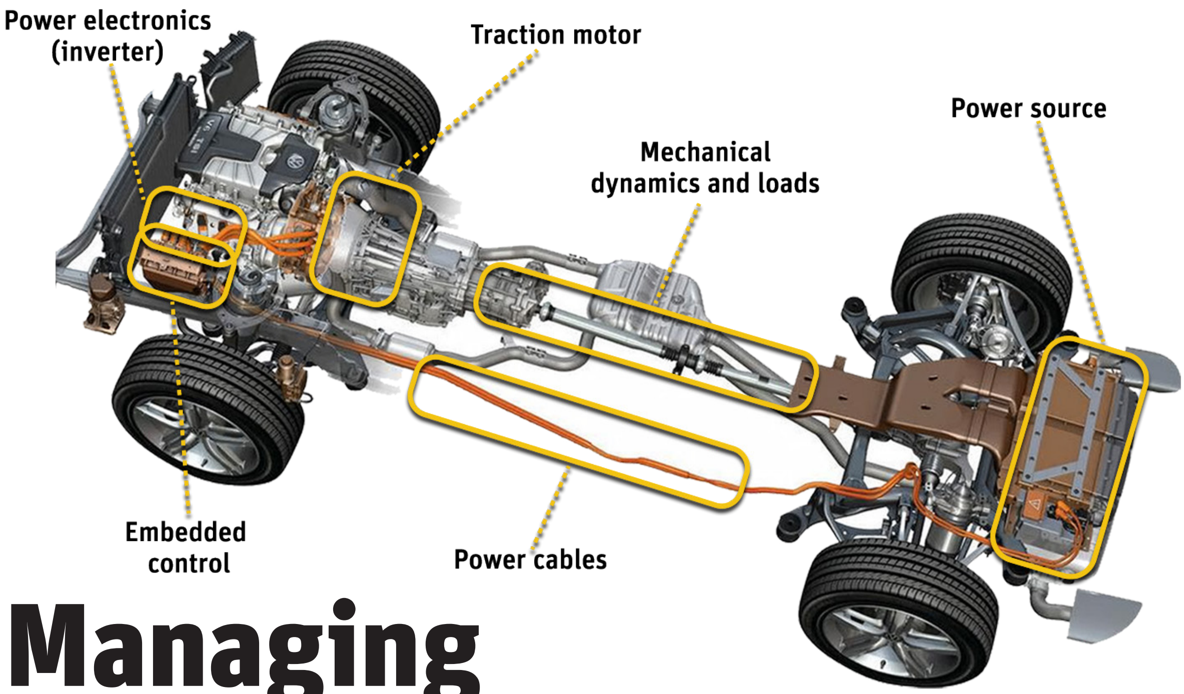

Managing Large-Scale Battery Systems

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Electrification for use by industries, including electrical mobility and distributed power generation applications, inevitably requires more batteries. This is obvious in rapidly growing transportation applications like automobiles and drones, and gaining prominence for energy storage and development of more electric aircraft. These batteries are not standalone but complex parts of larger systems that must operate optimally to ensure safe and efficient energy usage. Battery management systems (BMS) include both hardware and embedded software for real-time monitoring and control of rechargeable batteries to provide reliable power in complex applications. Ansys solutions for embedded software and functional analysis enable BMS development for secure, dependable and efficient battery operation.

According to Statista [1], electric vehicles (EVs) are expected to grow from 1 percent of the overall car market in 2017 to 14 percent by 2025. Every major automobile manufacturer is developing vehicles to compete in this growing market. As vehicles become more and more electric, with large banks of batteries powering the engine, air conditioning and heating, and infotainment systems of the car, monitoring and maintaining the operation of the battery system will be a critical function. Engineers are developing battery management systems (BMS) to ensure the smooth operation of this complex network. This requires the use of state-of-the-art software tools.

BMS Main Functions

A BMS is a sophisticated, software-driven control center of an electric vehicle. It is responsible for monitoring the cell voltage and temperature and preserving healthy operating

Electrical Drive Modeling through a Multiphysics System Simulation Approach
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“This combination of simulation tools is essential for rapid *virtual prototyping* of a BMS as more and more systems rely on battery power in the future.”

conditions; monitoring the state of the system connectivity; measuring current; calculating state of charge (SOC) and state of health (SOH); balancing electrical input and output among cells; and establishing connections between the battery and the powertrain or the charging system, among other functions.

In general, a BMS independently ensures the smooth, safe operation of a battery-powered vehicle at optimal performance conditions. It distributes resources where they can be put to best use and notifies the operator of potential problems well in advance. In a worst-case scenario, the BMS could physically disconnect batteries in the system to prevent damage or catastrophic failure that could endanger passengers in the vehicle.

Designing such a complex control center is a challenging proposition. Ansys solutions help engineers design the BMS throughout the development process and even manage it in real time in its operating environment. Ansys solutions for battery management include physics-based simulations to develop a system-level view of the battery using Ansys Twin Builder, Ansys medini analyze and Ansys SCADE embedded code for the BMS.

Ansys medini analyze and SCADE Embedded Code for Battery Safety

Ansys medini analyze performs key safety analysis procedures as specified by different standards in different industries (including hazard and operability analysis [HAZOP], fault tree analysis [FTA], failure mode and effects analysis [FMEA], and failure mode effect and diagnostic analysis [FMEDA]). For automotive systems, it checks that the BMS software satisfies the ISO 26262 functional safety standard for road vehicles.

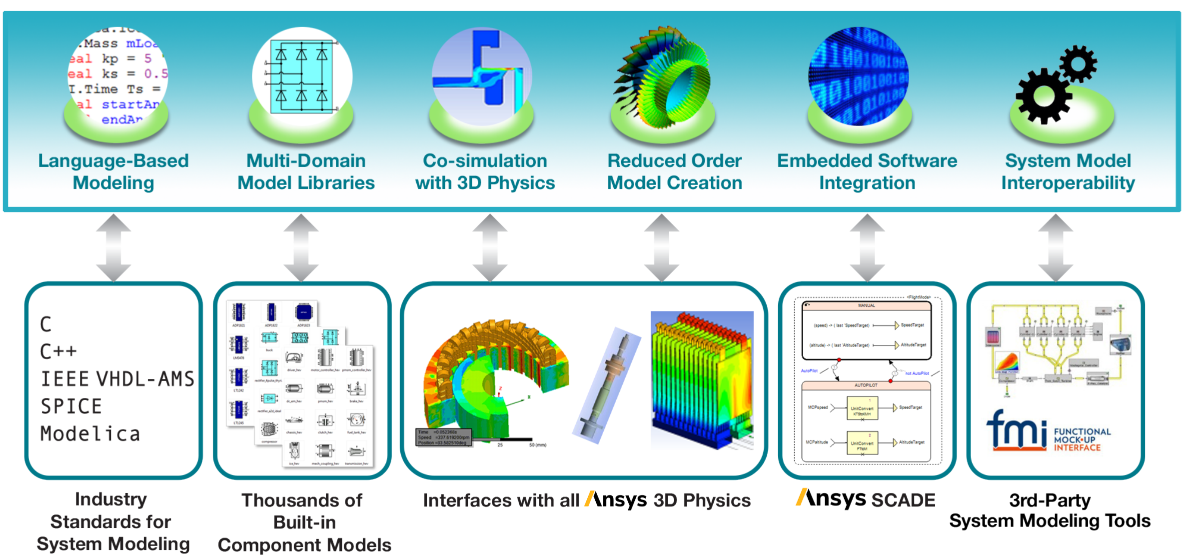
Safety analysis starts with the identification and description of functions and malfunctions of the BMS. Once malfunctions have been identified, a hazard and risk analysis (HARA) is performed to identify the hazardous events and their impact on safety by determining the automotive safety integrity level (ASIL) and corresponding safety goals and safety requirements. Some functions of the BMS require a rigorous development process, up to ASIL D, the highest safety integrity level in ISO 26262.

This requirement leads to very demanding safety requirements for the software as well.

A BMS typically has three architectural components:

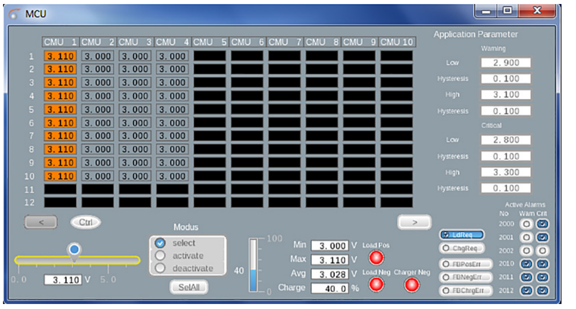
- A battery pack (cell stack) containing several individual cells
- A switch box
- An electronic control unit (ECU) that includes the software controller to monitor the voltage, current and temperature of the battery cells

The embedded software in the ECU can be generated



System modeling with Ansys Twin Builder

and verified automatically using Ansys SCADE Suite. The SCADE product line provides a model-based development environment for critical embedded software, such as flight control and engine control systems. SCADE Suite drastically reduces project certification costs by simplifying critical control application design and automating verification, qualifiable/certified code generation and documentation generation. This tool generates embedded software that can be certified under various industry standards, including DO-178C up to level A for the aerospace industry, ISO 26262:2011



Software simulation with SCADE Rapid Prototyper

MULTIPHYSICS SIMULATION FOR BATTERY OPTIMIZATION

The most popular batteries currently available are based on Li-ion technology, but researchers are constantly exploring other materials that will be more energy-efficient and less prone to overheating and burning.

For each system explored, scientists must make new discoveries about the fundamental processes of each material system. Because each material has unique thermal, structural, electromagnetic and electrochemical properties, Ansys multiphysics solutions are needed to thoroughly model a battery system. OEM battery manufacturers and their suppliers use a combination of Ansys Fluent for cell design, thermal management and thermal runaway; Ansys Mechanical for structural stresses and strains produced by differential heating and cooling; and Ansys Twin Builder for system-level modeling of a battery pack's operation. The complete solution helps engineers to account for all physical changes during a battery's design, manufacturing and operating lifecycle.

Fluent provides 3D computational fluid dynamics analysis based on a multiscale, multidimensional (MSMD) approach. This approach is effective for CFD simulation from the level of the materials (10^{-9} m) through the electrode pair (10^{-4} m) to the finished cell pack (10^{-1} m), covering up to 10 orders of magnitude in size. Fluent has three different electrochemistry models to optimize the power generation of the battery system.

Fluent can also be used to analyze heat flow between cells and modules in a battery to determine the temperature of prismatic-cell battery packs or cylindrical-cell battery packs under various forced cooling conditions. Controlling the temperature of a Li-ion battery is essential to prevent it from becoming too hot and, catastrophically, catching on fire.

As temperatures change in various parts of the battery during operation, materials expand and contract due to their different coefficients of thermal expansion. This expansion and contraction can produce compressive or tensile stresses on the battery's components, which could lead to deformation or failure if the induced strain exceeds a critical level for a given material. A two-way multiphysics simulation that couples Mechanical with Fluent can track the effects of temperature on the structure to ensure that the battery's components can withstand any thermal-induced stresses.

In an extreme case, such as when an EV is involved in a crash, thermal abuse of the battery is a concern. It starts with structural failure, which decreases the contact resistance in the impacted battery region. Ansys Mechanical can simulate structural failure in these conditions and determine whether a new design will prevent failure. Next, electrochemical reactions in the damaged battery generate heat, which can lead to thermal runaway if the heat generation rate exceeds the heat dissipation rate. Fluent simulation can help engineers to design batteries that will be resistant to thermal abuse of this type. Again, multiphysics coupling of Mechanical and Fluent is required to give engineers a complete picture of the structural, thermal and electrochemical response of a battery to rapid changes that occur in unexpected crash conditions.

Finally, when all the components of a battery system are ready to be connected, Ansys Twin Builder can simulate how they will work together to achieve optimal efficiency. Optimally designed components do not necessarily result in optimal systems. When these components are powered, sensed and controlled together as an integrated system, they might perform differently than when they were tested as standalone components. Twin Builder can perform closed-loop testing that encompasses the entire connected system to detect any component weaknesses and correct them to produce a battery system that operates at maximum efficiency.

> **"A BMS independently ensures the smooth, safe operation of a *battery-powered vehicle* at optimal performance conditions."**

up to ASIL D for automotive, and IEC 61508 2010 up to SIL 3 for the functional safety of electronic systems.

In the battery, operating conditions such as cell voltages, temperatures, and the overall pack voltage and current are monitored by the ECU. The ECU then sends data such as SOC and SOH (which compares the present condition of the battery to its ideal condition) to external components. It also transmits cooling and heating information.

Based on these outputs, the BMS can (1) adjust operating parameters to ensure that the battery is performing within its safe operating area (SOA), defined as the voltage and current conditions over which the device can be expected to operate without self-damage, and (2) perform an emergency disconnect of the battery in the case of a crash. If the BMS determines that the SOC or SOH is outside desired boundaries, it will issue a warning and/or move the system to a safe state.

Ansys Twin Builder for Complete System Simulation

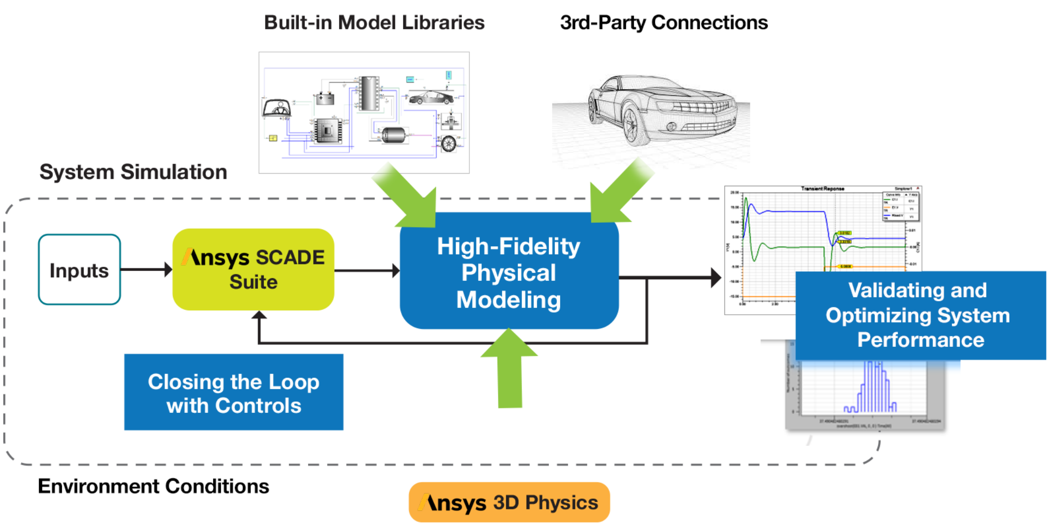
The final step is to perform a complete closed-loop, system-level battery pack simulation using Ansys Twin Builder to ensure that all components work together as designed. With Twin Builder, engineers create multiphysics models to design and validate system models of battery cells by simulating different physical effects, including the electrical and thermal behavior of the batteries.

Using Twin Builder, engineers can determine key design parameters like the peak power output of the battery system, the rate of charge and discharge of the batteries, the amount of heat generated by the operations, and the effect of this heat on electrical performance. Twin Builder has a Modelica-based library that includes four templates for battery equivalent circuit models (ECMs), which are a function of SOC and temperature, to predict battery performance.

Beyond lumped-parameter models for the battery's electric circuits, Twin Builder takes advantage of Ansys physics solvers' abilities to produce reduced-order models (ROMs). A ROM is a much smaller representation of the full-scale 3D model that can complete a simulation run in minutes or seconds without sacrificing accuracy, which is ideal for system-level modeling. A thermal ROM of the battery pack can be coupled in Twin Builder with the ECM model to determine the effects of heat on electrical performance.

The Complete BMS Solution from Ansys

Ansys medini analyze ensures the safety of the BMS design, Ansys SCADE Suite produces and verifies the embedded control software, and Ansys Twin Builder enables engineers to test and validate a complete electrical system in an EV for efficiency and reliability. This combination of simulation tools is essential for rapid virtual prototyping of a BMS as more and more systems rely on battery power in the future.



Closed-loop testing with Ansys Twin Builder