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Battery management system for Li-ion battery

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Abstract: Li-ion batteries are widely used in the fields of electric vehicles and energy storage because of high energy density, low self-discharge rate, long cycle life, and wide operation temperature range. To ensure safety and prolong the service life of Li-ion battery packs, a battery management system (BMS) plays a vital role. In this study, a combined state of charge (SOC) estimation method and passive equilibrium control are mainly studied for lithium cobalt oxide batteries. A BMS experimental platform is designed, including both software programming and hardware. The experimental platform has the following functions: voltage and current measurements, SOC calculation, balance control, over charging and over discharging alarm and protection, battery status detection, liquid crystal display etc.

1 Introduction

Along with the development and popularity of various portable devices, batteries are employed frequently as a kind of movable power source in many applications and even become one of the most important components which affect the performances of productions [1]. At the same time, Li-ion batteries are given great expectation because of their high specific energy, high output power and long cycle life [2]. While, the Li-ion batteries have obvious non-linearity, inconsistency and time-varying characteristics, which means there are more and more differences between batteries in charging capacity, the self-discharge rate and the capacity decay rate during cycles. The growing differences can cause large performance degradation of the whole pack, and even lead to explosion accidents [3–4]. Therefore, it is of great significance to implement effective battery management system (BMS) for Li-ion batteries to ensure safety as well as prolong the service life of batteries. It can online detect each stage of the battery cell voltage and current in real-time, calculate state of charge (SOC), implement balance control, diagnose the fault etc. However, many challenges still remain in developing BMS:

(i) The sampling circuit is complex, and requires high anti-interference ability.
(ii) SOC is difficult to estimate accurately.
(iii) The balance control of a large number of monomers in the pack is more complicated, and the capacity utilisation of the battery is low.

In this paper, a combined SOC estimation method and passive equilibrium control are mainly studied for lithium cobalt oxide batteries to respond to these challenges. A BMS experimental platform is designed to verify the high estimation accuracy and desirable equalisation effect.

2 SOC calculation for the pack

SOC is one of the most important parameters of Li-ion batteries, which plays an important role in BMS. Accurate SOC estimation is also a basic parameter to determine the mileage of electric vehicles, as well as a control index for BMS to improve the performance of the system. The SOC for a battery is calculated as follows:

$$\mathrm{SOC} = \mathrm{SOC}_0 - \frac{1}{Q_\mathrm{N}}\int_0^t \eta I \,\mathrm{d}t \tag{1}$$

where SOC_0 is the initial SOC, η the charge and discharge efficiency, I the discharge current, Q_N the rated capacity of the battery.

Currently, the SOC estimation algorithms mainly include the current integration method, open-circuit voltage method, artificial neural network method, fuzzy logic algorithm, Kalman filter algorithm etc. Current integration method is commonly used in practical applications because of its easy implementation and low cost. However, a major drawback of this approach is the existence of cumulative errors. Open-circuit voltage method requires long standing time, which is not applicable to the actual use of the battery. Artificial neural network and fuzzy logic algorithm are effective, but require a lot of experimental data and longer learning time. Kalman filter algorithm is difficult to apply due to huge amounts of calculation [5].

In this paper, we combined current integration method with open-circuit voltage method to calculate the average SOC of a Panasonic lithium cobalt oxide battery pack. When the battery pack is in a static state, open-circuit voltage method is used to correct the cumulative errors of the ampere hour counting. The main parameters of the lithium cobalt oxide battery are shown in Table 1. The open-circuit voltage curve of the battery shown in Fig. 1 is much steeper than that of lithium iron phosphate battery, which can reasonably increase the accuracy of this combined method. In addition, the function relationship between OCV and SOC is obtained by fitting, shown as (see (2))

3 Passive equilibrium control

In practical applications, Li-ion battery monomers must be connected in series or parallel to meet the voltage level and power requirements. However, the differences between the individual cells caused by the manufacturing process, tend to increase with cycling. The life of the whole pack depends on the worst battery, which results in the shorter cycle life and the lower capacity utilisation of a pack compared to an individual cell. Therefore, effective

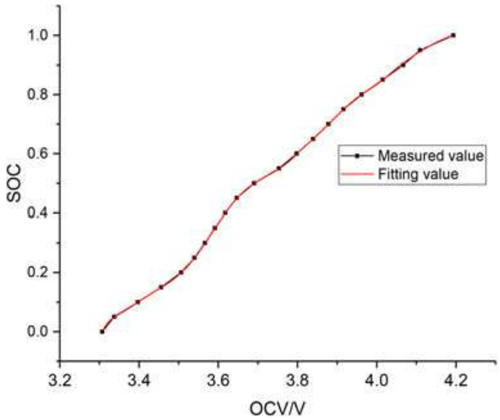

Fig. 1 *Open-circuit voltage curve of the 3400 mAh cobalt acid lithium battery*

Table 1 Main parameters of the lithium cobalt oxide battery

Type	Lithium cobalt oxide
theoretical capacity	3.4 Ah
actual capacity	3.2 Ah
lower limit voltage	2.8 V
upper limit voltage	4.3 V

balanced control measures must be taken to improve the pack's overall performance [6].

Balance control includes passive equalisation and active equalisation. The passive equalisation is to consume the excess energy from the fully charged cell(s) by parallel passive resistors until the higher voltage(s) decreases to the lower one(s). In addition, the active equalisation is to remove charge from higher energy cell(s) and deliver it to the lower one [7]. Considering the high cost and the unsatisfactory efficiency of the active balancing control, we still adopt the low-cost passive equilibrium control (PEC). The circuit topology of PEC is shown in Fig. 2.

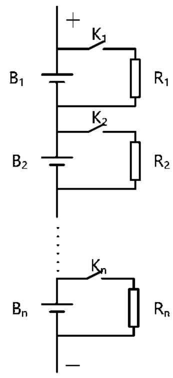

Fig. 2 *Circuit topology of the PEC*

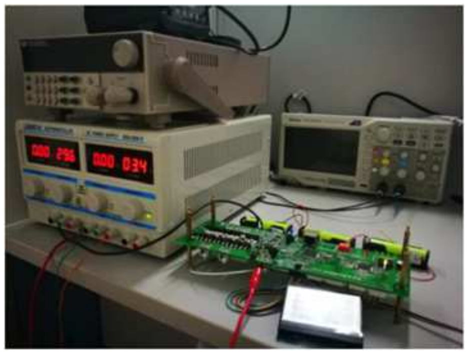

Fig. 3 *BMS prototype for three 3400 mAh cobalt acid lithium batteries in series*

4 BMS experimental platform and experimental results

Based on above arguments, the STM32F105VC is selected as the master chip to carry out the BMS research. We exploited a BMS prototype for three 3400 mAh cobalt acid lithium batteries in series, shown in Fig. 3, which includes software programming and hardware design. It has the following functions:

- battery voltage measurement and current measurement,
- the SOC calculation,
- battery equalisation,
- charging and discharging state detection and control,
- fault diagnosis and protection,
- liquid crystal display (LCD).

The whole structure and compositions are shown in Fig. 4.

4.1 Voltage measurement and current measurement

The MAX14921 is applied to the prototype as the analog front end to measure accurately sample cell voltages and provide level shifting for the battery pack. The device has the following characteristics:

- high accuracy(±0.5 mV cell voltage),
- integrated diagnostics,
- high flexibility,
- low power.

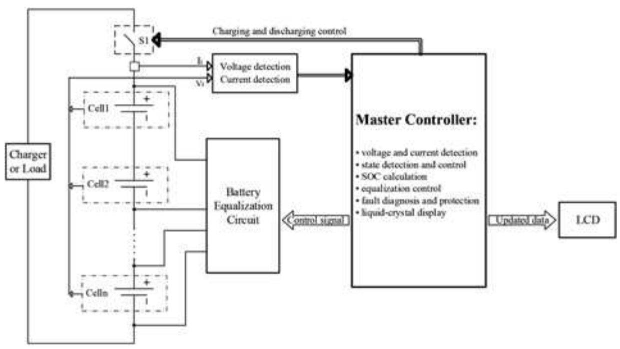

Fig. 4 *General compositions of BMS*

$$\mathrm{SOC}=\begin{cases} -36.89496+17.58024\times\mathrm{OCV}-2.03729\times\mathrm{OCV}^2 \quad 4.0150\mathrm{OCV}\le 4.1930 \\ -1.10449\mathrm{E}6+1.41853\mathrm{E}6\times\mathrm{OCV}-728640.45625\times\mathrm{OCV}^2+187108.0909\times\mathrm{OCV}^3 \\ -24020.21726\times\mathrm{OCV}^4+1233.26337\times\mathrm{OCV}^5 \quad 3.7980\le\mathrm{OCV}<4.0150 \\ -1.20084\mathrm{E}10+3.02417\mathrm{E}10\times\mathrm{OCV}-3.38354\mathrm{E}10\times\mathrm{OCV}^2+2.20739\mathrm{E}10\times\mathrm{OCV}^3 \\ -9.25401\mathrm{E}9\times\mathrm{OCV}^4+2.58534\mathrm{E}9\times\mathrm{OCV}^5-4.81328\mathrm{E}8\times\mathrm{OCV}^6+5.75847\mathrm{E}7\times\mathrm{OCV}^7 \\ -4.01716\mathrm{E}6\times\mathrm{OCV}^8+124502.31908\times\mathrm{OCV}^9 \quad 3.3072\le\mathrm{OCV}<3.7980 \end{cases} \tag{2}$$

Table 2 Measurement results of the cell voltages

Battery number	Actual voltage, V	Measurement voltage, V	Errors, V
#1	3.63	3.65	0.02
#2	3.71	3.68	0.03
#3	3.65	3.64	0.01

The measurements of the cell voltages are shown in Table 2. As can be seen, the maximum voltage measurement error is 0.03 V, which indicates that the voltage sampling has relatively high accuracy.

Unlike voltage measurement, the current measurement is critical to current integration and is required for much higher accuracy. The current sample circuit is shown in Fig. 5. It acquires the charge and discharge currents by sampling the amplified voltages of a small resistor cascaded in the charge and discharge circuits, and current magnifications are 100 and 200, respectively. In order to improve the sample accuracy, the charge current and discharge current are both linearly corrected. The correction formula and correction curve of the charge current are, respectively, shown in formula (3) and Fig. 6

$$I_{\mathrm{CHG-actual\,value}} = K_{\mathrm{CHG}} \times I_{\mathrm{CHG-measured\,value}} + B_{\mathrm{CHG}} \qquad (3)$$

where K_{CHG} is the charge current correction ratio, and B_{CHG} is the charge current correction bias.

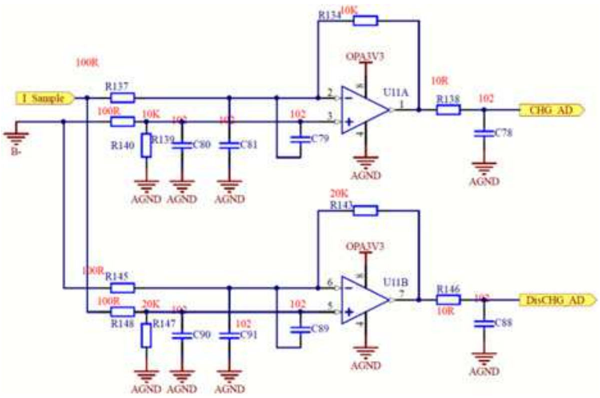

Fig. 5 *Charge and discharge current sample circuit*

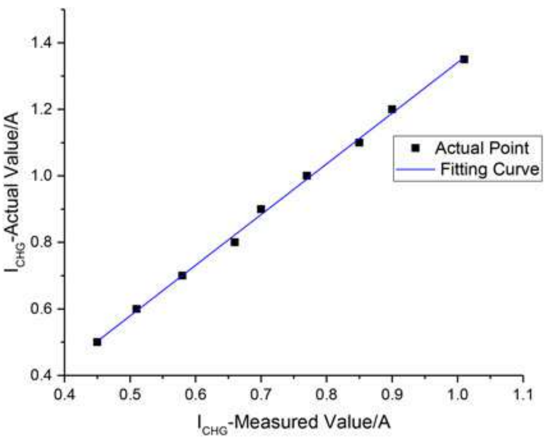

Fig. 6 *Correction curve of the charge current*

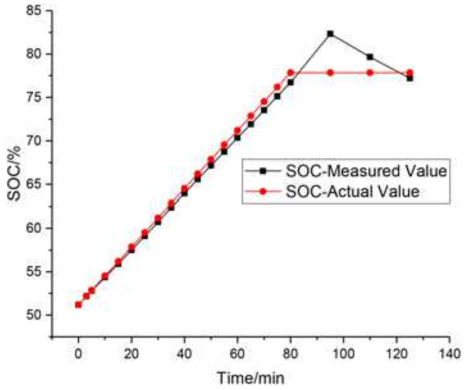

Fig. 7 *Contrast curve of the measured SOC value and actual SOC value*

By the sample-current corrections, the LCD can correctly display the charge and discharge currents of the battery pack.

4.2 SOC calculation results

On the basis of high current sampling accuracy, a DC regulated power supply is applied to output 0.2 C constant current to the lithium cobalt oxide battery pack. The battery pack is charged by constant current for 80 min and then rest for 45 min. Current integration method is used to calculate the SOC during the charging process and the open-circuit voltage method is adopted at the rest state. In the process, the SOC calculated by the BMS prototype is recorded as the measured value. The SOC calculated by the theoretical current integration method is regarded as the actual value. The contrast curve of the measured and the actual is shown in Fig. 7. The initial SOC of the battery pack is 51.2%. After 80 min charging, the measured value is 76.7%. The actual value is 77.8%, with errors of 1.1%. At the time of 95 min., the open-circuit voltage method corrects the SOC to 82%. That is because the battery voltage is higher than the actual open-circuit voltage, which needs much longer time to eliminate the influence of charge polarisation. As time goes by, the battery voltage is gradually stabilised to the actual open-circuit voltage, and the corrected SOC is stable to 77.2%, with errors of 0.6%.

4.3 Design and implementation of PEC

The design of PEC in this paper takes voltage as the balance variable. The strong cell, whose voltage exceeds the minimum voltage an equilibrium threshold, is discharged by the equilibrium resistance. The charge equilibrium threshold is 50 mV, and the static equilibrium threshold is 20 mV in this paper. Considering the power limit, the equilibrium resistance is designed to be 27 Ω. After the experimental process in 4.2, #1 battery is charged separately. In addition, the open-circuit voltage difference of the pack increases. When the voltages are all stable, the LCD is shown in Fig. 8. We verify the passive equalisation function in the static state, and the voltages change, shown in Fig. 9. As can be seen from the voltage waveform, after 2 h of passive equalisation, the

Fig. 8 *LCD in the static state of PEC*

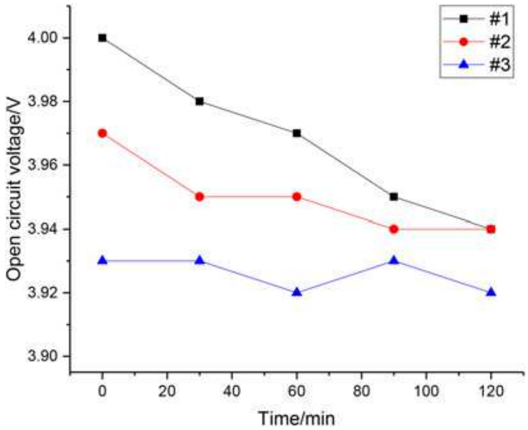

Fig. 9 *Voltage waveform of three batteries of PEC*

battery voltage uniformity has been improved. The 0.7 V difference is gradually reduced to 0.2 V.

5 Conclusions

This paper introduces the overall structure of lithium-ion BMS and its basic functions. In addition, a BMS experimental platform is designed for three 3400 mAh lithium cobalt oxide batteries in series. The experimental platform has the following functions: high accuracy voltage and current measurement, SOC calculation, balance control, LCD etc.

An SOC combined estimation method, which involves current integration method and open-circuit voltage method, is discussed. The experimental results show that this combined method has a cumulative error of 1.1% after the end of the 80 min charging process, and the calculation error can be reduced to 0.6% through the effective open-circuit voltage correction.

Besides, the PEC is considered more practical because of its simple control and low cost. In addition, the experimental results also that the passive equalisation control can effectively improve the consistency of the battery pack in the long process of use.

6 Acknowledgments

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