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Review

Dynamical modeling procedure of a Li-ion battery pack suitable for real-time applications

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ABSTRACT

This paper presents the modeling of a 50 A h battery pack composed of 56 cells, taking into account real battery performance conditions imposed by the BMS control. The modeling procedure starts with a detailed analysis of experimental charge and discharge SOC tests. Results from these tests are used to obtain the battery model parameters at a realistic performance range (20–80% SOC). The model topology aims to better describe the finite charge contained in a battery pack. The model has been validated at three different SOC values in order to verify the model response at real battery pack operation conditions. The validation tests show that the battery pack model is able to simulate the real battery response with excellent accuracy in the range tested. The proposed modeling procedure is fully applicable to any Li-ion battery pack, regardless of the number of series or parallel cells or its rated capacity.

Contents

1. Introduction

The evolution of the transportation and grid sectors towards a more sustainable future is leading the research and development of electrochemical energy storage systems, and batteries in particular. The relevance of batteries is increasing as new materials improve its power and energy density, allowing batteries to take a more relevant role in vehicle propulsion and smart grids. Lithium battery technology is currently dominant as it presents high energy density, power density, and long shelf life [1]. However, it can present unstable behavior that can potentially lead to thermal runway [22–24]. This is the main reason why lithium batteries need a

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battery management system (BMS). The BMS will protect the battery from undervoltage/overvoltage, short-circuit (maximum current limit) and thermal runway [2]. It will also measure cell voltage, module current, temperature, and estimate the battery state-of-charge (SOC) and state-of-health (SOH). It is usual to set the SOC operating limits to 20–80% in order to use battery efficiently [2,13], and may be even more restricted in some demanding applications [14].

Therefore, packs based on lithium technologies need a different modeling approach than other technologies due to the presence and operation of the BMS. Battery models for previous technologies still in use, such as nickel or lead, are exclusively based on the cell, as no BMS is present [25]. This practice has been extended to lithium technologies [26,27] too, disregarding the effect of BMS on the battery operation.

This paper presents a different modeling approach that considers the effect of the BMS on the battery operation. To frame this work with existing modeling techniques, a discussion of the mainstream lithium batteries modeling approaches is presented next.

The most detailed models include electrochemical or physical based models [3–5], of a single cell, which are able to accurately describe the internal phenomena taking place in the battery. Despite their accuracy, these models are very complex, the coupled non-linear differential equations that compose them are difficult to implement and require heavy computational work [6], and they model a single cell instead of a whole pack and thus are rarely used in real-time applications in BMS.

A common approach due to its simple design and fast computation is the electrical equivalent circuit model, which can be developed for both cell and pack models. The procedure to obtain these models can be through frequency or time domain tests. Frequency domain tests, even if they can render highly detailed models, are highly time consuming, need expensive equipment and are normally run on individual cells rather than on the whole pack [6,20]. These tests superpose a variable frequency signal to the battery current using an impedance analyzer, which is an expensive equipment. This allows obtaining the battery impedance over a wide frequency range, which gives insight to variable battery operation depending on the dynamic requirements [33]. However, this is at the cost of long testing times in order to reach the mHz frequency order. On the other hand, time domain tests can result in less detailed models, but can be less time and resource consuming and can be used to develop battery pack models. In this paper we will discuss models using time domain tests.

Some authors have designed simple electrical circuit models composed by an ideal voltage source in series with a constant internal resistance [6–8]. Such a model can only be used in an early stage of battery sizing, because it does not offer information regarding the dynamic behavior of battery [7,9] and [21]. In order to take into account other variables, like the state-of-charge (SOC), and electrochemical processes inside the battery, some improved models have been proposed. Circuit models suggested by [9–11] and [15] introduce a RC network to simulate battery kinetics and polarization process. More complex models have been developed by adding electric passive and nonlinear components able to reproduce battery runtime, non-linear processes and transient response [7,12,30] and [31].

However, all these models are focused on the short term dynamics on the battery and do not take into account the operational limitations due to the BMS operation, as they consider that the battery behavior is the same from 0% to 100% SOC and do not take into account the battery control restrictions present in practical applications. It is usual to set the SOC operating limits between 20% and 80% in order to use battery efficiently [2,13], and may be even more restricted in some demanding applications [14]. Also, most authors only experimentally validate the model for a single SOC. But the battery model may not be able to correctly reproduce other SOC, especially those near the minimum and maximum SOCs. The approaches used by these authors are only realistic if no BMS is involved. Lithium technologies do include the BMS, which influences the battery operation. Hence, the modeling approach must evolve into considering it.

A new approach that considers the BMS operation for this battery and its influence on the pack performance is proposed here. This paper will demonstrate that the whole pack model developed is able to represent the battery short and long term dynamics while considering the BMS. The short term dynamics will include transient diffusion and charge transfer process, whilst the long term will represent the long term dependence of the internal voltage with respect to the SOC. This long term dependency of voltage with SOC will be represented through a variable capacitor in order to better model the fact that a battery pack has a limited capacity. This voltage-SOC dependency is commonly modeled through an

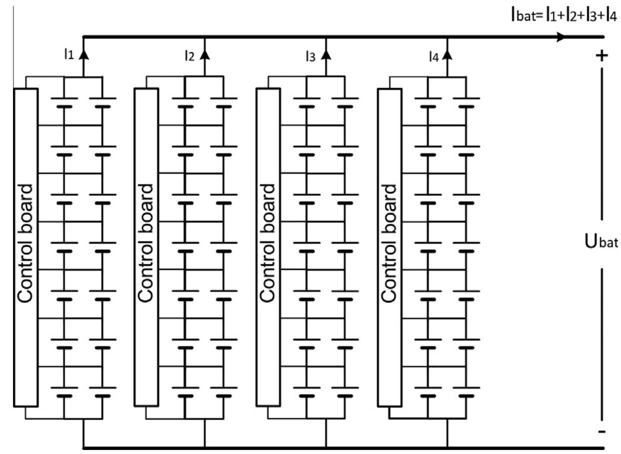

Fig. 1. Battery layout.

Table 1
Battery characteristics.

Rated voltage	25.9 V
Maximum voltage	29.4 V
Minimum cut-off voltage	20.3 V (approx. 2.9 V/cell)
Capacity	50 A h
Maximum current	50 A
Range of temperature (charge)	−20 °C to 60 °C
Range of temperature (discharge)	−30 °C to 55 °C

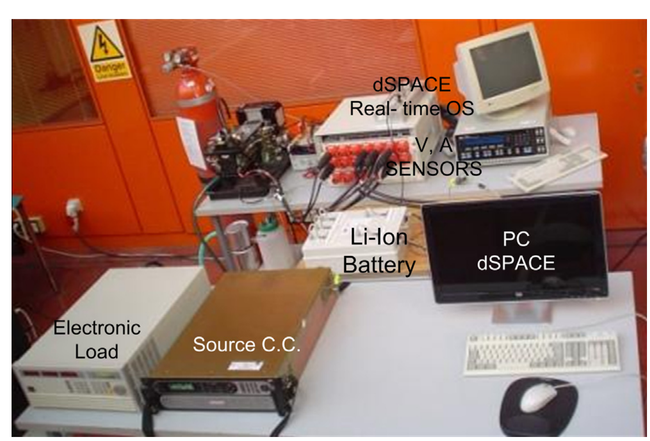

Fig. 2. Experimental setup.