Power transformer energy performance: landscape of market surveillance testing avenues

Worldwide and EU Technical standard and legislative framework

Franco Bua – Annalisa Marra
Engineering Consulting and Design
ECD
Pavia, Italy
franco.bua@ecd.it – annalisa.marra@ecd.it

Angelo Baggini
Università degli Studi di Bergamo
Engineering Faculty
Dalmine (BG), Italy
angelo.baggini@unibg.it

***Abstract*— This paper reports the results of the research carried out by Power transformer Task 2.1 „Worldwide and EU Technical standard and legislative framework into the WP2 - Landscape of testing avenues" of the INTAS project.**

Keywords*— *power transformres, energy performances, testing, technical standards, regulations, market surveillance

I. INTRODUCTION

The energy performance of power transformers is currently being improved around the globe. In the EU alone, total losses from inefficiencies in 2008 amounted to 93.4 TWh per year, equivalent to almost 12% of the continent's residential electricity consumption. A regulation covering this group was adopted in May 2014. The cost-effective improvement potential through more efficient design has been estimated in about 16.2 TWh per year in 2025, which corresponds to 3.7 Mt of CO2 emissions, with a projected loss of (aggregate of the 10-20% expected loss through non-compliance) of 1.6-3.2 TWh. There is a need to strengthen the capacity of Market Surveillance Authorities (MSAs) to conduct Ecodesign related market surveillance activities with respect to new and pending industrial and tertiary sector products. Especially in the case of customised products which are unsuitable for testing in laboratories. The focus of the research is to support Market Surveillance Authorities (MSAs) in monitoring, verification, and enforcement in order to ensure compliance for very large industrial products, specifically transformers and industrial fans, with the requirements of the Eco-design Directive. This paper discusses critically the technical boundaries, the existing energy performance metrics, the standardized measurement methods and provides a comparison highlighting issues and criticalities. The paper 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.

II. STANDARDIZED MEASUREMENTS METHODS

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

TABLE I. 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

A. *EN test methods*

EN test methods including measurement uncertainty evaluation methods are identical to the IEC ones except for the some additional prescriptions (taken from EN 50588-1 and EN 50629). Tolerances for factories acceptances tests and for Market surveillance, Transformers subject to maximum losses, Transformers subject to minimum PEI shall be in accordance with the COMMISSION REGULATION (EU) No 548/2014 of 21 May 2014. Uncertainties for market surveillance verification expressed by expanded uncertainty, as defined in IEC 60076 - 19 and referring to a coverage factor k = 2 (i.e. to a confidence level of about 95 % assuming a normal distribution) should not exceed 5 %.

B. *IEEE test methods*

With reference to the international standard method for measurement of transformer losses described in IEC documents, the IEEE method differs in many aspects.

C. *EN and IEEE test methods comparison*

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.

TABLE II. COMPARISON EN AND IEEE FOR GENERAL TEST CONDITIONS

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

2) Measurement of Load Losses

Between the EN 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 EN calls for a reference temperature of 75°C 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 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. EN, on the other hand, requires the resistance test to be a "routine test", 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. EN 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 must not exceed the specified values by more than 6%. Thus, the IEEE tolerance is tighter than EN.

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 EN 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 EN 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 III. COMPARISON EN AND IEEE FOR GENERAL TEST CONDITIONS

Aspect	EN 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°C8 (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; Rr is the winding resistance at the reference temperature; and Par 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	EN standards: no tolerances at factory tests, 5% at verification tests IEC 60076-1: +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%

Aspect	EN 60076-1 (2011)	IEEE C57.12.00-2010
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. Direct current must be used for the measuremen	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.

3) *Measurement of No-Load Losses*

Between the EN 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 EN 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 EN 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 EN 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, EN 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 IV. COMPARISON EN AND IEEE FOR MEASUREMENT OF NO-LOAD LOSSES

Aspect	EN 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 temperature6	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: P0 = Pm (1+d) where the measured no-load loss is Pm 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 = (r.m.s. voltage / average voltage)^2 T_m 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 (Sec. 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. (Sec. 8.3 of C57.12.90:2006)
Loss Tolerances	EN standards: no tolerances at factory tests, 5% at verification tests IEC 60076-1: +15 % for no-load loss, provided that the total losses does not exceed +10 % (section 10)	No load losses shall not exceed specified values by 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.

D. *National test methods*

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.

2) Brazil

The test method appears to be consistent with the approach followed in IEC 60076-1.

3) Canada

The test method 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”.

4) China

The test standard for measuring the efficiency of the transformer is the family of GB 1094 national standards, which are harmonised with IEC 60076.

5) European Union

The test method is the one stated in the discussed EN standards.

6) India

The testing code and procedure for the distribution transformers would be as per the Indian Standard (IS) 1180 (part 1): 1989 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):1989 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. For testing transformers, India is harmonised with IEC 60076.

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.

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.

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.).

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. Section, 6.2.1 Calculation of the efficiency 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. This method is consistent with the IEEE equation approach.

11) United States of America

The test method is the one stated in the discussed IEEE standards.

12) Vietnam

Vietnam measurement methods are based on IEC 60076.

E. 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 and other country level. 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.

TABLE V. COMPARISON AMONG LEGISLATIVE DOCUMENTS (MAY 2016).

Country Standard / Regulation	Transformers	Indicative Requirements
Australia / New Zealand AS2374.1.2-2003	1 phase: 10-50 kVA 3 phase: 25-2500 kVA Voltage: 11 and 22 kV	Min Efficiency at 50% load
Brazil ABNT NBR 5356	1 phase: 5 to 100 kVA 3 phase: 15 to 300	Max L and NL losses at 100% load

Country Standard / Regulation	Transformers	Indicative Requirements
	kVA Voltage: 15, 24.2 & 36.2kV	
Canada CSA C802.1	1 phase: 10-833 kVA 3 phase: 15-3000 kVA	Min Efficiency at 50% load
China JB/T 10317-02 GB 20052-2013	1 phase: 5-160 kVA 3 phase: 30-1600 kVA	Max L and NL losses at 100% load
European Union EU 548/14	1 and 3 phase: >1,1 kV > 1 kVA	Max L and NL losses at 100% load
India IS 1180	3 phase: 16-200 kVA for labelling	Max losses at 50% and 100% loading
Israel IS 5484	100-2500 kVA Voltage: 22kV or 33kV	Max losses 100%
Japan Top Runner	1 phase: 5-500 kVA 3 phase: 10-2000 kVA both 50 and 60 Hz	<500 kVA: 40% >500 kVA: 50%
Korea KS C4306; C4316and C4317	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	Min Efficiency at 50% load
Mexico	1 phase: 5-167 kVA 3 phase: 15-500 kVA Voltage: 15, 25 and 34.5 kV	Min Efficiency at 50% load
USA	1 phase: 10-833 kVA 3 phase: 15-2500	Min Efficiency at 50% load
Vietnam	25-2500 kVA, 0.4-35kV	Min Efficiency

III. CONCLUSIONS

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

$$\text{Efficiency}\,\text{EN} = \frac{(\text{Power}_{\text{input}} \quad \text{Losses})}{\text{Power}_{\text{input}}} \qquad \text{Efficiency}_{\text{IEEE}} = \frac{\text{Power}_{\text{output}}}{(\text{Power}_{\text{output}} + \text{Losses})} \tag{1}$$

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. 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. 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 VI. COMPARISON BETWEEN EN AND IEEE EFFICIENCY DEFINITION (SAME LOSSES) CONDITIONS

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	50 / (48.6 + (0.190 + 1.250)
Efficiency (%)	97.12%	97.12%

TABLE VII. 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

The energy performance of power transformers is not the same when operated on electricity systems with different rated frequencies (50 Hz or 60 Hz). Some 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. 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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V. REFERENCES

[1] AS 2374.1.2 - 2003 "Power Transformers Part 1.2: Minimum Energy Performance Standard (MEPS) requirements for distribution transformers (Australia / New Zealand)"

[2] AS 2374.1.2 Amdt1 - 2005 Power Transformers Part 1.2: Minimum Energy Performance Standard (MEPS) requirements for distribution transformers (Australia / New Zealand)

[3] ABNT NBR 5356-1 - 2012 Power transformers - Part 1: General (Brazil)

[4] CSA C802.1 - 2000 Minimum efficiency values for liquid-filled distribution transformers (Canada)

[5] CSA C802.2-12 - 2012 Minimum efficiency values for drytype distribution transformers (Canada)

[6] JB/T 10317-02 and GB 20052 - 2013 (China)

[7] IS 1180 Part 1 - Outdoor type oil immersed distribution transformers up to and including 2500 kVA 33kV (India)

[8] IS 5484 - Distribution transformers - energy efficiency requirements and marking (Israel)

[9] JIS C4304 - 2005 6 kV liquid-filled distribution transformers (Japan)

[10] JIS C4306 - 2005 (6 kV encapsulated-winding distribution transformers (Japan)

[11] KS C4306 - Single high voltage cover bushing transformers (Korea)

[12] KS C4316 - Tow bushing type pole transformer for 22.9 kV (Korea)

[13] KS C4317 - Distribution transformers not more than 3MVA for 22.9kV (Korea)

[14] NOM 002-SEDE - 2010 Safety requirements and energy efficiency for distribution transformers (Mexico)

[15] IEEE C57.12.90 - 2015 Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers (USA)

[16] IEEE C57.12.91 - 2011 Standard Test Code for Dry-Type Distribution and Power Transformers (USA)

[17] DOE 10 CFR 431 - ENERGY EFFICIENCY PROGRAM FOR CERTAIN COMMERCIAL AND INDUSTRIAL EQUIPMENT (USA)

[18] TCVN 8525 - 2010 Distribution transformers – minimum energy performance and method for determination of energy efficiency. (Vietnam)

[19] IEC EN 60076-1 - 2011 Power transformer - Part 1: Genera

[20] IEC EN 60076-11 - 2004 Power transformer - Part 11: Dry-type transformers

[21] IEC EN 60076-19 - 2013 Power transformer - Part 19: Rules for the determination of uncertainties in the measurement of losses in power transformers and reactors

[22] IEC 60076-20 - Power transformers - Part 20: Energy efficiency

[23] EN 50588-1 - 2015 Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV - Part 1: General requirements (Europe)

[24] EN 50629 - 2015 Energy performance of large power transformers (Um > 36 kV or Sr ≥ 40 MVA) (Europe)

[25] TCVN 6306-1 - 2006 Power transformers. Part 1: General (Vietnam)

[26] AS 2374.1. - 2003 Power Transformers Part 1: General (Australia / New Zealand)

[27] AS 2375 - Dry-type power transformers (Australia / New Zealand)

[28] GB 1094.1 - 1996 Power transformers--Part 1:General (China)

[29] GB 1094.11 - 2007 Power transformers - Part 11: Dry-type transformers (China)

[30] IS I2026: Part 1 - 2011 Power transformers: Part 1 General (India)

[31] IS I2026: Part 2 - 2010 Power transformers Part 2 Temperature-rise (India)

[32] KS C IEC 60076-1 - 2002.10.29 Power transformers－Part 1：General (Korea)

[33] KS C IEC 60076-11 - 2008.03.31 Power transformers－Part 11：Dry-type transformers (Korea)

[34] NMX J169-ANCE - 2004 Electrical Products – Distribution and Power Transformers and Autotransformers – Test Methods (Mexico)

[35] EC Directive 2009/125 - 2009 Directive framework for the setting of ecodesign requirements for energy-related products (European Union)

[36] EU Regulation 548/2014 - 2014 Regulation implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers (European Union)

[37] DOE 10 CFR 429 and DOE 78 FR 23335 and DOE 71 FR 24972 (USA)

[38] E3 - 2004 Equipment Energy Efficiency programme (Australia / New Zealand)

[39] Inter-Ministerial Directive 104/2013 - 2013 (Brazil)

[40] NRCan Canada Gazette April 12 2012 Part II - 2012 (Canada)

[41] GB 24790 - 2009 (China)

[42] DT Notification/Gazette (Schedule 4 - Distribution Transformer) 5 January 2010 - 2010 (India)

[43] No:2/11/(5)/03-BEE-3, Dtd: 05.03.2010 - 2010 (India) - 2013 Top Runner Program – Japan's Approach to Energy Efficiency and Conservation Measures (Japan)

[44] KS C4311 - Dry-type transformer (Korea)

[45] NEMA TP1 - 2002 Guide for Determining Energy Efficiency for Distribution Transformers (USA)

[46] NEMA TP2 - 2005 Standard Test Method for Measuring the Energy Consumption of Distribution Transformers (USA)

[47] IEEE C57.12.00 - 2015 IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (USA)

[48] ANSI C57.12.10 - 2010 IEEE Standard Requirements for Liquid-Immersed Power Transformers (USA)

[49] 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 (USA)

[50] 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) (USA)

[51] IEEE C57.12.01 - 2015 IEEE Standard for General Requirements for Dry-Type Distribution and Power Transformers (USA)