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Design and Application of Monitoring System of Li-ion Battery Pack

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Abstract

This paper has applied battery pack technologies in battery system based on the characteristics of charging and discharging process and composed big battery pack from single battery cells with MSP430 as micro control unit (MCU). The paper has also designed the monitoring hardware system of main control unit, data monitoring module, as well as the monitoring software of upper computer of CAN communication technologies with collected voltage, current and temperature of battery. The upper software is designed by module process with real-time monitoring function in voltage and temperature.

SOC on-line prediction can be obtained by the establishment of mathematical model of Li-ion battery based on Extended Kalman Filter algorithm (EKF), the accuracy of the prediction is about 2.7%. The algorithm can be applied in battery management system of Li-ion battery for electrical vehicles with the same application effect and accuracy.

Keywords: *battery pack technologies; monitoring hardware system; monitoring software; SOC; EKF algorithm*

1. Introduction

As the requirement and pursuit for modernization in current development is flourishing, the battery system, equipped as power and backup source, is applied widely and essentially in power, electric power department, traffic, communication, environment protection and other fields, especially for those requiring continuous power supplies for long time, and those banning power losses [1]. And power battery, as a type of clean power, embracing a unique advantage in environment protection, comparing to other traditional fossil fuel [2]. While, the large out power is another important index in application of military and other small civil facilities, which called for the need of monitoring the operation state of applied battery pack, the operation state of which is essential for the stability, reliability and security of various facilities [3].

This paper proposes a comprehensive monitoring system which is intended for Li-ion battery pack, with display module on upper computer to acquire data of battery pack like voltage, current, temperature and conduct real-time monitoring for battery system [4-5]. Estimation of SOC which is conducted with Extended Kalman Filter is also included in the paper combined with state observer and measurement models [6-7].

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2. Study in the Performance of Li-ion Battery

2.1. Battery Group Technology

Confined by the manufacturing techniques of cell battery with extreme capacity, the performance of cell battery cannot meet the requirement of application of large current discharging in power fields. The group techniques can largely alleviate the urgent needs for power source with high power and high energy, it is also an important method in extending life of applied battery.

For applying the techniques, traditional combination mode of applying large capacity battery is banished with a newly proposed mode. The battery pack is grouped from batteries connected with smaller capacity, and the pack of which can meet the requirements in voltage and capacity. The security, life and reliability of battery pack obtained from the mode above can be improved in advance when occurring a fatal error in a single battery cell in the pack, the cell can be abandoned from the pack without affecting other circuits.

2.2. Charging and Discharging Features

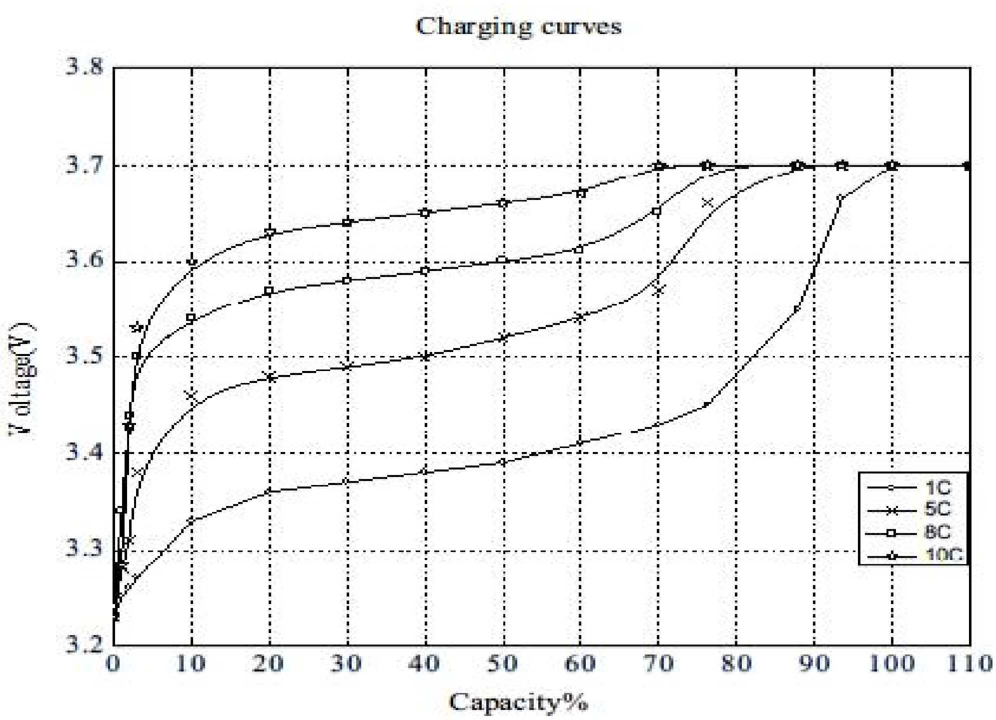

Figure 2-1. Charging Curves at Various Magnification

Charging and discharging experiments are conducted for aiming at the single Li-ion battery in large current discharging monitoring. The concrete standards are as follows: conducting constant current charging in a certain temperature environment with various magnifications of 1C/5C/8C/10C until the saturated voltage of 3.7V, then conducting constant current discharging after keeping battery still for a while with various magnifications of

1C/10C/20C/30C until the capacity is dead. The obtained data are collected as shown in Figure 2-1 and 2-2.

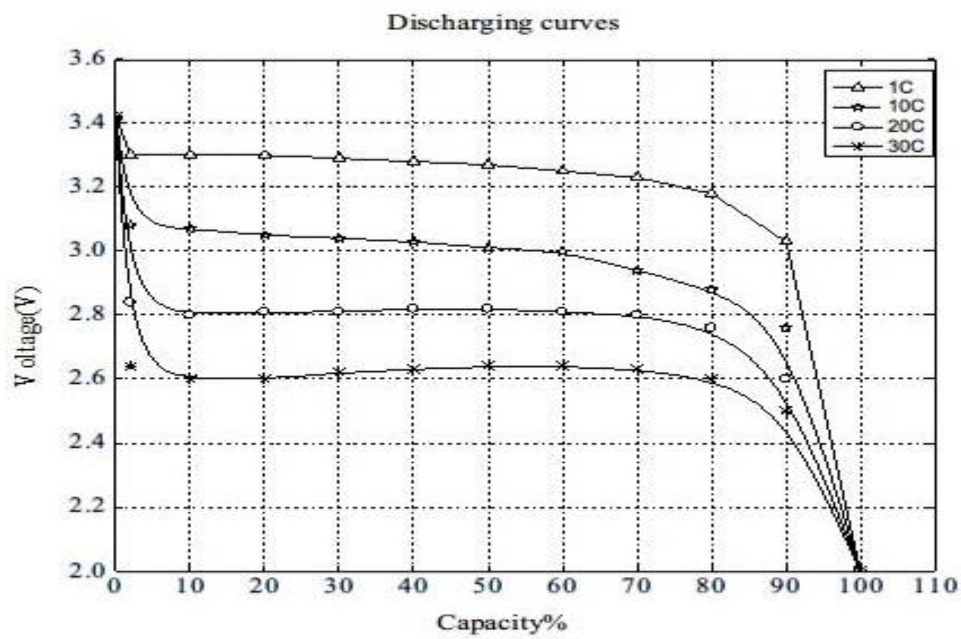

Figure 2-2. Discharging Curves at Various Magnification

2.3. Temperature Features

The dynamic characteristics under normal temperature of battery is largely confined when setting in a cold environment, however, the internal chemical reaction speeds up obviously and the efficiency of battery is improved when the battery is set in the hot environment, which may also induce the permanent damage to battery.

3. Monitoring System Design

3.1. Monitoring Modules Design

(1) Main control module: MSP430F169 is applied with accuracy, function and cost of chips that are taken into consideration. In order to reduce the extra volume of monitoring system, power source of the system is derived from battery itself. Micro-power DC/DC module is applied to reduce voltage fluctuation for voltage of ±15V, ±5V, 3.3V.

(2) Data monitoring module: Firstly, voltage monitoring is an important link within the system. Charging and discharging process should be halt when the voltage which is acquired from battery reached the threshold value, and the over-passed voltage can return to the working area with the built-in balanced circuit. The circuit should embrace energy transformation abilities in encountering voltage discrepancy between any single cell and other cells. Second, charging and discharging current can be very huge for power batteries, and Hall current sensors are applied for considering traditional measurement conducted by resistive subdivision and operation amplifier is feasible for small current. Then, temperature sensors are also a typical link in the system designed with DS18B20 for its low working voltage, easy setup characteristics.

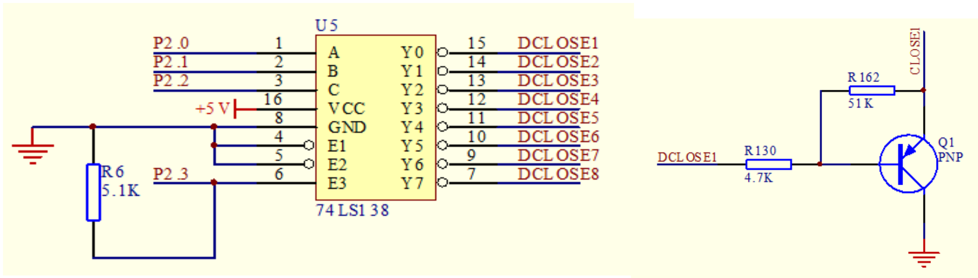

Figure 3-1. Part of the Design Cycle Monitoring

(3) CAN communication module: Extra CAN controller connected with built-in SPI interface is applied in the system with MCU. 2-channel photoelectric isolated is applied in the related system in proof for Electro Magnetic Compatibility (EMC).

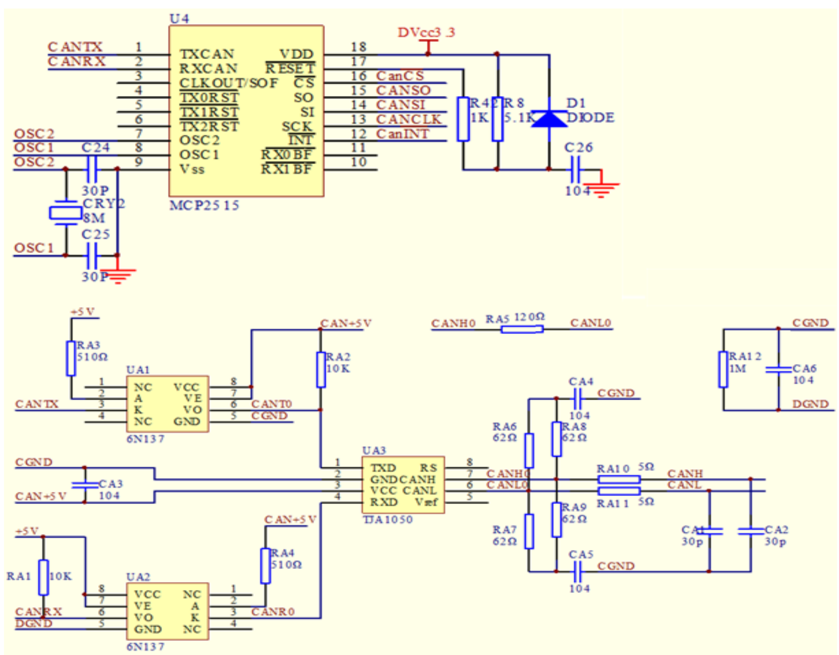

Figure 3-2. CAN Communication Circuit Principle Diagram

3.2. Related Software Design

The whole system is designed and developed based on embedded module mode with effective system service. The alarm line is set in the initialization program and software filtering can be achieved through related algorithm to obtain stable voltage, current and temperature. The communication interface with upper computer is also taken into consideration with CAN bus. The structure flowchart is shown in figure below.

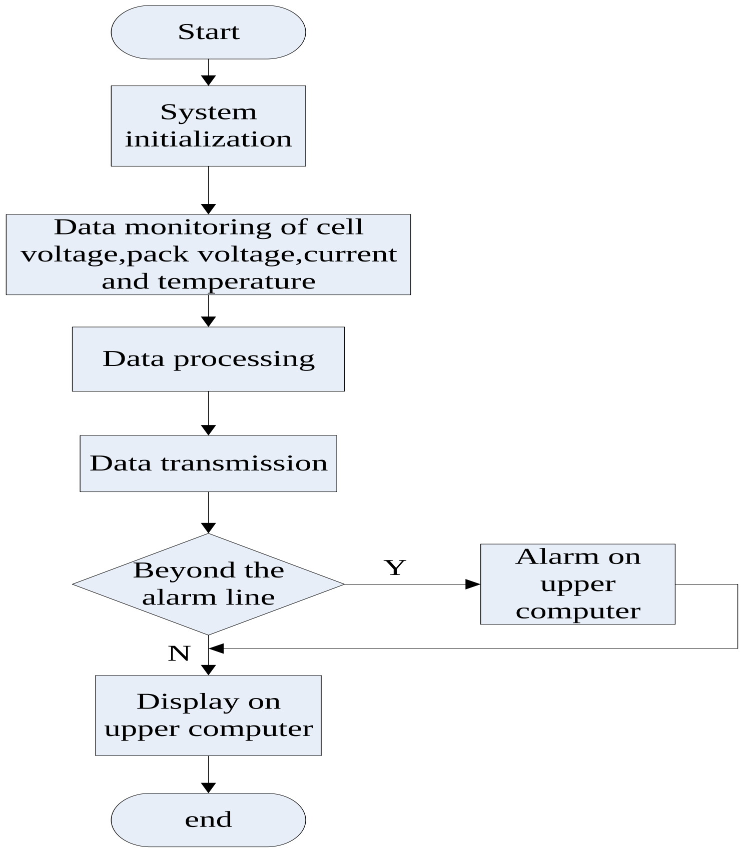

Figure 3-3. Structure Flowchart of the System

3.3. Upper Computer Monitoring

Upper monitoring software is designed with SQL data base, including communication module, data base module and display module. The SQL is applied for real-time data storage and monitoring, and if the battery voltage is higher than settled alarm line, it can be displayed on upper computer as well. The structure of module is shown in Figure 3-4.

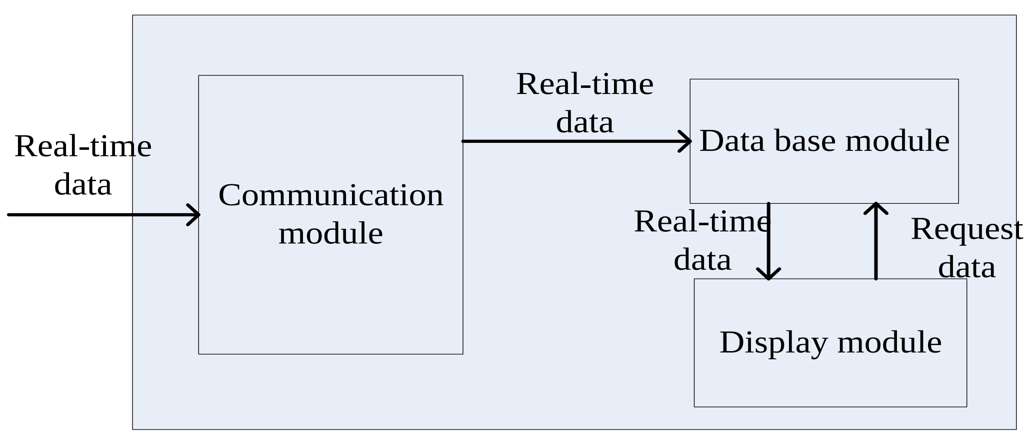

Figure 3-4. Structure of Upper Computer Module

4. SOC Estimation with EKF

4.1. SOC Estimation with EKF

This paper has introduced a compound model of state space model and measurement models, the parameters can be defined as follows, K1-K4 are the coefficients in the model:

$$A_{k-1} = \frac{\partial f(\mathrm{x}_{k-1}, \mathrm{i}_{k-1})}{\partial x_{k-1}} |_{x_{k-1}=\hat{x}_{k-1}} = 1 \quad (4\text{-}1)$$

$$C_k = \frac{\partial g(\mathrm{x}_k, \mathrm{i}_k)}{\partial x_k} |_{x_k=\hat{x}_k^-} = K_1/(\hat{x}_k^-)^2 - K_2 + K_3/\hat{x}_k^- - K_4/(1-\hat{x}_k^-) \quad (4\text{-}2)$$

Set k=0 to complete initialization, when k=1, 2… n, the time update equation is set as:

$$\hat{x}_k^- = f(\hat{x}_{k-1}^-, \mathrm{i}_{k-1}) \quad (4\text{-}3)$$

The time update equation of covariance of error is set as follows, where is the covariance of white noise:

$$P_k^- = A_k P_{k-1} A_K^T + Q_w \quad (4\text{-}4)$$

The obtained matrix of Kalman is set as follows, where is the covariance of observation noise:

$$L_k = P_k^- C_k^T [C_k P_k^- C_k^T + Q_v]^{-1} \quad (4\text{-}5)$$

The observation update equation of covariance of error is set as:

$$P_k = (E - L_k C_k) P_k^- \quad (4\text{-}6)$$

4.2. Simulation Experiment

Set the initial state of battery is charged with SOC0=80% in environment of 30℃±2℃ with EKF update time of 10s. Comparing the SOC estimation value with that obtained from battery management system, and the error curves is shown in the Figure 4-1.

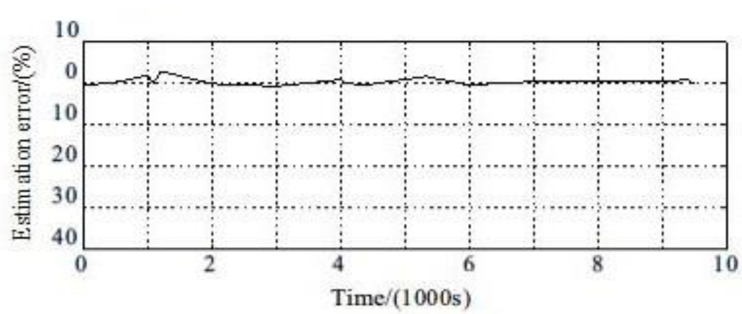

Figure 4-1. Estimation Error Curve with Initial SOC of 80%

It can be concluded that the estimation value is very close to the real measurement with tiny error with Extended Kalman Filter and compound model.

5. Conclusion

This paper has probed into the effect of battery group techniques to the performance Li-ion battery and proposed a battery monitoring system with real-time monitoring upper computer which are aiming at the specific characteristics of Li-ion battery.

Extended Kalman Filter is applied in the proposed model which is from state space model and measurement model. Experiment curves of estimation value and real value measured by battery management system have shown that the proposed estimation is feasible and with high precision.

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