



# HOT FLASH

Using a reduced-order method, engineers at Fairchild Semiconductor have been able to decrease development time for electronic components for electric and hybrid electric vehicles. By employing ANSYS Icepak for thermal management and ANSYS Simplorer for multi-domain systems design, the engineers performed dynamic thermal analysis under realistic power loss conditions approximately 2,000 times faster than a full 3-D thermal analysis.

By Roy Davis, Senior Manager, Ann Arbor, USA  
Klaus Neumaier, R&D Engineer, Fairchild Semiconductor, Munich, Germany

In electric vehicles (EVs) and hybrid electric vehicles (HEVs), many of the systems we take for granted in internal combustion automobiles must be implemented differently. In addition to the main powertrain motor-generator sets, some accessory systems are also electrified. For example, because the engines in these vehicles do not run continuously, electrically driven air-conditioning (AC) compressors and transmission oil pumps may be used instead of usual engine accessory belt-driven systems. All of these electric drives require fast, efficient and reliable power electronic converters.

Fairchild Semiconductor, a pioneer in the semiconductor industry, produces a wide range of power components suitable for these power electronic converters, as well as a complete portfolio of low- to high-power solutions for the mobile,

industrial, cloud, automotive, lighting and computing industries. A typical Fairchild inverter consists of an array of six insulated gate bipolar transistors (IGBTs), each of which is paired with an anti-parallel diode, to convert DC voltage provided by the vehicle's battery pack into three-phase AC voltage required to drive the AC motors. Two IGBTs and two diodes form each "half-bridge" powering one phase of the motor. A single IGBT and diode pair form one bi-directional switch and, in combination with the other switches in the inverter, operate according to a pulse-width modulation scheme to generate the AC waveforms necessary to control the motor. Switching the IGBTs on and off at 5 to 20 kHz results in pulsed DC voltages that average out to yield a sine wave on each phase, with the three sine waves being 120 degrees out of phase with each other. The three-phase

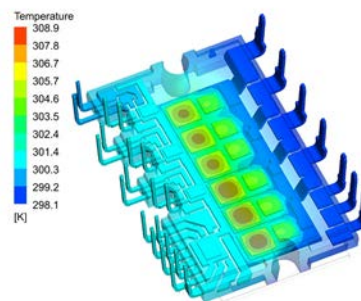
sinusoidal drive produces a rotating electric field in the electric motor, precisely controlled in a closed-loop feedback system to generate the necessary torque to drive the load.

EV or HEV power train inverters are rated in the 50 kW to 100 kW range, and AC compressors are in the 6 kW range, so the power dissipated in these devices is high, and thermal considerations are critical to their design. The traditional approach is to simulate the circuit to determine power dissipation under specified operating conditions. These power losses are then used as inputs to a 3-D thermal simulation that predicts junction temperatures on the IGBTs and diodes. This approach usually requires about 8 hours to simulate tenths of seconds of operating time needed to thermally characterize a design iteration under a given set of operating conditions. In addition, a considerable amount of engineering time is tied up running separate electrical and thermal simulations and manually

passing data back and forth. Fairchild engineers have improved the inverter design process by using ANSYS Icepak to develop a systems-level linear time-invariant (LTI) reduced-order model (ROM) that runs in the ANSYS Simplorer system simulation environment to predict thermal performance in minutes rather than hours or days.

**VALIDATING THE ROM METHOD**

Fairchild engineers created an Icepak model of the three-phase inverter, including its package and enclosure. They ran a few simple simulations to validate the model’s accuracy, and performed a steady-state simulation. Then they performed a series of step response analyses in Icepak for a set of input and output quantities to build a compact model. For the inverter, the power dissipation of the six IGBTs and six diodes, as well as the heat sink temperature, is typically used as input, while the junction temperatures provide the set of

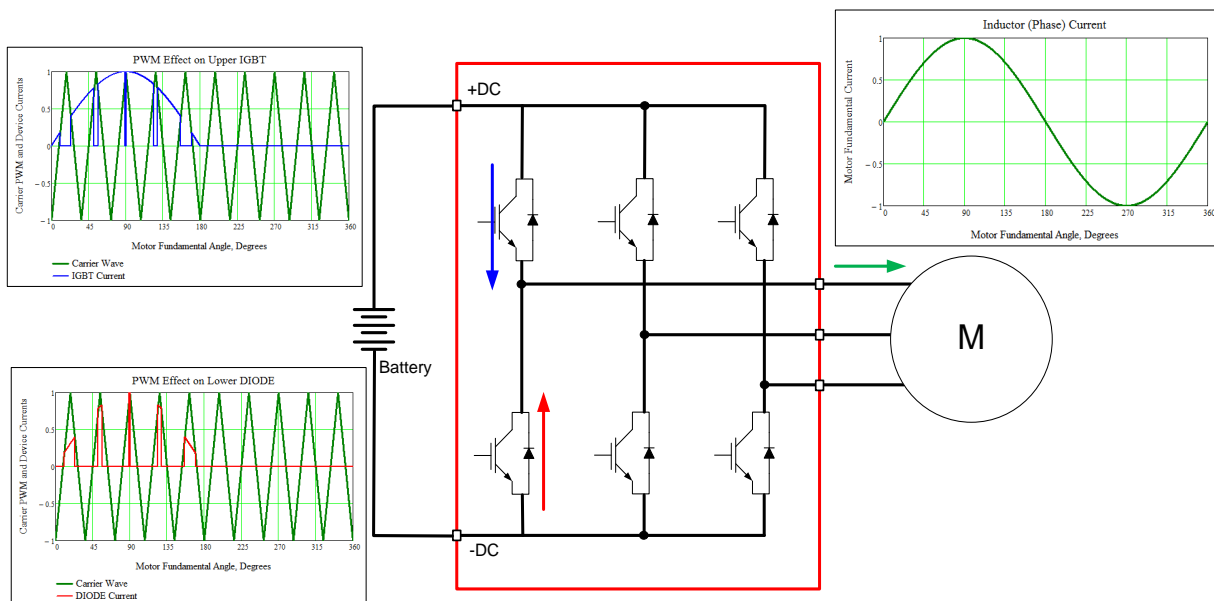


▲ 3-D thermal analysis accurately determines thermal status at a high computational cost.

output quantities. Based on the fully described thermal system, the team then used Icepak to generate a linear time-invariant reduced-order model (LTI ROM) that can be used in Simplorer to simulate specified electrical and thermal conditions in a fraction of the time required for a full 3-D thermal simulation.

Fairchild engineers evaluated their initial ROM against a full 3-D thermal

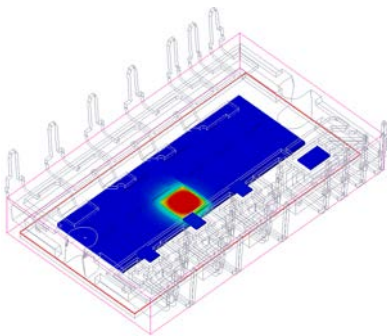
**In electric vehicles (EVs) and hybrid electric vehicles (HEVs), many of the systems we take for granted in internal combustion automobiles must be implemented differently.**



▲ The inverter converts direct current to three-phase alternating current by generating pulses that combine to yield a sine wave.

Trial No.	Upper U						Lower						Tref [C]	
	U		V		W		U		V		W			
	D	I	D	I	D	I	D	I	D	I	D	I		
1	300	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	300	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	300	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	300	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	300	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	300	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	300	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	300	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	300	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	300	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	300	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	300	0	0
13	20	20	20	20	20	20	20	20	20	20	20	20	125	0

6 IGBT, 6 Diode, Tref



13 Analyses ≈ 26h

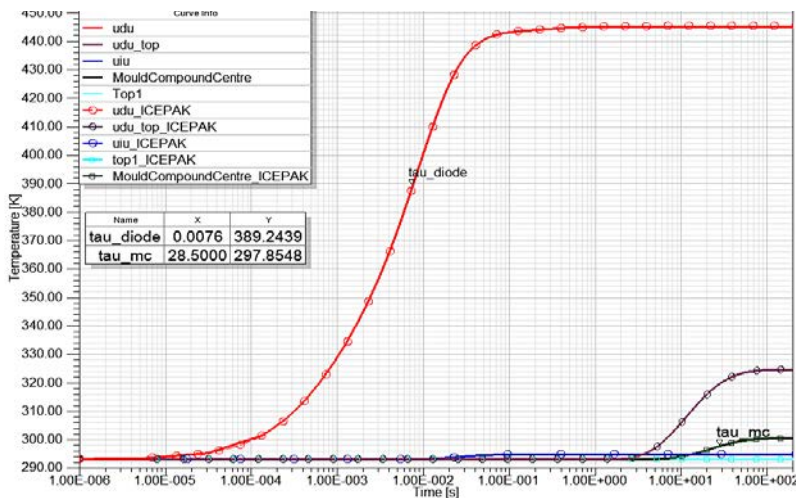
▲ A reduced-order model created by varying load on components and ambient temperature in 13 separate 3-D thermal analysis runs



analysis to test its accuracy. The temperatures of all components as predicted under a step-load test by the ROM were a near perfect match (below

1 percent error) with the predictions made by the full 3-D thermal analysis. The solver time for this full 3-D simulation was about two hours, while the ROM

ROM (Ideal HS) Versus 3-D Step Response Test




▲ A reduced-order model provides a near perfect match to 3-D thermal analysis results.

took about one minute to run. Then, a variety of pulse load tests were employed to compare the results of the ROM against 3-D thermal analyses. Again, the ROM results matched the 3-D analysis very closely (below 2 percent error level). In this case, the 3-D model took eight hours to solve for 150 milliseconds of operating time, while the ROM took four hours to solve a much longer 150-second time period. In this case, the ROM provided a 2,000-to-1 speedup, taking half the time to produce 1,000 times more information. Fairchild engineers did not feel the need to validate the results with physical testing because they have validated 3-D thermal analysis against physical testing many times and found a very close correlation every time.

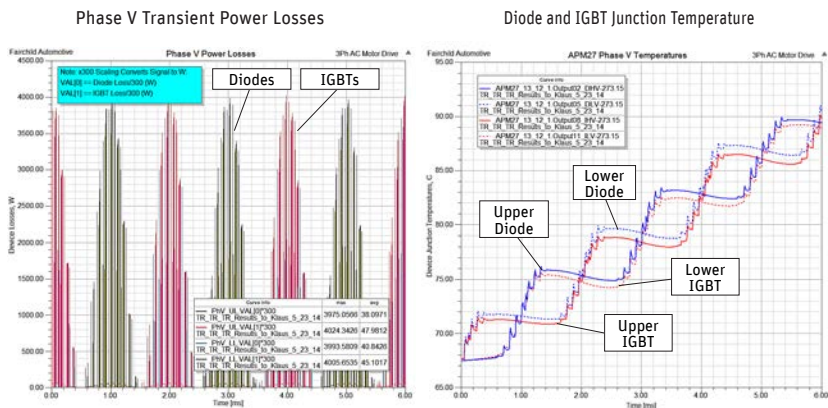
### FIRST USE ON ACTUAL PRODUCT

The Fairchild team used the ROM method to develop a three-phase inverter for an air-conditioning compressor for an EV. Engineers used Icepak to create a ROM of the components, package and enclosure. They imported the model into Simplorer and computed the demands on the inverter with the compressor motor spinning at 5,000 rpm when the air-conditioner is turned on. The ROM computed the junction temperatures of each device. Once the ROM was developed, the Simplorer environment enabled integration of device models, load models, package model and control systems elements

 **SYSTEM-LEVEL SIMULATION USING ANSYS ICEPAK AND ANSYS SIMPLORER – WEBINAR**  
[ansys.com/system101](https://ansys.com/system101)

**Fairchild engineers have improved the inverter design process by using a reduced-order model to predict thermal performance in a minute or two.**

**The ROM took half the time compared with the previous method to produce 1,000 times more information.**



▲ ANSYS Simplorer determines power losses and uses ROM to compute junction temperature.

to generate systems-level performance projections and design optimization. The engineer can also change circuit parameters to run under different operating conditions.

In this project, the ROM enabled Fairchild engineers to react to changes in design specifications and evaluate design alternatives in much less time than was possible in the past. For example, originally the customer said the heat sink would run at 85 C, but physical tests showed that it would actually run at 105 C. Engineers simply changed one parameter in Simplorer, and in a few minutes the ROM produced updated results. Motor operating conditions (such

as switching frequency) also changed several times during the design process; Fairchild engineers were able to quickly evaluate the impact of each change.

Fairchild engineers expect substantial time savings in developing robust, reliable inverters. Key engineering team members involved in the project are already experiencing significant workload reductions. They fully expect that completely integrating ROM-based analysis methods with ANSYS tools into the development process will reduce engineering expenses, encourage innovation, and enable the company to take on more product development projects. ▲

**Integrating ROM-based analysis methods with ANSYS tools into the development process will reduce engineering expenses, encourage innovation, and enable the company to take on more product development projects.**



**Automotive Simulation**  
WORLD CONGRESS

**Two dynamic  
conferences  
join forces**

**Munich, Germany  
June 7-8, 2016**

**REGISTER NOW**  
[ansys.com/aswc](http://ansys.com/aswc)

**Electronics  
Simulation  
EXPO**