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Experimental validation for Li-ion battery modeling using Extended Kalman Filters

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ABSTRACT

The battery management systems (BMS) is an essential emerging component of both electric and hybrid electric vehicles (HEV) alongside with modern power systems. With the BMS integration, safe and reliable battery operation can be guaranteed through the accurate determination of the battery state of charge (SOC), its state of health (SOH) and the instantaneous available power. Therefore, undesired power fade and capacity loss problems can be avoided. Because of the electrochemical actions inside the battery, such emerging storage energy technology acts differently with operating and environment condition variations. Consequently, the SOC estimation mechanism should cope with the probable changes and uncertainties in the battery characteristics to ensure a permanent precise SOC determination over the battery lifetime.

This paper aims to study and design the BMS for the Li-ion batteries. For this purpose, the system mathematical equations are presented. Then, the battery electrical model is developed. By imposing known charge/discharge current signals, all the parameters of such electrical model are identified using voltage drop measurements. Then, the extended kalman filter (EKF) methodology is employed to this nonlinear system to determine the most convenient battery SOC. This methodology is experimentally implemented using C language through micro-controller. The proposed BMS technique based on EKF is experimentally validated to determine the battery SOC values correlated to those reached by the Coulomb counting method with acceptable small errors.

Introduction

Today, whether in stationary or embedded systems, it is necessary to store large amounts of electrical energy. As embedded applications, the development of hybrid or full electric vehicles (EVs) in transport fields is accounted. Indeed, the electric battery is a key member of electric cars. It directly affects the performance and especially the autonomy of ecological automobiles. In modern electric power systems, as stationary applications, the integration of new and green technologies of energy storage components especially the novel battery technologies presents fundamental solutions for: (i) overcoming the negative emissions of establishing more new

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conventional power plants; (ii) attaining the desired energy supply/demand request; (iii) avoiding the probable risks and impacts caused by the intermittency of renewable energy sources within the power system; (iv) minimizing the climate change problems; and (v) coping with the commitments of reaching the European Commission 20-20-20 energy targets (20% energy efficiency increase, 20% CO_2 emission reduction, and 20% energy produced by renewables in 2020).

Recently, Li-ion batteries can drastically improve the technical characteristics of EVs for various uses. However, Li-ion batteries require very special supervision. Hence, the need to integrate battery management system (BMS) as a supervision system becomes of great interest. The accurate state of charge (SOC) determination has a key role for BMSs both to forecast the remaining charge range and to identify an effective management strategy. Therefore, safe, robust and reliable battery operation will be ensured.

Different approaches have been proposed to estimate the SOC [1–21]. The coulomb counting (Ah) method can be easily realized for online SOC measurements. Through the error accumulation of incorrect measurements, particularly with an inaccurate estimation of the battery initial SOC, the identification of accurate battery SOC remains difficult. Others methods based on detailed electrochemical equations have been introduced [1]. These methods are hard to implement because of their complex partial differential equation representation. Many recent studies have introduced the SOC determination approaches including: voltage-based correction [2,3] fuzzy logic based techniques [4–8], neural network (NN) [9–11], the kalman filter (KF) and the extended kalman filter (EKF) approaches [12–21] and the sliding mode observer (SMO) [6].

To the best knowledge of the authors, the state of the art of battery control strategies has been addressed for short term objectives using voltage based design limits. The improvement of the battery performance and the extension of its lifetime using the design limits have been rarely discussed particularly when accounting for the internal electrochemical variables.

Therefore, the original contribution of this paper is to properly introduce the experimental validation of the EKF approach of the BMS of Li-ion battery. As lithium-based battery technologies show rapid ongoing advancement, their key roles as energy storage systems –in future energy and automotive sectors– have to be verified. Therefore, the applicability of the EKF for the Li-ion battery modeling is theoretically studied and experimentally validated.

Developing an accurate SOC estimator for BMS design has attracted remarkable attention in both energy and transport system researches. Different studies have highlighted the importance of the precise SOC determination for the BMS design in various battery technologies. In Ref. [22], Xu et al. (2014) have presented an adequate online battery SOC determination approach with reduced prior battery testing information through initial parameter identification. Experimentally, the identified parameters could appropriately characterize the Li-ion battery under different drive cycles and accurately estimate online its SOC [22]. Farmann et al. (2015) have introduced a comprehensive discussion of the different methods/algorithms used for Li-ion battery on-board SOC and capacity identification [23]. In the study, the authors have demonstrated different algorithms for the on-board capacity determination in EVs and HEVs [23]. Ranjbar et al. (2012) have verified that the Li-ion batteries' have high levels of both energy and power density compared to other technologies [24]. A prediction approach of the terminal voltage in Li-ion batteries based on the impulse response concept has been theoretically proposed and experimentally verified [24]. Fang et al. (2014) have introduced an adaptive SOC estimator for BMS design and SOC determination in real time when the model parameters are unknown [25]. Through the simulation and experiment analyses, the estimator may hopefully have strong practical appeal owing to the adequate accuracy and easy implementation [25]. Zhang et al. (2014) have furnished a rigid method of Li-ion battery's SOC based on the robust EKF for the fabrication of hybrid electric vehicles (HEVs) [26]. The study tackles the problem of external parameters effect on SOC estimation through the use of EKF approach [26]. Sepasi et al. (2014) have presented the model adaptive extended kalman filter (MAEKF) for the SOC estimation of Li-ion batteries. The authors have shown that the accuracy of SOC estimated by EKF is sensitive to cell's electrical model resistors [27]. Optimization technique, therefore, would be necessary to update the electrical model parameters [27]. He et al. (2014) have proposed a NN–based battery model to determine the SOC based on a feed-forward NN and an Unscented kalman filter (UKF). Smooth estimations with sufficient accuracy have been attained when the UKF was adopted to produce the NN outputs and filter out the errors [28]. Dong et al. (2015) have verified that the state of energy (SOE) can be an important evaluation index for energy optimization and management of power battery systems in EVs. For the SOE, a method based on wavelet-NN has been proposed. To improve the model accuracy, the temperature and discharge rate have been considered. Although the hardware cost has been reduced, the complexity of the algorithm in use should be simplified in future studies [29].

Despite the numerous recent published papers concerned with this issue [30–33], there is still a technological gap particularly for BMS design, precise battery SOC, SOH, and lifespan determination. Therefore, the fundamental contribution of this study is to propose a BMS technique based on EKF to determine accurate SOC for the battery.

The rest of the paper is organized as follows: In Section Li-ion battery technology, a concise definition for the Li-ion battery technology, its advantages/drawbacks and the battery model are presented. The different SOC determination methods are explained in Section SOC determination. The description of two kalman-based methodologies is introduced in Section EKF approach. The parameter determination of the Li-ion battery electrical model besides the experimental validation for the EKF to properly estimate the SOC for ensuring an adequate BMS in comparison with the coulomb counting approach are presented using the bench-test prepared by the authors in Section Parameter determination and Experimental results respectively. Finally, the conclusions and the perspectives of the research are drawn.

Li-ion battery technology

Li-ion batteries: advantages and drawbacks

In comparison with other battery types, as shown in Fig. 1, Li-ion battery systems have relative higher energy density. Lead