Multi-Objective Optimization of Magnetics for Power Electronic Converters

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Overview

While power electronic converter topologies have evolved through the years, the design process has not. The aim of this project is to provide valuable design data that can improve the research and design process. The completed algorithm will have the ability to show trade-offs in power density, efficiency, and cost for various topologies and their applications.

Unlike other optimization algorithms, this setup does not require a closed-form set of equations; it uses a circuit simulator, such as Modellica, to model the converter. From there, the data is imported to MATLAB® for design. The magnetics design process is described in this poster.

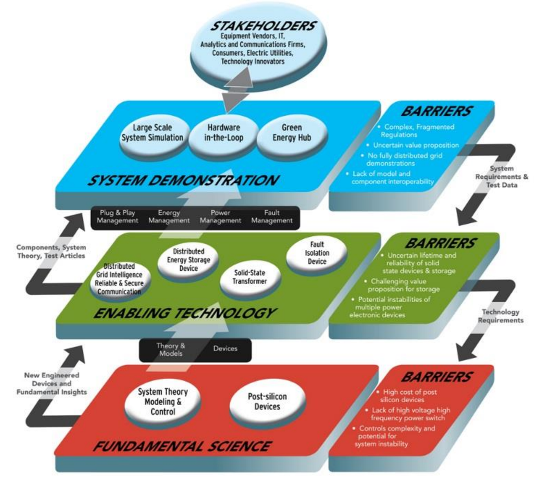


Fig. 1. FREEDM Systems Center 3-plane diagram.

Method

All models are handled as natural convection without the use of heat sinks. While the algorithm cannot predict all losses, it is accurate enough to reduce the design space for future iterations to a much smaller field of design points. The three key magnetics design components modelled are

1. magnetic design,
2. loss calculations, and
3. thermal considerations.

Given specifications for a single design point, the core size, turns ratio, winding type can be chosen using the methods in [1]. The limiting factors are the flux density and core cross-sectional area, so additional core sets are added to the transformer until the design is feasible. Then, the core and winding losses are calculated to determine the efficiency of the transformer. Lastly, heat dissipation is handled using thermal equivalent circuits to limit the temperature of the transformer. If at any point the design is no longer feasible, the process will restart by decreasing the flux density.

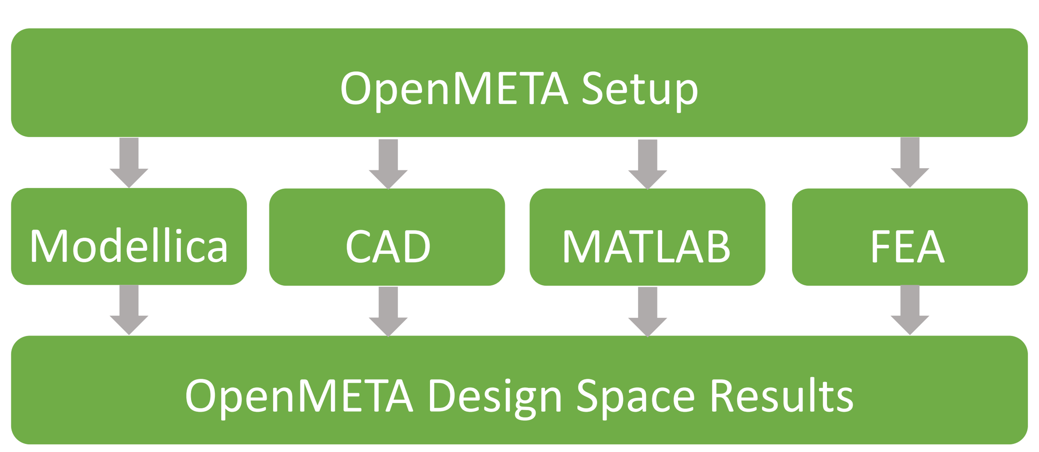
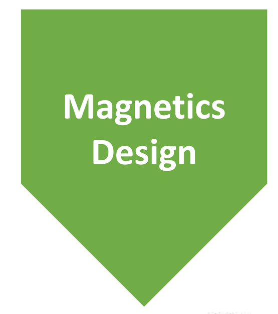


Fig. 2. OpenMETA multi-domain connections.

Algorithm Flow Chart



$$AP = \frac{[V_{pri}(A_{wp}) + V_{sec}(A_{ws})]D}{k_f f_{sw} B_m K_{cu}}$$

$$AP \leq W_A A_{core} Num_{core}$$

$$K_{cu} = \frac{N_{pri}A_{wp} + N_{sec}A_{ws}}{W_A} \leq 0.3$$

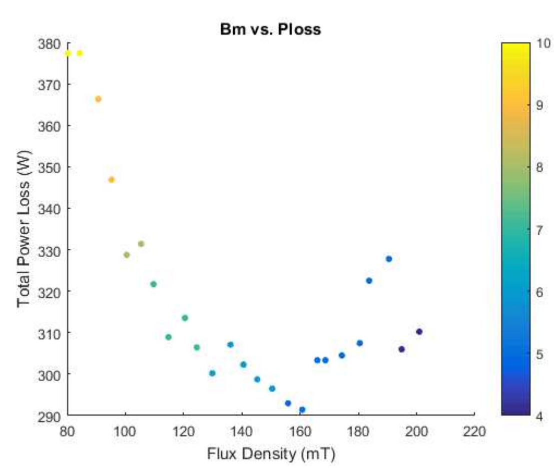


Fig. 3. Example of magnetics design sweep.

$$P_{v_{core}} = FWC_{sq}Kf^{\alpha}B^{\beta}$$

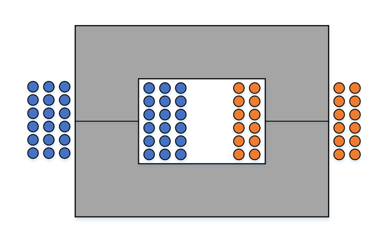


Fig. 4. Litz wire diagram.

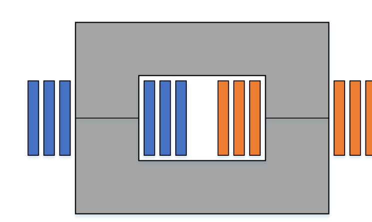
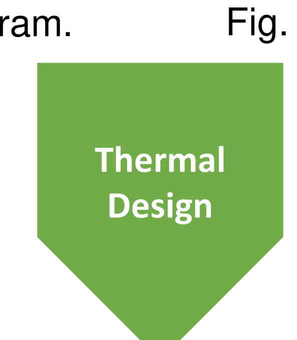


Fig. 5. Foil winding diagram.



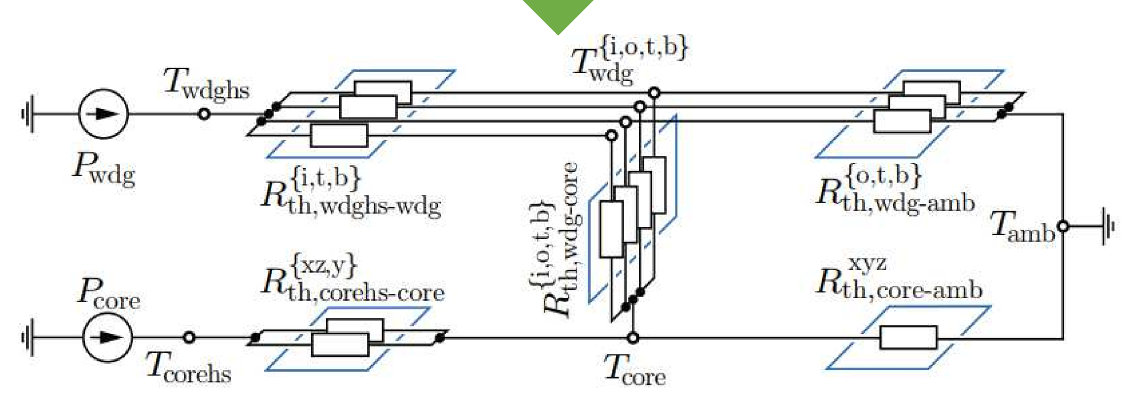


Fig. 6. Thermal equivalent resistive circuit [2].

$$R_{\text{th,cond}} = \frac{l_*}{\lambda_{\text{th},*} \cdot A_*}$$

$$R_{\text{th,rad}} = \frac{T_{1,*} - T_{2,*}}{\epsilon_{1,*} \cdot \sigma \left(T_{1,*}^4 - T_{2,*}^4\right)} \cdot \frac{1}{A_*}$$

$$R_{\text{th,conv}} = C_v \left(\frac{p}{p_{\text{ref}}}\right)^{0.477} \left(\frac{T_{\text{amb}}}{T_{\text{amb,ref}}}\right)^{-0.218} \frac{(T_* - T_{\text{amb}})^{0.225}}{L_{\text{ch},*}^{0.285}} \cdot \frac{1}{A_*}$$

Results

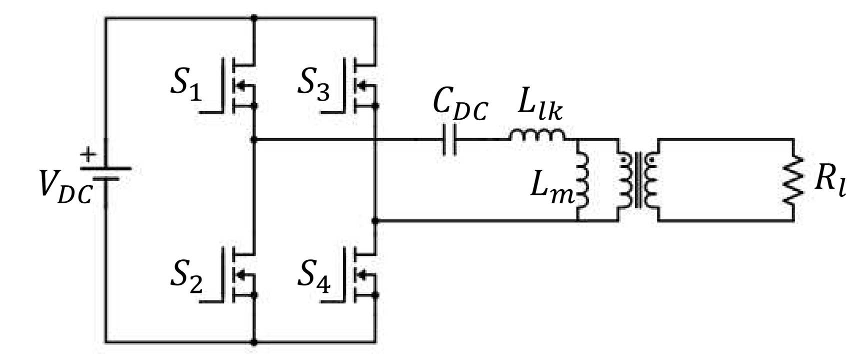


Fig. 7. Single U core test setup with the following parameters:

$C_{DC} = 2\ \mu F$, $L_{lk} = 27.5\ \mu H$

$R_l = 60.5\ \Omega$, $L_m = 322.5\ \mu H$

$f_{sw} = 50\ kHz$

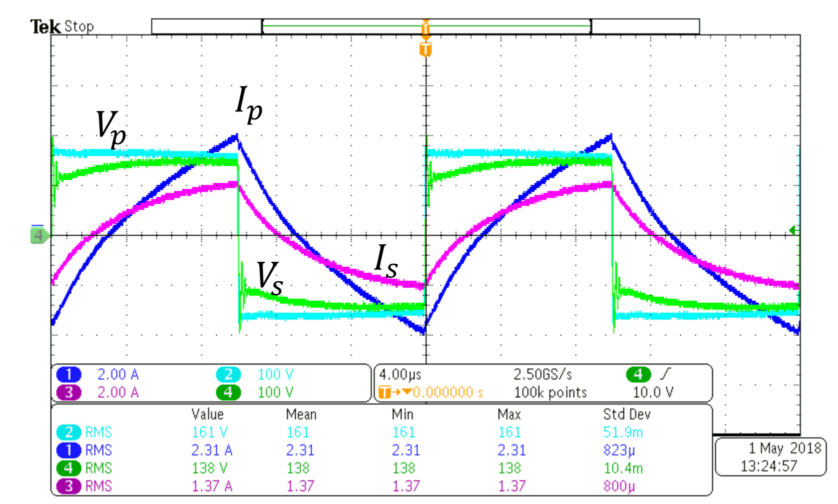


Fig. 8. Full load outputs.

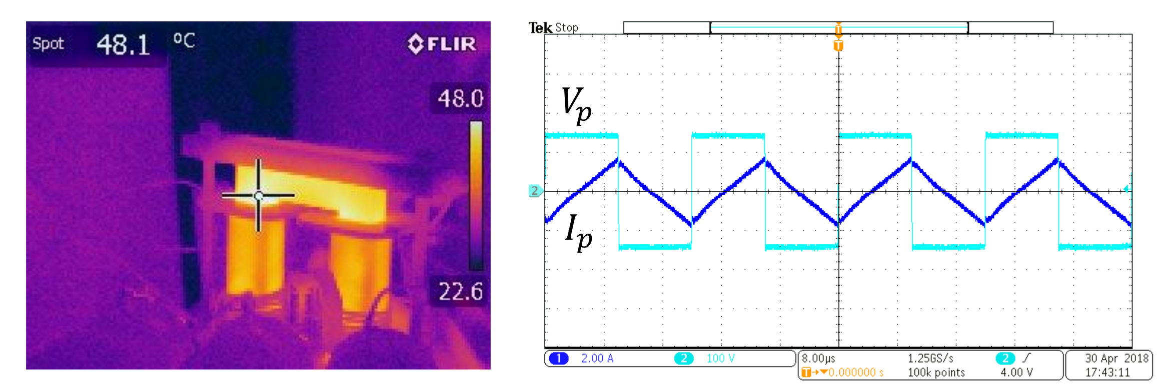


Fig. 9. No load (a) steady-state temperature and (b) outputs.

Table I: Comparison of Experimental Data to Model and FEA [3].

Experimental	Analytical	FEA
14.9 W	13.3 W	9.1 W
-	10.7% Error	38.9% Error

Future Work

The algorithm is currently limited to the magnetics design. Future work will expand the model to include switching components and capacitors. This model will then be incorporated into OpenMETA. The completed software will also include converter topology costs for the multi-objective optimization comparison.

Applications & Impacts

When completed, this multi-objective optimization algorithm can reduce development time and costs for any converter topology and application. Applications of interest include high power density converters, such as those used in electrified naval or aircraft systems, and high efficiency systems, like Solid State Transformer, EV fast charger, or server database centers.

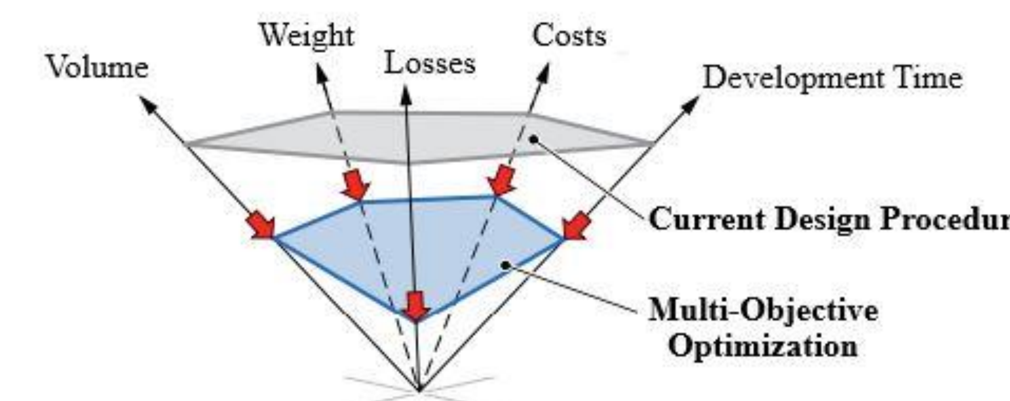


Fig. 10. Multi-objective optimization impacts on design.

References

[1] R. W. Erickson and D. Maksimović, "Fundamentals of Power Electronics." New York. Springer, 2001.

[2] Burkart, Ralph M. "Advanced Modeling and Multi-Objective Optimization of Power Electronic Converter Systems." *Thesis.* ETH Zurich. 2016.

[3] C. Xiao, G. Chen and W. G. H. Odendaal, "Overview of Power Loss Measurement Techniques in Power Electronics Systems," in *IEEE Transactions on Industry Applications*, vol. 43, no. 3, pp. 657-664, May-June 2007.

[4] I. Villar, U. Viscarret, I. Etxeberria-Otadui and A. Rufer, "Transient thermal model of a medium frequency power transformer," *2008 34th Annual Conference of IEEE Industrial Electronics*, Orlando, FL, 2008, pp. 1033-1038.

[5] A. K. Das *et al.*, "Thermal modeling and transient behavior analysis of a medium-frequency high-power transformer," *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, Beijing, 2017, pp. 2213-2218.

Partners

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