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State-of-charge estimation of valve regulated lead acid battery based on multi-state Unscented Kalman Filter

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ABSTRACT

As a vital part of the battery-employed system, battery management system (BMS) must correctly estimate values descriptive of the battery's present operating condition. As is known to all, state-of-charge (SOC) is a key battery state for BMS to estimate. In this paper, based on Unscented Kalman Filter (UKF) theory and a comprehensive battery model, a novel SOC estimation method is proposed. A nonlinear mapping process is involved to recursively calculate the system state variable, thus the errors caused by Extended Kalman Filter (EKF) can be effectively restrained; besides, compared with many simple battery models recently, the comprehensive model presented in this paper can track the operating performance of valve regulated lead acid (VRLA) battery more correctly. The whole estimation process is clearly given; then EKF and UKF are compared through experimental analysis; the results show that UKF method is superior to EKF method in SOC estimation for VRLA battery.

1. Introduction

Due to the energy crisis and globally increasing pollution problems, more and more countries have attached great importance to the research and development of renewable and clean energy sources. In such a case, storage battery is regarded as one of the most promising solutions. However, the nonlinear dynamic performance of the battery makes it difficult to monitor the operating states. With out a doubt, SOC is a key battery state to estimate, so SOC estimation is a popular research area now.

There are several common techniques recently for SOC estimation: Ah counting based on current integration; open-circuit voltage (OCV) method and electromotive force (EMF) method based on battery terminal voltage detection; neural network method based on massive sample data; Kalman Filter based on state space model; and some other methods based on chemical process analysis [1–4]. The UKF theory adopted here belongs to Kalman Filter family.

Kalman Filter is a powerful state estimation technique for dynamic system. It can give an optimal estimate of the system state with minimum error covariance. But when the system is nonlinear, then a linearization process needs to be done to approximate the real system, and this is the very concept of the EKF method. However, EKF also brings some other problems like linearization error and complicated computation of Jacobian matrix, so it is difficult to assure the estimation accuracy especially in the high nonlinear systems and the total cost is increased by powerful processor due to the intensive computation; besides, it has to be taken into consideration that EKF requires a precise model of cell dynamics, which changes as the battery ages, also EKF performance is poor in transients [5,6]. In order to get rid of these defects, Julier and Uhlmann proposed a nonlinear filter called UKF in 1990s. Unlike the EKF, UKF adopts a nonlinear unscented transformation (UT) and approximates a Gaussian distribution of the state random variable. It only needs a set of sample points that are refreshed at each time step, in this way the posterior mean and covariance can be recursively transmitted according to the nonlinear mapping, and at the same time Jacobian computation can also be avoided [7].

In this paper, UKF method is adopted in SOC estimation process combining with a comprehensive VRLA battery model. Unlike the commonly used empirical equation model described in [8], the battery model presented here takes an auxiliary state into account besides SOC state. As a result, the EMF method and Ah counting method are closely organized through UKF algorithm to form the final SOC estimator.

2. Comprehensive battery model

Thevenin model is a widely employed battery model, it can simulate the battery behavior well; and it is a first-order system [9–11]. So it is adopted here as part of our comprehensive model, shown in Fig. 1. *R*1 is an ohm resistance, *R*2 is a polarized resistance, *C* is an equivalent capacitor, *V* is OCV or terminal voltage,

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