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## **Simultaneous Measurement of All Cell Voltages and Pack Current, Delivers A New Level of Accuracy in Li-Ion Cell Balancing, Protection & SOH**

As previously discussed in a comprehensive [white paper](#) on cell balancing methodologies, the accuracy of cell voltage measurement can profoundly affect the balancing function, due to the flat voltage curve vs. state of charge of Li-Ion batteries. In this paper, we will delve into the importance of simultaneous measurement for achieving accurate cell voltage readings, and how time-multiplexed measurement methods can introduce errors that compromise the effectiveness of cell balancing, as well as other functions, such as the protection and impedance measurement functions, preventing the optimum use of the batteries.

In the pursuit of finding the ideal chemistry for manufacturing Li-Ion batteries, the industry has witnessed the emergence of several variations, each with its own pros and cons to cater to diverse applications. Among these chemistries, LiFePO<sub>4</sub> (lithium iron phosphate or LFP) has emerged as a leading contender for applications where high power, long life, and safety are paramount considerations. LFPs offer the following benefits:

1. **Enhanced Safety:** LFP batteries are known for their excellent safety characteristics. Compared to other lithium-ion chemistries, LFP batteries have a higher thermal stability and are less prone to thermal runaway, fire, or explosion.
2. **Longer Cycle Life:** LFP batteries have a longer cycle life compared to other lithium-ion chemistries. They can withstand a higher number of charge-discharge cycles without significantly degrading their performance.
3. **High Power Density:** LFP batteries offer a high-power density, allowing them to deliver high bursts of power. They can efficiently handle high-current applications, making them suitable for electric vehicles, power tools, and other devices that require instant power delivery.
4. **Wide Temperature Range:** LFP batteries can operate effectively across a wide temperature range. They perform well in both high and low temperatures, providing reliable power even in extreme environmental conditions.
5. **Environmental Friendliness:** LFP batteries are considered more environmentally friendly compared to some other lithium-ion chemistries. They are free from toxic metals like cobalt and lead, reducing the environmental impact during production, use, and disposal.
6. **Fast Charging Capability:** LFP batteries can be charged at a faster rate compared to some other lithium-ion chemistries. They have a higher charging efficiency and can tolerate high charge currents, enabling rapid charging times.

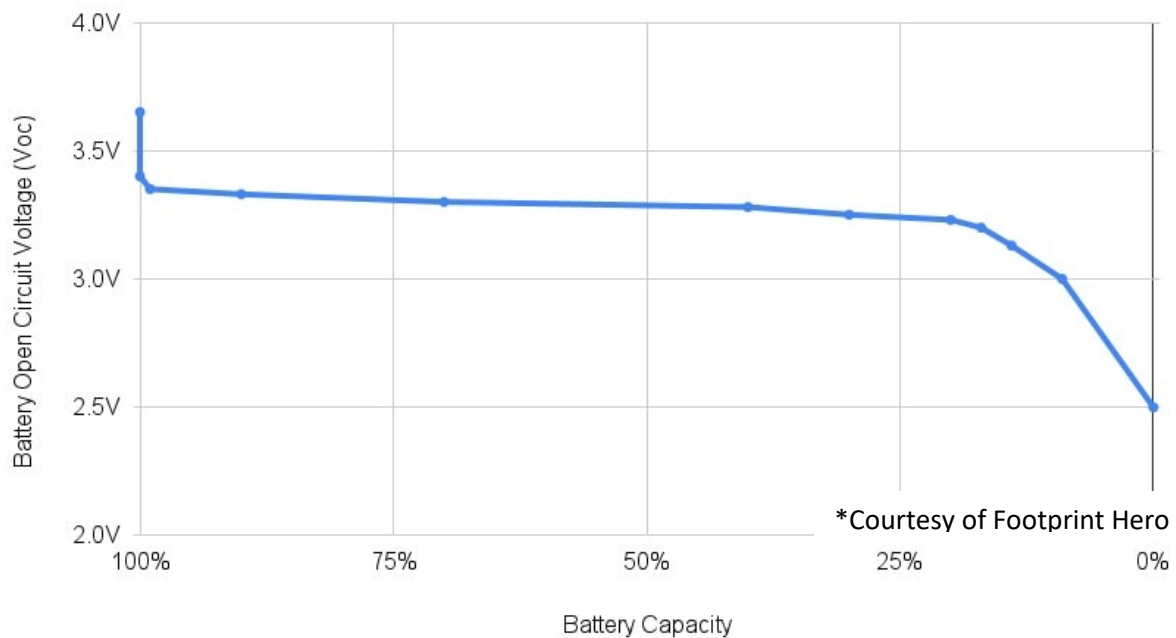
Compared to other lithium-ion chemistries, LiFePO4 batteries are also known for having a fairly flat voltage curve. LiFePO4 batteries exhibit a more stable voltage profile compared to other Li-ion chemistries like lithium cobalt oxide (LiCoO2) or lithium manganese oxide (LiMn2O4). Although each manufacturer and battery model have their own specific characteristics, finding LiFePO4 batteries with only 100mV or lower voltage difference between 20% and 90% state of the charge (SOC) marks is common.

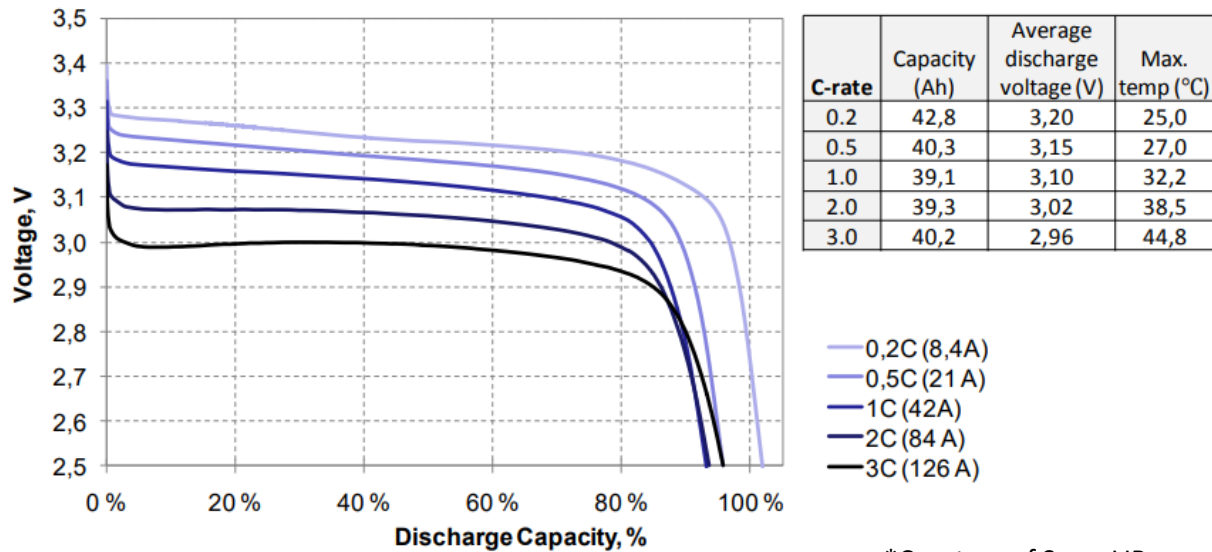
LiFePO4 batteries stand out with their nominal voltage of 3.2 volts per cell, which is lower compared to other Li-ion chemistries that typically operate within the range of 3.6-3.7 volts. This lower nominal voltage contributes to their unique characteristics. During discharge, LiFePO4 batteries maintain a relatively constant voltage until they reach a low state of charge. This flat voltage curve offers the advantage of delivering a consistent power output, which is highly beneficial in applications where a steady voltage is desired.

However, the flatness of the voltage curve, while desirable for power delivery, can create complexities, particularly for Battery Management System (BMS) solutions with low measurement accuracies. This complexity is further magnified when BMS systems employ a time-multiplexed measurement scheme. Inaccurate measurements can arise due to the challenges posed by the flat voltage curve, impacting the effectiveness of functions such as cell balancing, protection, and state-of-health assessment in the BMS.

Therefore, addressing the complexities associated with the flat voltage curve becomes crucial for BMS solutions, especially those with low measurement accuracies and time-multiplexed measurement schemes.

3.2V LiFePO4 Cell Voltage Chart





\*Courtesy of SuperLIB

The flat voltage curve of LiFePO4 batteries poses significant challenges to the balancing process, as it can result in inaccurate decisions. For instance, a modest cell measurement accuracy of +/-15mV, which is typical in many solutions, can lead to a substantial 20% error when comparing cells in terms of remaining charge. Clearly, with such limited accuracy and the consistent voltage profile of LiFePO4 batteries, a wide guard-band is necessary to prevent the risk of potentially reversing the balancing process. In essence, relying on such measurement accuracy and a flat voltage curve alone cannot ensure the functionality of the system. Thus, the attainment of precise and reliable measurements within this particular context becomes absolutely critical.

What is not so obvious is that this picture can get even worse, much worse when sampling and measurement of the cells are time-multiplexed.

Conventionally, battery management systems have employed one or two analog-to-digital converters (ADCs) to measure the voltage of multiple cells. This approach aims to reduce costs and improve measurement matching to minimize the aforementioned errors. However, in practice, this approach falls short of delivering the desired results.

In general, batteries, especially high-power batteries are designed to provide high currents to a load. The load can be a variety of system with various characteristics. Common loads can be a switching power supply, a motor with switching amplifier or a combination of both. Although these systems often incorporate an input filter to reduce the current ripple and EMI, the load is almost never constant, and neither is the input current. Switching circuits can create an input noise from tens of KiloHertz, to hundreds of KHz. Again, the input filters almost never completely clean this input ripple, and some are reflected back at the power source.

In general, all batteries have equivalent series resistance (ESR). The ESR causes a voltage shift, as current flows through the cell, such that  $V_{\text{measured}} = V_{\text{cell}} + (I \times \text{ESR})$ , when charging and  $V_{\text{measured}} = V_{\text{cell}} - (I \times \text{ESR})$ , when discharging. With time-multiplexed measurement scheme and variable load current, it is obvious that the current through each cell can randomly and substantially be different from other cells at the

time of each measurement, resulting in high degree of inaccuracy in measurements. It is important to note that this error is not accounted for in the specification, as the specification only reports on a single conversion accuracy, where this is a system driven issue. Considering the ESR of a cell can be a few to tens of milliohms, induced error can be in order of tens of millivolt, depending on the current ripple and the ESR. This error will be added to the original single measurement specified error, resulting in unexpected magnitudes.

Frequently, lowpass filters are employed in such systems to mitigate the ripple associated with variable current by filtering the cell voltage. At first glance, this may appear as a reasonable solution to address the issue, but a closer examination reveals a different reality. The challenge lies in the impedance of these filters. Since lowpass filters incorporate series resistance, the additional resistance can be significant, depending on the filter frequency. Moreover, most analog-to-digital converters (ADCs) draw input current, which is utilized in the switched-capacitor circuit within the frontend, serving as a level-shifter or sample-and-hold (S/H) circuit. The increased input impedance caused by the filter can result in a voltage drop, introducing another source of error. Paradoxically, while attempting to address the initial issue, the addition of a filter can inadvertently create a new problem. One potential approach to overcome this challenge is by implementing a slower system that allows for longer pauses to fully charge the input capacitance. However, this necessitates using a lower frequency filter, which in turn leads to a larger voltage drop, exemplifying the catch-22 situation. Unfortunately, even digital filters do not provide a great solution, as they result in a slower and less responsive system.

Thus far, our discussion has primarily focused on the implications of time-multiplexed measurement schemes on cell balancing. However, it's important to acknowledge that these errors also impact two other critical aspects: voltage protection thresholds and impedance measurement.

Li-Ion cells have predefined voltage limits, and surpassing these thresholds can be detrimental to the cell, potentially leading to catastrophic failure and fire hazards. Battery management systems constantly monitor cell voltages to ensure these limits are not exceeded. Erroneous voltage measurements can compromise the protection thresholds, jeopardizing the safety of the battery pack. To account for this, manufacturers often incorporate significant safety margins to prevent threshold violations, even with worst-case measurement errors. While this approach enhances safety, it reduces the effective capacity of the battery pack. By unnecessarily limiting the charge and discharge parameters, the overall capacity of the battery pack is compromised.

Additionally, the equivalent series resistance (ESR) and its rate of change serve as crucial indicators of a battery's health. ESR generally increases with battery aging, making it a valuable parameter for assessing the state of health (SOH) of a battery. High-quality battery management systems monitor and record the ESR of each cell. A sudden and excessive change in ESR can be an early indication of a failing or deteriorating cell. The simplified measurement scheme for ESR involves measuring the voltage change when a known current is applied. However, with time-multiplexed measurement methods, the uncertainty surrounding the actual current at any given cell measurement introduces a new level of complexity and compromises the accuracy of ESR measurements. Multiple measurements need to be taken, averaged, and subjected to various correction factors to obtain the actual ESR value, if possible.

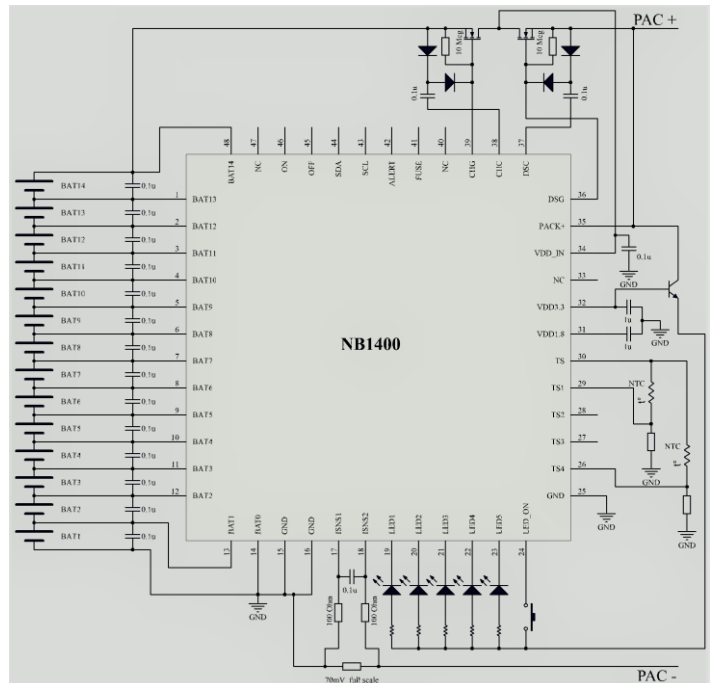
Given the implications and challenges associated with time-multiplexed measurement systems, it becomes pertinent to explore alternative approaches that can mitigate these issues while ensuring accurate and reliable measurements. Nova, a leading provider in this field, has developed a unique

approach that enables simultaneous measurement of all cells and current. This simultaneous measurement methodology eliminates secondary effects that can be even more significant than the primary measurement errors, leading to improved accuracy and reliable performance in cell balancing, protection thresholds, and SOH assessment.

Nova's revolutionary approach to measurement goes beyond simply achieving an unprecedented +/-1mV cell voltage measurement accuracy. With its unique methodology, Nova enables simultaneous measurement of all cells and current, effectively mitigating the adverse effects on critical functions such as Cell Balancing, Protection, and State of Health (SOH) assessment. This innovative approach sets Nova apart from conventional solutions and ensures accurate and reliable data for each cell.

By enabling simultaneous measurement, Nova eliminates the secondary effects that can often overshadow the primary measurement error. This means that not only the precise cell voltage measurements obtained, but the associated complexities and inaccuracies caused by time-multiplexed measurement schemes are completely avoided. The result is a BMS solution that provides unparalleled accuracy and reliability.

With Nova's groundbreaking methodology, accurate and simultaneous measurement of all cell voltages and the pack current becomes a reality. This breakthrough empowers precise cell balancing, facilitating the optimization of battery capacity utilization. Nova's flagship product, the NB1400, embodies this cutting-edge methodology, allowing for the simultaneous measurement of all 14 cell voltages and the pack current. As a result, the NB1400 stands as one of the most effective and advanced BMS solutions available in the market today.



In conclusion, the simultaneous measurement of all cell voltages and current offered by Nova's innovative solution represents a significant advancement in the field of battery management systems. By addressing the challenges associated with time-multiplexed measurement schemes, Nova's approach provides a new level of accuracy in cell balancing, protection, and SOH assessment. This enhanced accuracy translates into improved battery pack performance, increased safety, and extended battery life. With Nova's technology, manufacturers and users of Li-Ion batteries can confidently rely on precise and reliable measurements to optimize the functionality, efficiency, and longevity of their battery systems.

***Saving our planet, one battery pack at a time!***

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