Beyond Electromagnetic Component Modeling: Extending Finite Element Analysis to Include Multidomain System Simulation

Introduction

This paper describes how ANSYS® Maxwell® with its built-in system simulation capability facilitates the validation and evaluation of electromagnetic component designs when they are operated in their intended environments.

ANSYS Maxwell is a powerful 3D finite element analysis (FEA) simulation tool with many solvers for designing and analyzing vital components of electromechanical, power electronic and drive systems, such as motors, generators, sensors, transformers, inductors, actuators etc. Finite element analysis of electromagnetics is the foundation for designing these vital components. Subsequent comprehensive system designs require engineers to evaluate the performance of these components in their actual environments. In other words, the key to successful and final verification of a component's design requires that it function properly when included in the actual target system/circuit. Because the FEA capabilities of ANSYS Maxwell are bolstered with its additional multidomain, system-level simulation capability (ANSYS® Simplorer®), engineers can evaluate component designs in their intended systems or circuits. These intended environments could be electromechanical, power electronic or drive systems.

ANSYS Maxwell is the only simulation tool that includes multidomain system simulation with its robust FEA solvers — a significant benefit for evaluating the validity, performance and reliability of component designs in their intended systems. These additional features make Maxwell a comprehensive and cost-effective software tool for electromagnetic component modeling for power electronic and electromechanical systems.

As a result, engineers can model the target system/circuit in Simplorer by including a Maxwell design either through an equivalent model generated directly from Maxwell or by employing co-simulation techniques. Maxwell and its included Simplorer capability allows engineers to explore both top-down and bottom-up design strategies. As an example of a top-down design approach, engineers can gain insight into the big picture by simulating the entire system using standalone Simplorer models (Simplorer itself provides several levels of model libraries). From here, they can drill down to specific segments, i.e., examine the detailed component designs in Maxwell. Finally, the high-fidelity models from Maxwell can be incorporated into Simplorer for system-level simulations. These significant benefits help engineers design electromagnetic components in ANSYS Maxwell and evaluate their performance in multidomain system simulations.

Examples of Components in ANSYS Maxwell Coupled with Simplorer

Motor Drive System

Simplorer provides a system-level simulation environment wherein engineers can include models that are designed in Maxwell and other ANSYS tools based on their different physics. Figure 1, for example, shows a Simplorer schematic which represents a circuit for a motor drive design.

The motor was designed in RMxprt (part of Maxwell). Its equivalent model in Simplorer was coupled with the power electronics IGBT drive circuitry to drive the motor. The Hall Effect sensors were also designed in Maxwell, and their equivalent model in Simplorer provided feedback for the motor control.

The thermal models representing the IGBT package and the battery designs were created in ANSYS Icepak and ANSYS Fluent respectively while the embedded software for motor control was created in ANSYS SCADE. The analysis in Simplorer includes the entire motor control design to validate the interaction of all the components of the system to predict their performance.

Simplorer contains several levels of model libraries. The IGBT models, in this example, may vary from System Level, Averaged to Dynamic. The System Level IGBTs are used for faster simulations to evaluate control; the Averaged level for thermal simulations, where the detailed package thermal model is required to evaluate how much power could be processed by the IGBTs; and the Dynamic level, for detailed switching losses, EMI/EMC, detailed gate drive design, etc.

Figure 2a shows the device characterization tool in Simplorer for several types of devices based on the information available in the corresponding data sheets. The information is scanned from a data sheet and automatically inserted into the characterization tool. Figure 2b shows the motor currents and temperature profiles for the IGBTs and diodes during operation.

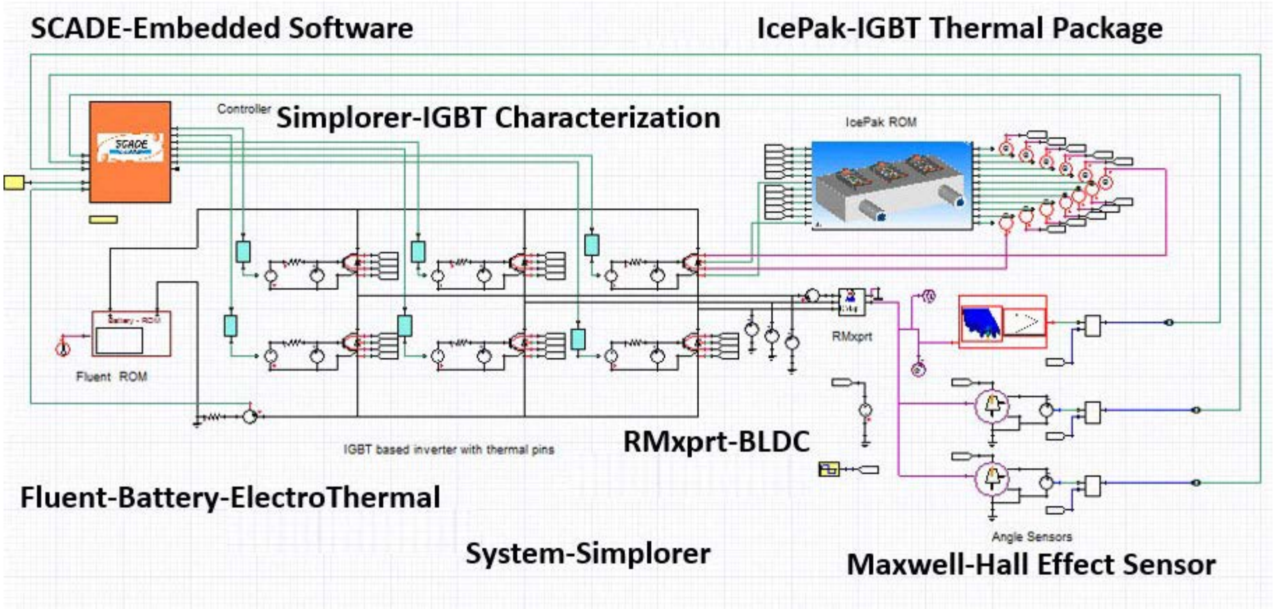
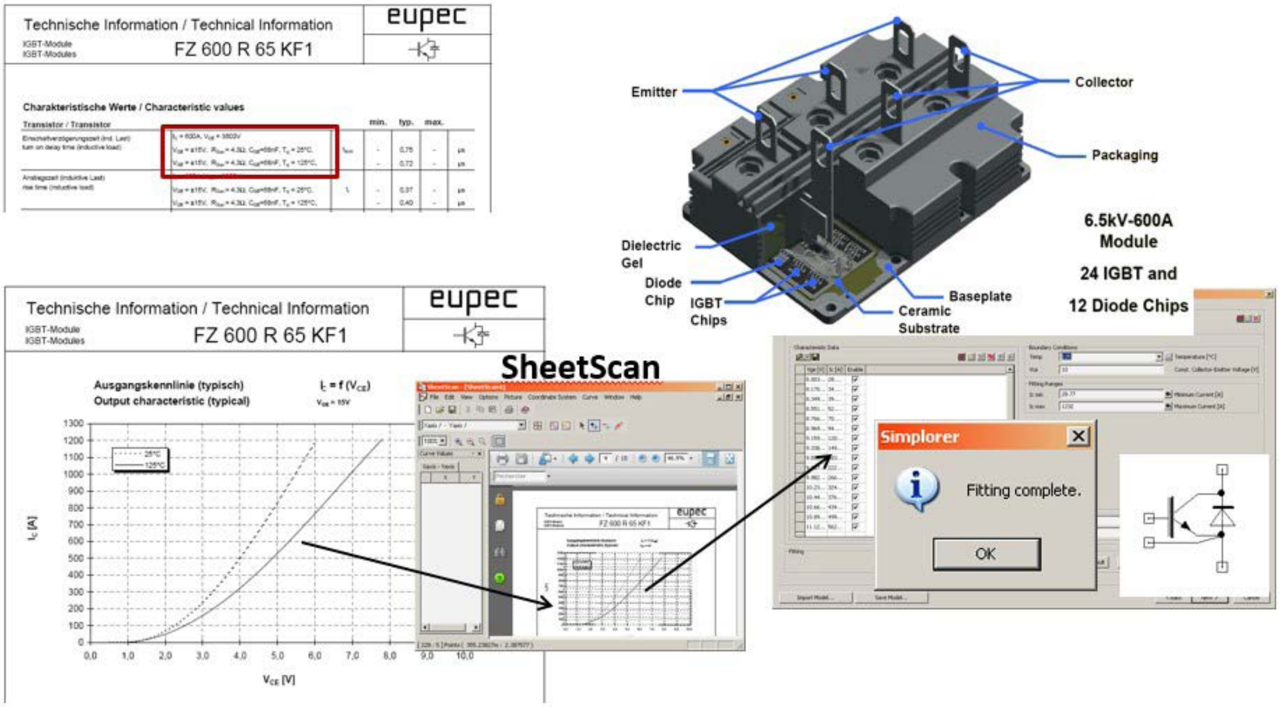


Figure 1. Motor drive system



Fitting complete.

Figure 2a. IGBT characterization tool in Simplorer

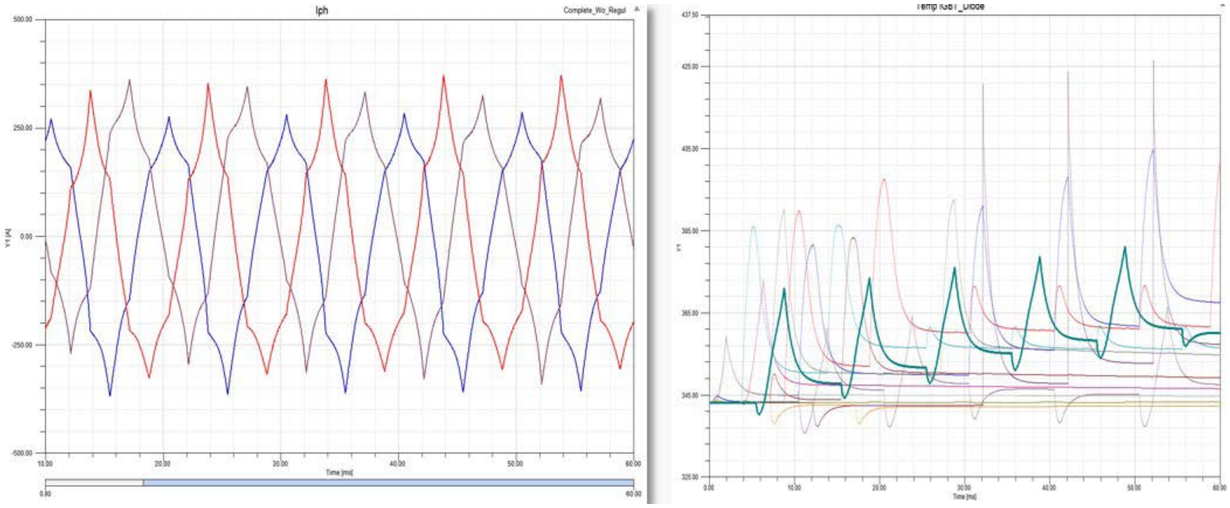


Figure 2b. Motor currents (left), IGBT and diode temperatures (right)

Wireless Power Transfer

Maxwell and Simplorer are extremely useful for wireless power transfer designs. Figure 3a shows a Simplorer schematic that includes a detailed magnetic design from Maxwell for an electrical vehicle wireless power transfer battery charging system. The wireless power transfer transformer, designed in ANSYS Maxwell, is a critical component of this design. To evaluate the performance of this transformer accurately, you must include the transformer with the power electronics that drives it and charges the battery from the power transfer as shown. This optimizes the transformer as well as the entire system. Such component-level and system-wide optimization can be accomplished using Simplorer's power electronics models in conjunction with the detailed Maxwell model — all within a single simulation environment. From the schematic, the input three-phase 60 Hz source is rectified and inverted at 85 kHz to drive the transformer and optimize the power transfer, which in turn, is rectified and used to charge the battery. Figure 3b shows the input and output currents of the transformer for power transfer.

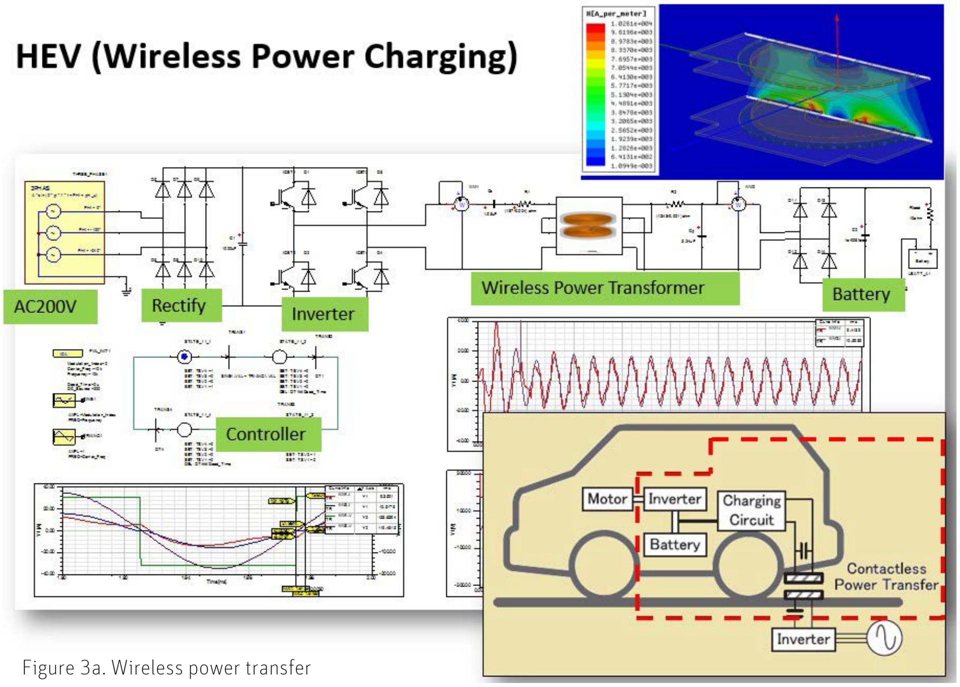


Figure 3a. Wireless power transfer

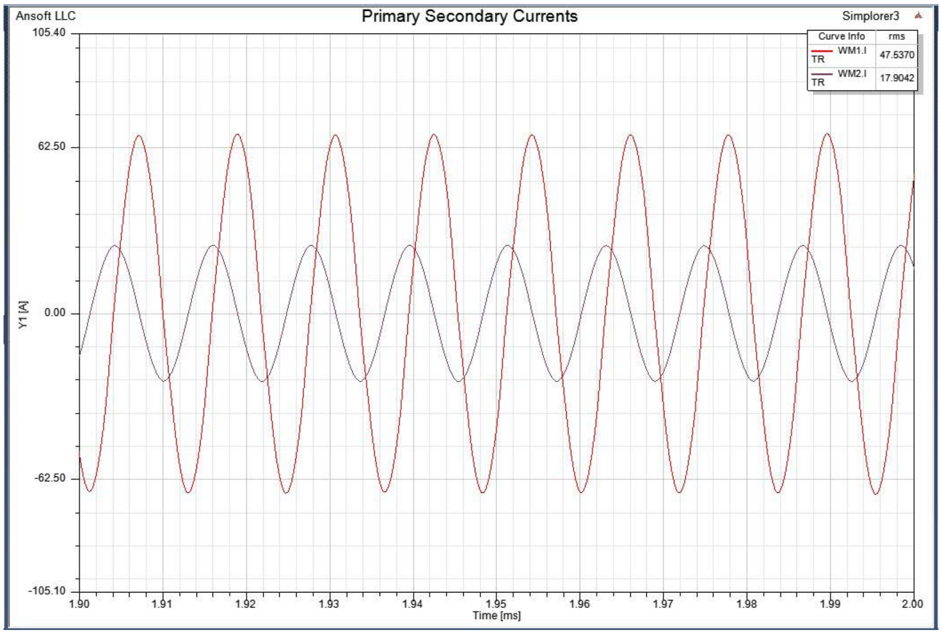


Figure 3b. Transformer currents

DC/DC Converter

Figure 4a shows the Simplorer schematic of a Flyback DC/DC converter. The detailed transformer design was created through PExprt, which uses Maxwell in the background. PExprt provides an intuitive user interface, enabling electrical engineers to design and model magnetic designs for power. The concept of these “xprt” tools is to provide the engineer with an intuitive UI specific to their design needs, and help to automatically create the Maxwell model. Because the process is automatic, you do not need prior knowledge to set up the FEA problem with appropriate boundary conditions, meshing, geometry creation, excitation etc. These tools aid in easy adoption of FEA modeling for engineers. In the example of a Flyback converter, the leakage inductance is important to consider in magnetic designs since it leads to unwanted transient spikes in the circuit. Determining this leakage inductance requires the FEA capabilities in Maxwell. To see the effects of this leakage inductance on the circuit, you need to place the Maxwell model in Simplorer where the rest of the circuit is realized.

Simplorer has a large library of models for different circuits/systems, and includes PWM controllers for the Flyback converter feedback. It also includes characterization tools for power devices such as IGBT, MOSFET, diodes, thyristor etc. Moreover, Simplorer can import SPICE models directly from the vendors. Figure 4b shows the voltage across the switching MOSFET using an initial transformer model from Simplorer, followed by the detailed FEA-based model from Maxwell which now includes the leakage inductance.

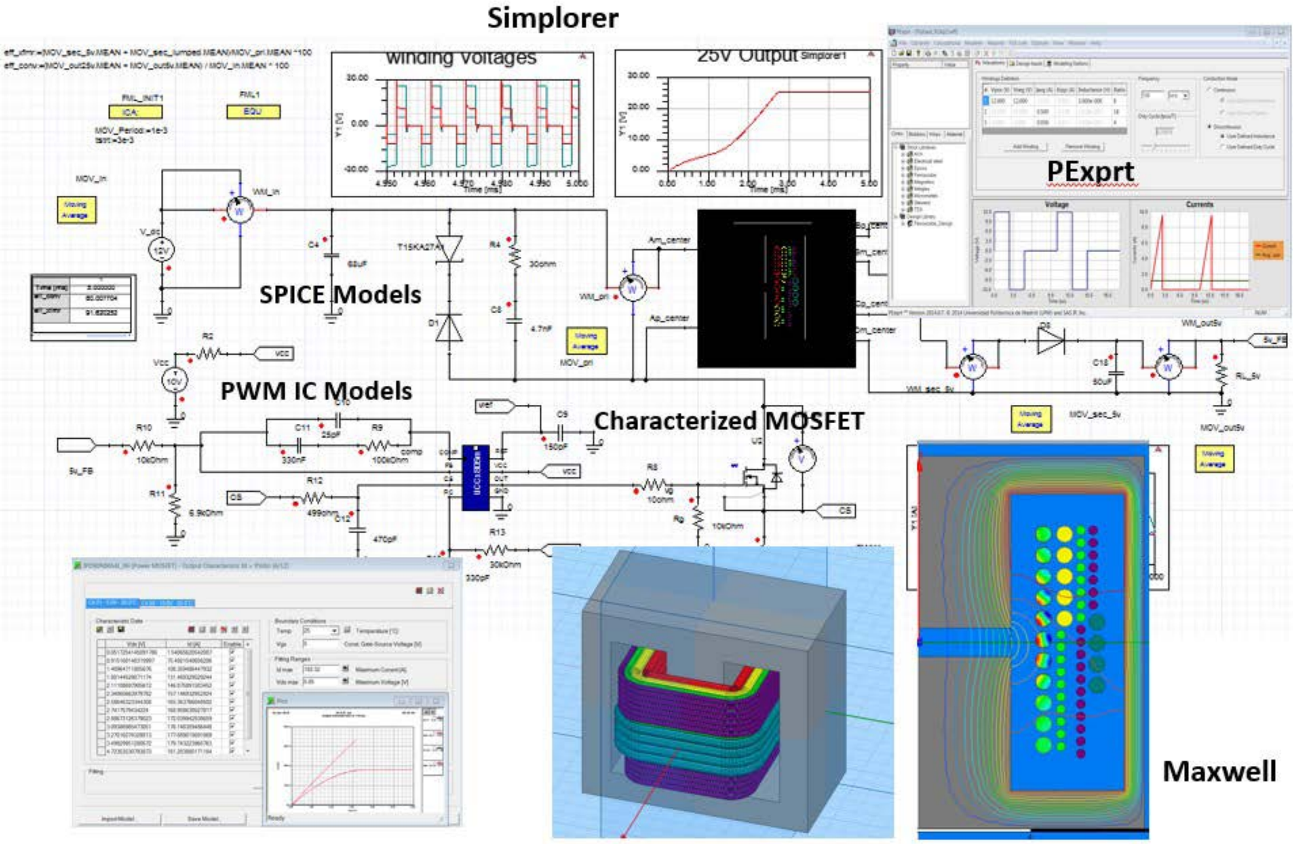


Figure 4a. Flyback DC/DC converter

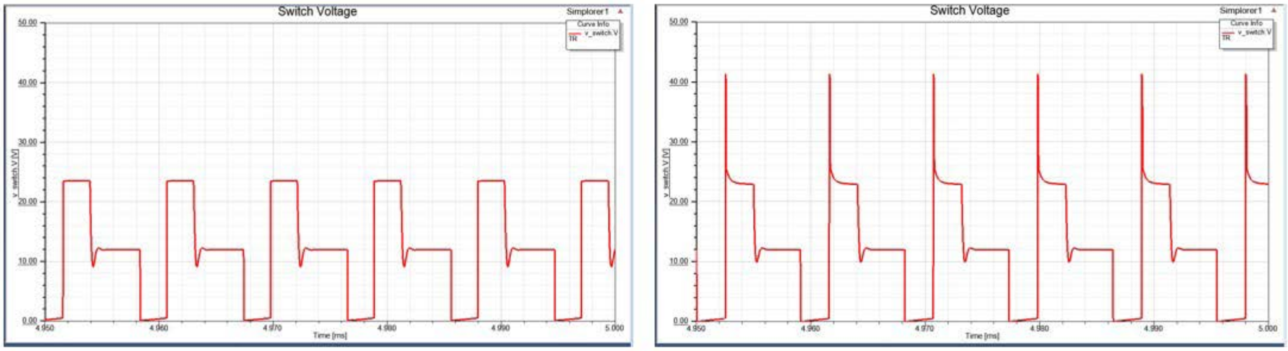


Figure 4b. Switch voltage using basic transformer model (left) vs. using Maxwell model (right)

Summary

This paper has shown three different applications where detailed electromagnetic models designed in Maxwell were included in corresponding Simplorer circuit/system level simulations to validate and evaluate each of the Maxwell models. Maxwell is a powerful FEA-based design, modeling and analysis tool for many electromagnetic components that are eventually included in larger systems. These electromagnetic components include motors, generators, magnetics, actuators, sensors, etc. The only way to truly validate and evaluate the performance of these components is to design them in Maxwell and include generated models in the larger intended systems using Simplorer. Simplorer lets you create the entire system using existing model libraries in conjunction with detailed FEA-based models generated from Maxwell.

Electromagnetic component designs are evolving rapidly, propelled by advanced design assistance systems or ADAS, aerospace electrification and industrial automation. To keep pace with innovation and rapid growth in these areas, it is critical to use simulation. Modeling and simulation tools like ANSYS Maxwell and ANSYS Simplorer facilitate design of electromagnetic components and help to validate their performance in the intended environment, allowing for system-wide optimization and improved reliability, performance and validation.

Authors

Steve Chwirka, Dr. Marius Rosu, Manohar Raju, Mark Ravenstahl.

Additional Resources

https://www.ansys.com/products/electronics/ansys-maxwell

https://www.ansys.com/products/systems/ansys-simplorer

ANSYS, Inc.
Southpointe
2600 ANSYS Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com