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News & Highlights

Better Battery Management Boosts Electric Vehicle Prospects

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Vehicle makers worldwide are betting big on electric vehicles (EVs). With nations globally mandating sharp reductions in gasoline-powered transportation [1,2], most leading vehicle manufacturers, including Volkswagen, General Motors (GM), Honda, Daimler, Ford, Volvo, and Nissan—among others—have announced moves to make EVs only or to build them in significantly greater numbers [3–9]. With rapid, international growth and standardization of charging infrastructure, technological improvements, favorable policies, and falling prices [2,10,11], EVs are approaching a critical threshold. Beyond it, their convenience (the ease of recharging their batteries when needed), range (on a fully charged battery), longevity (tied mainly to battery-pack lifetime), and performance are expected to pull ahead of equivalent metrics for comparably priced internal combustion engine (ICE)-powered vehicles.

Although efforts to achieve new breakthroughs in EV batteries have commanded the spotlight [12,13], other less visible but promising developments are poised to help tip the scales in the favor of EVs. In September 2020, Detroit-based GM, the US automaker with the largest domestic market share, drew attention to a common, but relatively obscure actor in EV safety and performance called the battery management system (BMS). Although not a component of an EV battery itself, this microprocessor module and its associated circuitry monitors voltages, currents, and temperatures of battery cells, and adjusts those levels by means of control signals to help maintain optimal vehicle performance while keeping battery operation within safe and sufficient ranges of charge and other parameters [11].

As part of GM's planned 27 billion USD transition to EV replacements for all of its light-duty, ICE-powered models by 2035 [4], the auto giant and its BMS collaborator Analog Devices, Inc. (ADI) of Wilmington, MA, USA, a major electronics component company, unveiled what they said is an automotive industry first—a wireless BMS (wBMS) for production vehicles that does away with nearly 90% of the usual wiring [14]. According to GM, this BMS enhancement is leading to gains in the energy density of forthcoming EV battery packs (an important factor in EV driving range), as well as improvements and cost reductions in EV design and manufacturing.

Meanwhile, other EV BMS innovators are advancing "model-based" BMS (mbBMS), the most sophisticated of which, while still experimental, simulate in near real time the detailed physics and chemistry of the vehicle's battery cells. To guide responses to sensor signals, ordinary EV BMS consult internal tables of factory-installed (and periodically updated) empirical data or simulate the battery with a simple model—such as a circuit containing a few electrical components. However, via more complex, yet quick and accurate, simulations, high-end mbBMS also continually predicts internal battery states inaccessible to direct measurement, such as charge levels within electrodes or interior voltages that can swing too high or low. With directly sensed voltages and other battery signals plus near real-time, model-provided guidance, the mbBMS more finely adjusts battery operating conditions in response to immediate circumstances than can a standard BMS—wired or not.

Laboratory tests of mbBMS by developers indicate that the technology could significantly improve EV driving performance, range, longevity, and recharging capabilities while minimizing premature aging or other harm to the vehicle's power source. Should the next major breakthrough in batteries take a while, mbBMS alone could potentially nudge battery-electric transport ahead of fossil-fuel options.

Unless EV battery packs are carefully monitored and managed, the Nobel-prize winning lithium-ion technology inside them can dangerously overheat or otherwise malfunction [15]. "Pretty much every EV has a management system of some sort," said GM engineer Fiona Meyer-Teruel, the company's technical lead on wireless battery electronics. "You need to know the states of the cells to operate the vehicle safely." Many other rechargeable electronic devices—mobile phones and other portable electronics among them—also incorporate BMS to monitor and indicate battery charge. However, the high-voltage battery packs in EV account, on average, for more than a fifth of the purchase price and may include hundreds to thousands of electrochemical cells [16]. "For cars, the stakes are much higher than cell phones," said Venkat Subramanian, professor of mechanical engineering and mbBMS expert at the University of Texas (UT), Austin.

A standard EV BMS typically makes electrical contact with every sector of the vehicle's battery pack via a web of wires entwining its tightly clustered cells (Fig. 1). By eliminating those wires, GM's new wBMS opens up the space they had occupied, recovering up to 15% of battery-pack volume that could be used for more electrochemical cells [17]. Adding cells within the fully available volume boosts the energy density of the vehicle's power source and therefore vehicle range. That is one of the ways that switching to wBMS can directly help GM's expected new fleet of EV gain ground against ICE-powered vehicles, said Meyer-Teruel. More range

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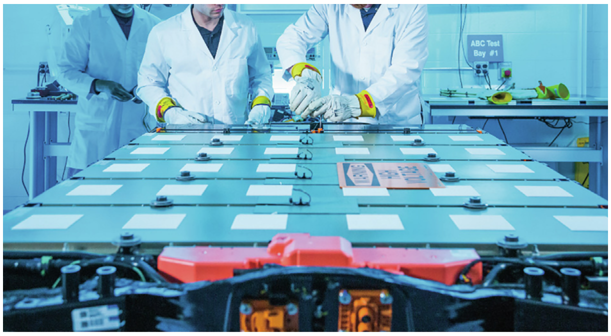

Fig. 1. Beneath the cover plates forming the uncluttered surface of this high-voltage EV battery pack in the GM Battery Electrical Laboratory in February 2020, multiple battery modules enclose close-packed electrochemical cells. The modules wirelessly communicate with each other and the vehicle's microprocessor-based battery monitoring system, an advance co-developed by GM and electronics maker ADI. Credit: Jeffrey Sauger/GM (public domain).

Fig. 2. The 2022 Hummer EV sports utility truck is slated to be the first EV using GM's new wireless BMS. The 200 kW·h battery-pack that the system will control produces 400 V, but charges at 800 V from an up to 350 kW charger. Comprising 24 battery modules in two layers, the pack ranks largest of the first generation Ultium packs, with maximum power of 746 kW. GM has also announced a 2024 sports utility vehicle model of the Hummer EV with about 20% lower peak power (619 kW), available in fall 2023. Credit: GM (public domain).

means less buyer anxiety about being able to reach destinations that has long bedeviled EV sales [1].

The wBMS is also yielding competitive benefits of a less obvious sort, said Meyer-Teruel, in the design—and soon in the manufacturing—of the 30 new EVs that GM announced it plans to introduce over the next four years. The company faces the big challenge of rapidly mass-producing a broad array of car-, light truck-, and sports utility vehicle models it has never made before. To accomplish this, the company has devised five versions of what it calls the "Ultium Drive," a set of interchangeable drive units (from front-wheel to all-wheel to specialty types) comprising electric motors, single-speed transmissions, and power electronics [18]. The drive units can contain up to two of three different powerful electric motors and some vehicles will feature more than one drive unit. For each new model on the assembly line, the manufacturer will install a selection of drive components, in differing numbers and configurations, onto a prefabricated, four-wheel, battery-laden "Ultium Platform" (i.e., undercarriage) [19], and enclose the assembly in a model-appropriate body.

But battery packs also vary widely from model to model—in size, shape, and numbers of electrochemical cells. To power GM's forthcoming EV fleet, a joint venture of the automaker and the Republic of Korea's LG Chem Ltd. has created a new lithium-ion electrochemical-cell type, also branded Ultium, with a novel chemical composition. A 2.3 billion USD factory to mass produce the batteries is under construction in the United States near Lordstown, OH, USA; plans to build a second factory in Tennessee at the same cost were announced in April 2021. Whereas the stacking of identical cells in EV batteries is inherently modular [20], Ultium cells can stack horizontally or vertically, enabling multiple form factors and configurations of battery-pack modules [21]. The sharply reduced hardwiring of those modules on account of the new wBMS and their use of wireless transmitters and receivers to communicate with each other and the management system via encrypted signals eases pack design and assembly. Because of such enhancements, "the wBMS allows us to build and redesign battery packs very quickly to make sure that new vehicles can get out the door faster," Meyer-Teruel said. For instance, in just two years, rather than the usual five-to-six years, GM engineers developed an exceptionally complex, nearly 600-cell battery pack for the up to 746 kW (1000 horsepower), all-electric, 2022 Hummer EV sports utility truck slated to go on sale later this year (Fig. 2).

In mbBMS research and development, engineers such as Subramanian have been working for more than a decade to simulate lithium-ion batteries' physical and chemical processes quickly and accurately enough to deliver better battery performance in real time to EV, renewable energy storage units, and other battery-powered devices. Subramanian—who co-founded the company BattGenie near Seattle, WA, USA, with Manan Pathak, a former student and now the firm's chief executive officer—describes his engineering teams primarily as "reformulators." They specialize in streamlining the mathematical representations of physics/chemistry-based models and converting those leaner versions into exceptionally fast computer algorithms and software. The resulting simulations generate useful results in tens of milliseconds—fast enough to keep pace with vehicle operation and charging, he said. For example, in the past several years, they have adapted to mbBMS a model type called Pseudo-2-Dimensional, which had previously been viewed as too complex to implement in an effective mbBMS [22].

Subramanian said his mbBMS work "really got traction" in 2012 when he was on the faculty of Washington University in St. Louis, MO, USA. He and colleagues at the US National Renewable Energy Laboratory (NREL) in Golden, CO, USA, were awarded a 5 million USD US Department of Energy grant to demonstrate several improvements to the performance of lithium-ion, electrochemical cells by means of mbBMS control. Those included faster charging that would not cause unwelcome reduction in the battery lifetimes. Since then, they and other experimenters worldwide in university and government labs have reported benchtop results indicating wide-ranging potential for the model-based approach to provide significant gains in EV battery performance. For example, the UT group and BattGenie have shown that model-based management can extend battery life by 100%–150% (Fig. 3) [23] and cut charging times by as much as 50%.

BattGenie has conducted mbBMS technology demonstrations at both the cellular and modular level for several EV makers, Pathak said, and the company aims to conduct full battery-pack simulations next and to place its first mbBMS in a production EV by the end of 2022. Building upon earlier steps from the NREL project, said Subramanian, BattGenie has also demonstrated to clients on selected electrochemical cells that mbBMS control can also make it possible to reduce battery footprint and weight by 20% without sacrificing performance. "In general," he said, "model-based control is good for everything—it is not just for more life and faster charging."

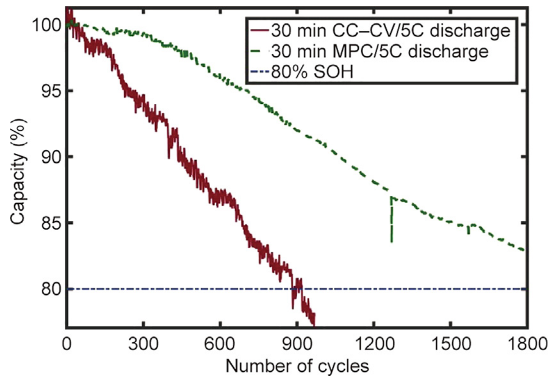

Fig. 3. Laboratory experiments demonstrated an increase of more than 100% (> 1800 charge/discharge cycles) in average lifetimes of 16 A·h nickel–manganese–cobalt, pouch-style, lithium-ion electrochemical cells under mbBMS control (green line) compared to a standard charging protocol (2CC–CV; red line) [23]. The findings were "the first to experimentally demonstrate … significant improvements in battery performance" from real-time physics-based model predictive control (MPC), the experimenters reported. EVs can no longer use batteries with capacity below 80%. SOH: state of health; CC–CV: constant current–constant voltage; 5C: discharge rate, 80 A over 12 min for these 16 A·h cells. Credit: Institute of Physics, with permission.

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