
Clarifications on the use of Department of Energy Design-Line 6, 7, and 8 transformers contained within 10 CFR 430 and 431, Energy Conservation Program for Commercial Equipment: Distribution Transformers Energy Conservation Standards

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1. Introduction

1.1. Purpose

To provide guidance to engineers regarding the efficiency levels of low voltage, dry-type distribution transformers and use of the Department of Energy Design-Lines 6, 7, 8 contained within 10 CFR 430 and 431.

1.2. Scope

This paper will provide information on the following topics:

- 1) History of LV Transformer Efficiency Requirements including both National Electrical Manufacturers Association (NEMA) and United States Department of Energy (DOE) actions.
- 2) Step by step instructions for the determination of transformer efficiency based on DOE 10 CFR 430 and 431.
- 3) The importance of proper use of the DOE actions and the role of efficiency standards.
- 4) Frequently asked questions (FAQs).

2. History of LV Transformer Efficiency Requirements

2.1. Energy Policy Act of 1992 (Pub.L. 102-486)

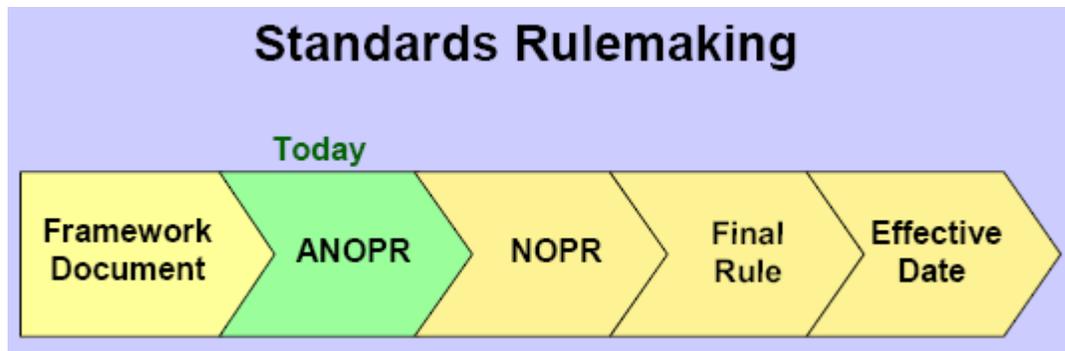
The Energy Policy Act of 1992 (EPAct 1992), amending the Energy Policy and Conservation Act (EPCA) empowered the DOE with the following responsibilities and scope.

Declaration of Policy – *It is hereby declared the policy of the State:*

(a) to ensure a continuous, adequate, and economic supply of energy with the end in view of ultimately achieving self-reliance in the country's energy requirements through the integrated and intensive exploration, production, management, and development of the country's indigenous energy resources, and through the judicious conservation, renewal and efficient utilization of energy to keep pace with the country's growth and economic development and taking into consideration the active participation of the private sector in the various areas of energy resource development; and

(b) to rationalize, integrate, and coordinate the various programs of the Government towards self-sufficiency and enhanced productivity in power and energy without sacrificing ecological concerns.

Section 124(a) of EPAct 1992 directed the Secretary of Energy to prescribe testing requirements for distribution transformers for which the Secretary made a determination that energy conservation standards would be technologically feasible and economically justified, and would result in significant energy savings. The Secretary published his determination on October 22, 1997. In accordance with this policy, the DOE began the task of evaluating the possible improvements in energy efficiency for distribution transformers. The evaluation process used the following steps:



ANOPR: Advance Notice of Public Rulemaking

NOPR: Notice of Public Rulemaking

2.2. NEMA TP1-1996/2002 Standard

In 1996, NEMA responded to the industry need for higher transformer efficiencies with the publishing of the NEMA TP1 standard. NEMA updated the standard in 2002 and received approval for inclusion of the TP1 requirements into the DOE Energy Star program.

2.3. ANOPR

The DOE rulemaking effort progressed to the ANOPR step and the notice was published July 29, 2004 titled, "10 CFR Part 430 'Energy Conservation Program for Commercial and Industrial Equipment: Energy Conservation Standards for Distribution Transformers (Proposed Rule)'" . 69 Fed.Reg. 45376. This proposed rule contained the beginnings of higher minimum efficiencies for all types of transformers within today's electrical power systems.

The ANOPR documented the candidate standard levels (CSLs) and the three representative low voltage transformer sizes or design lines which would be used for evaluation.

Candidate Standard Level (CSL) is a term used in the DOE efficiency evaluation process for transformers. The number following the term CSL is based on the range of transformer efficiency levels considered. The levels were determined based on the difference between the highest possible calculated design without consideration of material availability or cost and current high efficiency models in production. In the DOE efficiency evaluation, there were five levels equally spaced with CSL1 being equal to NEMA TP1 and CSL5 equal to the highest calculated value.

As part of the simplification process for analysis, the DOE chose representative transformer sizes for design lines for evaluation to the CSL levels. For LV dry transformers, 25 kVA, 75 kVA, and 300 kVA models were chosen as designs to evaluate in respect to the CSL efficiency levels.

The design lines for low voltage were:

DESIGN LINE 6: Cover all Single Phase Low Voltage Dry Distribution Transformers
Representative unit: 25kVA,

DESIGN LINE 7: Cover 15 to 150kVA Three Phase Low Voltage Dry Distribution
Transformers Representative unit: 75kVA

DESIGN LINE 8: Cover 225 to 1000kVA Three Phase Low Voltage Dry Distribution
Transformers Representative unit: 300kVA

The efficiency levels for CSL-1, CSL-2, CSL-3, CSL-4 and CSL-5 for three low voltage representative designs are shown in the following table.

Candidate Standard Levels evaluated for each design line

Design Line	CSL1		CSL2		CSL3		CSL4		CSL5	
	TP1+ (%)	Efficiency (%)								
DL6	0.00	98.00	0.20	98.20	0.40	98.40	0.70	98.70	0.79	98.79
DL7	0.00	98.00	0.30	98.30	0.60	98.60	0.90	98.90	1.09	99.09
DL8	0.00	98.60	0.20	98.80	0.40	99.00	0.60	99.20	0.67	99.27

CSL5 is the maximum level based on output of design programs for the Design Line as determined in the DOE Engineering Analysis. CSL1 is equal to NEMA TP1 levels and the remaining three levels are proportion between the three design lines for the evaluation.

DL6 $0.79/4 = .1975$ (portions were rounded up to 0.20)

DL7 $1.09/4 = .2725$ (portions were rounded up to 0.30)

DL8 $0.67/4 = .1675$ (portions were rounded up to 0.20)

2.4. Energy Policy Act of 2005

The Energy Policy Act of 2005 (EPA 2005), Public Law 109-58, amended EPCA to establish energy conservation standards at the NEMA TP1 levels for low-voltage, dry-type distribution transformers. This action removed low voltage dry-type transformers from the DOE's pending distribution transformer rulemaking, and foreclosed inclusion of DOE's work for Design Lines 6, 7, & 8 in their evaluation toward a final rule. DOE ultimately adopted the congressionally-mandated standards as their energy conservation standards for low voltage dry-type transformers. (10 CFR §431.196(a))

This action did not negate the original intent to include the work for Design Lines 6, 7, & 8 in the Final Rule nor changed the definitions of such efficiency levels (hence the need for this document to discuss the minimum efficiencies that would have been pushed).

The next step in DOE's process (NOPR) would have investigated the range of standard transformer sizes (Trial Standard Levels) to determine the efficiency improvements across a full range of kVA sizes.

The following formula can be used to interpolate the range of transformer sizes.

Formula to convert the Representative Transformer to the other kVA sizes:
Used to scale total losses (TL) from a representative unit to other kVA ratings (S) within an engineering design line

$$TL_1 = TL_0 \times (S_1 / S_0)^{0.75}$$

The scaling rule is valid when design parameters are held constant, including frequency, magnetic flux density, current density and insulation level.

3. Step-by-Step Procedure for accurate efficiency determination:

This section endeavors to detail the step-by-step procedure and location of the information needed to accurately determine the intent of the DOE definitions of transformer efficiency.

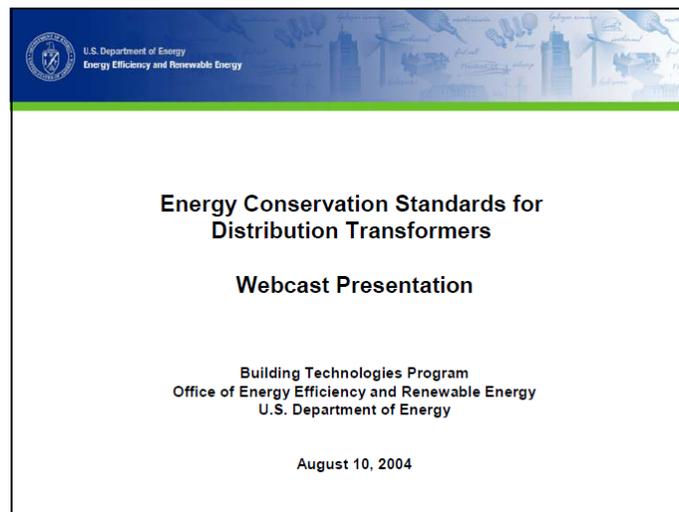
Procedure Summary

1. Determine the Design Line (DL) representative unit

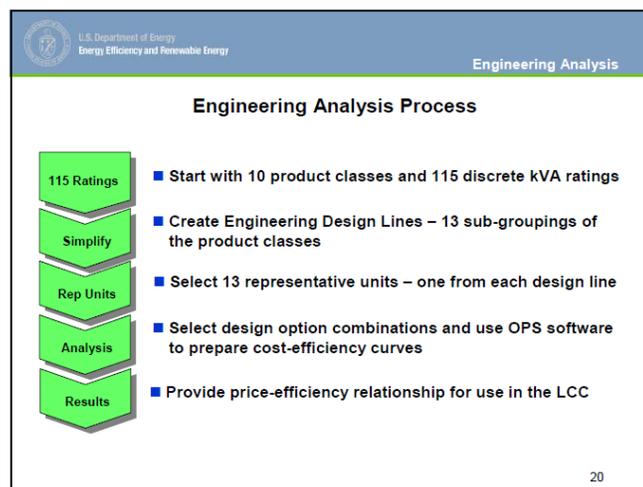
2. From the NOPR documentation – find the efficiency of the representative unit
3. Use the 0.75 Scaling Method to calculate the efficiency of a new kva from the two kva sizes and representative unit efficiency.

1.) *Determining the Design Line (DL) Representative Unit*

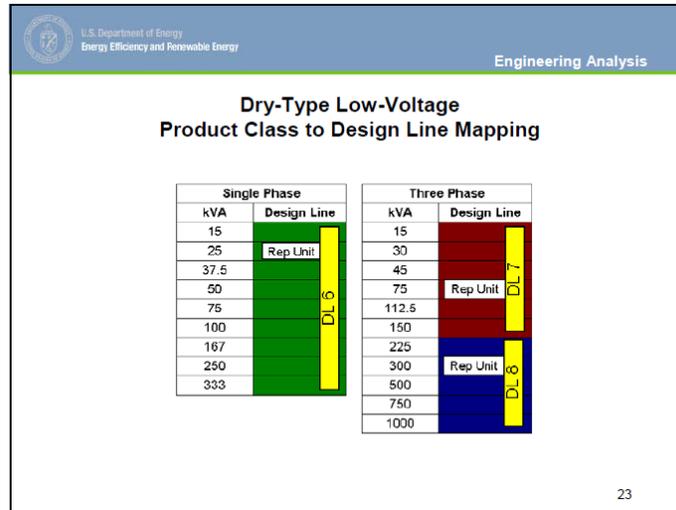
The background and basis of information determination comes from the “Energy Conservation Standards for Distribution Transformers – Webcast Presentation” – August 10, 2004 (located at: http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/dist_webcast_081004.pdf):



Slide 20 from this presentation shows us the ‘Engineering Analysis Process’:



This shows us that the original 115 discrete kva ratings were summarized into ‘Engineering Design Lines’ – 13 Sub-groups. From each Design Line, a Representative Unit kva is selected for additional analysis. For low-voltage, dry-type transformers - the design lines are 6, 7, and 8 - with the representative units being 25kva, 75kva, and 300kva respectively (page 23):



2.) Finding the efficiency of the Design Line (DL) Representative Unit:

The documentation building to the Final Rule includes a National Impact Analysis spreadsheet. Within the 'CSL Definitions & DL-PC Mapping' tab you'll find the completed efficiencies from the analysis of the Design Line Transformers (located at:

http://www1.eere.energy.gov/buildings/appliance_standards/commercial/docs/nia_dt_nopr_20050802.xls) shown below:

Efficiency Levels By Design Line

Design Line	CSL1	CSL2	CSL3	CSL4	CSL5	CSL6
DL 1	98.90%	99.04%	99.13%	99.33%	99.43%	99.53%
DL 2	98.70%	98.73%	98.76%	98.79%	98.96%	99.46%
DL 3	99.30%	99.38%	99.46%	99.54%	99.74%	99.75%
DL 4	98.90%	99.08%	99.26%	99.45%	99.58%	99.61%
DL 5	99.30%	99.36%	99.42%	99.47%	99.71%	99.71%
DL 6	98.00%	98.22%	98.44%	98.66%	98.90%	98.90%
DL 7	98.00%	98.32%	98.64%	98.95%	99.13%	99.13%
DL 8	98.60%	98.82%	99.04%	99.26%	99.33%	99.33%
DL 9	98.60%	98.82%	99.04%	99.26%	99.41%	99.41%
DL 10	99.10%	99.22%	99.30%	99.39%	99.51%	99.51%
DL 11	98.50%	98.67%	98.84%	99.01%	99.09%	99.09%
DL 12	99.00%	99.12%	99.23%	99.35%	99.51%	99.51%
DL 13	99.00%	99.15%	99.30%	99.45%	99.55%	99.55%

Design Lines to Product Classes Mapping

Product Class	Type	Phases	LVMV	BIL	Capacity
PC1	Liquid-Immersed	1	MV	Any	10-833
PC2	Liquid-Immersed	3	MV	Any	15-2500
PC3	Dry	1	LV	≤ 10 kV	15-333
PC4	Dry	3	LV	≤ 10 kV	15-1000
PC5	Dry	1	MV	20-45 kV	15-833
PC6	Dry	3	MV	20-45 kV	15-2500
PC7	Dry	1	MV	46-95 kV	15-833

A zoom-in of the area of interest – Design Lines 6, 7, & 8 is shown below:

DL 6	98.00%	98.22%	98.44%	98.66%	98.90%	98.90%
DL 7	98.00%	98.32%	98.64%	98.95%	99.13%	99.13%
DL 8	98.60%	98.82%	99.04%	99.26%	99.33%	99.33%

3.) The 0.75 Scaling Method and Determining complete table of low-voltage, dry-type transformers:

Information about the use of the 0.75 Scaling Rule is contained within the “Energy Conservation Standards for Distribution Transformers – Webcast Presentation” dated August 10, 2004 – reference above. On slide 72, the following information is contained:

U.S. Department of Energy
Energy Efficiency and Renewable Energy

National Impact Analysis

Site Energy Savings via 0.75 Scaling Rule

- Grouped 115 different kVA ratings into 13 design lines with representative units (selected high volume ratings)
- Translates findings from the unit analyzed to other kVA ratings within a given engineering design line

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The original ANOPR, dated July 29, 2004, 69 Fed.Reg. 45376, also contains a section describing the use of the 0.75 Scaling Method is found on page 45389:

9. Dry-type, medium-voltage, single-phase, ≥ 96 kV E
 10. Dry-type, medium-voltage, three-phase, ≥ 96 kV I

*Due to the low shipment volume in these three p
 medium-voltage (MV) dry-type distribution transforme
 adjust to single-phase.

From each of the thirteen engineering design lines, the Department selected one representative unit to study in detail in both the engineering and the LCC analysis. Once these two analyses were complete, the Department scaled the findings on these units to all the other kVA ratings within each of the thirteen design lines using the 0.75 scaling rule (see Chapter 5 in the TSD). This rule states that for similarly designed transformers, construction costs and watt losses scale to the ratio of kVA ratings raised to the 0.75 power.

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Technical Support Document (TSD) Appendix 5b, which DOE published along with the Final Rule for liquid-fill and medium voltage dry-type transformers, describes the 0.75 Scaling Rule in detail. This document can be found at:

http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/transformer_fr_tsd/appendix_5b.pdf with a summary of the formula being:

$$\text{Efficiency}_B = 100 - (100 - \text{Efficiency}_A) * (\text{kVA}_B / \text{kVA}_A)^{-0.25}$$

With Transformer 'A' being the information about the Representative Unit and Transformer 'B' being the unit being determined / requested

As an example, let us consider how we could determine the accurate CSL-3 efficiency of the 150 kva low-voltage, dry-type (Design Line 7) transformer. The representative unit for Design Line 7 is the 75 kva transformer with a Representative Unit efficiency of 98.64%. The formula will be:

$$\begin{aligned} \text{Efficiency of 150 kva} &= 100 - (100 - 98.64) * (150 / 75)^{-0.25} \\ &= 100 - (1.36) * (2)^{-0.25} \\ &= 100 - (1.36) * (0.8408964) \\ &= 100 - 1.1436 \\ &= 98.86\% \end{aligned}$$

Using this methodology, the minimum efficiencies based on transformer size are shown in Table 1 (below).

Table 1

CSL / TSL Level - Minimum Efficiency at 35% Loading of Nameplate with Linear/Resistive Load (%, percentage)						
Kva	Design Line	1	2	3	4	5 *
15	6	97.7	97.98	98.23	98.48	98.75
15	7	97.0	97.49	97.97	98.43	98.70
25	6	98.0	98.22	98.44	98.66	98.90 **
30	7	97.5	97.89	98.29	98.68	98.91
37.5	6	98.2	98.39	98.59	98.79	99.01
45	7	97.7	98.09	98.45	98.81	99.01
50	6	98.3	98.50	98.69	98.87	99.08
75	6	98.5	98.65	98.81	98.98	99.16
75	7	98.0	98.32	98.64	98.95	99.13 **
100	6	98.6	98.74	98.90	99.05	99.22
112.5	7	98.2	98.48	98.77	99.05	99.21
150	7	98.3	98.59	98.86	99.12	99.27
167	6	98.7	98.89	99.03	99.17	99.32
225	8	98.5	98.73	98.97	99.20	99.28
250	6	98.8	99.00	99.12	99.25	99.38
300	8	98.6	98.82	99.04	99.26	99.33 **
333	6	98.9	99.07	99.18	99.30	99.42
500	8	98.7	98.96	99.16	99.35	99.41
750	8	98.8	99.06	99.24	99.41	99.47
1000	8	98.9	99.13	99.29	99.45	99.50

* CSL/TSL 6 (max tech) not included as it represents no additional data at these design line levels

** Efficiency of Representative Unit

Design Line 6: Dry-type, Single Phase, Low Voltage, 10kV BIL, kva range: 15-333

Design Line 7: Dry-type, Three Phase, Low Voltage, 10kV BIL, kva range: 15-150

Design Line 8: Dry-type, Three Phase, Low Voltage, 10kV BIL, kva range: 225-1000

4. Conclusion

Transformers claiming compliance with DOE CSL levels should have minimum efficiencies meeting the levels presented [Table 1]

5. Frequently Asked Questions (FAQ):

What is a 'Design Line'?

A 'Design Line' is a grouping 'of similarly built distribution transformers' (69 Fed.Reg 45377, July 29, 2004). Within the CFR, there were 13 groupings / design lines used to simplify the engineering analysis estimates and relationship of cost and efficiency. A complete table of the original thirteen design lines and the product they represent are given in Table II.5 of the ANOPR on page 45389.

What is 'TSL / CSL'?

These are acronyms used to discuss different levels of efficiency. When the standard was initially proposed – the efficiencies were listed as ‘Candidate Standard Levels (CSL)’. As the standard matured through its cycle of ‘ANOPR -> NOPR -> Final Rule’ and the efficiencies became based on actual efficiency measurements from ‘Design Line Representative Units’ – the efficiency levels became known as ‘Trial Standard Levels’ with “the minimum equal to TP 1 and the maximum from the most efficient designs from the engineering analysis” (72 Fed.Reg 58199, October 12, 2007, Final Rule).

What about No Load Losses?

From the Final Rule, 72 Fed.Reg at 58206, “Transformer loading is an important factor in determining which types of transformer designs will deliver a specified efficiency, and for calculating transformer losses. Transformer losses have two components: no-load losses and load losses. No-load losses are independent of the load on the transformer while load losses depend approximately on the square of the transformer loading. Because load losses increase with the square of the load, there is a particular concern that, during times of peak system load, load losses can impact system capacity costs and reliability.”

Given the fact that transformer are not operated in a ‘no-load’ condition – it was important to evaluate transformer performance at an established standard of 35% loaded of name-plate with resistive load. No ‘minimum No-Load Loss’ tables exist within the standard to show compliance with a particular CSL/TSL level; only minimum efficiency.

What about Harmonic Mitigating Transformers?

In regards to these specialty transformers; the DOE’s ANOPR published July 29, 2004’ stated that “...there are two types of distribution transformers, those that correct harmonics (harmonic mitigating transformers - HMT) and those that simply tolerate, and do not correct harmonics (called harmonic-tolerating or K-factor transformers)” (69 Fed.Reg at 45382). In regards to the HMT, they stated that “the Department is excluding harmonic-mitigating transformers from this rulemaking” (69 Fed.Reg. at 45383). They noted that the K-factor transformer definition is not so clear and dealt with this type independently (with the majority being included within the rulemaking).

What is the 0.75 Scaling Rule?

As part of the simplification process of analysis from the original 115 different transformers found with the ANOPR – similar transformers would be grouped into Design Lines then “From each of the thirteen engineering design lines, the Department selected one representative unit to study in detail in both the engineering and the LCC analysis. Once these two analyses were complete, the Department scaled the findings on these units to all the other kVA ratings within each of the thirteen design lines using the 0.75 scaling rule (see Chapter 5 in the TSD). This rule states that for similarly designed transformers, construction costs and watt losses scale to the ratio of kVA ratings raised to the 0.75 power.” ANOPR, 69 Fed.Reg at 45389). Additional information and use can be found within July 9, 2004 ANOPR – 69 Fed.Reg. at 45416 while the actual 0.75 Scaling Rule formula and application are found in the ‘Final Rule – Technical Support Document (TSD) – Appendix 5B’.

Are these efficiency levels law?

Currently (circa 2010) within the United States of America, the minimum efficiency levels for low-voltage, dry-type transformers has been legislated by EPAAct 2005 and included in the Code of Federal Regulations by DOE at 10 CFR 431.196(a). . The minimum efficiency levels legislated by Congress are equivalent to NEMA TP1/CSL-1 efficiencies.

More information on NEMA transformer standards?

NEMA has responded to the industry need for a high efficiency low voltage transformer standard with the Premium Transformer Program. Premium transformers will provide 30% efficiency improvement over EPCACT 2005 for all standard LV transformer sizes. The NEMA Premium 30 program supplements the industry standards NEMA TP1, *Guide for Determining Energy Efficiency for Distribution Transformers*, NEMA TP2, *Standard Test Method for Measuring the Energy Consumption of Distribution Transformers*, and NEMA TP3, *Standard for the Labeling of Distribution Transformer Efficiency*, to provide the industry with the next generation of high efficiency requirements.