

Electrochemical Impedance Spectroscopy of Lithium-ion Battery Cells under Different Load Conditions

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Summary:

This paper analyzes the Electrochemical Impedance Spectroscopy (EIS) of a lithium-ion (Li-ion) battery cell under different load conditions and explores the corresponding equivalent circuit. The results analyze the EIS spectra at different State of Charge (SoC) levels and illustrate the changes in the electrical parameters. This study highlights the variations occurring during Li-ion battery discharge, which can serve as a basis for real-time EIS monitoring.

Keywords: Electrochemical impedance spectroscopy, SoC, lithium-ion, equivalent circuit

Title

Electrochemical Impedance Spectroscopy of Lithium-ion Battery Cells under Different Load Conditions.

Headlines

Investigating the applicability of real-time monitoring of electrochemical impedance spectroscopy of lithium-ion battery cells under different load conditions.

Background, Motivation an Objective

Electrochemical Impedance Spectroscopy (EIS) is a method of choice used to study the properties of linear time invariant electrochemical systems [1]. EIS works by applying an excitation current or voltage signal over a frequency range to the investigated system and measuring the resulting voltage or current. The derived transfer function represents the internal impedance of the battery cell and can be interpreted as an electric circuit composed of several elements.

EIS is used to analyze Lithium-ion (Li-ion) battery cells in an equilibrium state and under laboratory conditions. A rest period following a charge or discharge cycle is commonly implemented. Different rest periods will yield in different impedance spectra. Similarly, varying temperature values will lead to different results. For this reason, controlled measurement conditions are needed within the same EIS experiments.

Embedded EIS solutions allow impedance measurements using miniaturized and cost

efficient devices. Integrating these chips into Battery Management System (BMS) enhances the performance and provides insightful information about the battery cell during real-time operation. Nevertheless, due to the characteristics of Li-ion battery cells and the connected load, it remains ambiguous which measurement conditions can be used for accurate real-time EIS measurements. Additionally, a reasonable frequency range must be used to be feasible for fast measurements (performing EIS at a single frequency of 1 mHz requires a time period of at least 16.7 minutes).

The main objectives of this paper are to investigate the applicability of real-time EIS of a Li-ion battery cell during operation under different load conditions and analyze the equivalent circuit parameters.

Description of the New Method or System

The experiment was conducted on a lithium-ion LG 18650-MJ1 battery cell that was connected to the BCS6402 battery discharger with the aim of measuring and analyzing the EIS spectra at different load conditions. The battery cell was continuously discharged, while EIS was performed at certain State of Charge (SoC) levels using an embedded EIS development board from Infineon technologies within the measurement frequency range of 7800 Hz to 1 Hz.

Results

To investigate the impact of the load on the impedance spectrum, an EIS measurement was conducted without and with a load while discharging at a rate of 0.02C. As shown in Fig. 1, the impedance spectrum changes in the high-frequency range, while only minor variations occurred in the frequency range of interest (558 Hz to 1 Hz), which can be neglected in high ohmic Li-ion battery cells.

During battery discharge, electrons flow through the external circuit while ions move between electrodes through the electrolyte. Performing real-time EIS at different SoCs during battery discharge is expected to result in observable changes in the equivalent circuit parameters, including the ohmic resistance, double layer capacitance, charge transfer resistance and diffusion process as depicted in Fig. 2. The obtained impedance spectra at 95% and 65% SoC while discharging at different rates of 0.2, 0.5 and 1C is shown in Fig. 3.

Due to the parallel load connected to the battery cell, higher discharge currents are expected to result in lower total ohmic resistance, which can be extrapolated from the intersection of the Nyquist plot with the x-axis. However, due to the increased internal temperature in higher currents, the ohmic resistance of the battery decreases [2], which can be seen at 1C discharge rate.

Double layer capacitance results from the electrode electrolyte interface. At high discharge current density, the rapid movement of ions and current leads to a lower effective double layer capacitance [3]. This is because of the difficulty of ions to migrate quickly.

Charge transfer resistance represents the resistance of electrons transfer between an electrode and electrolyte. At high currents, the effective charge transfer resistance becomes smaller, following the Butler-Volmer equation [4].

During battery discharge, the movement of active species create a concentration gradient. At high and low SoCs concentration gradient becomes high, and this results in fast diffusion. As the battery discharges, the concentration gradient decreases and slows down the diffusion process.

This paper illustrates the EIS equivalent circuit parameters of a Li-ion battery cell while discharging under different load conditions. It highlights the difference if EIS is taken under laboratory conditions after a relaxation time and could be used as a basis for integrating EIS into BMS. Considering the fact that a full-range EIS measurement requires a period of approx. 2.5

minutes, the obtained real-time EIS spectrum might be misleading due to the rapid change in the SoC at high discharge currents. However, performing fast EIS at single frequency points could be considered in real-time EIS measurements.

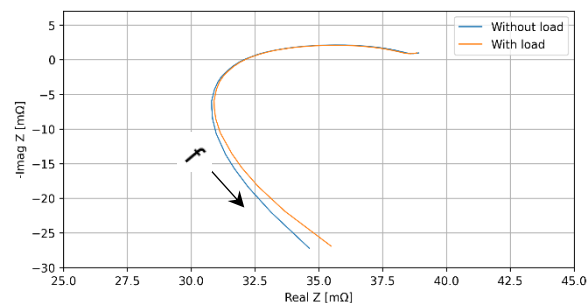


Fig. 1. Impedance spectrum without and with a load.

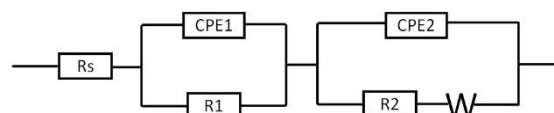


Fig. 2. Equivalent circuit representing the impedance spectrum.

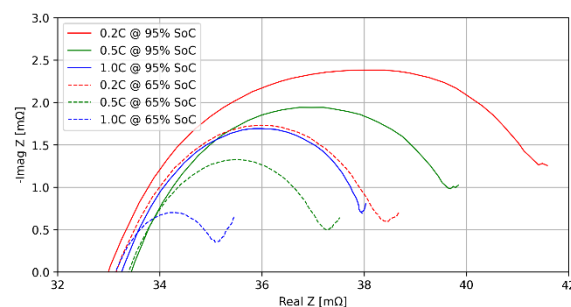


Fig. 3. Impedance spectra at 95% and 65% SoC .

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