ARTICLE IN PRESS

MR-12427; No of Pages 6

Microelectronics Reliability xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Electronic module for the thermal monitoring of a Li-ion battery cell through the electrochemical impedance estimation

Marco Ranieri [a,*], Diego Alberto [b], Hélène Piret [b], Viviane Cattin [b]

[a] CEA-LITEN, Grenoble, France
[b] CEA-LETI, Grenoble, France

ARTICLE INFO

Article history:
Received 11 February 2017
Received in revised form 1 June 2017
Accepted 7 June 2017
Available online xxxx

Keywords:
Battery monitoring system
Electrochemical impedance spectroscopy
Frequency domain estimation
Wideband identification
Embedded electronics
Sensorless temperature measurement

ABSTRACT

Electrochemical impedance is a not directly measurable parameter of the Li-ion cells that can be exploited to retrieve useful information about the state of the cell itself, such as the State of Charge or the internal temperature. This complex parameter depends on the frequency, which means that it's real and imaginary parts change in function of the frequency at which the cell is activated. Nowadays impedance is mainly measured using laboratory equipment as part of dedicated benchmarks, requiring expensive facilities and relatively long procedures. In this paper we propose a new solution to get the impedance value of a Li-ion cell by using both an efficient approach minimizing the test duration, and an innovative electronic solution suitable for automotive embedded needs. The electrochemical impedance is then analysed to deduce the cell's internal temperature with experimental results.

1. Background

The miniaturization of the analog and digital electronic components is leading the technology of embedded systems towards a higher level of both integration and complexity. The reduction of complexity is the main objective of the "3CCar" (Components for Complexity Control in affordable electrified Cars) European project [1], to which the CEA is contributing. At the same time, new applications in transport and energy storage require the use of Li-ion batteries. Advanced battery management systems (BMS) including electrochemical impedance measurement are studied for the determination of the state of the battery, the prediction of the autonomy and the failure and safety management. Joining these two domains, one of the main research axes developed in 3Ccar is the study and the integration of a Smart Cell. This term usually refers to a Li-ion battery cell to which a certain amount of electronics is coupled and integrated into the same sealed case. The aim is to enhance its interactions with the external world and to make it capable of self-measurement, self-protection and powerline communication.

One of the most substantial parameter that can be implemented into a Smart Cell is its electrochemical impedance estimation, often called EIS for Electrochemical Impedance Spectroscopy. This quantity is known to provide significant information on some most critical parameters of a Li-ion cell, i.e. the State of Charge (SoC[%]), the State of Health (SoH[%]) and especially the cell's internal temperature (T[°C]) [2,3,4]. Nevertheless, even though the EIS of Li-ion battery cells is widely used in laboratories, in test centres and production, its potential for embedded applications is hardly exploited. That is mainly because the EIS procedures are often time consuming and energy consuming for the cell under test, as well as inaccurate and not easy to be put in relation with only one physical phenomenon occurring inside the cell.

With the ambition to find a new path for the electrochemical impedance measurement application, in "3Ccar" the knowledge of this not directly measurable parameter is exploited for the prediction of the thermal state of the cell and the prevention of its thermal runaway. Thus, two sensorless temperature evaluation methods based on the continuous estimation of its impedance are used. These approaches come from the Technical University of Eindhoven (TU/e) [5], and the study of Richardson, Schmidt and Srinivasan [6–8], respectively. Our purpose aims at integrating them within a completely embedded system developed by the CEA.

2. Methodology

A method for the impedance estimation suitable for an embedded application is studied. Our approach, based on two technical breakthroughs, provides a good trade-off between measurement accuracy and test duration. Our innovative system was tested on the benchmark described below using a QinetiQ Li-ion cell [9] (QinetiQ is a member of the "3Ccar" consortium, UK). It is a 12 Ah poached cell, NCA-type

* Corresponding author.
E-mail address: marco.ranieri@cea.fr (M. Ranieri).

http://dx.doi.org/10.1016/j.microrel.2017.06.010
0026-2714/

(Lithium Nickel Cobalt Aluminum Oxide, LiNiCoAlO2), with an energy density of 220 Wh/Kg.

At this stage of the 3Ccar project, we are interested at the reliability verification of the analog circuit. For this reason, the preliminary results we are presenting come from one only cell and the digital signal processing has been performed offline. The statistical validation over different cells is foreseen and already scheduled in autumn 2017.

2.1. Wide band cell activation

We firstly chose to focus on the development of wide band frequency identification method [10] to estimate the cell impedance. This approach is generic, reliable and requires low computation means as it is based on Fast Fourier transform [11]. The choice of the frequency band to address depends on the application: for the internal temperature estimation we focused on the part of the impedance that is mainly affected by the temperature more than by the other cell's parameters, that is 80 Hz to 2 kHz for the used sample cells. To excite the system (Fig. 1), a *Pseudo Random Binary Sequence* (PRBS) [12] is applied as current input (Fig. 2), which simplifies electronics. The PRBS is characterized by a flat power spectral density on a precise frequency band adjusted in function of the frequency area required for the thermal monitoring (Fig. 3).

2.2. Embedded hardware for galvanostatic activation

We secondly developed an embedded electronic analog module capable to switch a controlled current from the cell (galvanostatic activation) on a controlled load during the measurement of the voltage variation of the cell. The switched current can follow any kind of time-shaped signal, allowing the smoothing of the current shape if required for the cell preserving. The onboard amplification of the cell's parameters provides optimal use of the conversion range of the ADC of a microcontroller, improving the accuracy of the estimation [13]. It is important to point out that all the embedded electronics, microcontroller included, are designed to be supplied by the cell itself without affecting the result of the impedance estimation. As the development of the software of the digital part of the embedded electronics will not be available before mid-2017, the acquisition and computation steps were implemented into a specific benchmark, to evaluate the performances of the analog electronics and assessing the reliability of the sensorless temperature measurement through the impedance estimation.

As mentioned above, a point that was carefully studied was how to supply the embedded electronics without affecting the impedance measurement, once the full system integration was achieved. We now have a hardware solution that satisfies this demand (patent pending).

2.3. Benchmark

The test chain we used is depicted in the block diagram of Fig. 4.

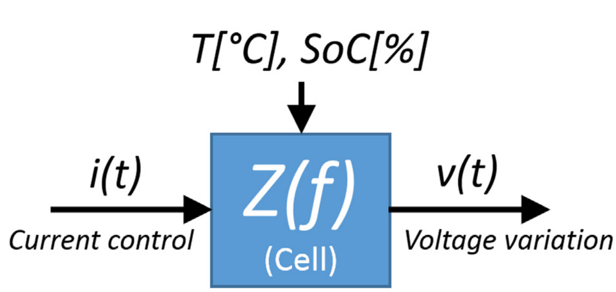

Fig. 1. Electrochemical impedance estimation with galvanostatic approach.

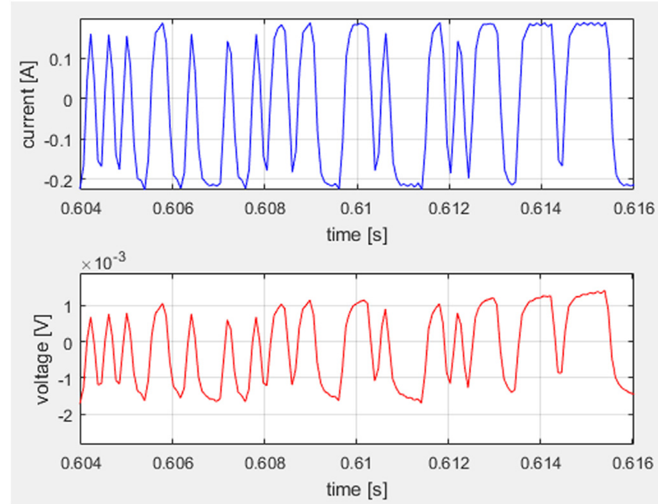

Fig. 2. Example of one single PRBS frame used as current input and measured on voltage output.

The meaning of each block of this benchmark is:

1. Li-ion cell, with 4-point connection to electronics (recommended for low-resistance measurements).
2. Analog electronic embedded circuit, power supplied by the cell itself. It consists on:
   i. A linear system controlling a resistive load connected to the cell, switching a precise amount of current depending on the amplitude of the voltage control applied at its input;
   ii. A high-pass high-gain amplifier for cell voltage;
   iii. A differential amplifier measuring on a 0.1 Ω shunt the current delivered by the cell.
3. OROS OR36 high resolution input/output system, recording the output of the two amplifiers and applying the voltage which controls the switched current.
4. PC controlling the whole benchmark, retrieving the recorded data from the OROS OR36 and performing impedance computation.
5. Tektronix AFG3102 waveform generator, playing a 12.6 ms-long PRBS in loop.

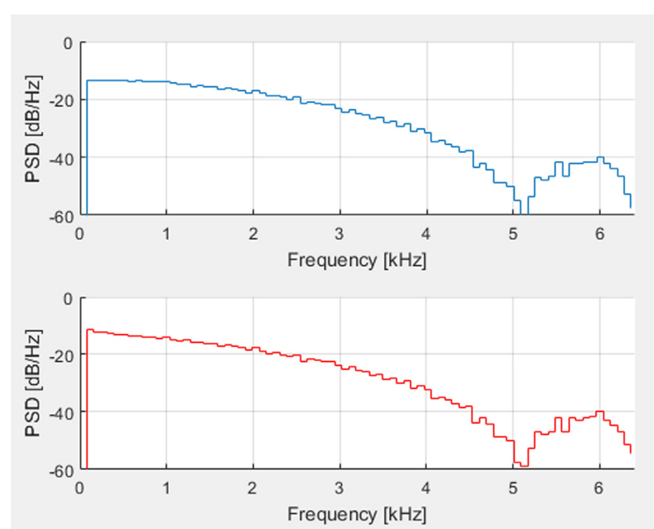

Fig. 3. Power spectral density of the PRBS frames reported in Fig. 2 (current top, voltage bottom). Detail of the nearly flat spectrum in the region 80–2000 Hz (this frequency interval depends on the analysed cell).