Research on Electric Vehicle Battery On-line Management System

Yanxing Qi¹, Xueyin Yang²,*

¹School of Automation and Electrical engineering, Linyi University, Linyi Shandong, China
²School of Mechanical and Vehicle Engineering, Linyi University, Linyi Shandong, China

*Corresponding author: yangxueyin@lyu.edu.cn

Abstract. This paper takes STM32 MCU as the control core to make deep research on the electric vehicle battery online management system. The internal resistance detection method and Kalman filter method are used to estimate the SOC value, and the equalization control circuit is used to make the SOC value of each single battery tend to be consistent, and the equalizing protection circuit is used to effectively protect the battery. Debugging and experimental results show that the system can accurately estimate the SOC value, solve the problem of inconsistent SOC value of each single battery, and effectively improve the efficiency of the battery.

Keywords: SOC Estimate; Internal Resistance Detection; Kalman Filtering; Equalizing Control.

1. Introduction

With the exhaustion of petroleum resources, electric vehicles will inevitably replace fuel vehicles. Nowadays, the research and development of electric vehicles has become a global research hotspot, and the key problem limiting the development of electric vehicles lies in the charging time, capacity and service life of the battery pack.

Correct management of batteries during charging and use will greatly affect the life of batteries. According to the data, the design life of the battery is mostly 3-5 years, while the average service life is only 1-2 years. The reason is that the State of Charge (SOC) of each battery will be different during the charging and using process of the battery pack, resulting in uneven charging and discharging. The worst cells determine the nominal capacity and efficiency of the battery pack, and efficiency and service life decline faster with time [1]. Therefore, the correct management of electric vehicle battery pack is very important. Aiming at this problem, this paper designs an electric vehicle battery online management system, which mainly solves SOC online estimation and charge and discharge balance control problems. There are many methods for SOC estimation. In this paper, the internal resistance detection method and Kalman filter method are used for SOC estimation.
2. Hardware Design

Electric vehicle battery management system is a complex system composed of several modules. Here, the structure of the system is presented and the main modules are analyzed. Electric vehicle battery online management system is shown in Fig1.

![Fig1. Block Diagram of System Structure](image)

![Fig 2. Correlation Detection Circuit](image)

The working process of the system is as follows: through online detection of voltage, current, internal resistance, temperature and other parameters of each single battery, real-time reflection of the working state of each battery. At the same time, these parameters are used to estimate the SOC value of each battery. If the SOC value of each battery is inconsistent, the equalization control circuit is started to make the battery power tend to be the same. When the battery pack is overcharged or over discharged, the equalization protection circuit will cut off the charging or discharging circuit to protect the battery.

In order to facilitate the realization of the communication function and the demand of the future upgrade, the system selects STM32 MCU as the control core. The MCU is an ultra-low power 32-bit microprocessor launched by STMicroelectronics, and its working frequency is up to 72MHz. With a large number of enhanced I/O ports, optional capacity of SAM and Flash, and a variety of communication interface, according to the need to choose the right model. This design chooses STM32F103ZET6.

2.1. Battery Internal Resistance Test

Among the SOC estimation methods, the Kalman filter method can continuously correct the SOC deviation and has higher estimation accuracy, but the larger initial SOC error will greatly affect the convergence in the early stage. In this design, the internal resistance method is used to correct the initial SOC value, so that the Kalman filter can get good convergence. Therefore, it is necessary to accurately detect the internal resistance of the battery.

The internal resistance of the battery is very small, generally between a few milliohms and dozens of milliohms. There are many detection methods, but each has its own advantages and disadvantages and limitations in application. Through comprehensive comparison, the AC impedance method is used to detect the internal resistance of the battery.

The process of AC impedance method to detect internal resistance is as follows: the sinusoidal signal of 1kHz is generated by the sinusoidal signal generator and applied to the battery, the terminal voltage of the battery is detected, the amplifier and filter processing are carried out, and then the internal resistance is obtained after being sent into the relevant detection circuit for relevant operation.

The correlation detection filter circuit can greatly improve the accuracy of internal resistance detection. In this paper, the high precision balance modulator AD630 is selected to do the correlation detection operation. In the specific design, two pieces of AD630 are used to form a two-channel correlation detection circuit. The correlation detection circuit is shown in Fig2.
2.2. Equalizing Control and Protect
In order to make the single battery as consistent as possible, the multi-flight capacitance equalization control circuit is adopted. The equalization control circuit is shown in Fig3, where BV represents the battery, C represents the flight capacitor, and V represents the switch tube.

The working process is: when \( VBV1 > VBV2 \), V1, V4, V5 and V8 are on, V2, V3, V6 and V7 are off. C1 stores the charge from BV1, and C2 takes the charge from BV1 to BV2. When \( VBV1 < VBV2 \), V1, V4, V5, and V8 are off, and V2, V3, V6, and V7 are on. C1 stores the charge from BV2, and C2 takes the charge from BV2 to BV1. The charges in C1 and C2 are alternately converted, and the charge is in dynamic transfer. The equalization time is short and the efficiency is high.

3. SOC Estimation
The key of battery detection is the estimation of SOC value. There are many estimation methods, such as open-circuit voltage method, ampere-hour integration method, internal resistance method, etc., but each has its own advantages and disadvantages. In application, many methods are often combined to improve the accuracy of SOC estimation. In this paper, the internal resistance method and Kalman filter method are used to estimate the SOC value.

The internal resistance method is mainly used to correct the initial SOC value, so that the Kalman filter has good convergence, and is used to improve the accuracy of SOC estimation.

3.1. Battery Model Building
The equivalent circuit model of the battery is needed to estimate the SOC of Kalman filter. Commonly used models include Randles model, PNGV model, Thevenin model and so on. By comprehensive comparison, although the structure of Randles model is complex, its accuracy is high [2-5]. In this paper, Randles equivalent circuit model of second order RC is adopted. The second-order equivalent circuit model of the battery is shown in Fig5.

In the figure: UOC is the open-circuit voltage; R0 is the ohmic internal resistance of the battery; Rp1 and Rp2 are polarization resistors. Cp1 and Cp2 are polarization capacitors; U is terminal voltage; I is the current inside the battery.

The battery state space equation is the basis of SOC estimation. Let the battery state vector be:

\[
X = [SOC, U_{p1}, U_{p2}]^T
\]  (1)
The state space equation of the battery is:

\[
\begin{bmatrix}
    \text{SOC} \\
    U_{p1} \\
    U_{p2}
\end{bmatrix} = \begin{bmatrix}
    -\frac{I(t)}{Q_c} \\
    \frac{U_{p1}(t)}{\tau_{p1}} + \frac{I(t)}{C_{p1}} \\
    \frac{U_{p2}(t)}{\tau_{p2}} + \frac{I(t)}{C_{p2}}
\end{bmatrix}
\] (2)

Where: \(Q_c\) is the battery capacity; \(\tau_{p1}, \tau_{p2}\) are the time constants of \(R_pC_p\) circuit and \(R_C\) circuit respectively.

3.2. Determination of the Initial SOC Value

The accuracy of estimating the initial SOC value is related to the accuracy of estimating the Kalman filter SOC, and the internal resistance method is used to estimate the initial SOC value.

In this paper, Tianeng 6-EVF-32A (12V32Ah) battery was selected for the experiment. After the battery was fully charged, it stood for 1 hour, and then the battery terminal voltage and internal resistance were measured every 10 minutes. The resistance-SOC curve was obtained from the measured data. The resistance-SOC curve is shown in Fig6.

3.3. Kalman Filtering Algorithm [6-8]

The state space equation and observation equation of Kalman filtering are as follows:

\[
x(k) = Ax(k-1) + Bu(k-1) + \omega(k-1)
\] (3)

\[
z(k) = Cx(k) + v(k)
\] (4)

Where: \(x(k)\) is the system variable; \(z(k)\) is the observed variable; \(\omega(k)\) is system noise; \(v(k)\) is the observed noise.

One-step prediction error covariance matrix:

\[
P(k) = AP(k-1)A^T + Q(k-1)
\] (5)
Kalman filter gain matrix:

\[ K(k) = P(k)C(k)^T (C(k)P(k)C(k)^T + R(k))^T \]  

(6)

Status update equation:

\[ x(k) = x(k) + K(k)(z(k) + C x(k)) \]  

(7)

Error covariance update equation:

\[ P(k) = (I - K(k)C(k))^T P(k) \]  

(8)

Where, Q is the covariance matrix of process noise; R is the covariance matrix of the observed noise. \( K(k) \) is the weight value, and its accuracy directly affects the convergence accuracy, so it is necessary to accurately predict the initial value.

4. Test Results and Conclusions

The test data were obtained in the laboratory. The battery used is Tianneng 6-EVF-32A (12V32Ah). Discharge the battery with an electronic load, and test the SOC value and SOC error during the process. After Kalman filtering algorithm is adopted, SOC calculation results and error curves are shown in Fig7. The SOC value has a large error before 20 seconds, because the Kalman filter algorithm needs a certain amount of adjustment time and has good following performance. The SOC estimation error is always around 0, about 4%, with high accuracy.

\[ \text{(A)} \quad \text{SOC calculation results} \quad \text{(B)} \quad \text{error curves} \]

**Fig7. SOC calculation results and error curves**

In this paper, the Kalman filter method is used to estimate the SOC value. In order to accelerate the convergence and improve the estimation accuracy, the internal resistance method is used to determine the initial SOC value. In order to improve the accuracy of internal resistance detection, AC impedance method and related detection techniques are used. After debugging and verification, the system can accurately estimate the SOC value, and carry out balanced control and protection according to the estimated results, which improves the battery efficiency and prolongs the service life.
References

[1] Li Xingyang, Yang Yuxin. Split Battery Management System for Pure Electric Vehicle Based on STM32 [J]. Microcontrollers & Embedded Systems, 2018(9):51-54.

[2] Gong Liying, Peng Yesheng, Huang Shenggao. Design of Lithium Battery Management System Based on Modified Kalman Filter [J]. Electronic Design Engineering, 2019, 27(4):167-170.

[3] Zhang Haitao, Zhou Ming, Lan Xudong. State of Charge Estimation Algorithm for Unmanned Aerial Vehicle Power-Type Lithium Battery Packs Based on the Extended Kalman Filter. Energies, 2019, 12, 3960.

[4] Xia Bizhong, Lao Zizhou, et al. Online Parameter Identification and State of Charge Estimation of Lithium-Ion Batteries Based on Forgetting Factor Recursive Least Squares and Nonlinear Kalman Filter [J]. Energies, 2018, 11, 3.

[5] Wang Xian, Song Zhengxiang. On-line Estimation of State of Charge Estimation for Liquid Metal Battery Based on Extended Kalman Filter Algorithm [J]. Power Capacitor & Reactive Power Compensation, 2018, 39 (5): 178-183.

[6] Si Wei, Feng Changjiang, Huang Tianchen. Power Capacitors and Reactive Power Compensation [J]. Computer Measurement & Control, 2018, 26(12):185-189.

[7] Ji Lei, Ryad Chellali. State of charge estimation of battery based on adaptive extended Kalman filter [J]. Battery Bimonthly, 2018, 48(4):240-243.

[8] An Zhisheng, Sun Zhiyi. Research on Estimation of Lithium Battery SOC Based on Fuzzy Adaptive Kalman Filter [J]. Fire Control & Command Control, 2014, 39 (4): 137-140.