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Broadband Methods for Battery Management Systems: Online Impedance Analysis

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Abstract

Lithium-ion batteries have become popular in many industrial and consumer devices. The batteries are often equipped with a battery management system (BMS) to ensure optimal operation and safe use. A key function of the BMS is to monitor the state of the battery's charge and capacity decay. These parameters are not directly measurable and the BMS uses models and tools to evaluate the state of the battery. Recently, the impedance of the battery has been shown to be linked to the state parameters. The impedance is conventionally measured by an electrochemical impedance spectroscopy (EIS) but the method requires a long measurement time (several tens of minutes) which effectively prevents using the method in online use. This paper presents broadband techniques with which the battery impedance can be accurately measured in a fraction of time compared to the EIS.

Introduction

Li-ion batteries can be efficiently characterized by the battery state of charge (SOC) and state of health (SOH), the measures of which are often applied by the battery BMS. The SOC indicates the remaining charge of the battery, while the SOH indicates the battery health conditions. The SOC and SOH cannot be directly measured but they can be estimated from other measurable variables such as the battery voltage, temperature and current. SOC and SOH are key parameters that a BMS must evaluate to ensure efficient and safe usage of the battery [1].

Recent studies have shown that the battery internal impedance varies with respect to the SOC and SOH [1]. The impedance is conventionally measured using a method based on electrochemical impedance spectroscopy (EIS). The method uses single-frequency sinewaves as injections and typically provides accurate impedance estimation, but the method is very slow; measuring an impedance can take up to 30 minutes which effectively prevents most practical applications. Alternatively, the impedance can be measured using broadband methods to decrease the measurement time to only a few seconds [2]. In the methods, the battery is charged and recharged according to the broadband injection, and Fourier techniques are applied to obtain the impedance.

Theory

In this work the battery impedance is measured by applying a broadband perturbation such as the pseudo-random binary sequence (PRBS) [3] and the discrete-interval binary sequence (DIBS) [2]. Both signals have energy at several frequencies making it possible to measure the impedance in a wide frequency band during one measurement cycle. As the signals are binary they are relatively easy to implement in practice using only low-cost components. The PRBS contains certain amount of spectral energy at each harmonic frequency but the DIBS is a computer-optimized sequence in which the spectral energy is maximized at certain user-defined frequencies at the cost of the energy at the other frequencies (without increasing the signal time-domain amplitude). Therefore, the DIBS is particularly useful when high signal-to-noise ratio is required due to, for example, strong external noise.

Experiments

Figure 1 shows the measurement setup to obtain the battery impedance. It consists of a NiDAQ USB-6363 -measurement card, Kepco BOP 50-20MG bi-directional power supply and PC to control the devices and to perform analysis of the measurement results. The measured circuit was composed of an INR18650-lithium-ion cell, a shunt resistor for current measurement and the bi-directional power supply to inject the excitations. The measurement was conducted at an SOC of 80 %.

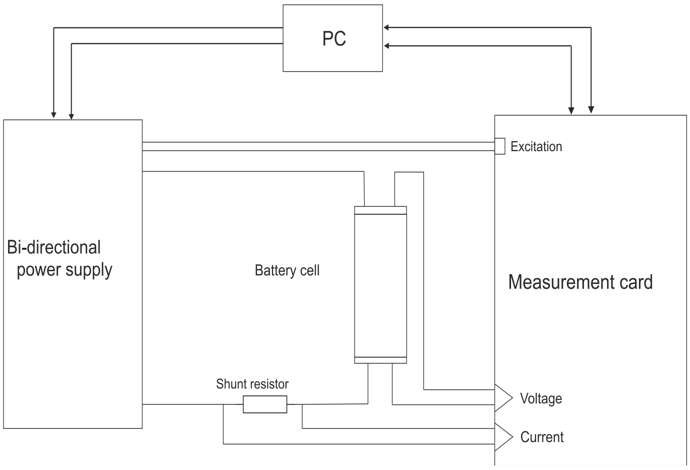

Figure 1:Schematic of the measurement setup

The impedance was measured both by the PRBS and DIBS. Both signals were 511-bit long and generated at 3 kHz. The lowest measured frequency was therefore 5.9 Hz. For the DIBS 20 harmonic frequencies were selected and their spectral energy maximized. Both signals had the same time-domain amplitude (20 mA). Instructions of the PRBS and DIBS design can be found in [3-4]. The impedance was also measured by the conventional EIS to provide a reference. The measurement results are shown in Figure 2.

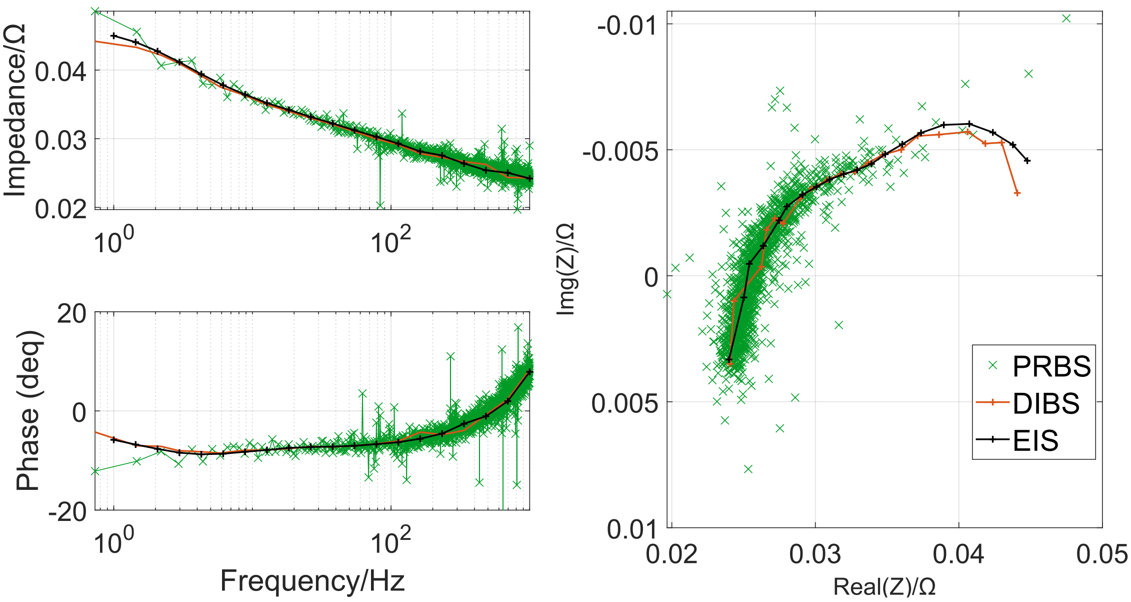

Figure 2:Measured impedance as Bode plot (left) and Nyqvist curve (right).

Figure 2 shows the measured impedance as a Bode plot and a Nyquist curve. As the figure shows, the curve obtained by the PRBS is somewhat scattered due to low SNR. The DIBS, however, follows the reference highly accurately in a wide frequency band.

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