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Use Cell Balancing To Enable Large-Scale Li-ion Batteries

Many applications need lithium-ion (Li-ion) battery packs with high cell counts. Large-scale arrays based on Li-ion batteries can provide the high voltage, current, and capacity required by many emerging markets. Yet designers of larger battery packs face many problems, including the issues around cell imbalance.

High capacity is achieved with many cells in parallel, while high rate capability can be achieved with specially designed cells or by oversizing the battery pack's capacity and lowering the effective C-rate. In general, applications requiring high current or more than 12 cells should use a custom solution for safety and cell balancing.

The electric vehicle market is driving battery technology to even larger forms. Tesla Motors' Lotus Elise-based Roadsters is one of the first electric vehicles on the market using Li-ion technology. To provide its acceleration from 0 to 60 mph in less than 4 seconds and a top speed of 125 mph with a range that's about 220 miles, Tesla had to design a custom microprocessor-controlled battery solution comprising almost 7000 individual cells and weighing nearly 1000 pounds.

KEY CHALLENGES

Thermal management of the heat created during charging and discharging is probably the first of many challenges that come to mind. Heatsinks and active cooling can be used during charging and discharging for thermal management, and large ICs can be used to accommodate high currents.

Also, many cell vendors do not want their products used in multi-cell packs. This is especially true for prismatic cells, and most vendors limit the size of prismatic packs to three or four cells. Shipping regulations are an issue for large batteries in general as well. Larger Li-ion packs must be shipped as fully regulated Class 9 hazardous materials.

Recent solutions will enable the much anticipated adoption of Li-ion technology in markets that had been dominated by sealed lead-acid (SLA) batteries such as telecom and transportation. Safety circuits are available as off-the-shelf products appropriate for most consumer types of applications, which operate at room temperature and require relatively low currents. However, issues associated with cell imbalance and other problems can be readily apparent in larger battery arrays.

To deliver a given wattage, high-series cell counts or high voltage are more efficient than a high parallel cell count, so high-series challenges are common. Also, out-of-balance cells can compromise pack reliability and cycle life. The pack will perform to the lowest-common-denominator cell, and cell imbalance will grow over multiple charge and discharge cycles. Self discharge will add to the problem.

Before designing a high-voltage pack, cell imbalance must be understood. Heat can cause the pack to unbalance over time even if cells are well matched at the start of use. Non-uniform thermal stress is a common problem and is often part of the poor design of the batteries' host device.

Because self discharge doubles for each 10°C rise in temperature, even heat from a microprocessor can cause radical differences in self discharge across a multi-cell battery pack. Non-uniform electrical loading of the pack causes the same uneven discharge, and high discharge rates can exacerbate these issues.

FIGHTING CELL IMBALANCE

Temperature becomes a great factor in very large battery arrays simply because the gradients are larger. Also, the physical cell arrangement can influence the temperature gradients and pack effects. Active cooling may not evenly affect the cells, so careful pack design is important as well. Pack design should minimize the gradients that cells are exposed to, but this may not be sufficient in very large packs. The solution, then, is to employ cell balancing.

There are two strategies—bypass and active redistribution—to implement cell balancing. But their ultimate purpose is the same: to deliver as much energy during discharge as possible and extend the cycle life of the battery pack by minimizing the difference in energy stored in each cell.

Also known as bleed balancing, bypass provides an alternative current path to a cell that is out of balance with the other cells in the series. This traditional, simple technique is the least expensive for low current. However, bleeding off excess energy represents a fundamental tradeoff between energy conservation in the long run and energy delivered.

Active balancing, or charge redistribution, moves charge from higher-charged cells to lower-charged cells in series. This strategy transfers energy between adjacent cells. The circuitry moves energy where and when it's needed to minimize global imbalance. The current path is outside of the charge and discharge path, so unlike the bypass strategy, active balancing can be implemented during charge, idle, and discharge periods. Choices include capacitive and inductive topologies.

For capacitive, there is a switch capacitor from the higher cell to the lower cell, and it is a simple higher-voltage to lower-voltage measurement and shuttle of energy. Unfortunately, this technique only works during times of peak voltage, at the end of the cycle. Its efficiency reaches a maximum of 50%.

The inductive method stores energy from the higher cell before delivering it to the lower cell. Redistribution is allowed anywhere in the pack. The system moves energy where and when it is needed to minimize global imbalance and is not as efficiency-challenged at mid-capacity levels. Yet the downside of the method is that it has a higher part count and cost.

Large battery arrays represent unique challenges. Yet they enable new markets to use the lighter, smaller, and more efficient Li-ion technology. Fortunately, the huge potential in this market has prompted the development of new, innovative solutions that attack cell imbalance due to thermal and electric gradients.

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