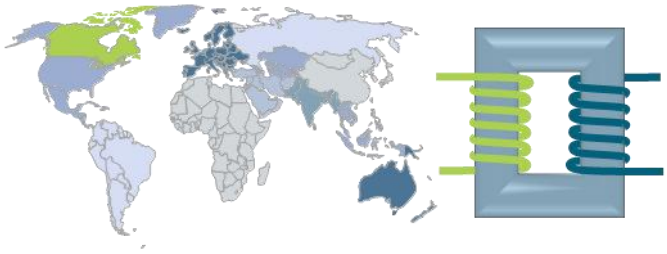
Mapping Document



Country: Canada

Technology: Distribution Transformers

Sub Category: Dry and liquid filled

Introduction

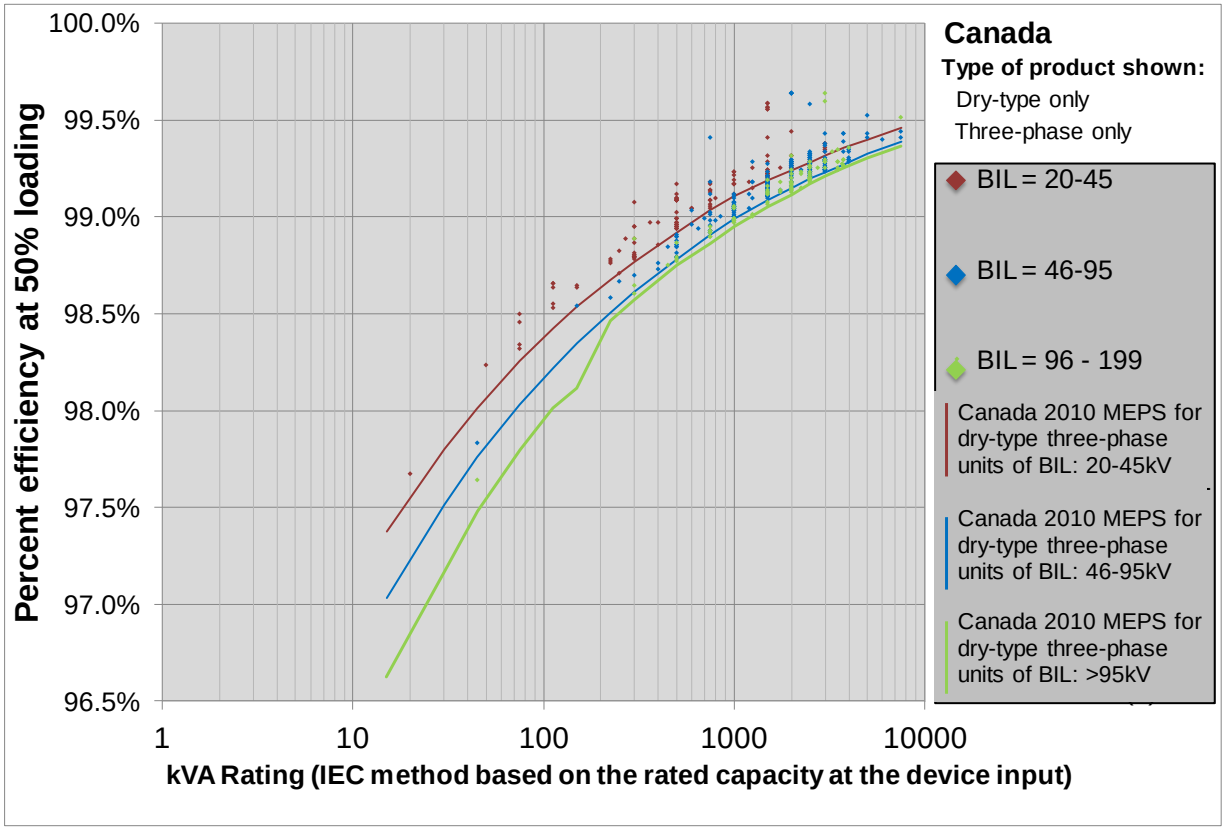
The first stage in the Mapping and Benchmarking process is the definition of the products, i.e. clearly setting the boundaries that define the products for use in data collection and analysis. This ensures the comparison between the participating countries is done against a specific and consistent set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

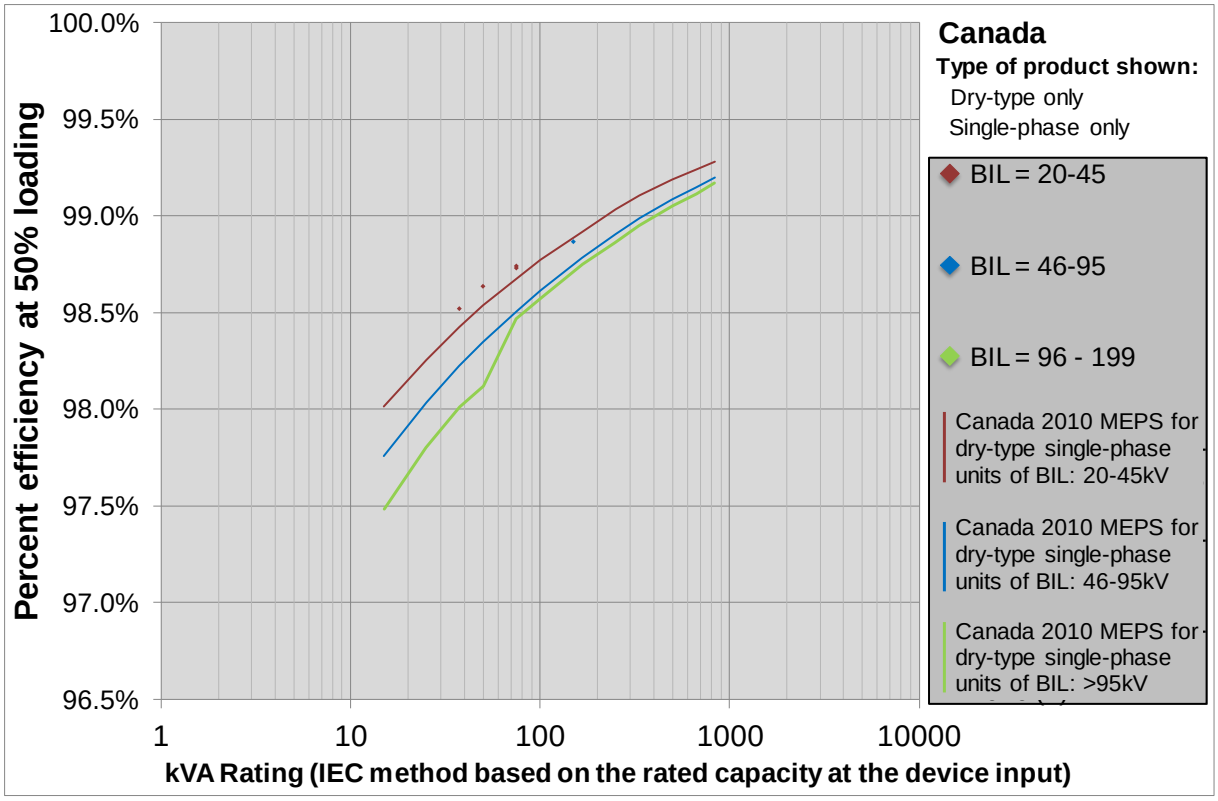
Percentage efficiency at 50% loading for distribution transformers in Canada: Three-phase dry-type transformers by BIL rating



Key notes on Graph (see notes section 1)

- The sources of data for this graph are the Canadian federal government regulatory scheme and the online databases of the Canadian certification bodies. Models reported for the 2005 MEPS that also meet the 2012 MEPS are presented alongside some newer products reported for the 2012 MEPS.
- This graph shows performance data for 439 distribution transformers (representing 99% of medium-voltage dry-type models in the dataset) efficiency calculated according to the Canadian Standards Association test method, which is based on IEEE (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 2012 and the models shown on the graph range from 15 to 7500 kVA.
- Products are differentiated by Basic Impulse insulation Level (BIL) rating, as the Canadian regulatory requirements are different according to the BIL rating. Low Voltage products with a BIL rating less than 20 kV are excluded.

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



Key notes on Graph (see notes section 1)

- The sources of data for this graph are the Canadian federal government regulatory scheme and the online databases of the Canadian certification bodies. Models reported for the 2005 MEPS that also meet the 2012 MEPS are presented alongside some newer products reported for the 2012 MEPS.
- This graph shows performance data for 5 distribution transformers (representing 1.1% of medium-voltage dry-type models in the dataset) with efficiency calculated according to the Canadian Standards Association test method, which is based on IEEE (rated capacity at the device outputs).
- The MEPS levels shown for 2012 span from 15 to 833 kVA, although the models shown on the graph range from 37.5 to 75 kVA.
- Products are differentiated by Basic Impulse insulation Level (BIL) rating, as the Canadian regulatory requirements are different according to the BIL rating. Low Voltage products with a BIL rating less than 20 kVA are excluded.

Major Policy Interventions (*see also notes section 2)*

The main policy instruments promoting energy-efficient distribution transformers in Canada are the establishment and maintenance of Minimum Energy Performance Standards (MEPS) for low-voltage and medium-voltage dry-type distribution transformers and a voluntary scheme for liquid-filled distribution transformers. These programmes are briefly described below. The efficiency standard is also referenced in the construction standards.

Mandatory performance requirements

Mandatory energy performance standards[1] were updated for dry-type distribution transformers and came into force in April 2012[2]. This regulation harmonised Canadian requirements with requirements for dry-type transformers in the USA. The more stringent Canadian standard superseded the previous one that covered dry-type transformers since 2005.

The current Canadian regulations apply to 60 Hz medium-voltage dry-type distribution transformers, 35 kV or less, single-phase rated 15 to 833 kVA, and three-phase rated 15 to 7500 kVA. Minimum efficiency requirements are set out separately for dry-type single-phase and three-phase transformers at 50% of the rated load.

Canada also has efficiency regulations that apply to 60 Hz low-voltage dry-type distribution transformers with a 600V primary or less.

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

Voluntary performance requirements

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. The efficiency standard is also referenced in the Canadian electrical code[3] which defines the installation of electricity using products and systems in Canada.

Details of the policy background and levels of these voluntary standards can be found in the section 2 of the notes.

[1] See http://oee.nrcan.gc.ca/regulations/bulletins/16910
[2] See http://oee.nrcan.gc.ca/regulations/17311
[3] The Canadian Electrical Code is the de facto regulatory mechanism for all authorities having jurisdiction over the design and installation of the electrical apparatus in Canada.

Cultural Issues

The market channel for electric utilities in Canada is generally direct, with the majority of utilities placing orders directly with distribution transformer manufacturers. When placing an order, generally the electric utility usually 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, many of which are local to the Canadian market, 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.

Notes Section 1. Percentage Efficiency Graphics

1.1 Test methodologies, Performance Standards

1.1.1 Test Methodology

The test method used by Canada for measuring the losses of the regulated dry-type distribution transformers is CSA-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).

To support its voluntary programme for liquid-filled distribution transformers, Canada maintains CSA-C802.1-00, “Minimum Efficiency Values for Liquid-Filled Distribution Transformers.” This Standard publishes the test method and minimum efficiency values derived from those defined for liquid- filled distribution transformers in Canada. The efficiency standard is also referenced in the Canadian construction standard for distribution transformers.

In both instances, the Canadian test standard is largely harmonised with the test method of the United States, which itself is based on IEE/ANSI and NEMA TP 2-2005 - Standard Test Method for Measuring the Energy Consumption of Distribution Transformers.

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.

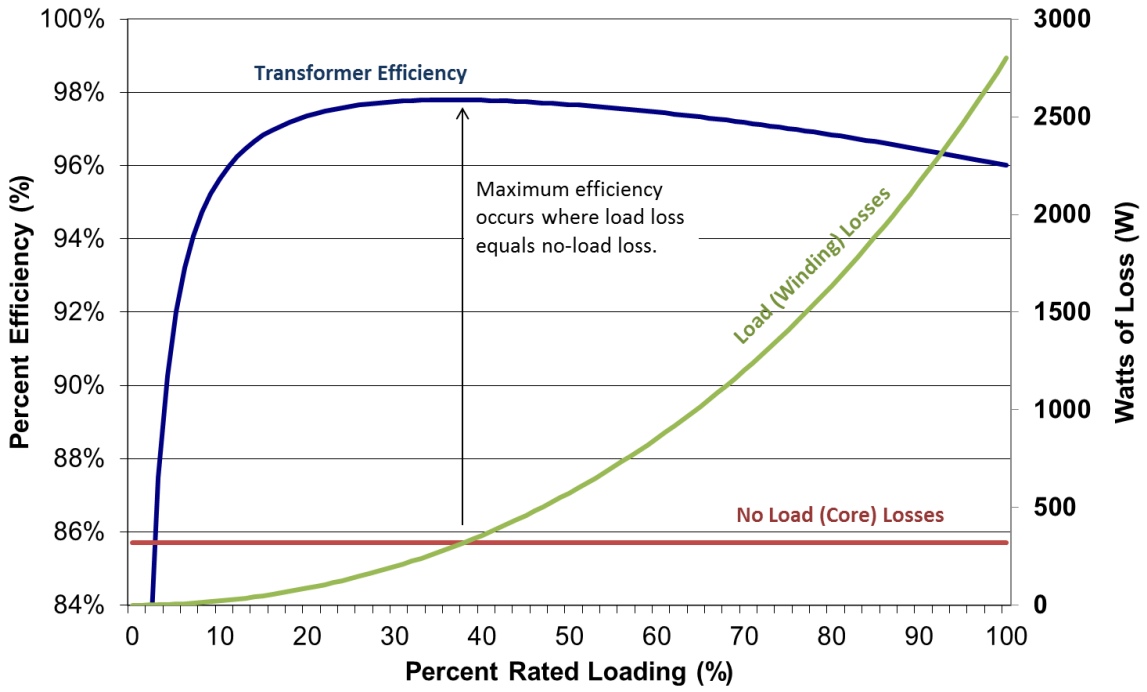


Figure A. Illustration of Relationship Between Losses and Efficiency

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

1.3 Data sources and limitations

Data is presented from three separate sources:

1. a downloaded in July 2013 of the Canadian mandatory government registration database[4] of products registered to the 2005 MEPS. These products are registered to the 2005 MEPS but only those that also meet the 2012 MEPS are presented.
2. A sample from the Canadian mandatory government registration database of products registered to the 2012 MEPS that is not yet available on the public website[5].
3. Another sample of products registered against the 2012 MEPS downloaded from the online databases of the Canadian certification bodies[6].

[4] http://oee.nrcan.gc.ca/pml-lmp/index.cfm?action=app.search-recherche&appliance=TRANS_DRY
[5] http://directories.csa-international.org/
[6] Source for UL data: http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/index.htm

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The combined Canadian data set consists of 283 products from 15 different manufacturers. 100% of products are of dry type and 99% 3-phase (3 single; 280 three). kVA ratings in the source dataset are based on the output rated power (CSA and IEEE method). BIL ratings range from 20 kV to 150 kV and products operate at 60Hz. The data set included the overall energy efficiency percentage, along with coil and core losses at 50% load.

It is assumed that this data set is highly representative of the Canadian dry type market because it is a regulated product.

1.4 Data manipulations and specific limitations

All Canadian 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).
- Medium-voltage dry-type transformers were classified into the following BIL classes: 20-45 kV; 46-95 kV and >96 kV.
- Low-voltage dry-type transformers were classified separately.

Notes Section 2. Major Policy Interventions

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. When 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).

Dry-type transformers

For dry-type transformers, Canada adopted levels for single and three-phase dry-type transformers in 2005. The regulations were then updated in 2012 to harmonise with the requirements for single and three-phase medium voltage dry-type transformers in the United States.

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 purpose 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 tables:

Table 1. Canadian Efficiency Regulations for Low-Voltage Dry-Type Distribution Transformers, measured at 35% load.

Capacity (kVA)	Single-Phase % Efficiency*	Capacity (kVA)	Three-Phase % Efficiency*
15	97.70	15	97.00
25	98.00	30	97.50
37.5	98.20	45	97.70
50	98.30	75	98.00
75	98.50	112.5	98.20
100	98.60	150	98.30
167	98.70	225	98.50
250	98.80	300	98.60
333	98.90	500	98.70
-	-	750	98.80
-	-	1,000	98.90

* Percentage efficiency at 35% nominal load.

Table 2. Canadian Efficiency Regulations for Single-Phase Medium-Voltage Dry-Type Distribution Transformers, measured at 50% load.

kVA	20-45 kV BIL % Efficiency*	> 45-95 kV BIL % Efficiency*	> 95-199 kV BIL % 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
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 3. Canadian Efficiency Regulations for Three-Phase Medium-Voltage Dry-Type Distribution Transformers, measured at 50% load.

kVA	20-45 kV BIL	> 45-95 kV BIL	> 95-199 kV BIL
	% Efficiency*	% Efficiency*	% 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.

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.

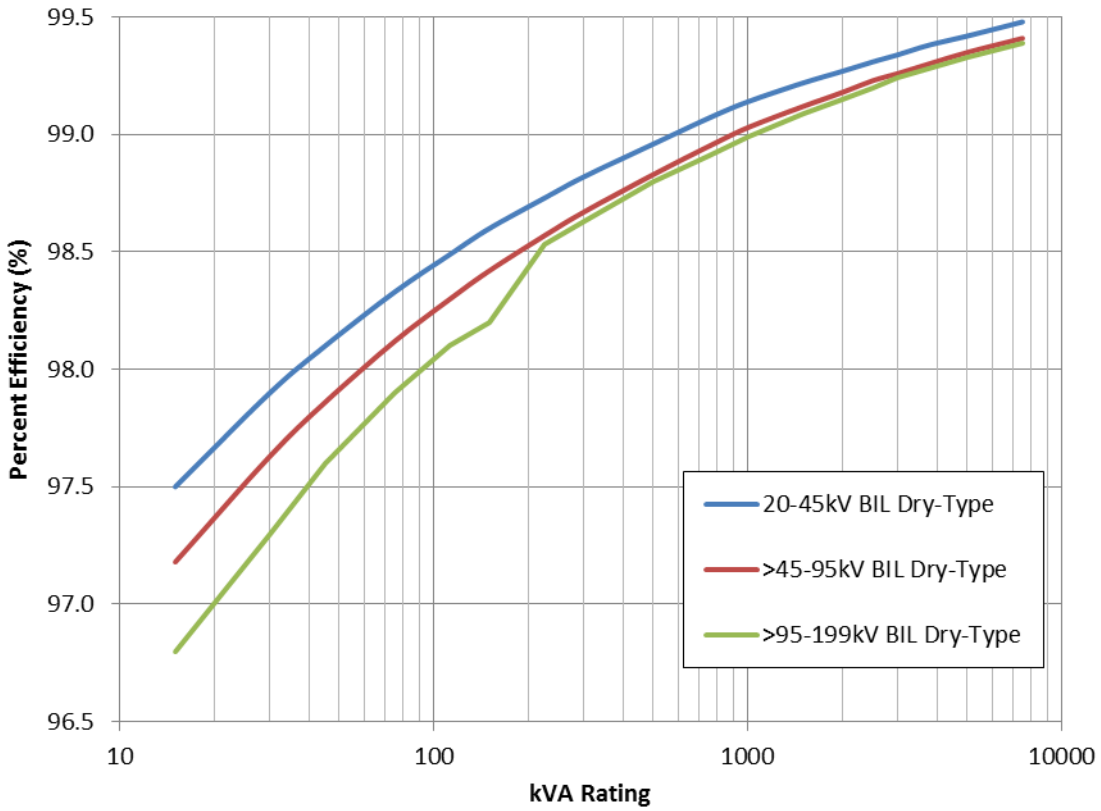

Figure 1. Plot of Canadian Medium-Voltage Dry-type Regulations (in force 2012)

Liquid-filled transformers

While Canada's *Energy Efficiency Regulations* does not contain mandated standards for liquid-filled distribution transformers, there are existing requirements for these types of transformers to meet a minimum efficiency by other regulatory means. When Canada considered efficiency regulations for liquid-filled transformers it found that there were but a few technically adept customers purchasing transformers and there was a high percentage already meeting the proposed minimum efficiency levels. In an effort to improve the efficiencies of the few remaining that did not meet the proposed levels, a formal memorandum of understanding was signed by the Canadian government and the association representing electrical utilities. The terms of the agreement were:

1. The association would gather and publish information on their transformer purchases, by efficiency, for monitoring purposes, and

2. Applicable Canadian standards relating to efficiency, design and safety would be revised to reference the minimum energy performance levels.

The requirements were included in the Canadian Electrical Code which is the de facto regulatory mechanism for all authorities having jurisdiction over the design and installation of the electrical apparatus in Canada. Monitoring over a five year period (2000-2004) showed

compliance with the minimum efficiency levels was attained by greater than 99% of product sold in Canada and indicated that this approach had been successful.

These standards for liquid-filled transformers 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. 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. Canadian Voluntary Efficiency Levels for Liquid-Filled Distribution Transformers, measured at 50% load.

Capacity (kVA)	Min. Low Voltage	Efficiency	Capacity (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.

Notes Section 3. Cultural Issues

(No further information).