SEAD Distribution Transformers Report Part 4: Country Profiles

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SEAD Standards & Labelling Working Group
Distribution Transformers Collaboration

Part 4: Country Profiles for Internationally-Comparable Test Methods and Efficiency Class Definitions for Distribution Transformers

A reference document presenting all the country-level information on energy-efficiency programmes and test methods for distribution transformers globally.

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ABOUT SEAD

The Super-efficient Equipment and Appliance Deployment (SEAD) Initiative, a five-year, US$20 million initiative under the Clean Energy Ministerial (CEM) and the International Partnership for Energy Efficiency Cooperation (IPEEC), helps turn knowledge into action to accelerate the transition to a clean energy future through effective appliance and equipment energy efficiency programs. SEAD is a multilateral, voluntary effort among Australia, Brazil, Canada, the European Commission, France, Germany, India, Japan, South Korea, Sweden, the United Arab Emirates, the United Kingdom, and the United States. The Collaborative Labeling and Appliance Standards Program (CLASP), a non-profit organization with deep experience in supporting international appliance efficiency efforts, serves as the Operation Agent for SEAD. For more information about SEAD, please visit: www.superefficient.org.

COMMENTS

This report is one part of a four part study which taken together presents an overview of distribution transformer losses globally, the savings potential, the technology options for improvement, and a comparison of some of the efficiency programmes from around the world. The intended audience for this four part study includes policy makers and the technical advisors who work with them on designing and developing sustainable market transformation programmes. CLASP contracted N14 Energy Limited to prepare these reports, and Michael Scholand of N14 Energy would welcome any comments or suggestions relating to the report at the following email address (change the "[at]" to "@"):
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Acronyms and Abbreviations

AC	Alternating Current
BEE	Bureau of Energy Efficiency (India)
BIL	Basic Impulse Insulation Level
CEM	Clean Energy Ministerial
CENELEC	European Committee for Electrotechnical Standardisation
CFR	Code of Federal Regulations (United States)
CRGO	Cold Rolled Grain Oriented
CLASP	Collaborative Labeling and Appliance Standards Program
CNIS	China National Institute of Standardization
CO_2	Carbon Dioxide
CSA	Canadian Standards Association
DOE	Department of Energy (United States)
EC	European Commission
ECCJ	Energy Conservation Centre Japan
EECA	Energy Efficiency and Conservation Authority (New Zealand)
EU	European Union
HEPL	High Efficiency Performance Level
Hz	Hertz
IEC	International Electrotechnical Commission
kg	kilogram
kV	kilovolt (i.e., thousand volts)
kVA	kilovolt-ampere
kW	kilowatt
LCC	life-cycle cost
MEPS	Minimum Energy Performance Standards
MVA	megavolt-ampere
MWh	megawatt-hours
NEMA	National Electrical Manufacturers Association
Pk	load-dependent coil losses (winding losses)
Po	no-load losses in the core
R&D	Research and Development
SEEDT	Strategies for Energy Efficient Distribution Transformers
SWER	Single Wire Earth Return
TCO	Total Cost of Ownership
TOC	Total Ownership Cost
US	United States
W	Watts

Consistent Terminology

There are many different naming conventions in practice around the world for the types of distribution transformers and their losses. The table below provides some of the examples of terminology used in the various documents reviewed, and the equivalent terms that will be used in this report for simplicity and consistency.

Examples of Terminology Used	Term Used in this Report
Oil-filled, oil-immersed, liquid-immersed, liquid-filled	Liquid-filled
Dry-type, open ventilated, cast-coil, resin-coil, epoxy-coil, encapsulated-winding	Dry-type
Core losses, iron losses, no-load losses, steel losses	Core loss
Coil losses, copper losses, winding losses, load losses	Coil loss

In this report, the terms “European Union” and “Europe” may be used interchangeably, however the intention is always to represent the twenty-eight member states of the European Union and the three countries of the European Economic Area. Together, this group includes: Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom. For these countries, the European Commission is in the process of establishing a MEPS requirement that would apply to distribution transformers in the European Union and European Economic Area countries.

1 Summary of Country Transformer Programmes

This report provides an overview of the energy-efficiency policies and programmes and test methods used in each of the countries that were profiled as part of this analysis. The promotion of more energy efficient transformers is supported by a number of policy instruments and programmes around the world. Examples of these policy instruments include:

- Minimum Energy Performance Standards (MEPS)
- Voluntary or mandatory product labelling
- Financial incentives, subsidies and tax breaks
- Communication and outreach materials
- Tools including on-line calculators and smart-phone apps for buyers
- On-site metering and audits
- Technical support and advice on procurement
- Support for R&D and demonstration projects

Of these, minimum energy performance standards (MEPS) are one of the most powerful tools, as they require that entire markets shift to higher levels of performance. When applied correctly and supported with communications and outreach programmes and monitoring, verification and enforcement, MEPS change markets and ensure national benefits from cost-effective energy savings are realised.

This report provides information on the regulatory instruments in place in some of the leading countries in the world who are working to transform their markets to use more energy-efficient distribution transformers.

The tables in this section are presented with the values from their respective source documents. In some cases, the values are comparable, but in others, there are underlying differences that prevent direct comparisons. For example, transformers must operate at the frequency of the system where they are installed (i.e., 50Hz or 60Hz) and the efficiency of a transformer will vary with the frequency of the network. Furthermore, some regulators establish energy performance requirements for transformers on a basis of maximum losses for the core and coil at full load separately, while others establish maximum losses summed together for a particular kVA rating. Still other regulators specify the efficiency at a percentage loading point.

In addition, there are some slight but important differences between how the power rating of a transformer is reported in different markets. In countries applying IEEE standards (generally North America), the kVA power rating of the transformer is defined as the rated capacity at the output of the device – that is, it represents the available capacity at the load point. However, in other parts of the world employing IEC standards, the kVA rating represents the rated input to the transformer – how much power is being supplied to a particular unit.[1] When rated as the output (i.e., the IEEE method), the power rating *excludes* the core and coil losses when the transformer is operating, whereas for the input capacity (i.e., the IEC method), the power rating includes those losses. In essence, the total losses represent the difference between the two types of kVA ratings, as shown in the table below. For illustrative purposes, the losses associated with the European BoBk level for three different kVA ratings are shown.

Table 1-1. Illustrative Comparison of kVA Ratings at Full Load, IEC and IEEE

kVA_{IEC}	Core Loss (Bo, Watts)	Coil Loss (Bk, Watts)	kVA rating in Watts	kVA_{IEC}	KVA_{IEEE}	% Difference in kVA ratings
50	190	1250	50,000	50.0	48.6	2.9%
400	930	4900	400,000	400.0	394.2	1.5%
2000	3150	21,000	2,000,000	2000.0	1975.9	1.2%

For the purposes of the comparison in Chapter 5 of this report, we will convert the IEEE method to the IEC method, as the IEC test method is more common among the countries that are active on distribution transformer efficiency requirements. The method selected also has an impact on how losses are treated in the efficiency metric. Efficiency is, broadly speaking, a measurement of power out divided by power in. However, the way that efficiency is calculated differs between IEC and IEEE. This difference stems from how transformers are rated – that is, the power capacity of a transformer. In IEEE, the equation is based on output power whereas for the IEC, it is based on input power, as shown in the following equations:

$$IEEE/ANSI\ Definition\ Efficiency = \frac{Power\ Output}{(Power\ Output + Losses)}$$

$$IEC\ Definition\ Efficiency = \frac{(Power\ Input - Losses)}{(Power\ Input)}$$

Where:

Power Output and *Power Input* are measured in Watts and are calculated by multiplying the kVA rating of the transformer (IEEE or IEC method) by the per unit load (e.g., 50% of rated nameplate);

Losses represents the sum of core and coil losses at the per unit load point; where *core loss* is the power loss in the core at rated voltage and *coil losses* are the square of the per unit load times the coil losses at rated capacity.

[1] It should be noted that this is essentially the key difference between the International Electrotechnical Commission (IEC) and the Institute for Electrical and Electronics Engineers (IEEE) standards and it has an impact on how efficiency is calculated.

Per unit load is the decimal equivalent of the percentage of rated load supplied by the transformer, such as 0.35 for 35% or 0.50 for 50% of rated capacity.

There are, in addition, some stray losses that occur in the transformer tank due to eddy current loss, for example, but these are usually small compared to the core and coil losses.

In the following subsections about the various country programmes, there are a variety of performance metrics used. The country programmes are presented exactly as they are published for accuracy.

2 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).

In 2004, Australia and New Zealand established minimum energy performance standards (MEPS) for distribution transformers that fall within the scope of Australian Standard AS2374.1.2-2003. Transformers are also required to carry a marking on their rating plate noting their compliance.[2]

Table 2-1. Scopes of the Australian and New Zealand Distribution Transformer Scheme

Country / Economy	Scope
Australia and New Zealand: AS2374.1.2:2003/Amdt1-2005	The Australian Standard AS2374.1.2:2003/Amdt1-2005 scope covers: *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 installed on 11 and 22 kV networks.*

The efficiency levels adopted in 2004 are similar to the voluntary Canadian national standard for liquid-filled distribution transformers (CSA 802.1-2000). The Standard, AS2374.1.2:2003/Amdt1-2005, Power Transformers: Part 1.2: Minimum Energy Performance Standard (MEPS) Requirements for Distribution Transformers, was published in March 2003 and took effect on 1 October 2004. The standard provides tables of minimum efficiency levels, with two efficiency values for each rating – a minimum efficiency level and a high efficiency level. New transformers sold after the commencement of regulation must meet the minimum level. The high efficiency level allows the easy identification of high performing products. Transformer importers and manufacturers may promote and use voluntary high efficiency levels which are detailed in the standard.

A joint investigation is currently in the process of reviewing and potentially revising the requirements on distribution transformers, with a preliminary impact assessment report published in May 2011.[3] The current proposal makes two major changes to the scope of transformers that would fall under the regulation, as well as proposing increasing the stringency of existing performance requirements. Firstly, the upper limit of kVA rating would be increased from 2500 kVA to 3150 kVA. Secondly, the range of network voltages covered would be extended to include all voltages less than 36kV.

[2] AS2374.1.2:2003/Amdt1-2005 Power Transformers Part 1.2: Minimum energy performance standard (MEPS) requirements for distribution transformers, http://www.energyrating.gov.au/transformers1.html

[3] Equipment Energy Efficiency Program, Consultation Regulatory Impact Statement, Review of Minimum Energy Performance Standards for Distribution Transformers, Prepared for the Equipment Energy Efficiency Program, May 2011.

The following table presents the liquid-filled distribution transformer regulations adopted in 2004 ("Current MEPS") and the proposed new requirements which are under consideration ("MEPS2 (proposed)").

Table 2-2. Current and Proposed requirements for Australian and New Zealand Liquid-Filled Transformers

Liquid-filled 50 Hz	kVA rating	Percent Efficiency at 50% Loading	
		Current MEPS	MEPS2 (proposed)
Single phase (and SWER[4])	10	98.30	98.42
	16	98.52	98.64
	25	98.70	98.80
	50	98.90	99.00
Three phase	25	98.28	98.50
	63	98.62	98.82
	100	98.76	99.00
	200	98.94	99.11
	315	99.04	99.19
	500	99.13	99.26
	750	99.21	99.32
	1000	99.27	99.37
	1500	99.35	99.40
	2000	99.39	99.40
	2500	99.40	99.40
	3150	-	99.40

NOTE: For intermediate power ratings the power efficiency level shall be calculated by linear interpolation.

The table below presents the MEPS for dry-type transformers in Australia and New Zealand. The regulation applies to dry-type transformers with the high voltage winding (Um) of 12kV and 22kV. As part of the current review of transformers standards, it is proposed to add requirements for a higher voltage class, Um=36kV within the standard. The following table presents the dry-type transformer regulations that were adopted in 2004 ("Current MEPS") and the draft new requirements which are under consideration ("MEPS2 (proposed)").

[4] Single Wire Earth Return (SWER) or single wire ground return is a single-wire transmission line for supplying single-phase electrical power from an electrical grid to remote areas at low cost. Its distinguishing feature is that the earth (or sometimes a body of water) is used as the return path for the current, to avoid the need for a second wire (or neutral wire) to act as a return path.

Table 2-3. Current and Proposed Requirements for Australian and New Zealand Dry-Type Transformers

Dry-type 50 Hz	kVA	Efficiency at 50% Loading					
		Um=12kV		Um=24kV		Um=36kV	
		Current MEPS	MEPS2 (proposed)	Current MEPS	MEPS2 (proposed)	Current MEPS	MEPS2 (proposed)
Single phase (and SWER)	10	97.29	97.53	97.01	97.32	-	96.87
	16	97.60	98.83	97.27	97.55	-	97.11
	25	97.89	98.11	97.53	97.78	-	97.37
	50	98.31	98.50	97.91	98.10	-	97.74
Three phase	25	97.17	97.42	97.17	97.42	-	96.92
	63	97.78	98.01	97.78	98.01	-	97.30
	100	98.07	98.28	98.07	98.28	-	97.58
	200	98.46	98.64	98.42	98.60	-	98.26
	315	98.67	98.82	98.59	98.74	-	98.44
	500	98.84	98.97	98.74	98.87	-	98.62
	750	98.96	99.08	98.85	98.98	-	98.77
	1000	99.03	99.14	98.92	99.04	-	98.87
	1500	99.12	99.21	99.01	99.12	-	98.99
	2000	99.16	99.24	99.06	99.17	-	99.00
	2500	99.19	99.27	99.09	99.20	-	99.00
	3150	-	99.27	-	99.20	-	99.00

NOTE: For intermediate power ratings the power efficiency level shall be calculated by linear interpolation.

The following figure presents a comparison of the efficiency requirements (MEPS) that were adopted in Australia and New Zealand in 2004 and the levels proposed for adoption under the current review. These show the level of increase in efficiency improvement that is currently under consideration in Australia and New Zealand.

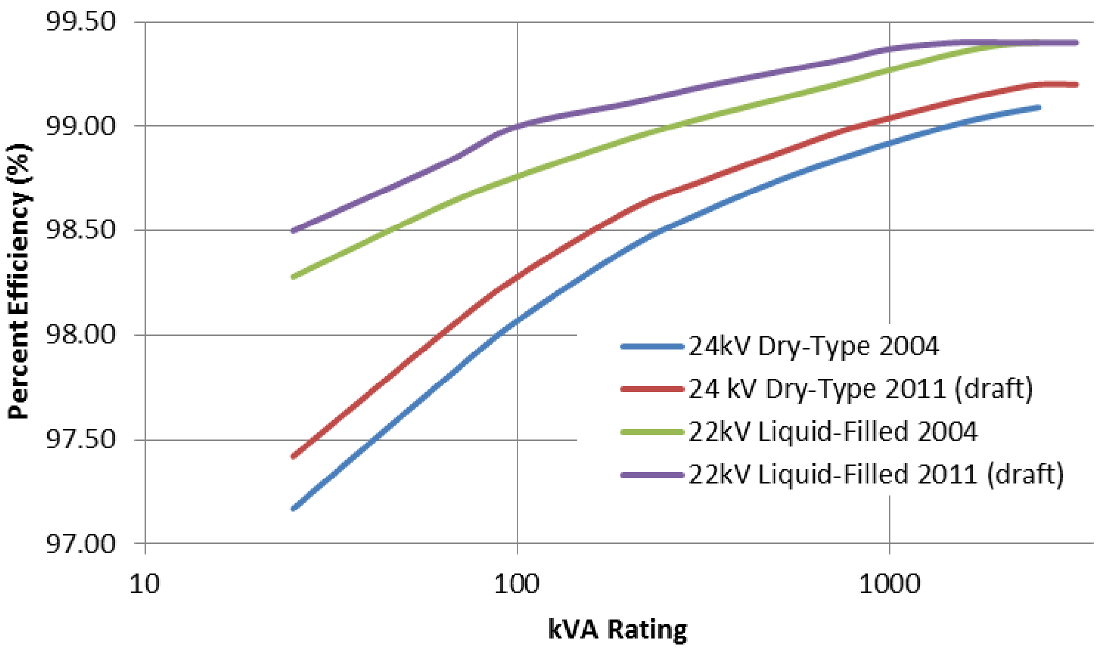

Figure 2-1. Comparison of Australian and New Zealand Requirements for Current and Proposed Requirements for Dry-Type Transformers

The Australia/New Zealand standard also include a table of high-efficiency levels for distribution transformers. These are voluntary 'high efficiency performance standards' (HEPS) in the literature, and in this report they are labelled 'high efficiency performance levels' (HEPL).

The 2004 regulation published HEPL for both liquid-filled and dry-type transformers, these are presented in the following two tables as the "Current HEPL". The HEPL are being revised in the regulatory process currently underway, and thus the following two tables also present "HEPL2 (proposed)" which represent the new high efficiency levels proposed in the review. The HEPL2 (proposed) levels were determined from a comparative assessment of international high efficiency tables for distribution transformers[5], which themselves are not mandatory requirements.

[5] EQUIPMENT ENERGY EFFICIENCY PROGRAM - CONSULTATION REGULATORY IMPACT STATEMENT; Review of Minimum Energy Performance Standards for Distribution Transformers; Prepared for the Equipment Energy Efficiency Program; May 2011.

Table 2-4. Current and Proposed Australian and New Zealand Voluntary High Efficiency Performance Levels for Liquid-Filled Transformers

Liquid-filled 50 Hz	kVA	Efficiency at 50% Loading	
		Current HEPL	HEPL2 (proposed)
Single phase (and SWER[6])	10	98.42	98.74
	16	98.64	98.83
	25	98.80	98.91
	50	99.00	99.10
Three phase	25	98.50	98.80
	63	98.82	98.94
	100	99.00	99.10
	200	99.11	99.26
	315	99.19	99.34
	500	99.26	99.42
	750	99.32	99.45
	1000	99.37	99.46
	1500	99.44	99.48
	2000	99.49	99.49
	2500	99.50	99.49
	3150	-	99.49

NOTE: For intermediate power ratings the power efficiency level shall be calculated by linear interpolation.

These HEPLs are plotted in the following figure, along with the MEPS levels (existing and proposed). This graph illustrates the fact that the draft MEPS levels proposed in 2011 are based on the 2004 HEPL, with a small change in the efficiency requirements for the largest kVA ratings. The only difference was at the very high end – for kVA ratings 2000 and 2500 – the HEPL from 2004 had shown efficiency ratings of 99.49% and 99.50% - however the 2011 MEPS proposal is 99.49% for these ratings and for the 3150 kVA rating.

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[6] Single Wire Earth Return (SWER) or single wire ground return is a single-wire transmission line for supplying single-phase electrical power from an electrical grid to remote areas at low cost. Its distinguishing feature is that the earth (or sometimes a body of water) is used as the return path for the current, to avoid the need for a second wire (or neutral wire) to act as a return path.

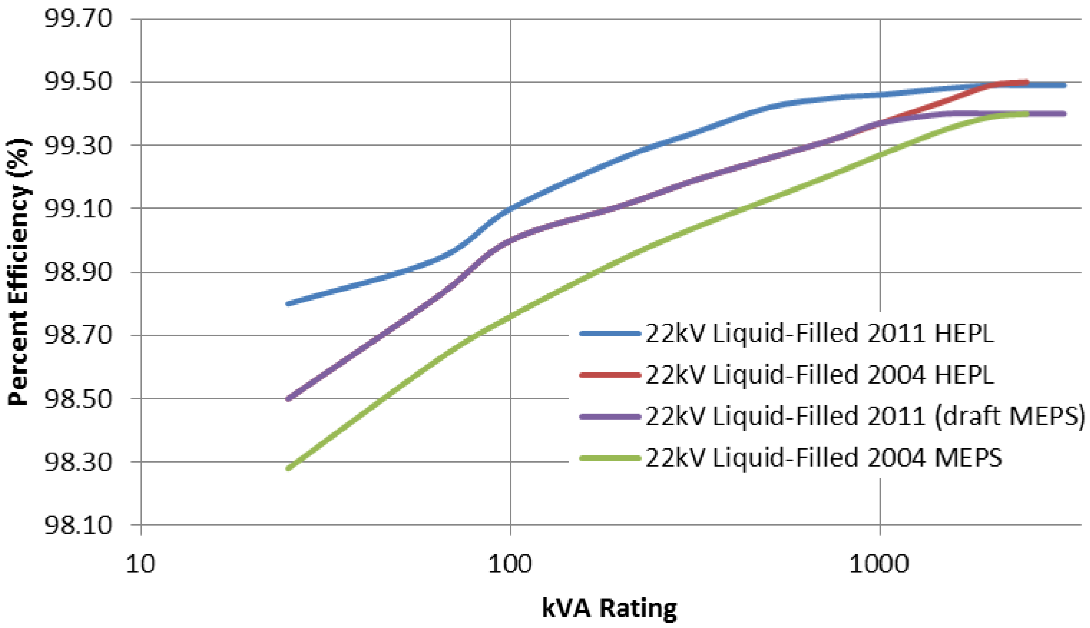

Figure 2-2. Comparison of Australian and New Zealand Current and Proposed Requirements for Liquid-Filled Transformers

The table below presents the voluntary high efficiency performance levels for dry-type transformers in Australia and New Zealand. As with the mandatory MEPS regulations, the HEPL increase the efficiency requirements of dry-type transformers, to extend coverage of three-phase units to 3150 kVA (as with liquid-filled), and to add a new higher voltage class – Um=36kV. The reason that the efficiency requirements are decreasing with higher voltages is due to the additional insulation needed at those higher insulation levels. As the insulation gets thicker, it increases the distance between the windings and the core steel, which increases the losses. Due to the fact that power is the product of voltage and current, operating a distribution network at a higher voltage may be more cost-effective for a utility, when it takes into consideration the losses in the power lines. The higher primary winding operating voltage will have a lower operating current, and thus lower losses in the power lines, and potentially (when including transformer losses) lower system losses overall.

Table 2-5. Current and Proposed Australian and New Zealand Voluntary High Efficiency Performance Levels for Dry-Type Transformers

Dry-type 50 Hz	kVA	Efficiency at 50% Loading					
		Um=12kV		Um=24kV		Um=36kV	
		Current HEPL	HEPL2 (proposed)	Current HEPL	HEPL2 (proposed)	Current HEPL	HEPL2 (proposed)
Single phase (and SWER)	10	97.53	98.20	97.32	97.90	-	97.50
	16	97.83	98.32	97.55	98.06	-	97.75
	25	98.11	98.48	97.78	98.20	-	97.98
	50	98.50	98.78	98.10	98.50	-	98.33
Three phase	25	97.42	97.88	97.42	97.88	-	97.55
	63	98.01	98.37	98.01	98.37	-	97.96
	100	98.28	98.61	98.28	98.61	-	98.25
	200	98.64	98.83	98.60	98.72	-	98.51
	315	98.82	98.95	98.74	98.87	-	98.63
	500	98.97	99.08	98.87	99.01	-	98.79
	750	99.08	99.19	98.98	99.13	-	98.91
	1000	99.14	99.26	98.04	99.19	-	98.99
	1500	99.21	99.33	99.12	99.26	-	99.08
	2000	99.24	99.37	99.17	99.30	-	99.14
	2500	99.27	99.39	99.20	99.33	-	99.19
	3150	-	99.39	-	99.33	-	99.19

NOTE: For intermediate power ratings the power efficiency level shall be calculated by linear interpolation.

Test Requirements

Australia and New Zealand share a common distribution transformer efficiency standard (AS2374.1.2:2003/Amdt1-2005) which covers both countries, therefore they are presented together in this chapter. AS2374.1.2:2003/Amdt1-2005 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.

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:

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

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)

3 Brazil

Brazil is currently working on policy measures associated with liquid-filled distribution transformers.

Table 3-1. Scope of the Brazilian Scheme

Scope
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. An image of the draft label is shown in the following figure.

Figure 3-1. Brazilian Label for Liquid-Filled Transformers

Also for liquid-filled distribution transformers, Brazil has adopted MEPS requirements, defined as maximum watts of energy consumption by voltage class and number of phases. The following tables present the maximum losses associated with the current regulation for liquid-filled transformers in Brazil. The table below presents the requirements, establishing maximum core losses and maximum coil losses, both of which are measured in watts.

Table 3-2. Brazil's Requirements for Single-Phase Liquid-Filled Distribution Transformers

kVA	15 kV		24.2 kV		36.2 kV	
	Core Loss (Watts)	Coil Loss (Watts)	Core Loss (Watts)	Coil Loss (Watts)	Core Loss (Watts)	Coil Loss (Watts)
5	35	140	40	155	45	160
10	50	245	55	265	60	270
15	65	330	75	365	80	380
25	90	480	100	520	105	545
37.5	135	665	145	740	150	740
50	165	780	190	925	200	935
75	205	1110	225	1210	240	1225
100	255	1445	275	1495	280	1480

Table 3-3. Brazil's Requirements for Three-Phase Liquid-Filled Distribution Transformers

kVA	15 kV		24.2 kV		36.2 kV	
	Core Loss (Watts)	Coil Loss (Watts)	Core Loss (Watts)	Coil Loss (Watts)	Core Loss (Watts)	Coil Loss (Watts)
15	85	410	95	470	100	460
30	150	695	160	790	165	775
45	195	945	215	1055	230	1075
75	295	1395	315	1550	320	1580
112.5	390	1890	425	2085	440	2055
150	485	2335	520	2610	540	2640
225	650	3260	725	3605	750	3600
300	810	4060	850	4400	900	4450

The Brazilian test standard for power transformers is published by the Brazilian Association of Technical Standards (ABNT): NBR 5356-1:2007 Version: 2010 "Power Transformers Part 1: General". 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 standard was prepared by Technical Committee ABNT/CB-03 Electricity and is published in Portuguese. The test method appears to be consistent with the approach followed in IEC 60076.1.

4 Canada

In June 1997, the Office of Energy Efficiency at Natural Resources Canada (NRCan) announced that it intended to develop minimum energy performance standards for transformers. If adopted, these regulations would apply to interprovincial trade and to transformers imported into Canada. NRCan organised a series of consultative workshops following this announcement, which included discussion around harmonising with TP-1 1996, the voluntary standard from the National Electrical Manufacturers Association (NEMA).

For liquid-filled transformers, efficiency levels were established by the Canadian Standards Association under CSA C802.1 in 2000. The CSA Standards apply to all liquid-filled single-phase and three-phase, 60 Hz, distribution transformers, rated between 10 and 833 kVA for single-phase and between 15 kVA and 3000 kVA for three-phase with a primary voltage of 34.5 kV or less. These CSA standards for liquid-filled distribution transformers are not mandatory, but instead are followed on a voluntary basis by the industry.

For dry-type transformers, Canada adopted levels for single and three-phase dry-type transformers in 2005, and these were then updated in 2010 to harmonise with the requirements on single and three-phase medium voltage dry-type transformers in the United States that took effect in January 2010. The Canadian amendment was published in the Canada Gazette, Part II in 2011 and the amendment came into effect six months later on April 12, 2012.

The table below summarises the scope of the Canadian policies on transformers.

Table 4-1. Scope of the Canadian Scheme

Scope
CSA C802.1 establishes minimum efficiency values for liquid-filled distribution transformers that are followed on a voluntary basis in Canada for liquid-filled single-phase and three-phase, 60 Hz, distribution transformers, rated between 10 and 833 kVA for single-phase and between 15 kVA and 3000 kVA for three-phase with a primary voltage of 34.5 kV or less. CSA C802.2 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.

The CSA standard for liquid-filled transformers was published in 2000, and a voluntary program was established in lieu of mandatory efficiency performance standards (MEPS). Canada is currently reviewing whether to adopt MEPS for liquid-filled transformers, however no decision has been made at this time. The table below presents the voluntary efficiency requirements in CSA C802.1 for liquid-filled transformers in Canada at 50% of rated capacity.

Table 4-2. Canadian Voluntary Standard for Liquid-Filled Distribution Transformers

kVA	Min. Low Voltage	Efficiency	kVA	Min. Low Voltage	Efficiency
10	120/240	98.20	15	208Y/120	97.89
15	120/240	98.41	30	208Y/120	98.20
25	120/240	98.63	45	208Y/120	98.41
50	120/240	98.84	75	208Y/120	98.63
75	120/240	98.94	150	208Y/120	98.84
100	120/240	98.94	225	208Y/120	98.94
167	120/240	99.05	300	208Y/120	98.94
250	120/240	99.15	500	208Y/120	99.05
333	120/240	99.01	750	208Y/120	99.15
333	277/480Y	99.15	1000	208Y/120	99.06
500	277/480Y	99.26	1000	480Y/277	99.15
667	277/480Y	99.37	1500	480Y/277	99.26
833	277/480Y	99.37	2000	480Y/277	99.37
-	-	-	2500	480Y/277	99.37
-	-	-	3000	480Y/277	99.37

Note: Temperature, no-load and load losses: 85°C; all efficiency values are at 50% of nameplate-rated load.

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.

Products that meet the regulatory definition of a dry-type transformer must meet or exceed the MEPS outlined in the following two tables:

Table 4-3. Single Phase Dry-type Transformer MEPS for Canada

Single Phase kVA Rating	20-45 kV BIL % efficiency	> 45-95 kV BIL % efficiency	> 95-199 kV % efficiency
15	98.10	97.86	97.60
25	98.33	98.12	97.90
37.5	98.49	98.30	98.10
50	98.60	98.42	98.20
50	98.60	98.42	98.20
75	98.73	98.57	98.53
100	98.82	98.67	98.63
167	98.96	98.83	98.80
250	99.07	98.95	98.91
333	99.14	99.03	98.99
500	99.22	99.12	99.09
667	99.27	99.18	99.15
833	99.31	99.23	99.20

Percentage efficiency at 50% nominal load. BIL means basic impulse insulation level.

Table 4-4. Three-phase Dry-type Transformer Minimum Energy Efficiency Standards

Three-phase kVA Rating	20-45 kV BIL % efficiency	> 45-95 kV BIL % efficiency	> 95-199 kV % efficiency
15	97.50	97.18	96.80
30	97.90	97.63	97.30
45	98.10	97.86	97.60
75	98.33	98.12	97.90
112.5	98.49	98.30	98.10
150	98.60	98.42	98.20
225	98.73	98.57	98.53
300	98.82	98.67	98.63
500	98.96	98.83	98.80
750	99.07	98.95	98.91
1 000	99.14	99.03	98.99
1 500	99.22	99.12	99.09
2 000	99.27	99.18	99.15
2 500	99.31	99.23	99.20
3 000	99.34	99.26	99.24
3 750	99.38	99.30	99.28
5 000	99.42	99.35	99.33
7 500	99.48	99.41	99.39

Percentage efficiency at 50% nominal load. BIL means basic impulse insulation level.

Canada has adopted MEPS for dry-type transformers only, and the test method that is used to refer to the requirements is C802.2-12, “Minimum efficiency values for dry-type transformers”. This standard was updated/reaffirmed in August 2012. The standard contains not only the scope of coverage and mandatory minimum efficiency values, but gives an overview of total ownership cost for utilities (Chapter 4) and non-utility (Chapter 5) customers and specifies the test methods that should be used when measuring the performance of a dry-type transformer (Chapter 6).

The following figure plots the Canadian MEPS for three-phase dry-type transformers, plotted for efficiency at 50% loading. From this graph it is clear to see that the efficiency requirements for the highest group of BIL ratings (>95-199 kV BIL) are set to closely track those of the middle group of BIL ratings starting around 225 kV BIL. In other words, at 150kVA, the difference in efficiency is 0.22%, but starting at 225kVA, the difference is just 0.04% and narrows to 0.02% at the highest kVA rating.

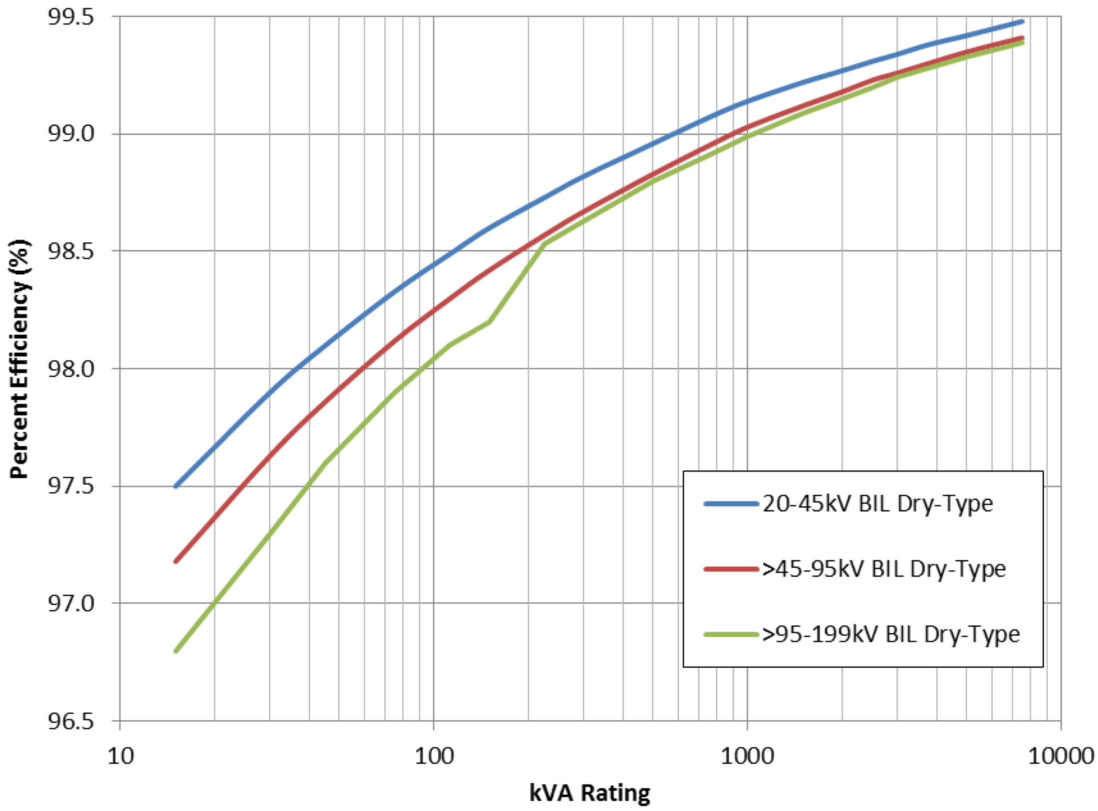

Figure 4-1. Canadian MEPS for Dry-type Transformers (log X-axis)

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[7]:

> *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.*

[7] Section 6 of the CSA standard C802.2-12, Minimum efficiency values for dry-type transformers, Published in August 2012 by CSA Group, Mississauga, Ontario, Canada.

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:

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

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
P_{L75} = load loss in watts at 75°C (see Annex A for basic loss calculation steps)

5 China

China has mandatory energy efficiency standards for distribution transformers – both liquid-filled and dry-type. The national standard GB 20052-2013 establishes the "Minimum allowable values of energy efficiency and energy efficiency grades for three-phase distribution transformers". This standard is maintained by the China National Institute of Standardization (CNIS).

GB 20052-2013 was released on the 9 June 2013 and took effect on 1 October 2013.[8] It supersedes GB 20052-2006, which had the same scope of coverage, but lower levels of efficiency (i.e., higher levels of allowable losses). The announcement (number 9 of 2013) in June by the National Standardization Management Committee approved this update to GB 20052 along with 61 other national standards on various other products.

This standard specifies the maximum allowable losses and sets test methods for liquid-filled and dry-type three-phase distribution transformers. It applies to liquid-filled transformers rated capacity of 30-2500 kVA and dry-type with capacity of 30-2500 kVA. China also has a machinery industry standard document (JB/T 10317-02) which applies to single-phase liquid-filled distribution transformers rated between 5 and 160 kVA.

Table 5-1. Scope of the Chinese Scheme

Scope
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. JB/T 10317-02: Technical Parameter and Requirement of Single-phase Oil-immersed Distribution Transformer; applies to 5 to 160kVA single-phase liquid-filled distribution transformers.

In addition to this regulation, China is one of the few economies in the world with efficiency standards on large power transformers, which are outside of the scope of this study. The national standard GB 24790-2009: Minimum allowable values of energy efficiency and the energy efficiency grades for power transformers applies to 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.

The following table summarises the requirements contained in the Chinese distribution transformer standard.

[8] Chinese Standard: http://www.cssn.net.cn/pagesnew/search/standard_detail.jsp?a001=NjcwOTk1MA==

Table 5-2. Summary of the Chinese Efficiency Standard for Distribution Transformers

Type	Grade III	Grade II		Grade I	
		Silicon	Amorphous	Silicon	Amorphous
Liquid-filled	S11	S13	S15	• No-load loss is equivalent to S13 • Loading loss is 20% lower than that of S13	• No-load loss is equivalent to S15 • Loading loss is 10% lower than S15
Dry-type	SC10	SC12	SCH 15	• No-load loss is 10% lower than SC 12 • Loading loss is 10% lower than SC12	• No-load loss is equivalent to SCH15 • Loading loss is 5% lower than SCH15

The standards have been regularly updated since 1999 with the Standard S7 and then S9 having been replaced by the current standard S11 (Grade 1 above), which defines maximum levels for no-load and load losses. S11 will soon be replaced by S13 which will specify lower maximum loss levels (i.e., more energy-efficient transformers).

The following tables present the Chinese efficiency requirements for liquid-filled and dry-type distribution transformers. The liquid-filled table provides one set of values for coil losses (i.e., load loss) measured at 100% of rated capacity and three different sets of values for core losses (i.e., no load loss). The three different levels - Grade 3, Grade 2 and Grade 1, with Grade 1 being the most efficient (lowest allowable losses).

The following table presents the standards for three-phase liquid-filled distribution transformers built with conventional electrical steel (cold-rolled, grain oriented - CRGO), based on GB 20052-2013.

Table 5-3. Maximum Loss for 3-Phase Liquid-Filled Transformers in China, GB 20052-2013

kVA	Grade 3, CRGO		Grade 2, CRGO		Grade 1, CRGO	
	No Load Loss (W)	Load Loss (W)	No Load Loss (W)	Load Loss (W)	No Load Loss (W)	Load Loss (W)
30	100	600	80	600	80	480
50	130	870	100	870	100	695
63	150	1,040	110	1,040	110	830
80	180	1,250	130	1,250	130	1,000
100	200	1,500	150	1,500	150	1,200
125	240	1,800	170	1,800	170	1,440
160	280	2,200	200	2,200	200	1,760
200	340	2,600	240	2,600	240	2,080
250	400	3,050	290	3,050	290	2,440
315	480	3,650	340	3,650	340	2,920
400	570	4,300	410	4,300	410	3,440
500	680	5,150	480	5,150	480	4,120
630	810	6,200	570	6,200	570	4,960
800	980	7,500	700	7,500	700	6,000
1000	1,150	10,300	830	10,300	830	8,240
1250	1,360	12,000	970	12,000	970	9,600
1600	1,640	14,500	1,170	14,500	1,170	11,600

The following table presents the standards for three-phase liquid-filled distribution transformers built with amorphous material in the transformer core. These requirements are also based on GB 20052-2013.

Table 5-4. Maximum Loss for 3-Phase Liquid-Filled Transformers in China, GB 20052-2013

kVA	Grade 2, Amorphous		Grade 1, Amorphous	
	No Load Loss (W)	Load Loss (W)	No Load Loss (W)	Load Loss (W)
30	33	600	33	540
50	43	870	43	785
63	50	1,040	50	935
80	60	1,250	60	1,125
100	75	1,500	75	1,350
125	85	1,800	85	1,620
160	100	2,200	100	1,980
200	120	2,600	120	2,340
250	140	3,050	140	2,745
315	170	3,650	170	3,285
400	200	4,300	200	3,870
500	240	5,150	240	4,635
630	320	6,200	320	5,580
800	380	7,500	380	6,750
1000	450	10,300	450	9,270
1250	530	12,000	530	10,800
1600	630	14,500	630	13,050

For dry-type three-phase distribution transformers, the Chinese standard has three different levels of no-load (i.e., core) losses – Grade 3 to Grade 1, with the latter being the most efficient. However, the standard also maintains a classification of load losses by the designed temperature rise. For example, class B windings are the most efficient with a 100°C temperature rise and class H are the least efficient with a 145°C temperature rise. For ease of presentation in this report, the temperature rise "F" losses are presented in the following tables, which represent a 120°C temperature rise.

The table below presents the standards for three-phase dry-type distribution transformers built with conventional electrical steel (cold-rolled, grain oriented - CRGO), based on GB 20052-2013.

Table 5-5. Maximum Loss for 3-Phase Dry-Type Transformers in China, GB 20052-2013

kVA	Grade 3, CRGO, F (120°C)		Grade 2, CRGO, F (120°C)		Grade 1, CRGO, F (120°C)	
	No Load Loss (W)	Load Loss (W)	No Load Loss (W)	Load Loss (W)	No Load Loss (W)	Load Loss (W)
30	190	710	150	710	135	640
50	270	1,000	215	1,000	195	900
80	370	1,380	295	1,380	265	1,240
100	400	1,570	320	1,570	290	1,415
125	470	1,850	375	1,850	340	1,665
160	540	2,130	430	2,130	385	1,915
200	620	2,530	495	2,530	445	2,275
250	720	2,760	575	2,760	515	2,485
315	880	3,470	705	3,470	635	3,125
400	980	3,990	785	3,990	705	3,590
500	1,160	4,880	930	4,880	835	4,390
630	1,340	5,880	1,070	5,880	965	5,290
800	1,520	6,960	1,215	6,960	1,095	6,265
1000	1,770	8,130	1,415	8,130	1,275	7,315
1250	2,090	9,690	1,670	9,690	1,505	8,720
1600	2,450	11,730	1,960	11,730	1,765	10,555
2000	3,050	14,450	2,440	14,450	2,195	13,005
2500	3,600	17,170	2,880	17,170	2,590	15,455

The following table presents the standards for three-phase dry-type distribution transformers built with amorphous material in the transformer core. These requirements are also based on GB 20052-2013.

Table 5-6. Maximum Loss for 3-Phase Dry-Type Transformers in China, GB 20052-2013

kVA	Grade 2, Amorphous, F (120°C)		Grade 1, Amorphous, F (120°C)	
	No Load Loss (W)	Load Loss (W)	No Load Loss (W)	Load Loss (W)
30	70	710	70	675
50	90	1,000	90	950
80	120	1,380	120	1,310
100	130	1,570	130	1,490
125	150	1,850	150	1,760
160	170	2,130	170	2,025
200	200	2,530	200	2,405
250	230	2,760	230	2,620
315	280	3,470	280	3,295
400	310	3,990	310	3,790
500	360	4,880	360	4,635
630	420	5,880	420	5,585
800	480	6,960	480	6,610
1000	550	8,130	550	7,725
1250	650	9,690	650	9,205
1600	760	11,730	760	11,145
2000	1,000	14,450	1,000	13,725
2500	1,200	17,170	1,200	16,310

China also has a professional standard (or an “industry standard”) which establishes maximum loss levels on single-phase liquid-filled distribution transformers: JB/10317-02 "Technical Parameter and Requirement of Single-phase Oil-immersed Distribution Transformer". The table below presents the maximum losses associated with these standards.

Table 5-7. Maximum Losses for Single-Phase Liquid-Filled Distribution Transformers in China, JB/10317-02

kVA	Single-Phase Liquid-Filled Transformers	
	No Load Loss (W)	Load Loss (W)
5	35	145
10	55	260
16	65	365
20	80	430
30	100	625
40	125	775
50	150	950
63	180	1135
80	200	1400
100	240	1650
125	285	1950
160	365	2365

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

Table 5-8. Chinese Standards Based on IEC 60076

Standard Number	Standard Title	Standard Title in English	Remarks
GB 1094.1-1996[9]	电力变压器 第1部分 总则	Power transformers--Part 1:General	1996-12-01实施,代替GB 1094.1-1985,GB 1094.4-1985
GB 1094.2-1996	电力变压器 第2部分 温升	Power transformers--Part 2:Temperature rise	1996-12-01实施,代替GB 1094.2-1985
GB 1094.3-2003	电力变压器 第3部分: 绝缘水平、绝缘试验和外绝缘空气间隙	Power transformers--Part 3: Insulation levels, dielectric tests and external clearances in air	2004-01-01实施,代替GB 1094.3-1985,GB/T 10237-1988
GB 1094.5-2008	电力变压器 第5部分：承受短路的能力	Power transformers - Part 5: Ability to withstand short circuit	2009-06-01实施,代替GB 1094.5-2003
GB 1094.11-2007[10]	电力变压器 第11部分：干式变压器	Power transformers - Part 11: Dry-type transformers	2008-04-01实施,代替GB 6450-1986

The two key standards for measurement of losses are GB 1094.1-1996 (Power transformers – Part 1: General) and GB 1094.11-2007 (Power transformers – Part 11: Dry-type transformers).

GB 1094.1-1996 was issued in March 1996 and was most recently reaffirmed in July 2010. It represents the adoption of IEC 60076-1:1993, and is described as being “equivalent” to the IEC standard.

GB 1094.11-2007 was issued in April 2007, replacing standard GB 6450-1986. It is based on IEC standard 60076-11:2004, however it is noted as being “modified” when it was adapted to the Chinese context, however it will be consistent with the IEC approach.

[9] http://220.194.5.109/stdlinfo/servlet/com.sac.sacQuery.GjbzcxDetailServlet?std_code=GB%201094.1-1996
[10] http://220.194.5.109/stdlinfo/servlet/com.sac.sacQuery.GjbzcxDetailServlet?std_code=GB%201094.11-2007

6 European Union

At the time of this writing, the Europe Union does not have a regulatory standard on distribution transformers. However, the European Commission initiated a Preparatory Study under the Ecodesign Directive in 2010 and has been progressively working toward establishing minimum performance levels. In the absence of a regulatory standard, the European market has had voluntary standards in place which have been followed by many manufacturers and utilities.

In this chapter, the voluntary standards are presented as well as the draft requirements for those same transformers from a copy of the draft implementing measure under the Ecodesign Directive that was published in 2012.[11] The scope of the European regulation under the Ecodesign Directive is working toward comprehensive coverage of a particular product. The overall objective of the regulatory measures is to have a wide scope of coverage and to set exemptions or exclusions only for those products that represent special purpose applications and are not likely to become substitutes for regulated products (i.e., loop-holes).

Table 6-1. Scope of the European Commission's Draft Scheme

Scope of the Draft Ecodesign Regulation
This draft regulation applies to small, medium and large power transformers with a minimum power rating of 1 kVA and used in 50Hz electricity transmission and distribution. It includes both liquid-filled and dry-type transformers, but excludes the following categories of transformers: (1) Instrument transformers; (2) Traction transformers on rolling stock; (3) Starting transformers; (4) Testing transformers; (5) Welding transformers; (6) Explosion-proof and underground mining transformers; and (7) Transformers for deep water (submerged) applications.

Although the discussion in this chapter focuses on distribution transformers, it is worth noting that the draft European regulation indicates that it will cover and apply to large power transformers if adopted.

The voluntary European industry standard was updated over the years, most recently in 2007 when it was renumbered as EN50464-1. This standard (which is still voluntary) applies to the same kVA ratings and maximum voltage as did HD 428. The maximum loss levels associated with the A, B and C ratings are given in the table below. The subscript "o" is assigned to losses associated with the core and "k" is assigned to losses associated with the coil. Thus, when a utility specifies a transformer, they will typically give a combination of core and coil losses, such as "AoBk" or "AoAk".

[11] A copy of the draft regulation can be viewed on this website: http://ec.europa.eu/enterprise/tbt/tbt_repository/EU146_EN_1_1.pdf

Table 6-2. Maximum Losses for European Voluntary Standard, 24 kV Liquid-Filled

24 kV	Core, Co	Coil, Ck	Core, Bo	Coil, Bk	Core, Ao	Coil, Ak
kVA	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)
50	125	1100	110	875	90	750
100	210	1750	180	1475	145	1250
160	300	2350	260	2000	210	1700
250	425	3250	360	2750	300	2350
315	520	3900	440	3250	360	2800
400	610	4600	520	3850	430	3250
500	720	5500	610	4600	510	3900
630	860	6500	730	5400	600	4600
630	800	6750	680	5600	560	4800
800	930	8400	800	7000	650	600
1000	1100	10500	940	9000	770	7600
1250	1350	13500	1150	11000	950	9500
1600	1700	17000	1450	14000	1200	12000
2000	2100	21000	1800	18000	1450	15000
2500	2500	26500	2150	22000	1750	18500

Table 6-3. Maximum Losses for European Voluntary Standard, 36 kV Liquid-Filled

36 kV	Core, Co	Coil, Ck	Core, Bo	Coil, Bk	Core, Ao	Coil, Ak
kVA	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)
50	230	1450	190	1250	160	1050
100	380	2350	320	1950	270	1650
160	520	3350	460	2550	390	2150
250	780	4250	650	3500	550	3000
400	1120	6200	930	4900	790	4150
630	1450	8800	1300	6500	1100	5500
800	1700	10500	1500	8400	1300	7000
1000	2000	13000	1700	10500	1450	8900
1250	2400	16000	2100	13500	1750	11500
1600	2800	19200	2600	17000	2200	14500
2000	3400	24000	3150	21000	2700	18000
2500	4100	29400	3800	26500	3200	22500

For dry-type distribution transformers, Europe had a similar system. CENELEC and SEEDT worked together to establish CENELEC HD 538 in 1992[12] for dry-type transformers at 50 Hz, rated between 100 and 2500 kVA, with a maximum voltage less than 36kV. These standards specified maximum allowable no load and load losses according to the kVA rating of the transformer. In 2011, CENELEC published EN 50541-1:2011 which superseded HD 538 and established three sets of efficiency tables for dry-type transformers covering three-phase dry-type distribution transformers covering 100 kVA to 3150 kVA, operating at 50Hz and with the highest voltage not exceeding 36 kV. The following tables provide the maximum losses from that voluntary standard.

Table 6-4. Maximum Losses Three-Phase Dry-Type, ≤12 kV and 4% Impedance

kVA	Coil, Ak	Coil, Bk	Core, Ao	Core, Bo	Core, Co
	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)
100	1800	2000	260	330	440
160	2500	2700	350	450	610
250	3200	3500	500	610	820
400	4500	4900	700	880	1150
630	6700	7300	1000	1150	1500

Table 6-5. Maximum Losses Three-Phase Dry-Type, ≤12 kV and 6% Impedance

kVA	Coil, Ak	Coil, Bk	Core, Ao	Core, Bo	Core, Co
	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)
100	1800	2000	260	330	440
160	2600	2700	350	450	610
250	3400	3500	500	610	820
400	4500	4900	700	880	1150
630	7100	7300	1000	1150	1500
800	8000	9000	1100	1300	1800
1000	9000	10000	1300	1500	2100
1250	11000	12000	1500	1800	2500
1600	13000	14500	1800	2200	2800
2000	15500	18000	2200	2600	3600
2500	18500	21000	2600	3200	4300
3150	22000	26000	3150	3800	5300

[12] CENELEC Harmonisation Document Three-Phase Dry Type Distribution Transformers 50Hz, from 100 to 2,500 kVA, with highest voltage for Equipment not exceeding 36kV. CENELEC HD528.1 (1992)

Table 6-6. Maximum Losses Three-Phase Dry-Type, 17.5 and 24 kV, 4% Impedance

kVA	Coil, Ak	Coil, Bk	Core, Ao	Core, Bo	Core, Co	Core, Do
	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)
100	1350	1750	330	360	400	600
160	1800	2500	450	490	580	870
250	2700	3450	640	660	800	1100
400	3800	4900	850	970	1100	1450
630	5300	6900	1250	1270	1600	2000

Table 6-7. Maximum Losses Three-Phase Dry-Type, 17.5 and 24 kV, 6% Impedance

kVA	Coil, Ak	Coil, Bk	Core, Ao	Core, Bo	Core, Co
	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)
100	1800	2050	280	340	460
160	2600	2900	400	480	650
250	3400	3800	520	650	880
400	4500	5500	750	940	1200
630	7100	7600	1100	1250	1650
800	8000	9400	1300	1500	2000
1000	9000	11000	1550	1800	2300
1250	11000	13000	1800	2100	2800
1600	13000	16000	2200	2400	3100
2000	16000	18000	2600	3000	4000
2500	19000	23000	3100	3600	5000
3150	22000	28000	3800	4300	6000

Table 6-8. Maximum Losses Three-Phase Dry-Type, 36 kV, 6% Impedance

36 kV	Core, Co	Coil, Ck	Core, Bo	Coil, Bk	Core, Ao	Coil, Ak
kVA	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)	Max Losses (W)
160	2500	2700	2900	850	900	960
250	3500	3800	4000	1000	1100	1280
400	5000	5400	5700	1200	1300	1650
630	7000	7500	8000	1400	1600	2200
800	8400	9000	9600	1650	1900	2700
1000	10000	11000	11500	1900	2250	3100
1250	12000	13000	14000	2200	2600	3600
1600	14000	16000	17000	2550	3000	4200
2000	17000	18500	21000	3000	3500	5000
2500	20000	22500	25000	3500	4200	5800
3150	25000	27500	30000	4100	5000	6700

At the time of this writing, the European Union does not have a regulatory standard on distribution transformers. The European Commission initiated a Preparatory Study under the Ecodesign Directive in 2010 and has been progressively working toward establishing minimum performance levels since then, but the process is not complete. However a draft copy of the regulation is available from the World Trade Organisation (see link below).[13]

The following two tables are taken from the draft European Commission's regulation and show the levels that were under consideration at that time for Tier 1 and Tier 2. It should be stressed that these may not be the final levels adopted, as these tables are taken from a draft document that is under active development by the Commission.

This following table gives the draft maximum load and no-load losses for liquid-immersed medium power transformers with the high voltage winding rated as 24 kV and below and the secondary winding at 1.1 kV and below. Note too that the Commission is considering to allow higher (greater) losses for pole-mounted transformers which are not shown in this table.

[13] Draft Transformer Regulation: http://ec.europa.eu/enterprise/tbt/tbt_repository/EU146_EN_1_1.pdf

Table 6-9. Maximum Losses Liquid-Immersed Medium Power Transformers (Draft, Europe)

kVA	Tier 1 (from July 2015)		Tier 2 (from July 2021)	
	Maximum Load Losses (W)	Maximum No-Load Losses (W)	Maximum Load Losses (W)	Maximum No-Load Losses (W)
25	900	70	600	63
50	1100	90	750	81
100	1750	145	1250	130
160	2350	210	1750	189
250	3250	300	2350	270
315	3900	360	2800	324
400	4600	430	3250	387
500	5500	510	3900	459
630	6500	600	4600	540
800	8400	650	6000	585
1000	10,500	770	7600	693
1250	11,000	950	9500	855
1600	14,000	1200	12000	1080
2000	18,000	1450	15000	1305
2500	22,000	1750	18500	1575
3150	27,500	2200	23000	1980

* Maximum losses for KVA ratings that fall in between the ratings given in this table shall be obtained by linear interpolation. Maximum losses for kVA ratings falling outside those given in this table shall be obtained by exponential extrapolation with exponent 0,75.

This following table gives the draft maximum load and no-load losses for dry-type medium power transformers with the high voltage winding rated as 24 kV and below and the secondary winding at 1.1 kV and below.

Table 6-10. Maximum Losses Dry-Type Medium Power Transformers (Draft, Europe)

kVA	Tier 1 (from July 2014)		Tier 2 (from July 2018)	
	Maximum Load Losses (W)	Maximum No-Load Losses (W)	Maximum Load Losses (W)	Maximum No-Load Losses (W)
50	1700	200	1500	180
100	2050	280	1800	252
160	2900	400	2600	360
250	3800	520	3400	468
400	5500	750	4500	675
630	7600	1100	7100	990
800	8000	1300	8000	1170
1000	9000	1550	9000	1395
1250	11000	1800	11000	1620
1600	13000	2200	13000	1980
2000	16000	2600	16000	2340
2500	19000	3100	19000	2790
3150	22000	3800	22000	3420

* Maximum losses for KVA ratings that fall in between the ratings given in this table shall be obtained by linear interpolation. Maximum losses for kVA ratings falling outside those given in this table shall be obtained by exponential extrapolation with exponent 0,75.

The European Norms EN50464-1 and EN50564-1 both reference the IEC 60076 family of standards for testing the losses associated with a transformer. EN 50464-1 simply states in section 3.10.1, Routine Tests, that “EN 60076-1 applies.” The standard also says that within the limits of tolerances in EN 60076-1, the application of penalties / bonus with regard to losses is left to the agreement between manufacturer and purchaser at the time of enquiry and order. The calculation of efficiency is given in EN50564-1, as the ratio of the output power divided by the input power. This is calculated as shown in the following equation:

$$\eta = 100 \cdot \left(1 - \frac{\alpha^2 \cdot P_{cc} + P_0}{\alpha \cdot S + \alpha^2 \cdot P_{cc} + P_0} \right) (\%)$$

where

P_{cc} = load loss at rated current and reference temperature;

P_0 = no load loss at rated voltage and frequency;

S = rated power;

α = load factor (p.u.).

7 India

On 5 January 2010, India adopted a mandatory labelling scheme for specific types of liquid-filled, naturally air-cooled, three-phase distribution transformers. These are the units referred to under Indian Standard IS 1180 (part I) and cover power ratings up to and including 200 kVA. More specifically, the standard ratings covered under the energy labelling scheme are 16, 25, 63, 100, 160 and 200 kVA.

Table 7-1. Scope of the Indian Labelling Scheme

Scope
DT Notification/Gazette (Schedule 4 - Distribution Transformer): 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. The standards ratings covered are 16, 25, 63, 100, 160 and 200 kVA and non standard ratings from 16 kVA to 200 kVA.

This scope of coverage in India is currently under review by the Bureau of Indian Standards and the Bureau of Energy Efficiency. In June 2013, BIS issued document number ETD 16(6648) which was addressed to all members of the Transformers Sectional Committee (ET 16), all members of the Electrotechnical Division Council and other interested parties.[14] The document title is "Outdoor type oil immersed distribution transformers up to and including 2500 Kva, 33kV [*Fourth Revision of* IS 1180 (Part 1)]". In this document, the revision of the national distribution transformer standard (BIS standard) extends the scope of coverage beyond 200 kVA and up to and including 2500 kVA and 33 kilovolts. This extension of the scope would bring India's coverage more in line with other major economies such as Australia, China and the United States.

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 figure below shows the mandatory labelling scheme for distribution transformers in India. The star system constitutes a useful tool for differentiating between models at the same rating. It is also important to note that in a notification dated 20 August 2010, the Central Electricity Authority (CEA) of India issued a requirement that all utilities in India must procure at least a 3 star distribution transformer.[15] Since that time, transformer purchase orders issues by the utilities prescribe minimum 3 star distribution transformers.

[14] Link to the BIS draft standard for comment: http://www.bis.org.in/sf/etd/ET16%20_6648.pdf

[15] Installation of energy-efficient 3-Star rated distribution transformers is required by the Indian Government. Notification was 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.

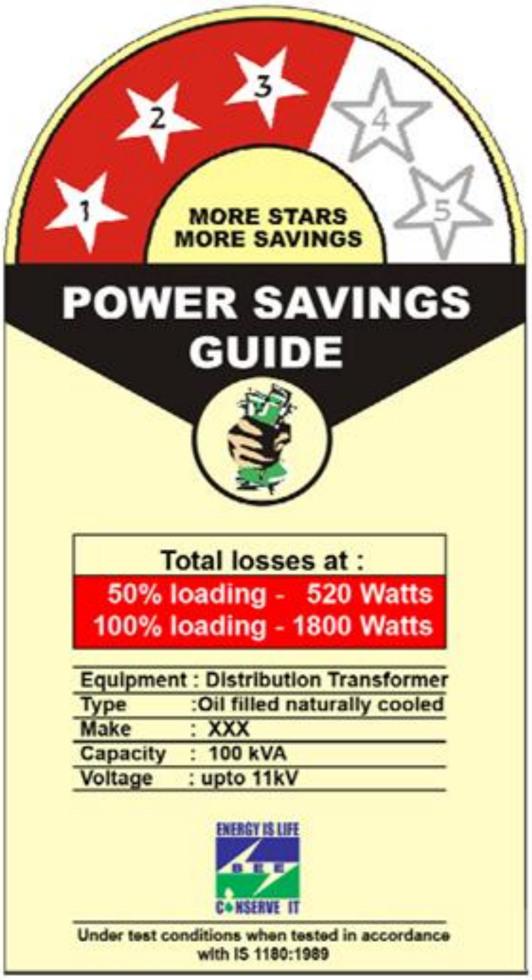

Figure 7-1. India's Energy Efficiency Label for Oil-Filled Distribution Transformers

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. The highest loss designs (i.e., the least efficient) are defined as one star and lowest loss segment (i.e., the most efficient) are defined as a five star. The basis for the star rating is given in the table below.

Table 7-2. India's Five Star Energy-Efficiency Label for Transformers

Case	Basis of Losses (Total at 50% Load Condition)
Base case 1 Star	Current purchasing practice (IS 1180 (part 1)Max Losses)
2 Star	Some utility purchase specifications like AP, NDPL
3 Star	Losses from Total Ownership Cost (TOC) design (Moderate)
4 Star	Losses from lowest TOC design
5 Star	High efficiency design

The table below presents the corresponding maximum total losses associated with each of the five star levels, measured at 50% and 100% of loading. These are total losses – in that they are the sum of the core and coil losses taken together. These maximum total loss levels are for liquid-filled distribution transformers, typical of those used by an electric utility in a distribution network.

Table 7-3. Maximum Losses for Liquid-Filled Distribution Transformers in India

Rating	1 Star		2 Star		3 Star		4 Star		5 Star	
kVA	Losses 50% (W)	Losses 100% (W)	Losses 50% (W)	Losses 100% (W)	Losses 50% (W)	Losses 100% (W)	Losses 50% (W)	Losses 100% (W)	Losses 50% (W)	Losses 100% (W)
16	200	555	165	520	150	480	135	440	120	400
25	290	785	235	740	210	695	190	635	175	595
63	490	1415	430	1335	380	1250	340	1140	300	1050
100	700	2020	610	1910	520	1800	475	1650	435	1500
160	1000	2800	880	2550	770	2200	670	1950	570	1700
200	1130	3300	1010	3000	890	2700	780	2300	670	2100

In India, the standard IS 1180 (Part 1): 1989[16] 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.

[16] http://www.standardsbis.in/Gemini/search/Browse.action?saleModeName=SOFT_COPY

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.

Table 7-4. Indian Standards Based on IEC 60076

Standard Number	Year	Title
IS 2026: Part 1	2011	Power transformers: Part 1 General
IS 2026 : Part 2	2010	Power transformers Part 2 Temperature-rise
IS 2026 : Part 3	2009	Power Transformers Part - 3 Insulation Levels, Dielectric Tests and External Clearances in Air
IS 2026 : Part 4	1977	Power transformers: Part 4 Terminal marking, tappings and connections
IS 2026 : Part 5	2011	Power Transformers Part 5 Ability to Withstand Short Circuit
IS 2026 : Part 7	2009	Power Transformers Part 7 Loading Guide for Oil-Immersed Power Transformers
IS 2026 : Part 8	2009	Power Transformers : Part 8 Applications guide
IS 2026 : Part 10	2009	Power Transformers : Part 10 Determination of sound levels

8 Israel

Israel has adopted national minimum efficiency regulations for distribution transformers, covering both efficiency requirements and labelling. The 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. The Israeli standards follow the IEC standards, so the kVA ratings will be complaint with IEC and the transformers are designed to operate in Israel's 50Hz distribution system.

Table 8-1. Scope of the Israeli Scheme

Scope
Distribution transformers operating at 50Hz with a nominal input voltage of 22kV or 33kV and a nominal output voltage of 400V, with power ratings up to 2500 kVA.

There are six tables of maximum core and coil losses that are given in the Israeli regulation. The regulations contain tables that are applicable to liquid-filled distribution transformers and tables that apply to dry-type (cast resin coil). The national standard does not apply to special purpose transformers such as metering transformers, testing transformers, welding transformers, starter transformers and other special-purpose transformers.

The following tables present the efficiency requirements for Israel, with maximum coil losses measured at 100% of rated capacity. The Israel efficiency requirements are similar to the Australian regulations, in that they have published both a minimum efficiency level (MEPS) and they have published a high efficiency performance level (HEPL) – both of which contain maximum loss levels.

Table 8-2. Maximum Losses for Liquid-Filled Transformers in Israel, MEPS

kVA	≤ 22kV Primary Minimum Efficiency (MEPS)		≤ 33kV Primary Minimum Efficiency (MEPS)	
	Max Core Loss (Po, W)	Max Coil Loss (Pk, W)	Max Core Loss (Po, W)	Max Coil Loss (Pk, W)
100	230	1760	240	1700
160	300	2330	300	2470
250	450	3330	450	3410
400	650	4670	650	4830
630	900	5460	950	5780
800	1180	8320	1450	7950
1000	1300	9700	1560	9450
1250	1500	11300	1810	10950
1600	1800	14500	2160	14250
2000	2150	16150	2580	16320
2500	2540	19100	2950	19850

Table 8-3. Maximum Losses for Liquid Transformers in Israel, High Efficiency Performance

kVA	≤ 22kV Primary High Efficiency Performance Level		≤ 33kV Primary High Efficiency Performance Level	
	Max Core Loss (Po, W)	Max Coil Loss (Pk, W)	Max Core Loss (Po, W)	Max Coil Loss (Pk, W)
100	190	1670	230	1410
160	260	2170	330	2075
250	380	2250	410	2960
400	550	3020	590	4120
630	690	4520	870	4520
800	790	6820	1040	6470
1000	930	7650	1250	7520
1250	1100	9550	1520	9570
1600	1320	11850	1870	11840
2000	1700	14240	2210	14900
2500	2000	17520	2650	17800

Table 8-4. Maximum Losses for Dry-Type (Cast-Resin) Transformers, MEPS and Efficient

kVA	≤ 22kV Primary Minimum Efficiency (MEPS)		≤ 22kV Primary High Efficiency Performance Level	
	Max Core Loss (Po, W)	Max Coil Loss (Pk, W)	Max Core Loss (Po, W)	Max Coil Loss (Pk, W)
100	550	1700	300	1700
160	750	2300	390	2300
250	1020	3300	550	3000
400	1380	4800	870	4700
630	1900	6930	1100	6300
800	2250	7800	1400	7500
1000	2650	9100	1550	8700
1250	3050	11000	2000	10600
1600	3600	13500	2250	13000
2000	4620	14500	2950	12500
2500	5750	17000	3400	14000

Israel has adopted national minimum efficiency regulations for distribution transformers, covering both efficiency requirements and labelling. The national standard, IS 5484, Distribution transformers - energy efficiency requirements and marking. 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.

9 Japan

Japan's transformers are a part of the "Top Runner" Energy Efficiency Program[17] which provides maximum efficiency target levels for permissible loss specifications for a variety of electrical equipment and appliances. Japanese Standards apply 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).

Japan's Top-Runner programme, which was updated in October 2013, applies to both liquid-filled and dry-type transformers[18], and efficiency is determined by establishing a maximum level (Watts) of energy consumption at defined loading points. These maximum loss levels are generated by an equation, which is based on the kVA rating of the transformer.

Table 9-1. Scope of the Japanese Scheme

Scope
The Japanese scheme applies to both 50 and 60Hz units, with requirements applicable to single-phase units from 5 to 500 kVA and three-phase units from 10 to 2000 kVA.

It is important to note however that the Top-Runner programme is a little bit different from MEPS programmes in other countries. The Top-Runner programme does not establish a minimum requirement for each individual distribution transformer. Instead, it establishes an average value that must be achieved across a production run of the transformers – in other words, the average of the population has to meet or exceed the Top-Runner value, with individual units falling above or below the requirement.

The Japanese Top-Runner programme establishes that all three-phase transformers above 500 kVA are subject to one empirical loss formula based on a 50% loading point, and those equal to or less than 500 kVA are subject to another empirical loss formula based on a 40% loading point. Single phase transformers are also subject to empirical loss formulae, but with slightly different constants and exponents to the kVA rating.

Thus, the assumed loading for calculating maximum allowable losses under the Top-Runner scheme is 40% for ≤500 kVA and 50% for >500 kVA. The Top-Runner equations are based around the total loss – summing together no-load and load-loss – using the following equation:

[17] ECCJ-Energy Conservation Council of Japan, "The Tope Runner Program – Japan's Approach to Energy Efficiency and Conservation Measures",2004, www.eccj.or.jp/top_runner/index.html

[18] The terminology used in this report is "liquid-filled" and "dry-type" for consistency, although we note that in Japan, the terms "oil-immersed" and "encapsulated-winding" are more common.

$$Total\ loss\ (W) = No\ load\ loss\ (W) + \left(\frac{m}{100}\right)^2 \times Load\ loss\ (W)$$

Here, the following values shall be used for m, the reference load factor:

Transformers whose capacity is 500 kVA or below (40% loading)
Transformers whose capacity is above 500 kVA (50% loading)

The Top-Runner programme excludes the following transformers from the requirements:

1) Those using gas as insulation material (gas-immersed transformers)
2) Those using H class insulation material (H class insulation dry-type transformers)
3) Scott-connected transformers
4) Those with 3 or more windings (multi-winding transformers)
5) Pole-mounted transformers
6) Those which are single-phase transformers and whose rated capacity is 5 kVA or below, or above 500 kVA
7) Those which are three-phase transformers and whose rated capacity is 10 kVA or below, or above 2,000 kVA
8) Those which are three-phase transformers using insulation material made of resin and used to transform three phase alternating current into single phase alternating current and three phase alternating current (Double power encapsulated-winding transformers)
9) Those whose rated secondary voltage is below 100 V or above 600 V
10) Those which are air-cooled type or water-cooled type

In addition, small manufacturers and importers supplying less than 100 units in total are excluded from the programme, however display obligations (such as product name, type, rated capacity, number of phases, energy consumption efficiency, standard load factor, etc.) must be met regardless of the number of transformers supplied.

Japan recently adopted new Top Runner target values in October 2013. These target standard values were originally published in December 2011[19]. The new levels are shown in the following table, and they are given as equations which use the kVA rating as the input variable and determine maximum watts of losses at either 40% or 50% loading.

[19] "Final Report by Power Transformers Evaluation Standards Subcommittee, Energy Efficiency Standards Subcommittee of the Advisory Committee for Natural Resources and Energy"; Ministry of Economy, Trade and Industry, Tokyo, Japan; December 2011.

Table 9-2. Japanese Top-Runner Programme Target Values

Category				Top Runner Target Standard Value
Type	Phases	Freq.	Capacity	
Liquid-filled	Single	50Hz	≤ 500 kVA	$E = 11.2 \times S^{0.732}$
		60Hz	≤ 500 kVA	$E = 11.1 \times S^{0.725}$
	Three	50Hz	≤ 500 kVA	$E = 16.6 \times S^{0.696}$
			> 500 kVA	$E = 11.1 \times S^{0.809}$
		60Hz	≤ 500 kVA	$E = 17.3 \times S^{0.678}$
			> 500 kVA	$E = 11.7 \times S^{0.790}$
Encapsulated-winding	Single	50Hz	≤ 500 kVA	$E = 16.9 \times S^{0.674}$
		60Hz	≤ 500 kVA	$E = 15.2 \times S^{0.691}$
	Three	50Hz	≤ 500 kVA	$E = 23.9 \times S^{0.659}$
			> 500 kVA	$E = 22.7 \times S^{0.718}$
		60Hz	≤ 500 kVA	$E = 22.3 \times S^{0.674}$
			> 500 kVA	$E = 19.4 \times S^{0.737}$

Note: For transformers that are not used under standard conditions described by JISC4304 and C4306, as well as JEMA standards 1474 and 1475, the target standard value is obtained by multiplying 1.10 for liquid-filled transformers and 1.05 for encapsulated-winding transformers to the respective formulas specified in the above category. Remarks: (1) Liquid-filled transformers are transformers that use insulating liquid as insulating materials; (2) Encapsulated-winding transformers are dry-type transformers that use resin insulating materials; (3) E and S express the following numeric values: E is standard energy consumption efficiency (unit: Watt) and S is the rated capacity (unit: kVA).

The methods used for measuring losses are those given in the Japanese Standards:

- JIS C4304 – 2005 (6 kV liquid-filled distribution transformers) and
- JIS C4306 – 2005 (6 kV encapsulated-winding distribution transformers).

Manufacturers perform their own determinations of performance and must have them available for inspection. The records are audited from time to time and there is a ‘name and shame’ element to the programme if a company is not seen to be effecting some continual improvement in efficiency levels.

In order to make a comparison between the Japanese Top Runner programme and some other distribution transformer requirements, the 60 Hz Japanese Top-Runner programme levels are calculated as percentage efficiency at 40% and 50% loading, depending on the kVA rating. These efficiency values are presented in the table below.

Table 9-3. Japanese Top-Runner Programme Values Converted to Efficiency

Liquid-Filled, Single-Phase (60Hz)			Liquid-Filled, Three-Phase (60Hz)		
kVA	E_{max} (watts)[1]	Efficiency[2]	kVA	E_{max} (watts)[3]	Efficiency[2]
10	58.9	98.55%	15	108.5	98.22%
15	79.1	98.70%	30	173.6	98.57%
25	114.5	98.87%	45	228.5	98.75%
37.5	153.6	98.99%	75	323.1	98.93%
50	189.3	99.06%	112.5	425.3	99.06%
75	253.9	99.16%	150	516.9	99.15%
100	312.8	99.22%	225	680.5	99.25%
167	453.7	99.33%	300	827.1	99.32%
250	607.9	99.40%	500	1169.4	99.42%
333	748.3	99.44%	750	2185.2	99.42%
500	1004.8	99.50%	1000	2742.7	99.45%
			1500	3778.3	99.50%
			2000	4742.4	99.53%

[1]The equation for maximum losses of single-phase, 60Hz liquid-filled transformers is $E = 11.1 \times S^{0.725}$
[2]Efficiency is defined at 40% loading for 500 kVA and below and 50% for units greater than 500 kVA.
[3]The equation for maximum losses of three-phase, 60Hz liquid-filled transformers is $E = 17.3 \times S^{0.678}$ for 500kVA and below, and $E = 11.7 \times S^{0.790}$ for greater than 500 kVA.

In addition to the Top Runner programme, Japan also promotes the use of energy-efficient equipment through a voluntary Energy Saving Labelling Programme. This programme is administered by the Energy Conservation Centre, Japan (ECCJ). The voluntary labelling programme was launched on August 21, 2000, and it allows consumers to compare energy efficiencies of similar products when making a purchase. As of August 2004, there were 18 target products covered as part of the programme including air conditioners, fluorescent lights, TVs, refrigerators, freezers, space heaters, gas cooking appliances, gas burning heaters, liquid burning water heaters, electric toilet seats, computers, magnetic disk units, distribution transformers, electric rice cookers, microwave ovens, switching devices, DVD recorders and routers.

The figure below shows the two types of labels used in the Energy Saving Labelling Programme – one to indicate the target has not been achieved and one to indicate it has been achieved. The label presents the target fiscal year, the achievement rate in terms of the energy conservation standards and the annual energy consumption in kWh/year. The symbol changes from an orange “e” to a green “e” once the target has been achieved – i.e., the ‘achievement rate of energy conservation standards’ has surpassed 100% of the target value.

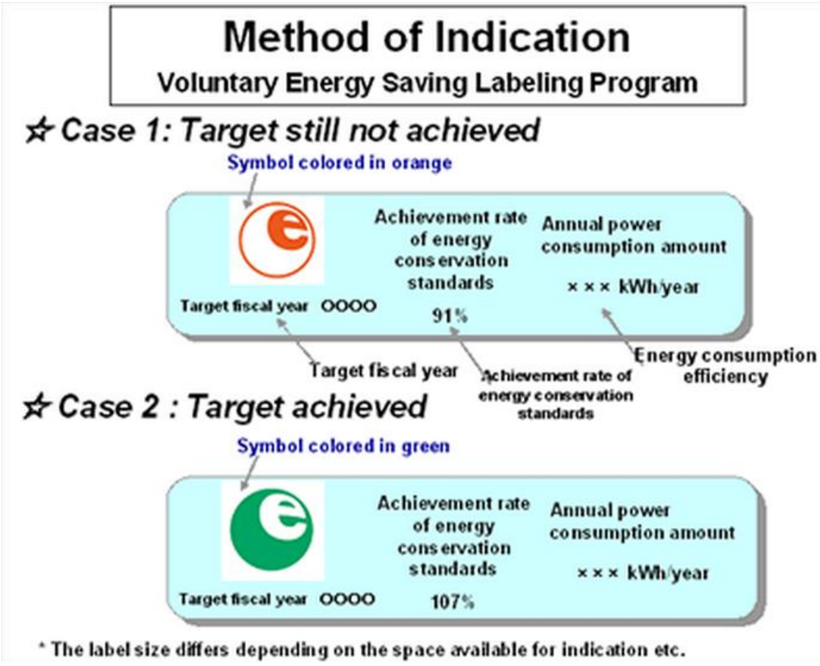

Figure 9-1. Energy Saving Labelling Programme in Japan

In Japan distribution transformer efficiency is covered by the general "Top Runner" efficiency scheme for electrical appliances and equipment. 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.

The methods used for measuring actual losses are those given in the Japanese Standards:

- JIS C4304 – 2005 (6kV oil-immersed distribution transformers) and
- JIS C4306 – 2005 (6kV Enclosed winding 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.

Table 9-4. IEC Standards Referenced and Modified for Japanese National Standards

IEC Standard	Title
IEC 60076-1:2000	Power transformers - Part 1: General
IEC 60076-2:1993	Power transformers - Part 2: Temperature rise
IEC 60076-3:2000	Power transformers - Part 3: Insulation levels, dielectric tests and external clearances in air
IEC 60076-4:2002	Power transformers - Part 4: Guide to the lightning impulse and switching impulse testing - Power transformers and reactors
IEC 60076-5:2000	Power transformers - Part 5: Ability to withstand short circuit
IEC 60076-10:2001	Power transformers - Part 10: Determination of sound levels

JIS C4306 (cast-coil distribution transformers) is also 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 same IEC 60076 standards reference in the table above.

10 Korea

In July 2012, Korea adopted mandatory efficiency standards for liquid-filled and dry-type distribution transformers. In a similar way to Australia, Korea establishes minimum performance efficiency requirements and then sets a higher level of efficiency and requires that manufacturers meet that level before they can market the product as highly energy-efficient. This is referred to as the 'High Efficiency Performance Levels' or HEPL.

Table 10-1. Scope of the Korean Scheme

Scope
The Korean efficiency standards apply to liquid-filled and dry-type (cast-coil), single-phase and three-phase, kVA ratings from 10 to 3000 kVA for the various combinations of single bushing transformers, and different primary and secondary voltage combinations, up through 22.9 kV.

The minimum performance requirements and high-efficiency performance labelling requirement took effect from July 2012. The efficiency of the transformer is measured at 50% load, in accordance with Korean National Standards: KS C4306, KS C4311, KS C4316 and KS C4317. Korea's electricity system operates at 60Hz.

In their tables of efficiency values, Korea designates the "MEPS" requirement for the Minimum Energy Performance Standard and the "TEPS" requirement for the Target Energy Performance Standard. Both values are presented in the tables below. Korea also states that if the kVA capacity is not contained in the table, then the user shall apply linear interpolation to determine the efficiency of the model.[20] Transformers that were sold prior to the effective date and special purpose transformer (e.g., multi-winding transformers with more than 3 windings, etc.), primary and secondary low-voltage transformers and transformers which have been repaired are not subject to the MEPS and TEPS requirements.

[20] In case that capacity of transformer is in the defined values of the table above, based on the standard number shall be rounded off to two decimal places after using interpolation. For example, in case of 130kVA 22.9kV/440V 3-phase liquid-filled transformer, linear interpolation shall be applied based on the defined capacity and standard (100kVA 98.0% and 150kVA 98.1%) as shown: 130kVA efficiency = 98%+(130-100)×(98.1-98.0)/(150-100)%= 98.06. It shall then be rounded off so that 98.1% shall be energy efficiency standard applicable to a 130kVA transformer.

Table 10-2. Korean MEPS and TEPS for Single Bushing Transformers

kVA	13.2 kV Primary / 230 V Secondary	
	Single Phase MEPS (% efficiency)	Single Phase TEPS (% efficiency)
10	98.3	98.7
20	98.5	98.8
30	98.7	98.9
50	98.8	99.0
75	98.8	99.1
100	98.9	99.2

Note: Testing according to KS C4306.

Table 10-3. Korean MEPS and TEPS for 3.3-6.6kV Dry-Type Distribution Transformers

kVA	Dry-Type, 3.3-6.6 kV Primary / Low Voltage Secondary			
	Single Phase MEPS (% efficiency)	Single Phase TEPS (% efficiency)	Three Phase MEPS (% efficiency)	Three Phase TEPS (% efficiency)
50	97.7	98.7	97.7	98.7
75	97.8	98.8	97.8	98.8
100	98.0	98.9	98.0	98.9
150	98.2	99.0	98.2	99.0
200	98.4	99.0	98.4	99.0
300	98.5	99.1	98.5	99.1
400	98.6	99.2	98.6	99.2
500	98.7	99.3	98.7	99.3
600	98.7	99.3	98.7	99.3
750	98.8	99.3	98.8	99.3
1000	99.0	99.4	98.9	99.4
1250	99.1	99.5	99.0	99.5
1500	99.1	99.5	99.0	99.5
2000	99.2	99.5	99.1	99.5
2500	99.3	99.5	99.2	99.5
3000	99.4	99.5	99.3	99.5

Note: Testing according to KS C4311.

Table 10-4. Korean MEPS and TEPS for 22.9kV Dry-Type Distribution Transformers

kVA	Dry-Type, 22.9 kV Primary / Low Voltage Secondary			
	Single Phase MEPS (% efficiency)	Single Phase TEPS (% efficiency)	Three Phase MEPS (% efficiency)	Three Phase TEPS (% efficiency)
50	97.6	98.7	97.6	98.7
75	97.7	98.8	97.7	98.8
100	97.9	98.8	97.8	98.8
150	98.1	98.9	98.0	98.9
200	98.3	99.0	98.2	99.0
300	98.4	99.1	98.4	99.1
400	98.5	99.2	98.5	99.2
500	98.7	99.2	98.7	99.2
600	98.7	99.3	98.7	99.3
750	98.8	99.3	98.8	99.3
1000	98.9	99.4	98.9	99.4
1250	99.0	99.4	98.9	99.4
1500	99.0	99.5	99.0	99.5
2000	99.1	99.5	99.1	99.5
2500	99.2	99.5	99.2	99.5
3000	99.3	99.5	99.2	99.5

Note: Testing according to KS C4311.

Table 10-5. Korean MEPS and TEPS for 22.9kV Dry-Type Distribution Transformers

kVA	Dry-Type, 22.9 kV Primary / 3.3-6.6 kV Secondary			
	Single Phase MEPS (% efficiency)	Single Phase TEPS (% efficiency)	Three Phase MEPS (% efficiency)	Three Phase TEPS (% efficiency)
50	97.6	98.7	97.6	98.7
75	97.7	98.8	97.7	98.8
100	97.8	98.8	97.8	98.8
150	98.0	98.9	98.0	98.9
200	98.2	99.0	98.2	99.0
300	98.4	99.0	98.4	99.0
400	98.5	99.1	98.5	99.1
500	98.7	99.2	98.7	99.2
600	98.7	99.3	98.7	99.3
750	98.8	99.3	98.8	99.3
1000	98.9	99.4	98.9	99.4
1250	98.9	99.4	98.9	99.4
1500	99.0	99.5	99.0	99.5
2000	99.1	99.5	99.1	99.5
2500	99.2	99.5	99.2	99.5
3000	99.2	99.5	99.2	99.5

Note: Testing according to KS C4311.

Table 10-6. Korean MEPS and TEPS for Low Voltage Liquid-Filled Distribution Transformers

kVA	Liquid-Filled, 3.3-6.6 kV Primary Low Voltage Secondary			
	Single Phase MEPS (% efficiency)	Single Phase TEPS (% efficiency)	Three Phase MEPS (% efficiency)	Three Phase TEPS (% efficiency)
100	98.4	99.0	98.0	99.0
150	98.4	99.0	98.1	99.0
200	98.4	99.0	98.2	99.0
300	98.5	99.1	98.3	99.1
400	98.5	99.1	98.4	99.1
500	98.6	99.2	98.4	99.2
600	98.6	99.2	98.5	99.2
750	98.6	99.2	98.5	99.2
1000	98.7	99.3	98.6	99.3
1250	98.8	99.3	98.7	99.3
1500	98.8	99.4	98.8	99.4
2000	98.9	99.4	98.8	99.4
2500	99.0	99.4	98.9	99.4
3000	99.0	99.4	99.0	99.4

Note: Testing according to KS C4316, KS C4317.

Table 10-7. Korean MEPS and TEPS for Low Voltage Liquid-Filled Distribution Transformers

kVA	Liquid-Filled, 22.9 kV Primary / 3.3-6.6 kV Secondary			
	Single Phase MEPS (% efficiency)	Single Phase TEPS (% efficiency)	Three Phase MEPS (% efficiency)	Three Phase TEPS (% efficiency)
100	98.4	99.0	98.1	99.0
150	98.5	99.0	98.2	99.0
200	98.5	99.0	98.2	99.0
250	98.6	99.1	98.3	99.1
300	98.6	99.1	98.4	99.1
400	98.7	99.2	98.5	99.2
500	98.8	99.2	98.6	99.2
600	98.8	99.2	98.6	99.2
750	98.9	99.3	98.6	99.3
1000	98.9	99.3	98.7	99.3
1250	99.0	99.4	98.8	99.4
1500	99.0	99.4	98.9	99.4
2000	99.1	99.4	99.0	99.4
2500	99.1	99.4	99.1	99.4

Note: Testing according to KS C4316, KS C4317.

Table 10-8. Korean MEPS and TEPS for 22.9kV Liquid-Filled Distribution Transformers

kVA	Liquid-Filled, 22.9 kV Primary Low Voltage Secondary			
	Single Phase MEPS (% efficiency)	Single Phase TEPS (% efficiency)	Three Phase MEPS (% efficiency)	Three Phase TEPS (% efficiency)
10	97.4	98.6		
15	97.7	98.6		
20	97.9	98.7		
30	98.1	98.8		
50	98.4	98.8		
75	98.6	98.9		
100	98.7	99.0	98.0	99.0
150	98.4	99.0	98.1	99.0
200	98.4	99.0	98.2	99.0
250	98.5	99.1	98.3	99.1
300	98.5	99.1	98.4	99.1
400	98.6	99.2	98.4	99.1
500	98.6	99.2	98.5	99.1
600	98.6	99.2	98.5	99.2
750	98.7	99.3	98.6	99.2
1000	98.8	99.3	98.7	99.3
1250	98.8	99.4	98.8	99.3
1500	98.9	99.4	98.8	99.3
2000	99.0	99.4	98.9	99.3
2500	99.1	99.4	99.0	99.4
3000	99.2	99.4	99.1	99.4

Note: Testing according to KS C4316, KS C4317.

The following figure is a screen capture of the Korean label for distribution transformers. It must be 7cm (length) x 7cm (height), but it can be adjusted slightly, given in its location.

Figure 10-1. Korean Label for Distribution Transformers

The standardisation process in Korea follows the basic principles for standards development outlined by the International Organization for Standardization (ISO), the IEC and the World Trade Organization (WTO) Technical Barriers to Trade Agreement (TBT). The Korean Agency for Technology and Standards (KATS) oversees the development of national Korean Standards (KS), coordinating input from public and private sector stakeholders through KATS' technical committees. KATS also acts as an accreditation body for laboratories.[21] There are over 20,000 published Korean Standards.

As discussed in the energy-efficiency measures report, Korea has adopted MEPS and Top Energy Performance Standards (TEPS) to help transform their market to use high-efficiency transformers in the electricity transmission and distribution system. Starting in July 2012, Korea established these requirements to promote more energy-efficient transformers. The requirements are based on a percentage efficiency that is calculated at 50% load, which is measured in accordance with the following four standards:

- KS C 4306 - Single high voltage cover bushing transformers
- KS C 4311 - Dry-type transformer
- KS C 4316 - Tow bushing type pole transformer for 22.9 kV
- KS C 4317 - Distribution transformers not more than 3MVA for 22.9kV

Within these 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.

The following table lists the standards that have been adopted by KATS. [22]

[21] 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.
[22] http://www.kssn.net/English/WebStore/C_WebStore_info2.asp?key=transformer&KS=KS&page=5

Table 10-9. Korean Standards Harmonised with IEC 60076

Standard	Description	Date
KS C IEC 60076-1	Power transformers－Part 1 ： General	2002.10.29
KS C IEC 60076-2	Power transformers－Part 2 ： Temperature rise	2002.10.29
KS C IEC 60076-3	Power transformer－Part 3 ： Insulation levels, dielectric tests and external clearances in air	2002.10.29
KS C IEC 60076-4	Power transformers－Part 4 ： Guide to the lightning impulse and switching impulse testing－Power transformers and reactors	2008.03.31
KS C IEC 60076-5	Power transformers－Part 5 ： Ability to withstand short circuit	2008.03.31
KS C IEC 60076-7	Power transformers－Part 7 ： Loading guide for oil-immersed power transformers	2008.11.20
KS C IEC 60076-8	Power transformers－Part 8 ： Application guide	2002.10.29
KS C IEC 60076-10	Power transformers－Part 10 ： Determination of sound levels	2003.12.29
KS C IEC 60076-10-1	Power transformers－Part 10－1 ： Determination of sound levels－Application guide	2008.11.20
KS C IEC 60076-11	Power transformers－Part 11 ： Dry-type transformers	2008.03.31

11 Mexico

Mexico began regulating distribution transformers with mandatory performance requirements over thirty years ago when it enacted Normas Oficiales Mexicanas (NOM)-J116 in 1977. In 1989, however, the status of these and all NOM requirements was changed from mandatory to voluntary under a presidential decree. NOM-J116 became NMX-J116, a Norma Mexicana (Mexican Testing Standard). Then, in 1992, the Ley Federal sobre etrología y Normalización (Federal Law on Metering and Standards) re-instated the mandatory aspect of the NOM (Official Mexican Standards) requirements. In addition, the 1992 law empowered the Secretaría de Energía (the Mexican Energy Secretary / Minister) to formulate and adopt mandatory performance standards for electrical end-use appliances and equipment.

In 1994, a new mandatory standard was enacted, NOM-001-SEMP-1994, to regulate the energy efficiency and safety of electrical equipment including distribution transformers. In 1997, Mexico's government proposed a revision to NOM-001 and a new national standard, NOM-002-SEDE-1997. NOM-002 was published in Mexico's Diario Oficial de la Federación (Official Registry) for public law and it was enacted in October 1999. In general, the mandated efficiency levels in this regulation were slightly lower than the Canadian voluntary standards and the National Electrical Manufacturer's Association (NEMA) voluntary standard, NEMA TP1-2002.

Table 11-1. Scope of the Mexican Scheme

Scope
The scope of coverage for liquid-filled distribution transformers in Mexico includes single-phase and three-phase units, 5 to 167 kVA capacity for single-phase and 15 to 500 kVA capacity for three-phase. The transformer has a rating of up to 34 500 V on the primary side and up to 15 000 V nominal on the secondary side. The regulation applies to pad, pole, substation and submersible; and applies to newly purchased as well as repaired / refurbished. Dry-type distribution transformers are used in Mexico, but no mandatory regulatory standards have been adopted yet.

The Mexican government revisited NOM-002 to update several aspects of the standard. The new version of the document, NOM-002-SEDE/ENER-2012, was presented to the Comité Consultivo Nacional de Normalización de Instalaciones Eléctricas (CCNNIE) on August 22, 2012 and was published in the Diario Oficial de la Federación on the 20 February 2013. The new standard levels adopted in this update to NOM-002 will take effect once the process is finalised, establishing new and updated requirements for safety and energy-efficiency for distribution transformers. The standard regulates liquid-immersed units, and is the only compulsory efficiency regulation of distribution transformers in Mexico. Dry-type distribution transformers are very rarely used in Mexico, therefore neither government nor industry has moved to regulate them.

NOM-002 includes both single-phase and three-phase liquid-filled transformers for pad, pole, substation and submersible installations, rated 15 to 167 kVA for single-phase and 15 to 500 kVA for three-phase. The requirements are presented in the national standard both in terms of per cent efficiency at 80% loading and as maximum watts.

The following two tables present the current requirements and the proposed new requirements for single phase and three phase liquid-filled distribution transformers, respectively. Within each table, the requirements are divided into three groups, based on the primary voltage. In both cases – percentage efficiency and maximum watts – the transformer's performance is measured at 80% of rated output.

Table 11-2. Mexican Standards for Liquid-Filled Distribution Transformers, Efficiency

kVA	Up to 95 BIL (15 kV)		Up to 150 BIL (18-25 kV)		Up to 200 BIL (34.5 kV)	
Single Phase						
Requirements	(draft)	(current)	(draft)	(current)	(draft)	(current)
5	-	97.90%	-	97.80%	-	97.70%
10	98.61%	98.25%	98.49%	98.15%	98.28%	98.05%
15	98.75%	98.40%	98.63%	98.30%	98.43%	98.20%
25	98.90%	98.55%	98.79%	98.45%	98.63%	98.35%
37.5	98.99%	98.65%	98.90%	98.55%	98.75%	98.45%
50	99.08%	98.75%	98.99%	98.65%	98.86%	98.55%
75	99.21%	98.90%	99.12%	98.80%	99.00%	98.70%
100	99.26%	98.95%	99.16%	98.85%	99.06%	98.75%
167	99.30%	99.00%	99.21%	98.90%	99.13%	98.80%
Three Phase						
Requirements	(draft)	(current)	(draft)	(current)	(draft)	(current)
15	98.32%	97.95%	98.18%	97.85%	98.03%	97.75%
30	98.62%	98.25%	98.50%	98.15%	98.35%	98.05%
45	98.72%	98.35%	98.60%	98.25%	98.48%	98.15%
75	98.86%	98.50%	98.75%	98.40%	98.64%	98.30%
112.5	98.95%	98.60%	98.85%	98.50%	98.76%	98.40%
150	99.03%	98.70%	98.94%	98.60%	98.86%	98.50%
225	99.06%	98.75%	98.96%	98.65%	98.87%	98.55%
300	99.11%	98.80%	99.02%	98.70%	98.92%	98.60%
500	99.20%	98.90%	99.11%	98.80%	99.03%	98.70%

Table 11-3. Mexican Standards for Liquid-Filled Distribution Transformers, Total Watts

kVA	Up to 95 BIL (15 kV)		Up to 150 BIL (18-25 kV)		Up to 200 BIL (34.5 kV)	
Single Phase						
Requirements	(draft)	(current)	(draft)	(current)	(draft)	(current)
5	-	107	-	112	-	118
10	113	178	123	188	140	199
15	152	244	167	259	191	275
25	222	368	245	394	278	419
37.5	306	513	334	552	380	590
50	371	633	408	684	461	736
75	478	834	533	911	606	988
100	596	1061	678	1163	759	1266
167	942	1687	1064	1857	1173	2028
Three Phase						
Requirements	(draft)	(current)	(draft)	(current)	(draft)	(current)
15	205	314	222	330	241	345
30	336	534	365	565	403	597
45	467	755	511	802	556	848
75	692	1142	759	1220	827	1297
112.5	955	1597	1047	1713	1130	1829
150	1175	1976	1286	2130	1384	2284
225	1708	2844	1892	3080	2057	3310
300	2155	3644	2375	3951	2620	4260
500	3226	5561	3592	6073	3918	6586

In 2010, NOM-002 was revised to update several aspects of the standard. The new version of the document, NOM-002-SEDE-2010, was approved by the Comité Consultivo Nacional de Normalización de Instalaciones Eléctricas (CCNNIE) on July 8, 2010. Once it is published in the Diario Oficial de la Federación, the new standard will take effect six months later. This standard, which regulates liquid-immersed units, is the only compulsory efficiency regulation of distribution transformers in Mexico. Dry-type distribution transformers are used in Mexico, but no mandatory regulatory standards have been adopted yet.

The following table is an extract from the Norma Oficial Mexicana NOM-002-SEDE-2010, Requisitos de seguridad y eficiencia energética para transformadores de distribución (Safety requirements and energy efficiency for distribution transformers). In section 6.2 of the regulation, it cross-references the Mexican testing standard that should be used for measuring the core and coil losses.

Table 11-4. Test Standard Cross-Reference from Mexican Regulation NOM-002-SEDE-2010

Mexican Standard	English Translation
6.2 Métodos de prueba aplicables a eficiencia energética Para verificar las características de eficiencia energética establecidas en el inciso 5.2 se deberá cumplir con lo siguiente: a) Para las pruebas de pérdidas en vacío, los transformadores de distribución deberán cumplir con lo establecido en el capítulo 7 relativo a "Pérdidas en vacío y corriente de excitación" de la Norma Mexicana NMX-J-169-ANCE-2004. b) Para las pruebas de pérdidas debidas a la carga, los transformadores de distribución deberán cumplir con lo establecido en el capítulo 8 relativo a "Pérdidas debidas a la carga e impedancia" de la Norma Mexicana NMX-J-169-ANCE-2004.	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. The following figure shows a screen capture of this section of the Official Gazette.

[23] http://www.paot.org.mx/centro/leyes/federales/pdf/DOF/DOF_2009_06_17.pdf

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.

Figure 11-1. The Calculation of Efficiency in Mexico

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

12 United States of America

The United States has been working on energy-efficiency for distribution transformers for over 20 years.[24] Starting with the Energy Policy Act of 1992, the US Department of Energy (DOE) initiated a process to review and establish energy conservation standards for distribution transformers. In parallel with that effort, the manufacturer's association in the United States, the National Electrical Manufacturer's Association (NEMA), prepared and published a voluntary standard, NEMA TP-1 in 1996, which was subsequently updated in 2002, covering the following distribution transformers:

- Liquid-filled distribution transformers, single and three-phase;
- Dry-type, low-voltage, single and three phase; and
- Dry-type, medium-voltage, single and three-phase.

Table 12-1. Scope of the USA Scheme

Scope
The US 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 Volts or less. The power ratings are from 10 to 2500 kVA for liquid-immersed units and 15 to 2500 kVA for dry-type units.

In September 2000, the US DOE initiated its work to develop energy conservation regulatory standards for liquid-filled (and dry-type) distribution transformers. In October 2007, the DOE completed its analysis, and published the Final Rule for Energy Conservation Standards for Distribution Transformers in Part 431 of Title 10 of the Code of Federal Regulations (10 CFR Part 431).[25] This regulation stipulates that all distribution transformers manufactured or imported into the United States after January 1, 2010 must have efficiencies that are no less than the specified efficiency values at 50% of rated load. The US national regulation applies to liquid-filled transformers rated between 10 to 2500 kVA and medium voltage , dry type distribution transformers, rated between 15 to 833 kVA for single phase and 15 to 2500 kVA for three-phase.

In addition to these regulations, US Congress passed the Energy Policy Act of 2005 which specified that the efficiency of all low-voltage dry-type transformers "manufactured on or after January 1, 2007, shall be the Class I Efficiency Levels for distribution transformers specified in table 4-2 of the 'Guide for Determining Energy Efficiency for Distribution Transformers' published by the National Electrical Manufacturers Association (NEMA TP-1-

[24] Link to US DOE Regulatory Page for Distribution Transformers: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/66

[25] Link to the electronic Code of Federal Register (eCFR) page which contains the Transformer regulations: http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=d9df3d628e4ba2743f7b31afd51eb3a9&rgn=div6&view=text&node=10:3.0.1.4.19.11&idno=10

2002)." In adopting this language, Congress established the NEMA TP-1 -2002 requirements as mandatory efficiency requirements for low-voltage dry-type distribution transformers.

In 2011, DOE initiated work on reviewing its regulations on distribution transformers, including all three groups – liquid-filled, low-voltage dry-type and medium-voltage dry-type transformers. In April 2013, DOE completed this process and it published the new efficiency requirements that will become effective in January 2016. For the liquid-filled and medium-voltage dry-type transformers, the efficiency values shown are at 50% load while the low-voltage dry-type transformers are at 35% of load. The following tables present the US regulations for all groups of distribution transformers, both the 2010 regulation and upcoming 2016 regulation.

Table 12-2. US Efficiency Regulations for Liquid-Filled Distribution Transformers

kVA	Single-Phase		kVA	Three-Phase	
	% Efficiency 2010	% Efficiency 2016		% Efficiency 2010	% Efficiency 2016
10	98.62	98.70	15	98.36	98.65
15	98.76	98.82	30	98.62	98.83
25	98.91	98.95	45	98.76	98.92
37.5	99.01	99.05	75	98.91	99.03
50	99.08	99.11	112.5	99.01	99.11
75	99.17	99.19	150	99.08	99.16
100	99.23	99.25	225	99.17	99.23
167	99.25	99.33	300	99.23	99.27
250	99.32	99.39	500	99.25	99.35
333	99.36	99.43	750	99.32	99.40
500	99.42	99.49	1,000	99.36	99.43
667	99.46	99.52	1,500	99.42	99.48
833	99.49	99.55	2,000	99.46	99.51
-	-	-	2,500	99.49	99.53

* All efficiency levels in this table are measured at 50% load.

The following table presents the low-voltage distribution requirements for the United States. The table has the correct number of significant digits associated with each requirement. The single-phase transformers will not increase in efficiency, but the three-phase are improving in 2016.

Table 12-3. US Efficiency Regulations for Low-Voltage Dry-Type Distribution Transformers

kVA	Single-Phase		kVA	Three-Phase	
	% Efficiency 2007	% Efficiency 2016		% Efficiency 2007	% Efficiency 2016
15	97.7	97.70	15	97.0	97.89
25	98.0	98.00	30	97.5	98.23
37.5	98.2	98.20	45	97.7	98.40
50	98.3	98.30	75	98.0	98.60
75	98.5	98.50	112.5	98.2	98.74
100	98.6	98.60	150	98.3	98.83
167	98.7	98.70	225	98.5	98.94
250	98.8	98.80	300	98.6	99.02
333	98.9	98.90	500	98.7	99.14
-	-	-	750	98.8	99.23
-	-	-	1,000	98.9	99.28

* All efficiency levels in this table are measured at 35% load.

Table 12-4. US Regulations for Single Phase, Medium-Voltage Dry-Type Transformers

kVA	20-45 kV BIL		46-95 kV BIL		≥96 kV BIL	
	% Efficiency 2010	% Efficiency 2016	% Efficiency 2010	% Efficiency 2016	% Efficiency 2010	% Efficiency 2016
15	98.10	98.10	97.86	97.86	-	-
25	98.33	98.33	98.12	98.12	-	-
37.5	98.49	98.49	98.30	98.30	-	-
50	98.60	98.60	98.42	98.42	-	-
75	98.73	98.73	98.57	98.57	98.53	98.53
100	98.82	98.82	98.67	98.67	98.63	98.63
167	98.96	98.96	98.83	98.83	98.80	98.80
250	99.07	99.07	98.95	98.95	98.91	98.91
333	99.14	99.14	99.03	99.03	98.99	98.99
500	99.22	99.22	99.12	99.12	99.09	99.09
667	99.27	99.27	99.18	99.18	99.15	99.15
833	99.31	99.31	99.23	99.23	99.20	99.20

* All efficiency levels in this table are measured at 50% load.

Table 12-5. US Regulations for Three Phase, Medium-Voltage Dry-Type Transformers

kVA	20-45 kV		46-95 kV		≥96 kV BIL	
	% Efficiency 2010	% Efficiency 2016	% Efficiency 2010	% Efficiency 2016	% Efficiency 2010	% Efficiency 2016
15	97.50	97.50	97.18	97.18	-	-
30	97.90	97.90	97.63	97.63	-	-
45	98.10	98.10	97.86	97.86	-	-
75	98.33	98.33	98.12	98.13	-	-
112.5	98.49	98.52	98.3	98.36	-	-
150	98.60	98.65	98.42	98.51	-	-
225	98.73	98.82	98.57	98.69	98.53	98.57
300	98.82	98.93	98.67	98.81	98.63	98.69
500	98.96	99.09	98.83	98.99	98.80	98.89
750	99.07	99.21	98.95	99.12	98.91	99.02
1,000	99.14	99.28	99.03	99.20	98.99	99.11
1,500	99.22	99.37	99.12	99.30	99.09	99.21
2,000	99.27	99.43	99.18	99.36	99.15	99.28
2,500	99.31	99.47	99.23	99.41	99.20	99.33

* All efficiency levels in this table are measured at 50% load.

The figure below provides a comparison between the 2010 and the 2016 efficiency levels for the US DOE regulations on liquid-filled and medium-voltage dry-type transformers. The new regulation has a smoother requirement across the kVA ratings. Please note that this graph has a logarithmic X-axis of kVA ratings.

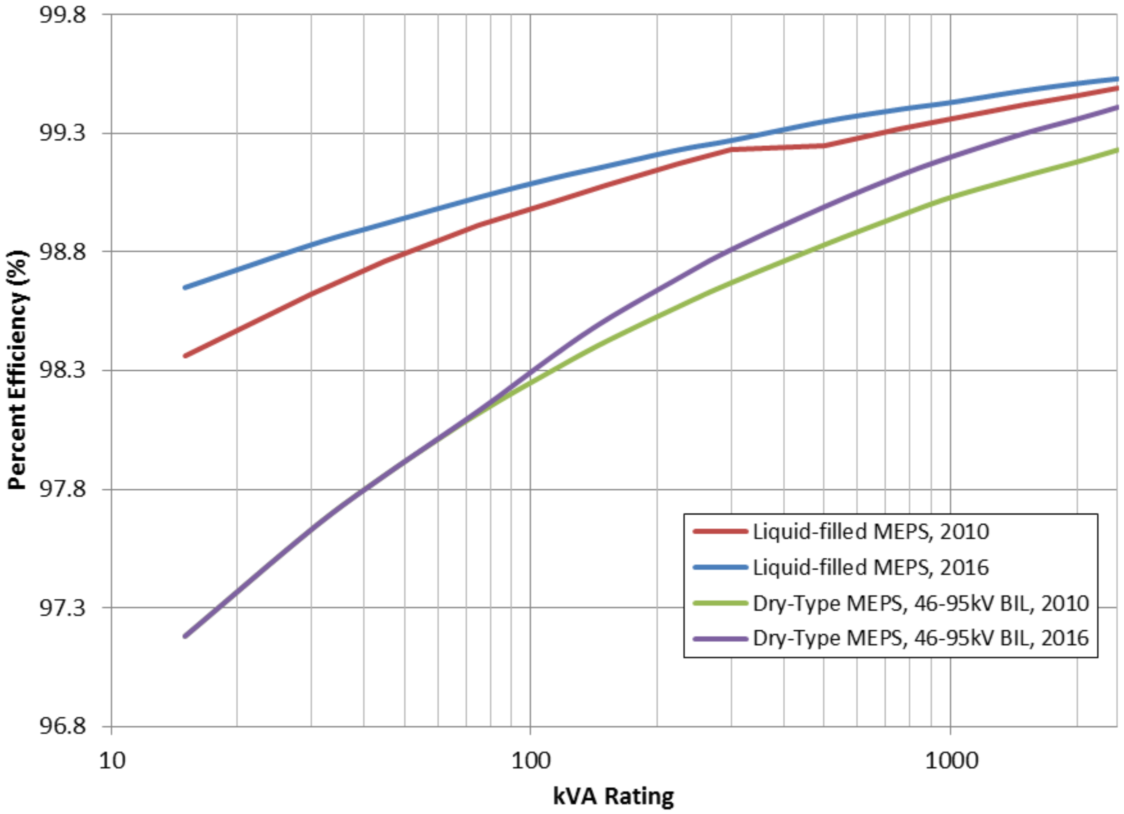

Figure 12-1. Comparison of Requirements for US DOE Regulations from 2010 and 2016

The US Department of Energy (DOE) adopted its test method for measuring the efficiency of distribution transformers in April 2006. The DOE's test procedure is based on the test methods contained in NEMA TP 2-1998 and IEEE Standards C57.12.90-1999 and C57.12.91-2001. The final rule, without reference to other sources, determines the energy efficiency of distribution transformers through the measurement of no-load and load losses. The DOE test method specifies the temperature, current, voltage, extent of distortion in voltage waveform, and direct current resistance of the windings. The standard also prescribes provisions for calculating efficiency. The DOE test method is freely available and is published in the electronic Code of the Federal Register, Title 10: Energy, Part 431— Energy Efficiency Program for Certain Commercial and Industrial Equipment, Subpart K—Distribution Transformers.[26]

Section 4.4.2 provides a summary of the steps for measuring the no-load losses.

> 4.4.2 No-Load Loss Test.
>
> (a) The purpose of the no-load loss test is to measure no-load losses at a specified excitation voltage and a specified frequency. The no-load loss determination must be based on a sine-wave voltage corrected to the reference temperature. Connect either of the transformer windings, primary or secondary, to the appropriate test set of Figures 4.1 to 4.4, giving consideration to section 4.4.2(a)(2). Leave the unconnected winding(s) open circuited. Apply

[26] http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=c3340b22047d664d6601c6036f98b88e&rgn=div9&view=text&node=10:3.0.1.4.19.11.67.5.43&idno=10

the rated voltage at rated frequency, as measured by the average-sensing voltmeter, to the transformer. Take the readings of the wattmeter(s) and the average-sensing and true rms voltmeters. Observe the following precautions:

(1) Voltmeter connections. When correcting to a sine-wave basis using the average-voltmeter method, the voltmeter connections must be such that the waveform applied to the voltmeters is the same as the waveform across the energized windings.

(2) Energized windings. Energize either the high voltage or the low voltage winding of the transformer under test.

(3) Voltage and frequency. The no-load loss test must be conducted with rated voltage impressed across the transformer terminals using a voltage source at a frequency equal to the rated frequency of the transformer under test.

(b) Adjust the voltage to the specified value as indicated by the average-sensing voltmeter. Record the values of rms voltage, rms current, electrical power, and average voltage as close to simultaneously as possible. For a three-phase transformer, take all of the readings on one phase before proceeding to the next, and record the average of the three rms voltmeter readings as the rms voltage value.

Note: When the tester uses a power supply that is not synchronized with an electric utility grid, such as a dc/ac motor-generator set, check the frequency and maintain it within ±0.5 per cent of the rated frequency of the transformer under test. A power source that is directly connected to, or synchronized with, an electric utility grid need not be monitored for frequency.

Section 4.5.2 provides a summary of the steps for measuring the load losses.

4.5.2 Tests for Measuring Load Losses.

(a) Connect the transformer with either the high-voltage or low-voltage windings to the appropriate test set. Then short-circuit the winding that was not connected to the test set. Apply a voltage at the rated frequency (of the transformer under test) to the connected windings to produce the rated current in the transformer. Take the readings of the wattmeter(s), the ammeters(s), and rms voltmeter(s).

(b) Regardless of the test set selected, the following preparatory requirements must be satisfied for accurate test results:

(1) Determine the temperature of the windings using the applicable method in section 3.2.1 or section 3.2.2.

(2) The conductors used to short-circuit the windings must have a cross-sectional area equal to, or greater than, the corresponding transformer leads, or, if the tester uses a different method to short-circuit the windings, the losses in the short-circuiting conductor assembly must be less than 10 per cent of the transformer's load losses.

(3) When the tester uses a power supply that is not synchronized with an electric utility grid, such as a dc/ac motor-generator set, follow the provisions of the “Note” in section 4.4.2.

The power-efficiency equation contained in the DOE testing standard is as follows:

$$\eta = 100\left(\frac{P_{OS}}{P_{OS} + P_{ts}}\right)$$

where:

P_{os} is the specified power efficiency load level, calculated from the rated transformer apparent power (name plate) times the per unit load level (description and equations are provided in section 5.1 of the testing standard), and

P_{ts} is the corrected total loss power adjusted for the transformer output loading specified by the standard (description and equations are provided in section 5.2 of the testing standard).

This equation used by the DOE for calculating the efficiency of a distribution transformer is the same as the equation used in the IEEE standards.

13 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, TCVN 8525:2010, Distribution transformers – minimum energy performance and method for determination of energy efficiency. This standard cross-references the IEC Standards and its measurement methods are based on IEC 60076.

Table 13-1. Scope of the Vietnamese Scheme

Scope
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. The standard does not apply to certain types of special transformers such as temporary mobile transformers and traction transformers.

The table below presents the per cent efficiency requirements for the covered transformers.

Table 13-2. Vietnam Minimum Efficiency Requirements for Liquid-Filled Transformers

Liquid-filled 50Hz Distribution Transformers, 0.4kV – 35kV			
kVA	**MEPS (% efficiency)**	**kVA**	**MEPS (% efficiency)**
25	98.28	500	99.13
32	98.34	630	99.17
50	98.50	750	99.21
63	98.62	800	99.22
100	98.76	1000	99.27
125	98.80	1250	99.31
160	98.87	1500	99.35
200	98.94	1600	99.36
250	98.98	2000	99.39
315	99.04	2500	99.40
400	99.08		

The national testing standards used to measure performance are called "Tiêu chuẩn Việt Nam" (TCVN), which in English means "Vietnam Standards". As discussed in the energy-efficiency report, Vietnam has adopted mandatory efficiency regulations for distribution transformers.

Vietnam's regulation on distribution transformers is contained in TCVN 8525: 2010, "Máy biến áp phân phối – Hiệu suất năng lượng tối thiểu và phương pháp xác định" (English: Distribution Transformers - the minimum energy efficiency and methods for determining energy efficiency). This standard establishes the MEPS and test method of determining the energy efficiency for three-phase liquid-filled distribution transformers with nominal capacity from 25 to 2,500 kVA and nominal voltage up to 35 kV and frequency of 50Hz.

In TCVN 8525:2010, the equation for efficiency is provided as shown below:

5.3 Xác định hiệu suất năng lượng

Hiệu suất năng lượng được xác định theo công thức:

$$E_{50\%} = \frac{0,5 \cdot S}{0,5 \cdot S + 0,25 \cdot P_k + P_0} \times 100\%$$

trong đó :

$E_{50\%}$ - hiệu suất tính bằng phần trăm của máy biến áp ở 50 % phụ tải và ở hệ số công suất bằng 1;

S - công suất danh định của máy biến áp phân phối tính bằng kVA;

P_k - tổn hao có tải của máy biến áp phân phối, tính bằng kW;

P_o - tổn hao không tải của máy biến áp phân phối, tính bằng kW.

Kết quả tính toán $E_{50\%}$ phải được hiệu chỉnh về nhiệt độ chuẩn là 75 °C theo TCVN 6306-1 (IEC 60076-1).

Figure 13-1. Vietnam Efficiency Equation from TCVN 8525:2010

This standard shows that the equation being used to calculate efficiency in Vietnam is actually the IEEE equation of efficiency, based on a 50% loading point. Efficiency is equal to half the nominal rated kVA capacity divided by the sum of half the rated capacity plus the coil losses at 50% load and the core losses.

In TCVN 8525:2010, the regulation cross-references loss measurement procedures adopted in the Vietnamese Standard TCVN 6306-1, which is harmonised with IEC 60076. The table below depicts the relevant standards that have been adopted in Vietnam which are based on the IEC method of loss measurement.

Table 13-3. Vietnamese Testing Standards Harmonised with IEC 60076

Standard	Vietnamese Title	English Translation
TCVN 6306-1:2006 (IEC 60076-1:2000)	Máy biến áp điện lực – Phần 1: Quy định chung	Power transformers. Part 1: General
TCVN 6306-2:2006 (IEC 60076-2:1993)	Máy biến áp điện lực – Phần 2: Độ tăng nhiệt	Power transformers. Part 2: Temperature rise
TCVN 6306-3:2006 (IEC 60076-3:2000)	Máy biến áp điện lực – Phần 3: Mức cách điện, thử nghiệm điện môi và khoảng cách ly bên ngoài trong không khí	Power transformers. Part 3: Insulation levels and dielectric tests and external clearances in air
TCVN 6306-5:2006 (IEC 60076-5:2006)	Máy biến áp điện lực – Phần 5: Khả năng chịu ngắn mạch	Power transformers. Part 5: Ability to withstand short circuit