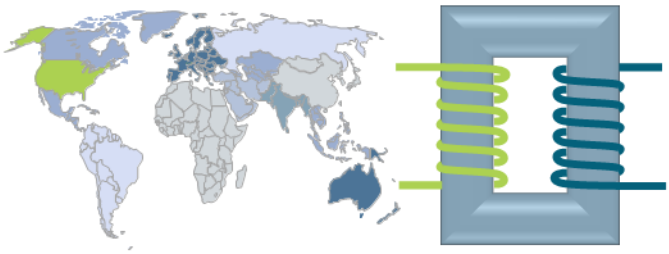
Mapping Document



Country:	USA
Technology:	Distribution Transformers
Sub Category:	Dry and liquid filled

Introduction

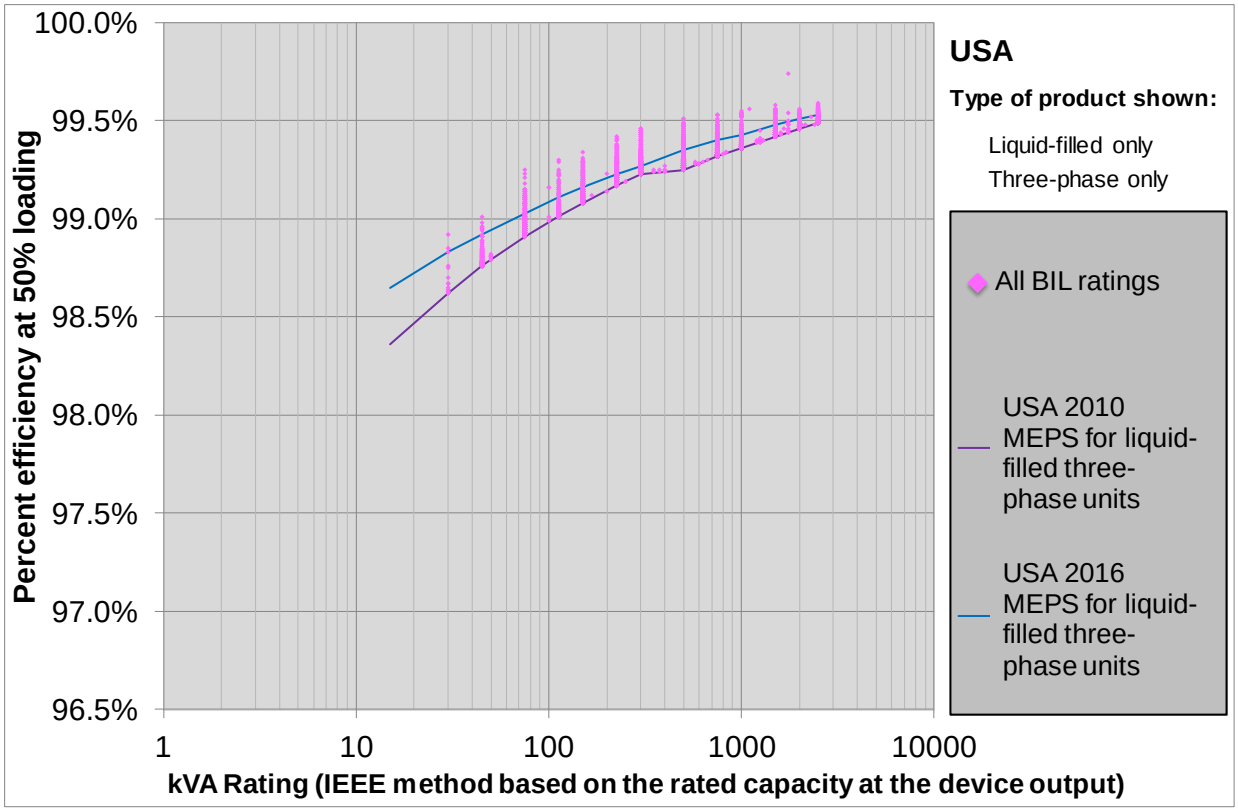
The first stage in the Mapping and Benchmarking process is the definition of the products, i.e. clearly setting the boundaries that define the products for use in data collection and analysis. This ensures the comparison between the participating countries is done against a specific and consistent set of products.

The summary definition for this product is:

M&B Category	Description
Definition and Scope	**Transformer** means a static piece of apparatus with two or more windings that, by electromagnetic induction, transforms a system of alternating voltage and current into another system of alternating voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power. A **distribution transformer** takes voltage from a primary distribution circuit and steps down to a secondary distribution circuit. Products included within scope of this analysis are distribution transformers including oil-immersed and dry-type, single-phase and three-phase, rated from 10 to 3150 kVA, with a primary voltage of 36kV or less, and designed to operate at 50 or 60 Hz.
Characteristics of interest to the analysis	• Type of cooling - liquid-filled (e.g., mineral oil) or dry-type (air-cooled) • Operating frequency, usually 50Hz or 60Hz • Number of phases: single-phase or three-phase • Power handling capacity (i.e., the kVA rating) • Voltage class, based on the primary winding insulation level • Designed for installation on a pad, a pole, or other
Exclusions	Special purpose transformers are excluded from the scope, including: instrument transformers, rectifier transformers , furnace transformers, auto-transformers , grounding transformers, starting transformers, testing transformers, welding transformers, explosion-proof transformers , underground mining transformers, and submerged transformers.

The detailed product definition can be found at the Annex website:
http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=15

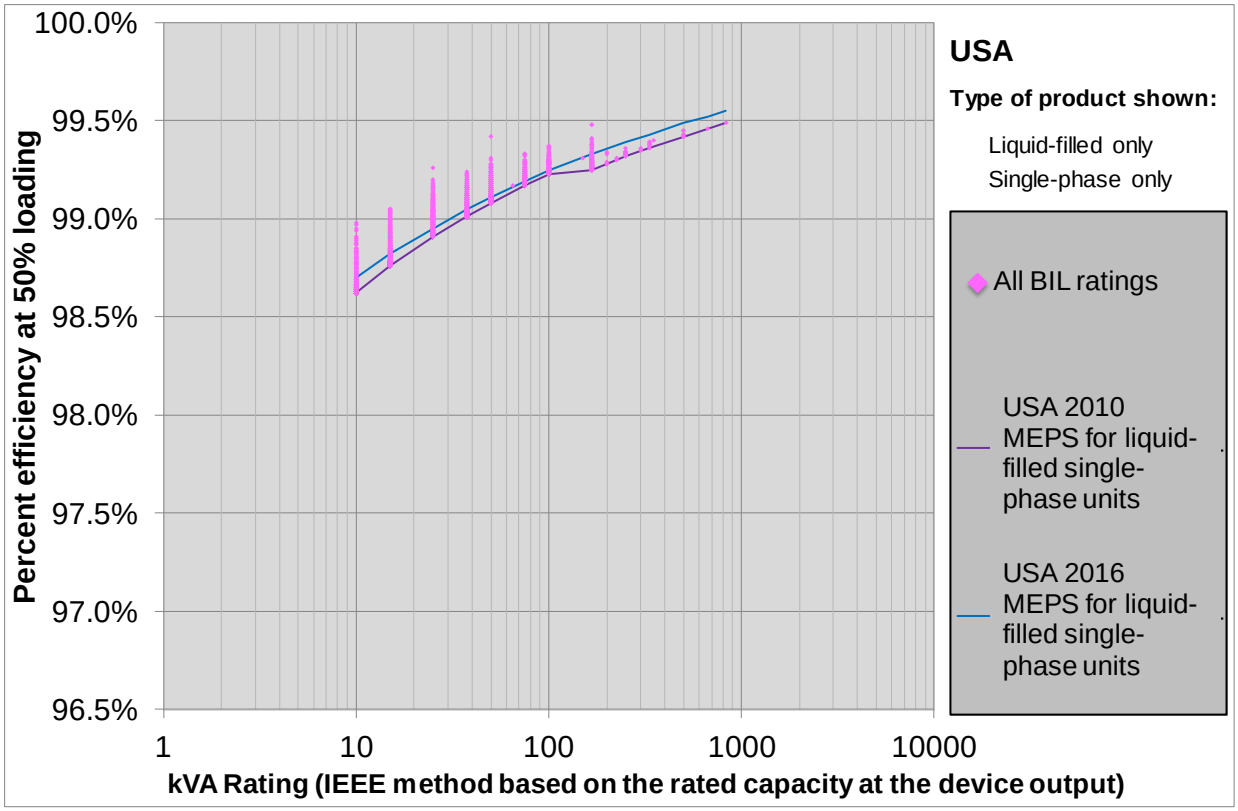
Percentage efficiency at 50% loading for distribution transformers in the USA: Three-phase liquid-filled transformers



Key notes on graph (see notes section 1)

- The source of data for this graph is the US DOE Compliance Certification Management System database as at September 2013 and all data is declared according to the US DOE Test Standard, 10 CFR 431 Subpart K, which is based on IEEE and NEMA test standards.
- This graph shows performance data for 5071 distribution transformers (representing 62% of liquid-type models in the dataset) with efficiency calculated according to the US DOE Test Standard (based on the IEEE method with rated capacity at the device output).
- The products shown in this graph are all three-phase liquid filled and operate at 60Hz.
- The MEPS levels shown for 2010 and 2016 span from 15 to 2,500 kVA, although the models shown on the graph range from 30 to 2500 kVA.
- Products are shown for all voltage classes (Basic Impulse insulation Levels (BIL)), as the US efficiency regulation does not differentiate product classes of liquid-filled distribution transformers by primary voltage.
- All of the models in the database meet the MEPS requirements.

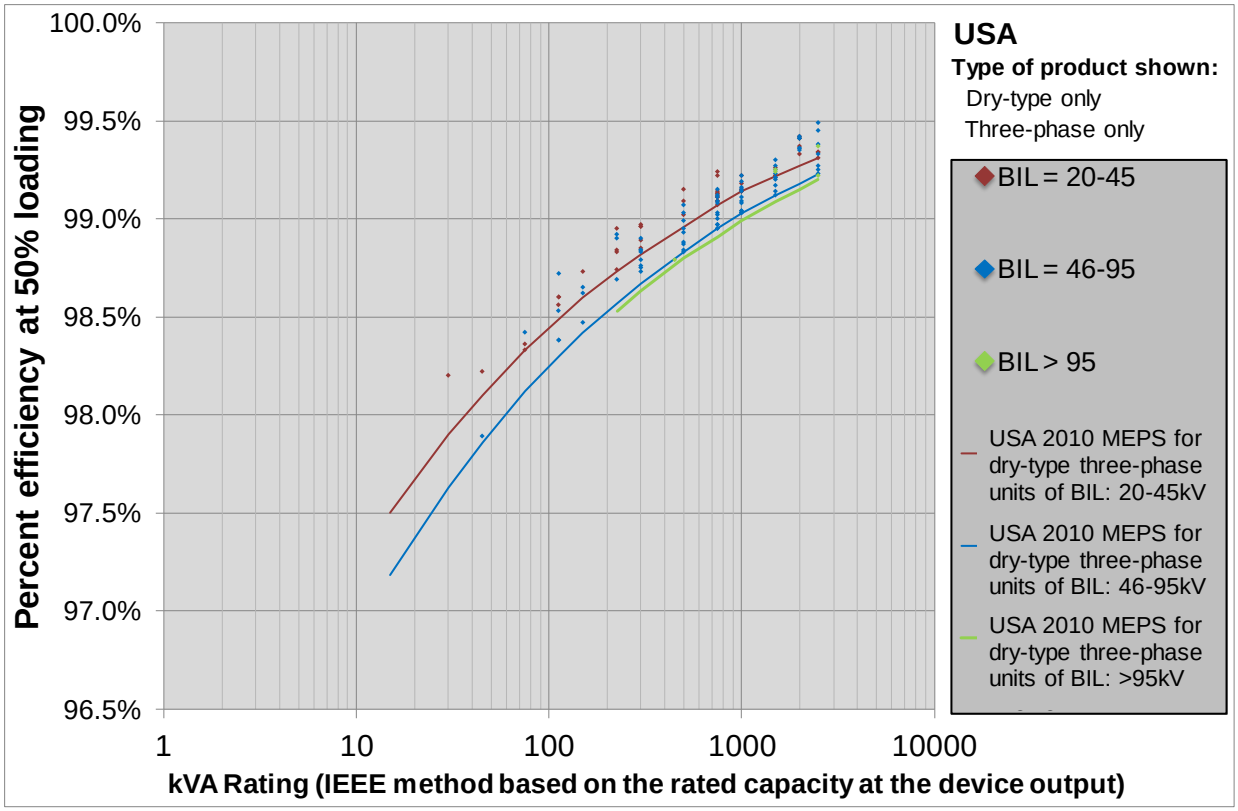
Percentage efficiency at 50% loading for distribution transformers in the USA: Single-phase liquid-filled transformers



Key notes on graph (see notes section 1)

- The source of data for this graph is the US DOE Compliance Certification Management System database as at September 2013 and all data is declared according to the relevant IEEE/ANSI test standard.
- This graph shows performance data for 3169 distribution transformers (representing 38% of liquid-type models in the dataset) with efficiency calculated according to the US DOE Test Standard (based on the IEEE method with rated capacity at the device output).
- The products shown in this graph are all single-phase liquid filled and operate at 60Hz with ratings from 10 to 833 kVA.
- Products are shown for all voltage classes (Basic Impulse insulation Levels (BIL)), as the US efficiency regulation does not differentiate product classes of liquid-filled distribution transformers by primary voltage.
- All of the models in the database meet the MEPS requirements.

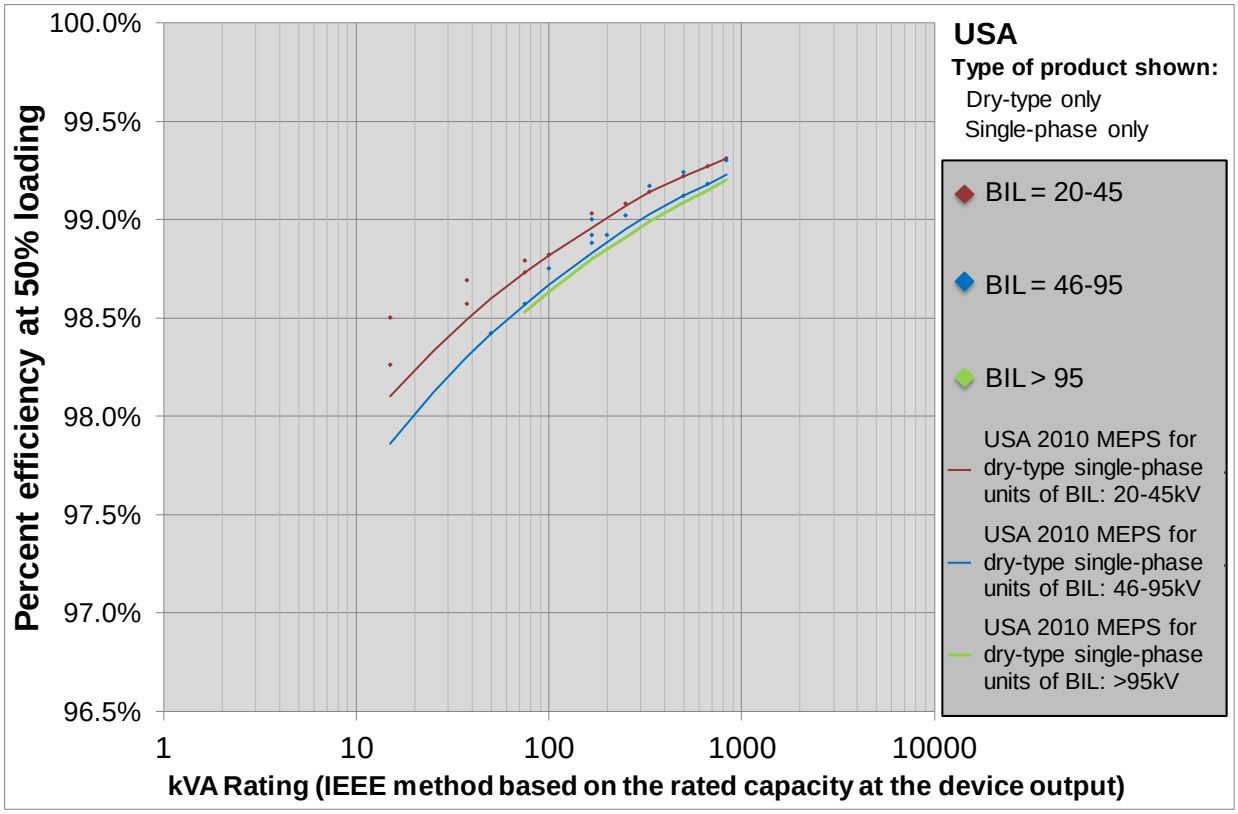
Percentage efficiency at 50% loading for distribution transformers in the USA: Three-phase dry-type transformers by BIL rating



Key notes on graph (see notes section 1)

- The source of data for this graph is the US DOE Compliance Certification Management System database as at September 2013 and all data is declared according to the relevant IEEE/ANSI test standard.
- This graph shows performance data for 135 distribution transformers (representing 87% of dry-type models in the dataset) efficiency calculated according to the IEEE method (rated capacity at the device outputs).
- The products shown in this graph are all three-phase dry type and operate at 60Hz.
- The MEPS levels shown for 2010 and 2016 span from 15 to 2,500 kVA, although the models shown on the graph range from 30 to 2500 kVA.
- Products are differentiated by Basic Impulse insulation Level (BIL) rating range, as the US regulatory requirements are different according to the BIL rating. Low Voltage products with a BIL rating less than 20 kV are excluded.
- The 2010 USA MEPS for dry-type three-phase units with BIL>95kV (i.e. the green curve) do not cover the same range of kVA ratings as the other two BIL groups. The BIL > 95kV curve starts at 225 kVA and extends to 2500 kVA, while the other two curves start at 15 kVA and extend to 2500 kVA.

Percentage efficiency at 50% loading for distribution transformers in the USA: Single-phase dry-type transformers by BIL rating



Key notes on graph (see notes section 1)

- The source of data for this graph is the US DOE Compliance Certification Management System database as at September 2013 and all data is declared according to the relevant IEEE/ANSI test standard.
- This graph shows performance data for 27 distribution transformers (representing 13% of dry-type models in the dataset) with efficiency calculated according to the IEEE method (rated capacity at the device outputs).
- The products shown in this graph are all single-phase dry type and operate at 60Hz with ratings from 15 to 833 kVA.
- Products are differentiated by Basic Impulse insulation Level (BIL) rating range, as the US regulatory requirements are different according to the BIL rating. Low Voltage products with a BIL rating less than 20 kVA are excluded.
- All of the models in the database meet the MEPS requirements.
- The 2010 USA MEPS for dry-type single-phase units with BIL>95kV (i.e. the green curve) do not cover the same range of kVA ratings as the other two BIL groups. The BIL > 95kV curve starts at 75 kVA and extends to 833 kVA, while the other two curves start at 15 kVA and extend to 833 kVA.

Major Policy Interventions (*see notes section 2)*

The main policy in USA is the establishment and maintenance of Minimum Energy Performance Standards for distribution transformers. But there are also two national voluntary schemes on low-voltage dry-type distribution transformers, specifically a voluntary scheme called "NEMA Premium" and the Consortium for Energy Efficiency's "Commercial and Industrial Distribution Transformers Initiative." These programmes are briefly described below.

Mandatory performance requirements

Mandatory standards[1] covering three types of distribution transformers exist in the USA:

- Minimum energy-efficiency standards for low-voltage dry-type distribution transformers that came into effect on 1 January 2007;
- Minimum energy-efficiency standards for liquid-filled and medium-voltage dry-type distribution transformers that came into effect on 1 January 2010;
- A second tier of requirements for all of these products that takes effect on 1 January 2016.

Details of the levels of these minimum energy-efficiency standards can be found in the section 2 of the notes.

NEMA Premium for distribution transformers

The new NEMA Premium Efficiency Transformer designation requires 30 percent fewer losses than existing DOE regulations (10 CFR 431) for single-phase and three-phase low-voltage dry-type distribution transformers.

Consortium for Energy Efficiency's Commercial and Industrial Distribution Transformers Initiative

The CEE's Commercial and Industrial Transformers Initiative has a two-tiered premium efficiency programme. The CEE members and other participating organizations include electric utilities, and state-wide or regional efficiency organizations, which may be utility-based. CEE's programme has a Tier 1 level that matches the NEMA Premium levels and a Tier 2 level for three-phase low-voltage dry-type only, which is more efficient than Tier 1.

[1] See http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/66

Cultural Issues (*see notes section 3)*

The market channel for electric utilities is generally direct, with the majority of these customers placing orders directly with distribution transformer manufacturers. It is estimated that electric utilities directly purchase over 90 percent of their distribution transformers from manufacturers.[2] However, there are some utilities, such as some rural cooperatives and municipalities, who may opt to make transformer purchases through distributors.

When placing an order, generally the electric utility provides a specification, including the value it places on future core and coil losses over the life of the transformer. This cultural market issue tends to get manufacturers to develop custom designs in their contract bids, reflecting the customer's performance requirements and the dynamic costs of material, equipment, and labour at a transformer manufacturer's facility.

The delivery channel for commercial and industrial customers can be complex, working through intermediaries such as stocking distributors and electrical contractors. Electrical contractors typically purchase transformers using specifications written by themselves or by agents. Some larger industrial customers buy transformers directly from distributors or manufacturers based on specifications drafted by in-house experts. Similarly, original equipment manufacturers (OEMs) know the exact specifications they require for their finished equipment and typically work directly with manufacturers when placing an order.

[2] US Department of Energy; Distribution Transformers Technical Support Document, 2013.

Notes Section 1. Percentage Efficiency Graphics

1.1 Test methodologies, Performance Standards

1.1.1 Test Methodology

DOE published a final rule test procedure for distribution transformers 71 FR 24972 in April 2006. This US test standard was developed between 1998 and 2006 by DOE in close consultation with manufacturers and other stakeholders and is largely based on IEEE/ANSI C57.12.90. IEEE/ANSI defines capacity on the basis of output (i.e. excluding losses).

1.1.2 Performance Metrics

Efficiency is a measure of the power consumed by a transformer, and it is determined in part by the sum of the core losses and winding losses experienced by the transformer. The efficiency of a transformer varies across the range of loading points that a transformer may experience in its lifetime. The measured efficiency of a transformer operating at 80% of rated load (where winding losses are likely to dominate) will probably be different to the efficiency of a transformer operating at 20% of rated load (where core losses are likely to dominate). Figure A (for a three-phase 75 kVA dry-type transformer) shows the efficiency curve relative to the watts of core and winding loss. This figure shows that the efficiency curve varies over the loading points, with its peak occurring where the core losses are equal to the winding losses.

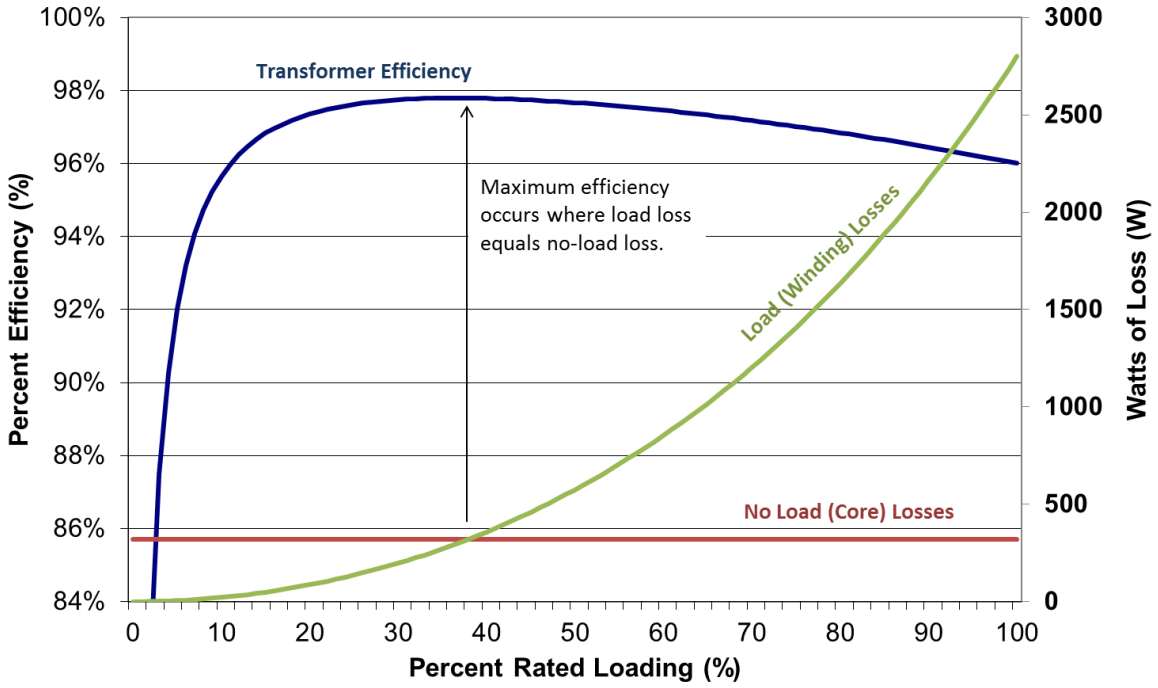


Figure A. Illustration of Relationship Between Losses and Efficiency

The equation used for determining efficiency for transformers under the ANSI/IEEE testing standards is:

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

The efficiency is declared at 50% of maximum load for IEEE/ANSI testing and this has been adopted for the purposes of this analysis.

1.2 Product Classifications

In the USA there are no product efficiency classifications - all products simply have to meet the relevant mandatory minimum standard.

1.3 Data sources and limitations

The source of data for this analysis is the US DOE Compliance Certification Management System (CCMS) database as at September 2013. All data is declared according to the relevant IEEE/ANSI test standard.

Three data sets were downloaded on 9 September 2013 and analysed:

1. Low voltage dry type (8,884 products; 15 to 1,000 kVA)
   from http://www.regulations.doe.gov/certification-data/CCMS-79222862337.html
2. Medium voltage dry type (162 products; 15 to 2,500 kVA)
   from http://www.regulations.doe.gov/certification-data/CCMS-79222359809.html
3. Liquid immersed (8,240 products; 10 to 2,500 kVA)
   from http://www.regulations.doe.gov/certification-data/CCMS-79222850817.html

On the CCMS web site for each of the three, the option was selected to download data 'based on basic model' (as opposed to 'based on kVA grouping').

It is assumed that this data set is highly representative of the US market because since the regulation has been in place, all 'basic models' must be certified and registered with DOE.

Overall data set consists of 17,286 products from at least 14 different manufacturers. 52% of dry type (9,046 dry; 8,240 liquid) and 75% 3-phase (4,332 single; 12,954 three). kVA ratings in the source dataset are based on the output rated power (IEEE system). BIL ratings varied between 20 and 14,400 kV; products operate at 60Hz. The data set included only the overall percentage efficiency and does not include coil or core losses.

1.4 Data manipulations and specific limitations

All US data was assumed to have been declared in accordance with the IEEE/ANSI test method and IEEE based efficiency at 50% load was used as the basis of graphics in this report - no manipulation was required. The specific steps in data cleaning were:

- Dual voltage distribution transformers were classified according to their highest voltage group (this corresponds with the insulation rating of the primary which will lower the efficiency).
- Transformers were classified into the following BIL classes: 20-45 kV; 46-95 kV and >96 kV.

Notes Section 2. Major Policy Interventions

Mandatory performance requirements

Further details of the mandatory performance requirements are given below and in the tables on the next two pages:

- **2007 requirements:** The Energy Policy Act of 2005 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-1-2002)." In adopting this language, Congress established the NEMA TP-1 -2002 requirements as mandatory efficiency requirements for low-voltage dry-type distribution transformers. See Table 1 for these efficiency requirements from 2007.
- **2010 requirements:** In October 2007 the DOE 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)[3]: 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 (see Table 2); dry type distribution transformers rated between 15 to 833 kVA for single phase (see Table 3) and 15 to 2500 kVA for three-phase (see Table 4).
- **2016 requirements**: In April 2013 DOE completed its review of regulations for distribution transformers and 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. These are also given in Tables 1, 2, 3 and 4 alongside the earlier requirements. (Note that the low voltage single-phase transformer requirements do not increase in stringency for 2016, but those for three-phase do increase).

The tables have the correct number of significant digits associated with each requirement.

Voluntary performance requirements

In 2008, NEMA established a voluntary programme called "NEMA Premium" which is a labelling scheme for low-voltage dry-type distribution transformers that exceed the 2007 MEPS by approximately 30 percent.[4] However, the 2016 MEPS exceed the NEMA Premium levels, therefore the table provided in this section will no longer apply from 1 January 2016.

In late 2011, the Consortium for Energy Efficiency launched a Commercial and Industrial Distribution Transformer Initiative which adopted the same levels as NEMA Premium for their Tier 1 levels and established higher Tier 2 efficiency values for three-phase low-voltage dry-type only.[5]

[3] 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

[4] Information about the NEMA Premium programme for Distribution Transformers can be found at: http://www.nema.org/Policy/Energy/Efficiency/Documents/NEMA_Premium_Efficiency_Transformer_Product_Specifications.pdf

[5] Information about the CEE Commercial and Industrial Distribution Transformer Initiative can be found at: http://library.cee1.org/sites/default/files/library/7313/Distribution_Transformers_Initiative_2012_1.pdf

Table 1. US Efficiency Regulations for Low-Voltage Dry-Type Distribution Transformers for 2007 and 2016, all measured at 35% load.

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 2. US Efficiency Regulations for Liquid-Filled Distribution Transformers, all measured at 50% load.

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.

Table 3. US Regulations for Single Phase, Medium-Voltage Dry-Type Transformers, all measured at 50% load.

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 4. US Regulations for Three Phase, Medium-Voltage Dry-Type Transformers, all measured at 50% load.

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.

Figure 1 provides a comparison between the regulatory requirements for three-phase liquid-filled and for 46-95kV BIL three-phase dry-type mandatory efficiency requirements that took effect in 2010 and will take effect in 2016. The new regulation has a smoother requirement across the kVA ratings. Please note that this graph has a logarithmic X-axis of kVA ratings.

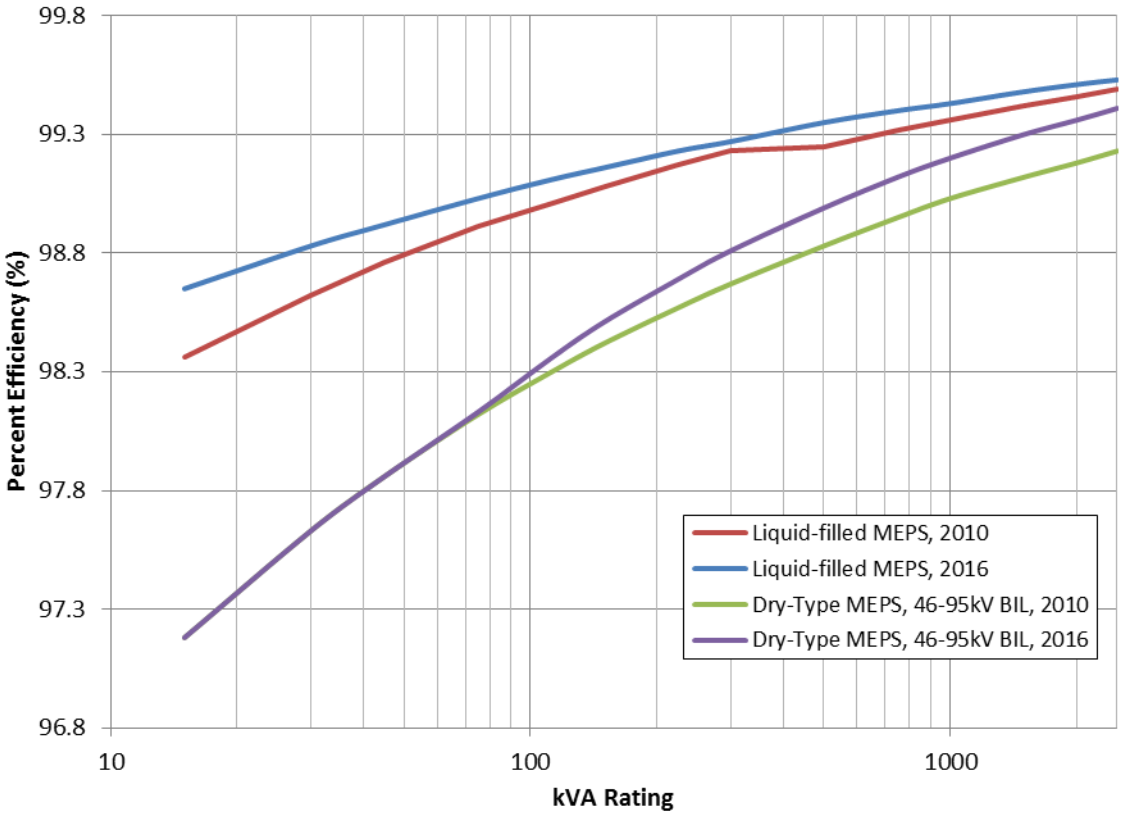


Figure 1. Comparison of Requirements for US DOE Regulations from 2010 and 2016

NEMA Premium for Distribution Transformers

Table 5. NEMA Premium voluntary programme for Low-Voltage Dry-Type Distribution Transformers, measured at 35% load.

kVA	Single-Phase	kVA	Three-Phase
	% Efficiency		% Efficiency
15	98.39	15	97.90
25	98.60	30	98.25
37.5	98.74	45	98.39
50	98.81	75	98.60
75	98.95	112.5	98.74
100	99.02	150	98.81
167	99.09	225	98.95
250	99.16	300	99.02
333	99.23	500	99.09
-	-	750	99.16
-	-	1,000	99.23

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

Consortium for Energy Efficiency's Commercial and Industrial Distribution Transformer Initiative

The levels of CEE Tier 1 are the same as NEMA Premium, however there is also a more ambitious CEE Tier 2 for three-phase low-voltage dry-type.

Table 6. CEE voluntary programme for Low-Voltage Dry-Type Distribution Transformers, measured at 35% load.

kVA	Single-Phase	kVA	Three-Phase	
	CEE Tier 1 % Efficiency		CEE Tier 1 % Efficiency	CEE Tier 2 % Efficiency
15	98.39	15	97.90	98.40
25	98.60	30	98.25	98.65
37.5	98.74	45	98.39	98.78
50	98.81	75	98.60	98.93
75	98.95	112.5	98.74	99.03
100	99.02	150	98.81	99.10
167	99.09	225	98.95	99.40
250	99.16	300	99.02	99.44
333	99.23	500	99.09	99.51
-	-	750	99.16	99.56
-	-	1,000	99.23	99.59

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

Notes Section 3. Cultural Issues

No additional notes.