Design of lithium-ion battery management system for mine electric vehicle

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Abstract. With the continuous improvement on mine equipment automation level and the progress of battery manufacturing technology, Lithium-ion batteries are widely used in mining transportation, monitoring communication and emergency facilities. This paper designs a kind of lithium-ion battery management system for explosion-proof mining electric vehicle according to GB3836-20210 series standard. And the management system takes STM32F103 as the main controller and LTC6811 as the core, using passive equalization strategy to realize battery voltage equalization. The test results show that the maximum error of 100 batteries after equalization is 0.32v, the average error is 0.03v and the maximum error between the monitoring value and the measured value is 0.3v, the average error is 0.0019v, which prove that the management system has high accuracy and effectiveness.

1. Introduction

Because the coal resource in Eastern China is exhausted that it takes high mining cost, and most of the sustainable resources in Central and Northeast are located in the deep. In addition, resources in western region are abundant that it has good mining conditions. In this context, the focus of coal production has gradually shifted to the western region. Most of the coal in the western region is open-pit mining, which adopts "single bucket truck" mining technology. The using of power source is imported diesel engine whether it is for single bucket or truck, and the parts are expensive and the annual maintenance costs up to 30% of total cost. Besides, the problems of high exhaust emission, high noise, high failure rate and poor safety exist in the operation of the above mining trucks [1]. With the development of coal industry and the progress of mining equipment technology, the electric transport vehicle represented by mine explosion-proof trackless rubber tyre electric vehicle has become the inevitable direction of future development. In the meanwhile, the new explosion-proof trackless rubber tyre electric vehicles such as 220 ton dump trucks and heavy trucks powered by LiFePO4 batteries have become the hotspot of research and application [2].

The output power of mine electric vehicle is generally large that the voltage of single battery cannot meet the demand. Therefore, mine battery is composed of hundreds of battery cells in series. After series connection, the battery pack increases the total voltage. But it is not good for management due to the huge number of batteries and the differences between each monomer. So part of the individual battery monomers inevitably appear the phenomena of overcharge and overdose, which exists potential safety hazards for battery pack [3]. It will cause a second explosion and endanger...
personal safety while using unsafe power battery in the special environment of coal mine. Consequently, it is necessary to design mine battery management system.

This passage is based on "Safety technical requirements for mine flameproof lithium-ion storage power supply"[4], which designs a lithium-ion battery management system for mine electric vehicle. The system can monitor the battery cell voltage, temperature and the current of battery pack, and using the way of passive equilibrium to adjust the inconsistency problem of monomer. At the same time, the system can improve the using environment of battery, reduce the potential safety hazards and make the performance of the battery pack play to the best state.

2. Structure and equilibrium analysis of battery pack

2.1. Choice of battery cell

According to "Management opinions on safety signs of lithium-ion batteries used in mining products", As the main power source of mine electric vehicles, lithium iron phosphate battery has the advantages of high energy density, large capacity, wide temperature range and high safety. In this passage, the electric core we use is produced by AVIC lithium (Luoyang) Co., Ltd. The specific parameters are shown in Table 1.

| Size: Long * wide * high (mm) | Rate Capacit y | Working current | Working Voltage | Working temperature |
|-------------------------------|----------------|-----------------|-----------------|---------------------|
| 180*71*279                   | 100Ah          | 1/3C 3C         | 4C (CC-CV)      | 3.65V (End-of-charge) |
|                               |                |                 | 12C (Hppc)      | 2.5V (Cut-off discharge voltage) |
|                               |                |                 |                 | 0~45°C (charge Current) |
|                               |                |                 |                 | -20~45°C (Discharge current) |

2.2. Structural analysis of the system

The typical group modes of battery are series mode, parallel mode and mixed mode. Among them, the mixed mode is divided into series connection before parallel connection and parallel connection before series connection. With the aging of the battery, there is no guarantee that the internal resistance of the battery cells is exactly the same. The current distribution is uneven in the parallel mode during charging and discharging, so it is easy to increase the inconsistency of internal resistance and leading to insecurity [5]. Therefore, the "Safety technical requirements for mine flameproof lithium-ion storage power supply" clearly stipulates that the lithium-ion batteries in mining electric vehicles are connected in series.

Battery management system generally adopts modular distributed structure design, and centralized BMS and distributed BMS are commonly used. Centralized BMS integrates master control module and slave control module, which reduces the volume and improves anti-jamming energy of the system. But it is not suitable for high capacity, and high output voltage scenarios [6]. For large mining transport vehicles, high capacity and high output voltage are the first choice for the whole system design. So the centralized BMS is not suitable for mine transport vehicles. Distributed BMS is also called master-slave time system topology, and the structure diagram is shown in Figure 1.

It can be seen from Figure 1, the BMS system consists of three sub can networks and the design transmission rate is 250kbps. The main controller is the intersection node of CAN bus. Ten slave controllers on Can1 and five motor controllers, vehicle controllers and fault diagnosis modules are connected to can2, on board display system is connected to can3. Among them, each slave controller monitors 10 battery cells, mainly responsible for measuring the voltage and temperature of monomer. Moreover, in order to monitor the current of the whole power system, a current monitoring bus is designed.
2.3. Equilibrium control analysis

Balance control is an important function of BMS, so reasonable selection of balance strategy can effectively reduce the cost and improve the safety of the battery pack. At present, the common equilibrium strategies include active equilibrium and passive equilibrium. Active equalization has the advantages of large balancing current, fast balancing speed and low energy consumption. However, balance strategy has complex technology, complex structure and high failure rate [7], so it is not suitable for mining electric vehicles. The passive equalization strategy is based on the principle of positive correlation between battery power and voltage and according to battery voltage data, the energy of high voltage is released in the form of heat energy through parallel resistance to keep the voltage at both ends consistent with that of other cells [8]. Mining electric vehicle is large, and it is used in the open northwest area. So the space of battery pack and the heat dissipation of parallel resistance need not be over considered. The passive equalization strategy is simple and easy to implement. Therefore, LTC6811 control chip is used to realize the passive equalization control of battery pack in this passage.

3. System hardware implementation

The results are analyzed in sections 2.3 and 2.4, the system hardware mainly consists of lithium battery pack, voltage acquisition and equalization, current acquisition, battery temperature measurement, charge and discharge control, LTC6811 chain circuit, STM32F103 main control board and display screen. The block diagram is shown in Figure 2.

It can be seen from Figure 2, voltage acquisition and equalization circuit to realize the voltage control of battery cell, and temperature measurement of battery cell by temperature measurement circuit. All data are transmitted to LTC6811 for AD conversion finally. The converted data is uploaded to STM32 main control board through SPI communication, and the current acquisition circuit directly transfers the total circuit current to STM32 main control board. Then the main control board processes all the received data and displays them on the display screen, judging whether to balance or charge and discharge through these data.

3.1. Voltage acquisition and equalization circuit

The acquisition accuracy of battery cell voltage is directly related to the performance of BMS. This passage introduces the problem of equalization control, determining a strategy for passive equilibrium control of lithium-ion batteries on mines. The voltage acquisition and control circuit based on LTC6811 are shown in Figure 3.

In Figure 3, C0 and C10 are the input pins of the battery, S1-s10 pins are used for battery equalization. When the voltage difference between two batteries is greater than the equilibrium voltage, the S pinned acts as the digital output of the gate driving MOS and discharges the battery with higher
voltage. The resistance of 33 Ω in the figure is discharging resistance. The LED display lamp is set in each battery. When balancing, the LED corresponding to the battery will light up. The passive equalization will release heat through the discharge resistance during equalization, which will lead to the temperature rise of the acquisition board and reduce the performance. Therefore, a heat dissipation circuit is added on the basis of the original circuit. There are five fans on each collection board, which are powered by batteries 1-2, 3-4, 5-6, 7-8 and 9-10 respectively. When one or two of the two batteries in charge of power supply need to be balanced, the spin will drive the equalization circuit and the heat dissipation circuit at the same time, and the heat dissipation circuit capacitor C7 in the figure can stabilize the circuit and reduce the voltage fluctuation. And through the coo circuit, the temperature of the acquisition board can be reduced to ensure the normal operation of the system.

3.2. Current acquisition circuit
The battery current collection and charging module is realized, which greatly effects the estimation of residual capacity and the security of the system. "Safety technical requirements of mine flameproof lithium ion storage power supply" clearly requires that the measurement error is less than 0.5%, and the output current of mine transport vehicle can reach 100A. Therefore the Hall current sensor ACS758LCB-100B is used in this system. The sensor is simplified as shown in Figure 4.
3.3. Temperature acquisition circuit

The temperature range of lithium-ion single battery is relatively large, but the mine electric vehicles are mostly used in high cold and high pressure areas where the temperature difference between day and night is large. In order to ensure that the battery pack works in the best state, thermal management of the battery pack is required. And obtaining the temperature data onto battery cell is the primary task of thermal management. This passage designs a temperature acquisition circuit, which is shown in figures 5.

Temp1 to 10 in the figure are NTC (Thermistor temperature sensor). Attach the NTC probe to the battery, its resistance will decrease with the increase of battery temperature. Then the voltage of input GPIO port changes and obtains the resistance valued by AD conversion. Finally the current temperature can be obtained by querying the relation table of temperature and resistance value. For the sake of reducing the burden of the main control board, the LTC1380 collects 8 channels of signals and converts them into 1 channel. Then it is amplified by LTC6255 and transmitted to LTC6811 for processing. LTC6811 uses two GPIO ports as control signal ports. One GPIO port is used as the signal input port, and the other two GPIO ports are used as the input ports of two temperature signals to complete a group of 10 channel temperature signal acquisitions and processing.

3.4. Cascade circuit

The communication between LTC6811 is based on isoSPI [9]. On the one hand, the device is simplified and the cost is reduced, the volume of BMS voltage acquisition board is compressed compared with the original LTC6802 and the extra cost of CAN communication circuit is saved. On the other hand, it keeps its strong anti-interference ability, using a twisted pair to realize full duplex communication. To realize the communication between MCU and ltc6811, it is necessary to convert the 4-wire SPI signal into 2-wire isoSPI signal. Specific voltage acquisition and communication circuit are shown in Figure 6.

3.5. System test

In this passage, 100 pieces of 100A • h lithium-iron phosphate batteries are used as the research object, and each LTC6811 chip detects 10 batteries. The system is used to charge and discharge the battery pack, and charge and discharge experiments were carried out with 25A current. The comparison diagram of monitoring data and measured data is shown in Figure 7.

In Figure 7, a, b, c and d represent the first, second, fifth and ten batteries respectively. Among the orange histogram represents the monitoring value and the green bar chart shows the measured value. In figure (a), the monitoring values of 10 batteries are consistent, and the error between the monitoring value and the measured value is also small. In figure (c), the voltage levels of battery monomers are not uniform, but the maximum error are only 0.02V. The voltage of sixth cells in diagram (d) is 0.32V voltage compared with other batteries. This shows that there are some differences in the monitoring values of 100 battery cells.
In figure 8, the error between the monitored voltage and the measured value of 100 cells is showed. In figure (a), the single voltage of 10 groups of 100 batteries after equalization, in which graph4-1, Graph4-2, Graph9-5, Graph10-3 and Graph10-6 batteries have poor consistency. The maximum error after equalization is 0.32V and the average error are 0.03V. This data reflects the health state of the battery pack and provides data basis of battery replacement. In figure (b), the error of monitoring voltage and measuring voltage was relatively large: graph4-1, Graph4-2, Graph9-5 and Graph9-10 cells, the maximum is 0.3V, and the average error is 0.0019V. This data reflected the accuracy of the system.
4. Conclusion
In this paper, the development of mine electric vehicles, and analyzes the structure and balance of mine battery packs are discussed. According to GB3836-2021 series standards and the “mining flameproof lithium-ion power storage safety technical requirements”, design of battery management system is based on LTC6811 chip. The system can accurately monitor the single battery voltage, temperature and the charging and discharging current of the whole power supply, which makes the management system of lithium ion battery of electric car for mine more safer, efficient, environmental protection and energy saving.

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