The Battery Management System Construction Method Study for the Power Lithium-ion Battery Pack

Jianchao Li[a], Shunli Wang[b*], Carlos Fernandez[c], Ni Wang[a], Hongqiu Xie[a]
[a] MianYang Product Quality Supervision & Inspection Institute
Mianyang, China
[b] School of Information Engineering, Southwest University of Science and Technology
Mianyang, China
[c] School of Pharmacy and Life Sciences, Robert Gordon University
Aberdeen AB10-7GJ, UK
e-mail: wangshunli@swust.edu.cn.

Abstract—**The quality of the lithium battery is not easy to grasp at the production process, there are subtle differences of the electric cores. The LiCoO2 lithium battery pack is taken as the research object, in which its characteristics are analyzed and the state of charge (SOC) estimation method is explored by using the Extended Kalman Filter (EKF) algorithm combined with the open circuit voltage method and current time integral method. The hardware and software are designed for the BMS, in which the STM32F103ZET6 is used as the controller, and the battery voltage detection circuit, current detection circuit, and temperature detection circuit are designed. The software development environment is Keil uVision5 and the software flowchart together with its subroutine flow chart is given. The BMS is built by the STM32 controller, detection circuit, alarm circuit and LCD display etc. to do the real-time monitoring and SOC estimation of lithium battery voltage, temperature, charge and discharge current. And it can trigger the alarm circuit when the battery is in the over charge and discharge, high temperature and on other abnormal conditions. The results show that the BMS can realize the detection of the voltage, current, temperature and other parameters of the battery pack together with the SOC estimation.**

Keywords-lithium battery pack; battery management system; circuit design; state of charge; safety monitoring

I. INTRODUCTION

Because of the voltage limitation of the single lithium battery cell, it is necessary to connect the lithium batteries in series to adapt to some specific high-power applications. However, the quality of the electric core is not easy to grasp in the production process of lithium batteries, resulting in the slight difference of the electric core at the factory. Because of the environmental factors such as aging, the inconsistency of the battery will be more and more obvious, which makes the battery efficiency and life to be poor. And especially in the case of excessive discharge, it may cause severe burning of lithium battery [1]-[3]. Therefore, the battery management system (BMS) for the real-time working state monitoring is necessary for the lithium battery usage, to ensure that the lithium battery does not occur over charge and discharge risks, in which the analysis and calculation of the battery power and the conversion is particularly important to ensure the safe operation of lithium battery.

At present, domestic and foreign researchers have voltage detection means, in which the battery SOC estimation method and battery equalization technology is convenient to do a more in-depth research and improve the SOC estimation precision performance and realize the lithium battery balancing strategy [4]-[7]. However, it is still a need for application in lithium batteries continue to research technology. Therefore, the BMS for a more in-depth study is necessary [8]-[10]. In this paper, a BMS is designed, in which the online SOC estimation is conducted by using the EKF algorithm [11] combined with the open circuit voltage [12] and current time integral methods [13] to protect the lithium battery. The lithium battery parameters of charge and discharge current, temperature and each battery cell voltage etc. [14] should be in real time monitoring. The BMS realizes the accurate parameters measurement of voltage, current and temperature of each single battery cell and the SOC estimation. It can realize the real-time battery parameter monitoring of the lithium batteries and protects the battery safety.

II. MATHEMATICAL ANALYSIS

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts if possible. True-Type 1 or Open Type fonts are preferred. Please embed symbol fonts, as well, for math, etc.

A. The State of Charge for Lithium Battery

The SOC is an important parameter used to describe the current remaining power of a battery. The real time and accurate estimation of this parameter can not only reflect the current remaining battery information accurately, but also is an important basis of the BMS to determine the control strategy. This parameter is used to reflect the remaining capacity of the battery, which can be defined as the percentage of the total capacity remaining in the battery as shown in equation 1.

978-1-5386-1306-1/17/$31.00 ©2017 IEEE

$$SOC=\frac{Q_C}{C_I}\times 100\% \tag{1}$$

Expression: the parameter Q_c indicates the remaining capacity of the battery, the parameter C_I represents the total capacity of the battery. If the battery has been discharged to obtain the remaining energy state of the battery, the SOC can be expressed as shown in equation 2.

$$SOC=1-\frac{Q}{C_I} \tag{2}$$

The SOC estimation has been the most important and difficult point in the research and design of BMS. Whether the SOC value of lithium battery can be estimated accurately has a direct impact on the life of lithium battery, the charge and discharge efficiency. Especially, the SOC of lithium battery is related to many factors, such as the battery temperature, polarization effect, and the battery life. The working characteristics is very strong nonlinear, which makes it to be very difficult to estimate the SOC real timely and online.

B. Analysis of the Main Factors Affecting SOC

1) The internal temperature

The outside ambient temperature for estimating SOC of lithium battery is very obvious. The severe degree of electrochemical reaction in the internal lithium battery is changed along with the temperature change. The lithium battery can release more energy along with the increase of temperature. However, when the temperature is too high, it will produce a large number of high temperature gas, and thus damage the battery. Meanwhile, the aging seriously affect the service life of the battery. Therefore, the proper temperature allows the battery to work efficiently, which will make it to release as much electricity as possible and extend battery life.

2) The charge and discharge rate

The magnitude of charge and discharge current is very important. The different charging and discharging currents will lead to different charge and discharge effect in the same time period. In general, the greater the discharge rate, the less power the battery emits.

3) The self discharge rate

T charge and discharge essence of lithium-ion batteries are electrochemical reaction. Therefore, even if the lithium battery is not used in the case, the internal is also a slow chemical change, which leads to the SOC change of the lithium battery. Because of the obvious influence of temperature on the electrochemical reaction rate of the battery, the lithium battery self discharge rate becomes large in the case of high temperature, thus speeding up the release of the battery and leading to the SOC decrease.

4) The aging of the battery

Due to the constant charge and discharge, the heating and cooling of the lithium battery will affect the internal structure of the battery, which leads to the aging of the battery. As the battery age intensifies, the SOC of the lithium battery will decline gradually until the battery cannot be used eventually. Generally, the aging degree of the battery is mainly affected by the number of battery cycles, the charge and discharge current of the battery, the charging mode and discharge depth.

C. SOC Estimation Based on Extended Kalman Algorithm

According to the Thevenin equivalent circuit model established, the function relationship can be obtained by the circuit model as shown in equation 3 and 4.

$$E=R_0 I(t)+U_c(t)+V(t) \tag{3}$$

$$\dot{U}(t)=I(t)/C-U_c(t)/(R_1 C) \tag{4}$$

The function relation between the current time integral method as shown in equation 5.

$$SOC(t)=SOC(t_0)-\int_{t_0}^{t}\eta i(t)d(t)/Q \tag{5}$$

The correction factor is the rated capacity of the lithium battery, the discrimination of which can be depressed by equation 6, 7, 8.

$$V(k)=E-U_c(k)-i(k)R_0 \tag{6}$$

$$U_c(k+1)=U_c(k)e^{(-T/\tau)}+i(k)R_1(1-e^{(-T/\tau)}) \tag{7}$$

$$SOC(k+1)=SOC(k)-\eta i(k)T/Q \tag{8}$$

A function of electromotive force in the sampling period. Taking the lithium battery as the state variable and the current of the battery as the input, the open circuit voltage of the battery is taken as the output, thus the state equation of the system is established. The above formulas are derived to obtain the state equation and the output equation of the system as shown in equation 9 and 10.

$$X_{k+1}=\begin{bmatrix} SOC(k+1) \\ U_c(k+1) \end{bmatrix}=\begin{bmatrix} 1 & 0 \\ 0 & e^{-T/\tau} \end{bmatrix}x_k+\begin{bmatrix} -\eta T/Q \\ R_1(1-e^{-T/\tau}) \end{bmatrix}I(k)+W_k \tag{9}$$

$$Y_k=V(k)=E[S(k)]-U_c(k)-R_0[I(k)]+V_k \tag{10}$$

They are system noise and measurement noise, respectively, and the corresponding variance is equal to. The system matrix can be obtained by the above expressions, which can be shown in equation 11, 12 and 13.

$$A=[\begin{matrix} 1 & 0 \\ 0 & e^{-T/\tau} \end{matrix}] \tag{11}$$

$$B=\begin{bmatrix} -\eta T/Q \\ R_1(1-e^{-T/\tau}) \end{bmatrix} \tag{12}$$

$$H[k]=[\dot{E}[SOC(k\,|\,k-1)]-1] \tag{13}$$

The EKF algorithm is specially applied to nonlinear systems, and its steps are similar to those of the Kalman filtering algorithm. The algorithm is mainly divided into six steps.

The first step: status prediction.

$$X(k|k-1) = AX[k-1|k-1] + BI(k) \tag{14}$$

The second step: Measurement and prediction.

$$Y(k|k-1) = E[SOC(k|k-1)] - U_c(k|k-1) - R_0[I(k)] \tag{15}$$

The third step is to compute the covariance matrix.

$$P(k|k-1) = AP(k-1)A^T + Q \tag{16}$$

The fourth step: solving the Kalman gain.

$$Lg(k) = P(k|k-1)H^T(k)/[H(k)P(k|k-1)H^T(k) + R] \tag{17}$$

The fifth step: to correct the estimate of the state.

$$X(k|k) = X(k|k-1) + Lg(k)[Y(k) - Y(k|k-1)] \tag{18}$$

The sixth step: update the current error covariance matrix.

$$P(k) = [E_2 - Lg(k)H(k)]P(k|k-1) \tag{19}$$

The given initial value, is a step to step six cycles through the EKF algorithm, revising the current time integral method of error estimation of SOC, making the SOC estimation value close to the true value. The main analysis of the main factors affecting the estimation of lithium battery SOC, including temperature, discharge rate, cell aging degree, and several existing SOC estimation methods are analyzed and compared, the open circuit voltage method suitable for estimating the initial SOC lithium battery, estimating real-time SOC online ah integration method suitable for lithium batteries. By understanding the extension principle of Kalman algorithm, the application of the extended Kalman algorithm in SOC estimation in the related research, the estimation method of EKF algorithm based on SOC, and analyzed the main parameters of the EKF algorithm, to determine the feasibility of estimation method of EKF algorithm and accuracy based on SOC.

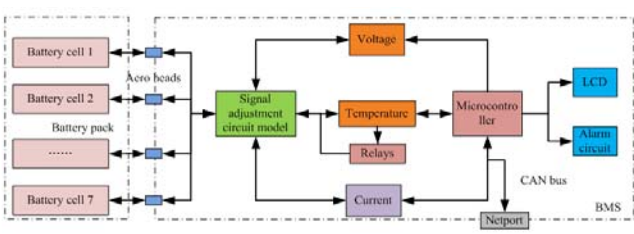

Figure 1. The BMS schematic diagram.

III. EXPERIMENTAL ANALYSIS

A. Establishment of BMS System

The main function of the BMS design of this project is to realize the detection of parameters consisting of 7 single battery voltage, cobalt acid lithium battery temperature and charge discharge current, and each single battery of lithium battery SOC estimation, and can be in an abnormal state in the battery current and temperature and the charged state of alarm. The BMS system consists of a voltage detecting circuit, charge discharge current detection circuit, temperature measurement circuit, SCM system, LCD display circuit and alarm circuit components, wherein the voltage detection circuit includes total battery voltage detection and battery cell voltage detection. The structure of the BMS is shown in Fig. 1.

The lithium battery parameter detecting circuit of the battery voltage, current, temperature and other parameters of information collected to the MCU main controller by the main controller through a filtering algorithm for data filtering and estimation of battery SOC value, and then through the display circuit, the real-time display of battery parameters, achieve the purpose of lithium battery real-time monitoring, the alarm circuit is mainly overcharge and over discharge of the battery temperature is too high when the battery sends an alarm signal to remind the user to achieve.

1) Master chip selection and minimum system of single chip microcomputer

As the brain of the whole BMS, the main control chip of MCU is used to realize the algorithm and control the circuit modules effectively. At present, there are 51 single-chip microcomputer series, AVR series, PIC series and other 8 bit microcontroller, MSP430 and Freescale Carle series of 16 bit microcontroller, and STM32, and many other 32 bit microcontroller based on the ARM architecture. STM32F103ZET6 ARM 32 based on Cortex-M3 kernel CPU, the highest frequency of 72MHz, with 11 timer, 3 12 ADC, 3 SPI and 2 IIC communication interface, is a good performance and low cost microcontroller.

The main control chip of the BMS designed in this paper is the selection of STM32F103ZET6, there are two main reasons: first, the chip has a strong data processing ability, has a large storage capacity, good user development environment, it has the advantages of low power consumption, rich on-chip resources etc.. Due to its high computing speed and chip's 12 bit high resolution ADC and multiple communication interfaces, BMS can be easily and efficiently implemented for data acquisition, processing and SOC estimation.

2) Voltage detection circuit design

At present, the detection methods of battery voltage are mainly common mode measurement, differential mode measurement, relay switching, V/F conversion, contact less sampling, linear circuit direct sampling and so on. The common use of pressure resistance measurement method, relative to the same reference point, using voltage precision resistance of each measurement point is proportional to the voltage attenuation, then each of the measurement points are subtracted, so as to get the voltage between the measuring point, the lithium battery cell voltage. The method is simple in circuit and few in components, but the measurement accuracy is low. It is not suitable for voltage measurement in SOC estimation.

Electrolytic capacitor relay and isolation of large capacity battery and a voltage detecting circuit using the relay switching method, the relay is closed to one side of the lithium battery, lithium battery for capacitor charging, charging is completed, the relay is closed to the side voltage detection circuit, lithium battery and capacitor and a voltage detecting circuit isolated due to capacitance retention a voltage signal, a lithium battery is measured the voltage detection circuit only by measuring the voltage across the capacitor, the voltage can be obtained corresponding to the value of lithium battery. Due to the mechanical action of the relay, the switching speed is slow, the service life is short, and the reliability is low.

The V/F voltage conversion method of the single battery of the battery pack were used, and the partial pressure as the V/F conversion of the input signal through the V/F conversion, output opt coupler isolation, and then sent to the analog switch processor through the analog switch frequency signal acquisition, so as to realize voltage detection. When the voltage is collected by the V/F conversion method, the response is slower and the accuracy is less in the small signal range.

The design of the lithium battery voltage acquisition circuit as shown in Fig. 2, with high common mode voltage INA117P differential amplifier differential circuit, because there is no direct electrical connection between the input and output, to achieve electrical isolation alternative isolation amplifier, OPA27 precision operational amplifier used in differential circuit inverse proportional amplifier. 3.3/4.7=0.7 times zoom of voltage, the output within the ADC acquisition range of STM32, and then use the 12 bit ADC STM32 with A/D conversion, realize the measurement of the single cell voltage of lithium battery.

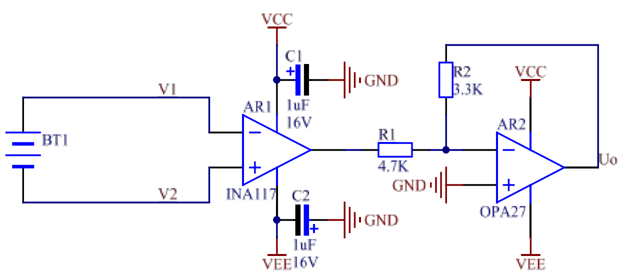

Figure 2. Schematic diagram of battery voltage detection.

The voltage sampling circuit is quite important, the reason of which is that its inverse proportion amplifying circuit can effectively suppress common mode signal, the voltage of each single battery of lithium batteries in series in that measure, which can effectively suppress common mode signal, improve the measurement accuracy. An analysis of the graphic circuit can be described as shown in equation 23.

$$Uo = \frac{R2}{R1}(V1 - V2) \tag{20}$$

Since the voltage range of the battery is 2.7V~4.2V, the output voltage range is 1.896V~2.949 V.

3) Design of temperature detection circuit

The temperature detection methods are generally thermocouple temperature detection, thermal resistance temperature detection and integrated temperature sensor detection. Thermocouple temperature measurement part is composed of two different materials thermoelectric pole, because of its contact potential and conductor properties and contact point temperature, it can be temperature measurement, the temperature signal into electrical signals. The thermal resistance is measured by the resistance of the conductor (semiconductor) with the temperature. The temperature detection circuit is shown in Fig. 3.

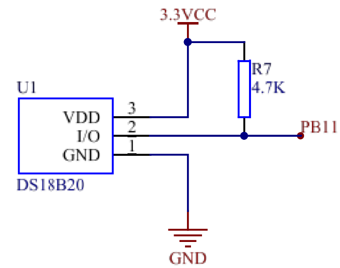

Figure 3. Schematic of DS18B20 circuit.

The DS18B20 digital temperature sensor is a common temperature detection element, the temperature range of -55 degrees, ~125 degrees centigrade. DS18B20 only needs a communication line to realize bidirectional data communication with the processor. It has the characteristics of small size, strong anti-interference ability, the small hardware overhead and high accuracy. The design selects the temperature sensor, and its I/O pin is directly connected with the PB11 pin of the STM32 microcontroller. The temperature of the lithium battery can be easily detected by using DS18B20.

4) Alarm circuit and display circuit

The alarm circuit designed in this paper uses the triode to drive the active buzzer, so as to realize the alarm function when the battery is in abnormal state. Lithium batteries are mainly to detect the abnormal state detection is the single battery overcharge and over discharge, the battery temperature is in normal working temperature range, and the charge discharge current is in a safe range, if the above abnormal state, the buzzer alarm should be realized. The alarm circuit of the BMS is shown in Fig. 4.

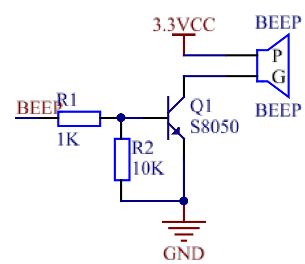

Figure 4. Buzzer alarm circuit.

The LCD monitor is used to display the parameters of the battery, such as voltage, current, temperature, and the SOC value of the battery. The 2.8 inch LCD display support SPI communication interface in BMS system design, convenient to connect with the main controller of communication and display each cell voltage and SOC value, total battery voltage, temperature and battery charge and discharge current and other related information, improve the visualization and user experience.

B. Experimental Results

In the welding of the hardware circuit and software debugging procedures, the design of BMS was tested using the BMS design of lithium cobalt acid lithium battery cell voltage, current and temperature were collected, and the realization of the SOC estimation, are shown in Table 1, including the actual voltage with the actual current multi-meter measured value, the design of BMS was obtained for temperature measurements, DS18B20 digital temperature sensor the temperature value.

TABLE I. MEASUREMENT DATA FOR BATTERY CELLS

Parameters	Value		
	1 Cell	*2 Cell*	*3 Cell*
U measuring /V	3.6542	3.822	3.7942
U actual /V	3.6382	3.8017	3.8014
ΔU/V	0.016	0.0203	-0.0072
I measuring /A	2.56	2.56	2.56
I actual /A	2.84	2.84	2.84
ΔI/A	-0.28	-0.28	-0.28
temperature/°C	27.85	27.85	27.85
SOC measurement	0.2121	0.6826	0.6514
SOC reality	0.2091	0.6844	0.6526
ΔSOC	0.003	-0.0018	-0.0012

IV. CONCLUSION

In this paper, the LiCoO2 lithium battery pack is taken as the research object, in which its characteristics are analyzed and the state of charge (SOC) estimation method is explored by using the Extended Kalman Filter (EKF) algorithm combined with the open circuit voltage method and current time integral method. The smallest system of STM32ZET6 microcontroller is used as the main control circuit, and a voltage acquisition circuit, a current acquisition circuit, a temperature acquisition circuit and a LCD display are designed to build the BMS. The voltage acquisition circuit, current sampling circuit, temperature acquisition circuit is designed and the PCB principle diagram drawing, and procurement of the required components, then the components of welding, circuit debugging and modification, and with keil uVision5 as software development tools, realized on the part of the BMS software programming and debugging. Finally, the hardware design and software design of BMS is realized. Experiment and test BMS for the design, found the existing problems in the design of hardware circuit, after analyzing the existing problems, put forward the corresponding solutions, and the possibility of the scheme is verified by simulation, and through the modification of the original design of the circuit, completed the revision and improvement of battery management the design of the system.

ACKNOWLEDGMENT

The work was supported by National Defense Scientific Research (No. B3120133002), Sichuan Science and Technology Support Program (No. 2017FZ0013), Scientific Research Fund of Sichuan Provincial Education Department (No. 17ZB0453) and Mianyang Science and Technology Project (No. 15G-03-3). We would like to thank the sponsors.

REFERENCES

[1] G. Dong et al., "Online state of charge estimation and open circuit voltage hysteresis modeling of LiFePO4 battery using invariant imbedding method," *Appl. Energ., vol.* 162, Dec. 2016, pp. 163-171.

[2] T. Gallien et al., "Magnetism versus LiFePO4 battery's state of charge: a feasibility study for magnetic-based charge monitoring," *IEEE Instru. Meas. Mag., vol.* 64, no. 11, Apr. 2015, pp. 2959-2964.

[3] X. Gong et al., "A data-driven bias-correction-method-based lithium-ion battery modeling approach for electric vehicle applications," *IEEE T. Ind. Appl., vol.* 52, no. 2, Aug. 2016, pp. 1759-1765.

[4] A. Lee et al., "Efficient Inter Prediction Mode Decision Method for Fast Motion Estimation in High Efficiency Video Coding," *ETRI J.*, vol. 36, no. 4, Aug. 2014, pp. 528–536.

[5] H. He et al., "Real-time estimation of battery state-of-charge with unscented Kalman filter and RTOS mu COS-II platform," *Appl. Energ., vol.* 162, Dec. 2016, pp. 1410-1418.

[6] M. Hoque et al., "Voltage equalization control algorithm for monitoring and balancing of series connected lithium-ion battery," *J. Renew. Sustain. Ener., vol.* 8, no. 2, Aug. 2016, pp. 1-15.

[7] M. Klein et al., "In-plane nonuniform temperature effects on the performance of a large-format lithium-ion pouch cell," *Appl. Energ., vol.* 165, Dec. 2016, pp. 639-647.

[8] T. Kuo et al., "State of charge modeling of lithium-ion batteries using dual exponential functions," *J. Power Sources, vol.* 315, June. 2016, pp. 331-338.

[9] K. Oh et al., "A novel thermal swelling model for a rechargeable lithium-ion battery cell," *J. Power Sources, vol.* 303, Feb. 2016, pp. 86-96.

[10] A. Ovalle et al., "An electric vehicle load management application of the mixed strategist dynamics and the maximum entropy principle," *IEEE T. Ind. Electron., vol.* 63, no. 5, Aug. 2016, pp. 3060-3071.

[11] S. Pramanik et al., "Electrochemical model based charge optimization for lithium-ion batteries," *J. Power Sources, vol.* 313, June. 2016, pp. 164-177.

[12] T. Tanim et al., "State of charge estimation of a lithium ion cell based on a temperature dependent and electrolyte enhanced single particle model," *Energy, vol.* 80, Apr. 2015, pp. 731-739.

[13] K. Goswami et al., "Early Coding Unit–Splitting Termination Algorithm for High Efficiency Video Coding (HEVC)," *ETRI J.*, vol. 36, no. 3, June 2014, pp. 407–417.

[14] S. Wang et al., "Online dynamic equalization adjustment of high-power lithium-ion battery packs based on the state of balance estimation," *Appl. Energ., vol.* 166, Apr. 2016, pp. 44-58.