Integrated BMS and ASIC Technology Creates Charge Isolation Safety Architecture in Large Battery Systems

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ABSTRACT

Battery safety and longevity issues are significantly magnified in large battery system structures such as those employed in Battery Electric Vehicles (BEVs), Underwater Autonomous Vehicles (UAVs), and specialized aerospace, army, and naval applications. 1Power Solutions' charge isolation architecture provides thermal balance and equal charge and discharge within +/- 2mV for individual battery cells in large systems. In under one hour every cell will tightly balance in any combination of rows, modules, arrays, or strings of batteries. This new, innovative, and safe method of battery control is generic, scalable, seamless, and neutral to chemistry, size, and form-factor. Given the general applicability to all forms of mobile power, including vehicles, consumer electronics, and backup storage, 1Power Solutions' integrated Battery Management System (BMS) and ASIC technology should revolutionize key markets that depend on large battery systems, including, notably, transportation.

Keywords: battery, cell, BMS, charge, discharge

1 BATTERY MANAGEMENT OVERVIEW

Large battery systems are arranged in banks of relay boards, as Figure 1 illustrates for a vehicle system. For example, a system may have four Relay Boards, each of which controls twenty to thirty Cell Modules. Each Cell Module consists of four rows of battery cells and a cell monitor , as illustrated in Figure 2.

Communication of data between the Cell Modules and a Relay Board occurs across a Controller Area Network (CAN) bus, as does the communication between the Relay Boards and the Battery Management System board.

1Power Solutions' innovation is three analog integrated circuit (IC) products that allow control of discharge balance, charge balance, and thermal balance between individual cells in a cell row, and between cell rows in a Cell Module. This solution is applicable to vehicle systems, notebook computers and other forms of mobile power.

Figures 2 and 3 illustrate the arrangement of the three 1Power Solutions products. Each cell monitor contains one

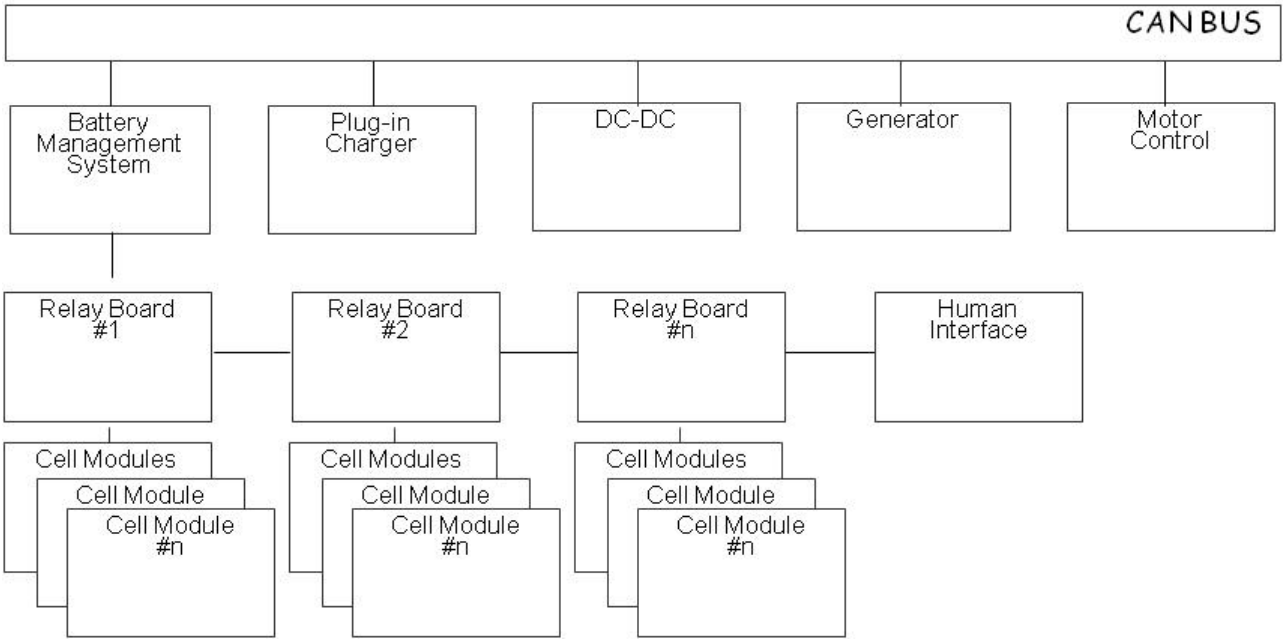

Figure 1: Vehicle System

BP4000 battery module monitor product to monitor temperature and voltage and to facilitate discharge balancing between rows of battery cells. In turn, each individual battery cell contains one BP2000 disconnect IC and one BP1000 charge balancing IC.

The key point is that ICs are used to monitor and control the operation of individual battery cells.

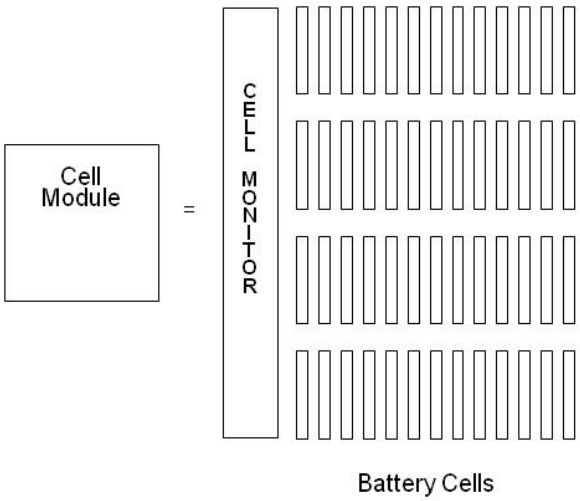

Figure 2: Cell Monitor Contains BP4000 Product

2 BATTERY SYSTEM SOLUTIONS

There are three basic problems:

- *How to manage a defective cell*
- *How to manage aging cells*
- *How to balance the charge in every cell*

2.1 Discharge Balancing

Cells discharge at different rates depending on age, temperature, chemistry, and even distance from the terminal if resistive voltage drops are involved. In a row, the cells are connected in parallel. This means a cell with low charge or capacity will draw charge from the other cells in the row, making the entire row less effective at delivering charge externally. One poor cell sets the performance for the whole row.

The voltage in the row will be maintained at the termination voltage for all cells up to the point that cells are severely discharged. At that point, cells stop behaving as a capacitor and start behaving as a resistor. The cells begin to drop in voltage and can actually reverse polarity and permanently damage the entire row if discharge continues.

One of the features of the BMS is to protect against this scenario. The BMS is designed to shut down the entire battery when low voltage is detected for a problem row.

1Power Solutions put instruments at the row level instead of just at the battery terminal to measure and characterize battery performance. Our conclusion for a bad cell is to disconnect it from the row so that a) the remaining cells can continue to perform, and b) the BMS will not shut down the entire battery system. This is the function of the BP2000 product (see Figure 3.)

The problems described for cells in a row are magnified when comparing row to row. Here the challenge is that one row may do a disproportionate amount of the total work in delivering charge externally. This is due, again, to the fact that different rows have different capacities and characteristics. In particular this is due to aging and temperature effects since the defective cell problem is neatly solved by the BP2000 device.

Working some rows harder than others can cause cells in those rows to age prematurely, and it reduces the ready capacity of the battery. So the goal is to have all rows discharge at the same rate by efficiently transferring charge from high energy to low energy rows. One of the functions of the BP4000 product is to make a very rapid transfer from high energy to low energy rows, ensuring that all rows discharge at the same rate. The BP4000 product is located in the Cell Monitor (see Figure 2.).

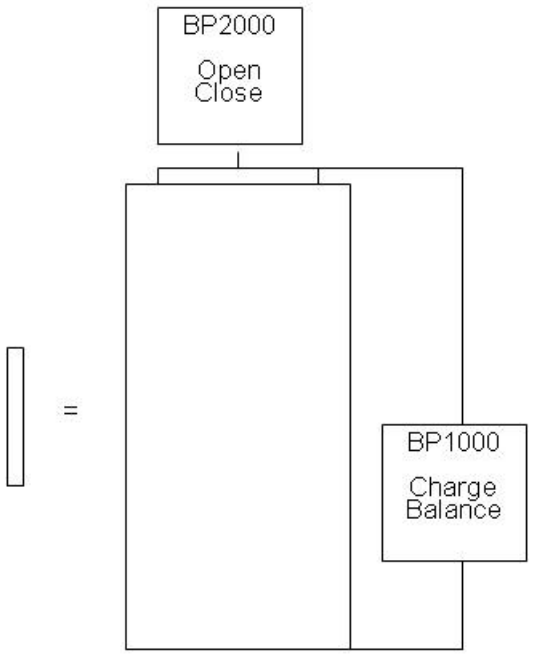

Figure 3: Individual Battery Cell

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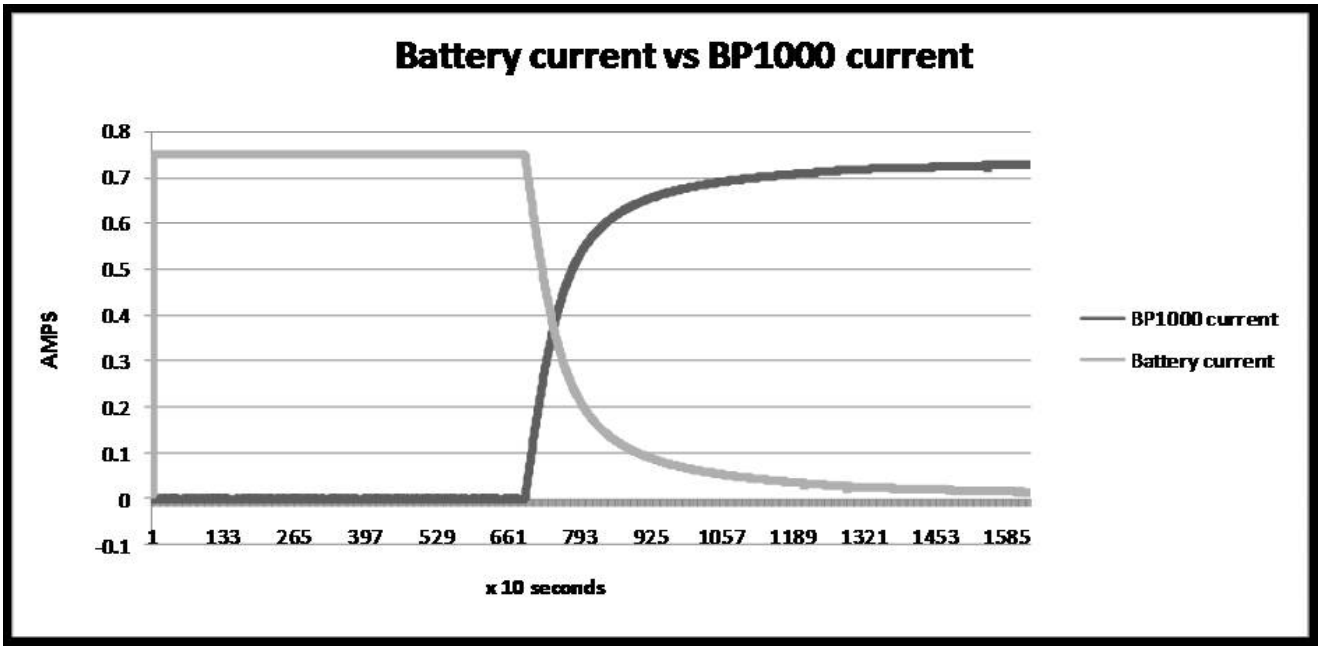

Figure 4: Battery Charging Characteristics and Matching BP1000 Bypass Current

2.2 Charge Balancing

During charging a battery cell (or row) will reach a certain percentage of charge at which the internal resistance begins to increase until a State Of Charge (SOC) is reached where further charging is not possible. This characteristic reduction in charging current (rate of charge) is illustrated by the lighter curve in Figure 4 (Battery current). As with the discharge balancing problem, the exact point where SOC is reached can vary between cells or rows.

If battery cells or rows are connected in series, the unit that has reached SOC will limit the charging current for the entire series, and none of the cells (or rows) can charge. This means, shockingly, that performance of a battery system with 2000 cells may be dictated by a single poorly performing cell or row.

The tried and true antidote for this phenomenon is to fully discharge the entire system and then charge again – a time consuming method recommended by every vendor of equipment with rechargeable lithium batteries.

Safety concerns for lithium batteries also dictate that the battery should never be overcharged. Due to internal chemistry, this can result in an oxidation-reduction reaction (fire) that cannot be extinguished because all of the constituents needed to sustain the reaction are contained within the battery chemicals. The BMS must safeguard against overcharging; but how can it do this for individual cells?

The BP1000 product provides a solution for charge balancing at the cell level. When a cell reaches SOC, this IC product will shunt the charging current through itself so that every other cell in the series connection may receive full current. This is illustrated in Figure 4 by the darker curve, BP1000 current.

The BP1000 is designed to regulate the voltage on all the cells to within +/- 2mV of the termination voltage of the battery. That is the voltage of the highest charged row in the battery, either 4.2 V or 3.65 V depending on the cell chemistry. This provides a considerable safety margin over conventional systems.

Some manufacturers have chosen to avoid SOC and heat problems by restricting the battery charge to between 65% and 85% of capacity. This solution fails to utilize the full assets because 20% of rated battery capacity is ignored. The BP1000 provides an opportunity to safely use this extra 20%.

The deep discharge-charging cycle, from 25% charge to a fully charged battery is the region of operation where most safety and balance problems occur. Without the BP1000 device, a number of rows will not be fully charged, so the range of energy available to the vehicle will be reduced. Additionally, the row that gets fully charged first is likely to become over-charged. With the IC attached to every battery cell, all cells will charge at the fullest possible rate and will remain fully balanced during the process.

2.3 Thermal Balancing

The last piece of the puzzle concerns thermal regulation. Battery cells heat up when current flows, due to internal impedance. Additionally, as Figure 4 illustrates, current is shunted from the battery cell through the BP1000

device when the cell reaches SOC. This energy is dissipated as heat in the BP1000.

Overall, heat must be evenly distributed and dissipated to avoid altering the performance and operation characteristics of the battery.

To compensate and regulate, the BP4000 device contains an algorithm to modulate (evenly spread) charging by monitoring temperature and voltage for every row. The object is to produce the least amount of heat in the IC products.

In contrast, most systems today only monitor at the whole battery level.

3 MARKET IMPLICATIONS

3.1 Applications

Applications include:

- Traditional Hybrid Vehicles
- Plug-In Hybrid Vehicles
- New Serial Hybrid Vehicles
- Electric Vehicles
- Submarines
- Laptop Computers

Traditional Hybrid Vehicles are gas-driven vehicles with battery assist. These vehicles are currently enjoying an immense appeal for environmental reasons as well as the ever-increasing price of gasoline.

New Serial Hybrid Vehicles reverse the set-up. They are basically electric vehicles with a gasoline engine assist, and represent a next step in environmentally friendly technology.

Electrical-only vehicles are gaining more appeal as the technology to increase their range is being realized.

3.2 Scale

Battery configurations for current Traditional Hybrid Vehicles range roughly from 1824 cells arranged in 76 rows to 2304 cells arranged in 96 rows. Recall that each cell requires one BP2000 product and one BP1000 product, and each cell module requires one BP4000 product. The battery configuration for an Electric Vehicle is four times as large (8064 cells in 84 rows).

Existing notebook computers charge in two to three hours. With the 1Power Solutions charge isolation architecture, a Fast Charge Notebook is possible that will charge in thirty to forty-five minutes.

4 SUMMARY

1Power Solutions' charge isolation architecture performs the system management tasks necessary to ensure thermal balance and equal charge and discharge for individual battery cells in large systems.

In charge balance and discharge balance, the system regulates individual cells to within +/- 2mV of optimal voltage, to provide safer system control than conventional battery management configurations.

In less than one hour every cell will tightly balance in any combination of rows, modules, arrays, or strings of batteries. This new, innovative, and safe method of battery control is generic, scalable, seamless, and neutral to chemistry, size, and form-factor.

The system is the first to utilize characterization of battery operation at the row level as a means for designing and implementing individual cell and row controls. The system consists of three integrated circuit products. BP4000 battery module monitor product installs in the Cell Monitor. BP2000 disconnect product and BP1000 charge balancing product install in each individual cell.

Although people have studied the characteristics of battery charging for decades, none have put forth an IC solution at the individual cell level. 1Power Solutions has patents pending for this unique IC approach. Our system enables better usage of battery assets, a higher degree of safety and thermal management, and a much more even and rapid charge and discharge rate. This architecture is expected to revolutionize the battery management markets.

5 CONCLUSION

The deep discharge-charging cycle, from 25% charge to a fully charged battery presents the greatest opportunity for safety and balance problems to occur. 1Power Solutions' IC approach provides an opportunity to solve the problems in this region.

Without the BP1000 device, a number of rows will not be fully charged, so the range of energy available to the vehicle will be reduced. Additionally, the row that gets fully charged first is likely to become over-charged. With the IC attached to every battery cell, all cells will charge at the fullest possible rate and will remain fully balanced during the process.

With the BP2000 device, defective cells are disconnected from the battery. With the BP4000 device, battery row temperature and voltage are monitored and managed to maintain thermal balance, and discharge balance is managed.

This system is unique in using ICs to manage individual cells in the battery.

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