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Electric Motors Advanced by "Ultra" Power Storage

Electromechanical simulation tools aid in the design flow of hybrid–electric systems.

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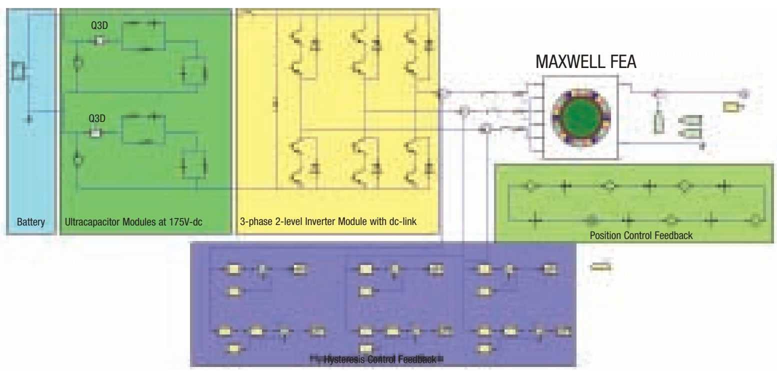
In the energy storage industry, electric double-layer capacitors are becoming widely accepted both in stand-alone applications and in combination with batteries. Also known as ultracapacitors, these devices combine a relatively vast electrode surface area with a molecular-scale charge separation distance, providing capacitances that are several orders of magnitude higher than more common electrostatic or electrolytic capacitors. As the technical and economic benefits of these power-dense components become more widely understood, there is increased interest in the active combination of ultracapacitors as electrical storage elements with energy-optimized batteries, such as nickel metal-hydride and lithium-ion, as the means to offer reliable energy storage over wide temperature and operational limits.

Computer simulation of ultracapacitors and advanced batteries is becoming more widespread as the engineering community becomes better attuned to global climate change and the subsequent demand for more efficient energy storage systems. Examples of ultracapacitors working in combination with advanced batteries continue to proliferate, primarily in the electric and hybrid–electric commercial transportation segments such as transit buses and trains. In such systems, brushless DC (BLDC) motors and their component power electronics play a significant role in increasing the overall system efficiency. These motors supplement the output of the internal combustion engine when extra power is needed. They are also used to start the engine, as opposed to the conventional starter and solenoid method.

When designing a variable-speed drive for a BLDC motor, however, designers face a variety of problems due to the combination of several engineering domains interacting in the device. Some of the major challenges include magnetic design for linear and rotating electrical machines; power electronics design for converters, inverters and DC links; mechanical design for the load profile and oscillations; control design for digital and analog signal components; and multiphysics interaction design for electromagnetic compatibility (EMC) and interference (EMI) requirements.

To address the variable-speed design requirements in a hybrid–electric system, engineers can employ a comprehensive design flow including several electronic design automation tools from Ansoft. Their first step is to select a feasible design for the given rated performance specifications of the electrical machine — for example, current, torque or speed. RMxprt software, a tool designated for the electrical design of rotating machines, allows designers to create a machine model by entering rotor, stator and rating information in addition to cost functions into a parameterized input module.

To validate the initial design produced by the RMxprt tool, the model is transferred to Maxwell electromagnetic field simulation software to perform a finite element analysis. Maxwell technology provides the designers with critical parameters, including flux linkage versus current for



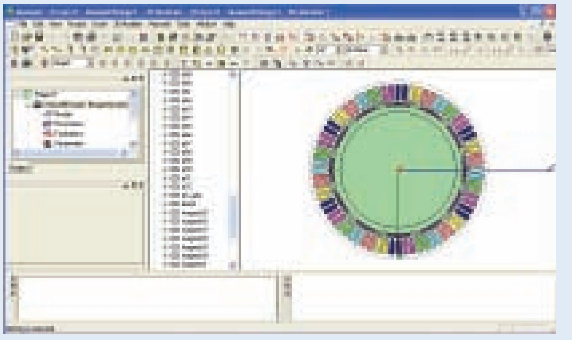
Hybrid–electric system topology in Simplorer software from Ansoft different angular positions of the rotor. The rotor position information is then used in the controller to synchronize the triggering of each phase of the stator coils with the position of the rotor. To account for unwanted, or parasitic, effects on the bus bar interconnects in the ultracapacitor design, Q3D Extractor parasitic extraction software can be used to compute resistance, inductance, capacitance and conductance (RLCG) parameters and automatically generate an equivalent subcircuit computed at nominal frequency or S-parameters (signal scattering coefficients) calculated for a large spectrum of frequencies.

Ultimately, the analyzed characteristics of different components within the entire power system topology are then assembled within the Simplorer electomechanical simulation software package to verify the complete drive system. When the BLDC model is imported from Maxwell software to the Simplorer tool, the analog-digital characteristics of the circuitry can be modeled. Mixed-signal circuits can then be simulated with both block diagram– and state machine diagram–based representations of the controller, allowing the performance of the system to be optimized.

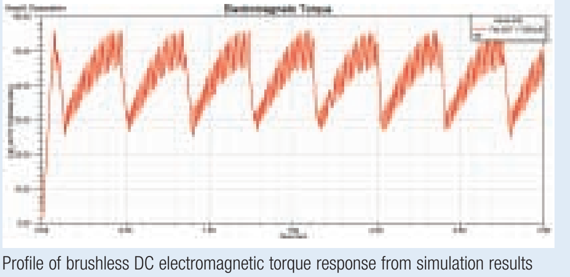
The simulation of the complete drive system enables the verification of the C-code that will be running on a digital signal processor (DSP) or embedded controller, since such code can be part of the system-level simulation. In Simplorer software, multi-domain components (power electronics, mechanical, hydraulic and thermal) are available to enable more complex study on existing power system design. Engineers can use Simplorer software to create the entire design analysis framework because of the variety of components in the Simplorer tool's signal characteristics library dedicated to measuring the performance and design quality of the power system.

The motor's electronic controller contains three-phase bi-directional drivers, which drive high-current DC power and are independently controlled by a block diagram scheme and a state machine diagram. The state machine–based scheme compares the rotor position to determine when the output phase should be advanced. The block diagram uses a hysteresis, or history-dependent, control scheme to chop the phase currents between upper and lower admissible band values in order to allow the electrical motor to develop a sufficient electromagnetic torque to sustain the mechanical load. As an immediate consequence of the hysteresis band control and power inverter switching frequency, the ripples induced in the electromagnetic torque and the harmonic content of the currents affect the overall performance of the system.

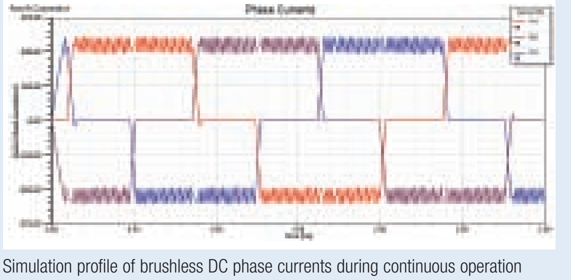
At heavy system loads, the ultracapacitor experiences high bursts of power, from both charging and discharging. This eventually will lead to corresponding high carbon loading, which, combined with high current cycling, eventually leads to a reduction in component life. The construction must be robust enough to tolerate high electrical, thermal and mechanical stresses. Hybrid–electric system designers benefit from Ansoft software because the tools provide a comprehensive design flow capable of addressing multi-domain and mixed-signal design by allowing a coupled analysis of the motor, circuit, controller and drive systems. ■



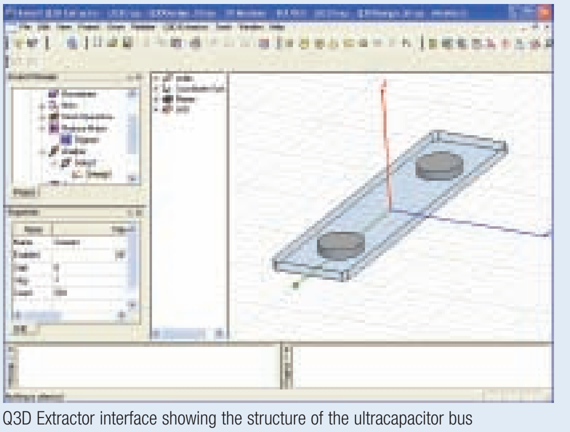
Maxwell interface showing brushless DC (BLDC) geometry



Profile of brushless DC electromagnetic torque response from simulation results



Simulation profile of brushless DC phase currents during continuous operation



Q3D Extractor interface showing the structure of the ultracapacitor bus bar interconnects