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Dynamic model of lithium polymer battery – Load resistor method for electric parameters identification

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ABSTRACT

Maximum battery runtime and its transients behaviors are crucial in many applications. With accurate battery models in hand, circuit designers can evaluate the performance of its developments considering the influence of a finite source of energy which has a particular dynamics; as well as the energy storage systems can be optimized. First, this work describes a complete dynamic model of a lithium polymer battery. In the sequel a simple and novel procedure is used to obtain the electric parameters of adopted model with the advantage of using only one resistor to represent the battery load and a pc-connected multimeter. The methodology used to identify the parameters of the battery model is simple, clearly explained and can be applied to various types of batteries. Simulation and experimental results are presented and discussed, demonstrating the good performance of the proposed identification methodology.

1. Introduction

Batteries have been more and more pervasively used as the energy storage and power source for various electrical systems and devices, such as communication systems, electronic devices, renewable power systems, electric vehicles, etc. Although the popularity of portable electronics has propelled battery technologies, such as nickel cadmium (NiCd), nickel-metal hydride (NiMH), lithium-ion (Li-ion), and polymer Li-ion, those battery technologies cannot yet meet the progressive energy demands and size limitations of today's portable electronics [21,22] and mobile robots [1,2].

Many traditional designers of a lot of battery-powered devices tend to assume that the battery is ideal, that is, it would have a constant voltage throughout the discharge, and would also have a constant capacity for all discharge profiles, which is not always true.

Battery models are essential for any battery-powered system design that aims at extending the battery's expected life and in battery power management using energy optimization approaches [3]. On the other hand, some devices must be tested taking into account the fact that the electric voltage used is neither constant nor ideal.

In recent years, a number of researchers have begun to investigate the characteristics of battery sources and their impact on low-power circuit optimization techniques and power management strategies. Many battery models have been proposed in the literature and the respective parameters are identified by different methods. In Ref. [27] the Gauss–Hermite quadrature filter (GHQF) is introduced to estimate battery state of charge (*SOC*) based on a common electrical analog battery model useful for real time applications. The authors in [28] propose an Unscented Kalman Filter (UKF) for 'online' estimation of the Lithium-Ion battery model parameters and the battery SOC, based on the updated model. All these techniques required not simple equations and add power consumption related to perform the necessary calculations [26].

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Moreover, the procedure to identify the battery parameters is not entirely clear in the literature; e.g. in [7], the values of resistors and capacitors of the proposed model are estimated by fitting experimental points, but it is not clear how these points have been experimental obtained.

But the other hand Ari Hentunen et al. [32] presents an analytical time-domain-based parameter identification method for Thevenin-equivalent circuit based lithium-ion battery models. In Ref. [33] online adaptive parameter identification for lithium-polymer battery cells is presented and an observer based on the updating model to estimate the SOC is proposed. The authors in Ref. [34] proposes an adaptive hybrid battery model-based high-fidelity state of charge (SOC) and state of health (SOH) estimation method for rechargeable multicell batteries, where hybrid battery model consists of an enhanced coulomb counting algorithm for SOC estimation and an electrical circuit battery model. In all this cases the parameters identification is well explained and the presented methods perform well, but many electronic equipments are needed to perform the proposed experiment (electronic loads, power analyzer, current sensor, battery testing system).

This paper describes a novel and simple test-procedure that can be used to derive electric parameters of a lithium-polymer battery model in order to identify the parameters with a good tradeoff between accuracy and complexity. The state of charge of the battery can be obtained online through simple equations as demonstrated hereinafter. The major contributions of this work is a simple and rapid method for identifying electrical parameters of the adopted battery model by using only one resistor, instead of an electronic load as used in the literature.

This work is organized as follows: Section 2 reviews the state of the art in battery models. Section 3 explains the battery model adopted, presenting its main advantages and highlighting the dynamics of interest. Section 4 describes a battery test system and experimental procedure used to identify the parameters of the model adopted. Section 5 presents the simulations results comparing with experimental data. Finally, some concluding remarks are presented in Section 6.

2. Background

Battery is a dynamic and nonlinear system with many chemical reactions. Its internal characteristics and circuit parameters change according to the state of charge (SOC) and the operational temperature. To understand how the batteries work, some authors have proposed mathematical models to predict the battery behavior under several workload conditions. In [8], a closed form analytical expression to predict the remaining capacity of a lithium-ion battery is presented. Rakhmatov and Virudhula [9] developed an analytical expression to estimate battery lifetime though various time-varying loads by taking into account the changes in the concentration of the electroactive species inside the battery. A nonchemical based partially linearized (in battery power) input–output battery model, initially developed for lead-acid batteries, was developed in Ref. [10]; then after tuning the parameter values, the model can be extended to different types of batteries such as lithium-ion, nickel-metal hydride and alkaline. In order to present a battery model from a systems and controls perspective, a novel compact form of existing electrochemical model from literature is introduced in Ref. [11].

On the other hand, many electrical models of batteries, from lead-acid to polymer Li-ion batteries, have been presented in the literature [7,12–14]. Electrical models are more intuitive and easy to handle when they are used in circuit simulators and alongside application circuits. Almost all the propose models include different interconnection topologies of resistors, capacitors and inductors (e.g. Thevening, Impedance and runtime-based electrical battery models). Heuristically, more *RC* circuits provide a better modeling accuracy; however, some criterions must be enacted to demonstrate how much it is appropriate. Thus, in Ref. [17] a single *RC* circuit was used justifying that it offers a suitable trade-off between performance, complexity and usability. In contrast, three *RC* circuits have been used in Ref. [13]. By the other hand, a simple resistor-capacitor battery model is proposed in Ref. [18], where the modeling errors caused by the simple model are compensated by a sliding mode observer. Moreover, a single resistor is used by the authors in Ref. [19] and the thermal effect is considered to generate a holistic understanding of the battery. In the same context, taking into account high switching frequency applications, in Ref. [14] the authors have considered an inductance and two *RC* networks. This inductive component (insignificant at low frequency), has the property that the impedance increases in the high-frequency region.

In the battery, ohmic resistance is as a consequence of the finite conductivity of electrodes and separators, the concentration gradients of ionic species near to the electrodes and the limited reaction rates (kinetics) at the electrode surfaces. The capacitive effects arise from double-layer formation at the electrode/solution interface which includes capacitance due to purely electrical polarization and capacitance from diffusion limited space charges (pseudo-capacitance). Both capacitive effects influence the transient response of the battery, especially during high rate reaction. The magnitude of each effect depends on the particular battery chemistry and on the design parameters (such as geometry, pore structure and materials of electrodes, electrolytes and discharge rate).

Moreover, in order to evaluate the best battery discharge policy, many authors are interested in the charge movement during discharge and recovery, then different models have been used like 'diffusion model' and 'Kinetic Battery model' (KiBaM) [21–24]. The main disadvantage of these models is the absence of I–V information which is important for circuit simulation and optimization.

In order to obtain specifics dynamics captured by different models, some authors have proposed a mixed model of the battery as demonstrated in Ref. [25]. Furthermore, T. Kim and W. Qiao [16], have proposed a hybrid battery model, which takes the advantages of an electrical circuit battery model to accurately predict the dynamic circuit characteristics of the battery and an analytical battery model to capture the nonlinear capacity effects for the accurate tracking and runtime prediction of the battery state of charge (SOC). In addition, it is important to note that many efforts are still being conducted to find ways to model the behavior of the batteries, taking into account different operating conditions. This is evident in the recent literature [5,6,31].

In any case, the study of the state of the art suggests that a good starting point for choosing a specific battery model is to predefine the particular type of application and under which conditions the battery will work (in other words, the dynamics to be excited).

3. The battery model

In this work the model adopted is the hybrid one, which is based on a mix of the electrical circuit battery model and Kinetic battery model (KiBaM) [16]. This model was chosen due to its capability of capturing nonlinear capacity effects (such as the recovery effect and rate