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A novel dual H infinity filters based battery parameter and state estimation approach for electric vehicles application

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Abstract

An accurate battery parameter and state estimation method is one of the most significant and difficult techniques to promote the commercialization of electric vehicles. This paper tries to make three aspects of effort. First, to avoid the battery state-of-charge (SoC) estimation inaccuracy brought by the variation of the model parameter under different aging level and operation condition, a novel dual H infinity filters was proposed and employed to execute the online measured data based battery parameter and SoC estimation. Second, to overcome the drawback of the H infinity filters are sensitive to their initial noise information. An adaptive H infinity filter employing the covariance matching approach was proposed and applied to realize a robust SoC estimation. Last, the accurate estimate of battery parameter and SoC were obtained real-timely through model-based dual H infinity filters. A systematic evaluation on the different algorithms based SoC estimation was carried out. Experimental results on various degradation states of lithium-ion polymer battery cells further verified the feasibility of the proposed approach.

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Keywords: Battery management system; H infinity filter; the dual H infinity filters; Adaptive update

1. Introduction

With the superiority of high specific energy and power, the lithium-ion battery promotes the development of electric vehicles and stationary energy storage systems. For the safe and efficient operation during the entire life-cycle of battery, an intelligent battery management system (BMS) is indispensable to online estimate the battery states and monitor its condition. As one of the core functions in BMS, SoC estimation is the basis of fault diagnosis, health management, thermal management.

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To better practical application, there are a wide variety of SoC estimation methods proposed continuously, which can be divided into four categories: look-up table methods, ampere-hour methods, model-based methods and data-driven methods in [1]. Look-up table methods are simple, but these methods require regular recalibration for offline parameter, which isn't suitable for the actual application [2, 3]. The ampere-hour methods can achieve the online estimation of SoC with low computational cost expediently and quickly [4, 5]. However, as the open-loop methods, it is easy to be greatly affected by a small disruption, such as the change of working temperature. Different from the above-mentioned two methods, the model-based methods are the close-loop methods, which provides the robust performance for the SOC estimation by sustained revision of error, and are widely used, such as KF, EKF, SPKF, AEKF, etc. [6–8]. Data-driven methods include the neural network method, the method of fuzzy controller, support vector regression (SVR) and so on. Recent results from [9–11] showed that these methods have their respective advantages and their estimation precision is very high for training data, which isn't affected by nonlinear model, but relatively low when the data are new.

However, the uncertainty of model parameters influences the estimation performance significantly. For the almost model, SoC is obtained with offline parameters and these parameter value will change greatly with different degrees of aging, which will lead to inaccurate estimation value and even some more serious results, such as over charge/discharge, thermal abuse, etc.. In order to overcome these drawbacks, online parameter identification methods were proposed. Suns [12] researched the joint estimation of state and parameters with recursive least square (RLS) and adaptive extended Kalman filter (AEKF). But RLS and AEKF are independent modules in this method, which is hard to ensure its convergence performance. So this paper proposes the dual estimation algorithm to obtain the state and parameters in steps. Compared with the separate calculation of state and parameters in above joint estimation method, this dual estimation method can realize cooperative convergence by the same correction equation. Meanwhile, [13] proposed that H infinity filter can obtain the accurate results when model exists error and input is uncertain, which exhibits a better robustness than series of KF. So the dual H infinity filters algorithm was further put forward, and got successful application aiming at the uncertain SoC initial value and parameters.

The purpose of this paper is to establish general battery parameter and state dual estimation method using dual H infinity filters. The description of algorithms is presented in Section 2. Section 3 describes their implementation flowchart in the battery system. To evaluate these approaches, the verification experiments shown in Section 4 were done. The experiment, simulation results and evaluation of the proposed methods are reported in Section 5 and the conclusions are drawn in Section 6.

2. Dual H infinity filters

The KF provides an efficient approach for estimation of the state of a discrete-time dynamical system. It is assumed that the system model is accurate and the statistical characteristics of external input is known, but in fact it is impossible to meet it. In order to achieve the accurate estimation of state when the model exists error and the noise is uncertain, H infinity filter that has better robustness is put forward [14]. For better practice application, this paper has improved the above algorithm, which is shown in Table 1.

Furthermore, considering that H infinity filter can be used to identify parameters as well, this paper proposes a novel dual H infinity filters to achieve dual estimation of battery parameter and state estimation on line, and it is summarized in Table 2.

Finally, based on the above analysis, the adaptive update of noises in [8], which could change statistical characteristics of the noises by the historical data, also can be used in these algorithms.

$$M_k \approx \frac{1}{N}\sum_{i=k-N+1}^{k} e_i e_i^{\mathrm{T}},\ \ R_k = M_k - C_k \Sigma_k^{-} C_k^{\mathrm{T}},\ \ Q_k \approx \frac{1}{N}\sum_{i=k-N+1}^{k} K_i e_i e_i^{\mathrm{T}} K_i^{\mathrm{T}} \tag{1}$$