ENERGY STAR® Guide to Buying More Energy Efficient Distribution Transformers

The simple choice for energy efficiency.

ENERGY STAR

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How to avoid transformer energy waste?

Significant electricity network losses are due to distribution transformers, which waste 3–5% of the power passing through them[1].The use of lower-loss distribution transformers that are designed for intended load factor and go beyond the U.S. Department of Energy (DOE) standard can yield large energy and monetary savings over their lifetime. For example, replacing 20 percent of the U.S. stock with transformers meeting the criteria outlined in this document instead of minimum DOE-compliant units would save an estimated 1.4 TWh annually.[2] Distribution transformers with lower losses can run cooler, and generally have lower total ownership cost, improving the bottom line for both utilities and their ratepayers.

What does this guide cover?

In addition to specifying energy efficiency criteria for distribution transformers by load factor, this guide briefly addresses the cost effectiveness of energy efficient transformers, regulatory and purchasing considerations, and procurement planning.

Who is the audience for this guide?

The primary audience for the buying guide is utility purchasers, but the guide should also be useful to other purchasers of applicable transformer types including military bases, corporate and college campuses, and solar and wind developers. In addition, utility regulators and energy efficiency advocates may find the document useful for defining what it means to purchase an energy efficient distribution transformer.

What types of distribution transformers are included in this guide?

Medium-voltage, liquid-immersed, specifically:

Type	Liquid-Immersed, Excluding vault-type
Capacity	10 kVA – 500 kVA single-phase; 2500 kVA three-phase
Voltage	Input: 34.5 kV or less; Output: 600 V or less
BIL[3]	≤ 150 kV

Although step-up transformers used in wind and solar farm application are not considered distribution transformers, the energy savings criteria discussed in this document should also be helpful for understanding and specifying lower-loss step-up transformers. Since step-up transformers are not covered by the DOE standard, a comparative baseline for step-up transformers is not discussed. (Energy savings would likely be greater given that there is no federal standard for step-up transformers).

What does it mean to purchase an energy efficient transformer?

Since 2007, DOE has set minimum energy conservation standards for medium-voltage, liquid-immersed distribution transformers. The most recent standard was published in the Federal Register on April 18, 2013, with a compliance date of January 1, 2016.[4] Most distribution transformers are purchased based on this standard. Utility regulators usually require that energy efficiency measures be defined as achieving energy savings above that required by law (in this case, above the minimum DOE standard). As discussed

1 Jeff Triplett, "Evaluating Distribution System Losses Using Data from Deployed AMI and GIS System," 2010. http://www.powersystem.org/docs/publications/triplett_ieee-2010-repc-final.pdf

2 EPA analysis, November 2016.

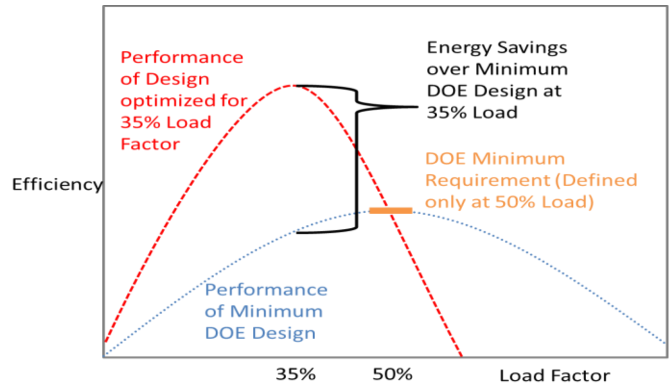
3 Basic Impulse Insulation Level (BIL) is the measure of resistance to very large changes in voltage, like those from a lightning strike.

4 78 FR 23336.

below, some states are beginning to allow regulated utilities to count grid-side efficiency measures toward required efficiency standards or goals, enhancing the need to define energy efficiency criteria for distribution transformers in a meaningful way.

In addition, purchasing a transformer only considering the DOE minimum requirements is typically not the lowest loss or most cost-effective option because minimally DOE-compliant distribution transformers are optimized for operation at 50% load factor,[5] while many transformers are installed in circuits with lower load factors—a trend that is likely to continue due to ongoing investment in energy efficiency and growth of distributed energy resources.

As illustrated in the graphic at right, the DOE standard (solid line) is set at 50% load factor. The minimum DOE-compliant design is optimized to just meet the standard at 50% load factor. However, the realized efficiency diminishes significantly the farther the actual loading is above or below this loading point (dotted line). Additional energy savings can be achieved (while still complying with the DOE standard) by optimizing transformer design to the expected load factor, which is utility and/or location specific. In this example, the expected load factor (dashed line) is 35 percent.



The EPA ENERGY STAR program recommends the following criteria for a meaningful level of energy savings above the DOE standard. Depending on load factor and output power, using these criteria ***distribution transformer losses can be reduced by 11 to 29 percent***. (Throughout the remainder of the document, these criteria are referred to as "recommended energy efficiency criteria" and are implied when discussing "energy efficient transformer(s)".)

Recommended Energy Efficiency Criteria for Medium-Voltage, Liquid-Immersed Distribution Transformers

Range of Utility Specified Load Factors:				< 30%	30–40%	> 40–55%	> 55%
Specific Load Factor at which Requirements Should Be Met:				25%	35%	50%	65%
				↓	↓	↓	↓
Design Line	Number of Phases	Tank Shape	Capacity Range (kVA)	Percentage Energy Savings over Minimum DOE compliant Design (%)			
1	1	Rectangular	≤ 167	25%	12%	11%	21%
2	1	Round	≤ 167	25%	12%	14%	25%
3	1	Round	> 167	25%	12%	20%	27%
4	3	Rectangular	≤ 500	25%	12%	19%	29%
5	3	Rectangular	> 500	25%	12%	16%	16%

[5] Load factor: The ratio of the average load over a period of time to the peak load during that time.

The following equation is used to determine the energy savings over the DOE minimum compliant design:

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

Where:

- $\boldsymbol{Savings}$ is the percentage energy savings over the minimum DOE-compliant design at the utility-specified load factor;
- $NL_{DOE} = \frac{kVA}{4} \times \frac{(1-Efficiency_{DOE})}{Efficiency_{DOE}} \times 1000$, where kVA is the capacity and, ***Efficiency***$_{DOE}$ is the DOE minimum efficiency specified in 10 CFR 431.196(b)(2) as a decimal;
- $LL_{DOE} = 4 \times NL_{DOE}$
  L is the load factor at which the losses are evaluated, with 100% load factor equal to capacity;
- LL_{TOC} is the full load winding 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.

Additional details and definitions supporting these criteria can be found in the ENERGY STAR Final Draft Distribution Transformer specification.

Cost effectiveness

Most energy efficient distribution transformers have a slightly higher initial purchase price (<10%), [6] but in many cases a lower Total Owning Cost (TOC). Based on EPA analyses, the criteria recommended in this buying guidance are cost effective for distribution systems or circuits with the following characteristics:

- Low to medium load factor with a no-load loss evaluation (A-factor) greater than or equal to $5/watt.[7] (This corresponds to an average retail price ≥ 9.7 cents/kWh[8]—about 22% of U.S. utilities have A-factors at or above this level.[9])
- Medium to high load factor with a no-load loss evaluation (A-factor) ≥ $5/watt to $7/watt depending on the design line. (This corresponds to an average retail price between 9.7 and 13.5 cents/kWh[10]—about 19% of utilities have A-factors above this range.[11])

Cost effectiveness can be documented or confirmed using the following equation:

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

Where:

- ***TOC*** is the Total Owning Cost;

[6] EPA, "Distribution Transformers Draft 2 Data Analysis Memo", October 2016, https://www.energystar.gov/sites/default/files/Distribution%20Transformers%20Draft%202%20Data%20Analysis%20Memo.pdf.
[7] EPA, "Distribution Transformers Draft 2 Specification Analysis", August 2016. https://www.energystar.gov/ia/products/downloads/ENERGY%20STAR%20Distribution%20Transformers_Draft%202%20Analysis.xlsx
[8] EPA Analysis based on U.S. Energy Information Administration (EIA) data, January 2017.
[9] EPA, "Distribution Transformers Draft 2 Data Analysis Memo", October 2016.
[10] EPA Analysis based on U.S. Energy Information Administration (EIA) data, January 2017.
[11] EPA, "Distribution Transformers Draft 2 Data Analysis Memo", October 2016.

- ***P*** is the bid price in dollars (USD);
- ***A*** is the utility's equivalent first cost of no-load losses, in dollars per watt;
- ***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
- $LL_{85^\circ C}$ is the load loss power corrected to the reference temperature of 85°C and incorporating ohmic and stray losses, in watts.

For more information on calculating A and B factors, consult IEEE Guide no. C57.120 - Loss Evaluation Guide for Distribution and Power Transformers

Regulatory considerations

It is common practice for utilities to capitalize the cost of purchasing distribution transformers. Increasingly, particularly in states with aggressive energy efficiency goals, states and/or their public utility commissions are allowing grid-side energy savings to count toward clean energy goals. Both are discussed briefly below:

Capitalizing Costs - Utilities can capitalize the cost of purchasing distribution transformers, which have an average lifespan of 32 years.[12] Capital costs are amortized and recovered by a utility through rates. Even though the cost of purchasing an energy efficient distribution transformer will be higher compared to a minimum-cost DOE-compliant one, the net present value (NPV) will be lower, due to lower TOC. These savings can be passed on to ratepayers.

Credit Toward Energy Efficiency/Clean Energy Goals - In some jurisdictions, installation of energy efficient transformers may be allowed to contribute toward meeting state mandatory energy efficiency or clean energy goals.

Examples include the following:

- Maryland regulators allow grid-side energy efficiency to count toward the state Energy Efficiency Resource Standard (EERS). During the second half of 2016, PEPCO installed 954 transformers, yielding 600 MWh in annualized energy savings for an estimated 203 MWs in demand savings and 18,003 MWh in life cycle energy savings.
- Washington and Oregon both define conservation as reductions in consumption resulting from "efficiency of energy use, production, or distribution".
- Minnesota enables energy efficient distribution transformers to contribute to utility energy efficiency requirements and provides detailed quantification in its state Technical Reference Manual for Energy Conservation Improvement Programs. (See pp. 509-513, http://mn.gov/commerce-stat/pdfs/mn-trm-v2.1.pdf.)
- Ohio legislation allows programs implemented by a utility to include "transmission and distribution improvements that reduce line losses."[13]

More information on grid-side energy efficiency opportunities and related state policies can be found in Section 7.5 of the EPA Energy and Environment Guide to Action.

Purchasing considerations

Availability - Since transformers are custom-built, manufacturers can optimize designs to meet the recommended energy savings criteria described in this buying guide by balancing the techniques and materials they use to reduce load and no-load losses. The two parts of a transformer that are responsible for losses are the coils (responsible for

[12] U.S. Department of Energy, "Life-cycle Cost and Payback Analysis", *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment Distribution Transformers*, April 2013, pp. 8-32.

[13] http://codes.ohio.gov/orc/4928.66

load losses) and core (responsible for no-load losses). The peak efficiency of a transformer occurs at the percentage loading where core losses are equal to coil losses.[14]

- Core losses result from energizing the laminated steel core. These losses are virtually constant from no load to full load. Core losses can be reduced with thinner laminations, better magnetic orientation, or by using core materials such as amorphous steel.[15]
- Coil losses are also called load losses because they are proportional to the square of the load on the transformer. They are due to the resistance of the winding material (copper or aluminum). Coil losses can be reduced with bigger (less resistive) conductors.

Since distribution transformers are custom built to order, supply is not an issue—all major manufacturers are capable of producing energy efficient transformers.

Other technical considerations - Purchasing an energy efficient transformer can save energy, lower operating costs, and possibly extend transformer life; however, buyers should be aware that energy efficient transformers are sometimes slightly heavier or larger as noted in the table at right.

A question sometimes arises with pole-type transformers (applicable only to design lines 2 and 3) regarding the additional weight of some efficient transformer units and what weight increase would trigger the need for pole replacement. (Additional weight is not generally an issue with design lines 1, 4, and 5 as they are pad-mounted and sit on the ground.) During the development of the 2016 federal standard, DOE assumed that a pole change-out would be necessary for design line 2, only if the weight increase was greater than 15% *and* 150 lbs.[19] In addition, DOE noted that poles are selected by utilities based on horizontal (lateral) load (due to wind, ice, etc.) and not vertical load and are, therefore, typically over-sized.[20] This is corroborated by Rural Utilities Service guidance, which considers vertical loads negligible.[21] The expected weight increase of units conforming to this guide is less than or equal to 11%; where weight remains a concern, it can be mitigated with alternate materials.

	Pros	Cons
All energy efficient transformers	Lower operating cost	Slightly heavier (≤11%, can be mitigated with different grade core material) Higher initial cost (<10%)[16]
Amorphous core transformers	Usually lower core losses, higher efficiency, and longer transformer life[17]	In addition to above, slightly larger[18]

[14] EPA, "ENERGY STAR Market and Industry Scoping Report: Medium Voltage Distribution Transformers," February 2014. https://www.energystar.gov/sites/default/files/asset/document/MV_Utility_Distribution_Transformers_Scoping.pdf
[15] Ibid.
[16] EPA, "Distribution Transformers Draft 2 Data Analysis Memo," October 2016. https://www.energystar.gov/sites/default/files/Distribution%20Transformers%20Draft%202%20Data%20Analysis%20Memo.pdf.
[17] Man Mohan, "An overview on Amorphous Core Transformers," 2012. http://jeteas.scholarlinkresearch.com/articles/An%20Overview%20on%20Amorphous%20Core%20Transformers.pdf
[18] EPA, "Distribution Transformers Draft 2 Data Analysis Memo," October 2016.
[19] A typical 25 kVA pole unit is less than 400 pounds.
[20] U.S. Department of Energy, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment Distribution Transformers*, April 2013, Section 6.3.1, https://www.regulations.gov/document?D=EERE-2010-BT-STD-0048-0241
[21] U.S. Department of Agriculture, Rural Utilities Service, *Unguyed Distribution Poles—Strength Requirements*, Bulletin 1724E-150, August 2014, p. 6, https://www.rd.usda.gov/files/UEP_Bulletin_1724E-150.pdf

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Planning for procurement

Since most distribution transformers are replaced due to failure, it is important to be proactive about specifying energy efficient transformers. This includes establishing policies favorable to efficient purchases, coordinating among relevant organizational units, and identifying opportunities to derive additional value from energy efficiency.

Utilities that set procurement policies to install energy efficient transformers as a matter of practice are in a better position to ensure necessary capital is available to cover additional incremental costs associated with energy efficient transformers. In addition, manufacturers have noted that utilities often procure based on outdated load factors. Having up-to-date information about load factors and load trends is important to specifying optimal design. As discussed previously, this is particularly important given the trend toward lower load factors due to ongoing investment in energy efficiency and growth of distributed energy resources in some jurisdictions. Many utilities have installed smart meters throughout all or part of their service territories providing precise information to inform load factors.

Simply purchasing based on prior procurements is an understandable but suboptimal process. Setting a default practice such as requiring that purchases be based on the recommended energy efficiency criteria contained in this guide (unless deemed technically ill-suited for a particular application or not cost effective based on TOC) makes procuring energy efficient distribution transformers the default practice and shifts the onus to documenting the rationale for purchasing a less efficient transformer. Similarly, consider strategies for ensuring a range of energy efficient distribution transformers optimized for appropriate load factors are included in your utility's spare distribution transformer stock for emergency replacements.

Make Energy Efficient Transformer Purchasing a Priority

- ✓ Establish an energy efficient transformer purchasing policy
- ✓ Educate purchasing agents, management, and other key staff about the policy
- ✓ Ensure necessary capital is available to cover higher first-cost; link to lifetime lower total ownership cost
- ✓ Have updated A and B factors on hand
- ✓ Understand technical considerations like size and weight restrictions when considering transformer materials
- ✓ Explore whether energy savings can count towards energy efficiency goals or improve the business case for grid modernization efforts

In addition, for jurisdictions that can claim associated energy savings, coordination between the demand-side management department and the distribution planning department is advised to ensure that procurements align with approved efficiency requirements and that appropriate data is collected before and after the procurement. For example, situational factors such as early replacement may allow additional energy savings to be claimed with supporting data.

Finally, grid modernization efforts represent a good opportunity to upgrade to energy efficient transformers, as capitalizing on energy efficiency benefits can help improve the business case for such efforts.