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Li-ion battery-packs modeling based on joint time-frequency analysis for vehicle applications

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1. Introduction

This work presents a modeling procedure based on time and frequency tests that includes the different time constants associate with the internal processes that occur inside the battery-pack. From experimental results the parameters of an electrical circuit associated to different frequencies are calculated.

The Li-ion battery-pack tested in this work has four parallel-connected strings, each one composed by a series of seven groups of two cells in parallel (in total, 56 MP-176065 Saft cells), as shown in Fig. 1. There is a battery management system (BMS) that controls each of the four parallel strings and the whole pack. The main battery pack characteristics are: rated voltage 25.9 V, maximum voltage 29.4 V, capacity 50 Ah, and maximum current 50 A.

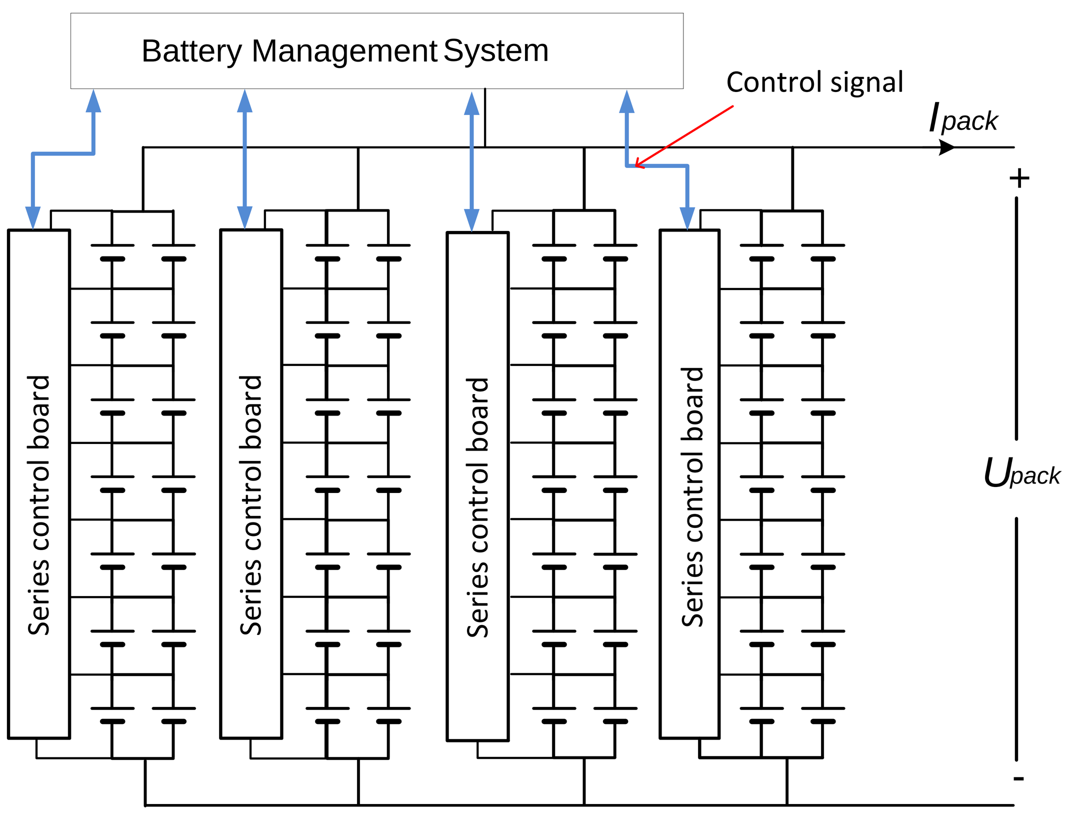

Fig. 1. Battery-pack scheme

2.1. Time domain tests

To determine the SOC-OCV characteristic the battery-pack has been discharged and charged at 10 A current-pulses. The OCV is measured at packs terminals when the relaxation time ends in both discharge and charge tests. The results of charge tests are shown in Fig. 2. The voltage source Eo represents the relationship between OCV-SOC and it is defined by eq. 1

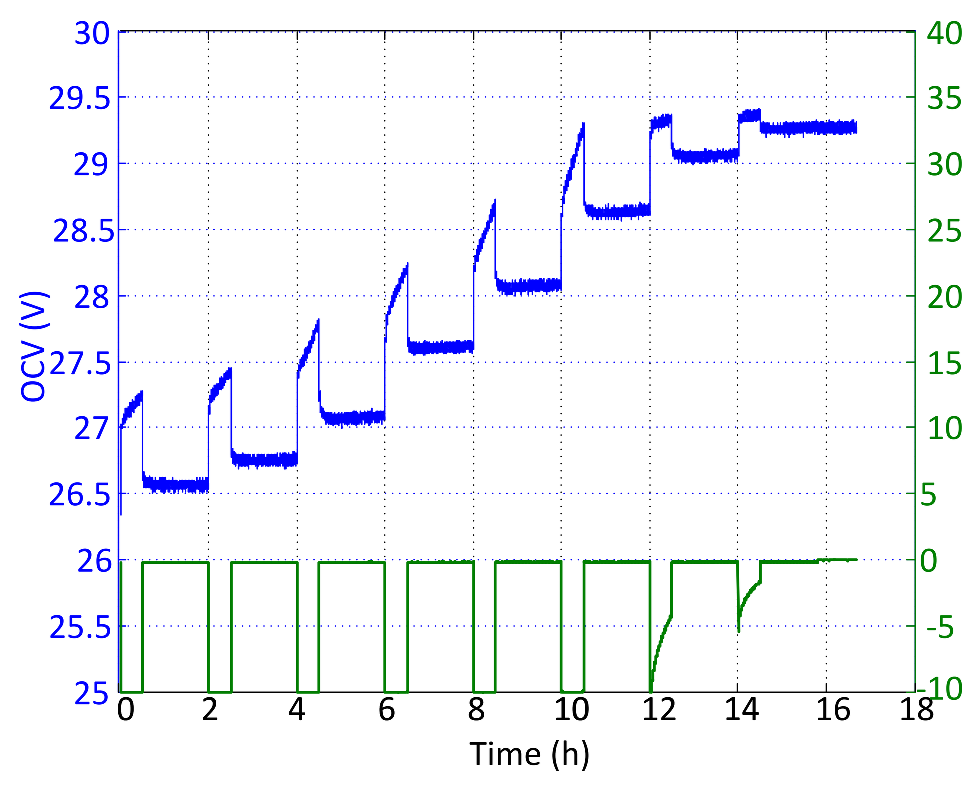

Fig. 2. Charge tests results

$$Eo = 26.05 - 0.15 \cdot SOC + 3.51 \cdot SOC^2 \quad (1)$$

2.2. Frequency domain tests

In Fig. 3 the EIS results to 20% of SOC and its impedance circuit are presented. To reproduce the capacitive behavior three elements are used: a Warburg impedance (W) and two constant phase elements (CPE) in parallel with resistances. The internal resistance is represented by Ro. Finally, to represent the inductive behavior an inductance (L) is included.

The model of the battery-pack based on time-frequency tests is presented in Fig. 4. *Upack* represents the battery-pack voltage and it is defined by *Upack*= *u*$_{Ro}$–*u*$_{C1}$–*u*$_{C2}$-*u*$_{C3}$. *Ipack* is the current.

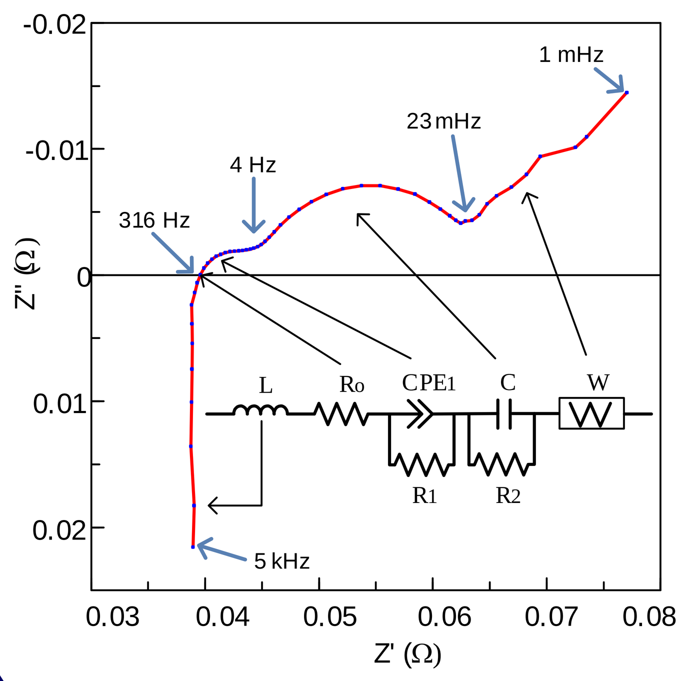

Fig. 3. EIS tests results

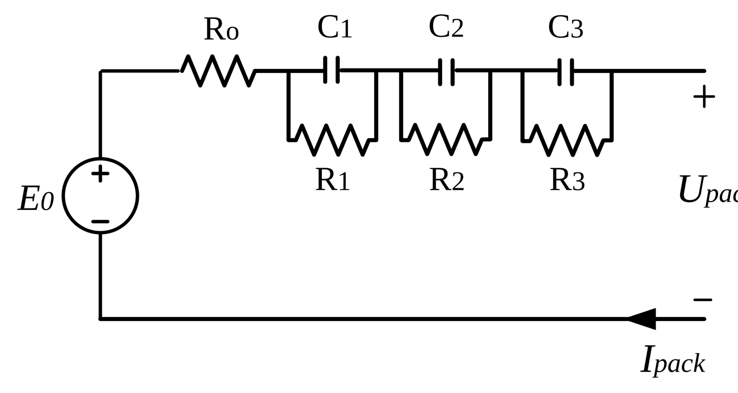

Fig. 4. Battery-pack model

3. Experimental validation

The battery-pack model is experimentally validated for an electric vehicle application. For this purpose the electric vehicle is simulated using a hardware-in-the-loop simulation (HIL). During the HIL simulation the current profile and the voltage of the battery-pack at each driving cycle are recorded. The signals of the current profiles have been introduced as the input of the pack model (Fig. 4) which has been implemented in Matlab/Simulink®. To determine the model accuracy the voltage response of the battery-pack model has been compared with the real voltage measurements at battery-pack terminals.

Fig. 5. HIL test bench

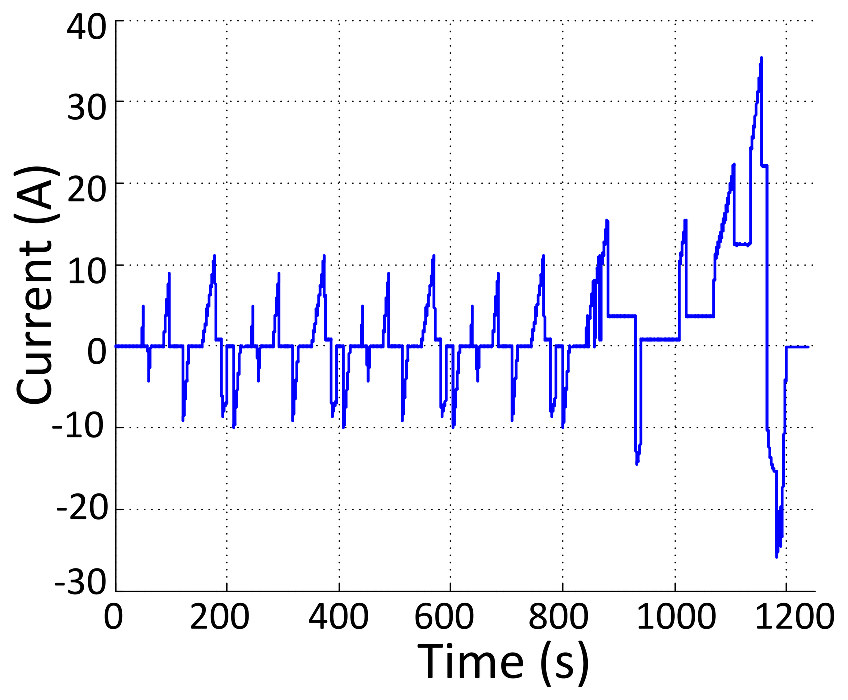

Fig. 6. Current at NEDC

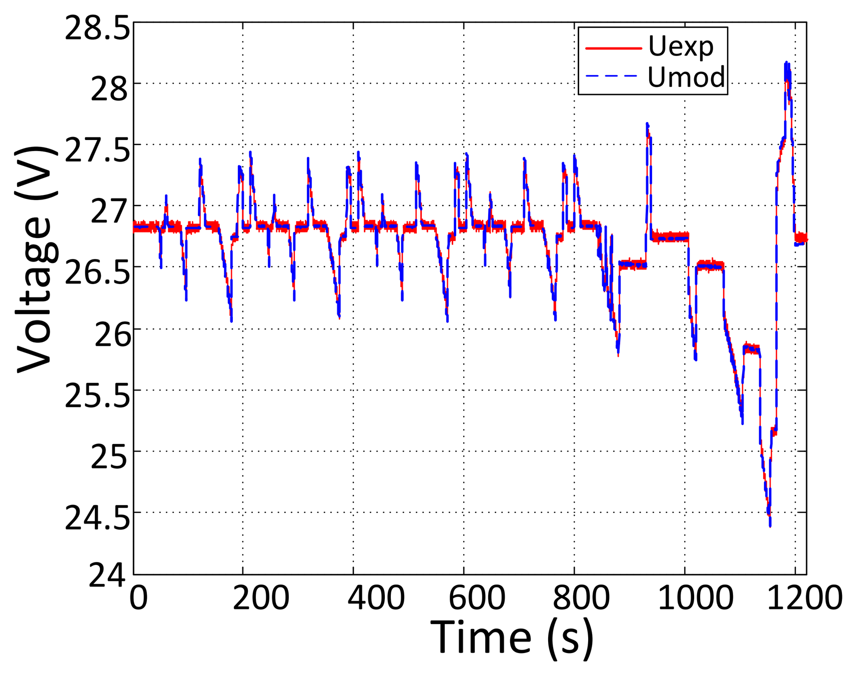

Fig. 7. Voltages comparison

4. Conclusions

From current interruption and EIS tests the parameters of the electrical model have been calculated. The model includes three RC networks which reproduce the dynamic behavior of the battery-pack. The model was validated for different driving cycles by means of a HIL experimental test bench. Validation tests show that the model is consistently accurate (maximum error less than 1%) to reproduce the battery-pack response under vehicle applications.