ecodesign directive covered energy-using products, which use, generate, transfer or measure energy, including consumer goods such as boilers, water heaters, computers, televisions, and industrial products such as transformers. The implementing measures focus on those products which have a high potential for reducing greenhouse gas emissions at low cost, through reduced energy demand.
The first Working Plan of the Ecodesign Directive was adopted on 21 October 2008.
It establishes a list of 10 product groups to be considered in priority for implementing measures in 2009–2011:

- Air conditioning and ventilation systems, including air conditioning system pumps
- Electric and fossil-fuelled heating equipment
- Food-preparing equipment
- Industrial and laboratory furnaces and ovens
- Machine tools
- Network, data processing and data storing equipment

- Refrigerating and freezing equipment
- Sound and imaging equipment
- Transformers
- Water-using equipment

A7.1.2 Low Voltage Directive (LVD) 2014/35/EU

The first Low Voltage Directive (LVD) (Now 2014/35/EU) is one of the oldest Single Market Directives adopted by the European Union before the "New" or "Global" Approach. The Directive provides common broad objectives for safety regulations, so that electrical equipment approved by any EU member country will be acceptable for use in all other EU countries. The Low Voltage Directive does not supply any specific technical standards that must be met, instead relying on IEC technical standards to guide designers to produce safe products. Products that conform to the general principles of the Low Voltage Directive and the relevant particular safety standards are marked with the CE marking to indicate compliance and acceptance throughout the EU. Conformance is asserted by the manufacturer based on its conformity assessment.

The directive covers electrical equipment with a voltage at input or output terminals between 50 and 1000 V for alternating current (AC) or between 75 and 1500 V for direct current (DC). Importantly, it does not cover voltages within equipment The directive does not cover components (broadly, this refers to individual electronic components).
Certain classes of equipment, covered by other technical standards, are listed in Annex III of the Directive as excluded from its scope. These items include medical devices, electricity meters, railway or maritime equipment, and electrical plugs and sockets for domestic use.

In May 2016 it has not yet clarified definitively if a power transformer with a LV winding is to be considered or not in the scope of this Directive.

The Directive is implemented in European countries by national laws.

A7.1.3 EMC directive 2014/30/EU

On 20 April 2016, Directive 2004/108/EC is replaced with 2014/30/EU. The new Directive makes very little practical difference to the requirements or procedures which manufacturers must apply to products and is mainly intended to clarify the obligations of importers and distributors to bring the Directive into line with the other consumer product related directives.

In essence the requirements of the Directive are very simple - it basically states that products must not emit unwanted electromagnetic pollution (interference) and, because there is a certain amount of electromagnetic pollution in the environment, that products must be immune to a reasonable amount of interference. The Directive itself gives no figures or guidelines on what the required level of emissions or immunity are, nor does it state the frequency band limits. This interpretation of the Directive's requirements is left to the standards that are used to demonstrate compliance with the Directive.

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In addition to these essential protection requirements, the Directive requires the manufacturer to compile technical documentation which shows that the essential requirements have been met, to put the CE logo on the product and to complete a Declaration of Conformity. Manufacturers must also identify themselves on the equipment and ensure that, where necessary, instructions are supplied to ensure that the use of the equipment meets the essential protection requirements.

The Directive has a very wide application, but it's important to highlight that the scope includes only products "intended for the end user" meaning that products which are intended for incorporation into other products are not within the scope of the Directive, unless that incorporation is done by the end user.
With reference to power transformer subassemblies the application of the directive has never been definitively cleared.

In order to show that a product complies with the essential requirements, its manufacturer is required to complete an 'EMC assessment' which provides a record of a technical analysis justifying a manufacturer's claim of compliance.

Tests are an alternative to an assessment. Tests are not mandatory under the Directive but it can often be difficult to be sure of a product's EMC performance without them. Even where testing is useful, the tests can be performed by a manufacturer in house, they do not have to be performed by a Notified Body.

For the purposes of being able to test whether or not equipment complies with the Directive, tests are divided into five classes:

- Radiated emissions - Checks to ensure that the product does not emit unwanted radio signals;
- Conducted emissions - Checks to ensure the product does not send out unwanted signals along its supply connections and connections to any other apparatus;
- Radiated susceptibility - Checks that the product can withstand a typical level of radiated electromagnetic pollution;
- Conducted susceptibility - Checks that the product can withstand a typical level of noise on the power and other connections.
- Electrostatic discharge - Checks that the product is immune to a reasonable amount of static electricity.
- Other tests, such as mains harmonics and 'dips and flicker' can be considered as subsets of these five categories.

Definitions of the levels above which emissions are defined as unwanted or below which pollution and noise are accepted as being reasonable are contained in the relevant test standards. The manufacturer (and any test house performing tests on the equipment) must agree on which of the various standards for each category apply to the product in question. Since the different standards have different levels for emissions or immunity, it would theoretically be possible for the same product to be acceptable in one application but not in another - for instance noise emission levels acceptable in an industrial environment may be excessive when created in a domestic setting. In practice the scope of the different standards is fairly clearly defined, but even so it is important for manufacturers or importers of products to have a good idea of where they are intending their product to be used.

While the essence of the Directive is, of course, to ensure that products meet the essential protection requirements for immunity and emissions, the Directive also has certain administrative requirements. These are as follows:

Compile technical documentation - the manufacturer must produce a file of evidence which describes the product and how it is shown to comply with the Directive. This will typically include information on how to identify the equipment, a copy of the instructions, the EMC assessment, and any test data.

Control of production - although tests may be performed on a sample of the equipment, the Directive requires that all units produced comply with its requirements. The manufacturer will need appropriate quality control procedures accordingly.

Sign a Declaration of Conformity - the manufacturer must sign a document to identify the equipment and confirm the steps they have taken to comply with the Directive. This document is kept on file by the manufacturer - it does not need to be sent to any official body (although sometimes customers may ask to see it).

Put the CE logo on the product - it must be put on the equipment, or on its packaging or instructions.

Power transformer are out of the scope of this Directive but may incorporate devices in the scope of this Directive.

The Directive is implemented in European countries by national laws.

A7.1.4 EU Regulation n° 548/2014

On 21 May 2014, the European Commission adopted Regulation (EU) n° 548/2014 implementing Directive 2009/125/EC with regard to ecodesign requirements for small, medium and large power transformers.

It entered into force on 11 June 2014 and started applying from 1 July 2015.

Regulation (EU) n° 548/2014 applies to power transformers with a minimum power rating of 1 kVA used in 50 Hz electricity transmission and distribution networks or for industrial applications. Ecodesign requirements have been defined according to the types of transformers identified in the Regulation.

The specific ecodesign requirements apply in two phases: from 01/07/2015 and from 01/07/2021 as follow:

- Small power transformers: No specific ecodesign requirements.

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- Medium power transformers: Ecodesign requirements are related to maximum allowed load and no-load losses or to minimum Peak Efficiency Index (PEI) values depending on the type of medium power transformers.
- Large power transformers: Ecodesign requirements are related to the minimum PEI values only.

There are other types of transformers which are not covered by specific ecodesign requirements due to their specific function (see art. 1.2 of the Regulation). However, they are covered by information requirements.

Product Information requirements apply from 01/07/2015 as follow. Information requirements shall be included in any related product information, including manufacturers' free access website, and, in some cases, on the rating plate of power transformers.

In the Annex III the Regulation specifies the verification procedure.

When performing the market surveillance checks referred to in Article 3 of Directive 2009/125/EC, the authorities of the Member States shall apply the following verification procedure for the requirements set out in Annex I of the Regulation:

- *Member States authorities shall test one single unit per model;*
- *The model shall be considered to comply with the applicable requirements set out in Annex I of the Regulation if the values in the technical documentation comply with the requirements set out in Annex I, and if the measured parameters meet the requirements set out in Annex I within the verification tolerances indicated in the Table of this Annex;*
- *If the results referred to in point 2 are not achieved, the model shall be considered not to comply with this Regulation.*

The Member States authorities shall provide all relevant information, including the test results if applicable, to the authorities of the other Member States and the Commission within one month of the decision being taken on the non-compliance of the model. Member States authorities shall use the measurement methods and calculation methods set out in Annex II. Given the weight and size limitations in the transportation of medium and large power transformers, Member States authorities may decide to undertake the verification procedure at the premises of manufacturers, before they are put into service in their final destination. The verification tolerances set out in this

Measured parameter	Verification tolerances
Load losses	The measured value shall not be greater than the declared value by more than 5 %.
No load losses	The measured value shall not be greater than the declared value by more than 5 %.
The electrical power required by the cooling system for no load operation	The measured value shall not be greater than the declared value by more than 5 %

Annex relate only to the verification of the measured parameters by Member States authorities and shall not be used by the manufacturer or importer as an allowed tolerance to establish the values in the technical documentation.

Practical implementation measures of the verification procedure are specified in the relevant EN standards (see paragraphs A5.2.1 , A5.2.2 , A5.2.3).

No national legislative documents dealing directly with energy efficiency performances of power transformers have been found in this research.

A7.2 Legislation at USA level

DOE has established:

- regulations on distribution transformers in the CFR (Code of Federal Regulation) at 10 CFR Part 431. These regulations cover energy conservation standards and test procedure for distribution transformers
- regulations on certification, compliance, and enforcement in the 10 CFR Part 429. These regulations cover statistical sampling plans, certified ratings, certification reports, record retention, and enforcement.

The US mandatory DOE regulation on distribution transformers covers both liquid-filled and dry-type units, single-phase and three-phase rated with a 60Hz frequency and a primary voltage of 34 500 V or less. The power ratings are from 10 to 2500 kVA for liquid-immersed units and 15 to 2500 kVA for dry-type units.

A7.2.1 DOE 78 FR 23335

DOE 78 FR 23335 is the rule published by DOE on April 18, 2013 prescribing the energy conservation standards for distribution transformers as defined in CFR 431.192.

Distribution transformers manufactured and distributed in commerce, as defined by 42 U.S.C. 6291(16), must meet the energy conservation standards specified in the Code of Federal Regulations at 10 CFR 431.196.

DOE has not exempted any state from this energy conservation standard. States may petition DOE to exempt a state regulation from preemption by the Federal energy conservation standard. States may also petition DOE to withdraw such exemptions. For details, see 10 CFR part 431, subpart V or subpart W.

A7.2.2 CFR Title 10: Energy Subpart K - Distribution Transformers

A7.2.2.1 10 CFR Part 431

The code contents cover:

- Purpose and scope (431.191)

- Definitions (431.192)
- Test procedures for measuring energy consumption of distribution transformers (431.193)
- Energy conservation standards and their effective dates (431.196)
- Uniform Test Method for Measuring the Energy Consumption of Distribution Transformers (Appendix A)

This code defines a distribution transformer as a transformer that:

1. has an input voltage of 34.5 kV or less
2. has an output voltage of 600 V or less
3. is rated for operation at a frequency of 60 Hz
4. has a capacity of 10 kVA to 2500 kVA for liquid-immersed units and 15 kVA to 2500 kVA for dry-type units.

The term “distribution transformer” does not include a transformer that is an:

- autotransformer
- drive (isolation) transformer
- grounding transformer
- machine-tool (control) transformer
- nonventilated transformer
- rectifier transformer
- regulating transformer
- sealed transformer
- special-impedance transformer
- testing transformer
- transformer with tap range of 20 percent or more
- uninterruptible power supply transformer; or welding transformer.

The code specifies the meaning of “basic model” as a group of models of distribution transformers manufactured by a single manufacturer, that have the same insulation type (i.e., liquid-immersed or dry-type), have the same number of phases (i.e., single or three), have the same standard kVA rating, and do not have any differentiating electrical, physical or functional features that affect energy consumption. Differences in voltage and differences in basic impulse insulation level (BIL) rating are examples of differentiating electrical features that affect energy consumption.

MEPS are specified in terms of minimum efficiency values are at 50 percent of nameplate rated load, determined according to the DOE Test Method for Measuring the Energy Consumption specified in 431.193 and hereunder summarized for the scope of this report.

The efficiency of a transformer is computed from the total transformer losses, which are determined from the measured value of the no-load loss and load loss power components. Each of these two power loss components is measured separately using test sets that are identical, except that shorting straps are added for the load-loss test. The measured quantities will need correction for instrumentation losses and may need corrections for known phase angle errors in measuring equipment and for the waveform distortion in the test voltage. Any power loss not measured at the applicable reference temperature must be adjusted to that reference temperature. The measured load loss must also be adjusted to a specified output loading level if not measured at the specified output loading level. Test distribution transformers designed for harmonic currents using a sinusoidal waveform (k = 1).

The same test set may be used for both the no-load loss and load loss measurements provided the range of the test set encompasses the test requirements of both tests. Calibrate the test set to national standards to meet the tolerances in Table 2.1 in section 2.0 (reproduced hereunder for convenience).
In addition, the wattmeter, current measuring system and voltage measuring system must be calibrated separately if the overall test set calibration is outside the tolerance as specified in section 2.0 or the individual phase angle error exceeds the values specified in section 4.5.3.

A test set based on the wattmeter-voltmeter-ammeter principle may be used to measure the power loss and the applied voltage and current of a transformer where the transformer's test current and voltage are within the measurement capability of the measuring instruments. Current and voltage transformers, known collectively as instrument transformers, or other scaling devices such as resistive or capacitive dividers for voltage, may be used in the above circumstance, and must be used together with instruments to measure current, voltage, or power where the current or voltage of the transformer under test exceeds the measurement capability of such instruments. Thus, a test set may include a combination of measuring instruments and instrument transformers (or other scaling devices), so long as the current or voltage of the transformer under test does not exceed the measurement capability of any of the instruments.

In measured and calculated data, retain enough significant figures to provide at least 1 percent resolution in power loss data and 0.01 percent resolution in efficiency data.

Accuracy requirements specified by this code are the following ones.

2.0 Accuracy requirements
Equipment and methods for loss measurement shall be sufficiently accurate that measurement error will be limited to the values shown in Table 2.1.

TABLE 2.1—TEST SYSTEM ACCURACY REQUIREMENTS FOR EACH MEASURED QUANTITY

Measured quantity	***Test system accuracy***
Power Losses	*±3.0%*
Voltage	*±0.5%*
Current	*±0.5%*
Resistance	*±0.5%*
Temperature	*±1.0 °C*

Only instrument transformers meeting the 0.3 metering accuracy class, or better, may be used under this test method.

[…]

6.0 Test Equipment Calibration and Certification
Maintain and calibrate test equipment and measuring instruments, maintain calibration records, and perform other test and measurement quality assurance procedures according to the following sections. The calibration of the test set must confirm the accuracy of the test set to that specified in section 2.0, Table 2.1.

6.1 Test Equipment
The party performing the tests shall control, calibrate and maintain measuring and test equipment, whether or not it owns the equipment, has the equipment on loan, or the equipment is provided by another party. Equipment shall be used in a manner which assures that measurement uncertainty is known and is consistent with the required measurement capability.

6.2 Calibration and Certification.
The party performing the tests must:

- *(a) Identify the measurements to be made, the accuracy required (section 2.0) and select the appropriate measurement and test equipment;*
- *(b) At prescribed intervals, or prior to use, identify, check and calibrate, if needed, all measuring and test equipment systems or devices that affect test accuracy, against certified equipment having a known valid relationship to nationally recognized standards; where no such standards exist, the basis used for calibration must be documented;*
- *(c) Establish, document and maintain calibration procedures, including details of equipment type, identification number, location, frequency of checks, check method, acceptance criteria and action to be taken when results are unsatisfactory;*
- *(d) Ensure that the measuring and test equipment is capable of the accuracy and precision necessary, taking into account the voltage, current and power factor of the transformer under test;*
- *(e) Identify measuring and test equipment with a suitable indicator or approved identification record to show the calibration status;*
- *(f) Maintain calibration records for measuring and test equipment;*
- *(g) Assess and document the validity of previous test results when measuring and test equipment is found to be out of calibration;*
- *(h) Ensure that the environmental conditions are suitable for the calibrations, measurements and tests being carried out;*
- *(i) Ensure that the handling, preservation and storage of measuring and test equipment is such that the accuracy and fitness for use is maintained; and*
- *(j) Safeguard measuring and test facilities, including both test hardware and test software, from adjustments which would invalidate the calibration setting.*

A7.2.2.2 10 CFR Part 429

This part sets forth the procedures to be followed for certification, determination and enforcement of compliance of covered products and covered equipment with the applicable conservation standards set forth in parts 430 and 431 of CFR Title 10: Energy Subpart K.

A7.2.2.3 CCMS

DOE has also created Compliance Certification Management System (CCMS). This is a uniform database for all products where manufacturers can publish their product data which also works as "self-certification" of their models (see link below). This tool can also help user find out what products and efficiencies are available from which supplier in the market place. As you can see it works for standardized "consumer" products but not much useful to user in case of transformers.

https://www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*

A7.3 Legislation at other country level

A7.3.1 Australia and New Zealand

Australia and New Zealand operate a joint energy efficiency standards and energy rating labelling program called the Equipment Energy Efficiency (E3) programme. The two countries adopt identical energy efficiency requirements, as closely as possible, to facilitate the free flow of trade as agreed under the Trans-Tasman Mutual Recognition Agreement (TTMRA).

The Equipment Energy Efficiency (E3) program is a cross jurisdictional program through which the Australian Government, states and territories and the New Zealand Government collaborate to deliver a single, integrated program on energy efficiency standards and energy labelling for equipment and appliances.

It is one of a number of programs implemented by the Council of Australian Governments' (COAG's) Energy Council. An Inter-Governmental Agreement provides the framework for national cooperation on the E3 Program. A similar arrangement has also been developed to ensure alignment with New Zealand.

On 1 October 2012, the Greenhouse and Energy Minimum Standards (GEMS) Act 2012 came into effect, creating a national framework for product energy efficiency in Australia. The GEMS Act is the underpinning legislation for the program.

The GEMS Regulator, based in the Commonwealth Department of Industry, Innovation and Science, replaced the previous state regulators and is the sole party responsible for administering the legislation in Australia.

In New Zealand, the Energy Efficiency (Energy Using Products) Regulations 2002 have a similar role and are administered by the Energy Efficiency and Conservation Authority (EECA).

The program objectives are the following ones:

- To reduce energy bills for households and businesses in a cost effective way by driving improvements to the energy efficiency of new appliances and equipment sold;
- To improve the energy efficiency of new appliances and equipment that use energy and to also improve the energy performance of products that have an impact on energy consumption; and

- To reduce appliance and equipment related greenhouse gas emissions through a process which complements other actions by jurisdictions.

Since 2004, Australia and New Zealand established a mandatory minimum energy performance standards (MEPS) for distribution transformers that fall within the scope of Australian Standard AS2374.1.2.

Transformers are also required to carry a marking on their rating plate noting their compliance.

A7.3.2 Brazil

For liquid-filled, Brazil is proposing a mandatory minimum energy performance requirement through an energy labelling programme for distribution transformers. (Inter-Ministerial Directive 104/2013, from The Minister of Mines and Energy). Brazil is proposing to establish MEPS for single-phase transformers from 5 to 100 kVA, and with voltage classes of 15 kV, 24.2 kV and 36.2 kV and three-phase liquid-filled transformers from 15 to 300 kVA, and with the same three voltage classes.
Brazil is looking at adopting a mandatory minimum energy performance standard to be supported by a labelling programme which must be formatted in a specific way and applied to all transformers where it will be visible to the user. The objective of this work is to establish a maximum acceptable level of loss and encourage the specification and purchasing of more energy-efficient liquid-filled distribution transformers, new and reconditioned, through the national energy conservation label (ENCE), in compliance with Brazilian national law No 10.295/2001, concerning the National Policy for the conservation and rational use of energy.
The labelling programme for distribution transformers includes the manufacturer, model, type, kVA rating and voltage class. The label then calls for the watts of losses at no load, total watts of loss at full load, temperature rise and BIL (Basic-Impulse Insulation Level) of the transformer at both the nominal tap and the ‘critical’ tap meaning the one furthest from the nominal.

A7.3.3 Canada

The Office of Energy Efficiency at Natural Resources Canada (NRCan) adopted:

- a mandatory minimum energy performance standards for dry-type distribution transformers, published in the Canada Gazette, Part II in 2011 and the amendment came into effect six months later on April 12, 2012.
- a voluntary program for liquid immersed distribution transformers in lieu of mandatory efficiency performance standards (MEPS).

Please note that an update to the regulation for dry-type transformers is proposed for amendment 14 in spring of 2017 http://www.nrcan.gc.ca/energy/regulations-codes-standards/18318

A7.3.4 China

The Chinese energy performance regulation of power transformers is based on mandatory GB standards for power transformers – both liquid-filled and dry-type (see Section A5.4.8).

A7.3.5 India

On 5 January 2010, by DT Notification/Gazette (Schedule 4 - Distribution Transformer), India adopted a mandatory labelling scheme for specific types of liquid-filled, naturally air-cooled, three-phase distribution transformers.
The energy labelling applies to oil immersed, naturally air cooled, three phase, and double wound non-sealed type outdoor distribution transformers up to 200 kVA, 11 kV specifications.
These are the units referred to under Indian Standard IS 1180 (part I) and more specifically, the standard ratings covered under the energy labelling scheme are 16, 25, 63, 100, 160 and 200 kVA.

Since 20 August 2010, installation of energy-efficient 3-Star rated distribution transformers is required by the Indian Government. Notification issued by the Government of India vide No:2/11/(5)/03-BEE-3, Dtd: 05.03.2010 and the Central Electricity Authority Notification No: CEA/TETD/MP/R/01/2010 dt: 20.08.2010 under section 177 of Electricity Act 2003 on the procurement of Star Rated Energy Efficient Distribution Transformer.

A7.3.6 Israel

Israel has adopted national minimum efficiency regulations for distribution transformers, covering both efficiency requirements and labelling.
The regulations refer to national standard is Israeli Standard (IS) 5484, Distribution transformers - energy efficiency requirements and marking, and it applies to distribution transformers with nominal input voltage of 22kV or 33kV and a nominal output voltage of 400V, with power ratings up to 2500 kVA.

A7.3.7 Japan

In Japan distribution transformer energy performance is covered by the general “Top Runner” efficiency scheme for electrical appliances and equipment: Japan, “The Top Runner Program – Japan’s Approach to Energy Efficiency and Conservation Measures”,2004, www.eccj.or.jp/top_runner/index.html

Under the Top Runner scheme the listed efficiency levels are not mandatory but are set at very high levels with the aim being to provide a targeted level that can be used to encourage manufacturers into striving continually to improve efficiency.
The Top Runner transformer efficiency levels are not given as specific efficiency values or maximum watts of loss, but are determined from aggregate core and coil losses derived from an empirical equation based on the transformer rating at a specific loading point.

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Japanese Top Runner applies to both 50 and 60 Hz units (there are both types of electrical distribution systems in Japan), and the requirements are divided into single-phase (rated between 5 and 500 kVA) and three-phase (rated between 10 and 2000 kVA).

Two types of labels are used one to indicate the target has not been achieved and one to indicate it has been achieved.

A7.3.8 Korea

In July 2012, Korea adopted mandatory minimum energy performance requirements and labelling requirement for liquid-filled and dry-type distribution transformers.
The adopted energy performance metric is efficiency of the transformer is measured at 50% load, in accordance with Korean National Standards: KS C4306, KS C4311, KS C4316 and KS C4317.

A7.3.9 Mexico

Mexico adopted mandatory minimum energy performance requirements only for liquid-filled distribution transformers and not for dry-type.
NOM-002 was published in Mexico’s Diario Oficial de la Federación (Official Registry) for public law and it was enacted in July 2014.

A7.3.10 Vietnam

Vietnam has a national programme promoting energy efficiency across a range of appliances and equipment. Some aspects of the programme are mandatory and others are voluntary. Distribution transformers are included in the programme, establishing minimum efficiency levels that were published in 2011 and became mandatory in 2013.
The methods of energy efficiency measurement for their performance scheme are detailed in the Vietnamese National Standard,
Vietnam’s programme applies to liquid-filled, three-phase, 50Hz liquid filled with a nominal capacity from 25 kVA to 2500 kVA and nominal voltage up to 35 kV.
Regarding to new National standard of MEPS (TCVN 8525:2015), it is mandatory to both liquid-filled and dry type, 3-phase. The capacity range is up to 4000kVA (see TCVN 8525:2015)

A7.4 Comparison among different MEPS

Comparing different MEPS based on different performance indexes is sometimes impossible mainly because of different:

- Rated power definition
- Reference temperature
- Rated frequency
- Rated maximum voltages of the equipment
- Rated power definition

In EN standards, transformer rated power represents the rated input to the transformer while for instance in IEEE standards the rated power is defined as the transformer output power. This affects transformer energy performances definition (See Section A3.5.2):

$$EfficiencyEN = \frac{(Power_{input} - Losses)}{Power_{input}} \qquad \mathrm{Efficiency}_{\mathrm{IEEE}} = \frac{\mathrm{Power}_{\mathrm{output}}}{(\mathrm{Power}_{\mathrm{output}} + \mathrm{Losses})}$$

Where “Losses” represents the sum of load and no load losses. Although the two equations seem to give the same numerical results, in reality they are important underlying differences (Table 1).

- Transformers with the same losses specified according to EN or IEEE practices can be considered to have the same efficiency only as long as the rated power definition is consistent (i.e. based on the same power, either input or output).
- Transformers with the same rated power (because of standardization of the series) and the same efficiency specified according to EN or IEEE practices do not have the same total losses, being the total losses of the transformer specified according to IEEE larger than the ones specified according to EN.

Although the first point above is quite apparent, in the practice it is not considered, since both EN and IEEE refer to the same numerical values of rated powers in their series. Similarly, also loss values defined according to IEEE standards cannot be compared directly with the same figures specified to EN standards, because they are actually referring to different rated powers.

A7.4.1 Reference temperature

The EU Regulation for ecodesign specifies a reference temperature of 75°C for load losses of liquid immersed transformers. US DOE refers instead to 55°C, while in IEEE standards 85°C are used. This is a remarkable difference, since an increase of few degrees in the reference temperature corresponds to several percentage points higher load losses.

Table 15 - Comparison between EN and IEEE efficiency definition (same losses)

Method	EN	IEEE
Rated power	50 kVA	48.6 kVA
No load losses	0.190 kW	0.190 kW
Load Losses	1.250 kW	1.250 kW
Eff. equation	(50 – (0.190 + 1.250))/50	48,6 / (48.6 + (0.190 + 1.250)
Efficiency (%)	97.12%	97.12%

Table 16 - Comparison between EN and IEEE efficiency definition (same rated power and efficiency).

Method	EN	IEEE
Rated power	50 kVA	
Efficiency (%)	97.12%	
Eff. equation	(50 – TL)/50	50 / (50 + TL)
No load losses + Load Losses (TL)	1.440 kW	1.482 kW

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A7.4.2 Rated frequency

The energy performance of power transformers is not the same when operated on electricity systems with different rated frequencies (50 Hz or 60 Hz). The following general facts can be observed.

- At lower frequencies, more core material (and conductor material consequently) is needed, making the transformer larger and more expensive.
- At higher frequencies, both the no load and load losses feature higher eddy current losses.

Comparing the performance of transformers operating at different frequencies may require finding suitable conversion factors. However, since this is not so straight-forward, from a practical point of view it makes more sense to take note of the energy performances of each transformer at its specific operating conditions.

In general it can be said that simply no-load losses in Europe will be lower for the same transformer operating at 60 Hz frequency

A7.4.3 Rated maximum voltages of the equipment

The energy performance of medium power transformers is not the same when operated on electricity systems with different rated voltages. Other conditions being equal:

- the lower the rated voltage of the LV winding / the higher the expected losses / the larger the quantity conductor material.
- The higher the rated voltage of the MV winding / the higher the expected losses.

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A8. Conclusions

The research carried out for the Power transformer product group (Group A) in the Task 2.1 „Worldwide and EU Technical standard and legislative framework into the WP2 - Landscape of testing avenues“ of the INTAS project shows that in the EU and in the major surveyed economies the main standards and legislative tools to help MSA in testing power transformers are available. Important background differences are evidenced in terms of:

- adopted energy performance indexes
- basics concepts/quantities assumed by the reference standards:
    - Rated power definition
    - Reference temperature
    - Rated frequency
    - Rated maximum voltages of the equipment

In reference to the EU, some key aspects need further development in standardisation and regulation:

- Exception formalisation (how to manage possible exemptions)
- Which/how data shall be made public and how in the perspective of MSA
- Declared value definition confirmation
- Measurement uncertainty mandatory limits
- Very low power factor loss measurements
- Repaired transformer definition
- Dual voltage transformer definition
- Cooling consumption treatement
- Declaration of conformity standardized template

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A9. Database

Annexed to this report is the data base of the documents considered. The database is an Excel spreadsheet with the following fields and meanings.

A9.1 Relevance

This field contains the relevance of the record with the INTAS scope.

0. The document is focused on power transformers no relevance with the scope of this report
1. The document is focused on power transformers but it has a low relevance with the scope of this report
2. The document is focused on power transformers and it has a low relevance with the scope of this report
3. The document is important for the scope of this report

A9.2 Mandatory

This field records if the document is mandatory or not.

YES – The document is mandatory
NO – The document is not mandatory

A9.3 Type

This field records the type of the document:

- Standard
- Technical report
- Legislative document

A9.4 Country

This field records the geographical scope of the document:

- Australia and New Zealand
- Brazil
- Canada
- China

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- Europe
- European Union
- India
- Israel
- International
- Japan
- Korea
- Mexico
- United States of America
- Vietnam

A9.5 Organisation

This field records the name of the issuing organisation of the document.

A9.6 Organisation code

This field records the code of the issuing organisation of the document.

A9.7 Reference

This field records the code of the document.

A9.8 Title

This field records the title of the document.

A9.9 Original Title

This field records the original title of the document.

A9.10 Function

This field records the function of power transformers covered by the document.

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A9.11 Insulation

This field records the type of insulation of power transformers covered by the document.

- Dry type
- Liquid immersed
- Oil
- Gas
- More than one of the previous categories

A9.12 Voltage

This field records the range of rated voltages of transformers covered by the document.

A9.13 Power

This field records the range of rated power of transformers covered by the document.

A9.14 Frequency

This field records the type of rated frequency of power transformers covered by the document.

A9.15 Phases

This field records the number of phases of power transformers covered by the document.

A9.16 Windings

This field records the number of windings of power transformers covered by the document.

A9.17 IEC/EN/IEEE like

This field records if the document is coherent with IEC/EN/IEEE practices or not.

- Identical – the document is identical to the corresponding IEC/EN/IEEE one
- With deviations – the document is similar to the corresponding IEC/EN/IEEE one but with some deviations
- It is – the document is IEC/EN/IEEE
- Aligned – the document is covering something not addressed in the IEC/EN/IEEE documents but it coherent with IEC/EN/IEEE approach

A9.18 Test

This field records if the document deals with power transformer tests or not.

PTT - The document deals with power transformer tests
EPT- The document deals with energy performance tests for power transformer
NO - The document does not deal with power transformer tests

A9.19 MEPS

This field records if the document contains power transformer MEPS or not.

YES - The document contains power transformer MEPS
NO - The document does not contain power transformer MEPS

A9.20 MEPS type

This field records the type of MEPS adopted by the document.

- LXX – Maximum Losses at XX% of load
- EXX – Minimum efficiency at XX% of load
- PEI – Peak Efficiency Index

A9.21 Label

This field records if the document contains power transformer labelling system or not.

YES - The document contains power transformer a labelling system
NO - The document does not contain power transformer a labelling system

A9.22 Link

This field contains the internet link to the document.

A9.23 Notes

This field contains additional notes about the document.

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More information
about the INTAS project activities
and all of its results
are published on:

www.INTAS-testing.eu

Contact to the project coordinator:
Ingrid Weiss
Ingrid.Weiss [at] wip-munich.de

Contact to the WP leader:
Angelo Baggini
angelo.baggini [at] unibg.it

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