Application Note

Real-time Monitoring of Lithium-ion Battery Thermal Runaway Behavior using SI-9300R Battery Analyzer

Application Note: 2024

The SI-9300R is a battery testing system manufactured by Ametek Scientific Instruments. This system is designed specifically for performing comprehensive testing and analysis of various types of battery cells, including lithium-ion batteries (LIBs). This Application Note aims to deliver guidelines for real-time monitoring of LIBs using SI-9300R Battery Analyzer.

Introduction

Lithium-ion batteries (LIBs) are increasingly vital in various applications, particularly in electric vehicles (EVs). However, ensuring their safety remains a significant concern, particularly in understanding and preventing thermal runaway events. Thermal runaway, characterized by uncontrolled temperature increase, can lead to catastrophic failures such as fire or explosion. Real-time monitoring of internal battery temperature is crucial for early detection and prevention of such events.

This application note explores the utilization of the SI-9300R Battery Analyzer from Ametek Scientific Instruments for monitoring the behavior of lithium-ion batteries, specifically during thermal runaway, as demonstrated by Niklas Kisseler et al.[1] at the Chair for Production Engineering of E-Mobility Components, RWTH Aachen University.

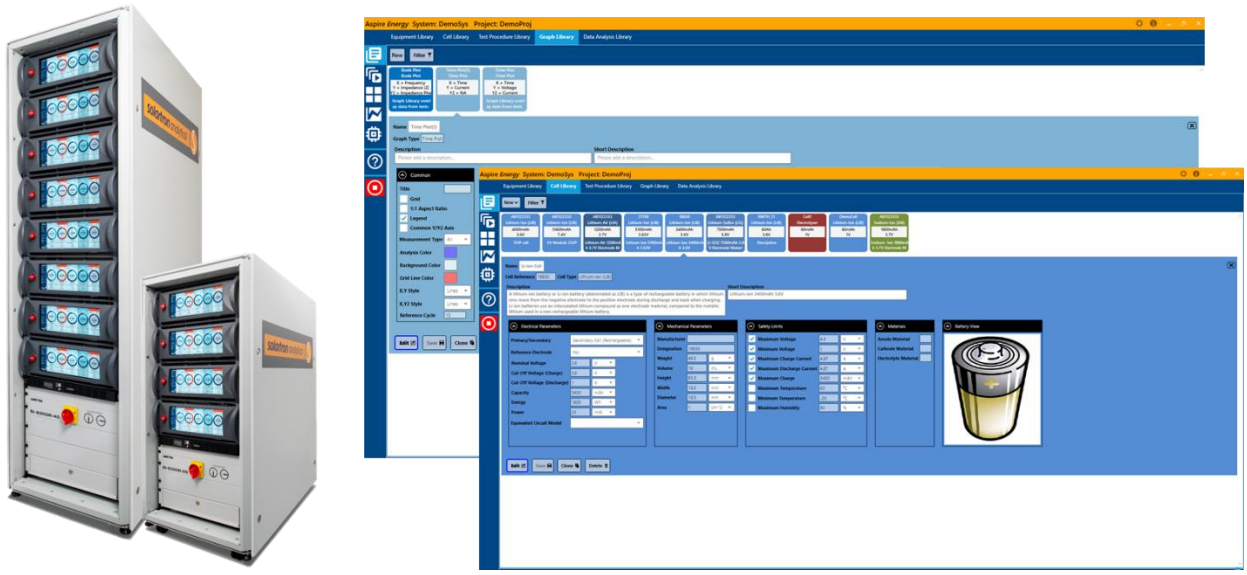

Figure 1. SI-9300R Battery Analyzer and the Aspire Software interface.

Key features of the Ametek SI-9300R battery analyzer typically include:

Voltage and Current Measurement: The SI-9300R offers accurate voltage and current measurements providing essential data for precious control over the various DC measurement techniques and the charging and discharge process.

Electrochemical Impedance Measurement: Renowned Solartron FRA technology on each measurement channel provides high-quality impedance measurements.

Auxiliary Channels: Each main channel has two auxiliary voltage measurement channels as standard allowing impedance measurements on individual electrodes within a cell.

Temperature Monitoring: This system often includes temperature monitoring capabilities, allowing users to measure the temperature of battery cells during testing. This feature is crucial for assessing thermal behavior and safety.

Safety Features: To ensure safe testing procedures, the SI-9300R includes built-in safety features such as overcurrent protection, overvoltage protection, and thermal management.

Compatibility: The system is designed to be compatible with a wide range of battery cell formats and chemistries, making it suitable for research, development, and quality control applications across industries. Aspire Energy PC software is compatible with data loggers including the EX1401 from VTI-Ametek.

Instrumentation and Methodology

The study employs prismatic lithium-ion cells with integrated thermocouples for internal temperature monitoring. The SI-9300R Battery Analyzer is utilized for charge-discharge cycling and real-time data acquisition. Key steps in the experimental setup include:

1. Cell Preparation and Sensor Integration: Thermocouples are integrated into the prismatic cell structure using a systematic process to ensure safety and reliability without compromising cell integrity. The exact positions are shown in Figure 2.

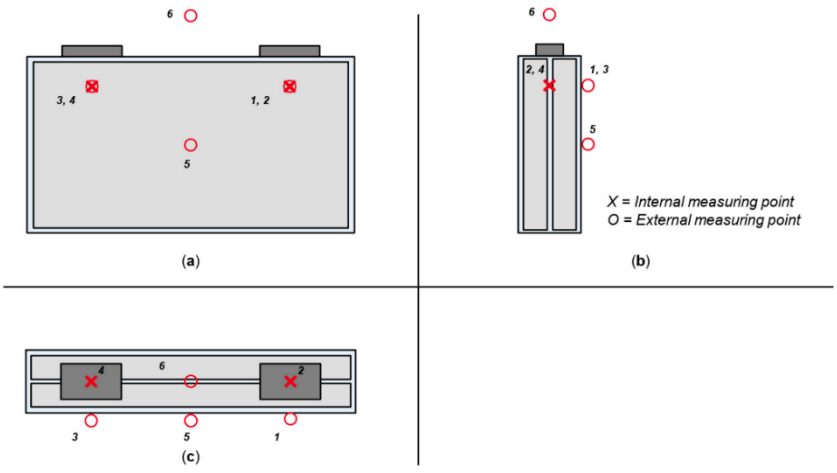

Figure 2. Projection view of the cell with thermocouple position; (a) front view; (b) side view.[1]

2. Cyclization Pre-tests: Cells undergo several charge-discharge cycles to evaluate electrochemical behavior and temperature gradient across the cell cross-section.

3. Thermal Runaway Tests: Cells are subjected to overcharging to induce thermal runaway, while temperature data is continuously monitored using the SI-9300R Battery Analyzer.

Results and Discussion

1. Cyclization with Integrated Thermocouples

The integration of thermocouples did not significantly affect the electrochemical behavior of the battery cell, as shown below in Figure 3. However, compensating for electrolyte evaporation during sensor integration is essential to prevent capacity loss.

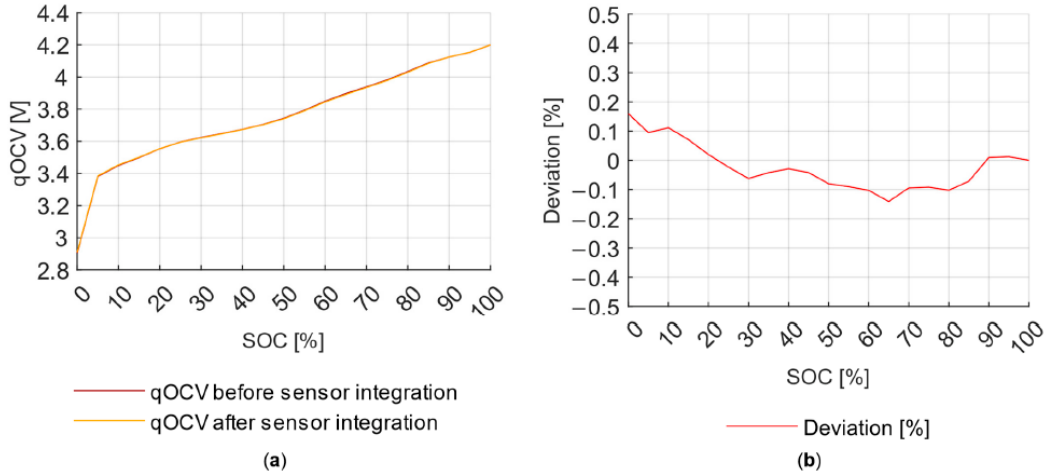

Figure 3. Comparison of (a) the qOCV curve for $Cell_{INT}$ before and after sensor integration and (b) the relative deviation. [1]

2. Thermal Runaway with Integrated Thermocouples

Real-time temperature monitoring using integrated thermocouples enabled the early detection of thermal runaway. The study demonstrated:

- Early Detection: Thermal runaway onset was detected 21 seconds earlier compared to surface temperature measurement, highlighting the effectiveness of internal temperature sensing for early warning.

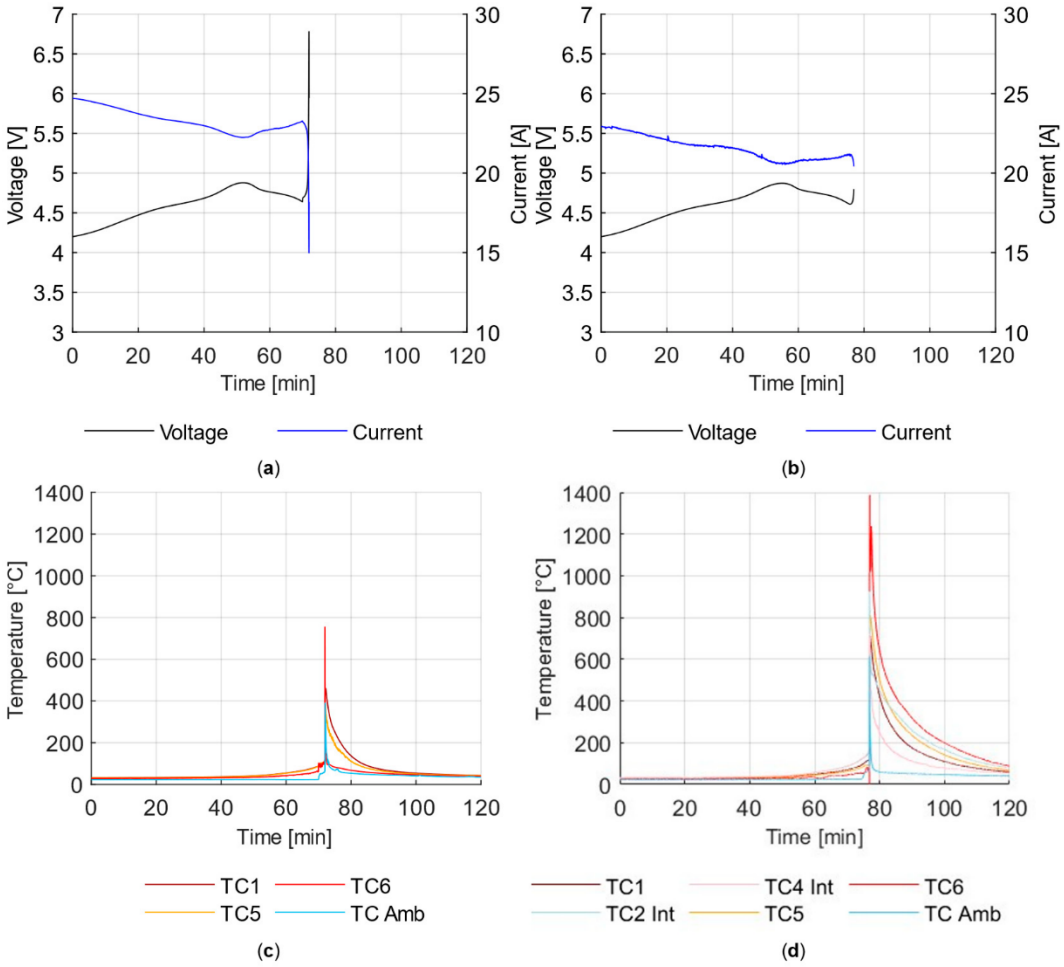

Figure 4. Test data from overcharging CellINT and CellREF without integrated sensors: (a) voltage and current data from the point of the end-of-charge voltage to the thermal runaway for CellREF; (b) voltage and current data point of reaching the end-of-charge voltage to the thermal runaway for CellINT; (c) course of the surface temperature and the ambient temperature above the vents of CellREF during overcharging and thermal runaway; (d) course of the surface temperature and the ambient temperature above the vents of CellINT during overcharging and thermal runaway. [1]

- Temperature Gradient: Significant temperature gradients were observed between internal and surface temperatures, providing valuable insights into heat dissipation within the cell.

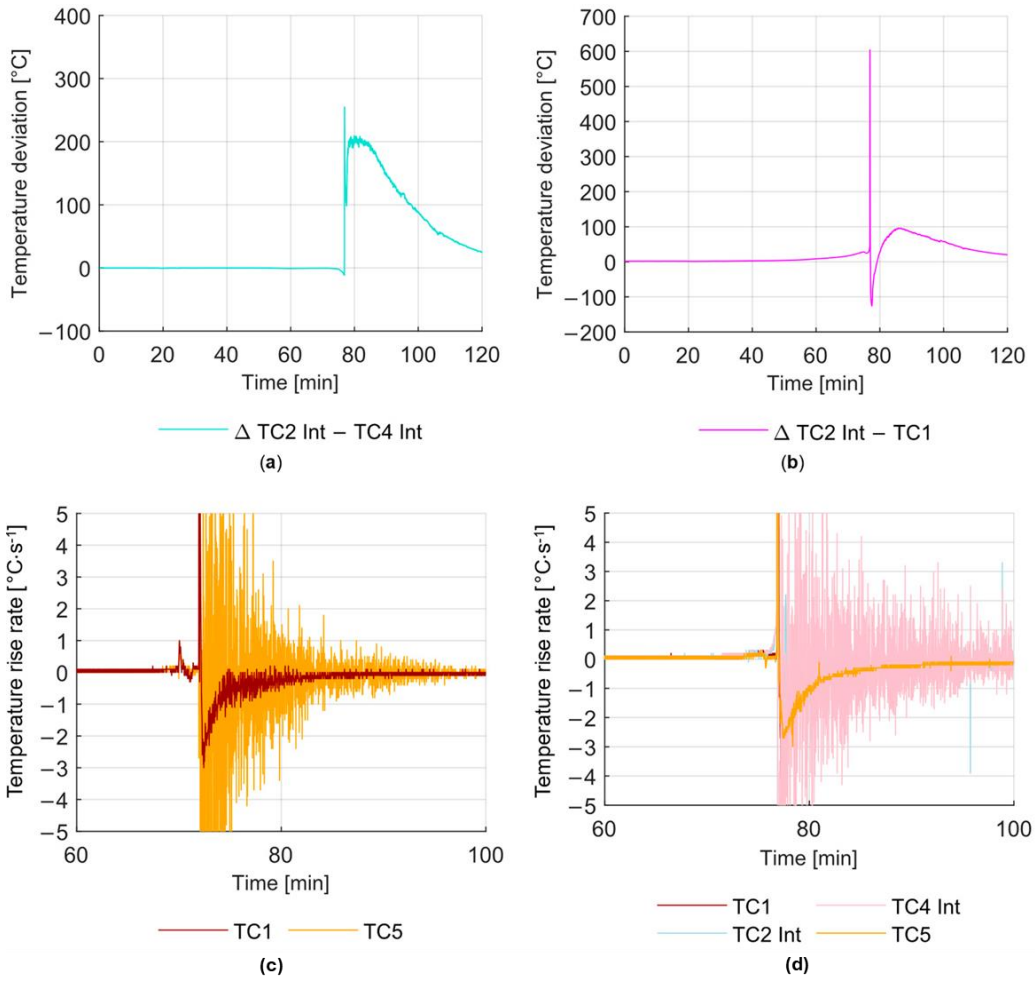

Figure 5. Temperature difference between the thermocouple pairs of CellINT: (a) temperature difference between internal measurement points 2 and 4; (b) temperature difference between internal measurement point 2 and surface measurement point 1. Temperature change rate at various measuring points before, during, and after the thermal runaway limited to an observation range of +/−5 ◦C: (c) surface temperature at measurement points 1 and 5 of $Cell_{REF}$; (d) surface temperature at measurement points 1 and 5 as well as internal temperature at measurement points 2 and 4 of $Cell_{INT}$. [1]

Conclusion

The SI-9300R Battery Analyzer, in conjunction with integrated thermocouples, offers a robust solution for real-time monitoring of lithium-ion battery behavior, particularly during critical events like thermal runaway. Key conclusions drawn from the study include:

1. Compatibility: Existing sensor integration methods for small-format cells can be adapted for large-format prismatic cells without significant impact on cell properties.

2. Added Value: Internal temperature sensing provides valuable data for understanding internal processes and detecting critical conditions earlier, enhancing battery safety.

3. Future Directions: Standardization of sensor integration methods is essential for better comparability and transferability of results in battery development.

In summary, the SI-9300R Battery Analyzer proves to be a reliable tool for researchers and engineers involved in lithium-ion battery research, offering advanced capabilities for real-time monitoring and safety assessment.

Reference

1. Kisseler, N.; Hoheisel, F.; Offermanns, C.; Frieges, M.; Heimes, H.; Kampker, A. Monitoring of Thermal Runaway in Commercial Prismatic High-Energy Lithium-Ion Battery Cells via Internal Temperature Sensing. Batteries 2024, 10, 41. https://doi.org/10.3390/batteries10020041

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