Intelligent battery management and charging for electric vehicles

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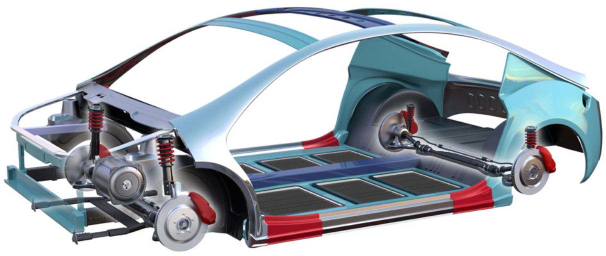
Introduction

As the green movement increases in popularity, more and more electric vehicles (EVs) of all kinds—from electric scooters to cars to buses and cargo trucks—will grace the roads. Power designers will be challenged to provide systems that can be adapted to a wide variety of different types of batteries and vehicles with vastly diverse performance requirements. This white paper examines the key considerations that are best suited to meeting the challenges of including battery performance, lifespan and, of course, safety while designing intelligent battery management and charging systems.



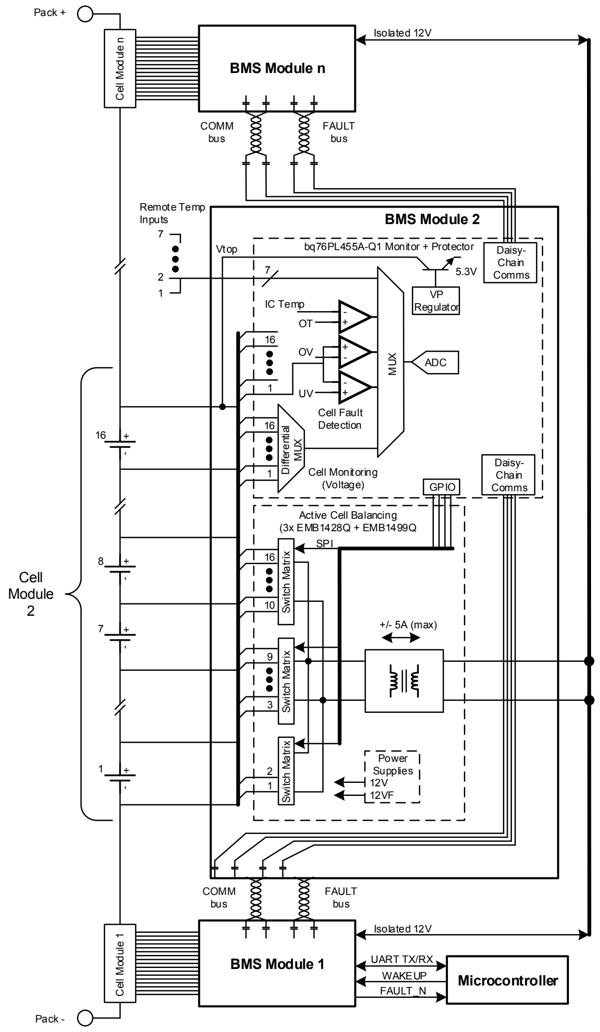


Figure 1: *Multiple battery cell modules stack up to form a battery pack*

EV battery packs are made up of multiple cell modules arranged in series and in parallel. Arranged around the battery pack and throughout the vehicle, the battery management system (BMS) is comprised of several components, including monitoring components close to the battery cells themselves, one or more power-conversion stages dictated by the needs of the vehicle, and intelligent controllers or embedded processors placed at strategic locations in the architecture to manage various aspects of the power subsystem.

Intelligent Cell Monitoring

During the charging and discharging of an EV battery, it is imperative that each cell within the battery pack is closely and accurately monitored because any number of out-of-spec conditions can, at a minimum, quickly cause internal damage of the battery and vehicle or threaten the safety of the vehicle's occupants. EV batteries contain the energy equivalent to a small explosive. Over-voltage or under-voltage conditions can lead to thermal runaways that might cause a battery failure.

A battery monitoring integrated circuit (BMIC) or cell-balancer device is typically assigned to monitor the voltage of each battery cell in a module, the temperature of various points in the module and other conditions. This data is reported to a cell management controller (CMC) and, depending on the complexity of the system, on to higher-order processing elements, such as one or more battery management controllers (BMC). The precision of these measurements and the frequency of the communications from the BMIC to the CMC and BMC is key to detecting a condition of concern early on and taking corrective action before it becomes hazardous. For example, the BMC might stop regenerative charging or reduce the power draw from a pack to return individual cell temperatures to an acceptable range or the driver of the vehicle might be alerted to such a condition through a "check engine" light on the dashboard. In any case, the BMICs must be capable of very accurate measurements and robust communications with the CMCs so that a BMC can take the right corrective action in a timely fashion. An EV is indeed very challenging in terms of designing an effective communication network because of the abundance of electrical noise in the environment.

Often, the robustness of the BMIC's and CMC's communications depends on the overall design and routing of the network connecting the various devices in the BMS.

A BMC aggregates the voltage information from the CMC's monitoring of the many cells in the battery pack. It also calculates the state-of-charge (SOC) of the battery, which is used to determine the charge remaining in the battery and, in turn, the distance the vehicle can travel before the battery will need to be recharged. Another calculation, called state-of-health (SOH), provides important insight into the operating conditions of the battery so that its remaining lifespan can be projected and the appropriate maintenance procedures recommended.

Intelligent Battery Management

Depending on the complexity of the vehicle, several intelligent microcontrollers (MCUs) oversee and manage various critical tasks with regards to the battery and the power subsystem. Usually, these MCUs contain multiple processing cores. Some may be comprised solely of general-purpose reduced instruction set computing (RISC) processors, such as ARM® cores, while others, which are responsible for tasks that are mathematically intense, usually feature one or more digital signal processing (DSP) core, like TI's C28x DSP cores.

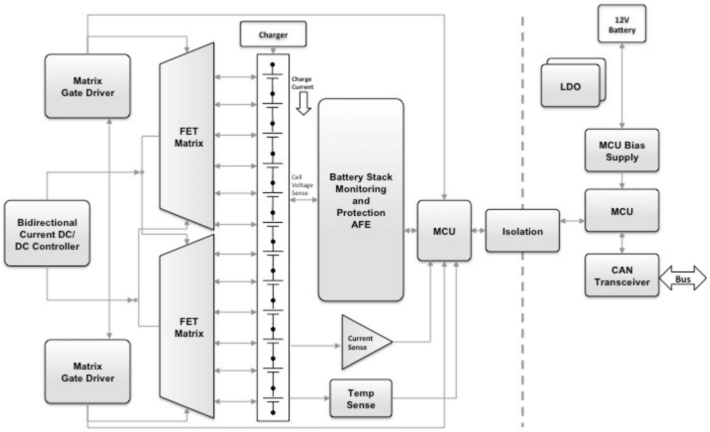


Figure 2: *BMS system overview with battery cell control and main control*

CMCs, working in concert with BMICs, play an important role in ensuring the performance of the battery and its useful lifespan. For example, during a charging cycle, the BMICs might detect that the effects of heat have degraded one of the battery cells to the point where it is charging only to 4.1 V, while the rest of the cells are charging to 4.2 V. The charging process could then be effectively managed so that none of the cells are charged above 4.1 V. This would reduce the stress placed on all of the cells, extending the life of the battery pack as a whole and ensuring that the battery pack will efficiently store energy and deliver as much power needed by the motor the instant it is needed.

Of course, real-time responsiveness is essential in a real-time system, especially when the system is an electric vehicle traveling at 60 mph. A BMIC must be able to frequently—in a matter of microseconds—report to the CMC the conditions it is monitoring so that the CMC or higher-level controller can quickly take any needed corrective actions, such as reducing the power drawn from the package to reduce overheating, before the situation worsens.

Intelligent Battery Charging

Charging and discharging the battery efficiently is important as it avoids thermal runaways or other conditions that would either reduce the battery's capacity or its lifespan. To do this, requires a certain amount of intelligence in the controlling MCU since the parameters of the battery itself will change over time. The MCU responsible for the actual charging of the battery must be able to quickly adjust and adapt in real-time to the battery's changing properties, like oxidation on the terminals, cell voltages and others. During charging in particular, the MCU must be able to respond quickly to over-voltage conditions. Otherwise, it might cause the battery to overheat and catch on fire.

When designing battery charging modules such as an on-board charger, higher-order microcontrollers that feature DSP cores and specialized co-processors or hardware-based accelerators can be deployed to meet specific real-time operational needs for closed-loop control of on-board charging input current, intermediate DC bus voltage, battery charging current and battery terminal voltage. These control loops require the use of computation-intensive algorithms such as a PID controller or two-pole two-zero compensators. A MCU with a DSP core(s) running special instruction sets supporting special trigonometric math operations can significantly reduce the number of processor cycles needed for these algorithms. For example, whereas a RISC core might need 60 cycles to complete a math-intense sine or cosine operation, a DSP core could achieve the same result in two or three cycles. Such microcontrollers could also support driving multiple power topologies and multiple control loops for voltage, current plus other system parameters with such high performance that minimizes "missing" changes in battery characteristics.

Moreover, high-performance processing is required to support certain advanced operating modes in EVs and Hybrid Electric Vehicle (HEV), such as stop/start mode and town and country mode.

- **Stop/start mode** allows the gas engine in an HEV to be stopped to save fuel when the vehicle is stopped at a traffic light or stuck in traffic.
- **Town and country mode** lets an HEV switch back and forth between the gas engine and the electric motor depending on which would be more efficient. For example, the gas engine would propel the vehicle on the highway at higher speeds while the electric motor would operate in slower city traffic with its frequent stops.

EV and power supply manufacturers can also take advantage of the adaptability and versatility of digital power MCUs to leverage the same software framework to control similar power topologies with different power ratings, different input/output voltages and different PWM frequencies. In other words, the same software developed for a specific topology (ex: totem pole PFC or resonant LLC full bridge DC/DC) using a digital power MCU or a family of MCUs can be used from low power to high power with appropriate changes only in digital control parameters and a few software parameters related to the new power stage. So, digital power MCUs let manufacturers effectively re-use or re-apply their investment in developing power-control software over and over again in power supplies with a wide range of power ratings that meet application requirements.

This adaptability is particularly important today as innovations and new materials continue to be introduced into power-stage components.

Power Stage Innovations

In particular, new wide bandgap technologies are emerging for EV onboard charging applications. These technologies, which better accommodate direct connection to AC outlets that tap into the power grid, let EV manufacturers reduce the size and weight of the vehicle’s charger, which translates into a longer range per charge for the vehicle. Plus, these new power-stage technologies have improved power efficiencies, so less power is lost during charging and charge times are reduced. Gallium-Nitride (GaN) and Silicon Carbide (SiC) are two examples of new wide bandgap technologies that offer higher switching capabilities and lower on-resistance than the traditional silicon MOSFET.

GaN power stages, such as LMG3410, provide a high power rating up to 600 V along with a GaN FET, an optimized driver and protection feature for overcurrent and under-current conditions. SiC is particularly well suited to switching devices in battery charging applications for both AC-to-DC and DC-to-DC power conversions (see **Figure 3** and **Figure 4**).

Safety

Every design project involves tradeoffs among design goals, such as cost, performance, durability and others. The only exception for an EV power supply system is safety. Chief among the safety concerns are thermal runaways which could cause

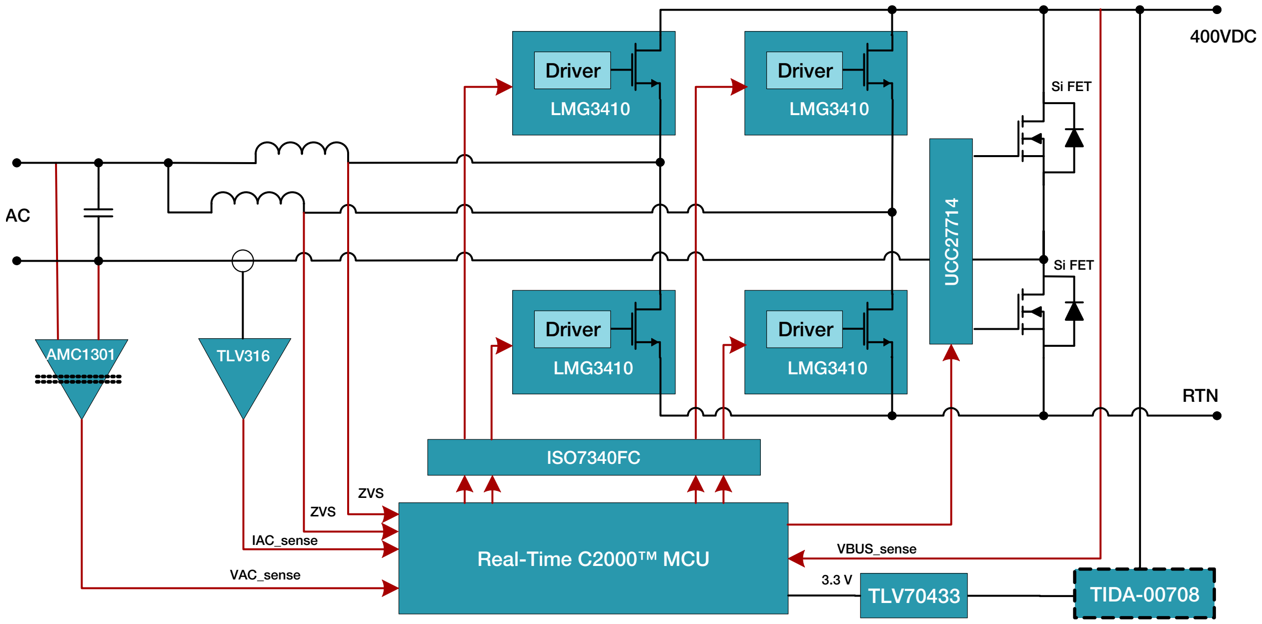


Figure 3: *C2000™ MCU controlling 2-phase interleaved totem pole PFC*

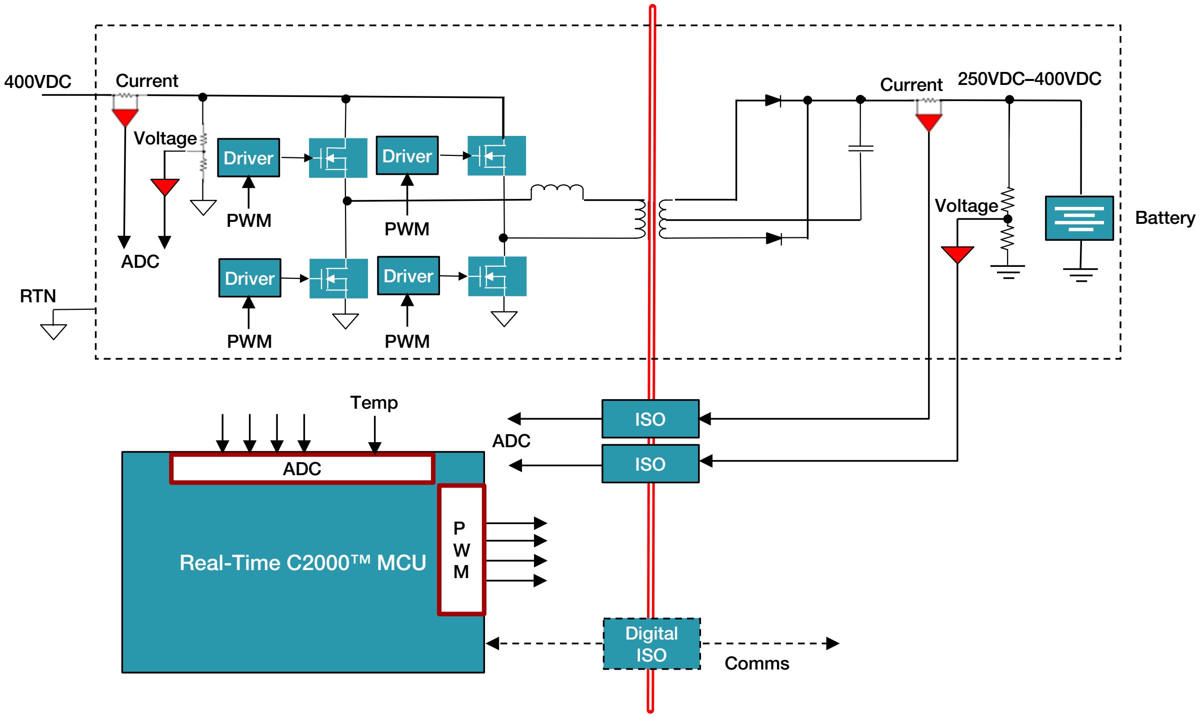


Figure 4: *C2000 MCU controlling full bridge LLC DC/DC*

a fire in the vehicle's battery. Thermal runaways can be brought about by several malfunctions, such as overcharging or discharging too quickly. To help avoid unsafe events, the BMS must be able to constantly monitor and detect changing operating parameters and notify the CMCs or BMCs to take a protective action like shutting down a battery cell that is overheating. Another safety capability that must be included is the ability to verify that alarms/alerts are genuine and not a failure in the BMS. And, of course, the BMS must have built-in protection functionality that can instantaneously take the proper and most effective action to head off a runaway condition before it potentially becomes unsafe.

At a very basic level, components must be qualified under AEC-Q100, a specification of the Automotive Electronics Council. In addition, components in a BMS must support the safety capabilities defined in the ISO 26262 functional safety standard for electric vehicles. ISO 26262 requires that the BMS must be able to analyze operating conditions and assess the potential risk that any change in a parameter may pose to the vehicle and its passengers.

Meeting the functional requirements of ISO 26262 will mean that the BMS must be a failsafe system featuring redundant resources such as processing units, each of which must have its own dedicated facilities like memory, multiple ADC converters and others. In addition, the BMS must have self-diagnostics to verify that it is functioning properly and not providing false alarms. Lastly, fast response protection mechanisms are essential to a BMS so that, for example, a battery pack or other functional element can shut down immediately should a thermal runaway condition be detected and verified.

Some of the most advanced MCUs deployed in EV power systems feature dual-processing cores that mirror each other and execute in lockstep, comparing and validating each processor on every instruction executed. Component-level diagnostic techniques, such as error correction code (ECC) in memory, help provide accuracy of the data in the system and feed into the larger system-wide self-diagnostics capabilities.

TI's Hercules™ TMS570 MCUs are certified by TÜV SÜD as meeting ISO 26262:2011 requirements up to ASIL-D. TÜV SÜD is an internationally recognized and independent assessor of compliance with quality and safety standards. The Hercules MCU family is a scalable family with the functional and safety architectures the same from MCU to MCU. There are pin-to-pin compatible MCUs from 128 KB Flash to 4 MB and 80 MHz to 300 MHz.

TI Hercules TMS570 MCUs offer dual-core CPU lockstep/compare and memory Error Correction Code (ECC) real-time diagnostics, as well as hardware-based CPU Logic Built-In Self-Test (LBIST) and SRAM Programmable Built-In Self-Test (PBIST). These hardware-based safety features help diagnose errors in mission-critical blocks and offer high diagnostic coverage with minimum software overhead.

There are TI Design reference designs demonstrating such examples:

- Active cell balancing BMS with basic balancing algorithms using a TMS570 MCU with bq76PL455A-Q1 + EMB1428 (**TIDM-TMS570BMS**)
- Active cell balancing with bq76PL455A-Q1 + EMB1428/EMB1499 (**TIDM-00817**)
- Passive cell balancing with bq76PL455A-Q1 (**TIDA- 00717**)

For a non-lockstep solution with multi-processing cores, TI's C2000 MCUs, well-known for their real-time control performance, provide the required functional safety for BMS applications. Leveraging the heterogeneous asymmetric architecture, each processing element in C2000 MCUs are independent allowing the implementation of algorithm-level cross-checking as described by the EGAS safety concept defined years ago. Add ECC memory and a redundant interrupt vector table, and the compute elements are well protected.

Not only do C2000 MCUs provide DSP-level computational performance that BMS needs, but the MCUs also address the entire control system for functional safety. Redundant ADCs and multiple analog comparators that directly disable PWMs instantaneously if an analog signal is outside a defined range, provide the diagnostics needed to protect input signals, whether that is temperature, battery voltage, or any another critical signal.

Conclusions

An intelligent power management system with innovative power-stage components is most likely to optimize the performance and lifespan of the vehicle's battery while performing the tasks to help validate the safety of the battery. Thorough and frequent monitoring of vital operating parameters, robust communications among all of the nodes on all of the control loops within the system, and fast decision making followed by effective control and protection mechanisms are essential in EV or HEV power systems.

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