C802.2-06

Minimum efficiency values for dry-type transformers

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Minimum efficiency values for dry-type transformers

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Preface

This is the second edition of CSA C802.2, *Minimum efficiency values for dry-type transformers.* It supersedes the previous edition, published in 2000.

Major changes to this edition include

(a) revision of the list of products not covered by this Standard (see Clause 1.5);
(b) addition of new definitions for clarity;
(c) revised minimum efficiency values and calculation methods for tested efficiency; and
(d) a new Annex A specifying the basic loss calculation steps for determining efficiency.

This Standard is considered suitable for use for conformity assessment within the stated scope of the Standard.

This Standard was prepared by the Subcommittee on Dry-Type Transformer Efficiency, under the jurisdiction of the Technical Committee on Industrial Equipment and the Strategic Steering Committee on Performance, Energy Efficiency, and Renewables, and has been formally approved by the Technical Committee. It will be submitted to the Standards Council of Canada for approval as a National Standard of Canada.

August 2006

Notes:

(1) *Use of the singular does not exclude the plural (and vice versa) when the sense allows.*

(2) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*

(3) *This publication was developed by consensus, which is defined by* CSA Policy governing standardization — Code of good practice for standardization *as "substantial agreement. Consensus implies much more than a simple majority, but not necessarily unanimity". It is consistent with this definition that a member may be included in the Technical Committee list and yet not be in full agreement with all clauses of this publication.*

(4) *CSA Standards are subject to periodic review, and suggestions for their improvement will be referred to the appropriate committee.*

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Requests for interpretation should

(a) define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;
(b) provide an explanation of circumstances surrounding the actual field condition; and
(c) be phrased where possible to permit a specific "yes" or "no" answer.

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C802.2-06
Minimum efficiency values for dry-type transformers

1 Scope

1.1
This Standard specifies energy efficiencies for dry-type transformers. The total ownership cost (TOC) methodology is recommended as the means for achieving these energy efficiencies, particularly for electric utilities. This Standard also specifies an optimal method for users other than utilities, based on a modified TOC methodology that meets the conditions of energy cost.

Note: *See Table 1 for minimum efficiency values.*

1.2
This Standard covers single-phase and three-phase self-contained units or components of larger assemblies, 60 Hz, ANN, rated 15 to 833 kVA for single phase and 15 to 7500 kVA for three phase.

1.3
This Standard describes the special features that influence efficiency and provides modifications to the efficiency values specified in Table 1 where such modifications are necessary.

1.4
This Standard specifies the test methods and procedures for determining transformer efficiencies.

1.5
This Standard does not apply to

(a) autotransformers;
(b) instrument transformers;
(c) rectifier transformers;
(d) sealed transformers;
(e) nonventilated transformers;
(f) testing transformers;
(g) furnace transformers;
(h) welding transformers;
(i) encapsulated transformers;
(j) drive (isolation) transformers with two or more output windings or a rated low-voltage line current greater than 1500 A; and
(k) transformers with a nominal frequency other than 60 Hz.

1.6
In CSA Standards, “shall” is used to express a requirement, i.e., a provision that the user is obliged to satisfy in order to comply with the standard; “should” is used to express a recommendation or that which is advised but not required; “may” is used to express an option or that which is permissible within the limits of the standard; and “can” is used to express possibility or capability. Notes accompanying clauses do not include requirements or alternative requirements; the purpose of a note accompanying a clause is to separate from the text explanatory or informative material. Notes to tables and figures are considered part of the table or figure and may be written as requirements. Annexes are designated normative (mandatory) or informative (non-mandatory) to define their application.

2 Reference publications

This Standard refers to the following publications, and where such reference is made, it shall be to the edition listed below, including all amendments published thereto.

CSA (Canadian Standards Association)
C9-02
Dry-type transformers

CEATI (CEA Technologies Inc.)
161 D 456 A (1993)
Economic Loading of Distribution Transformers

NEMA (National Electrical Manufacturers Association)
TP 2-2005
Standard Test Method for Measuring the Energy Consumption of Distribution Transformers

3 Definitions

The following definitions apply in this Standard:

ANN (air cooled, natural convection, natural circulation of outside air) — dry-type natural cooling.

Authority having jurisdiction — the governmental body responsible for the enforcement of any part of this Standard or the official or agency designated by that body to exercise such a function.

Autotransformer — a transformer that has
(a) one physical winding that consists of a series winding part and a common winding part;
(b) no isolation between its primary and secondary circuits; and
(c) during step-down operation,
  (i) a primary voltage that is equal to the total of the series and common winding voltages; and
  (ii) a secondary voltage that is equal to the common winding voltage.

Cost of load loss — the present value of load loss, or load loss multiplied by the coefficient of load loss as employed in a loss evaluation formula.
Note: *The coefficient may also be described as the equivalent first-cost factor of load loss.*

Cost of no-load loss — the present value of no-load loss, or no-load loss multiplied by the coefficient of no-load loss as employed in a loss evaluation formula.
Note: *The coefficient may also be described as the equivalent first-cost factor of no-load loss.*

Drive (isolation) transformer — a transformer that
(a) isolates an electric motor from the line;
(b) accommodates the added loads of drive-created harmonics; and
(c) is designed to withstand the additional mechanical stresses resulting from an ac adjustable frequency motor drive or a dc motor drive.

Dry-type transformer — a transformer, including a transformer that is incorporated into another product, in which the core and coils are in a gaseous or dry-compound insulating medium and that
(a) is single phase and has a capacity of 15 to 833 kVA or three phase and has a capacity of 15 to 7500 kVA;
(b) has a nominal frequency of 60 Hz; and
(c) has a rated low-voltage line current of less than 4000 A.
Note: *Dry-type transformers do not include*
(a) autotransformers;
(b) instrument transformers;

(c) rectifier transformers;
(d) sealed transformers;
(e) nonventilated transformers;
(f) testing transformers;
(g) furnace transformers;
(h) welding transformers;
(i) encapsulated transformers; and
(j) drive (isolation) transformers with two or more output windings or a rated low-voltage line current greater than 1500 A.

Efficiency — the value calculated based on the specified losses of the transformer. Efficiency is expressed as a percentage and is rounded to two decimal places.
Notes:
(1) *The efficiency value is derived from the parameters of output* kVA*, divided by output* kVA *plus losses, and multiplied by 100. It may be expressed at a given per unit load and at a specified reference temperature.*
(2) *The acceptable efficiency range of a transformer when its no-load and total losses are within the single unit tolerances defined in CSA C9 is known as the "efficiency tolerance".*

Encapsulated (sand-resin potted) transformer — a transformer designed to have the core and coils encapsulated in a solid medium.
Note: *Cast coil transformers are not considered encapsulated transformers.*

Furnace transformer — a three-phase step-down transformer that is designed to be connected to an electric-arc furnace and has a high-voltage delta-wye switching arrangement and high-voltage taps for changing the level of the low voltage supplied to the furnace.

Instrument transformer — a transformer that, while substantially preserving the phase relation and waveform, reproduces in its secondary circuit the voltage and current of the primary circuit within a defined and known proportion.

Nonventilated transformer — a transformer constructed to prevent external air circulation through the coils of the transformer while operating at zero gauge pressure.

Rectifier transformer — a transformer that operates at the fundamental frequency of an ac system and is designed to have one or more output windings conductively connected to the main electrodes of a rectifier.

Sealed transformer — a transformer designed to remain hermetically sealed in gaseous fluid under specified conditions of temperature and pressure.

Tested efficiency — transformer efficiency calculated in accordance with Clause 6.4.

Testing transformer — a transformer used in a circuit to produce a specific voltage or current for testing electrical equipment.

Total ownership cost (TOC) — transformer first cost + cost of no-load loss + cost of load loss.

Transformer first cost — the price paid or the cost of acquisition.

Welding transformer — a transformer that is designed to have its output winding supply energy to an electric welding apparatus.

4 Total ownership cost for electric utility transformers

The methodology of total ownership cost (TOC) is presented as a means by which electric utilities can select transformers that best suit projected local conditions. Such conditions include utility load, projected peak loads, generation capability and availability, generation reliability, and fuel prices.

TOC is calculated as follows:

TOC = transformer first cost + cost of no-load loss + cost of load loss

where

cost of no-load loss = $A \times$ no-load loss, W

cost of load loss = $B \times$ load loss, W

where

A = present value factor of no-load loss, $/W

B = present value factor of load loss, $/W

5 Total ownership cost for other than electric utility transformers

For users other than utilities, factors A and B, as specified in Clause 4, may have values that differ from those used by the local utility. The rationale is that there is only the energy cost as seen by the user, rather than load characteristics, projected peak loads (demand), generation capability, and other factors. When users adapt TOC to their needs, they should take into account inflation index, demand, the number of years of operation of the transformer, and the projected interest rate.

TOC for commercial/industrial users is calculated as follows:

TOC = transformer first cost + cost of no-load loss + cost of load loss

= transformer first cost + ($A \times$ no-load loss) + ($B \times$ load loss)

where

A = present value (PV) factor of no-load loss, $/W

= PV of an inflation series × purchaser's cost of energy ($/kWh)/1000 × hours/year

$$= \frac{1-\left[\frac{1+a}{1+i}\right]^{n}}{i-a} \times \frac{EL}{1000} \times \frac{\text{hours}}{\text{year}}$$

where

a = per unit inflation index

i = per unit interest rate

n = number of years

EL = purchaser's cost of electricity, $/kWh

B = present value factor of load loss, $/W

= $A \times P^2$

where

P = per unit load

= 0.50 for the purposes of this Standard

As an alternative to TOC, energy efficiency may be calculated at the load that is most typical of how the transformer will be used. The efficiency formula in Clause 6.4 may be used with $P = 0.50$ or another appropriate value, e.g., $P = 0.35$ for Class 1.2 kV transformers.

Note: *See CEATI 161 D 456 A for more information on TOC.*

6 Test methods

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

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

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

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

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

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)

7 Minimum efficiency values for dry-type transformers
Transformers covered by this Standard shall meet the minimum efficiency values specified in Table 1, except as modified by Clause 8. Transformers shall be tested at linear loads and efficiency values shall apply to the 60 Hz frequency only. Low-voltage winding shall have a basic insulation level (BIL) rating less than or equal to 30 kV.

Corrections have been applied to load losses for

(a) the reduced per unit loads; and

(b) the 75 °C reference temperature for the windings identified in Annex A.

The minimum values specified in Table 1 shall be maintained regardless of the method used for calculating the TOC.

8 Special electrical features
Where a transformer has one or more special features, the minimum efficiency value specified in Table 1 may be modified, provided that

(a) efficiency values for nonpreferred kVA ratings are evaluated by interpolating between efficiency values specified for the preferred kVA ratings in Table 1; and

(b) for a three-phase transformer having multiple high-voltage windings and a voltage ratio other than 2:1, the minimum efficiency value specified in Table 1 is reduced by 0.11.

Note: *For example, a* 150 kVA, *27600GrdY/15935 × 8320Y/4800V transformer would require a minimum efficiency of 98.20 – 0.11 = 98.09%.*

9 Marking

Products meeting the requirements of this Standard shall have appropriate markings as evidence of compliance, e.g., "Efficiency per CSA C802.2" or equivalent wording. The type and nature of such markings shall be as specified by the authority having jurisdiction or by the verification agency, as applicable.

Table 1
Minimum efficiency values for dry-type transformers
(See Clauses 1.1, 1.3, 6.4, 7, and 8.)

Single phase				Three phase			
	Voltage class = 1.2 kV	Voltage class > 1.2 kV			Voltage class = 1.2 kV	Voltage class > 1.2 kV	
		BIL ≤ 60 kV	BIL > 60 kV			BIL ≤ 60 kV	BIL > 60 kV
kVA	Efficiency, % at 0.35 per unit nameplate load	Efficiency, % at 0.5 per unit nameplate load	Efficiency, % at 0.5 per unit nameplate load	kVA	Efficiency, % at 0.35 per unit nameplate load	Efficiency, % at 0.5 per unit nameplate load	Efficiency, % at 0.5 per unit nameplate load
15	97.70	97.60	97.60	15	97.00	96.80	96.80
25	98.00	97.90	97.90	30	97.50	97.30	97.30
37.5	98.20	98.10	98.10	45	97.70	97.60	97.60
50	98.30	98.20	98.20	75	98.00	97.90	97.90
75	98.50	98.40	98.40	112.5	98.20	98.10	98.10
100	98.60	98.50	98.50	150	98.30	98.20	98.20
167	98.70	98.80	98.70	225	98.50	98.40	98.40
250	98.80	98.90	98.80	300	98.60	98.60	98.50
333	98.90	99.00	98.90	500	98.70	98.80	98.70
500	—	99.10	99.00	750	98.80	98.90	98.80
667	—	99.20	99.00	1000	98.90	99.00	98.90
833	—	99.20	99.10	1500	—	99.10	99.00
				2000	—	99.20	99.00
				2500	—	99.20	99.10
				3000	—	99.20	99.10
				3750	—	99.30	99.20
				5000	—	99.30	99.20
				7500	—	99.30	99.20

Annex A (normative)
Basic loss calculation steps for determining efficiency

Notes:
(1) *This Annex is a mandatory part of this Standard.*
(2) *See NEMA TP 2, Section 5, for more information on the calculation method used.*

The following basic steps shall be used to calculate losses in order to determine efficiency:

(a) Before the load loss test (see Clause 6.4), high-voltage (HV) and low-voltage (LV) winding resistances shall be measured in ohms at the rated voltage tap ($R_{DC\text{-}HV}$ and $R_{DC\text{-}LV}$, respectively).

(b) No-load loss (*NL*) at rated voltage and ambient temperature shall be measured in watts.

(c) Load loss (P_L) at rated current and ambient temperature shall be measured in watts.

(d) Resistive loss at ambient temperature (P_e) shall be calculated in watts, as follows:

$$P_e = \left(I_{HV}^2\right)\left(R_{DC\text{-}HV}\right) + \left(I_{LV}^2\right)\left(R_{DC\text{-}LV}\right)$$

where

I_{HV} = high-voltage-side current, A

$R_{DC\text{-}HV}$ = high-voltage-side dc resistance, Ω

I_{LV} = low-voltage-side current, A

$R_{DC\text{-}LV}$ = low-voltage-side dc resistance, Ω

(e) Transformer stray and eddy loss at ambient temperature (P_s) shall be calculated in watts, as follows:

$$P_s = P_L - P_e$$

(f) The load loss temperature correction factor at 75 °C (T_{75}) shall be calculated as follows:

$$T_{75} = \frac{T_k + 75}{T_k + T_{DC}}$$

where

T_k = 234.5 for copper
= 225 for aluminum

T_{DC} = ambient temperature in degrees Celsius during load loss test

(g) Load loss at 75 °C (P_{L75}) shall be calculated in watts, as follows:

$$P_{L75} = \left(P_e\right)\left(T_{75}\right) + \frac{P_s}{T_{75}}$$

Annex B (informative)
Bibliography

Note: *This Annex is not a mandatory part of this Standard.*

The following Standards served as background material in the preparation of this Standard and contain related technical information:

CSA (Canadian Standards Association)
CAN/CSA-C22.2 No. 47-M90 (R2001)
Air-cooled transformers (dry type)

IEEE (Institute of Electrical and Electronics Engineers)
C57.12.91-2001
IEEE Standard Test Code for Dry-Type Distribution and Power Transformers

NEMA (National Electrical Manufacturers Association)
TP 1-2002
Guide for Determining Energy Efficiency for Distribution Transformers

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