Optimization of Electric Vehicle Battery Management under System on Chip Estimation and Distributed Structure

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Abstract

To improve the use efficiency of electric vehicles (EVs) batteries, extend the service life of batteries, and reduce the operating cost of batteries, the optimization of EVs battery management system based on system on chip (SOC) estimation and distributed structure is studied. First, the three commonly used battery management structures are compared, and the distributed structure of EVs battery management structure is selected. Then, the SOC estimation algorithm based on the improved extended Kalman filter algorithm is proposed. Finally, the simulation results of SOC estimation based on improved extended Kalman filter algorithm and the optimization results of EVs battery management system based on SOC and distributed structure are discussed. The results show that the improved extended Kalman filter algorithm proposed in this study has a priority over other algorithms, and its estimation the error of the SOC curve is always very small, almost zero. The whole battery management system has high acquisition precision and accuracy. In conclusion, this research has good guiding significance for the power battery industry in China.

Keywords

SOC estimation; Distributed structure; EVs; Battery management system.

1. Introduction

With the development of the global economy, the environmental damage and energy loss caused by various means of industrialization continue to increase. In order to improve the living environment of human beings, it is an urgent problem for human beings to find new energy. According to relevant data and statistics, automobile exhaust is the main factor of environmental pollution. Traditional fuel-powered vehicles will emit polluting gases when converting the chemical energy of fuel into kinetic energy [1,2]. Therefore, in order to fundamentally solve automobile exhaust, it is necessary to replace the power system provided by automobiles. New energy electric vehicle is a very hot topic at present.

Since the beginning of the 20th century, China has realized the harm of fuel vehicles to environmental pollution and started to advocate new energy EVs. After decades of development, China's EVs have now been formally put into use [3]. According to relevant authoritative statistics, it is estimated that by 2030, the number of EVs will reach 10 million. China's favorable policy conditions have promoted the rapid development of EVs, and the power battery has also ushered in an unprecedented development [4,5]. China began mass production of power batteries in 2015. At the same time, the power battery has all kinds of problems, such as production process problems. The problem is getting worse, and the power battery has to be restructured. At this rate of development, the number of scrapped power batteries in China will even exceed 200,000 tons. The main reason for this phenomenon is that there is no reasonable management of batteries. It is urgent to solve the problem of extending battery life while avoiding the scrapping of batteries, so as to ensure the stable and reasonable development of the power battery industry [6].

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To sum up, the distributed structure and estimation are adopted to optimize the design of EVs battery management system. First, the optimal design of EVs battery management system is proposed. Then, the SOC estimation algorithm is optimized. Finally, the simulation results of SOC curve estimated by the improved extended Kalman filter algorithm and the optimization results of EVs battery management system based on SOC and distributed structure are discussed. The purpose of this study is to provide some reference value for battery safety in China's power battery industry.

2. Methods

2.1 Optimal design of battery management system for EVs

At present, the topological structure of the battery management system is mainly divided into centralized structure, distributed structure and distributed structure. Different structures have different characteristics.

I. The management structure of the centralized battery system is compact. The entire power battery of the car is controlled by only one battery management system control panel. The control process is to transfer the collected data to the MCU, then conduct data processing through the MCU, and issue control commands. In this way, the management of the whole vehicle battery pack is achieved. Although the structure of centralized battery system is simple, with low development cost and simple design algorithm, the whole battery management system is flexible, and the changes of hardware and software are also arbitrary. Although the centralized battery system management structure has many advantages, the use of a control panel to manage the vehicle's power battery will make the wiring more complicated. In addition, the information collection of the battery pack is relatively simple, so it is impossible to manage every battery, and it is also impossible to timely discover the car's safety hazards [7].

II. Decentralized battery management system structure is decentralized, each battery is equipped with a monitoring module, this structure realizes the information collection and processing of each battery, and timely sends the results to the vehicle control. The structural advantage of distributed battery management system is that it can control each battery, which greatly improves the safety performance of the battery. But this way is too flexible, which needs to have multiple modules, and once there is a failure, it is difficult to troubleshoot.

III. The distributed battery management system combines the characteristics of the above two battery management structures. Composed of a main control board and multiple unit boards, each unit board can be controlled to manage the information collection of several batteries. Then the collected information is transmitted to the main control board for unified processing. This method is convenient for managing each battery, with high data acquisition accuracy and data transmission reliability, but the connection is not complex, and the expansion is good.

In summary, the distributed battery management system has good functionality, therefore, discrete components are adopted to design the battery management system. Taking a small electric car as an example, its battery capacity is 60Ah and the total battery voltage is 230V. In this study, lithium iron phosphate battery is used. The nominal capacity of the battery is 60Ah and the maximum charging voltage is 3.6v. Therefore, to satisfy the small EV, 64 pieces are needed. The functional diagram of the battery management system designed in this study is shown in figure 1, and the distributed structure is shown in figure 2. As shown in the figure, the whole system adopts the distributed structure of master control board + unit board. The master control board is composed of five modules in the figure, and the acquisition module is responsible for collecting the total voltage and current. Different modules have different task commands. For example, the acquisition module is complex to collect the current, voltage, and temperature of the battery pack.

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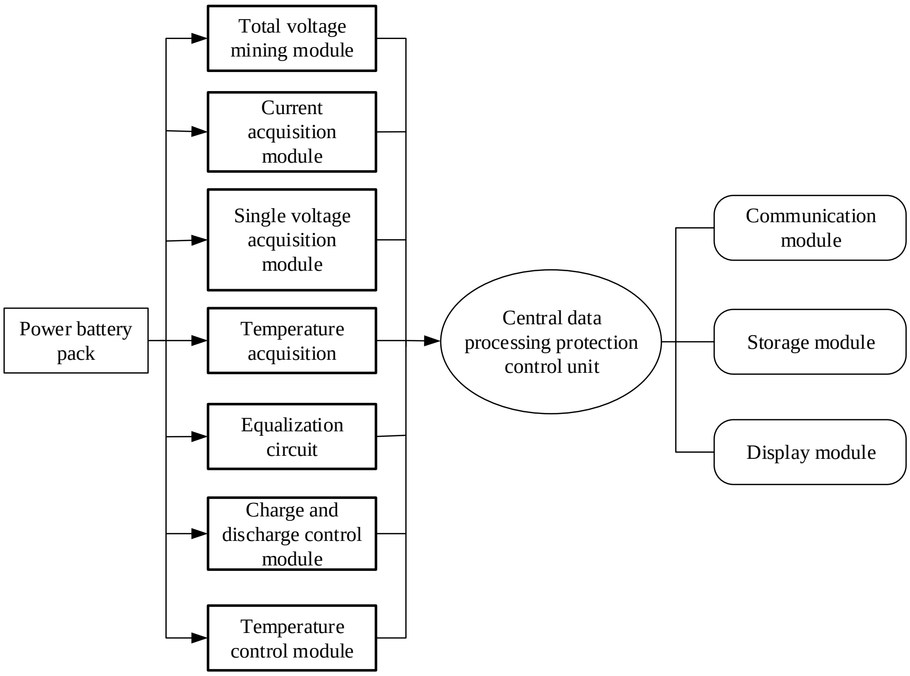

Figure. 1 Schematic diagram of the battery management system

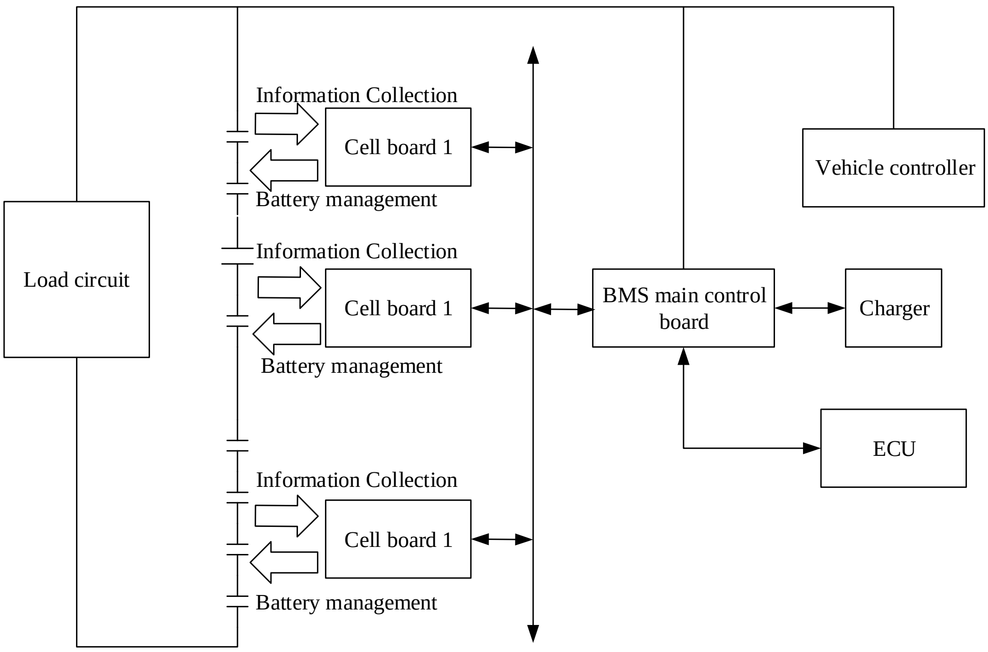

Figure. 2 Distributed structure of battery management system

2.2 SOC estimation of EVs battery

A SOC estimation algorithm based on improved extended Karman filter is proposed in the study. SOC estimation algorithm is proposed based on the theory of ampere-hour integration method and extended Kalman filter algorithm. The state variables, observed variables, and excitation variables of the battery management system are determined and the battery state equation and observation equation are established.

In this study, the voltage U_p and U_l of the battery SOC and two RC circuits are taken as the state variables of the system.

$$X_k = [SOC_k U_{p,k} U_{l,k}]^T \tag{1}$$

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In the equation, the construction of SOC state equation is based on the modified ampere-hour integral method.

The state equation is as follows.

$$\begin{bmatrix} SOC_k \\ U_{p,k} \\ U_{l,k} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \exp(-\frac{T}{R_pC_p}) & 0 \\ 0 & 0 & \exp(-\frac{T}{R_lC_l}) \end{bmatrix} \begin{bmatrix} SOC_{k-1} \\ U_{p,k-1} \\ U_{l,k-1} \end{bmatrix} + \begin{bmatrix} -\frac{k_tk_\eta T}{k_tQ_0} \\ R_p(1-\exp(-\frac{T}{R_pC_p})) \\ R_l(1-\exp(-\frac{T}{R_lCl})) \end{bmatrix} i_{k-1} + \begin{bmatrix} w_{1,k-1} \\ w_{2,k-1} \\ w_{3,k-1} \end{bmatrix} \tag{2}$$

The observation equation is as follows.

$$U_{0,k} = U_{oc}(\mathrm{SOC_k}) - R_e i_k - U_{p,k} - U_{l,k} + v_k \tag{3}$$

In the equation, Q_0 is the rated capacity of the battery. T is the sampling period of the system. $U_{p,k}$ and $U_{l,k}$ are the voltage estimates of the internal resistance R_p and R_l at time k, respectively. $w_{1,k-1}$, $w_{2,k-1}$, and $w_{3,k-1}$ are all system noise with covariance Q. v_k is the measurement noise of covariance R. $U_{oc}(\mathrm{SOC_k})$ is the corresponding relationship of $U_{0,k}$ and SOC_k, which is a nonlinear function and can be obtained by electromotive force method.

The state equation and observation equation need to be linearized after they are determined. The equation of state in equation (2) is a linear equation, and the observation equation in equation (3) is a nonlinear equation. Therefore, equation (3) should be linearized, and the coefficient after linearization can be expressed as follows.

$$H_k = \frac{\partial U_o}{\partial X_k} = \begin{bmatrix} \frac{\partial(U_{oc} - R_e i_k}{\partial SOC} & -1 & -1 \end{bmatrix} \tag{4}$$

Once the linearized coefficients are obtained, the process of linearizing the equation is completed. Then the state variables are initialized and the value of SOC is estimated according to the recursive iteration step of the extended Kalman filter algorithm. In the process of estimation, the equation coefficient is calculated from the identified second-order RC circuit model parameters, and the model parameters will change with the charging and discharging. Therefore, the equation coefficient also varies with the model parameters, which fully takes into account the influence of chemical reactions in the battery during charging and discharging.

3. Results

3.1 Simulation results of SOC estimation based on improved extended Kalman filter algorithm

In this study, a battery management system based on SOC algorithm and distributed structure is simulated, and a battery simulation model is built in Simulink. Table 1 shows the parameters of this simulation model battery pack.

Table 1 Parameters of the simulation model battery pack

Parameter	Value	Parameter	Value
Rated voltage	12.8V	Sampling interval	1s
Rated capacity	15Ah	The initial value P0	10^6
Initial battery capacity	0.8	Process noise	10^{-3}

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The simulation sample pulse current is used to charge and discharge the battery. The battery is discharged with 3C current for 180s at the beginning, and then after a period of time, the battery is charged and discharged with 2C current for 100s. The method is cycled until the battery charge is less than 0.2. In order to more intuitively demonstrate the accuracy and superiority of the proposed algorithm, the proposed algorithm is compared with the simulation results of the Ann integration method. The simulation results are shown in figure 3.

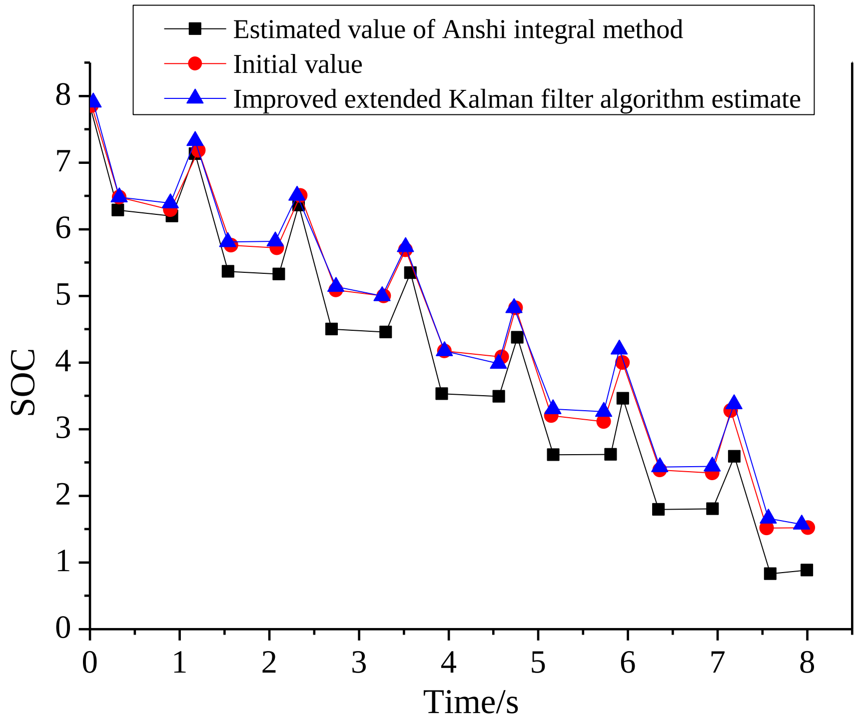

Figure. 3 Estimation of SOC curve based on Ann integral and estimation of SOC curve based on improved extended Kalman filter algorithm

From the simulation image in Figure 3, it can be found that the accuracy of the Ann integral method estimation is quite different from the theoretical value, while the results of the improved extended Kalman filter algorithm estimation are almost consistent with the theoretical value, indicating that the improved extended Kalman filter algorithm proposed in this study has better advantages. It can also be found directly from the figure that with the increase of the estimated value, the error of the ampere-hour integration method becomes larger and larger, indicating that the ampere-hour integration method will accumulate errors in the process of estimating SOC. However, it can be found from the figure that the error of the SOC curve estimated by the improved extended Kalman filter algorithm is always small and almost zero in the whole process, which also indicates that the improved extended Kalman filter algorithm has the ability to eliminate the cumulative error.

3.2 Analysis of optimization results of EVs battery management system based on SOC and distributed structure

First, the accuracy of the total voltage acquisition is tested for the battery management system. Table 1 shows the error values of the total voltage acquisition results and temperature acquisition of the battery pack. As shown in the figure, the measurement results of the unit plate designed in this study are not different from those of the multimeter, with the maximum error of 0.26%. Therefore, the measurement results of the optimized battery management system can meet the requirements of precision measurement. Then the temperature acquisition of the battery management system is tested. It is found that the error between the temperature acquisition and the actual temperature is controlled within ±0.5°C, which can meet the requirements of the battery management system.

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Table 2 The total voltage and temperature of the battery pack acquisition

Times	The total voltage			Temperature		
	Total voltage/V	Total voltage acquisition/V	Error /%	Measurement temperature/V	Temperature acquisition/V	Error/%
1	12.596	12.617	0.16	11.9	11.7	0.2
2	12.814	12.783	-0.23	12.5	12.4	0.1
3	12.828	12.854	0.20	13.1	12.8	-0.3
4	12.957	12.989	0.25	13.5	13.4	-0.1
5	13.063	13.091	0.22	13.9	13.8	0.1
6	13.131	12.166	0.26	14.3	14.4	0.1
7	13.167	12.202	0.26	14.8	14.7	0.1
8	13.201	13.229	0.22	15.2	15.0	0.2
9	13.285	13.306	0.165	15.7	15.5	0.2

4. Conclusion

In order to extend the life of the battery pack of the electric vehicle, realize accurate control of the battery, and effectively avoid potential safety hazards in the electric vehicle, the optimization of EVs management system based on SOC estimation and distributed structure is studied. First, three different battery management system structures are compared. According to the characteristics of the three different structures, the distributed structure battery management system is selected, and the structure topology of the battery management system is designed. Then the simulation results of SOC estimation of the improved extended Kalman filter algorithm are presented. Experimental results show that the proposed algorithm has high accuracy and the ability to eliminate cumulative errors. Finally, the battery management system of electric vehicle based on SOC and distributed structure is tested. The results show that the battery management system has high accuracy in both total voltage acquisition and temperature acquisition.

The research helps to promote the development of EVs in China, but the research still has some limitations. The battery management system is designed without interference, but in reality, the battery management system will be subject to a variety of interference, so this will be the focus of the future research.

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