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Electrical Drive Modeling through a Multiphysics System Simulation Approach



The electric drive system is a key application in power electronics. Optimizing such complex mechatronic system requires in-depth analysis, expertise and rigorous methodology. This can be realized in several ways, optimizing each component of the system separately. But using optimal components does not guarantee optimal behavior of the whole drive. This calls for a system simulation approach integrating each individual part of the drive system into a common simulation platform.

Products Used

ANSYS® Simplorer®, ANSYS SCADE Suite®, ANSYS Icepak®, ANSYS RMxprt™, ANSYS Maxwell®

Keywords

Electrical drive, power electronics, system simulation, reduction-order modeling, IGBT characterization, electrical machine, multiphysics modeling, Esterel technologies, thermal management, control systems

Electrical Drive

An electric drive is a system that converts electrical energy into mechanical energy. It also provides electrical control of the whole process through several devices and technologies (Figure 1). The objective is to create a smooth and versatile control to achieve a specific speed-torque characteristic. It is a key component of the power conversion chain between power sources and loads.

The AC drive controls the speed of an electrical motor, which can be a synchronous or induction machine. Depending on the application, the speed of the electrical motor may need to be adjusted, which is accomplished through the power supply's frequency — hence, the adjustable or variable frequency drives.

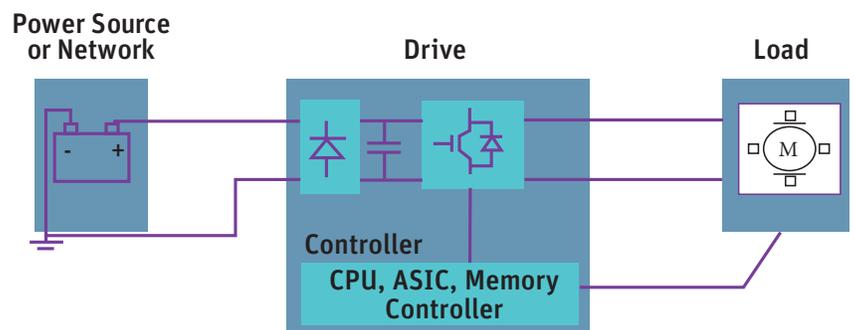


Figure 1. Main elements of electric drive system: rectifier, DC circuit, inverter

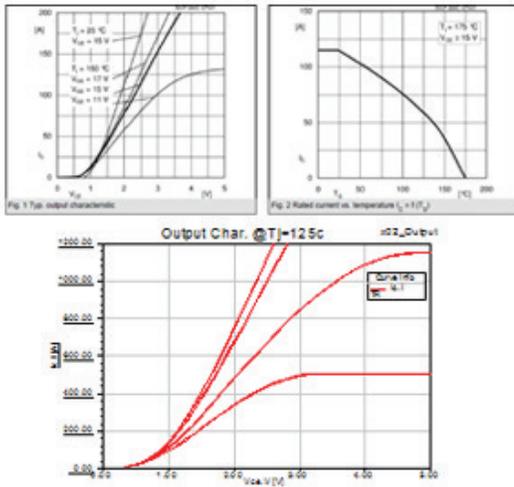
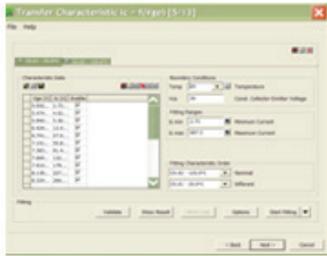
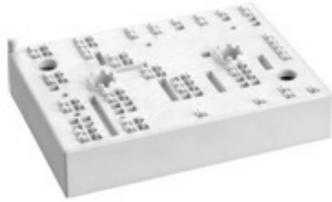


Figure 2. Simplorer semiconductor characterization tool model building from a manufacturer datasheet

Drives are used in a wide range of applications in the industry: food blenders, fans, pumps, mills, oil drilling platforms, mining, compressors, HVAC systems, industrial equipment, traction motors for cars, railway applications and more.

System Approach

Electric drive technology has advanced significantly over the past few decades, reducing cost and size of as well as improving efficiency and performance through better semiconductor technology, topologies optimization, control technology and software.

In designing next-generation drives, the challenge is to handle and study complex multiphysics issues. Electrical optimization, thermal management, fatigue, and software–hardware interaction must be considered in a global view.

A system simulation approach is required so designers can accomplish such challenges and solve issues in the early stages of the development cycle. One tool is ANSYS Simplorer, multi-domain system simulation software with multiphysics modeling capabilities. It integrates multiple modeling technologies such as block diagrams, state machine, language (C++, VHDLAMS, SML, PSPICE) modeling, electronics circuit, and coupling capability with 2-D/3-D ANSYS simulation tools.

Semiconductor Modeling

Semiconductors are used as electrical switching devices in power electronics applications. This technology has advanced greatly in past years, with design of new gates, bulks and internal topologies as well as wide-gap material-based devices.

To correctly model semiconductors, ANSYS Simplorer offers a characterization tool that enables building IGBT (and other devices) from manufacturer datasheets or measurement data, no matter the semiconductor technology used. Three types of IGBT models are available: average, basic dynamic and advanced dynamic. Depending on the type of simulation and electrical focus, a designer can choose the system electrothermal model (average), dynamic accurate models for EMC/EMI study, and gate-drive optimization (basic dynamic and advanced dynamic models).

Figure 2 shows an example: the average type IGBT model. Through the characterization tool’s wizard, the different data and electrical curves are needed to build a model. Simplorer then creates a compact model according to the electrical characteristics selected.

Cooling Device

In power electronics, thermal management is a key element for good design. Heat dissipation is critical in semiconductors; the operating junction temperature must be controlled both to avoid electrothermal failures and to enhance reliability of the whole power inverter. Many types of cool-

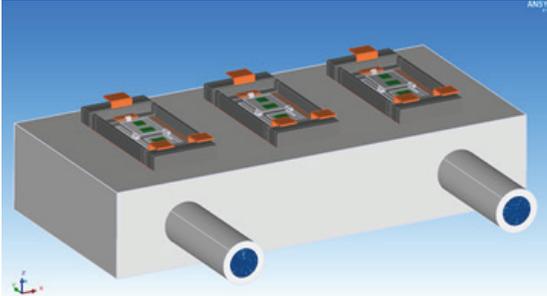


Figure 3. One-side cooling system of cold plate modeling for power modules

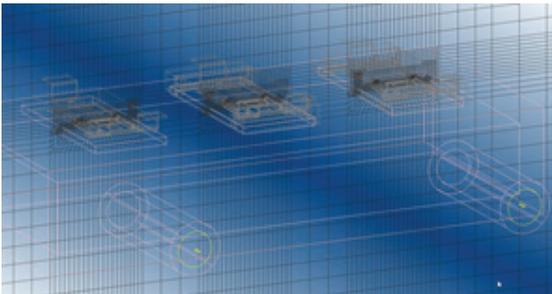
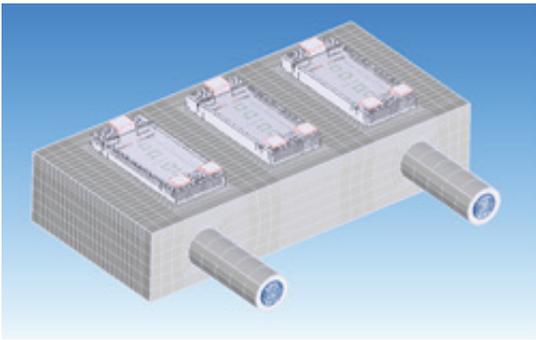


Figure 4. Mesh plot of geometry

ing systems exist. As an example, one commonly used in railway applications is the cold-plate liquid cooling system.

There are several cold-plate designs, and they usually use channels for water flow. The cooling plate in this example includes a hollowed aluminum block with a glycol solution (Figure 3). Consideration must be given to the different interfaces between the chip and cooling system. Classical stacking incorporates solders, metallization, ceramic substrate, a base plate for mechanical consideration and a thermal interface.

Modeling and simulating the cold plate can be performed with ANSYS Icepak, a thermal-CFD simulation tool for electronic cooling devices. The Icepak model uses forced convection with ambient and cooling liquid temperature of 70°C. The model size is 2.4 million (Figure 4).

For system simulation, Simplorer is used to generate an equivalent thermal model to be coupled to the IGBT models. One accurate and robust technique is to develop a reduced-order model (ROM) from high-fidelity Icepak results. To make the ROM, Icepak creates step responses of the thermal system (Figures 5 and 6). Based on the step responses, the ROM can be created so it has the same step responses.

Subsequently, the ROM can be used inside ANSYS Simplorer for temperature calculation with excellent accuracy under arbitrary heat profiles.

Simulating Complete Drive System

The appropriate simulation methodology should enable designers to validate each step of product design by incorporating simulation models early in the process.

In this way, power electronics designers have realistic temperature operating points, software developers can test and validate codes with realistic hardware models, and mechanical and thermal engineers can dispose of accurate data such as losses values and distributions.

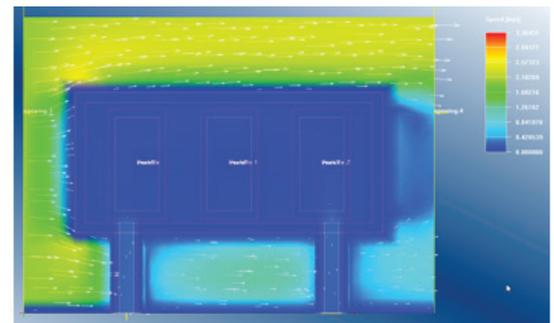


Figure 5. Steady-state results for fluid flow calculation

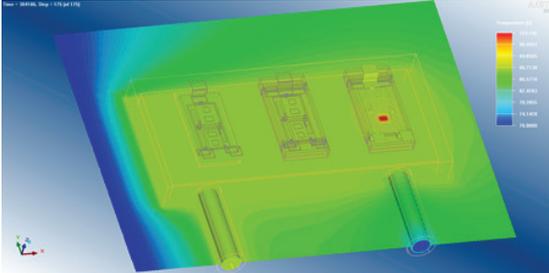


Figure 6. Transient simulation example of trial #12 and temperature field covering whole system

The drive is modeled by a DC circuit, a three-phase inverter based on IGBT switches, controlling a DC brushless motor. A thermal cooling system and the control system are simulated along with the power electronics. DC parts can be modeled by an ideal source or a battery model. The whole system is shown in the figure 7.

Following inverter modeling, the control system model can be put in place using ANSYS Scade Suite. This tool offers the ability to integrate and test in an analog system flow the actual embedded code that will be loaded in the final hardware target. Scade Suite enables automatic generation of a certified code through a comprehensive graphical interface (Figure 8).

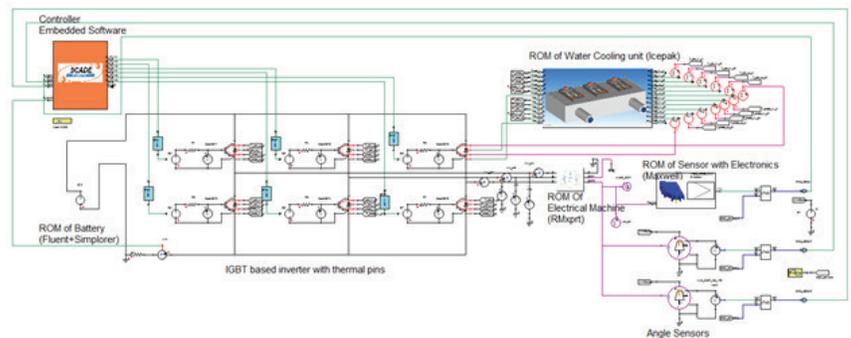


Figure 7. Complete drive system simulation with Simplorer

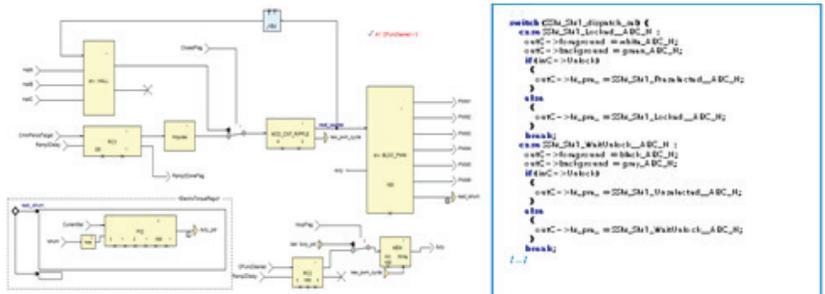


Figure 8. Scade Suite for embedded software models the control.

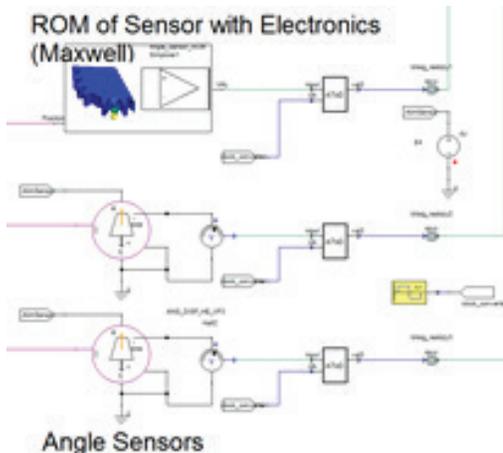


Figure 9. Position sensors modeling includes analytical native model and ROM from Maxwell.

The control can be done with an open loop in the first step and then in closed loop at a final stage. Electrical control is done through measuring the return current and mechanical data, such as rotor position, speed and motor torque. To capture rotor position, Hall effect sensors can be used (Figure 9). These are modeled from lumped elements from Simplorer library; they also can be modeled via ROM for more accuracy from 2-D/3-D ANSYS Maxwell software, a general-purpose finite element electromagnetic simulation tool. The benefits from using ROM instead of cosimulation technology (when physics allow) include a drastic reduction in time simulation without loss of accuracy compared to high-fidelity field results. The analog information from the sensors is then converted into numerical data and sent back to the control model from Scade Suite.

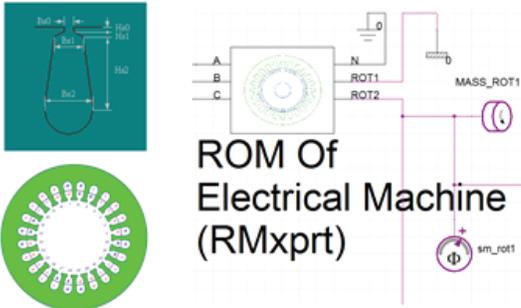


Figure 10. View of ANSYS RMxprt electrical machine model with mechanical load

The motor is modeled from either Maxwell 2-D/3-D or RMxprt, an electrical machine design tool that provides accurate analytical models for all standard electrical machine types (single and three-phase induction motor, synchronous machine, switched reluctance motor, generic rotating machine). You can quickly configure and set up a very large set of parameters allowing accurate description of the machine. The software enables editing rotor and stator slots, stator windings configuration, conductor data (material), coil arrangement and more (Figure 10). The example here is a BLDC motor.

Finally, thermal management of the active electronic part must be considered along with the power electronics. Cooling of the power inverter was modeled in a 3-D electronics thermal design tool (in this case, ANSYS Icepak). The ROM created from the high-fidelity 3-D model results is thoughtfully incorporated into Simplorer simulation (Figure 11).

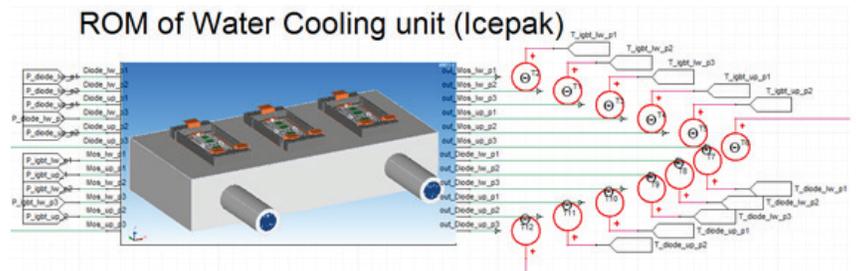


Figure 11. ROM (linear time invariant model) of cooling system for power electronics

As a result, you can validate the behavior of each subcircuit and mutual interactions between physics, then identify the key points of enhancement early in the design by monitoring and analyzing essential quantities, such as junction temperature of semiconductors or three-phase currents (Figure 12).

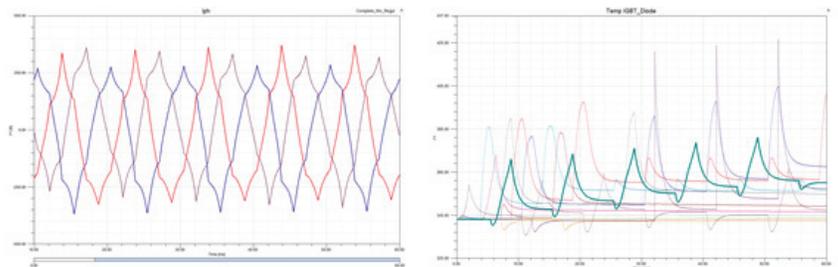


Figure 12. View of three-phase currents (left) and junction temperature of IGBTs and diodes (right)



Electrical Drive Modeling through a Multiphysics System Simulation Approach

Summary

The ANSYS system simulation strategy has been demonstrated through a combination of multiphysics system simulation with embedded software development for power electronics. Through a comprehensive system solution known as Simplorer, integration of detailed robust accurate models coming from field tools can be realized for each physics domain to obtain early diagnosis and study of the whole product optimization.

The approach is extensible with more-detailed models (3-D) of different hardware components, depending on the need and analysis case.

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