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Eaton helps data center and commercial customers meet 2016 U.S. Department of Energy efficiency requirements

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New U.S. Department of Energy (DOE) efficiency standards for distribution transformers, which went into effect on January 1, 2016, require an increase in the electrical efficiency of critical equipment that distributes power. The changes impact transformer designs and costs for data centers and other commercial applications. Understanding the new standard and its impact will help ensure a seamless transition to compliant transformer designs. This effort underscores the increasing emphasis on reducing the financial and environmental impact of data centers for businesses.

The benefits of transformer efficiency

Small increases in transformer efficiency can result in substantial energy savings because transformers typically operate continuously. Even when lightly loaded, or not loaded at all, transformers are consuming energy. As a result of the new efficiency requirements, there will be an associated reduction in greenhouse gases.

Over the next 30 years, the benefits of increasing transformer efficiency on a national basis are expected to eliminate the need for 3.63 quadrillion British thermal units (Btu) of energy, which is roughly equivalent to the energy consumed by 40 million American households in one year. Approximately 264.7 million metric tons of carbon dioxide emissions will also be avoided, which is comparable to removing more than 51 million passenger vehicles from the road for one year. Additional expected benefits include the removal of 203,000 metric tons of nitrogen oxides, 182,900 metric tons of sulfur dioxide, and 1,200 pounds of mercury.

For data center applications, the increased efficiency requirement underscores the critical importance of maximizing energy-efficiency to minimize costs and risk. Data centers are one of the largest and fastest growing consumers of electricity in the U.S. According to the Natural Resources Defense Council (NRDC), U.S. data centers consumed an estimated 91 billion kilowatt-hours of electricity in 2013, enough energy to power all the households in New York City twice over. Further, data centers are on track to reach 140 billion kilowatt-hours by 2020.

Energy is also the second highest operating cost in 70 percent of worldwide data center facilities. The new guidelines will drive improvements in infrastructure efficiency and help data centers and other commercial applications reduce energy and lifecycle costs.

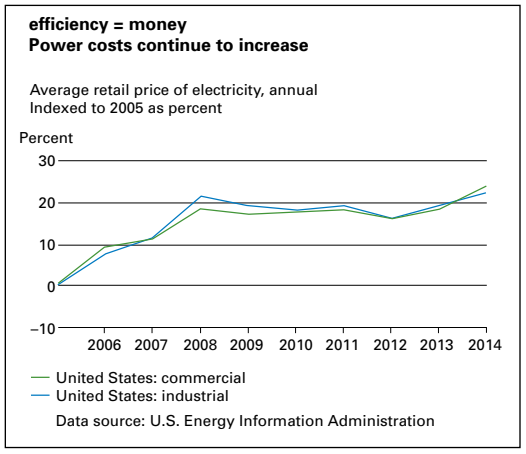

Figure 1. Rising power costs

Increasing costs of electricity are propelling an increased emphasis on achieving power reliability in the most efficient way. The new DOE transformer efficiency requirements can help data centers implement solutions that reduce electricity consumption.

Transformer design changes

Manufacturers are changing transformer designs to meet the DOE 2016 requirements; as a result, transformer size, weight, and cost may increase. Additionally, for low voltage dry-type transformers, electrical characteristics such as impedance, inrush current, and the available short-circuit current will also change. These changes will be design-dependent and determined based on changes between pre-existing designs and transformer designs that meet the new efficiency standards. Manufacturers are leading the transition to the new standard and working with customers to plan for the impact of the efficiency changes.

Powering Business Worldwide

Exploring the scope of the new standards

The DOE 2016 standards have impacted distribution transformers manufactured for sale in or imported into the U.S. as of January 1, 2016. This includes medium- and low-voltage dry-type distribution transformers as well as liquid-immersed medium voltage distribution transformers. The required efficiency increases vary by transformer type, kilovolt amperes (kVA) size, and voltage rating.

Table 1. DOE 2016 scope ①

Ruling applies to the following transformers	Ruling does not apply to the following transformers
• Manufactured (or imported) for sale in the U.S. after January 1, 2016 • Low voltage dry-type • Medium voltage dry-type • Liquid-filled distribution • Single-phase: 10–833 kVA • Three-phase: 15–2500 kVA • Input voltage of 34.5 kV or less • Output voltage of 600 V or less	• Autotransformers • Drive (isolation) • Grounding • Machine-tool (control) • Non-ventilated • Rectifier • Regulating • Sealed • Special impedance • Testing • Those with tap ranges of 20 percent or more • Those that are used, rebuilt, or refurbished • Underground mining (medium voltage dry-type only) • Uninterruptible power supply • Welding

① This list is not exhaustive, but covers common exceptions.

The new requirements update the 2007 and 2010 DOE-established guidelines. The 2007 ruling applied to low voltage dry-type distribution transformers, whereas the 2010 ruling applied to medium voltage distribution transformers. The increase in efficiency levels is the only significant change since 2007 and 2010 guideline requirements were mandated. The new rule is much like the previous ones, being identical in scope, compliance methodology, and exceptions. The regulations outline efficiency requirements according to transformer type (liquid versus dry-type distribution transformers), single- or three-phase transformers, ampere rating, and basic impulse level (medium voltage dry-type transformers only).

Dry-type transformer

In typical medium and large data center applications, high-performance low voltage transformers that meet or exceed the latest DOE efficiency requirements can reduce energy losses and heat output to yield energy and cooling savings.

The previous 2007 mandate for low voltage dry-type distribution transformers required efficiencies between 97.7 percent and 98.9 percent for single-phase transformers, and between 97.0 percent and 98.9 percent for three-phase transformers. The DOE 2016 requirements maintain single-phase efficiencies where they have been since 2007, and increase three-phase efficiencies to between 97.89 percent and 99.28 percent. **Table 2** shows the 2007 and 2016 minimum efficiencies for low voltage dry-type distribution transformers.

Table 2. Low voltage dry-type distribution transformer efficiencies ①

Single-phase			Three-phase		
kVA	DOE 2007 efficiency percent	DOE 2016 efficiency percent	kVA	DOE 2007 efficiency percent	DOE 2016 efficiency percent
15	97.7	97.70	15	97.0	97.89
25	98.0	98.00	30	97.5	98.23
37.5	98.2	98.20	45	97.7	98.40
50	98.3	98.30	75	98.0	98.60
75	98.5	98.50	112.5	98.2	98.74
100	98.6	98.60	150	98.3	98.83
167	98.7	98.70	225	98.5	98.94
250	98.8	98.80	300	98.6	99.02
333	98.9	98.90	500	98.7	99.14
			750	98.8	99.23
			1000	98.9	99.28

① Efficiency measured at 35 percent load and 75 degrees Celsius.

For medium voltage, liquid-immersed distribution transformers, the DOE 2010 regulations previously targeted efficiencies ranging from 98.36 to 99.49 percent. The updates that take effect in 2016 further increase efficiency, ranging from 98.70 to 99.55 percent. **Table 3** and **Table 4** show the efficiency requirements for liquid-immersed distribution transformers per the DOE 2016 regulations.

Table 3. Single-phase liquid-immersed distribution transformer efficiencies

Phase quantity	kVA	DOE 2010 efficiency percent	DOE 2016 efficiency percent
1	10	98.62	98.70
1	15	98.76	98.82
1	25	98.91	98.95
1	37.5	99.01	99.05
1	50	99.08	99.11
1	75	99.17	99.19
1	100	99.23	99.25
1	167	99.25	99.33
1	250	99.32	99.39
1	333	99.36	99.43
1	500	99.42	99.49
1	667	99.46	99.52
1	833	99.49	99.55

Note: Department of Energy Conservation Program: Energy Conservation Standards for Distribution, 2013

Table 4. Three-phase liquid-immersed distribution transformer efficiencies

Phase quantity	kVA	DOE 2010 efficiency percent	DOE 2016 efficiency percent
3	15	98.36	98.65
3	30	98.62	98.83
3	45	98.76	98.92
3	75	98.91	99.03
3	112.5	99.01	99.11
3	150	99.08	99.16
3	225	99.17	99.23
3	300	99.23	99.27
3	500	99.25	99.35
3	750	99.32	99.4
3	1000	99.36	99.43
3	1500	99.42	99.48
3	2000	99.46	99.51
3	2500	99.49	99.53

Note: Department of Energy Conservation Program: Energy Conservation Standards for Distribution, 2013

It is important to note that the increases in efficiency requirements for many dry-type transformers are substantially greater than corresponding increases for liquid-filled transformers. These requirements will likely lead to greater increases in the initial purchase costs for some dry-type transformers relative to liquid-filled alternatives.

Liquid-filled transformer design benefits

As a result of these requirements, now may be the time to use liquid-filled transformers in lieu of dry-type transformers. While on a percentage basis, the efficiency increase in the DOE 2016 standard is greater for certain dry-type transformers, the actual efficiency of liquid-filled transformers is significantly higher. Using liquid-filled transformers can result in less radiated heat inside buildings and help reduce ventilating and air conditioning (HVAC) costs. A typical dry-type transformer has a 150-degree Celsius temperature rise versus a liquid-filled transformer with a 65-degree Celsius rise. When you also factor in that liquid-filled transformers typically have lower losses, the operational cost savings can be substantial. Furthermore, liquid-filled transformer technology can help extend equipment life and enhance safety for indoor applications, compared to dry-type transformers.

Envirotran™ HDC transformers

For large data centers, high-efficiency liquid-filled transformers that meet the latest DOE requirements will help improve efficiency at higher distribution voltages.

Historically, liquid-filled transformers that were installed indoors often contained polychlorinated biphenyls (PCBs) insulation. This was the prevailing technology between 1929 and 1977. Since the mid-1970s, the Environmental Protection Agency (EPA) has regulated the use, storage, and disposal of this technology. Since this time frame, dry-type transformer technology has been prevalent for indoor applications.

Over the years, insulation and dielectric fluid technology for liquid-filled transformers has substantially evolved. Today, environmentally friendly insulation technology is available for liquid-filled transformers that amplify the 2016 DOE requirement. For example, there is liquid-filled transformer technology that uses Envirotemp™ FR3™ ① high fire point dielectric fluid. This liquid-filled transformer technology provides the benefits noted above and uses a non-toxic fluid that is soybean-based, biodegradable, and renewable, and reduces greenhouse gas emissions relative to mineral oil, the most common liquid-filled dielectric insulating fluid used in the transformer industry.

① Envirotemp and F3 are licensed trademarks of Cargill, Incorporated.

Liquid-filled transformer technology installed indoors must meet the National Electrical Code® (NEC®) 450.23, which provides guidelines for installing transformers inside or close to buildings. It is also recommended that transformer designs meet FM Approval® and its Approval Standard 3990, which addresses concerns related to fire safety. In recent years, there have been a number of fires related to dry-type transformers in some high-profile data centers. Conversely, transformers using Envirotemp FR3 fluid have enjoyed an impeccable record when it comes to fire safety. With more than 500,000 FR3-filled transformers installed over the last 20 years, there has yet to be any reported fires.

In addition to the availability of environmentally friendly insulation, liquid-filled transformers provide a host of additional benefits:

- Lower operating temperatures compared to cast resin or vacuum pressure impregnated (VPI) insulation, reducing HVAC costs
- Increased energy-efficiency over dry-type transformers, yielding lower losses and operating costs
- Reduced operating costs
- Increased overload capacity
- Reduced footprint—enabling smaller electrical rooms
- Reduced sound level, which means fewer sound mitigation requirements
- Resistance to contamination, as transformers are sealed

Table 5. Medium voltage transformer energy-efficiency comparison

Three-phase kVA	Liquid-filled transformer efficiency at 50% load	Dry-type transformer efficiency at 50% load	Liquid-filled transformer efficiency advantage
500	99.35%	98.99%	35.64%
1000	99.43%	99.20%	28.75%
1500	99.48%	99.30%	25.71%
2000	99.51%	99.36%	23.44%
2500	99.53%	99.41%	20.34%

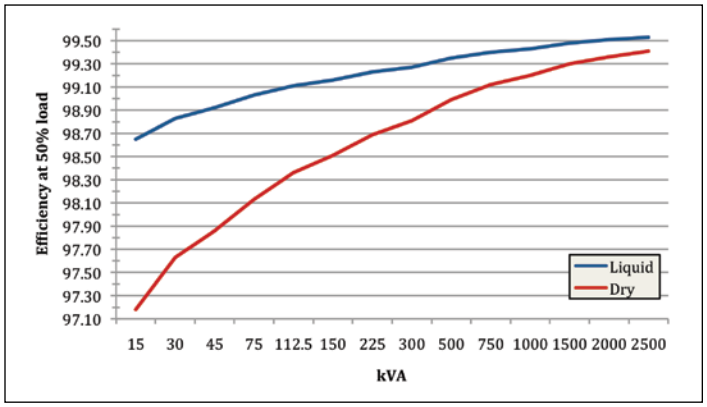

Figure 2. DOE 2016 efficiency comparison

Optimizing core materials

As the industry develops transformer designs to meet the DOE 2016 requirements, different types of core material may be used, including conventional grain-oriented electrical steel (GOES) and amorphous metals. Manufacturers will select materials based on what is most economical to build for specific applications.

It is anticipated that amorphous metals will primarily be used in three-phase medium voltage transformer designs with high current secondary voltages, while evidence suggests that conventional core steel materials will provide the lowest cost option for 2016-compliant single-phase medium voltage and low voltage dry-type distribution transformer designs. For transformers having equivalent DOE efficiencies, the amorphous design may be more efficient at low loading levels and the conventional steel design may be more efficient at higher loading levels.

Single- and three-phase medium voltage distribution transformers are engineered to order based on specific application requirements. Criteria such as impedance, loading factors, temperature rise requirements, fluid requirements, overloading, space constraints, and many others must also be considered when designing transformers that meet the DOE 2016 efficiency levels.

Conclusion

Electrical manufacturers will play an integral role in managing the transition to the DOE 2016 standard and ensuring transformers manufactured for use in the U.S. are compliant. It is imperative that end users embrace and understand the impact of the DOE 2016 efficiency requirements and work with manufacturers to implement a transition plan. Customers that plan in advance for the impact of the new standard will be better positioned to meet project deadlines and goals.

The DOE is likely to further increase energy-efficiency requirements at some point in the future. It is critical to work with manufacturers that are able to accommodate evolving regulations effectively to ensure the new efficiency standards are not only met, but also cost-effectively address project, application, functionality, and equipment objectives.

Eaton is a long-time power management leader and continues to deliver innovative and high-efficiency technology to customers. The expansion and upgrades of all Eaton transformer manufacturing facilities will help meet the growing demand for distribution transformers, enhancing the company's capabilities to deliver high-quality products with shorter lead-times. The projects will also add capacity for the transformer business and support increased core and coil manufacturing to accommodate the DOE 2016 efficiency standards.

Eaton is optimizing transformer designs to meet the new DOE requirements while maintaining customer-specific design attributes. For more information about Eaton's transformers and other data center solutions, visit www.eaton.com/datacenter.

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About Eaton

Eaton is a power management company with 2015 sales of $20.9 billion. Eaton provides energy-efficient solutions that help customers effectively manage electrical, hydraulic, and mechanical power more efficiently, safely, and sustainably. Eaton has approximately 97,000 employees and sells products to customers in more than 175 countries. For more information, visit www.eaton.com.

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