Achieving cell balancing for lithium-ion batteries

Cell balancing allows the selection of a much smaller battery to achieve a desired output capacity

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Lithium-ion batteries were introduced in 1991 and have become the preferred technology for many applications, ranging from satellites to land vehicles to model airplanes, as well as laptop computers and cell phones. This is primarily due to their outstanding energy density, which is the ratio of stored energy to weight.

Voltage drop

Li-ion cells are designed to provide a voltage in the range of approximately 3.0 to 4.3 V. It is extremely important to maintain the voltage of a Li-ion cell between its design limits at all times, or the cell will be irreparably damaged. If a cell's voltage is allowed to drop below 3.0 V, the cell can go into a state of deep discharge, from which it may take hours or even days to recover.

In fact, deep discharge may cause the cell to short-circuit, an event from which it will not recover. Overcharging to a voltage greater than 4.3 V can be even worse because this can cause the cell to destruct, possibly with severe overheating or other catastrophic results. In simple applications using only a single Li-ion cell, the electronic control circuit must protect the cell by shutting off the load when the cell voltage drops below 3.2 V and limiting the voltage during charging to less than 4.2 V.

Li-ion construction

A Li-ion battery is constructed by connecting two or more cells in series. In this configuration, the battery voltage is equal to the sum of the individual cell voltages. For example, a 96-V battery is obtained by connecting 24 Li-ion cells in series. When a load is applied, the load current flows out of all 24 series cells. When the battery is being charged, the charger supplies charging current to the series string of cells. In both cases, the discharging and charging currents in all the cells are equal.

Over the life of the battery, the battery may be charged and discharged for hundreds or even thousands of cycles. As this occurs, the individual cells may age differently. Some cells may become slightly (or more than slightly) mismatched with respect to the others. If this phenomenon is not corrected, one or more cells may become undercharged or overcharged, either of which can lead to failure of the battery.

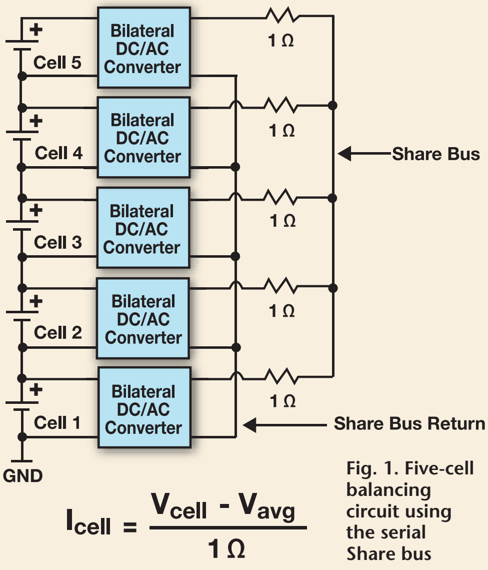

Fig. 1. Five-cell balancing circuit using the serial Share bus

Balancing

The methodology for correcting this condition is called balancing. Balancing is the process of forcing all of the cells to have identical voltages. This is accomplished by a balancing circuit.

The Aeroflex balancing circuit uses a Share bus, which has a voltage equal to the average voltage of all the cells. The balancing circuit takes charge from the cells that are above the Share bus voltage and injects the charge into the cells that are of lower voltage, using high-efficiency bilateral dc/ac converters.

The magnitude of the balancing current is proportional to the voltage difference, that is, as the cells become closer to being perfectly balanced, the balancing currents approach zero. *Figure 1* illustrates a five-cell balancing circuit, with 1–Ω resistors setting the transfer ratio, which is the ratio of the imbalance voltage (V_{cell}/V_{avg}) to the balancing current (I_{cell}).

For batteries of relatively large capacity (typically 20 Ah or more), balancing currents up to 1-A are desirable in order to minimize the time to reach balance. For these applications, the bilateral dc/ac converter circuit uses planar transformers operating at a frequency of about 100 kHz.

The battery electronics unit

Each circuit is a forward converter with resonant reset, and the switching frequency is controlled by a phase-locked loop to provide precise low-loss switching and high efficiency. *Figure 2* shows a battery electronics unit (BEU) for a 24-cell Li-ion battery satellite application using this circuit topology. This BEU also features individual cell voltage monitoring, with the voltage of each cell measured with an accuracy of 10 mV, using a 12-bit A/D, and

Fig. 2. Dual redundant BEU targeting 24-cell battery applications.

serial data telemetry.

For smaller batteries, a circuit with reduced balancing current capability and higher transfer ratio is appropriate. *Figure 3* shows a low-current cell balancer, the Aeroflex Model 8645-13. This unit is a circuit card approximately 6 x 2.3 in. and balances 13 cells. This cell balancer is embedded in the battery housing and does not include monitoring.

Advantages of balancing

The use of cell balancing enables the system engineer to select a battery with larger capacity for an application, because balancing allows the battery to achieve a higher state of charge (SOC). Without the enhancement of cell balancing, a conservative design does not allow the SOC to approach 100%.

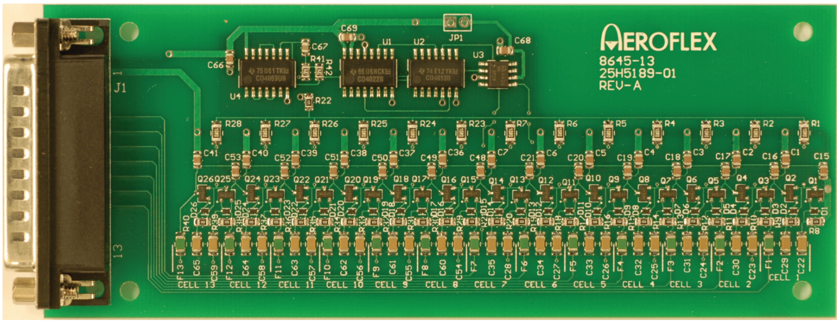

Fig. 3. Low-current balancer for a 13-cell battery is embedded in the battery housing.

The battery cells are connected in series, and all cells are charged with the same current. The charger monitors the total battery voltage and continues charging until a predetermined voltage is reached, which is typically 4.2 V per cell.

For example, a 10-cell battery might be charged to 42 V for 100% SOC. If the cells are not balanced, it cannot be assumed that each cell will be at precisely 4.2 V. It is possible, for example, that one cell might be charged to 4.4 V, making it susceptible to becoming overcharged and damaged. For this reason, the SOC of an unbalanced battery must be kept substantially below 100% to ensure that one or more of its cells cannot be overcharged.

On the other hand, in a battery that is properly balanced, all of the cell voltages are very close to the average cell voltage, and it is possible to charge the battery to close to 100% SOC, based on the charging circuit measuring the total battery voltage.

As a result, in an application without cell balancing, a battery may typically be used in the range of 20% to 80% SOC, providing a battery use of only 60%. If balancing is added, the SOC range might be from 5% to 95%, increasing the use to 90%. Thus, a cell-balancing system allows the selection of a much smaller battery to achieve a desired output capacity. This can result in a large saving in overall weight, even when the weight of the balancer is included.

The concept of cell balancing is not new, and has been used on nickel-cadmium (NiCd) batteries for at least 30 years. Earlier balancing systems generally used brute-force techniques, using power resistors to reduce the voltage of overcharged cells.

By today's standards, these systems were relatively large, heavy, and inefficient. In a modern cell-balancing system, charge is transferred from cells with higher voltages to cells with lower voltages, through a Share Bus, until equilibrium is achieved and all cells are at the same voltage. In this topology, therefore, almost no power from the battery is wasted. ■

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