Monitoring the temperature of every cell to maximize safety and performance of high power batteries

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Within any electric vehicle (EV), which increasingly includes passenger, commercial and industrial transportation, the voltage, current, and temperature of the battery pack must be monitored continuously to ensure that the cells remain within their designated safe operating area (SOA). Given the critical importance of safety, accurate and frequent monitoring of the battery pack is vital. Furthermore, as well as monitoring the internal cells, an EV's battery management system (BMS) needs to manage connections to charging networks; all while accounting for the impact of internal cell and external environmental temperature.

Therefore, ensuring accurate battery cell monitoring is critical to the vehicle's smooth operation. This is particularly important when charging, as the continuous high current raises the battery pack's temperature, causing variations in cell heat due to inherent manufacturing variances and thermal properties of the pack.

Prismatic cells equipped with Dukosi Cell Monitors

The impact of temperature on battery performance

Accurate temperature measurement is vital during charging, since the charging rate of a cell is frequently constrained by thermal factors. As the current increases, the cell temperature rises, with heat dissipating to its surroundings. When there is uncertainty about the temperature of each cell, it is important for a fast-charging controller to be cautious, as only an approximation of cell temperatures can be determined for areas without direct temperature sensors.

Similarly, cold temperatures also pose a significant risk during rapid charging due to increased chances of lithium plating and dendrite growth. This leads to unwanted loss of active lithium and weakens the cell upon returning to its normal operating temperatures.

For the best performance, it is advised to maintain the temperature of an EV battery pack between 15ºC and 35ºC. According to the US Office of Energy Efficiency & Renewable Energy, EV range can be reduced by as much as 39% in freezing temperatures[1]. Maintaining the recommended temperature range is crucial for achieving maximum efficiency, reliability, and safety. Significant deviations from this range can result in noticeable decreases in performance and accelerated cell deterioration.

While a battery pack is charging, the cells produce heat, but variations in manufacturing can lead to differences in temperature distribution. This can lead to one cell becoming much hotter than the others (Figure 1).

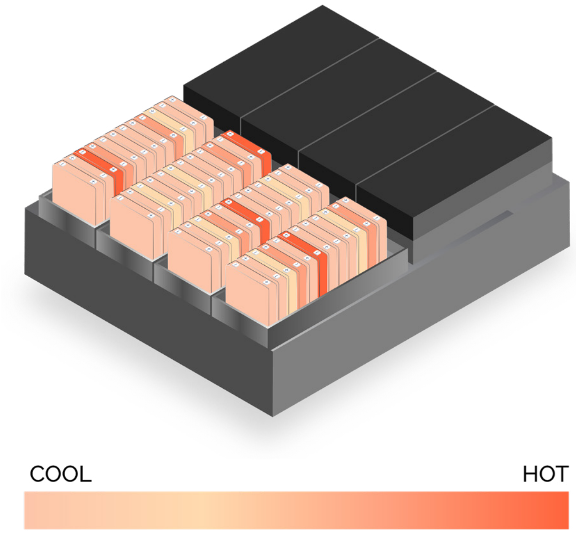

Figure 1 – A visual representation showing temperature variations in a typical EV battery pack

Without a temperature sensor on that cell, any abnormal temperature rise may go undetected, but if there is a sensor in every cell, the abnormal behavior of that one cell can be quickly identified. Enhancing the monitoring process strengthens the safety measures being taken, and potentially helps optimize the vehicles' fast-charging performance.

Temperature sensor packaging considerations

An EV battery pack is typically composed of several cell modules, with each module containing 12 to 24 cells. Economic and packaging constraints have a significant impact on the number of temperature sensors that can fit in a battery pack. Incorporating a network of sensors, wiring, and connectors into a pack adds extra weight, material expenses, and increases the chance of short circuits and reliability failures.

Temperature sensors are usually required to be strategically placed by pack designers as a compromise, which restricts the insight of what's happening inside. These sensors are placed either on the side of a 12-24 cell module or at the end of the pack in Cell-to-Pack designs, and are usually quite far from the monitoring boards.

Understanding thermal runaway events

Although certain packaging setups may enhance the distribution of temperature sensors, the majority of cells will still lack sensors and will depend on temperature transmission between adjacent cells for detection.

This delay in transmission can reduce the efficiency of battery thermal regulation systems and cause a delay in detecting thermal runaway events. These events occur when the temperature of a damaged cell in an electric vehicle exceeds a certain threshold, leading to a chain reaction.

In a thermal runaway event, the rising temperature causes the separator between the electrodes to melt. As a result, the cell has the potential to emit flammable gasses and ignite, creating a real danger of fire spreading to nearby cells.

Let's consider a situation where several prismatic cells are placed in a linear configuration within a module, assuming the usual setup of one temperature sensor for every eight cells.

If a cell experiences damage, its temperature might begin to increase, potentially surpassing the maximum temperature recommended by the manufacturer. However, in this specific example, the cell that is damaged does not have a temperature sensor, and the closest sensor is positioned several cells away. Due to the design, there is a possibility of a delay in the BMS detecting a breach in the thermal limit. Therefore, it is crucial to identify any abnormal behavior before a 'thermal runaway' event takes place in order to maximize safety.

Case Study: A real-world experiment

Dukosi collaborated with Nordic Marine Power (NMP) to undertake a live experiment on eight prismatic cells.

Download the case study (PDF)

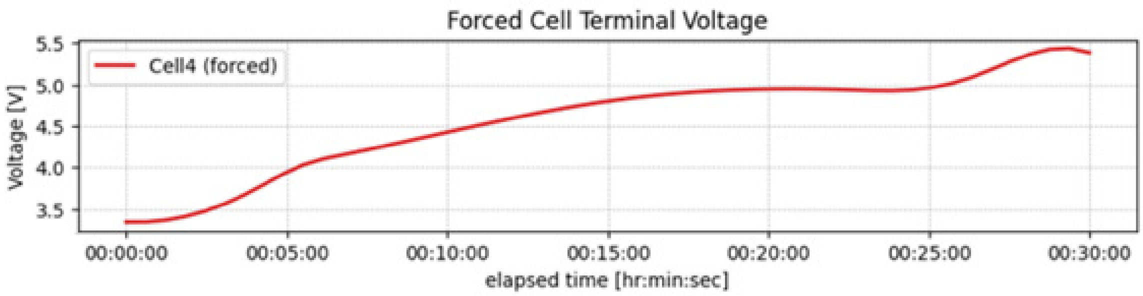

Figure 2 – A graph detailing the forced rise in voltage of cell 4 in the module

In the experiment, the cells were packaged as a contiguous block with sensors set up to record the voltage and temperatures in real-time. No additional cooling or heating elements were included.

Located in the middle of the module, cell 4 was forced into thermal runaway by overcharging it. This can be seen in the top plot, where the cell terminal voltage rises steeply from 3.2V through its rated maximum of 4.2V and upwards. Note that the Dukosi Cell Monitor is only rated to 5.0V, so any measurements above that may be subject to inaccuracy, but even 5V is dangerously outside the cell's safe operating area.

The temperature measured on each cell during this time is shown in the graph below.

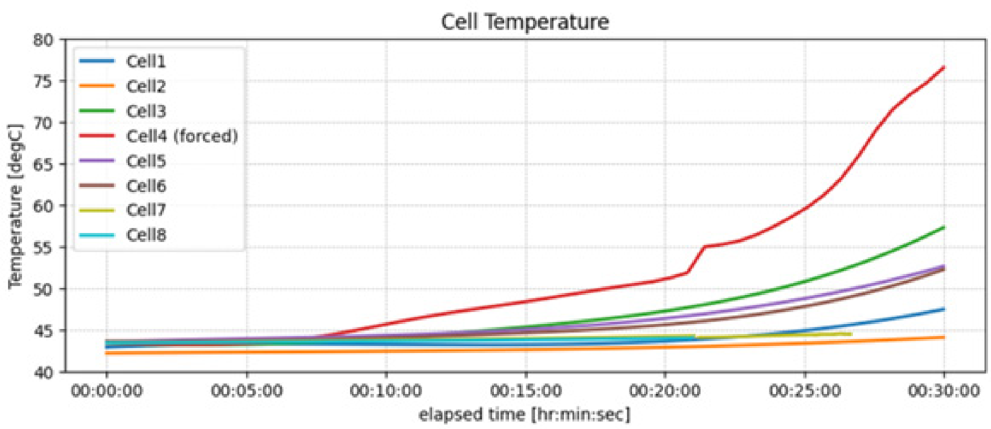

Figure 3 – A graph illustrating the spread of heat transfer among eight cells packed in a contiguous block

The graph shows that the temperature of cell 4 starts to rise at about 5 minutes, around the same time as the cell voltage goes through its rated maximum. Subsequently, the temperature of the other cells also starts to rise as the heat propagates from cell to cell, and we observe adjacent cells 3 and 5 rise in temperature. Cells further away also record rising temperatures, albeit delayed as the heat propagates through the module.

Thermal Runaway Scenario

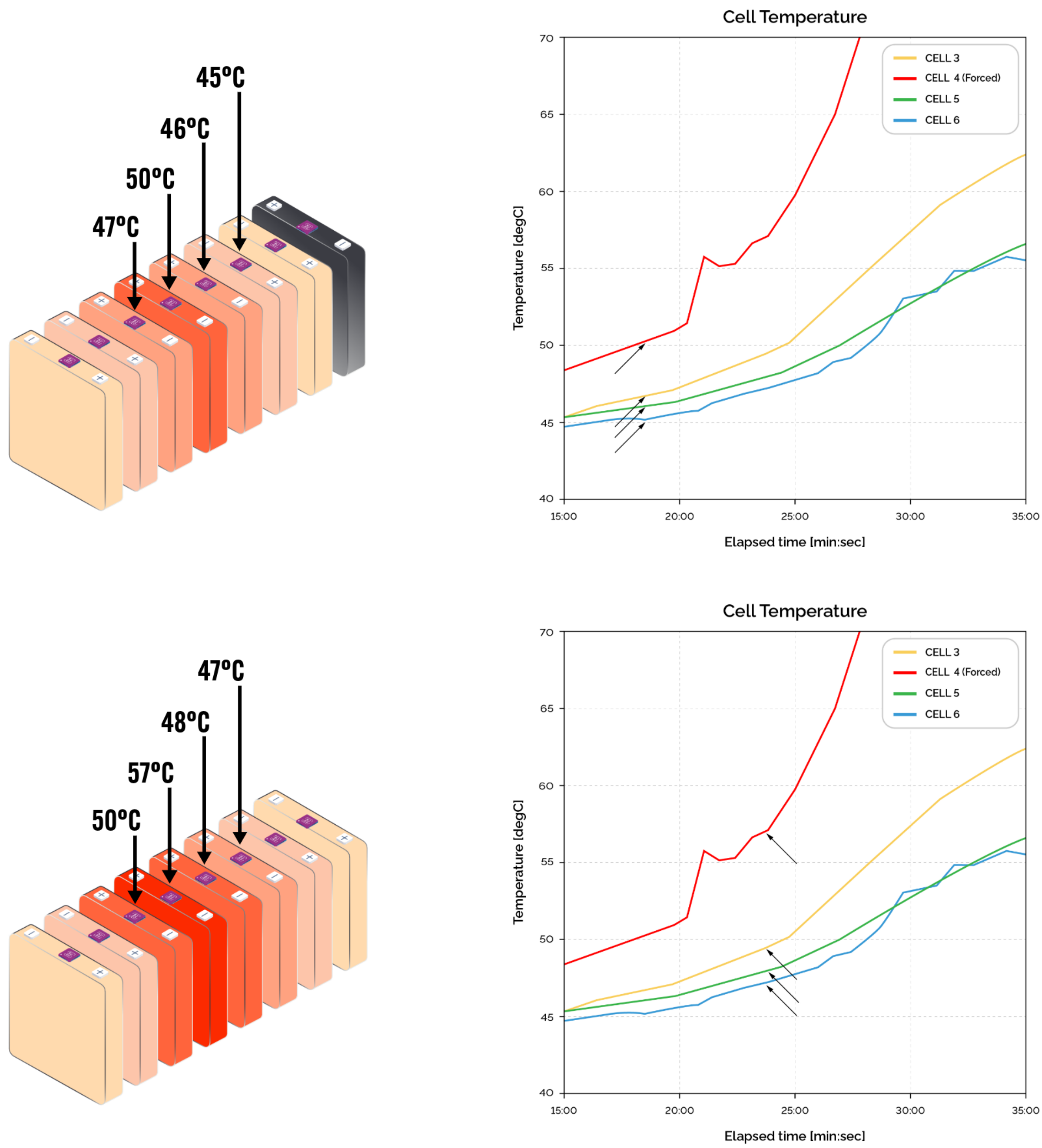

Figure 4 – Graphs demonstrating the difference in cell temperatures during a 5 minute window.
While Cell 4 induces heat into other cells, it exhibits a more rapid temperature increase on its path to thermal runaway.

If cell 4 (the one forced into runaway) had been equipped with a temperature sensor, the BMS host would have been able to detect the issue as soon as it crossed a predefined threshold, for example 60˚C. At this early stage, if the module was on charge, then it could be disconnected, and thermal runaway averted. The pack must be taken out of use, but a safety hazard will likely have been avoided.

For comparison, if only neighboring cell 3 had a temperature sensor, the BMS would not detect a similar failure until 5 minutes later (figure 4). If the temperature sensor was two cells away on cell 6, the delay would increase to over 10 minutes. If the threshold was higher, at 70°C, the neighboring cells would never have set off the alarm.

The provided example portrays a simplified version of a standard battery pack, whereas a well-designed pack would also integrate gas and pressure sensors to identify such a catastrophic failure when the initial cell starts venting gasses. Nonetheless, this technique is considerably slower, taking about 10 minutes longer than employing a temperature sensor on every cell, and our aim is to prevent catastrophic failure, not detect one after the fact.

Nearly all modern EVs have tackled this issue by utilizing specialized materials to contain and prevent the spread of heat. However, it is important to note that there might still be a delay of several minutes before detecting the problem. Placing a temperature sensor on every cell without adding any complexity (sensor already embedded inside the Dukosi cell monitor) is a simple yet effective solution to the critical safety problem caused by the delay. As evidenced by our data, it's another, effective safety layer to use.

How Can We Prevent Thermal Runaway?

We must work towards eliminating thermal runaway scenarios. However, there is no silver bullet solution, and a multitude of technologies will be required to achieve it. In striving towards this goal, the Dukosi Cell Monitor is designed to be placed on every cell and monitors both cell voltage and temperature. This feature allows for thermal monitoring of each individual cell without incurring additional expenses or complicating the design with external thermocouples. However, if design requires, each Cell Monitor is still capable of supporting up to two optional external thermistors, allowing up to three real-time temperature measurements per cell; this is an ideal choice for larger cells, or applications that are particularly safety conscious, like electric aircraft, or marine use.

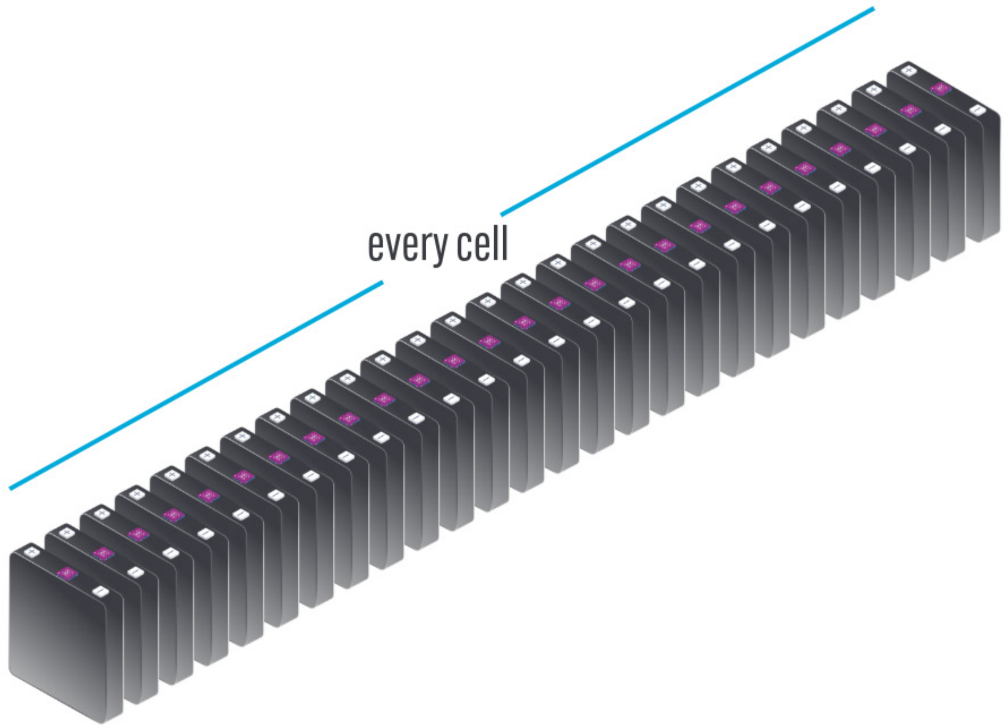

*Figure 5 – A 24 cell module example with Dukosi Cell Monitors,
including on-chip temperature sensors, installed on every prismatic cell*

Conclusion

Keeping battery cells operating within the recommended range is a challenging task for vehicle manufacturers. However, by accurately monitoring the temperature of each cell, they can enhance operational safely, and the battery pack's lifespan and performance will also be maximized. In addition, the ability to record temperature measurements on every cell provides valuable information for diagnostics and preventive maintenance, enabling early detection of any abnormalities or potential issues. By utilizing Dukosi's technology, battery designers can proactively monitor and address overheating risks. This results in a more reliable and resilient energy storage system, guaranteeing optimal performance and safety for electric vehicles and other high density, battery-powered applications.

Learn more about the safety, performance and cost advantages Dukosi Cell Monitoring System can bring to large capacity batteries.

References

[1] Energy Efficiency & Renewable Energy