

Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid, 19-21 April 2016, Maldives

Model-based state-of-charge estimation approach of the Lithium-ion battery using an improved adaptive particle filter

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Abstract

Accurate state of charge (SoC) estimation is of great significance for a lithium-ion battery. This paper presents an adaptive particle filter (APF)-based SoC estimation algorithm for lithium-ion batteries in electric vehicles. Firstly, the lithium-ion battery is modeled using the resistance-capacitance network based one-state hysteresis equivalent circuit model and its parameters are determined by the particle swarm optimization method. Then, an improved adaptive particle filter has been proposed and applied to the battery SoC estimation. Finally, the two typical lithium-ion battery, LiFePO₄ and NMC lithium-ion, have been used to verify the proposed SoC estimator.

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Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid.

Keywords: Battery management system; APF; improved APF; PSO.

1. Introduction

Lithium-ion batteries (LIBs) have taken the dominant position for electric vehicles, which own many merits such as high energy/power density, long cycle lifetime, low self-discharge rate and environmental friendliness. State of charge (SoC) is a crucial indicator for LIBs and it is difficult to measure directly due to the intrinsic electrochemical process occurring while in working operation.

In fact, a lot of efforts have been taken to investigate the estimation method and each has its own advantage reviewed in [1-4]. The ampere-hour (Ah) integral method is a very precise and low-cost approach if the initial SoC knowledge is true and the current measurement electronics is of high fidelity. Several model-based approaches [1-4] are studied, which show high SoC estimation accuracy and reliability. But the strong dependency on the correction of models and the trade-off between complexity of models and estimation accuracy are critical issues should be concerned. Besides, some intelligent algorithms [5-6] are

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employed to estimate the SoC. Although they are capable of achieving desirable results, the necessity of priori knowledge is the primary weakness.

To improve the robustness and the speed of convergence for SoC estimation, an improved adaptive particle filtering method is presented in this paper and the main contributions are expressed as follows: 1) The first order RC networks model with hysteresis effect is selected and particle swarm optimization (PSO) method is adopted to identify parameters 2) An effective criterion of analysis of errors is added into the traditional APF, through which, the new algorithm of improved adaptive particle filtering (improved APF) can elevating the robustness to initial states' offset and the ability of convergence. 3) Two types of batteries are tested to verify the effectiveness of this algorithm. The results indicate the characteristic of convergence has been improved tremendously comparing with the traditional APF.

The rest of this paper is organized as follows: Section 2 describes the parameters identification. Section 3 illustrates the core concept and key steps of proposed algorithm. In section 4 and 5, batteries are tested under different dynamic cycles to verify the validity of the proposed method and the relative analysis of results are given in the final section.

2. Parameters identification

The particle swarm optimization (PSO) method is utilized to identify the parameters of the first order RC networks model with hysteresis effect. PSO is a kind of evolutionary algorithm, through evaluating the results of fitness function, the optimal solution can be carried out. The variance of errors of terminal voltage is set as the fitness function (see Eq.(1)) and the parametric vector $\theta = [V_{oc,1}, \dots, V_{oc,12}, R_0^+, R_0^-, \kappa, H^+, H^-, R_p, \tau]^T$ is the parameter in the first order RC networks model with hysteresis effect.

$$\min f = \sqrt{\frac{1}{w} \sum_{i=k-w}^k (U_i^e)^2} \quad (1)$$

where U^e is battery terminal voltage error, w can decide the length of identification interval. f is the RMS of errors of terminal voltage.

3. Algorithm implementation

PF and has become an attractive algorithm in solving optimal estimation problems for non-linear non-Gaussian state space models [7]. PF and APF depend on the noise variance to realize the accurate estimation and the ability of convergence, however, the traditional PF or APF can't adjust noise variance very well especially when the initial error is very large or changeable. In this paper, an improved adaptive particle filter based estimator has been established to estimate SoC of the Lithium-ion battery, contrast to traditional APF, the analysis of error is added in the algorithm, which can give more appropriate noise variance to elevating the robustness to initial states' offset and the ability of convergence. The algorithm of improved APF is described in Table 1 and the flowchart is shown in Fig.1.

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