ENERGY STAR® Product Specification for Distribution Transformers

Eligibility Criteria Draft 2 Version 1.0

Following is the Version 1.0 ENERGY STAR product specification for Distribution Transformers. A product shall meet all of the identified criteria if it is to earn the ENERGY STAR.

1 DEFINITIONS[1]

A) <u>Product Classifications</u>:

1. <u>Transformer:</u> a device consisting of 2 or more coils of insulated wire that transfers alternating current by electromagnetic induction from 1 coil to another to change the original voltage or current value.
2. <u>Distribution Transformer</u>: a transformer that:
    a) Has an input voltage of 34.5 kV or less;
    b) Has an output voltage of 600 V or less;
    c) Is rated for operation at a frequency of 60 Hz; and
    d) Has a capacity of 10 kVA to 2500 kVA for liquid-immersed units and 15 kVA to 2500 kVA for dry-type units.
    e) The term “distribution transformer” does not include a transformer that is an—
        i. Autotransformer;
        ii. Drive (isolation) transformer;
        iii. Grounding transformer;
        iv. Machine-tool (control) transformer;
        v. Nonventilated transformer;
        vi. Rectifier transformer;
        vii. Regulating transformer;
        viii. Sealed transformer;
        ix. Special-impedance transformer;
        x. Testing transformer;
        xi. Transformer with tap range of 20 percent or more;
        xii. Uninterruptible power supply transformer; or
        xiii. Welding transformer.

[1] U.S. Department Of Energy, "Energy Conservation Program for Certain Commercial and Industrial Equipment: Distribution Transformers: Definitions", 10 CFR 431.192.

B) Product Types:

1. Liquid-immersed Distribution Transformers: a distribution transformer in which the core and coil assembly is immersed in an insulating liquid.
2. Low-voltage Dry-Type Distribution Transformer: a distribution transformer that:
   a) Has an input voltage of 600 volts or less;
   b) Is air-cooled; and
   c) Does not use oil as a coolant.
3. Medium-voltage Dry-type Distribution Transformer: a distribution transformer in which the core and coil assembly is immersed in a gaseous or dry-compound insulating medium, and which has a rated primary voltage between 601 V and 34.5 kV.

C) Operational Power States:

1. No-Load Loss (or Core Loss): losses that are incident to the excitation of the transformer.
2. Load Loss (or Coil Loss): those losses incident to a specified load carried by the transformer, including losses in the windings as well as stray losses in the conducting parts of the transformer.
3. Total Loss: the sum of the no-load loss and load loss for a transformer.

D) Basic Model: a group of models of distribution transformers manufactured by a single manufacturer, that have the same insulation type (i.e., liquid-immersed), have the same number of phases (i.e., single or three), have the same standard kVA rating, and do not have any differentiating electrical, physical or functional features that affect energy consumption. Differences in voltage and differences in basic impulse insulation level (BIL) rating are examples of differentiating electrical features that affect energy consumption.

E) Per Unit Load: The ratio of the current through a transformer's output winding multiplied by the nameplate voltage and divided by the capacity, at unity power factor and zero input voltage distortion.

F) Load Factor: The ratio of the average load over a period of time to the peak load during that time.[2]

Note: EPA has retained the originally proposed definitions for Transformer and No-Load Loss in order to harmonize with the Department of Energy's (DOE's) definitions and avoid confusion of the meaning of the terms in the marketplace. However, EPA has added definitions for Per Unit Load and Load Factor, replacing the term "Capacity Factor" previously used in Draft 1, based on stakeholder feedback that these terms are more widely used among industry stakeholders.

2 SCOPE

2.1 Included Products

2.1.1 Products that meet the definition of Liquid-Immersed Distribution Transformers are eligible for ENERGY STAR certification.

[2] IEEE PC57.120/D13 Loss Evaluation Guide for Distribution and Power Transformers and Reactors, March 2013, 18.

Note: EPA continues to propose including only Liquid-Immersed Distribution Transformers within the scope of this specification due to a lack of data or feedback specific to the energy savings opportunities with other types of transformers. According to EPA findings outlined in its Scoping Report[3], Liquid-Immersed Medium Voltage Distribution Transformers represent the majority of sales in the market and have the greatest energy efficiency savings potential.

2.2 Excluded Products

2.2.1 Products that are covered under other ENERGY STAR product specifications are not eligible for certification under this specification. The list of specifications currently in effect can be found at www.energystar.gov/specifications.

2.2.2 The following products are not eligible for certification under this specification:

i. Low-voltage Dry-Type Distribution Transformer;

ii. Medium-voltage Dry-type Distribution Transformer;

3 CERTIFICATION CRITERIA

3.1 Significant Digits and Rounding

3.1.1 All calculations shall be carried out with actual measured (unrounded) values. Only the final result of a calculation shall be rounded.

3.1.2 Unless otherwise specified, compliance with specification limits shall be evaluated using exact values without any benefit from rounding.

3.1.3 Directly measured or calculated values that are submitted for reporting on the ENERGY STAR website shall be rounded to the nearest significant digit as expressed in the corresponding specification limit.

3.2 Total Owning Cost

3.2.1 Manufacturers are encouraged to highlight for purchasers the total owning cost savings over the lifetime of the product, based on a utility's no-load and load loss evaluation factors. Manufacturers should calculate the total owning cost savings taking into account the utility's A (no load) and B (load) loss evaluation factors and comparing them to that for the manufacturer's design that just complies with Federal standards.

i. TOC shall be calculated per Equation 1.[4]

Equation 1: Total Owning Cost

$$TOC = P + A \times NL + B \times LL_{85°C}$$

Where:

- *TOC is the Total Owning Cost;*
- *P is the bid price in dollars;*
- *A is the utility's equivalent first cost of no-load losses, in dollars per watt;*

[3] U.S. Environmental Protection Agency, "ENERGY STAR Market and Industry Scoping Report: Medium Voltage Distribution Transformers", February 2014, http://www.energystar.gov/ia/products/downloads/MV_Utility_Distribution_Transformers_Scoping.pdf

[4] IEEE PC57.120/D13 Loss Evaluation Guide for Distribution and Power Transformers and Reactors, March 2013, 8–9.

- *NL is the no load loss power corrected for wave-form distortion and then to the reference temperature of 20°C, in watts;*
- *B is the utility's equivalent first cost of load losses, in dollars per watt; and*
- *$LL_{85°C}$ is the load loss power corrected to the reference temperature of 85°C and incorporating ohmic and stray losses, in watts.*

> **Note**: ENERGY STAR specifications are set such that a selection of certified products provide for the recovery of any additional upfront costs associated with efficiency within a reasonable amount of time. Reinforcing this principle, stakeholders provided substantial feedback that a Total Owning Cost (TOC) approach when purchasing transformers allows for greater transparency and understanding of the total cost of a transformer, over its lifetime, given the purchase price and the expected energy losses and financial costs associated with those losses. Thus, using a TOC approach makes clear that transformers that are more expensive at point of purchase often can deliver greater cost savings than a product with a lower initial cost due to lower energy losses over the life of the product. To this end, EPA encourages manufacturers to promote taking a TOC approach. EPA is also promoting a TOC approach such that purchasers are attuned to the total costs of losses over time, which correlate with energy losses.
>
> In the case of transformers, greater energy efficiency usually correlates with higher initial purchase price. Products typically achieve greater efficiency via investments in new, higher quality, or additional material to reduce losses. As such, when assessing the costs of a transformer, EPA is recommending that purchasers consider a product's TOC.
>
> EPA is citing IEEE PC57.120 (currently under development) as development work on IEEE C57.12.23 has been sunset. In Draft 2, EPA has added the TOC equation and a reference to the IEEE standard for best practices for utilities on calculating various input parameters.
>
> Given EPA's promotion of TOC in the specification via inclusion of a formula for calculating TOC for a model and the Agency's careful consideration of cost effectiveness when developing efficiency requirements, EPA is not expecting to create an online tool for purchasers. EPA seeks feedback from stakeholders on its proposed approach in Draft 2.

3.3 Energy Savings at Optimized Load Factor

3.3.1 The Percentage Energy Savings over the minimum DOE-compliant Design, calculated per Equation 2 , shall be greater than or equal to the requirement specified in Table 1, subject to the following requirements.

i. A model meeting the requirements at one of the load factors can become ENERGY STAR certified for that specific load factor. The model will thus need to be marketed as certified only for use at the load factors where it meets the requirements in Table 1.

> **Note:** EPA revised the above requirements to reflect the updated content in Table 1, with some minor additional clarifications.

Equation 2: Percentage Energy Savings over Minimum DOE-compliant Design

$$Savings = \frac{(LL_{DOE} \times L^2 + NL_{DOE}) - (LL_{TOC} \times L^2 + NL_{TOC})}{LL_{DOE} \times L^2 + NL_{DOE}} \times 100\%$$

Where:

- *$Savings$ is the Percentage Energy Savings over the minimum DOE-compliant at the utility-specified load factor;*
- *LL_{DOE} is the full load loss power of the minimum DOE-compliant design corrected to the reference temperature of 55°C and incorporating ohmic and stray losses;*
- *L^2 is the load factor at which the losses are evaluated, with 100% load factor equal to capacity.*

- NL_{DOE} *is the no load loss power of the minimum DOE-compliant design corrected for wave-form distortion and then to the reference temperature of 20°C;*
- LL_{TOC} *is the full load loss power of the TOC-optimized design corrected to the reference temperature of 55°C and incorporating ohmic and stray losses; and*
- NL_{TOC} *is the no load loss power of the TOC-optimized design corrected for wave-form distortion and then to the reference temperature of 20°C.*

Note: EPA updated Equation 2 to clarify the calculation that would be performed by manufacturers when responding to a bid, to illustrate energy savings of a TOC-optimized design.

EPA is proposing to express the requirements as a percentage better than the minimum DOE-compliant design, rather than an absolute value expressed as an efficiency percentage or kWh energy limit. Since materials are continuously improving, having relative requirements to a DOE standard would ensure the longevity and relevancy of an ENERGY STAR specification in the market. The requirement is also simpler to implement because, where applicable, the same requirement could apply over a wider range of load factors and kVA capacities.

Per stakeholder feedback, EPA has also clarified that load losses will be temperature-corrected to 55°C. EPA is proposing this temperature for consistency with DOE. However, EPA welcomes comment whether 85°C would be more reflective of the average temperatures of the transformer.

Table 1: Minimum Percent Energy Saving at Operating Load Factors

				Percentage Energy Savings over Minimum DOE-compliant Design at Utility Specified Load Factor (%)		
Design Line	Number of Phases	Tank Shape	Capacity Range (kVA)	< 30% Load Factor	30–40% Load Factor	> 40% Load Factor
1	1	Rectangular	≤ 167	25%	12%	11%
2	1	Round	≤ 167	25%	12%	14%
3	1	Round	> 167	TBD	TBD	20%
4	3	Rectangular	≤ 500	25%	12%	19%
5	3	Rectangular	> 500	TBD	TBD	16%

Note: In response to stakeholder feedback that purchasers of distribution transformers need products optimized at different load factors, in Draft 1, EPA proposed developing energy savings criteria at load factors ranging from 10% and 70% in increments of 5%. Stakeholders provided new input at EPA's public meeting on August 20, 2015 that three groups of load factors would suffice. As such, with this Draft 2, EPA proposes to set ENERGY STAR criteria in three groups of load factors: <30%, 30-40%, and >40%. These load factors encompass the average load on transformers for the rural residential customer (15%), average nationwide load factor (35%) and for the heavy industrial customer (≥50%). EPA's proposed criteria would recognize products that deliver energy savings beyond those mandated by DOE minimum efficiency standards.

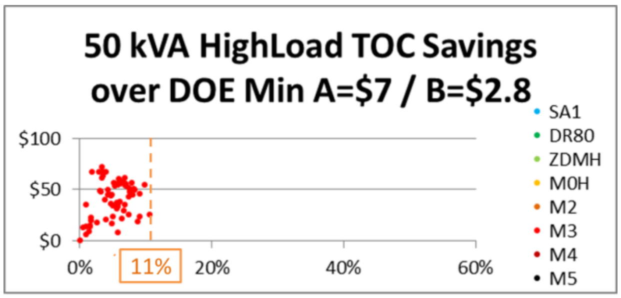
EPA's intent is for manufacturers to highlight for purchasers transformers that deliver both energy savings and total owning cost savings over a minimum DOE-compliant design, as demonstrated by using a TOC approach. Thus, the proposed requirements are based on an analysis of achievable energy savings that also result in TOC savings over the minimum DOE-compliant design. According to EPA's methodology and dataset outlined below, energy and cost savings can be achieved through more than one core technology at each load factor. For example, some M3 and other steel cores are able to meet the proposed criteria in addition to the amorphous core technologies.

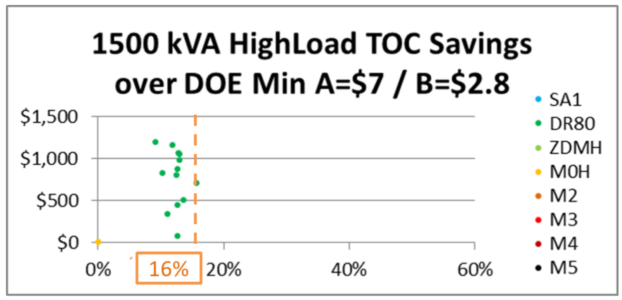
Methodology for the >40% load factor: To develop the proposed criteria at >40% load factor, EPA used the DOE 2013 Final Rule dataset, because many of the models were already optimized for the 50% load factor. EPA supplemented DOE's 2013 Final Rule dataset with designs using M0H and DR80 core steels, which were modeled by scaling DOE-developed ZDMH designs using the following assumptions:

- M0H core losses were equal to ZDMH and costs were 1.3x M3 (0.89x ZDMH)
- DR80 core losses were 0.8x ZDMH and costs were 1.125x ZDMH

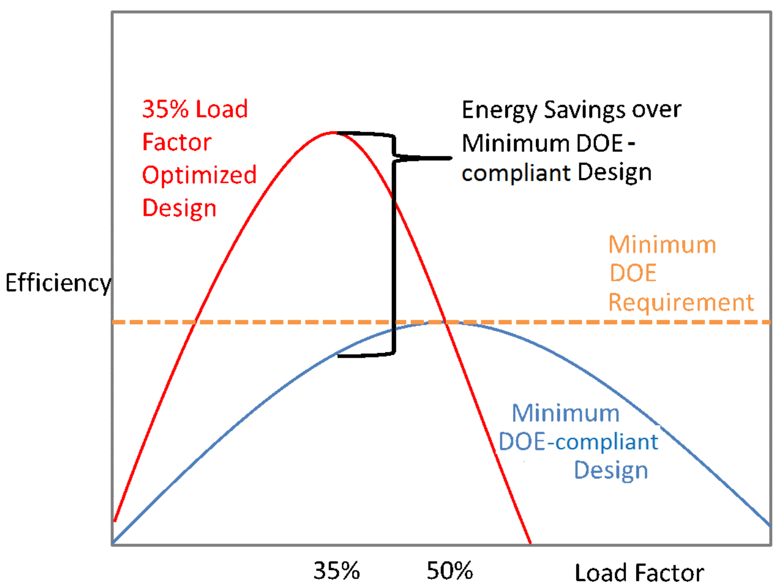
In the interest of ensuring ENERGY STAR certified models deliver on the program principle of cost effectiveness, EPA then based the energy savings requirement on the highest savings achievable by a positive TOC design using non-amorphous core material (typically DR80) at evaluation factors A = $7/watt/B = $2.75/watt and high load factor (50%). EPA selected these evaluation factors based on input from stakeholders that they represented the median A and B factors in regions or circumstances with relatively higher no-load core losses, where a TOC approach illustrates favorable energy savings over time.

For example, below are the results for the 50 kVA representative unit in Design Line 1, and the 1500 kVA unit in design line 5, showing 11% and 16% energy savings with positive TOC achievable with M3 and DR80 steel, respectively.





Methodology for the <30% and 30–40% load factors: In developing the proposed criteria for the low (<30%) and mid (30–40%) load factors, EPA was unable to reference the DOE's data because most of the designs in the dataset are optimized for 50% load factor. As a next step, EPA modeled the theoretical savings of a design optimized for 35% load factor that, at a minimum, meets the DOE requirement at 50% load factor. Such a design would provide 0% energy savings over a minimum DOE-compliant design at 50% load factor, but positive energy savings at lower load factor as its efficiency there exceeds that of the minimum DOE- compliant design, as illustrated below.



This design was developed by setting core losses equal to winding losses at 35% load factor (the optimum operating point) and then setting the total losses at 50% load factor to be equal to:

$\frac{Capacity}{2} \times \frac{1-eff}{eff}$, where *eff* is the DOE efficiency requirement.

Such a design would provide savings of 12% at 35% load factor and 25% at 20% load factor over the DOE minimum-compliant design. EPA confirmed the presence of designs providing similar savings for the 30-40% load factor and <30% load factors, respectively, in the DOE dataset and via stakeholder inputs confirming EPA's findings for 25 kVA. The table below provides examples of 25 kVA representative unit in Design Line 2 that support the savings requirements. Data for the DR80 model that EPA received also proved cost effective (positive TOC compared to a DOE minimum design) down to evaluation factors of A=$6/W and B=$0.75/W. As such, EPA is proposing 12% savings over the DOE min design at 35% load factor and 25% at 20% load factor for lower kVA rated designs, namely single-phase designs rated at ≤167 kVA and three-phase designs rated at ≤500 kVA. EPA seeks feedback from stakeholders on whether the proposed energy saving criteria would apply across all lower rated kVA designs to deliver both TOC savings and energy savings over minimum DOE-compliant unit. At this time, EPA lacks sufficient data to propose energy saving criteria for designs >167 kVA single phase and >500 kVA three phase (DL 3 & DL5). As such, EPA requests additional data from stakeholders for such designs.

Source	Core Loss (W)	50% Winding Loss @ 55°C (W)	100% Winding Loss @ 85°C (W)	Peak Eff. Load Factor*	Savings over DOE Min. Design	
					20%	35%
Min cost Design	66	66	286	50%	–	–
Design 1	44	89	384	35%	25%	12%
Design 2	52	81	349	40%	16%	7%
Design 3	47	84	363	37%	21%	11%
Design 4	51	82	355	39%	17%	8%
Design 5	52	81	351	40%	15%	7%
Design 6	44	84	370	36%	25%	14%
Design 7	43	89	393	35%	25%	12%
Design 8	44	88	389	35%	24%	12%

Note: Table is based on actual calculations but Losses are rounded off for clarity.

* Peak Efficiency calculated from 50% WL @ 55C

Note: EPA has removed the toxicity requirements based on the European Union Reduction of Hazardous Substances directive as distribution transformers are not subject to this directive.

4 TESTING

4.1 Test Methods

4.1.1 Test methods identified in Table 2 shall be used to determine certification for ENERGY STAR.

Table 2: Test Methods for ENERGY STAR Certification

Product Type	Test Method
All	U.S. Department of Energy, "Test procedures for measuring energy consumption of distribution transformers", Appendix A to Subpart K of 10 CFR Part 431

4.2 Number of Units Required for Testing

4.2.1 Basic Model shall be selected for testing per the requirements in the Department of Energy Certification Requirements for Distribution Transformers, 10 CFR 429.47.

i. For certification of an individual product model, the Basic Model shall be the model which is intended to be marketed and labeled as ENERGY STAR.

ii. For certification of multiple product models under the Basic Model definition, the Alternative Efficiency Determination Method (AEDM) may be used to certify all subsequent models that meet the Basic Model parameters.

Note: EPA proposes to allow transformer manufacturers to follow the same laboratory testing procedures when certifying a product to ENERGY STAR as they do when reporting their product performance to DOE. As such, manufacturers would be able to use both the same actual test results submitted to DOE as well as modeled results from the same alternative efficiency determination method (AEDM) they currently use to demonstrate DOE compliance, allowing for more timely response to potential customers regarding ENERGY STAR status of design options. Like other ENERGY STAR product categories where the majority of testing is conducted in manufacturers labs, the lab would need to sign up with a Certification Body’s (CB’s) Supervised Manufacturers Testing Lab (SMTL) Program and to have the CB review the test data as part of the certification process.

5 EFFECTIVE DATE

5.1.1 Effective Date: The Version 1.0 ENERGY STAR Distribution Transformers specification shall take effect on **TBD**. To certify for ENERGY STAR, a product model shall meet the ENERGY STAR specification in effect on the model’s date of manufacture. The date of manufacture is specific to each unit and is the date on which a unit is considered to be completely assembled.

Note: EPA anticipates completing this specification development effort in the coming months. Manufacturers may certify products to the new specification as soon as it is finalized,

5.1.2 Future Specification Revisions: EPA reserves the right to change this specification should technological and/or market changes affect its usefulness to consumers, industry, or the environment. In keeping with current policy, revisions to the specification are arrived at through stakeholder discussions. In the event of a specification revision, please note that the ENERGY STAR certification is not automatically granted for the life of a product model