AUTOMATING BATTERY PACK DESIGN
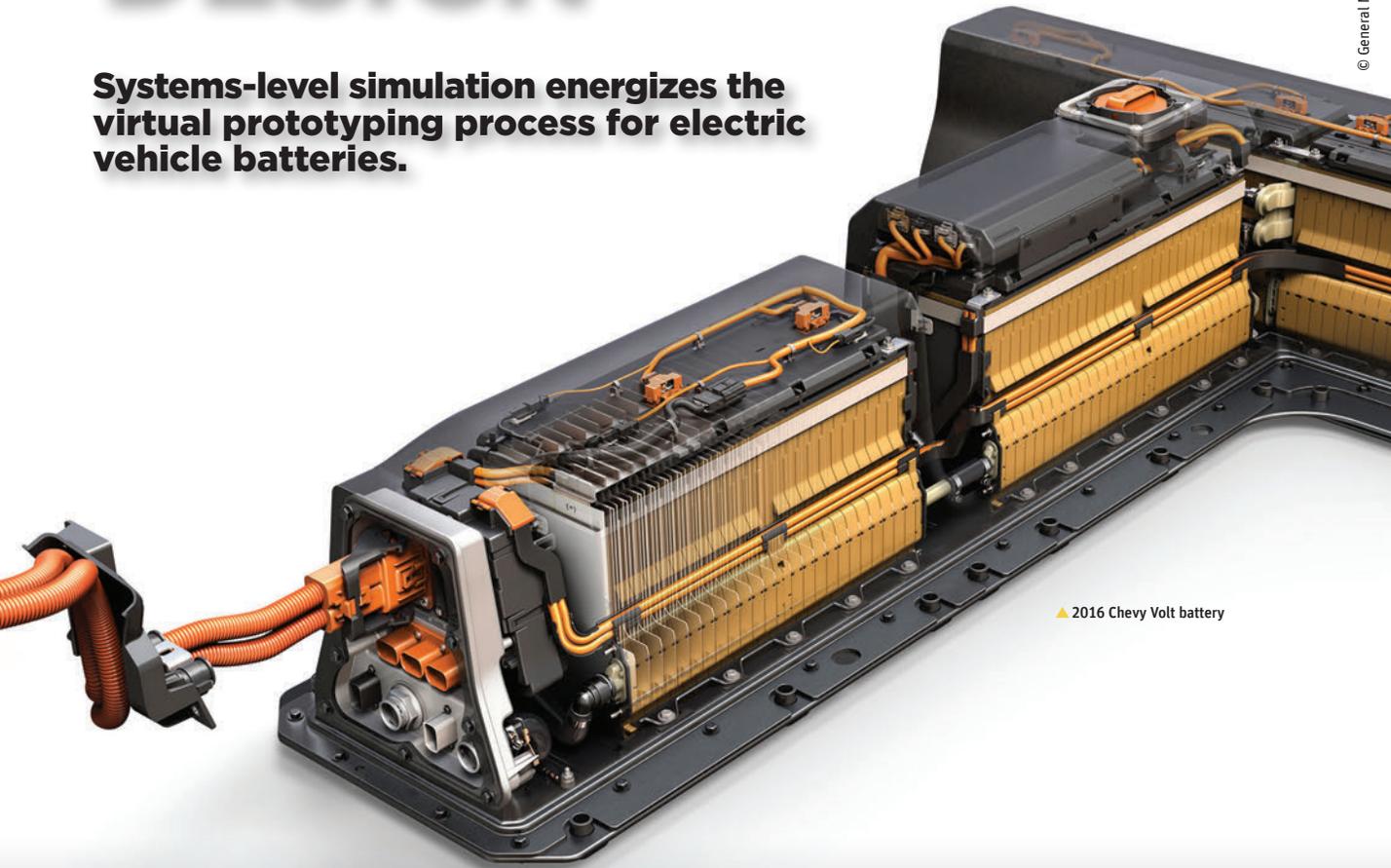
Systems-level simulation energizes the virtual prototyping process for electric vehicle batteries.

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▲ 2016 Chevy Volt battery

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Since their commercial introduction in the early 1990s, lithium-ion batteries have emerged as the most popular form of rechargeable energy storage devices in the portable electronics and electric vehicle markets. The lightweight lithium compounds that comprise the electrodes result in a high specific energy (watt-hours/kilogram) as compared to other types of batteries. While a few battery cells may be sufficient for a phone or laptop, it is necessary to connect many hundreds of individual cells together as part of a much

For electric vehicle makers, designing an efficient and robust cooling system for the battery pack is a key engineering task.
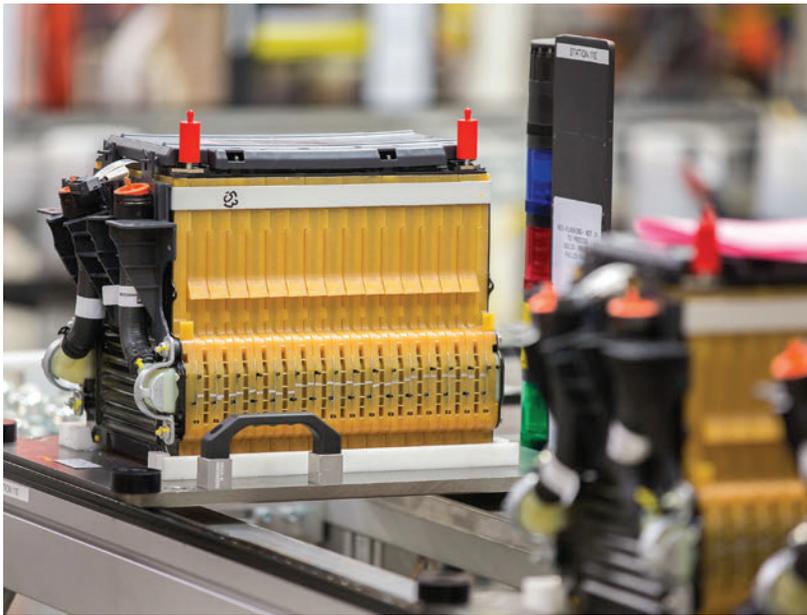
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▲ General Motors electric vehicle battery production
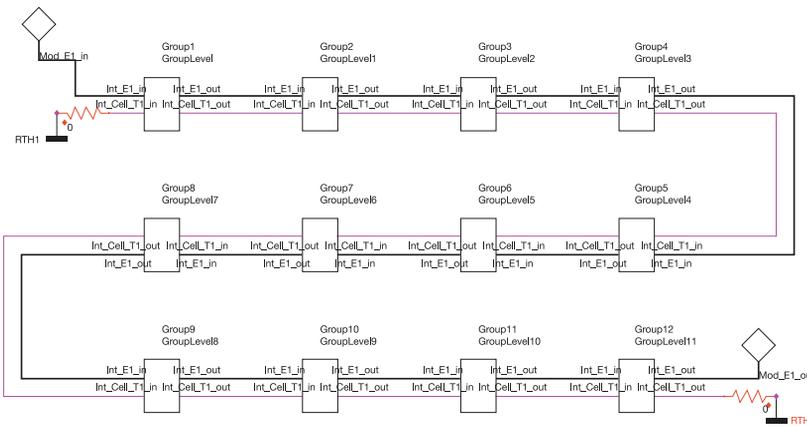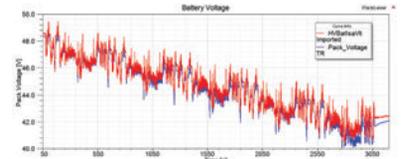

▲ ANSYS Simplorer model of 24-cell battery module, consisting of 12 two-cell units with automatic electrical and thermal connections

a)

b)

c)

d)

▲ ANSYS Simplorer predictions for a 24-cell battery module in blue as compared to experimental data in red measured using the US06 driving schedule for overall pack voltage a), cell state-of-charge b), average cell temperature c), and pack heat generation d).

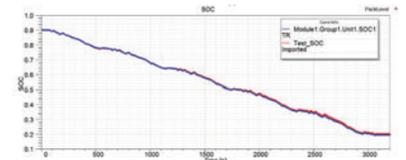larger battery pack system to power an electric vehicle.

Seeking to further increase the specific energy of electric vehicle (EV) batteries, while also reducing the overall size and weight of the battery system and maintaining safe operating conditions, automakers and their suppliers have worked together — with the support of the U.S. Department of Energy (DOE) Vehicle Technologies Office — to attack several grand challenges put forth in the EV Everywhere technology blueprint. To meet the ambitious goals of EV Everywhere — which include reducing energy costs to $125 U.S.D./kilowatt-hour by 2022 — the use of simulation tools to design battery systems and

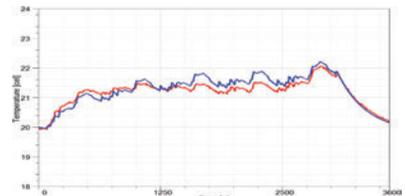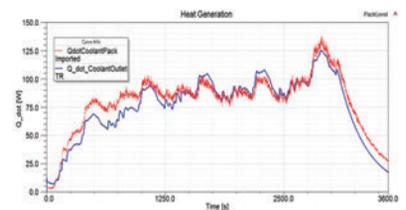accurately predict their performance is a vital component of the R&D strategy.

Beginning in 2012, General Motors led a team working under a program administered by DOE's National Renewable Energy Laboratory known as the Computer-Aided Engineering for Electric Drive Vehicle Batteries (CAEBAT) project. The team consisted of GM researchers and engineers, ANSYS software developers and applications engineers, and the staff of ESim LLC. One of the objectives of the GM CAEBAT project has been development of battery pack design tools, which included leveraging and extending the capabilities of systems-level simulation packages.

CAEBAT BATTERY THERMAL MANAGEMENT PROJECT BY GENERAL MOTORS, ANSYS AND ESIM
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PACK-LEVEL ANALYSIS

Because a vehicle battery pack may contain hundreds or even thousands of cells that exhibit tightly coupled electrochemical and thermal behavior, one particular challenge is to maintain an optimum range of system operating conditions to minimize material degradation and loss of capacity. From the perspective of an automotive OEM, keeping the whole pack within the temperature range of 25 C to 35 C (77 F to 95 F) is crucial for the reliability of

Incorporating this kind of simulation into the process helps guide the overall pack design direction as automakers seek to meet DOE's programmatic goals and address the demands of the growing EV consumer market.

the system. Because temperatures in the surrounding environment can span from −40 C to 50 C (−40 F to 122 F), the temperature uniformity of the individual cells is maintained by a dedicated thermal management system. For electric vehicle makers, designing an efficient and robust cooling system for the battery pack is a key engineering task.

To analyze the coupled electrochemistry and heat transfer of a pack, it is desirable to have predictions based on fine spatial resolution of the entire system of battery cells. However, such information may be available only through resource-intensive, time-consuming full-field simulation, which is not always practical during tight vehicle development cycles. In addition, engineers must capture transient conditions that affect the load on the pack during a variety of driving schedules, such as the EPA's US06 cycle that represents aggressive driving behavior with a variety of brisk changes in speed. A systems-level approach using ANSYS Simplorer can provide an effective solution when complete field data is not necessary. Automotive engineers require quick turn-around time between design iterations to evaluate potential cooling system designs.

A SYSTEM OF UNIT MODELS

To address these kinds of design challenges, GM researchers deconstructed the full pack domain in Simplorer to first create a representation of a battery unit model. The unit model is a combination of one or more battery cells and the adjacent cooling channel. Using off-the-shelf Simplorer components to represent the internal resistors, capacitors, and sources of both electrical


▲ Chevy Bolt concept battery electric vehicle

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and thermal behavior, the research team created several unit-model variations based on theoretical and empirical formulations for both circuit and heat-transfer modeling. Once completed, these units are easily stored in a Simplorer user library for later use by a production pack designer.

Within the pack, the individual cells are wired electrically in parallel to form groups, and the groups are wired in series to form modules. To automate the process of replicating and connecting units, groups and modules together into a pack, the CAEBAT team created a Python-scripted extension to the Simplorer user interface that requires just a few integer value inputs to specify the pack configuration. With the positioning, wiring and hierarchical layout complete, the Simplorer extension then adds custom components written in the VHDL-AMS modeling language to represent the coolant manifold, along with the transient load to represent the driving schedule. The pack designer can then change the parameters for any individual unit in the pack to analyze potential thermal runaway, or can replace units with others from the user library to consider the effects of cell-to-cell manufacturing variations. This combination of automation and flexibility enables the CAEBAT team to evaluate numerous pack configurations, consider different profiles for the coolant flow rate, and predict the thermal and electrical responses to driving schedules like US06.

VALIDATION AND FUTURE WORK

GM's researchers validated the systems-level approach by comparing the Simplorer model of a 24-cell reference battery module to experimental test results. The GM unit model included a six-parameter electrical circuit sub-model coupled to a thermal circuit sub-model. Resulting Simplorer predictions of the overall pack voltage, the state of charge and the average temperature of each cell closely followed the trends observed in laboratory experiments. In the longer term, CAEBAT team partners are investigating further enhancements to the systems-level simulation approach. These include the addition of battery-life modeling to
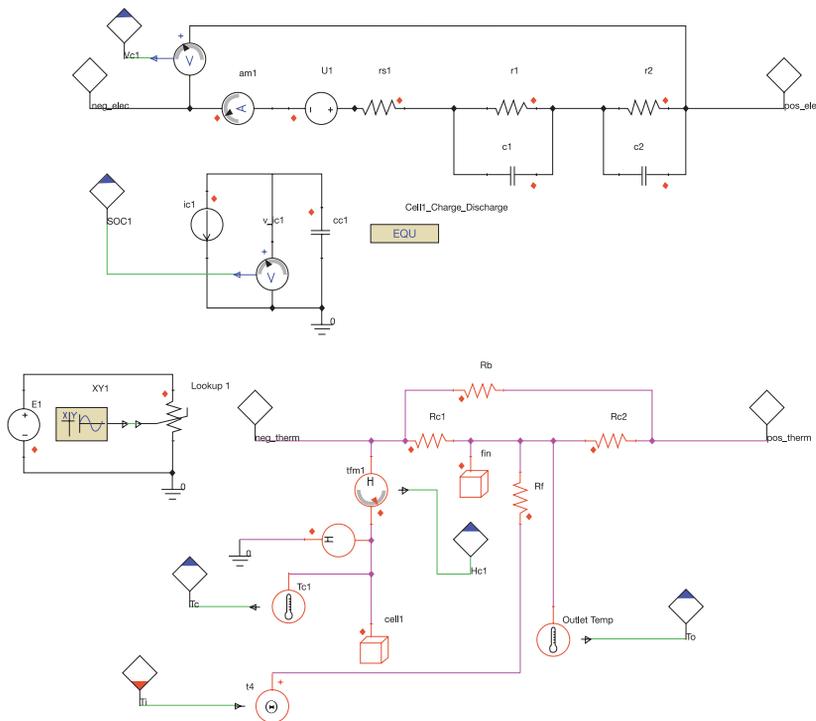
▲ Example ANSYS Simplorer unit model, including six-parameter electrical circuit model (top) and thermal model representing a battery cell and cooling channel (bottom)

The combination of automation and flexibility enables the CAEBAT team to evaluate numerous pack configurations.

predict the capacity fade of cells over long-term use, and expanding the capability to examine individual cells in more detail by replacing selected units in the Simplorer pack model with full 3-D ANSYS Fluent cell models as well as reduced-order models. The information provided by the systems-level approach will be especially critical to GM for trade studies regarding questions — such as air cooling versus liquid cooling, battery form factor or effects of battery management system control logic — that must be answered before building costly prototype hardware. Incorporating this kind of simulation into the process helps to guide the overall pack design direction as automakers seek to meet DOE's programmatic goals and address demands of the growing EV consumer market. ∧
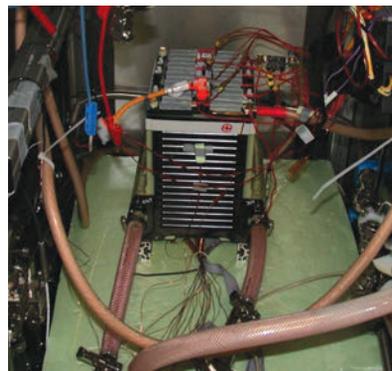
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▲ GM prototype 24-cell module featuring steady-state liquid cooling used for experimental validation

ACCELERATING DEVELOPMENT OF EV BATTERIES THROUGH COMPUTER-AIDED ENGINEERING
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