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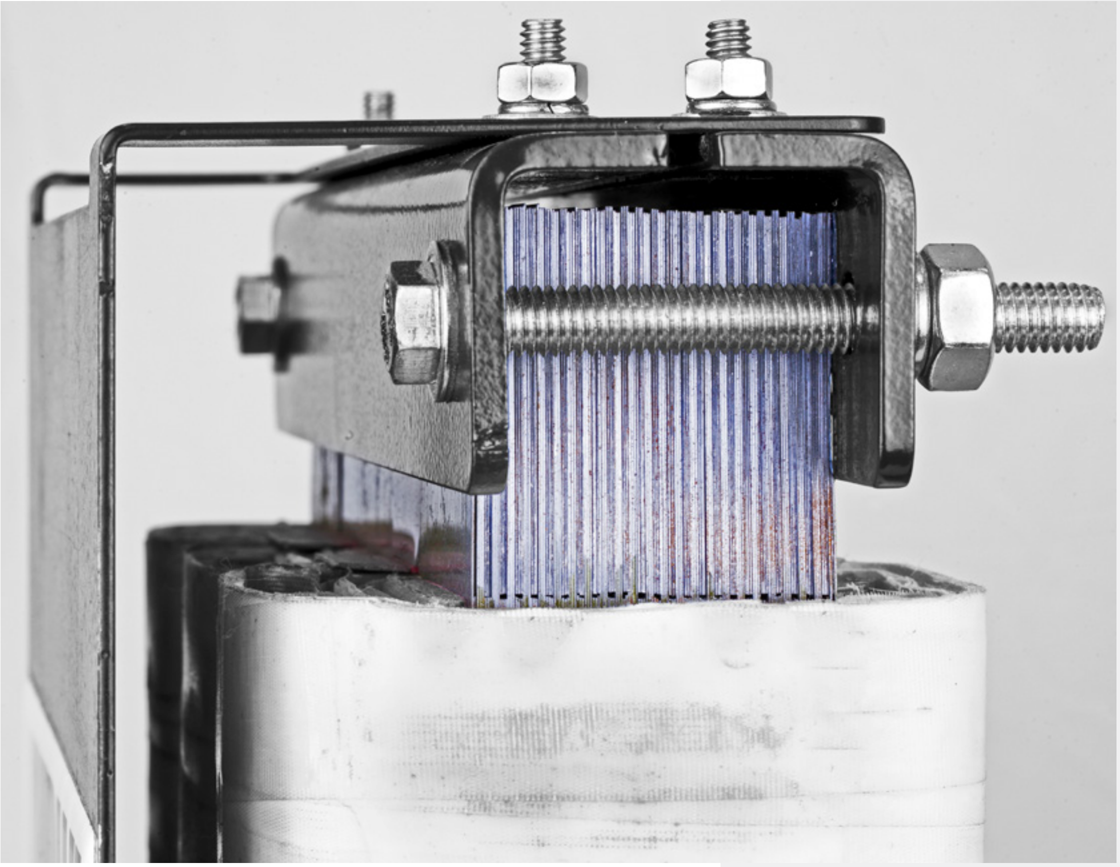
WHITE PAPER



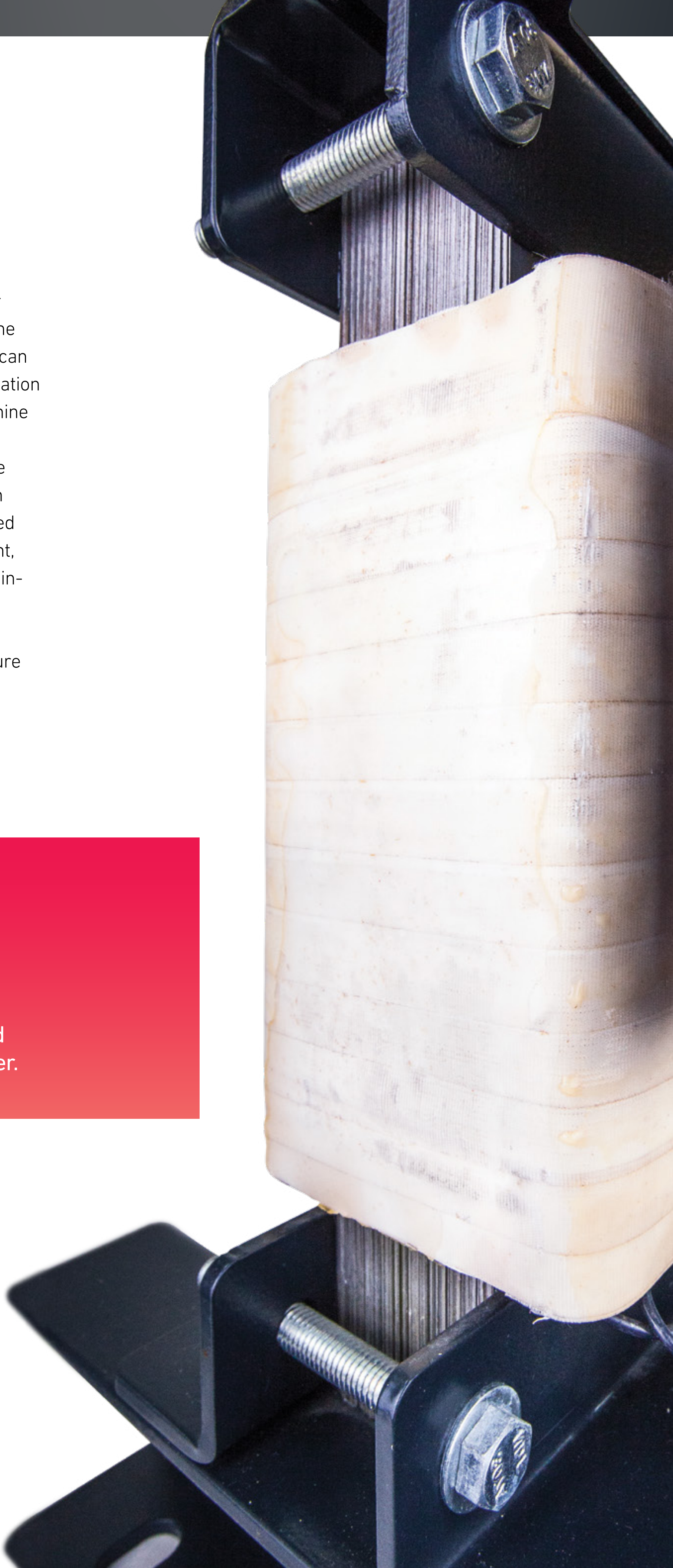
REDUCING SIZE AND WEIGHT FOR CRITICAL APPLICATIONS

Smaller, lighter and 46% more power dense transformers from Hiperco® 50A

SUMMARY

The miniaturization of electrical machines is important for building a sustainable energy distribution technology for the decades ahead. The transportation of large transformers can present a number of issues, including increased transportation costs, logistical and installation challenges, potential machine damage, and disruption to loads. The large size of the transformer also impacts the life of the vehicles, and there are weight restrictions imposed on the transformer size in many cases. Additionally, isolation transformers, often used in naval and aerial defense applications, require small, light, and efficient machines. Incumbent technology such as grain-oriented electrical steel (GOES) M6 provides a reasonably efficient solution. However, the system tends to be heavy and bulky, incurring transportation problems and premature vehicle failure due to load.

To improve transformer performance in critical applications, Carpenter Technology and NWL Transformer jointly designed, built, and tested a compact, efficient 3 kVA transformer prototype based on Carpenter Technology's Hiperco 50A high-magnetic alloy. This solution was compared to a commonly used GOES M6-based transformer.



SPECIFICATIONS

First, the team used 0.014 in. grade (M6) laminations of GOES to build a prototype transformer. GOES was operated at 14 kG, relative to 20 kG operations of Hiperco 50A. Hiperco 50A is a high-induction magnetic alloy made from iron and cobalt, which can reach up to 23 kG. Because higher magnetic induction operation increases the core loss of the machine, a 0.010 in. lamination of Hiperco 50A was selected to offset additional losses.

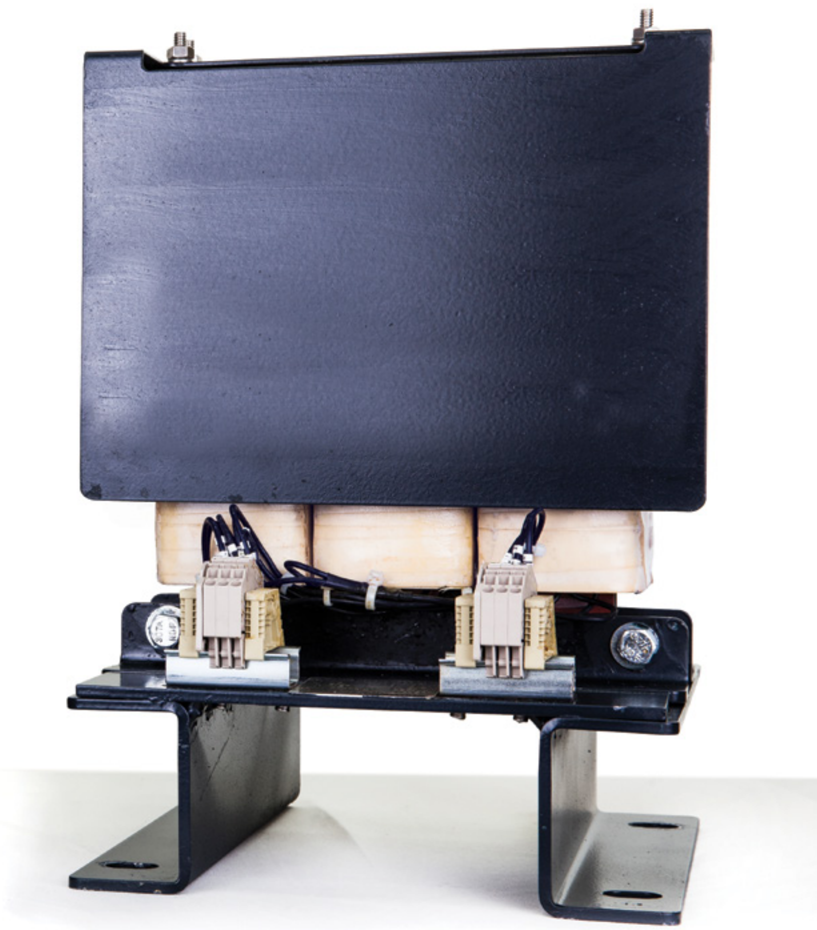
The tables below show the specifications and parameters used for both transformer prototypes: GOES M6 and Hiperco 50A.

MATERIAL SPECIFICATIONS FOR THE CORE BUILD

CORE MATERIAL	OPERATING MAGNETIC INDUCTION	LAMINATION THICKNESS
	kG	IN
Grain-oriented electrical steel (GOES) M6	14	0.014
Hiperco 50A	20	0.010

TRANSFORMER PARAMETERS

Power	3 kVA
V_{in}	440 V
Frequency	60 Hz
Overvoltage	1.35 times V rated
Primary condition	Delta
Secondary voltage	208 V
Secondary condition	Wye
Temperature rise	115°C max



SIZE, WEIGHT AND POWER DENSITY

The prototype transformers in figure 1 show the Hiperco 50A core-based transformer's smaller footprint. The comparison between size and power density is shown in figure 2.

The higher magnetic flux density of Hiperco 50A enabled a 31% smaller volume and weight for the transformer. The power density of the Hiperco 50A-based transformer was 46% more than the GOES M6-based transformer.

FIGURE 2 — GOES M6-BASED TRANSFORMER VS. HIPERCO 50A-BASED TRANSFORMER IN VOLUME, WEIGHT, AND POWER DENSITY. THE HIPERCO 50A CORE YIELDED A 31% SMALLER AND LIGHTER SYSTEM WITH 46% IMPROVED POWER DENSITY.

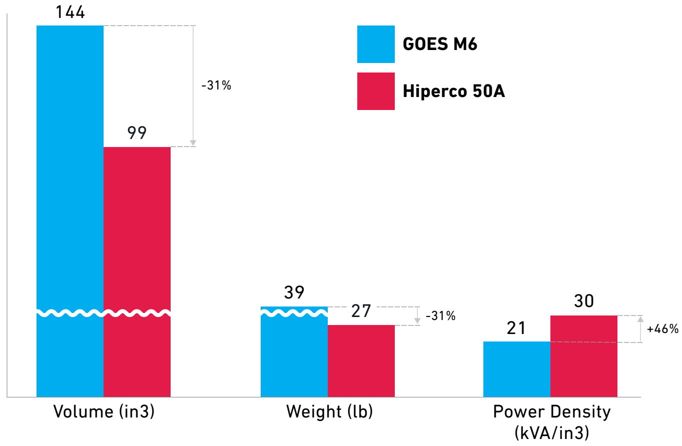
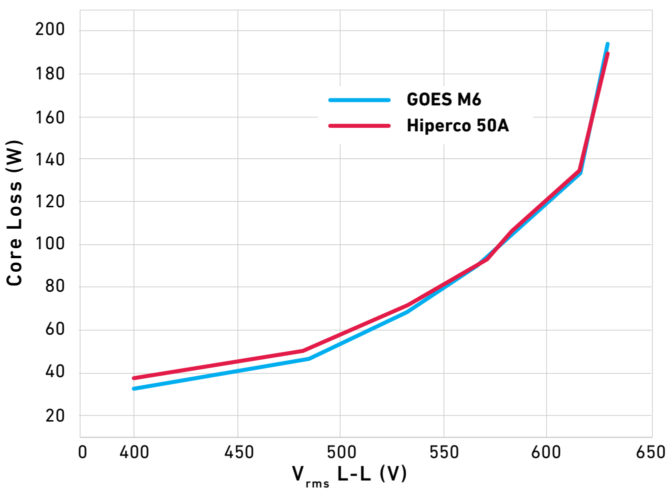


FIGURE 1 — TRANSFORMER PROTOTYPES MADE FROM GOES M6 CORE (LEFT) AND HIPERCO 50A CORE (RIGHT). THE HIPERCO 50A CORE IS 31% SMALLER AND LIGHTER.

CORE LOSS

Core loss for Hiperco 50A and GOES M6 is compared in figure 3. At 400 V and 480 V, the core loss was 15% and 8% higher for the Hiperco 50A core, respectively. At an operating voltage of 440 V, the Hiperco 50A core is 12% more lossy than the GOES M6 core. However, at higher operating voltages, core loss is comparable.

FIGURE 3 — CORE LOSS OF TRANSFORMERS MADE FROM GOES M6 AND HIPERCO 50A CORES.



Although the Hiperco 50A-based transformer had increased core loss compared to the GOES M6-based transformer, the main goals of the project were the reduction of size and weight while increasing power density. However, core loss in Hiperco 50A cores can be engineered to a lower value by reducing lamination thickness.

The following equation shows the eddy current loss (the main component of the core loss), P_e:

$$P_e = \pi^2 f^2 B^2 d^2 / 6.\rho$$

P_e = Eddy current loss, f = Frequency, B = Magnetic induction, d = Lamination thickness, ρ= Resistivity

Based on the equation, eddy current loss is proportional to the square of the thickness of the laminations. If the lamination thickness of the Hiperco 50A core is reduced further to 0.006 in., the core loss will be significantly reduced as well.

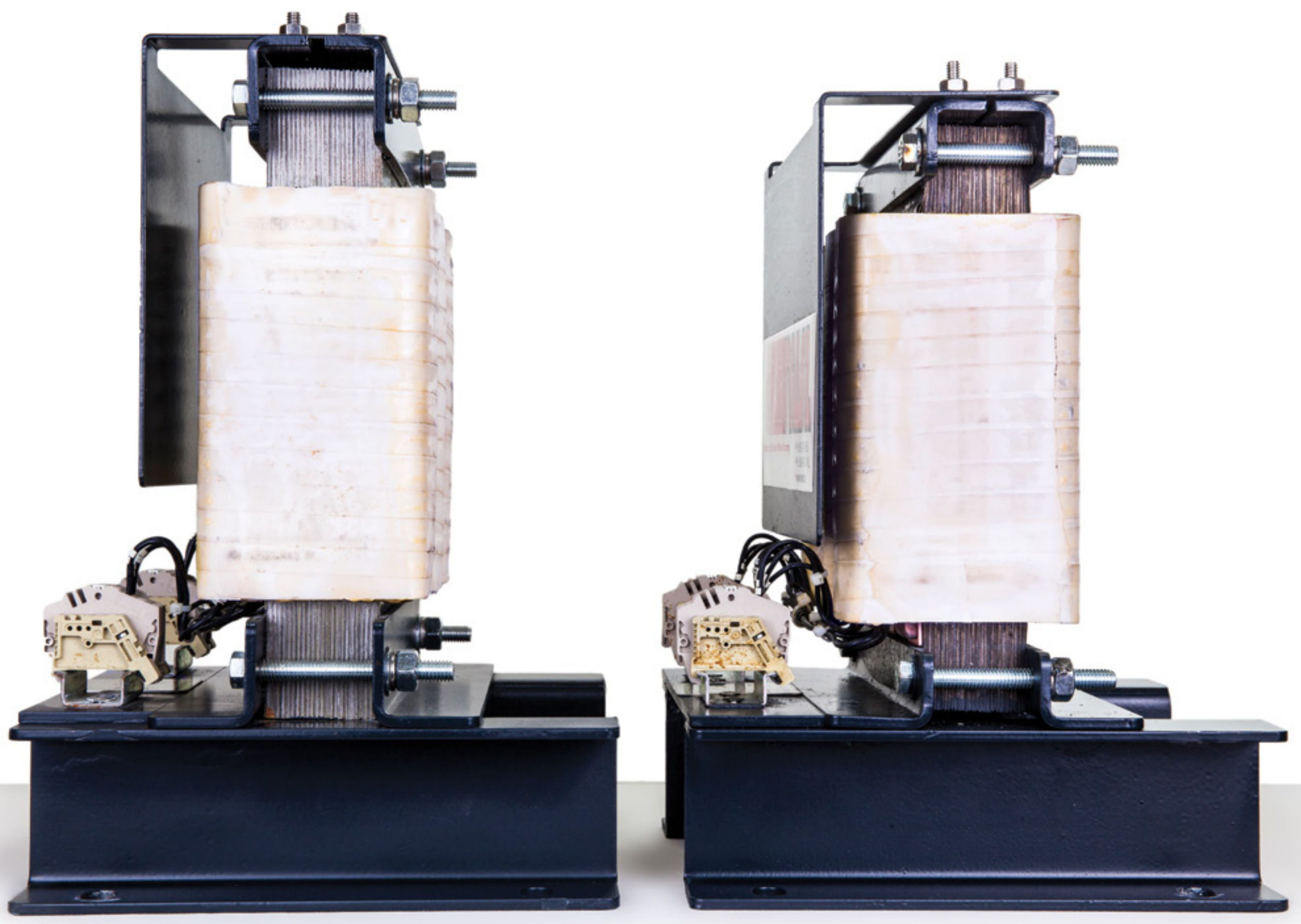
With correct assembly practices, reducing lamination thickness should not affect transformer size or power density. One can preserve the improvements in size, weight, and power density of the transformer while reducing the associate core loss.

CONCLUSION

The Hiperco 50A core-based transformer prototype proved smaller, lighter and more power dense than its GOES M6 counterpart:

- 46% higher power density
- A 31% smaller and lighter transformer
- Core loss of Hiperco 50A-based transformers can be reduced to the level of GOES M6 by using a lamination thickness of 0.006 in.
- Further core loss reductions are possible with laminations thinner than 0.006 in.

The benefits of using high magnetic saturation alloy Hiperco 50A are clear. For the next generation of sustainable energy solutions, this technology will play a vital role in the miniaturization of machines with high efficiency and functionality.



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