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Online State-Estimation of Lithium-Ion Battery's Operational States Using the Electrochemical Model Based Nonlinear Kalman Filter

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Extended Abstract

The fossil fuel downsides and the energy crisis are the driving force toward clean and sustainable energy sources. Energy storage technology is a crucial solution to the shortcomings of renewable energy sources such as availability and portability. Due to their high specific energy and energy density, Li-ion batteries are known as the most popular and applied energy storage technology in portable electronic devices and electric vehicles [1]. Nevertheless, to ensure their safe and efficient performance, and also to prolong their life, battery management systems (BMSs) are used to monitor and control them during the charging and discharging process. The Li-ion battery performance is reported using the battery's operational states such as state of charge (SOC) and state of health (SOH). However, because of the impreciseness of sensor measurements, the model-based battery state estimation is the more preferred approach. BMS is based on empirical models such as equivalent circuit models, these models lack physical inside [2]. This study aims to use the continuum electrochemical lithium-ion battery model in addition to the Kalman filter algorithms to predict battery external and internal dynamic behavior. In this regard, the diffusion and migration of Li-ion in the electrolyte, the salt diffusion inside porous electrodes, as well as the charge balance inside each solid/liquid phase are considered to simulate the battery's dynamic behavior. Therefore, the lithium-ion battery electrochemical model is suitable not only to mimic macro-scale Li-ion cell outputs but also to shed a light on their micro-scale internal variables' dynamics. On the other hand, the Li-ion battery model's parameters are temperature dependent. Hence, the environmental temperature and generated heat during battery operation strongly affect their performance. Considering the time fluctuations of input and environmental conditions, the transient thermal behavior of the lithium-ion battery should be followed as well [3], [4]. The pseudo-two-dimension (P2D) model is the most well-known Li-ion battery electrochemical-based model introduced by Doyle et al. [5] in which the battery cell model comprises two porous electrodes maintained apart by a separator. However, the full-order P2D model's high computational time represents an essential shortcoming for the onboard applications. The simplified electrochemical model presented here can predict the Li-ion battery's behavior accurately almost fifteenth time faster than the full-order model. In the proposed simplified model, each electrode is considered a single spherical particle that has an active area equivalent to the porous electrode. It also considers the nonlinearities stemming from temperature and concentration dependency of parameters, and it is implemented as a base model to design a nonlinear Kalman filter estimator to predict the battery's operational states. To test both efficiency and robustness of the nonlinear electrochemical model-based Kalman filter, its performance was investigated under two different kinds of input current loads, constant C-rate and US06 (a highway driving schedule). The result reveals the estimator can predict the battery's macro and micro scale states with and without error in the estimator model's initial conditions. The results show when the estimator model starts simulation with a 30% error in the states' initial conditions, the estimated SOC can reach less than 1% error with real value in less than 50 seconds.

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