Battery Impedance Spectroscopy obtained from Electrochemical Model

Pol Miro, Angel Cuadras

Abstract— **We investigate impedance spectra obtained from an electrochemical model using pulsed signals. We characterize the dependence of NiMH battery parameters such as electrodes porosity and conductivity on impedance. We are able to relate impedance to simulated battery aging. Impedance as a function of state of charge is also investigated. Further characterization on accuracy and resolution and results on temperature dependence will be submitted.**

***Index Terms*—Battery, state of health, degradation, impedance spectroscopy.**

I. Introduction

BATTERY state of health (SoH) determination is a crucial parameter in battery operation. Experimental determination from open circuit or cell voltage, Coulomb counting, impedance or algorism approaches are quite common [1], [2]. Impedance spectroscopy is a reliable experimental technique that has been used for battery characterization for long [3], [4]. It provides an insight that allows discriminating time rates behavior, spatial resolution, and electrical performance when it is conveniently supported by a model. Impedance spectra are obtained from different experimental signals, such as sinusoidal, pulsed, random or even noise.

Pulsed signals offer a simple experimental setup at the cost of mathematical processing [5] in comparison to sinusoidal excitation. Accuracy can be similar in both approaches. Impedance is obtained from the Fourier Transform of the current and voltage signals. Fourier Transform is mathematically processed via the Fast Fourier Transform algorithm FFT.

$$Z = V(\omega)/I(\omega) = \mathrm{FFT}(V(t))/\mathrm{FFT}(I(t))$$

For a better understanding of battery performance, several models attempt to describe their behavior, even in lab environment or in real operation. Models to describe battery degradation have been developed from several approaches, such as electrochemical, electrical or algorithmic [6]–[8]. Electrochemical models are valuable to understand cell performance, electrical models are devoted to battery applications and operation while algorithmic are ideal for battery management.

The combination of experimental techniques and simulation models is a valuable approach to understand the aging mechanisms in the battery cells. We developed an electrochemical model, able to reproduce battery key parameters, voltage and temperature, during charge and discharge. Also, it allowed the battery to be cycled and thus, we could study battery degradation as a function of cycle number and evolution of lithium concentration, porosity and conductivity [9]. In this contribution we investigate the impedance evolution obtained from pulsed signals for NiMH cells and we compute the impedance spectroscopy as a function of battery parameters.

II. Results and discussions

The electrochemical model is able to supply V(t), I(t) and T(t), as illustrated in Fig. 1. Time domain data is transformed to frequency domain and thus, impedance can be obtained

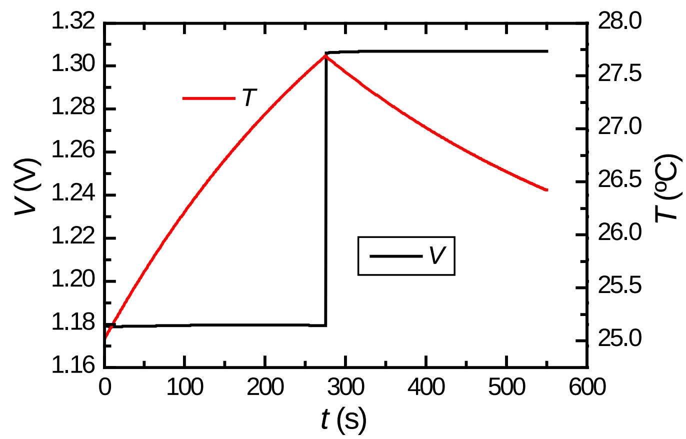

Fig. 1 – Cell voltage and temperature evolution during the injection of a squared signal at 1C of 275

Impedance spectra are function of current pulse, time duration of the pulse, total measurement time and sampling time. A detailed analysis of these variables and their influence on impedance spectra will be presented.

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A. Impedance spectroscopy as a function of DoD

The model is able to simulate the dependence on the depth of discharge (DoD as the complementary of State of Charge SoC), as illustrated in Fig. 2. We observe how impedance changes as a function of DoD.

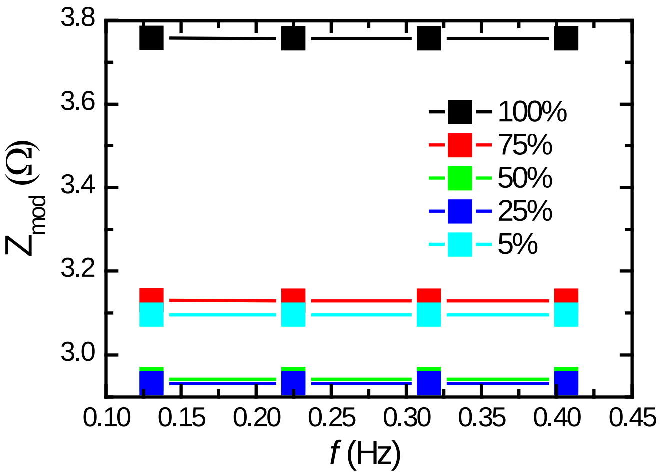

Fig. 2 – Impedance dependence on DoD for a pulsed signal of 10 s, sampling frequency of 1 Hz and total measurement time 550 s.

B. Impedance dependence on porosity and conductivity

In order to characterize cell aging, we modify the values of porosity and conductivity of the electrodes. The reference porosities are 0.481 and 0.5 for the negative and positive electrodes respectively. The conductivities are 1000 Sm^{-1} and 28 Sm^{-1}. Negative porosity was varied between 0.2 and 0.6 for the negative electrode and between 0.25 – 0.75 for the positive electrode. Conductivities varied between 100 and 10000 for the negative and 1 and 1000 Sm^{-1} for the positive. A clear influence on impedance is found for both porosity and conductivity. Dependence on temperature will be also investigated.

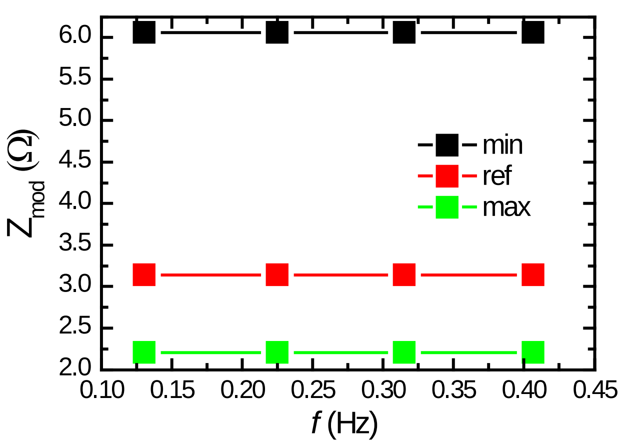

Fig. 3 – Impedance dependence on porosity for a pulsed signal of 10 s, sampling frequency of 1 Hz and total measurement time 550 s

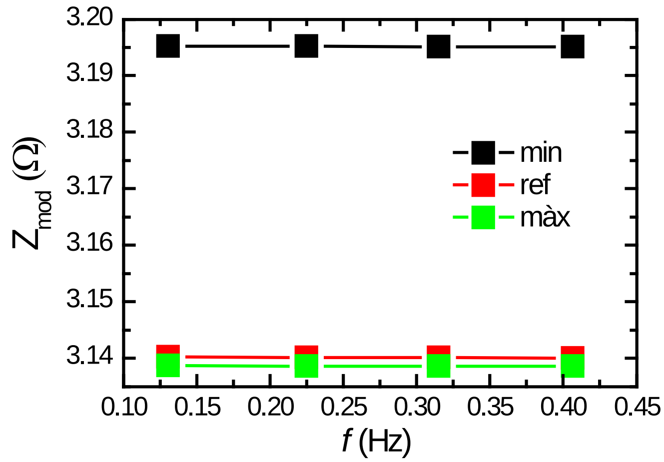

Fig. 4 – Impedance dependence on conductivity for a pulsed signal of 10 s, sampling frequency of 1 Hz and total measurement time 550 s.

III. Conclusion

We theoretically validated a framework to obtain the experimental SoH of a battery. The framework consists of an electrochemical model able to simulate temporal I-V curves. Obtained impedances depend on electrochemical parameters, temperature, DoD and SoH. Thus, the framework can be of interest for a general characterization of electrochemical cells.

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