Enerstone Active Balancing Technology: Welcome to Extended Battery Life

1. Overview

A Battery Management Systems (BMS) is an electronic circuit that protects the battery during charging and discharging and estimates the battery state-of-charge. It is a key component of lithium batteries to ensure safety.

One of the key functions of a BMS is to balance the cells in order to prevent battery capacity loss. Today, there are two types of cell balancing: passive and active. In this white paper, we present the reasons for which batteries need balancing and how Enerstone Active Balancing optimizes the charge of every cell, bringing multiple benefits to the final customer:

✓ Extended Battery Life
✓ Faster Charging
✓ Improved Battery Safety

With Enerstone Active Balancing, gain at least 30% battery life by unlocking the capacity left unused by passive balancing circuits, while saving time and energy at every charge!

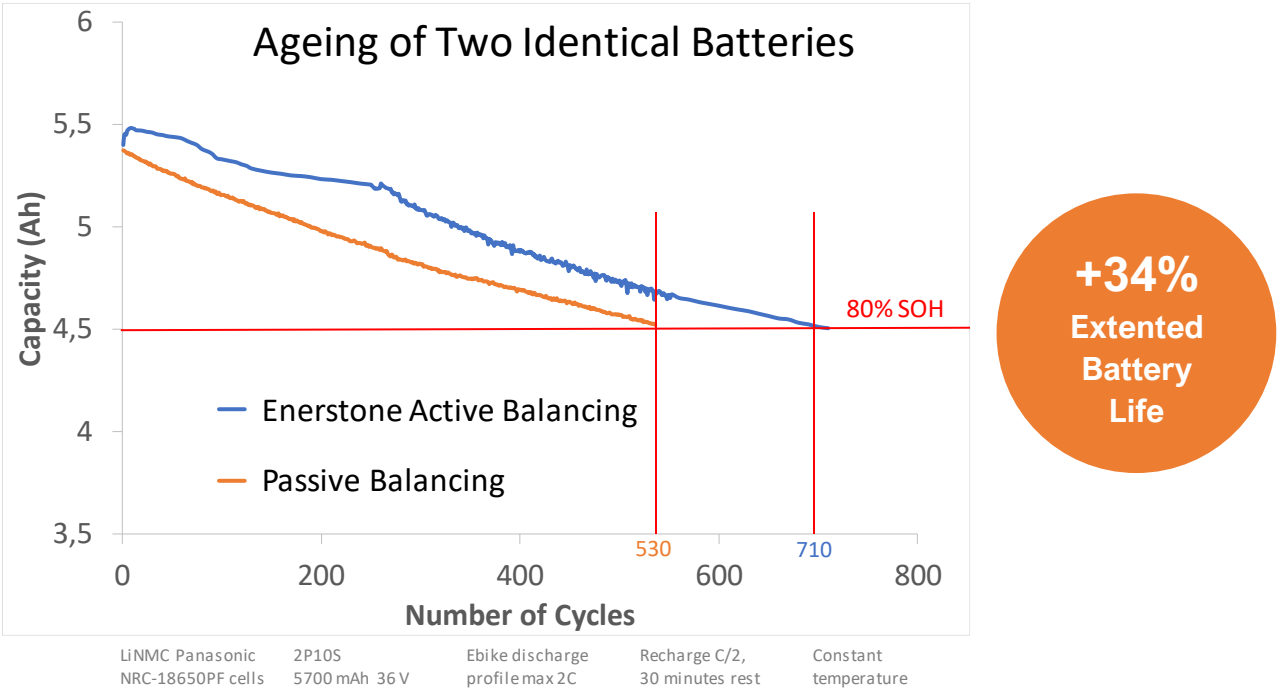


Figure 1. Comparison between passive balancing & Enerstone Active Balancing, resulting in a +34% gain in battery life

2. Why do Batteries Age? The Problem of Cell Dispersion in Lithium Batteries

Batteries are made of many cells connected in parallel and in series. Thousands of cells may be used to provide enough power for the equipment, like in electric car batteries.

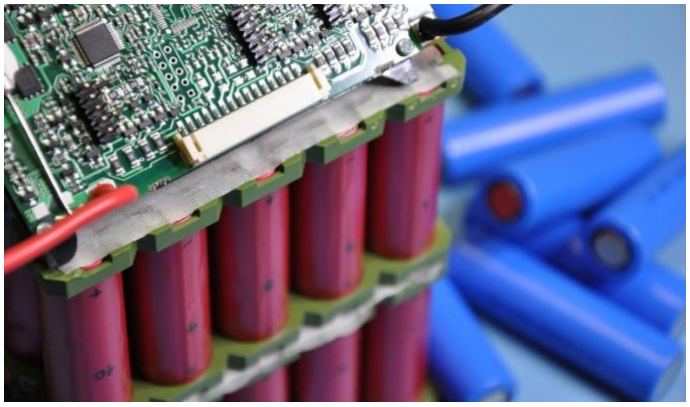


Figure 2. Inside an Electric Bike Battery: 18650 lithium cells and a BMS

The cells constituting a battery are not perfect, they have very small manufacturing differences related to the quality and purity of their raw materials and the assembly process. After a few charge / discharge cycles, a small difference in voltages can be observed across the cells of the pack, that will cause the charge and discharge to terminate prematurely.

The consequence on the battery is a loss of usable capacity and premature ageing.

Many researchers have studied cell dispersion. For example, Baumhofer (2014) studied the ageing of 48 identical 18650 cells and observed that their capacity evolved in an unpredictable manner. Only cycling can reveal weaker cells and a loss of capacity of up to 25% to 84% of SOH (Figure 3 below).

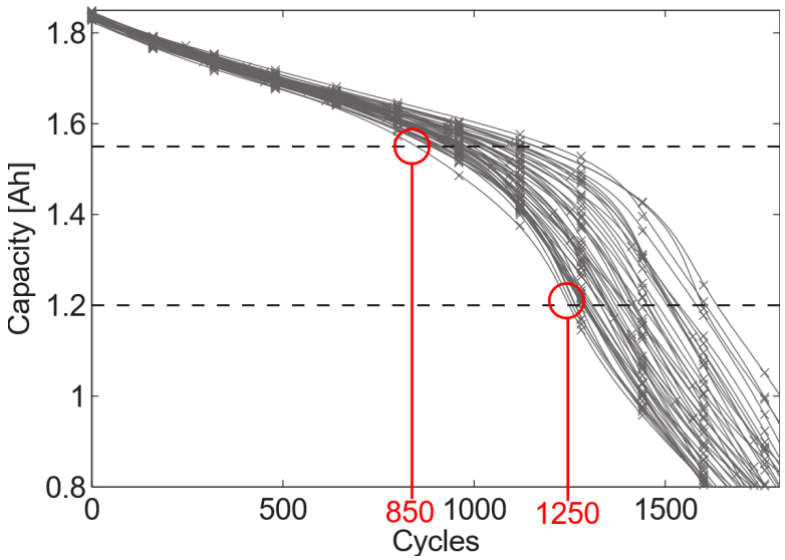


Figure 3. Ageing of 48 identical cells show important dispersion in capacity (T.Baumhöfer et al. / Journal of Power Sources 247-2014)

When the cells are assembled in a pack, more parameters will accelerate ageing, like the size and structure of the battery and heat management. These parameters will have an impact on the dispersion of the cells. The only way to rectify this imbalance is to act on each cell, using some mean of re-balancing.

Figure 4 depicts a used electric bike battery discharge, with the voltage of each individual cell shown (10 cells in total). As soon as the first cell reaches the end-of-discharge voltage (red line), the discharge must stop. At least 8 cells are still operational, but their energy is unusable.

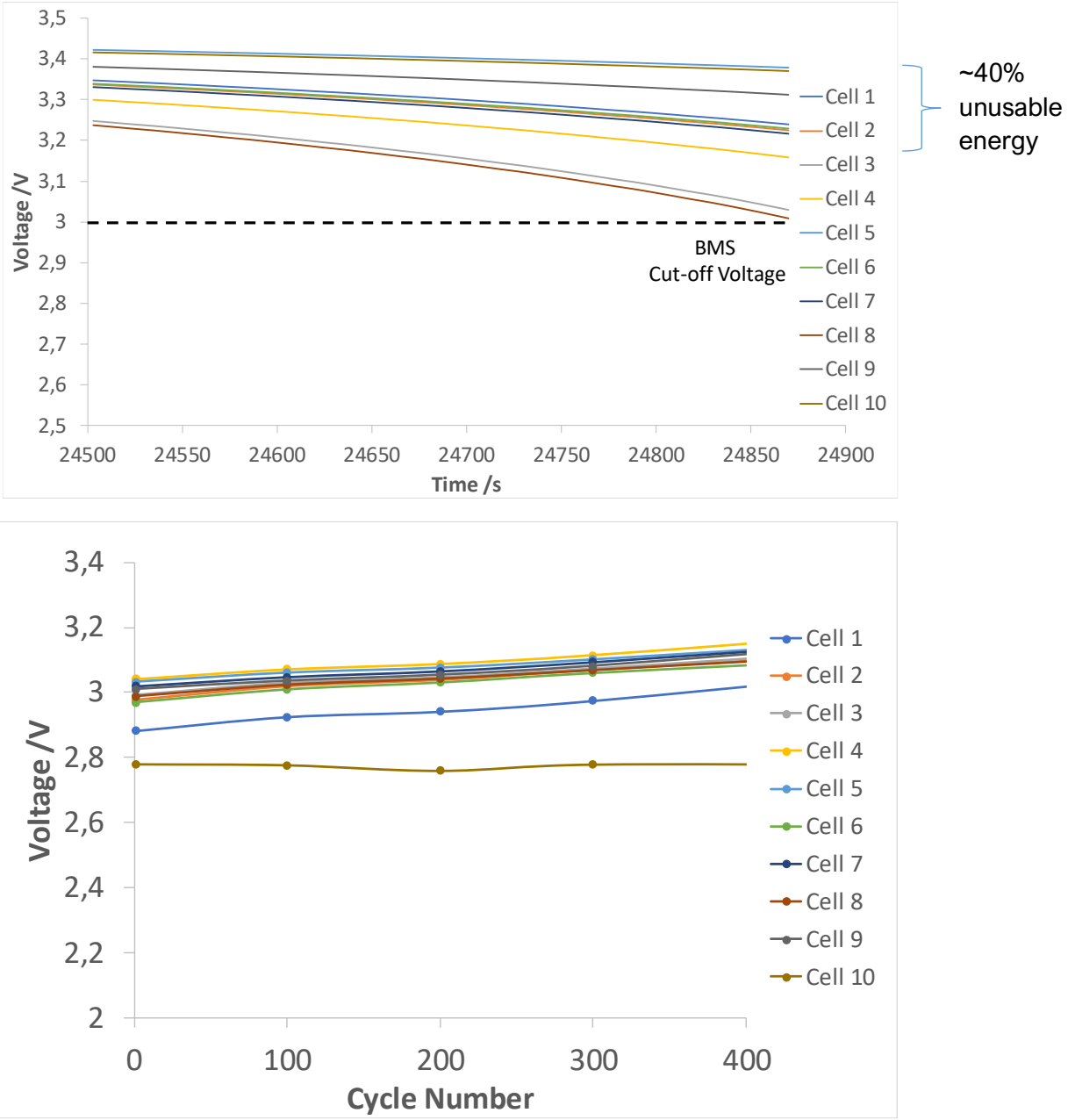


Figure 4. (TOP) Voltage dispersion on a used battery with a dissipative BMS: discharge of the battery ends as soon as the first cell reaches the low voltage threshold. (BOTTOM) Evolution of Voltage dispersion with a dissipative BMS

Most BMS implement a passive balancing system to address cell dispersion. This consists in "bleeding" the energy of already full cells in a resistor. The main advantage of this solution is its low cost. The bleeding current varies between 50mA and 1.5A and can hardly go higher

because of the heat generated (about 0.5W to 1W / cell). Passive balancing is usually performed at the end of charging, when a cell reaches a pre-defined voltage threshold.

Passive balancing has a limited impact on cell dispersion and therefore on battery life, because of the low balancing current and operation limited to the end of charge. It tends to lengthen charging time as the battery age and suffers more dispersion. The battery shown in Figure 4 has a passive balancing system that was never able to fix this dispersion, as can be seen on the right.

3. Active Balancing: a New Standard in Battery Performance

To overcome the limitations of passive balancing, active balancing was proposed as an alternative in the early 90's. With the advent of lithium-ion batteries, the need for electronic balancing became omnipresent while the solution became more difficult. The main problem with active balancing lied in the cost and complexity of electronic needed to perform active balancing on each individual cell.

Due to the high cost and safety issues of lithium batteries, their balancing became a major issue. In small, "disposable" batteries (power tools, electronics), this could be solved with passive balancing systems. The problem remained for larger capacity batteries (from e-bike, professional power tools to large stationary storage), where high current balancing is required.

What appears today is that very few commercial batteries contain active balancing. Here are the reasons that, we think, explain this, and how Enerstone addresses each point:

- Active balancing is costly and difficult to implement, and its design is not within the usual competencies of battery manufacturers or system integrators.

  ➔ Enerstone has designed its active balancing circuit with the end in mind: industry-ready, modular, cost optimized, taking advantage of the latest semiconductor technologies. This required 3 years of research and development and the combination of know-how in power electronics, embedded software and electrochemistry, making smart battery management a core competency.

- Even with an active balancing circuit hardware, the challenge is not solved: one must develop the balancing algorithm, which is specific to the battery chemistry, design and sometimes the application.

  ➔ Enerstone active balancing is fully controlled by software and implements an algorithm that results from extensive field experience. The algorithm considers both the battery structure and the chemistry of the cells. The active balancing is performed during charge, discharge or rest of the battery.

- The battery industry has put a lot of emphasis on cell chemistry, alleging that high-quality cells are perfectly identical, limiting the need for electronic balancing.

  ➔ We observed that all batteries suffer from dispersion. Just by sitting unused on a shelf, battery cells experiment self-discharge at slightly different rates. When in use in the equipment, the cells are not at the exact same temperature, which leads to more dispersion. Even "perfectly identical" cells show important drifts in capacities after 600 cycles, as shown in the literature.

We think that, with the development of high-quality, larger lithium-ion batteries and the availability of commercial balancing solutions like Enerstone, the market is ready for a paradigm shift. Batteries can be made to last, and active balancing is likely to become the main standard for quality lithium-ion batteries.

Figure 5 illustrates a case study of active balancing on the same e-bike battery as above, where the effect of active balancing on cell voltage dispersion is clearly seen.

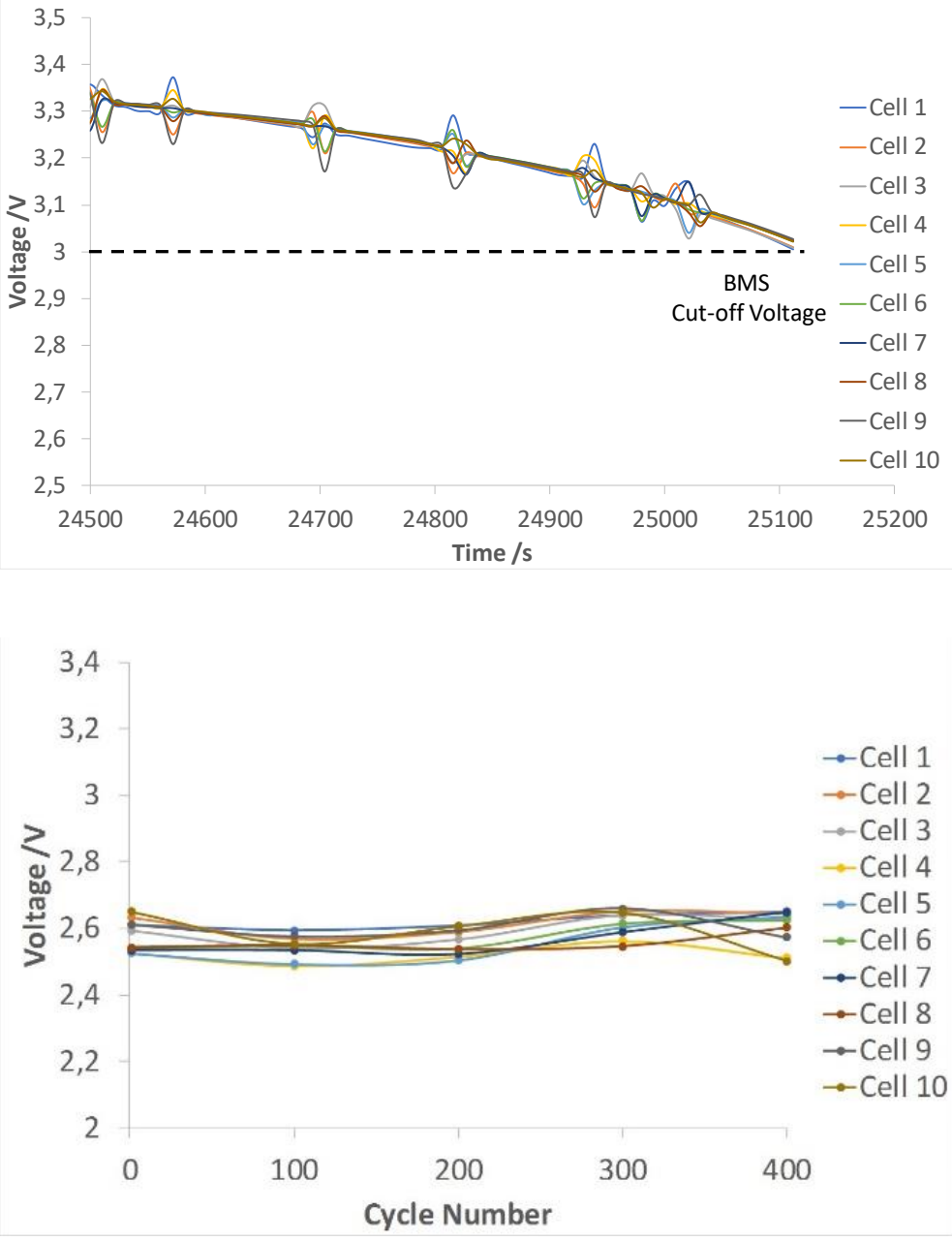


Figure 5. (TOP) Voltage dispersion with an Enerstone BMS on a used battery after 5 cycles of rebalancing. (BOTTOM) Voltage dispersion with an Enerstone BMS on a new battery after 400 cycles.

Active balancing can be found today in some commercial products and R&D projects, the next section will compare the available options.

4. Enerstone Enhanced Active Balancing Vs Competition

Of the few BMS that implements active balancing, two main types can be found: next to next and one to many. The Figure below provides an overview of the different approaches and solutions available on the market.

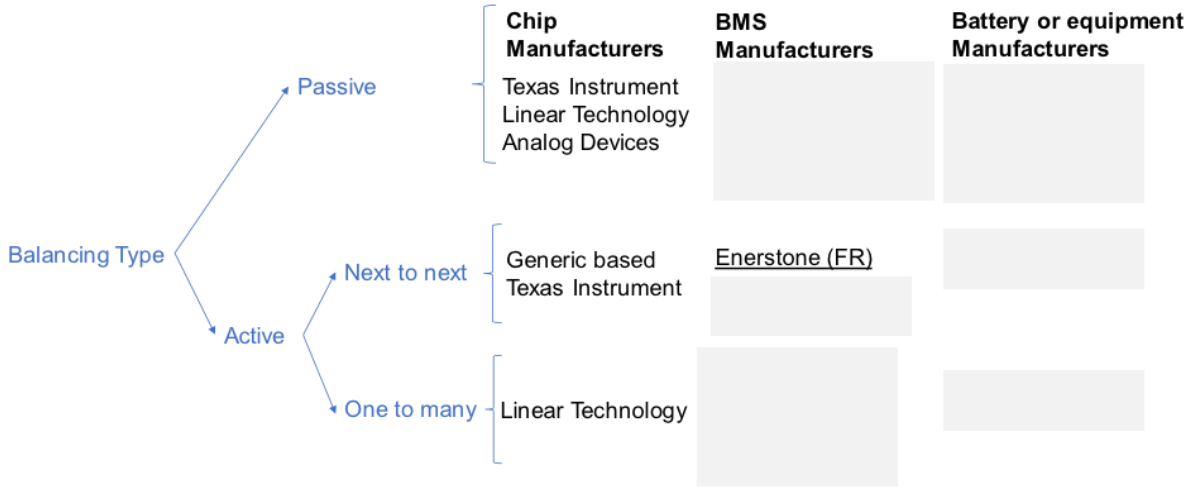


Figure 6. Balancing Types and example companies that commercialized them (full data available on request)

The passive balancing systems is a crowded space, dominated by low-cost BMS. The key differentiators on this market are: quality, support and software tools. Conformance to standards like automotive or aeronautical may also be important for some customers.

We already mentioned that passive balancing has a very limited impact on battery life because of limited balancing current during a short time.

Enerstone uses a bidirectional 2A balancing current. This results in a 20x more powerful balancing and a reduction of 90% in energy waste, since the energy is redistributed in the battery.

This argument is valid for active balancing systems in general. What differentiates Enerstone from the other active balancing systems is summarized in the following competitive advantages.

1. Balancing efficiency

An important criterion is the capability of a balancing system to compensate cell unbalance, for a given BOM (Bill of Material) cost. This indicator depends on many factors, like the type of battery used, the amount of dispersion in the battery and the balancing algorithm.

Enerstone patented an original Interleaved Next-to-Next topology which is up to three times faster than regular next-to-next.

Regarding the one-to-many systems, we must consider a specific number of cells to balance. For this example, we will consider a 48V battery made of 14 cells.

- For unidirectional one-to-many, Enerstone will balance the battery about 3 times faster.
- For bidirectional one-to-many, Enerstone will balance the battery about 1.6 times faster, with a PCB size of about 2/3 and thus lower cost.

2. Battery Diagnostic

A key competitive advantage of Enerstone Interleaved Next-to-Next is that it can be finely controlled in software to perform individual cell diagnostic. In fact, different waveforms like sinusoidal currents and step currents may be injected in the cells to measure different parameters. Even if some competitor's topologies would allow that, they do not leave this possibility to the system designer, since this would make the system design very complex.

The key point here is that mastering the software and hardware parts of an active balancing BMS opens the way for innovative diagnostic solutions. This is our next move on the path to even smarter battery management.

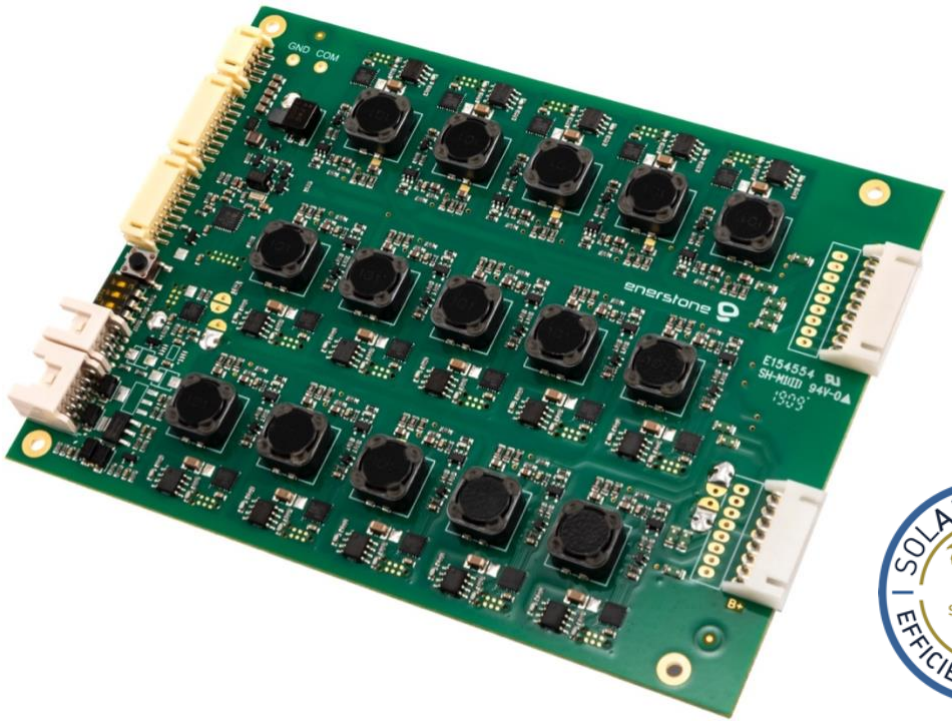
Enerstone has packed its know-how in an Active Balancing BMS called the MetaCard. This product targets batteries from 4S (12V) to 16S (48V) with capacities up to 200Ah and provides all the BMS functions.

We provide below a picture of the MetaCard and a comparison with a competitor's active balancing solution.

MetaCard, the BMS with Active Balancing

Up to **50%** less expensive*

3x smaller*



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*Comparison made with a 16S Active BMS competitor based on 100 units volume.

Enerstone Active Balancing technology can be integrated in any battery from 4 cells in series and is available in three formats:

- as a full-featured BMS
- as a standalone module coupled to an existing BMS even if passive balancing is present
- as a licenced design for a perfect integration in your product

Enerstone Active Balancing can work in parallel with an existing passive balancing system, thus providing an easy solution for benchmarking the balancing options.

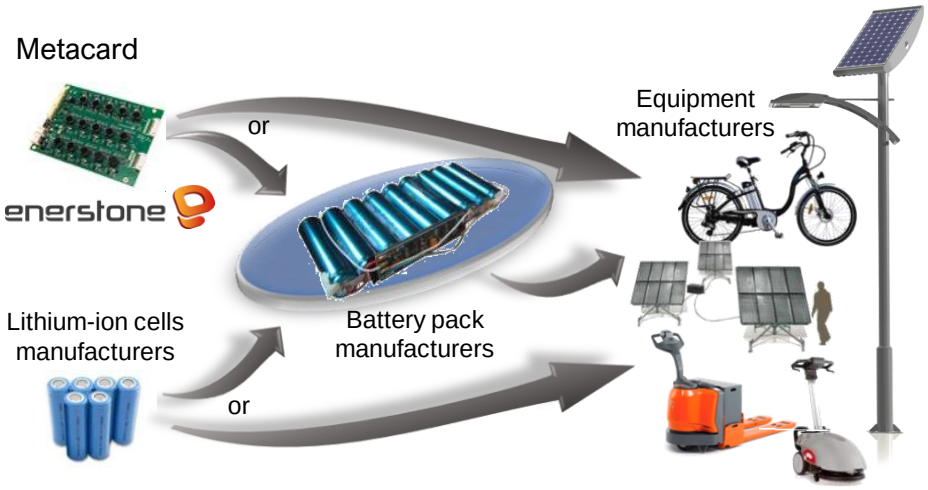

Figure 7. How the Active Balancing BMS fits in the battery value chain

Contact us today to discuss about your project.

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