The Experiments of Dual Kalman Filter in Lithium Battery SOC Estimation

Yungan Wang¹ ² a, Yingnan Wang³, Zhongfeng Wang², Fengli Han³, Li-gang Li², Xiaotian Wang¹ ²

¹University of Chinese Academy of Sciences, China
²Shenyang Institute of Automation Chinese Academy of Sciences Shen-Yang, China
³Shenyang Power Supply Company Liaoning State Grid

E-mail: wangyungan@sia.cn

Keywords: Dual Kalman filter; lithium battery; Thevenin model; state of charge

Abstract. For dual Kalman filter SOC estimation algorithm, this paper designs experiment based on lithium battery Thevenin model according to different conditions. Verification experiment is divided into three stages, namely to verify the constant current charge or discharge, continuous change, mutation of short-term conditions, and do a detailed analysis. Results show that the algorithm can estimate battery SOC with high accuracy online, can solve the problem of accumulated error and allowed initial SOC effectively. The model can react the true state of the inside battery better by calibrating Thevenin model using dual Kalman filter algorithm. Finally, the experiments verified the DEKF algorithm’s convergence speed and good robustness.

Introduction

Currently substation is used in lead-acid batteries, but there are some inherent disadvantages, such as short life, unwanted safety performance, and poor discharge characteristics. Based on this, we have study the Phosphate-Iron lithium battery group which have rated voltage of 232V. The remaining electric contrast rated capacity called state of charge at the same conditions when the battery at a certain discharge rate [1-2]. The accurate estimate of the SOC has an important role in the battery pack for examining health of battery and making the battery performance excellent [3].

Battery performance depends on many factors, such as the state of charge and environment temperature and work current and battery life and battery discharge and so on [4]. However, the parameters and structure of battery model will not change when model has been finished. The general time-invariant model is not satisfactory because it cannot reflect the dynamic characteristics of internal battery [5]. This paper has effective dual Kalman filter algorithm. It solves the problems of battery model’s dynamic parameters deviation and accuracy error in SOC estimation.

EXPERIMENTAL DESIGN

The lithium battery pack includes sixty-eight single batteries, connected one by one, which nominal capacity is 10AH. So the total capacity is 680AH. We choose eight lithium-ion batteries randomly from the sixty-eight batteries as experimental subjects for shorten test time and ensure the accuracy of experiment. The designed current of experiment is shown in Figure 1. The main purpose is to test the estimation accuracy in different work conditions, and whether the algorithm can accurately estimate battery parameters online.

The current is divided into three phases in experiment. The first place is from the beginning until 2400s. It tests the estimation accuracy when it is long charge-discharge case. The second stage is from 2400s to 6000s. It tests current estimation accuracy in different algorithms. The third stage is from the 6000s to 7000s. It tests estimation accuracy under extreme environmental conditions, Shown in the local extension of fig1.

The parameters of initial values of DEKF are set with white noise as follows during the test. SOC Initial value is 80%. Sampling time is 0.5s. Time constant τ is 9. Battery Capacity is 10Ah. Battery resistance R0 is 190mΩ.
In the experiments, battery polarization voltage estimated by DEKF algorithm shown in Figure 2. The figure shows that the value difference of polarization voltage estimated by Dual Kalman filter and the actual voltage is less, which is the base of estimation battery's SOC accurately using DEKF.

![Fig.1 The Current Curves](image1)
![Fig.2 Polarization Voltage](image2)
![Fig.3 SOC Estimation Curve](image3)

**EXPERIMENTAL RESULTS AND ANALYSIS**

The figure 3 shows SOC estimation curve of three stages. Figure 4 shows estimated SOC curve at three different stages. Fig4-a is a graph of the first stage of the experiment, as can be seen from the figure, when a sudden change of the current direction happen, the estimation error of AH is bigger than DEKF. Fig4-b shows a graph of the second stage. We can found that both of the two estimation methods are dealt with a small error when the discharge current decreases gradually. But since the SOC of battery is discharged to less than 20%, the estimation error of AH algorithm increases significantly, which throws a message that AH algorithm gets a big estimation error under low SOC condition. In this stage of the charging phase, the accumulated error of AH is also reflected more and more obvious, while DEKF reduce the accumulated error through recursive iterations. The third stage estimation expanded chart of SOC is shown in Fig 4-c. Dual Kalman filter algorithm can adapt to the extreme operating environment better. It is related to the own characteristics of Kalman filter. We can get the real values through loop recursive way.

The error curve of the two algorithms is shown in figure 5. In the beginning phase, the results of the two methods is almost estimated quite. There are less than 3% deviations. The error mainly comes from initial value which is set. The error increases to about seven percentages with time, which is mainly caused by two reasons. The first reason is the initial value of SOC that is not accurate and the method of current integration has cumulative error in itself. That measured voltage has error is the second reason. Especially, the current appears large fluctuation when the battery is charged and discharged. The voltage of battery will be floating obvious. It is determined by the characteristics of battery itself. For example, the estimated value of dual Kalman filter algorithm is 27.5% when the time is at 5200s. However the estimated value of AH is approximate 30% at the same condition. We make an open circuit voltage experimental that need to stand the battery for 3 hours to judge which method is more accurate. The voltage is 21.73V which draws a conclusion that the estimate value is approximately 27% based on the relation curve of SOC-U when the time is at 5200s. So the Kalman filter algorithm is close to the true value and has smaller error.

![Fig.4 The Three SOC Estimation Curve](image4)

The figure 6 shows the curve of R0 resistance of battery which is estimated by two Kalman filter. The initial values are set to 240mΩ and 200mΩ. We can see that although the initial values are different, but after a short period of time, the algorithm can converge to the same stable value. There will be an apparent float in the initial stage of power up. So the equivalent resistance is large. After some time, the resistance becomes smaller and stable. It is related to characteristics of battery and environment temperature and so on.
We can see from the figures, the SOC raise peak at the 2500s while the resistance is the minimum. The SOC is the minimum and the resistance is at its peak at 4200s. The SOC becomes smaller and resistance gradually increases after 6100s. This reach a conclusion that the resistance of battery is simple inverse relationship with SOC. The SOC is greater, the resistance is smaller.

**ALGORITHM CONVERGENCE ANALYSIS**

When making use of AH method to reach the SOC of Lithium battery, the battery management system is based on a test result of last time. However, the lithium battery itself has polarization, self-healing and self-discharge characteristics. It will produce the cumulative error day after day. So it is often difficult to obtain an accurate SOC. In order to clear the online SOC estimation of DEKF algorithm’s ability that this algorithm can solve the problem of cumulative error, we need to analyze the convergence of the algorithm. We obtain the battery's initial value of SOC through experiments in this paper. The battery is estimated by AH method with initial value of SOC of 70%. This method can more accurately reflect the SOC state of lithium battery when experimental time is short and initial SOC is accurate. The initial value of Kalman filter algorithm is set to 80% and 75% and 65% and 60%.

Figure 7 describes the convergence of DEKF when it is in different initial value of SOC. We can see from the experimental results. The DEKF algorithm can converge to the true value well when it is in different initial values. The DEKF algorithm adjusts the gain K to make the estimation error lower. If the initial error is large, the value of K is larger too. It ensures the observations converge to the true value when the error is small. So the different initial values of SOC can converge to the true value, but it will not cause cumulative error and has good robustness.

**CONCLUSION**

We use Thevenin battery model as a research base to deal with lithium battery SOC estimation problem. Kalman filter algorithm is used to online estimate the battery resistance R0 which improves Thevenin model accuracy. The SOC is estimated using Kalman filter algorithm and the improved model. It solves the initial value estimation error of SOC that is caused by AH method and accumulation error problems. The experimental results show that the algorithm can improve the SOC estimation algorithm accuracy and reliability. Compared to AH method, the maximum error is less than 5%. Finally, the experiments show that the algorithm has better convergence, and different initial values of SOC can converge to the true value.

**Acknowledgement**

This work was supported by Lab. Of Networked Control System, the Natural Science Foundation of China under contact (61233007, 61202418, 61004068), the Important National Science and Technology Specific Project under contact 2013ZX03005004, the National High Technology Research and Development Program of China (863 Program: 2011AA040101), Foundation of Chinese Academy of Sciences under contact (KGCX2-EW-104).
References


