Benefits of Cell Balancing in BLUESHAPE Li-Ion battery packs

Matching complications in large Li-Ion packs

To match the voltage required by digital broadcasting cameras, Li-Ion packs need to be designed commonly with 4 cells in series. In order to provide enough power and extend runtime, each cell in series needs to be connected in parallel with one or more further cells.
The final layout will consist in a combination of cells that may not be as efficient as it should be, often with a reduced capacity and lifetime performance.
The reason for this is that any minor capacity mismatch between cells connected in series (or groups of), results in a reduction of overall pack capacity. During charging or discharging of the pack, individual cell differences lead to different voltages in each cell group.
Since the charger monitors only the overall voltage, some cells can result undercharged and others overcharged.
Undercharging leads to a decrease in overall pack capacity whereas overcharging can lead to cell damage, shortening of the life cycle and creation of safety issues.

The need for Cell Balancing

There are two instances where cell unbalance can lead to problems during charging of Li-Ion cells connected in series:

- state of charge (SOC) of each individual cell
- full charge capacity of each individual cell

Let us consider what happens during charge of a 4-cells in series battery when, even though starting with an equal state of charge, one of the cells fills up more than the other three due to a smaller full charge capacity.
Constant-current/constant-voltage (CC/CV) charging should bring the pack to 4.20V x 4 = 16.80 V (typical). However, individual cell voltages will not remain matched during charge: the low-capacity cell will have a rather higher voltage than the remaining cells, whereas the normal-capacity cells will remain at a lower voltage than 4.2V. The sum of the cell voltages will still be 16.8V depending on the accuracy of the charger's algorithm.

If the lower cell has a capacity deficiency above 10%, its cell voltage will begin to rise inside the dangerous region above 4.25V, which could result in unwanted degradation of the cell and create a safety concern (4.25V is the typical acceptable overcharge voltage maximum quoted by most cell manufacturers).
Of course safety issues may be prevented by additional safeguards normally present in good quality Li-Ion packs, such as the cell overvoltage control: the battery protection system terminates the charging operation whenever an individual cell voltage exceeds the programmed cell overvoltage threshold.
However, terminating the charge at this point also means leaving the pack appreciably undercharged. Despite prevention of the safety hazard, this situation may gives the wrong impression that the pack is approaching the end of its useful life.

Unfortunately, the effects of cell degradation caused by unbalance are auto-accelerating. Once a cell has a lower capacity, its exposure to the higher charge voltage degrades it faster, further reducing its capacity, closing the runaway circle.
This consideration makes cell balancing one of the most critical issues related to the cycle life of a battery pack.

Cell manufacturers usually grade brand new cells so that their capacities are within a narrow voltage tolerance range. However, during use individual cells degrade differently depending on several factors such as prevailing temperature environment and the inherent unpredictability of the degradation process.
To prevent initial small capacity differences from growing into large differences, cell balancing during the charging process is therefore essential.

Similar effects occur when there is already a difference in cell, state of charge levels during assembly or when this condition develops during pack operation due to differences in individual cell self-discharge rates. The cell that originally had a higher charge is exposed to a higher charge voltage, degrading it faster. In this scenario, a harmless, easily correctable difference in initial cell condition turns into irreversible damage leading to decreased pack performance and premature failure.

Cell Balancing implementation in BLUESHAPE Li-Ion batteries

The starting point towards a successful pack assembly is the selection of high quality cells. Consistency is a mandatory issue when many cells are assembled together. Once the initial homogeneity is assured by the manufacturer, a further selection is made to

detect cells in stock that could have developed different self-discharge rate, by matching open circuit voltages within a narrow range prior to putting them together inside a pack.
This operation further reduces the risk of assembling cells with sensible mismatch in capacity.
However good this process is, the development of a high power pack designed to deliver large currents cannot rely solely on this. To allow high capacity packs to operate continuously with a maximised performance time after time, cycle after cycle, we have implemented an efficient cell balancing algorithm that works to equilibrate any small mismatch in the cells that could develop during pack life.

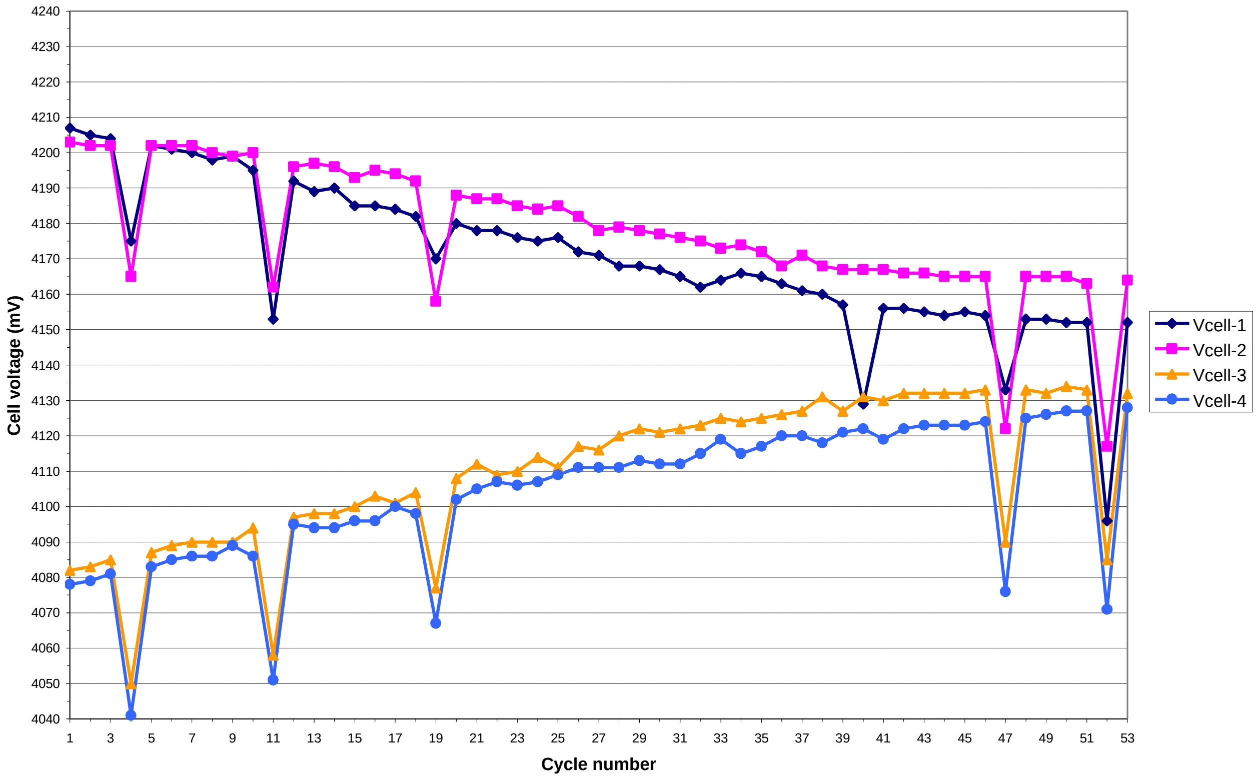
The cell balancing system implemented in BLUESHAPE Li-Ion packs consists of an intelligent electronic mechanism that operates to divert charge current out from higher voltage cells. This avoids their excessive charge and allows the lower voltage cells to catch up with the others in order to achieve a uniform state of charge. This mechanism works automatically on every charge cycle and does not influence the total charging time.
If the cells are balanced within a programmed threshold, no interactions are made during the charge process.

If this method is applied to a well-balanced pack, it simply operates as a watchdog preventing any potential unbalance. As soon as some of the cells in charge begin to develop a voltage unbalance out of the accepted threshold, it steps into operation. The result is a maximised available capacity at every cycle and an exploitation of the pack service life to the maximum extent possible, avoiding any premature or unexpected cell and pack deterioration.

We have conducted some experiments to demonstrate the behaviour of the BLUESHAPE internal cell balancing system.

The first test aims to show how much, the balancing system is capable of re-equalising a severely unbalanced pack.
In a fresh BV070 pack we have forced a critical non-uniformity among cells by discharging 2 of the 4 cells connected in series, thus removing 10% of their capacity. The result was a pack with a reduced overall capacity and wide differences in cell voltages.
By cycling the pack with reiterated charge-discharge cycles, we have observed the trend of each single cell voltage (measured after a 10 minutes resting period to allow for cell stabilisation).
At the beginning, the end-of-charge voltages showed quite large but expected differences with maximum unbalances of 130mV (between cell #1 and cell #4). See picture below, showing the data log.

Cell balancing test - End of Charge Voltage after 10 minutes rest



Cell#3 and cell #4 have a voltage much lower than the others do. If this situation is not corrected, any subsequent cycle could lead to a more severe unbalance, self-incrementing cycle after cycle, with a fast drop of pack performance and a premature termination of service life.

Albeit the initial situation, the balancing mechanism has reduced this trend and after several cycles has brought the cells within the accepted threshold of 40mV maximum unbalance.
The reason why it took so long to obtain good cell equalisation is due to the large and artificial applied initial unbalance. It is unrealistic in our assembly processes to assemble cells in this situation- the large unbalance was instrumental for testing purposes only.
Nevertheless, it demonstrates that the BLUESHAPE balancing system is well designed and works in the desired way.

The second test is more realistic, and describes the real behaviour of a BLUESHAPE pack on the field.
We have conducted a life-cycle test on a BV070 pack, simulating frequent charge /discharge cycles as described below:

- charge in CC/CV mode with a 4A charging current
- rest for 30 minutes
- discharge at 30W
- rest for 30 minutes
- loop

The starting point was a pack taken off the shelf ready to be shipped, thus representing the true BLUESHAPE quality behaviour on the field. Naturally, this pack had already been balanced during our assembly processes in the normal ways already described.
However our intention was to observe the efficiency of the balancing system by monitoring the individual cell voltages at end of charge after several cycles. The desired result would be a pack that never develops unbalances out of set threshold.
The results obtained are shown in the table hereunder:

Cycle #	Voltage at end of charge after 15 minutes rest (mV)					Max unbalance between cell (mV)
	Pack	Cell 1	Cell 2	Cell 3	Cell 4	
1	16794	4202	4199	4200	4193	**9**
100	16799	4208	4198	4201	4194	**14**
200	16777	4203	4192	4195	4187	**16**
300	16780	4204	4193	4196	4188	**16**
400	16784	4206	4198	4194	4186	**18**

- The initial maximum unbalance of 9mV has never developed into a larger unbalance out of the programmed threshold.
- Even after 300 charging cycles the pack appears to be in good shape: the performance is optimised because the charge process can charge the pack to its maximum allowed and the same happens during the discharge performance.
- The pack service life is only affected by normal deterioration factors such as of cell ageing and not by other external factors such as cell unbalance or cell overvoltage or cell undervoltage.
- Using this system we feel confident in extending our guarantee to 400 cycles. We have measured and found that the pack performance is still well over 70% of the initial performance after 400 cycles.
- Considering the fact that BLUESHAPE batteries are batteries with very high energy densities and performance, the fact that they contain mechanisms to prolong their cycle life and ensure consistency and uniformity between the pack members should delight our most demanding end-users.

Conclusion

In our opinion, cell balancing is a feature that must be taken very seriously and no multiple cell pack should be without some form of a cell balancing mechanism. We cannot over-stress the need to avoid unwanted situations especially cell overvoltage - situations that apart from compromising the battery performance and useful lifetime, could also compromise safety.
A cell balancing mechanism may add to the costs in pack construction but the benefits obtained, both from the manufacturer and users' ends far outweigh any cost issues.