Vehicle and industrial equipment manufacturers typically demand battery lifetimes exceeding ten years, and they also specify the required usable battery capacity. The challenge to the battery system designer is to squeeze the maximum capacity out of the smallest battery pack. To accomplish this, the battery system must carefully control and monitor the batteries using precision electronics.

High-power battery pack systems

High-power battery pack systems used for electric vehicles or industrial equipment consist of dozens of batteries stacked in series. A typical pack might have a stack of 96 batteries, developing a total voltage in excess of 400 V for Li-ion batteries charged to 4.2 V.

While the system sees the battery pack as a single, high-voltage battery—charging and discharging the entire battery pack at once—the battery control system must consider each battery’s condition independently. If one battery in a stack has slightly less capacity than the other batteries, then its SOC (state of charge) will gradually deviate from the rest of the batteries over multiple charge/discharge cycles.

If that cell's SOC is not periodically balanced with the rest of the batteries, then it will eventually be driven into deep discharge, leading to damage, and eventually complete battery stack failure. Thus, each cell’s voltage must be monitored to determine state of charge. In addition, there must be a provision for cells to be individually charged or discharged to balance their SOCs.

Monitoring system communication

An important consideration for the battery-pack-monitoring system is the communications interface. For communication within a PCB (printed circuit board), common options include the serial peripheral interface (SPI) bus and inter-integrated circuit (I²C) bus. Each has low communications overhead, suitable for low-interference environments.

Another option is CAN, which has widespread use in vehicle applications. CAN is very robust, with error detection and fault tolerance, but it carries significant communications overhead and high materials cost. While an interface from the battery system to the main CAN may be desirable, SPI or I²C communications can be advantageous within the battery pack.

Devices such as the LTC6802 battery stack monitor IC from Linear Technology measure the voltages of up to twelve stacked cells. Multiple LTC6802s can be stacked in series from the bottom to the top of the battery stack. The device also has internal switches that provide for the discharge of individual cells to bring them into balance with the rest of the stack.

To illustrate the battery stack architecture, consider a system with 96 Li-ion cells. Eight battery-stack ICs would be required to monitor the entire stack, with each device operating at different voltage levels.

Using 4.2-V Li-ion batteries, the bottom-monitoring device would straddle twelve batteries with potentials scaling from 0 V to
50.4 V. The next group of batteries would have voltages ranging from 50.4 V to 100.8 V, and so forth, up the stack.

Communicating between these devices, at different potentials, presents a difficult challenge. A variety of approaches have been considered, and each has advantages and disadvantages in light of the priorities of the system designers.

**Battery-monitoring requirements**

At least five major requirements need to be balanced when deciding between battery-monitoring-system architectures. Their relative importance depends on the needs and expectations of the end customer.

- **Accuracy:** To take advantage of the maximum possible battery capacity, the battery monitor needs to be accurate. Vehicles and industrial systems, however, are noisy, with electromagnetic interference over a wide range of frequencies. Any loss of accuracy will adversely affect battery pack longevity and performance.

- **Reliability:** Automotive and industrial manufacturers must meet extremely high reliability standards, irrespective of the power source. Furthermore, the high energy capacity and potentially volatile nature of some battery technologies is a major safety concern. A fail-safe system that shuts down under conservative conditions is preferable to catastrophic battery failure, although it has the unfortunate potential of stranding passengers or bringing a manufacturing line to a halt. As a result, battery systems must be carefully monitored and controlled to ensure complete control over their entire life in the

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system. To minimize both false and real failures, a well-designed battery pack system must have robust communications, minimized failure modes, and fault detection.

- **Manufacturability**: Modern vehicles already contain a vast array of electronics with complicated wiring harnesses. Adding sophisticated electronics and wiring to support an EV/HEV (electric vehicle/hybrid electric vehicle) battery system provides an additional challenge for automobile manufacturing. The total number of components and connections must be minimized to meet stringent size and weight constraints and ensure that high-volume production is practical.

- **Cost**: Complicated electronic control systems can be expensive. Minimizing the number of relatively costly components, such as microcontrollers, interface controllers, galvanic isolators, and crystals, can significantly reduce total system cost.

- **Power**: The battery monitor itself is a load on the batteries. Lower active current improves system efficiency, and lower standby current prevents excessive battery discharge when the vehicle or equipment is off.

### Battery monitoring

Four architectures for battery-monitoring systems are described below. Each architecture is designed to be an autonomous battery-monitoring system and assumes a 96-battery system organized into eight groups of twelve batteries (see Figure 1). Each provides a CAN interface to the main CAN network and is galvanically isolated from the rest of the system.

**Parallel independent CAN modules:**

Each 12-battery module contains a PC board with an LTC6802, a microcontroller, a CAN interface, and a galvanic isolation transformer. The large amount of battery-monitoring data required for the system would overwhelm the main CAN network, so the CAN modules need to be on local CAN subnets. The CAN subnets are coordinated by a master controller that also provides the gateway to the main CAN network.

**Parallel modules with CAN gateway:**

Each 12-battery module contains a PC board with an LTC6802 and a digital isolator. The modules have independent interface connections to a controller board containing a microcontroller, a CAN interface, and a galvanic isolation transformer. The microcontroller coordinates the modules and provides the gateway to the main CAN network.

**Single monitoring module with CAN gateway:**

In this configuration, there is no monitoring and control circuitry within the 12-battery modules. Instead, a single PC board has eight LTC6802 monitor ICs, each of which is connected to its battery module. The LTC6802 devices communicate through non-isolated SPI-compatible serial interfaces. A single microcontroller controls the entire stack of battery monitors via the SPI-compatible serial interface, and it also is the gateway to the main CAN network. A CAN transceiver and a galvanic isolation transformer complete the battery-monitoring system.

**Series modules with CAN gateway:**

This architecture is similar to the single monitoring module, except each LTC6802 is on a PC board within its 12-battery module. The eight modules communicate through the LTC6802 non-isolated SPI-compatible serial interface, which requires a three- or four-conductor cable to be connected between pairs of battery modules.

A single microcontroller controls the entire stack of battery monitors via the bottom monitor IC, and also acts as the gateway to the main CAN network. Once again, a CAN transceiver and a galvanic isolation transformer complete the battery-monitoring system.

The first and second architectures are generally challenging due to the significant number of connections and the external isolation required for the...
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parallel interface. For this added complexity, the designer has independent communication to each monitor device. The third (single monitoring module with CAN gateway) and fourth (series modules with CAN gateway) architectures are simplified approaches with minimal limitations. The LTC6802 can address all four configurations, leaving the choice to the system designer. Two variants of the device have been created, one for series configurations and one for parallel configurations. The LTC6802-1 is designed for use in a stacked SPI interface configuration. Multiple devices can be connected in series through an interface.

Table 1: Comparison of the four architectures for battery-monitoring

<table>
<thead>
<tr>
<th></th>
<th>Parallel Independent CAN Modules</th>
<th>Parallel Modules with CAN Gateway</th>
<th>Single Monitoring Module with CAN Gateway</th>
<th>Series Modules with CAN Gateway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>LTC6802-2 local to battery module</td>
<td>LTC6802-2 local to battery module</td>
<td>Sensitive analog wires routed to single board</td>
<td>LTC6802-2 local to battery module</td>
</tr>
<tr>
<td>Reliability</td>
<td>CAN interface not as robust as CAN over cables, but parallel communications minimize negative impact</td>
<td>Communications local to a single board, minimizing cable connections and sensitivity to communications interference</td>
<td>Communications in series between modules</td>
<td>Communications in series between modules</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>Significant parallel communications wiring required</td>
<td>High-speed digital isolators have significant current draw</td>
<td>Minimal circuitry, but SPI interface requires more power to communicate between boards</td>
<td>Minimal circuitry, but SPI interface requires more power to communicate between boards</td>
</tr>
<tr>
<td>Cost</td>
<td>Multiple microcontrollers and CAN interfaces require excessive power consumption</td>
<td>Single microcontroller and CAN transceiver, together with precision PC boards with digital isolators</td>
<td>Single microcontroller, CAN transceiver, and isolator, on one precision PC board</td>
<td>Single microcontroller, CAN transceiver, and isolator, on one precision PC board</td>
</tr>
<tr>
<td>Power</td>
<td>Microcontrollers, CAN interfaces, and isolation in every module, plus a main controller board</td>
<td>Multiple microcontrollers and and CAN interfaces require excessive power consumption</td>
<td>Multiple microcontrollers and CAN interfaces require excessive power consumption</td>
<td>Multiple microcontrollers and CAN interfaces require excessive power consumption</td>
</tr>
</tbody>
</table>

The French-based company Actia Automotive launched the IP66/67-rated SPU 25-15 (25 inputs, 15 outputs) and the IP65-protected APU 63-53 (63 inputs, 53 outputs) control units for harsh environments featuring up to two CAN interfaces and a 32-bit CPU. The SPU 25-15 complies with the SIL 2 according to the EN 61508. The APU 63-53 supports the Diag on CAN, CANopen and J1939 protocols.

The company’s Vehicle Electronics and Diagnostics department located in India provides the Multiplexed Smart Power 2944 device with three CAN interfaces, one EIA-485 port, 29 software configurable inputs and 44 outputs. The device replaces traditional relays and fuses from exposed environments on the vehicle with reliable solid-state computer-controlled switch-es, which manage electrical loads, reduce electrical noise and integrate diagnostics into the vehicle. The Windows-based AMPS software is used for application authoring and simulation, software download and vehicle diagnostics.

I+ME Actia from Germany manufactures BMS Master, BMS Slave and BMS Slave C battery management systems. The Slave C module is a microprocessor-controlled module for measurement (e.g. voltage, temperature and related limit values) and monitoring of five to ten Li-ion battery cells with arbitrary charging capacity. The modules work in connection with the BMS Master (connected via EIA-485) allowing systems with up to 300 battery cells. The Master manages the tasks of system monitoring, data processing and communication with the superior ECUs. It communicates via CAN with the BMS Slave or a current/voltage measurement module. CAN is also used for communication with other control units.

Electronic DC loads and power supplies

The microprocessor-controlled loads of the series EA-EL 3000 (400 W) and EA-EL 9000 (2 400 W to 7 200 W) by the German Elektro-Automatik are used in industrial and R&D applications. The four common regulation modes for constant voltage (V), current (C), power (P) and resistance (R) can be used in any combination with the three operation modes. The battery test mode is used for a controlled discharge of various battery types. All necessary actual and set values are displayed on a backlit, blue-white, two-line dot display. The analog interfaces serve as set value inputs for V/C/P/R, monitoring outputs for voltage and current, control inputs (e.g. remote on/off), signaling output for errors and a trigger input. Interface cards may be used to control the load with a PC and to implement it into existing networks such as CAN. Labview support is possible. Cards for CAN, USB, EIA-232, GPIB/IEEE and Ethernet/LAN are available.

The company also offers a broad range of programmable power supplies with CAN connectivity for use in laboratories and industrial applications.

www.actia.com

CANopen in Swiss double-deck train: Correction

In the last issue (03/2010), starting on page 22, the cover story about CANopen interconnected double-deck train was published. Unfortunately, the author’s name was left unmentioned. The author of the article is Bernd Riedel from the Swiss control solutions and PLC provider Selectron Systems. (of)

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