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TRANSFORMER TECHNOLOGY MAG

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## The Dry-Type Revolution

## Dry-Type Transformers: Everywhere But Unnoticed

Interview with Wayne Bishop Jr.
VP Meetings at IEEE Power and Energy Society

Interview with Martin Robinson
CEO of IRISS

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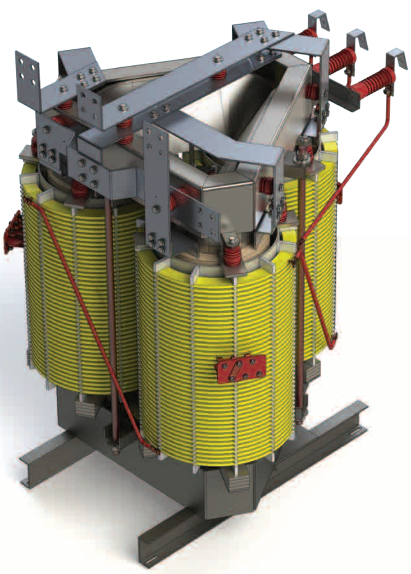

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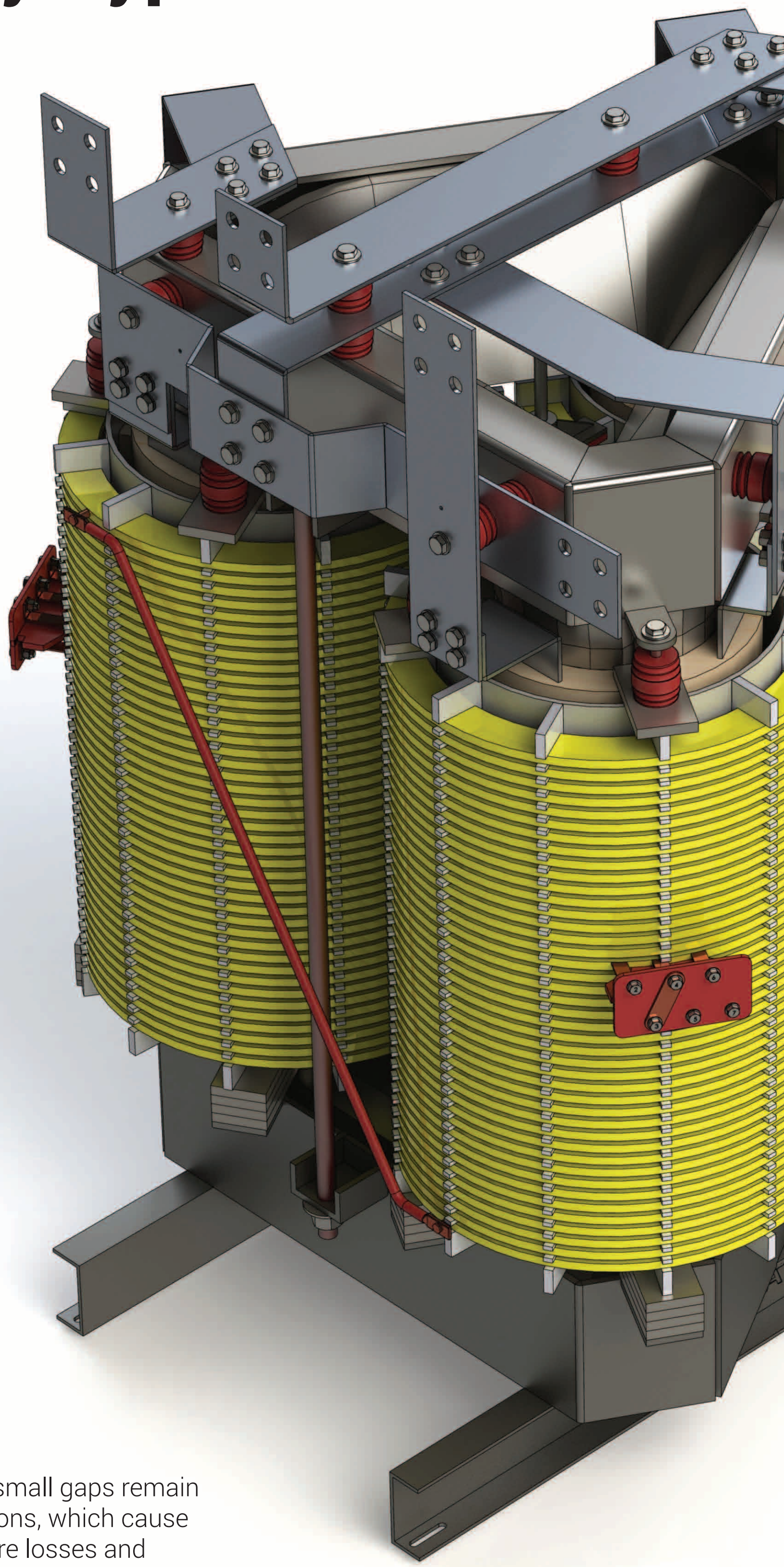
Kevin Eaton presents the difference between a conventional, three-legged stacked core against a symmetrical triangular (wound) core used in dry-type transformers, discussing the manufacturing process and providing further insight to the improved characteristics and physical advantages of the triangular-wound core transformers.

# Reshaping the Dry-Type Transformer

by **Kevin Eaton**

**Kevin Eaton** is the Marketing and Sales Manager at SGB-USA with more than 20 years of experience within the electrical industry in many different capacities. He obtained his bachelor's degree in engineering technology from Middle Tennessee State University. He is an active IEEE member and author of numerous conference papers, presentation topics, and articles for the transformer industry.

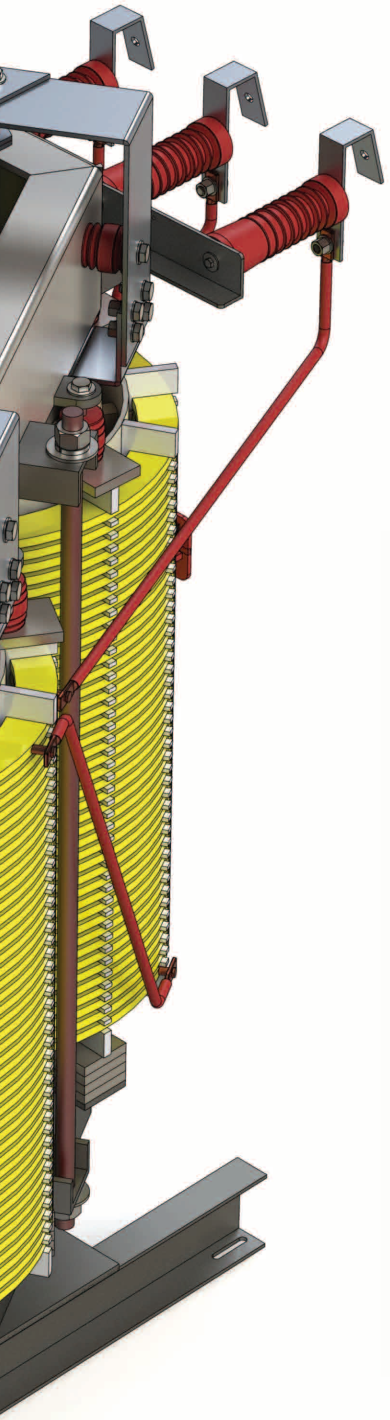


## A look back - the conventional stacked core

During the 19th century, when three-phase transformer technology was beginning to come to fruition, it was commonly acknowledged that three identical core legs proved to be the best method for electrical performance for a transformer. The technical challenges in producing a core from a manufacturing perspective—and the unpractical cost—made this method not a viable solution for mass supply to the electrical industry.

What evolved during that time, and what is still dominating the market space today, is a linear stacked three-legged core. A linear core for a three-phase transformer consists of essentially five main components that are combined: three individual core legs and the top and bottom yokes which are all made up of stacked straight sheets of electrical steel, Figure 1.

Upon assembly, small gaps remain at the joint locations, which cause an increase in core losses and magnetizing current. The use of overlapping layers (the step lap method) does reduce these effects and is the typical construction style of the linear core provided for the dry-type and conventional distribution market space, Figure 2.



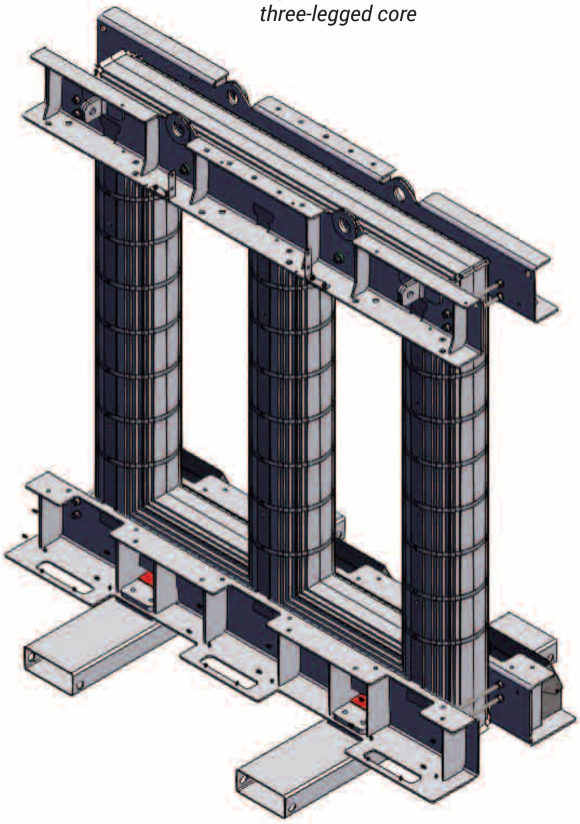


*Figure 1. Linear core stacking*

*Figure 2. Assembled linear stacked three-legged core*

Photo: SGB-USA

Since 2010, the Department of Energy (DOE) has continued to move toward increasing efficiency level requirements (per the Code of Federal Regulations at 10 CFR 431.196) for all distribution transformers, including dry-type transformers rated 2500 kVA or less [1]. The combination of the increase in efficiency level requirements and the advancements in transformer manufacturing capabilities has allowed the original symmetrical transformer design to become a viable and cost-effective solution for the electrical transformer market space.

## How is a wound triangular core transformer even made?

A wound core construction, which produces a symmetrical structure in triangular footprint, consists of only three main pieces. Each of these three core sections is wound from one continuous strip of magnetic sheet steel on a mandrel. Because it is continuously wound, the losses associated with joints are greatly reduced.

The individual core windings are rectangular in appearance with rounded edges. The width of the core sheet varies continuously to produce an almost funnel-shaped cross section. Each leg of this three-phase triangular core contains two core windings: the funnel-shaped cross sections which then meet to form essentially a circular disk.
That gives a high fill factor of core material for the coil windings, which is important for a compact and cost-efficient transformer. When comparing the conventional stacked core path via the core legs and yokes, flux is now also possible via the triangular arrangement of yokes.
If the magnetic flux in the yoke sections of one of the core windings becomes so great that they become saturated, the flux can pass through the other two windings and back again, amounting to a flux through the three yokes arranged in a triangle.

**A wound core construction, which produces a symmetrical structure in triangular footprint, consists of only three main pieces.**

Because the core uses a continuous winding method, this means that it cannot be opened to allow installation of the coils on the core legs. In turn, the coils are wound directly on the core in place. The core assembly is fixed in place on the winding machine while the low voltage coils and high voltage coils are made. The coils produced still utilize the same materials (insulation and conductor) that are employed in the traditional stacked-core method, and they follow the same vacuum pressure impregnation (VPI) dipping process that the conventional stacked method uses for protection from humidity and for mechanical integrity. The assembly process for the triangular-wound core is illustrated in Figure 3.

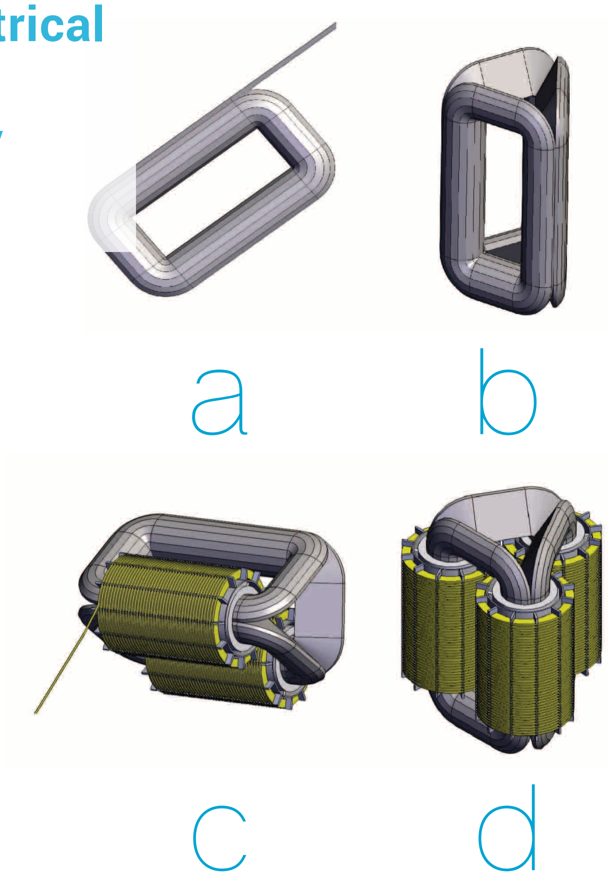



*Figure 3. Assembly process for the triangular-wound core:*

*a – Each core will be continuously wrapped around to form a funnel shape*

*b – Three core legs are placed together and wrapped with a special insulation material*

*c – The LV and HV coils are wrapped around the core that is located within a fixed position*

*d – The entire core/coil will go through the varnish/dipping process*

**The triangular design provides a more compact transformer with a smaller overall footprint, with the typical space savings for the triangular construction falling anywhere between 15% and 35%.**

## The physical advantages that truly make a difference

As an example, let's compare a traditional stacked core and a triangular core construction rated at 2500 kVA, 95 kV BIL, with a voltage rating of 13.8 kV delta primary and 480 Y secondary using aluminum windings and a 150°C temperature rise.

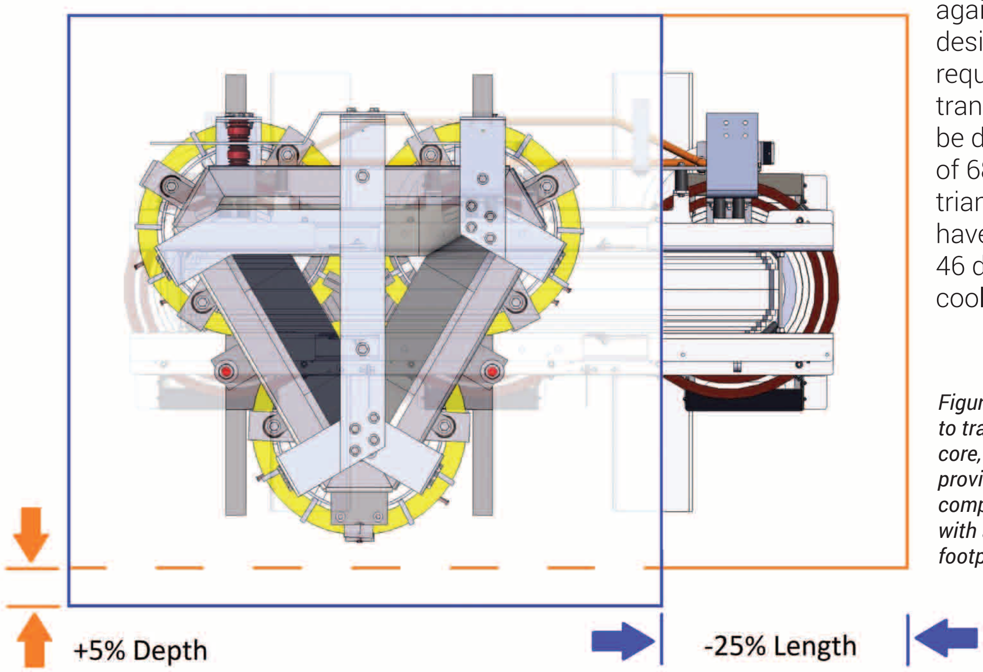
One of the most noticeable differences between the two technologies is also one of the biggest advantages of this triangular design—it provides a more compact transformer with a smaller overall footprint. The typical space or footprint savings for the triangular construction will fall anywhere between 15% and 35%.

Photo: SGB-USA

**Due to the reduced size in core mass and the elimination of joints in the manufacturing process of the triangular core, the sound level of the transformer can be reduced by approximately 5 to 10 dB**

When comparing these two 2500 kVA designs, you can see in the layout that the compact design increased in depth by 5% but reduced the length by 25%, which equates to an overall footprint savings of 20%, Figure 4. This creates major advantages from a new installation standpoint, as typical substation lineups are always trying to maximize in space savings where possible.

This reduced footprint also creates an advantage in retrofit purposes. Because of the DOE's increased efficiency requirements, it can be a challenge to physically fit the same sized transformer meeting today's efficiency levels back in the same footprint of the existing transformer. The triangular construction may make this task much easier or even provide ability to increase the base kVA rating of the transformer.




The overall weight is also reduced with the triangular construction. When comparing the 2500 kVA conventional design against the triangular design, the weight is reduced by approximately 22%. This may not be quite the advantage as the footprint savings, but in certain installations it could be a decisive factor. Indoor transformer installations, for example, are often limited by the load-bearing capacities of floors, or by limitations in elevator lifting capabilities.

## What?! I can't hear that transformer humming?!

Due to the reduced size in core mass and the elimination of joints in the manufacturing process of the triangular core, the sound level of the transformer can be reduced by approximately 5 to 10 dB across the board in all sizes when comparing against a traditional stacked core design. The IEEE Std C57.12.01 [2] requirement for a 2500 kVA transformer, for comparison, should be designed to meet a sound level of 68 dB or lower. By comparing the triangular compact design, it would have an approximate sound level of 46 dB at the same 2500 kVA, self-cooled rating.

*Figure 4. Compared to traditional stacked core, triangular design provides a more compact transformer with a smaller overall footprint*

## What happened to the stray magnetic fields?

In sensitive locations or applications, stray magnetic fields can be a great concern as they could impede the functioning of equipment, especially in areas like research facilities, hospitals, or data centers.
The symmetrical structure of the compact triangular core can cause the stray fields of the individual phases to essentially cancel each other out. The reduced EMC relevant magnetic stray fields decay faster than the required clearance distance, which can benefit the installation within these sensitive areas and eliminate some of these concerns.

## Increased efficiency level benefits

The reduction in size and weight of the transformer core, elimination of burrs and seams during the manufacturing process with the cutting core laminations, and the lack of joints in assembly lead directly to a reduction in the no-load losses of the transformer. Transformers produce two types of losses: no-load, which is directly reflective of the core design and is always constant, and the load losses in which the operational losses vary depending on the amount of energy demand required. Most transformers in field operate at a 50% or less load factor. This allows for lower operating costs over the life of the transformer as well as ecological benefit of reduced carbon dioxide emissions.

## Other performance benefits

The symmetrical design advantages of the triangular-wound core also assist in reducing inrush currents and the harmonic content of the excitation current. Reducing inrush currents can provide advantages to systems that may be configured with network protection schemes. Some network protection schemes rely on additional sensitive equipment. A reduction in concerns of the inrush current may allow in the elimination to some of these components to the costly protection schemes. In addition, transformer damage could be potentially avoided in the event of a malfunction. A comparison example is shown in Figure 5.

When comparing the conventional stacked core and the triangular-wound core, you can see in Figure 6 that there is improved harmonic behavior in 3rd, 5th and 7th harmonics and reduced 7, 4.5 and 3.5 times. This reduction in transformer harmonics will help in reducing the transformer losses and reduce the potential variability in the transformer output.

The triangular-wound core also has the potential to extend the life of the transformer. When comparing the conventional stacked core, the hottest phase when operating is the middle phase (or B leg) of the transformer. A key factor in determining the life expectancy of the transformer is the insulation and heat absorbed.

**The symmetrical structure produces additional savings and benefits in areas such as harmonic content, stray magnetic fields, reduced no-load losses, improved efficiency levels, and life expectancy extension.**

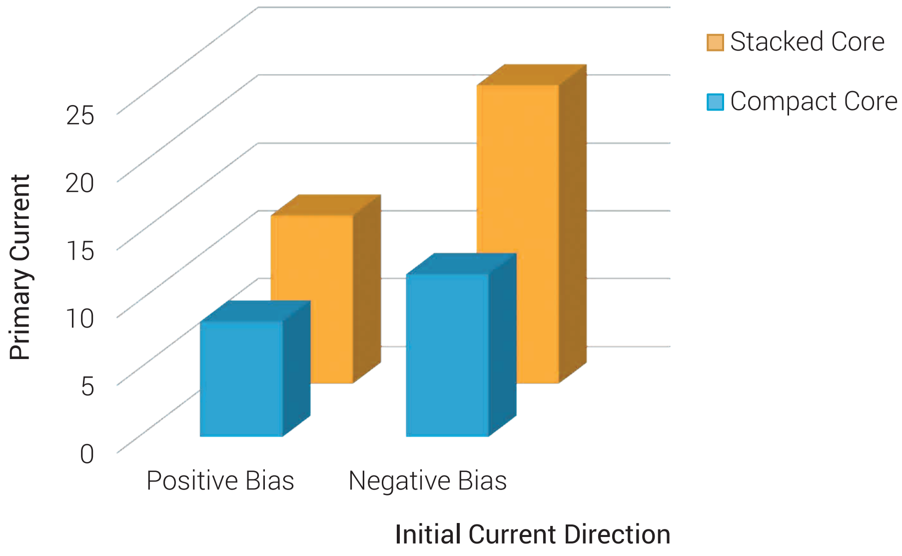
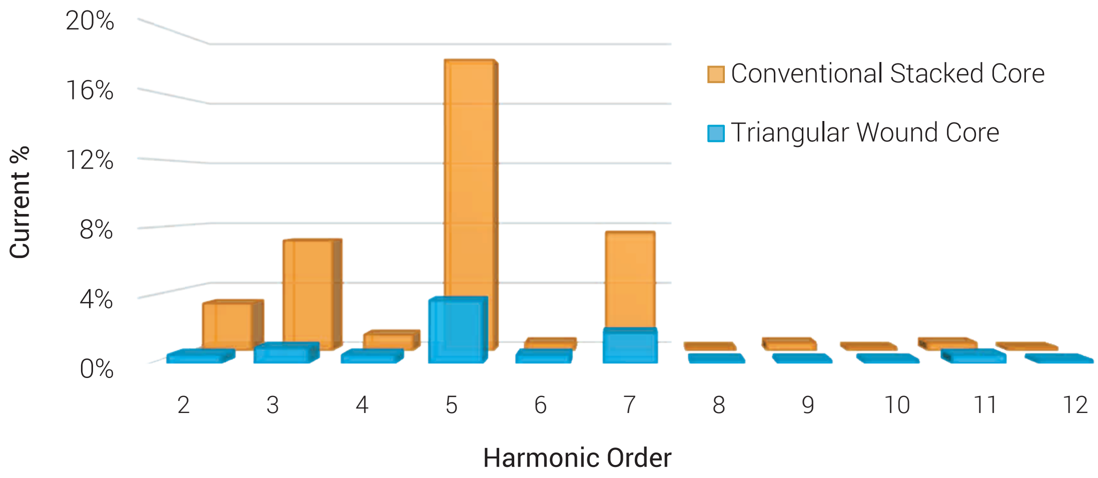



*Figure 5. Inrush currents comparison*

*Figure 6. Harmonics comparison*




The middle phase is putting out its own heat during operation and absorbing more heat from both A and C phases. This is why you typically observe the B phase operating at the higher temperature. The triangular core eliminates a middle phase as all coils are evenly spaced symmetrically on the core. Therefore, all coils shall operate at the same temperature with evenly distributed loads.

## Conclusion

Advancements in manufacturing techniques and increased performance demands have paved the way for making this cutting-edge triangular-wound technology possible. The symmetrical structure produces great savings and benefits in areas such as footprint, weight, reduction in sound levels, harmonic content, stray magnetic fields, improved efficiency levels, and life expectancy extension.

**References**

[1] US Department of Energy, 42 U.S.C. 6291(16), *Code of Federal Regulations at 10 CFR 431.196.* https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=55&action=viewcurrent#current_standards, [Accessed 5/1/2019]

[2] IEEE Standard C57.12.01 – *IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers, Including Those with Solid-Cast and/or Resin Encapsulated Windings*, 2005