Importance of Temperature Monitoring to Improve Safety and Reliability of Battery Energy Storage Systems

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Battery Energy Storage Systems (BESS) are essential to the renewable energy landscape and are increasingly being adopted in large grid-scale deployments. Previously1, we addressed cost-related considerations in stationary BESS and discussed how safety and reliability contribute to achieving a lower total cost of ownership. Today, the safety and reliability of these systems are critical factors in securing both initial approval and long-term viability.

Commercial operating contracts often include requirements for minimum uptime and total power availability, which are determined by system performance and reliability. Local and national safety standards must also be strictly observed. Beyond legal implications, insurance costs also impact profitability, making risk reduction essential wherever possible. In all these areas, Dukosi's unique battery architecture offers several advantages over traditional battery designs, particularly in the accuracy of temperature monitoring of battery cells in BESS.

Meeting and exceeding safety standards for energy storage

We believe thermally monitoring every cell is not just a novel feature, but an essential asset to battery safety. In their own independent assessment, the Electric Power Research Institute (EPRI), agrees with this:

"Lithium ion battery energy storage systems (BESS) have been operated successfully, efficiently, and safely for many years. BESS safety design starts at the most basic level, with the cell, and expands outward to encompass every part of the system." [2]

The EPRI encourages BESS developers and owners to go beyond simply meeting existing codes and standards by incorporating state-of-the-art technology and protocols. Its research shows that, although failures are rare, they tend to occur during the early years of a project, especially during installation and commissioning.

Safety standards such as IEC 62933-5-2:2020, UL9540A and BS EN 62933 Part 5-2, and organizations such as the NYS Inter-Agency Fire Safety Working Group and Energy Storage Reference Fire Hazard Mitigation Analysis outlined by the Energy Storage Integration Council (ESIC), consider various risk factors and the scope of reactions to when things go wrong. In their own language, each calls out cell temperature monitoring as a key functional safety item. The Battery Management System (BMS) is routinely considered the first line of defense against the threat of thermal runaway, even though it acts at the battery-level, not cell-level. Dukosi technology goes beyond currently suggested practices, enhancing the speed and accuracy by directly monitoring the thermal situation of every cell.

A grid-scale energy storage system must balance energy flow across all its battery packs and meet the grid's supply-demand needs. At the battery level, each BMS receives instructions and responds accordingly, while managing essential internal factors, including monitoring cell voltage, current, and temperature to ensure they remain within the designated safe operating area (SOA), supporting safe and reliable operation. This is especially critical during charging and discharging at higher C-rates, such as during frequency regulation and grid balancing. Under these conditions, continuous high current raises the temperature of the battery pack, causing variations in cell heat due to inherent manufacturing variances and the thermal properties of the pack.

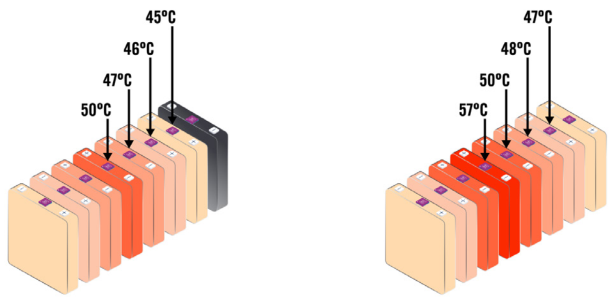
The impact of temperature on battery performance

Accurate temperature measurement is vital for safe operation, particularly during charging, as the cell charge rate (C-rate) is often constrained by thermal factors. As current increases, cell temperature rises, with heat dissipating into the surroundings. Similarly, winter months and cold environments can cause cell temperatures to fall below the minimum safe operating area (SOA), posing significant risks during rapid charging due to increased chances of lithium plating and dendrite growth. This can lead to an unwanted loss of active lithium and weaken the cell upon returning to normal operating temperatures.

To maximize operational life, performance, and safety, it is recommended to maintain the temperature of an ESS battery pack between 15˚C and 35˚C[3,4]. Significant deviations from this range can result in noticeable performance decreases and accelerated cell deterioration, impacting reliability and profitability.

As a battery pack charges and discharges, the cells generate heat, but manufacturing variations can lead to differences in temperature distribution, causing one cell to become much hotter than others. When the temperature of each cell is uncertain, the BMS host must exercise caution, as only an approximation of cell temperatures is available for areas without direct temperature sensors, as is typical in conventional battery designs.

Therefore, ensuring a temperature sensor on every cell enables quick and accurate detection of abnormal behaviors, alerting the BMS to take preventative action. Without a temperature sensor on each cell, any abnormal temperature rise may go undetected until the heat propagates through neighboring cells to a sensor, potentially causing unseen damage to that cell and its neighbors, or, in the worst-case scenario, leading to a thermal runaway event.



Temperature sensor packaging considerations

An ESS battery typically consists of several cell packs, with each pack containing approximately 416 cells. Economic and packaging constraints significantly impact the number of temperature sensors that can be included in a battery pack. Incorporating a network of sensors, wiring, and connectors increases the risk of short circuits and reliability failures. The pack's bill of materials (BOM) is also increased, meaning even small savings are amplified by the size of the deployment. As a result, temperature sensors are usually placed strategically, with only a few per module, as pack designers balance space and cost. These sensors are positioned either on top of the pack or on the bus bar and are generally quite distant 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 thermal transmission between adjacent cells for detection. The detection delay experienced as the heat propagates through cells reduces the effectiveness of battery thermal regulation systems.

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. Nearly all modern ESSs install specialized materials to contain and prevent the spread of heat. However, it doesn't prevent individual cells from overheating, and may further delay over temperature detection by several minutes[5].

Alternatively, placing a temperature sensor on every cell utilizing chip-on-cell monitoring is a simple and effective solution to eliminating detection delay, identifying problems much earlier than alternative solutions so preventative action can be taken, rather than a reaction to an already serious situation.

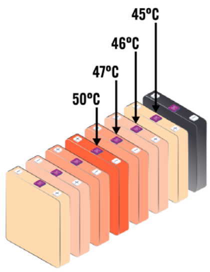
Case Study: A real-world experiment in cell temperature propagation

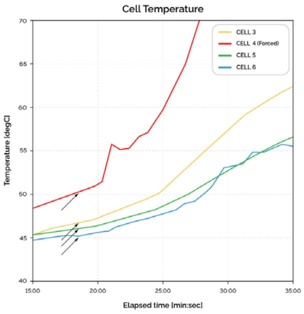
Dukosi collaborated with [Nordic Marine Power (NMP)](#) to undertake a live experiment studying thermal propagation through eight prismatic cells.

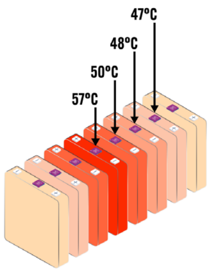
[Download the case study (PDF)](#)

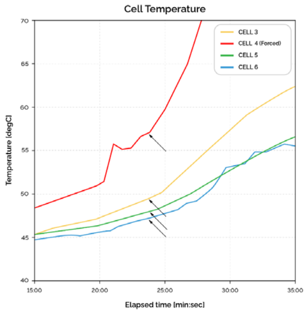
The case study reflects a real-life situation where several prismatic cells are placed in a linear configuration within a module. Assuming the usual setup of one temperature sensor for every eight cells, if a cell experiences damage, its temperature might begin to increase, potentially surpassing the 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 several minutes of a delay in the BMS detecting a breach in the thermal limit. Therefore, it is crucial to identify any abnormal behavior as early as possible.









Real-time detection of abnormal thermal behavior of every cell in a battery - requiring a temperature sensor on every cell - changes operational behavior from reactive to preventative action, which is crucial to improving safety, and reliability. This also provides an unprecedented level of insight into daily, seasonal, and long-term battery operation. Such data intelligence is highly valuable – it can feed into digital twins[6] to spot areas of weakness for preventative maintenance and operational optimization, and it can be used to create next-generation BESS designs that are more effective.

Designed from the ground-up for applications such as BESS, the Dukosi Cell Monitoring System (DKCMS) is a novel battery architecture that builds simpler, safer and smarter batteries. A Cell Monitor is installed on every cell to individually monitor both cell voltage and temperature. This innovation allows for thermal monitoring of each cell directly, greatly simplifying the battery design. For especially large cells or cells connected in parallel, up to two further thermocouples can be strategically installed per Cell Monitor chip, allowing up to three real-time temperature measurements per cell; this is an ideal choice for larger cells and for paralleled cells. In addition to temperature monitoring advantages, DKCMS offers best-in-class voltage monitoring, which feeds into SOC and SOH calculations[7] and can be used to identify cells that are degrading prematurely, triggering preventative maintenance to preserve reliability standards. These are only some of many advantages DKCMS offers BESS deployments: learn more about the safety, performance and cost advantages here[8].

Conclusion

As the adoption of battery energy storage systems continues to grow, enhancing safety and reliability is key to improving operational factors and deployment success. Keeping battery cells within the recommended temperature range is a challenging task for BESS designers and operators. However, by accurately monitoring the temperature of each cell, they can enhance real-time operational safety while also maximizing the battery pack's lifespan and performance. Additionally, the ability to capture temperature measurements for each 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, resulting in a more reliable and resilient energy storage system that guarantees optimal performance and safety for battery-powered applications.

References

[1] Lowering TCO & reducing deployment risks in battery energy storage applications

[2] Lithium Ion Battery Energy Storage Fire Safety Measures: An EPRI Perspective (PDF)

[3] Temperature effect and thermal impact in lithium-ion batteries: A review

[4] MODULAR PHASE CHANGE MATERIAL (PCM) THERMAL MANAGEMENT SYSTEMS FOR CYLINDRICAL LI-ION CELLS

[5] Thermal runaway still the biggest topic in battery storage insurance, says kWh Analytics

[6] Create better battery digital twins with cell-level intelligence

[7] Sensitivity of Lithium-Ion Battery SOC and SOH Estimates to Sensor Measurement Error and Latency

[8] Lowering TCO & reducing deployment risks in battery energy storage applications