

December, 2015

DOE liquid filled transformer efficiency requirements

Most are aware that the U.S. Department of Energy (DOE) has put in place a mandate specifying minimum energy efficiencies for distribution transformers. There is however much confusion as to what these requirements are and just what transformers are included. The object of this paper is to provide you with both clarification as well as a ready reference.

On Oct. 12, 2007, the DOE issued in the Federal Register, 10 CFR Part 431, “Energy Conservation Program for Commercial Equipment, Distribution Transformers Energy Conservation Standards; Final Rule”. This regulation covered all distribution transformers manufactured after Jan. 1, 2010, and defined the minimum efficiency standards in the design of distribution transformers under federal law. The minimum efficiencies for liquid filled transformers resulting from the ruling are listed below.

1/1/2010			
Single phase		Three phase	
kVA	Efficiency (%)	kVA	Efficiency (%)
10	98.62	15	98.36
15	98.76	30	98.62
25	98.91	45	98.76
37.5	99.01	75	98.91
50	99.08	112.5	99.01
75	99.17	150	99.08
100	99.23	225	99.17
167	99.25	300	99.23
250	99.32	500	99.25
333	99.36	750	99.32
500	99.42	1000	99.36
667	99.46	1500	99.42
833	99.49	2000	99.46
		2500	99.49

Note:
All efficiency values are at 50% of nameplate rated load, as per DOE Test Procedure.

Pacific Crest Transformers

300 West Antelope Road - Medford, Oregon 97503

Tel : (541) 826 - 2113 Fax : (541) 826 - 8847

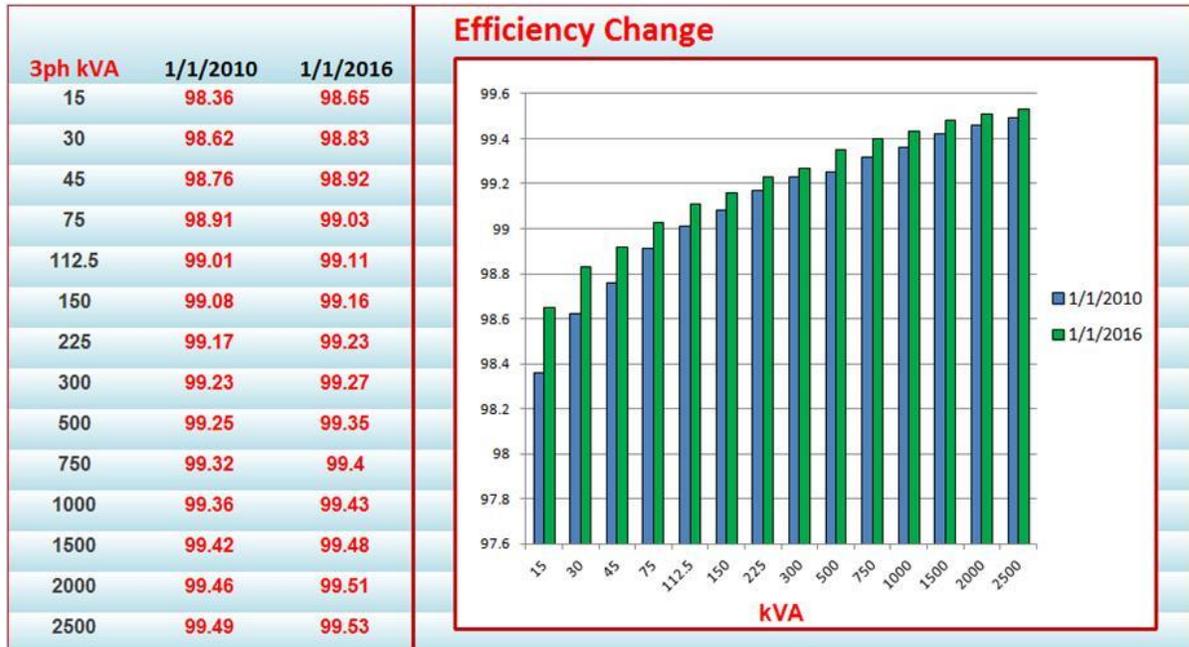
These efficiency requirements represented a significant reduction in maximum transformer losses previously set by the industry standard NEMA TR1 specifications which required the use of higher grade electrical steel and other features designed to lower flux density and reduce losses and audible sound levels.

Due to continued environmental pressures however, on April 18, 2013 the DOE published 78 FR 23335, a Federal Register notice of final rule amending energy conservation standards for liquid-immersed and dry-type distribution transformers. The distribution transformers final rule was the DOE’s first “negotiated rulemaking,” conducted under the Federal Advisory Committee Act and the Negotiated Rulemaking Act. In this final rule, DOE adopted even more stringent energy conservation standards for distribution transformers having determined that these amended conservation standards will result in significant increased energy savings and that they are technologically feasible and economically justified. The resultant efficiency levels for liquid filled transformers, effective as of January 1, 2016 are as follows:

1/1/2016			
Single phase		Three phase	
kVA	Efficiency (%)	kVA	Efficiency (%)
10	98.7	15	98.65
15	98.82	30	98.83
25	98.95	45	98.92
37.5	99.05	75	99.03
50	99.11	112.5	99.11
75	99.19	150	99.16
100	99.25	225	99.23
167	99.33	300	99.27
250	99.39	500	99.35
333	99.43	750	99.4
500	99.49	1000	99.43
667	99.52	1500	99.48
833	99.55	2000	99.51
		2500	99.53

As with the 2010 DOE ruling, all of the above efficiency ratings are based on 50% of the nameplate rated load.

Although even higher efficiencies were contemplated, the DOE noted the potential for a disruption in the electrical steel market supply due to its' limited domestic manufacturing capacity. DOE will continue to monitor the electrical steel supply chain and liquid-immersed distribution transformer markets to determine whether re-evaluating and adjusting efficiency requirements in the future is justified.



The data above provides a visual of the required improved efficiency by kVA for 3 phase liquid filled transformers.

These efficiency requirements cover all liquid filled distribution transformers that:

- Have an input voltage of 34.5 kV or less;
- Have an output voltage of 600 V or less;
- Are rated for operation at a frequency of 60 Hz; and
- Have a capacity of 10 kVA to 833 kVA for single phase and 15 kVA through 2500 kVA for 3 phase

Transformers not meeting the above criteria are **exempt/excluded** as are those listed and defined below:

➤ **Autotransformer**

- One physical winding that consists of a series winding part and a common winding part;
- No isolation between its primary and secondary circuits; and
- During step-down operation, has a primary voltage that is equal to the total of the series and common winding voltages, and a secondary voltage that is equal to the common winding voltage.

➤ **Drive (isolation) transformer**

- Isolates an electric motor from the line;
- Accommodates the added loads of drive-created harmonics; and
- Is designed to withstand the additional mechanical stresses resulting from an alternating current adjustable frequency motor drive or a direct current motor drive.

➤ **Grounding transformer**

- A three-phase transformer intended primarily to provide a neutral point for system-grounding purposes, **either** by means of:
- A grounded wye primary winding and a delta secondary winding; **or**
- A transformer with its primary winding in a zig-zag winding arrangement, and with no secondary winding.

➤ **Machine-tool (control) transformer**

- A transformer that is equipped with a fuse or other over-current protection device, and is generally used for the operation of a solenoid, contactor, relay, portable tool, or localized lighting.

➤ **Rectifier transformer**

- A transformer that operates at the fundamental frequency of an alternating-current system and that is designed to have one or more output windings connected to a rectifier.

➤ **Regulating transformer**

- A transformer that varies the voltage, the phase angle, or both voltage and phase angle, of an output circuit and compensates for fluctuation of load and input voltage, phase angle or both voltage and phase angle.

➤ **Sealed transformer**

- A transformer designed to remain hermetically sealed under specified conditions of temperature and pressure.

➤ **Special-impedance transformer**

- Any transformer built to operate at an impedance outside of the normal impedance range for that transformer's kVA rating. The table to the right lists the normal impedance range for each kVA rating for liquid-immersed transformers. Impedance ratings outside these ranges are not subject to the DOE ruling.

Single-phase transformers		Three-phase transformers	
kVA	Impedance (%)	kVA	Impedance (%)
10	1.0-4.5	15	1.0-4.5
15	1.0-4.5	30	1.0-4.5
25	1.0-4.5	45	1.0-4.5
37.5	1.0-4.5	75	1.0-5.0
50	1.5-4.5	112.5	1.2-6.0
75	1.5-4.5	150	1.2-6.0
100	1.5-4.5	225	1.2-6.0
167	1.5-4.5	300	1.2-6.0
250	1.5-6.0	500	1.5-7.0
333	1.5-6.0	750	5.0-7.5
500	1.5-7.0	1000	5.0-7.5
667	5.0-7.5	1500	5.0-7.5
833	5.0-7.5	2000	5.0-7.5
		2500	5.0-7.5

- **Testing transformer**
 - A transformer used in a circuit to produce a specific voltage or current for the purpose of testing electrical equipment.
- **Transformer with tap range of 20 percent or more**
- **Uninterruptible power supply transformer**
 - A transformer that is used within an uninterruptible power system, which in turn supplies power to loads that are sensitive to power failure, power sags, over voltage, switching transients, line noise, and other power quality factors.
- **Welding transformer**
 - A transformer designed for use in arc welding equipment or resistance welding equipment.

Prior to DOE rulings, transformer efficiencies were primarily addressed by end users via loss evaluation. Transformers are very efficient with losses typically totaling 1 percent or less of nameplate rating. The value of these losses as determined by customers varies based on calculated loading, local cost of power, and anticipated transformer life. Manufacturers adjust design parameters to optimize material usage per loss evaluation formula. DOE efficiency requirements eliminated these variations in loss evaluation for affected transformers since all manufacturers are required to meet specific minimum loss levels.

Winding and core losses comprise the majority of losses in a transformer. The winding loss is determined by the conductor (copper or aluminum) resistance. Lowering the amperes per square inch results in lower losses but requires more conductor. More conductor results in larger coils at an increase in material cost. These losses vary with the load... i.e., the higher the load, the higher the winding losses.

Unlike winding losses, the transformer's core loss is constant at rated voltage and does not vary with the load. With this being the case, a higher emphasis is placed on the core loss since it equates to a constant cost which through optimization can be lowered.

The core provides the path for electromagnetic induction of the voltage from the input windings of a transformer to the output windings. The voltages induced into the core create eddy currents. Laminating the core reduces the effective cross-sectional area through which the eddy currents circulate, thereby increasing the resistance to these currents which in turn reduces the associated core loss. The grade and quantity of the material used in the core design determine the level of core losses generated. These losses, plus the winding and stray losses comprise the total losses. The total losses produce heat which is dissipated via the cooling/insulating fluid, transformer tank surface, and cooling radiators. The higher the losses, the higher the amount of cooling provisions. The transformer losses are used to determine the transformer efficiency.

Today's conventional grain oriented steel (GOS) grades referred to as M3, M4, M5, and M6 were developed in the 1960s. Grain oriented electrical steels are iron-silicon alloys that were developed to provide the low core loss and high permeability required for efficient and

economical electrical transformers. Grain orientation of the steel lessens the resistance to the flow of flux within the core. Lowering this resistance lowers the losses. Hi-B grain oriented steel grades were developed in the early 1980s providing a higher level of grain orientation. Further enhancement to grain orientation has been made possible through laser scribing. The more efficient the core material, the higher the cost per pound. Engineering determines the optimum core material used for a DOE compliant transformer.

The DOE efficiency requirements simplify the purchasing process for covered transformers since it eliminates the need for loss evaluation. The efficiency requirements basically “standardize” the product offerings among transformer manufacturers.

As listed earlier however, there are a large number of transformers not covered by the DOE mandate.. In such cases the total cost of ownership (TCO) should be calculated to determine the best offering. Taking only purchase price and the current cost of losses into account the TCO can be calculated as:

$$TCO = PP + (E\$ * CL) + (E\$ * LL)$$

where:

PP – the purchase price of transformer

E\$ – energy cost per kW

CL – transformer core loss in watts

LL – load loss in watts

The “E\$” value is determined via analysis of:

- average percent loading of transformer
- hours of operation per year
- present energy cost
- anticipated annual increase in energy cost
- transformer lifespan

These variables are entered into a TCO calculator which are readily available on line. By determining the TCO, the payback period for selecting a higher priced transformer with low losses is revealed. This period routinely works out to be between 3-5 years which, when considering the lifespan of a transformer, can result in a considerable long term savings.

Whether a transformer need is covered by DOE energy efficiency requirements or is outside of the parameters, PCT has the expertise to design, build , and deliver the optimum solution for a wide range of applications at a cost competitive price.

Pacific Crest Transformers: Providing innovative solutions for today’s complex challenges