IOP Conf. Series: Materials Science and Engineering **234** (2017) 012014 doi:10.1088/1757-899X/234/1/012014

An Balancing Strategy Based on SOC for Lithium-Ion Battery Pack

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Abstract. According to the two kinds of working state of a battery pack, we designed a balancing strategy based on SOC, and expounds the working principle of balanced control strategy: the battery is charging, the battery charged state of the highest monomer battery is balanced discharge, strong single battery charging current decreases, while the other single cell in the same group is not affected; the battery is in a discharge or static state, single cell battery is the weakest balanced charge, while the other single cell in the same group are not affected. In this paper, we design a kind of lithium ion battery charging and discharging equalizer based on Buck chopper circuit and Boost-Buck chopper circuit. The equalizer is balanced charging and discharging experiments of series four lithium iron phosphate battery, the experimental results show that this equalizer has not only improved the degree not equilibrium between single cells, and improve the battery charge and discharge capacity.

1. Introduction

Due to the low nominal voltage of the single lithium ion battery, about 3.6V, we need to use a number of such cells in series to meet the different voltage requirements[1-4]. For single Lion battery, overcharge or over discharge will lead to reduced capacity, the impact of life, and even lead to direct battery damage or explosion[5-7].

Between each single battery in series in the process of using state of charge or voltage inconsistencies exist, such as the four monomer battery series shown in figure 1, in the charging process, if there is a single battery or reach full charging voltage, the charging process must stop; and in the process of discharge if a battery is empty or reach the discharge voltage, discharge must be stopped.

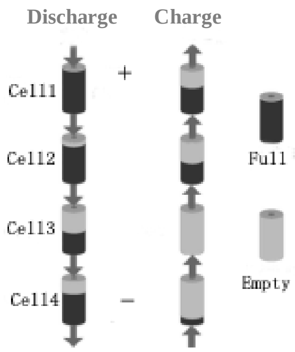


Figure 1. Charging and Discharging diagram of the serially connected battery cells

If you do not take measures to balance, tandem disproportion between single cells which increases along with the increase of the number of charge discharge cycles, the discharge capacity of battery charging will gradually decrease, resulting in battery scrap in advance, so we need to take effective measures to extend the balance of battery life, improve battery charge discharge capacity group.

2. Balancing strategies

According to the balancing of the single cell and the balancing energy flow, the balancing strategy can be divided into the following categories:

(1) for the battery in the battery terminal voltage or the state of charge of the highest battery balancing discharge, the energy is consumed by the resistor[8] or return to the battery pack [9]. This balancing strategy can only be used in the battery charging process, and the equilibrium energy is one-way, which can only be released by a balanced single cell.

(2) In the process of battery charging and discharging, equilibrium energy can only be transferred between adjacent monomer batteries[10,11,12]. This energy balance strategy for the balancing of the battery does not need to have a number of charging and discharging, on the one hand, affect the life of the battery, on the other hand, low speed, large switching loss.

(3) On the process of battery charging and discharging, the energy is transferred from the single cell in the middle of the battery to the lowest single cell based on the terminal voltage[13].

(4) in the process of battery discharge, the balancing strategy for the balancing of the single battery charge in the end of the battery pack[14].

(5) The equilibrium strategy used for battery discharge[15], balancing the energy through the transformer from the batteries to the group end single battery voltage minimum transfer; battery charging, energy balance from the batteries in the end single battery voltage the highest transfer to the battery pack by transformer. This equilibrium strategy is balanced by a single battery selectable and balanced energy is bidirectional.2.1 Analysis on Maglev electromagnetic environment.

In summary, from the analysis of the control ability of the equilibrium current, balancing scheme adopts inductance as storage elements, the control ability of the equilibrium current; from equilibrium strategy, equilibrium strategy of ideal is fifth, which is single cell equilibrium, and the equilibrium energy bidirectional flexible. But the fifth equilibrium strategies and equilibrium in single cell is balanced, the other cells in the same group are affected, and the completion of the first energy conversion, before and after the current single battery is balanced relatively large changes, affect the service life of the battery.

In the battery charging, the battery terminal voltage or state of charge of the highest monomer battery balancing discharge, energy balance from the strong single battery charging current equalizer to transfer the balance of the monomer battery decreases, and the same group of all other single cells is not affected, the the charging current is constant; when the battery charging, battery balancing of the weakest in the battery, energy balance by the equalizer to the weak single cell transfer, the discharge current balancing process of the weak single cells decreased, and the same group of all other single battery in the battery is not affected; static the can, with the above two kinds of equilibrium strategy, but in order to increase the battery energy storage, can be a choice of equilibrium strategy of battery discharge, so only the weakest in the battery cell is balanced charge, while the same group The current in other batteries is zero.

We have designed the balancer which has the following advantages:

1)The transformer is omitted, but also has the balancing of the monomer battery selectivity and balanced energy two-way;

2)Balanced current can be controlled, just adjust the duty cycle of the switch PWM, you can control the size of the current balance;

3)When the balance is only need to carry on the PWM control to a switch, other related switches need to be turned on only, so the switching loss is low, the equalizer control is simple, easy to realize.

3. Balancer Structure and Working Principle

3.1. alanced circuit topology

Figure 2 shows a battery pack equalization module that contains series single cells, which can be used to select the number of individual cells. The topology of the equalization circuit is shown in the dashed box in the figure2.

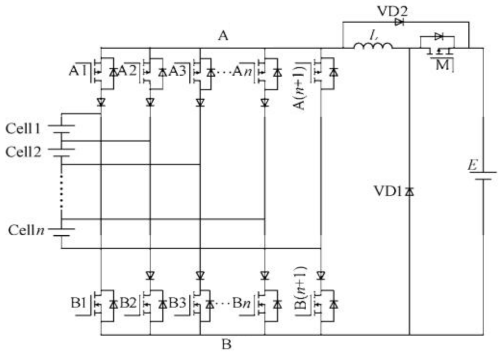


Figure 2. Balancing circuit topology

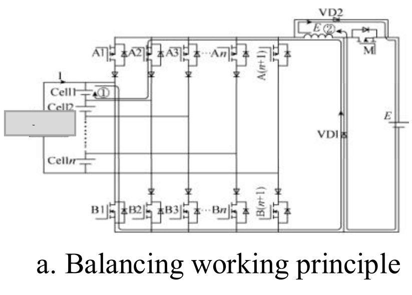
A bridge switch matrix (group A and group B), one inductor L, two freewheeling diodes VD1 and VD2, voltage source E and control power supply E power switch M. Due to the adoption of the group equalization, the utility model can select the switch device with small power, and the small power

Field effect transistor MOSFET saturation resistance in general m, and small driving power, so use a small power MOS transistors as the power switch M and A, B two group switch device. Due to the existence of parasitic diode in the MOS transistors, in order to prevent the short circuit of the battery, we need to use the diode in series. According to the actual situation select the appropriate capacity and voltage of the same type of battery series as the voltage source E.

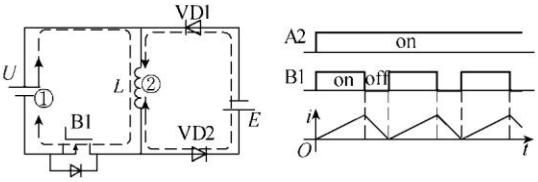
3.2. Balanced discharge control strategy and working principle

In the battery charging process, the group of SOC value within the single cell equilibrium discharge is the highest, the balance of energy transfer to the equalizer, in other words, to improve the capacity of the battery charging method of charging current is reduced by high energy battery in the battery charging process. Specific control process and working principle:

Figure 3 shows the maximum SOC value of the battery Cell1, when the battery Cell1 discharge switch B1 and A2 are turned on, the Cell1 can be stored in the inductor L through the circuit①. When the Cell1 discharge switch is switched off, the equalizer can store the energy in the inductor through the loop②. In order to reduce the switching loss and simplify the switch control, the balance of the switch in the lower arm of the B1 PWM control, so that the upper arm switch A2 has been in the conduction state. Balanced circuit for Boost-Buck chopper circuit[16] typical, as shown in Figure3b, where U is the single battery voltage equalization circuit has two working modes: continuous current mode and discontinuous current mode; switch driving signal and the equilibrium current waveform as shown in Figure 3C, by adjusting the duty ratio can adjust the equilibrium current the size of the transfer of a cycle in the size of the energy balance.



a. Balancing working principle

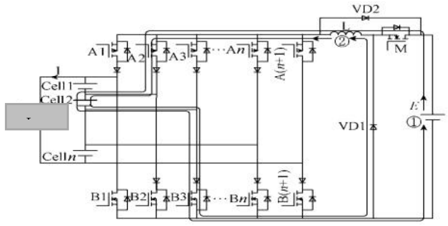


b. Boost-Buck equivalent circuit c. Waveform

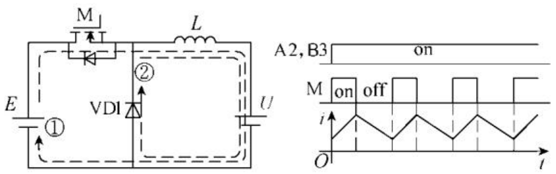
Figure 3. Balancing working principle

3.3. Balanced charging control strategy and working principle
In the process of battery discharge or static, the single cell of the lowest SOC value in the group is balanced. The discharge current decreases low energy single battery in the battery discharge process to improve the discharge capacity of the batteries; while standing on the weak single cell energy supplement, improve the battery energy storage.

Balanced circuit for the typical Buck chopper circuit [16], the specific control process and working principle:Battery Cell2 hypothesis SOC in Figure 5 the minimum balance needed to charge A2 Cell2 switch and B3 has been in the conducting state, and the power switch M PWM control, when M conduction through the loop① to the equalizer inductor and the battery Cell2 release energy, when M can open off amount of inductor. After the loop② is transferred to Cell2.



a. Balancing working principle



b.Buck equivalent circuit c.Waveform

Figure 4. Balancing working principle

As shown in Figure 4b, the equalizer circuit is a typical Buck chopper circuit. As shown in Figure 4C, A2 Cell2 in the process of equalization charging switch and B3 has been in a conducting state, only the PWM control of the switch M, the equilibrium current as shown in the graph, by adjusting the duty cycle to achieve equilibrium current can be controlled and adjusted.

3.4.Characteristic for Balancer and Balancing strategy
A single cell n contains the equalization module, and its monomer batteries are Cell1, Cell2, Cell3, Cellx, Celln, the equalization module has the following characteristics:

(1) The bridge matrix circuit contains a number of switches of 2(n+1).

(2) When the battery is charged, the strongest single battery in the battery pack is discharged to the equalizer, assuming that the battery Cellx is the strongest single cell, and only need to switch the Cellx and the A (x+1) of the two discharge switch of the battery Control, so that the upper arm switch A

(x+1) has been on, and the lower arm switch Bx PWM control can be achieved by the power of the battery to the equalizer Cellx transfer. the battery discharge or static, equalizer for weak single battery in the battery charging, the battery Cellx is single cell hypothesis of the weakest, only need to control the charging switch Ax and Cellx two B (x+1) has been conducted, and the power switch M PWM control can be achieved by the energy balance to the weak battery Cellx transfer.

4. Balance experiment

4.1. Battery Management System

The battery management system includes the functions of single cell parameter detection, balance management, thermal management, data processing and communication.

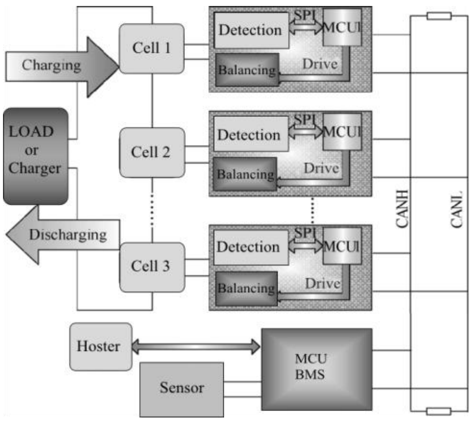


Figure 5. Battery management system

Balanced system is an integral part of the battery management system is an important part, as shown in figure 5 of the battery management system, the battery management and equalization. Each group contains a master controller to realize parameter detection and processing, and then according to the SOC value of each single cell, the corresponding switch action is driven in the equalization module. Therefore, the accurate estimation of SOC is the precondition to ensure the balanced experiment.

4.2. E-SOC curve extraction of LiFePO4 battery

This method adopts electric potential method and the combination of ampere hour method to estimate SOC value and EMF method needs E-SOC curve extraction of single cell. The E-SOC curve extraction experiment was carried out on the lithium iron phosphate battery with a rated capacity of 60A, h and rated voltage of 3.2V, using the c-KGCFS micro battery charging and discharging power supply. As shown in Figure 6, first of all, the SOC curve and discharge SOC curve of the lithium iron phosphate battery are extracted, and then the average value of the two is E-SOC curve. The measured E-SOC curves are stored in EEPROM for the controller to read at any time to correct the initial value of SOC.

4.3. Balance experiment

4.3.1. Equipment and Balancer circuit device. The experimental,which contains one hundred series of lithium iron phosphate battery and battery management system, rated capacity of single battery is 60A/h, rated voltage of 3.2V. Select the four single cells to complete the equalization experiment, the initial SOC value of 39.5%, respectively, 30%, 30% and 20%.

C-KGCFS, A battery charge and discharge power, the DC output voltage of 0 ~ 350V continuously adjustable DC output current of 0 ~ 500A continuously adjustable, can be realized on the battery constant current charging, constant voltage charging, constant current limiting static discharge, etc..

The 3 E cells with rated capacity of 20A, h and rated voltage of 3.2V are used as the power supply in the equalizer, and the initial SOC value of each cell is 60%.

The Balancer used in the experiment is based on the design of 6 lithium ion cell, in order to reduce the loss of the equalization circuit and choose a small power switching device, the specific selection is: A group switch using P channel MOS transistors SPD50P03L, the rated voltage and current were 30V And 50A, the maximum drain source resistance value of 12.5mmΩ; group B and M switch . The N channel MOS transistors IPD135N03L, the rated voltage and current are respectively 30V and 30A, the maximum drain source resistance value is 13.5m; equalization module in series diode and two diode using 42CTQ030 Schottky diode, the voltage and current ratings are 30V and 40A, the maximum turn-on voltage drop of 0.38V.

4.3.2. Charging experiment. The 10A current is supplied by the c-KGCFS power supply to charge the four series batteries, and when the SOC of the battery pack rises to 80%, the charging is stopped. The SOC curve of each cell in the equilibrium process is shown in figure 6, the charging time is 181min, the SOC value of each monomer battery after charging is 80%, 79%, 79% and 69.5%, respectively.

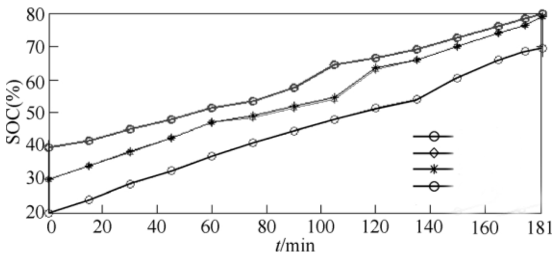


Figure 6.SOC curves in battery charging

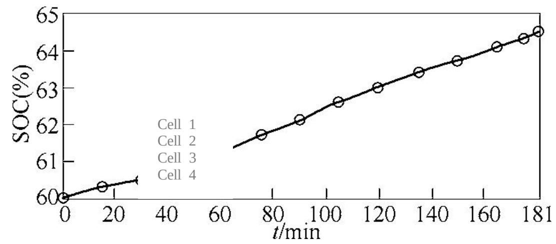


Figure 7. SOC curve of the power E

The SOC curve of the power supply E is shown in figure 7. At the end of the experiment, the SOC value of each individual cell is 64.5%.

4.3.3. Discharging experiment. The 10A current is supplied by the c-KGCFS power supply to discharge the four series batteries, and when the SOC value of the battery group is reduced to 20%, the discharge experiment is stopped.

The SOC curve of each cell in the equilibrium process is shown in figure8, the discharge time is 210 min, the SOC value of each monomer battery after discharge is 21%, 20.5%, 20.5% and 20%, respectively. The SOC curve of the power supply E is shown in figure 9, the SOC value before the experiment is 64.5, at the end of the experiment, the SOC value of each single cell as 52%.

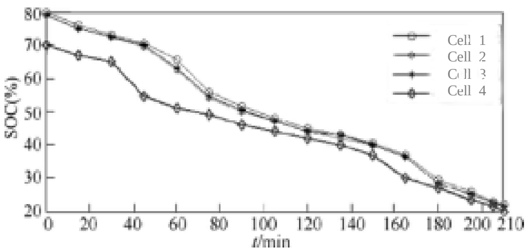


Figure 8. SOC curves in battery discharging

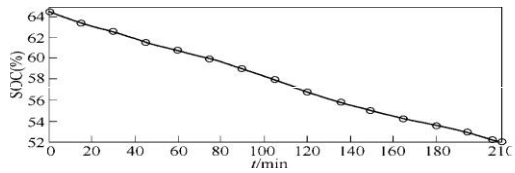


Figure 9. SOC curve of the power E

4.4. Results analysis

The initial SOC four single cell values were 39.5%, 30%, 30% and 20%, if you do not take measures to balance in the charging process, so when the battery SOC value rose to 80% when the single battery SOC values were 80%, 70.5%, 70.5% and 60.5%, but as shown in Figure 7 because, to take a balanced discharge on the No. 1 battery in the charging process, therefore its SOC curve rise speed decreased, thus charging after the expiry of the time delay, charging at the end of each monomer.The SOC values of the cells were 80%, 79.5%, 79.5% and 69.5%.

In charge of the experiment, the balanced energy transfer from 1 batteries to power E, changes in the charge value of SOC before and after the experiment can calculate the ampere hour capacity 1 batteries for 5.1A h by the release of No. 1 batteries and 2 batteries, and can calculate the power ampere hour capacity of E absorption was 2.7A h by SOC curve in Figure 8, which can balance the energy transfer efficiency was calculated as 53% battery charging process. In the experiment, the equilibrium energy is transferred from the power supply E to the 4 cell, so the equilibrium energy transfer efficiency of the battery during discharge is calculated according to the experimental results, which is about 68%. It can be seen that the equilibrium energy transfer efficiency is relatively high, and the loss of equalizer is mainly the loss of MOS transistors and diode. The soft switching technique can be used to further improve the efficiency of energy transfer.

5.Conclusion

Equalizer to inductance is the energy storing element, take a balanced strategy of the strong single battery battery in the battery, and the battery discharge and take static equilibrium strategy to charge the battery in a single cell. The equalization current is controllable and the energy transfer efficiency is high, and the equalization circuit is simple and easy to realize. The charging and discharging experiments of four series lithium iron phosphate batteries show that the equalizer improves the charge capacity and discharge capacity of the whole battery pack.

In order to reduce the switching loss and select the rated voltage and rated current of the switch device is relatively low, so the battery pack can not be too much in a single cell battery. Power supply of the E equalizer is composed of each monomer battery additional series, need to provide management for the single battery, in actual use, according to the number of equalizer in the actual system, the battery will all equalizer of grouping management. The equalizer can be used in the balance management of lithium ion batteries and the balance management of energy storage system.

Acknowledgments

This research was supported by Educational Commission of Zhejiang Province, China.
Project number: Y201534868

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