Comparative study on Equalization Technology of Lithium Battery packs for Electric vehicle

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Abstract. As an important part of battery management system (BMS), battery equalization technology is of great significance to improve the utilization efficiency of battery energy and the mileage of automobile, as well as to prolong the service life of battery. This paper introduces the mainstream equalizing circuit and equalizing control strategies, as well as the estimation algorithm of equalization reference variables, points out their advantages and disadvantages, and finally analyzes the future improvement direction of equalizing technology in combination with the current.

1. Introduction
New energy vehicles are a modern product of energy conservation and environmental protection. Compared with traditional fuel vehicles, electric vehicles as new energy vehicles are put forward more requirements, and the performance of its power battery is also higher. Lithium battery has become the first choice for electric vehicle power output due to its high energy density, no memory, and low thermal effect [1]. Usually, the single cells are connected in series or in parallel to meet the voltage output requirements of the automobile. Each battery has certain differences due to the production process. This inconsistency is gradually amplified during the use of the battery, which seriously affects the overall efficiency of the battery pack. It will even affect the safety of the whole vehicle.

In addition to improve that manufacturing process, the battery equalization technology is an effective method to solve the problem of battery inconsistency. Which is of great significance for improving the service life of the battery pack and increasing the battery endurance. It is an important way to improve the efficiency of battery pack by improving the structure of equalizing circuit and optimizing the strategy of equalizing control [2]. In recent years, researchers at home and abroad have put forward a variety of equalization methods and strategies, and have carried out experimental verification, and have also achieved some results [3-4]. In this paper, several mainstream and new equalization methods and strategies are described, their strengths and weaknesses are analyzed, and their future development trends are discussed.

2. Equalization circuit
For the equalization control of the battery pack, the main purpose is to reduce the state of charge (SOC) difference or voltage difference of the single battery as much as possible, so as to ensure that the battery in the battery pack runs synchronously in the same or similar state [5]. Equalization circuits are usually divided into two types, one is a passive equalization circuit using passive devices, and the other is an active equalization circuit using active devices.
2.1 Passive equalization circuit
The passive equalization circuit is relatively easy to implement, that is, energy-consuming components such as resistors are connected in parallel to every single cell. When the voltage of the single cell is too high, the corresponding switch of the resistance circuit is closed, the current flows through the resistor, and the excess energy of the battery is converted into heat loss by the resistor. The passive equalization circuit has many shortcomings, and its equalization current is difficult to control. When the current is too large, the energy dissipation is fast, and the resistance generates a large amount of thermal energy, thereby causing heat dissipation. When the equalizing current is small, the equalization time will become longer and the equalization efficiency will be lower, but the most prominent problem is that the energy loss is large, and most of the excess energy is lost in the form of heat energy, causing serious waste of resources [6]. However, the circuit structure and equalization control are relatively simple, and the cost is low. It is a relatively mature equalization method and is mainly used in the charging phase [2].

2.2 Active equalization circuit
Active equalization typically uses active devices such as inductors, capacitors, and transformers to achieve energy transfer between the cell and the cell or between the cell and the battery pack. This method greatly improves the energy utilization rate and reduces the waste of energy, but there are also problems such as relatively complicated control process.

2.2.1 Buck-boost equalization circuit. An inductor circuit structure without additional energy storage elements is proposed in reference [7]. Each cell in series is connected to a common inductor through two MOSFETs. During charging, when the cell SOC in the battery pack is too high, excess power is transferred to the battery pack through the MOSFET and the inductor. During the discharge process, the battery pack transfers energy to a cell with a lower SOC. The circuit structure reduces the extreme difference between the cells, and at the same time increases the total charge and discharge capacity of the battery.

A single inductor bidirectional equalizer circuit is proposed in reference [8]. The circuit combines the Buck-Boost converter with the switching matrix, which selectively connects the single cells to the charge holder (composed of inductance, capacitance, MOSFET). The charge holder has a Boost mode and a Buck mode, and the two modes are switched by adjusting the PWM, and the energy is transferred from the cell to the charge holder and then transferred to the cell. The circuit uses time-division multiplexing to reduce the number of components in the circuit, and the inductance current is in intermittent mode, eliminating the effect of charge-discharge crossover between cells, and can independently control each single cell.

The common disadvantage of equalization circuit based on Buck-Boost is that there are relatively many switching devices [9], such as high cost, complex control process, and when the difference between single batteries is large, the number of switching actions and switching losses will increase [10-11].

2.2.2 Cuk chopper equalization circuit. In reference [12], a battery pack equalizer based on hybrid chopper circuit is proposed, and every cell is connected to an external voltage source through a power switch. During the charging equalization process, the cell with a higher SOC transfers energy to the external voltage source through the boost chopper circuit. During the discharge equalization process, the external power supply transfers energy to the lower SOC cell through the buck chopper circuit. When in a resting state, the energy transfer sequence is a cell with a higher SOC to an external power source to a cell with a lower SOC. The circuit reduces the equivalent charge-discharge current of the single cell, thus increasing the available energy of the battery. At the same time, it has the advantages of fast equilibrium speed, continuous equilibrium energy and strong controllability. However, the switching of power switches is complex, and the switching loss of the circuit is large.

Literature [13] proposed an equalization method based on Cuk chopper circuit, which can achieve
energy balance between arbitrary cells. It divides the single cells in one battery pack into multiple battery packs and connects one Cuk equalizer to each new battery pack. When the cells in the same battery pack need to be equalized, the corresponding switch is controlled so that the battery can be connected to the Cuk equalizer at the same time to achieve equalization. When the cells in different battery packs need to be balanced, the cells are connected to the Cuk equalizer and then connected to the common wires between the battery packs to achieve equalization. The circuit realizes the balance between long-distance cells, which is very suitable for the large number of series single cells, and it is easy to modularize. However, compared with other equalization circuits, the structure is more complicated and the cost is higher.

2.2.3 Other equalization circuit. A bidirectional full-bridge equalizing control circuit is proposed in reference [14]. The equalization circuit adopts bidirectional full-bridge DC-DC converter, one side of which is connected to the battery pack and the other side is connected to the single cell. When the circuit is in boost mode, the diodes on the side of the battery group form bridge rectifier by adjusting the MOSFET, and the energy of the single cell is transferred to the battery pack. When the circuit is in the buck mode, the diodes on the cell side form bridge synchronous rectification, and the energy of the battery pack is transferred to the cell, so that the power between the cells is maintained at the same level. The equalization circuit structure is relatively simple, and the equalization current is large, and the loss during rectification is small, which effectively increases the energy that the battery can be charged. However, the direction of power transfer is limited by the buck-boost mode, and the equalization efficiency is low.

Literature [15] proposed a two-layer quasi-resonant switched capacitor equalization circuit. The circuit uses an inductor in series with the capacitor and then in parallel to form a resonant circuit. By controlling the switch to work alternately, the cell is time-divisionally connected to the resonant tank. The battery with a high voltage is first charged to the resonant circuit, and after the switch state is switched, the resonant circuit charges the battery with a low voltage. This method uses soft switching technology to effectively reduce switching loss and energy loss in the circuit. However, when the inconsistency of cells in the battery pack is large, the equalization time is longer.

The active equalization circuit of battery pack based on LTC3300 is designed in reference [16]. One end of each flyback transformer in the circuit is connected to the positive and negative poles of the corresponding single cell, and the other end is connected to the positive and negative bus bars of the battery pack, and the switch tube is connected at the same end of the primary coil and the same name end of the secondary coil. The LTC3300 chip pin issues an equalization control command to adjust the operating state of switches. The cell with high power is charged to the primary coil of the corresponding transformer, the second coil transmits energy to the secondary coil of the transformer corresponding to the cell with low power, and the primary coil of the cell with low charge recharges the cell. A multi-transformer circuit structure is adopt in this circuit to achieve efficient energy transfer between the cells and between the battery packs. However, the transformer has the disadvantages of large volume, high cost and complex control.

Each equalization circuit has its own strengths and weaknesses. Table 1 compares the equalization circuits mentioned in this paper. The circuit is evaluated from five aspects: energy loss, equalization efficiency and so on. Each evaluation criterion is divided into three grades, "A" for the best, "B" for the medium, and "C" for the worst.

| Equalization type | Circuit structure     | Number of switching devices | Energy loss | Cost | Volume | Equalization efficiency |
|-------------------|-----------------------|----------------------------|-------------|------|--------|-------------------------|
| Passive           | parallel resistance   | A                          | C           | A    | A      | C                       |
| Active            | Buck-Boost            | C                          | A           | B    | B      | A                       |
|                   | Cuk                   | B                          | A           | B    | B      | A                       |
|                   | Bridge equalization   | B                          | A           | C    | C      | B                       |
3. Equilibrium strategy

3.1 Equalization reference variable

In order to achieve an effective balance of the battery, accurate battery state estimation is an important prerequisite, and voltage or SOC is usually selected as a reference variable. Due to the nonlinearity of the internal parameters of the battery, the voltage is different, which leads to the inaccuracy of the equalization control. However, because of its simple measurement method, the battery voltage as a reference variable still use in many researches. SOC is an ideal reference variable, which can accurately display the battery power, can ensure that the battery is in the same charge-discharge level, but there are also problems such as SOC estimation difficulty. The SOC estimation methods mainly include open circuit voltage method, ampere-hour integral method, neural network method and Kalman filter algorithm [17-18].

In reference [19], a SOC estimation method based on neural network and unscented Kalman filter (UKF) is proposed. The integral of current to time is added to the equation of state to predict the state, and then the deviation value is obtained by comparing with the measured value. Using the state and deviation values of the UKF for state prediction processing, as the initial value of the next prediction, this method can control the SOC estimation deviation within 3%. An improved momentum term BP neural network estimation algorithm is proposed in reference [20]. The internal resistance and discharge of the battery are added to the traditional BP neural network algorithm as input, and the dynamic adjustment is made according to the mean square deviation of the real-time measurement value and the expected value deviation of the model. The fast convergence of the algorithm is achieved and the estimation accuracy is improved to 2%.

3.2 Equalization Control Strategy

The equalization control strategy is the key to make the equalization circuit reach the optimal operating state. It is mainly used to control the magnitude and direction of the equalization current and reduce the loss in the circuit, which is of great significance for improving the circuit equalization efficiency [21-22].

A fuzzy control equalization strategy is proposed in reference [23]. Taking the SOC and the battery terminal voltage as variables, the fuzzy control algorithm is used to control the switch on and off in the circuit, and the magnetization energy of the transformer in the circuit is used to balance the cells. The equalization accuracy is greatly improved, and the maximum pressure difference between single cells is reduced to 1.98%.

A decentralized logic equilibrium strategy is proposed in literature [24]. Based on the adaptive voltage adjustment method, a droop control method with variable parameters is designed by adding SOC parameters. By changing the droop characteristics of the component equalization converter, the energy distribution between the batteries is adjusted to complete the equalization. The method can effectively reduce the voltage deviation from 1.44V to less than 40mV.

In reference [25], a fuzzy PID automatic control method is proposed, which combines fuzzy control algorithm with PID control. The parameters such as current are processed by fuzzy logic and input into the PID controller, and the circuit is further controlled to improve the equalization efficiency. The equalization time is 18% faster than that of the mean method.

In reference [26], the hybrid equalization strategy is used on the basis of DC-DC chopper equalization circuit. A modular equalization control (MEC) with low speed but high accuracy is
combined with an energy average control (EAC) method with low accuracy but fast equalization, and a HEC control strategy is proposed. The battery pack with voltage deviation of 0.5V tends to be consistent rapidly within 40s.

4. Conclusion and prospect

Equalization technology is a very important part of battery management system (BMS). This paper introduces some mainstream equalization methods from two aspects of equalization circuit and equalization strategy. According to the existing technologies, the following improvements are put forward.

(1) The passive equalization circuit will eventually be replaced by active equalization due to its waste of energy. But many switching devices are used in active equalization circuits. Equalizing circuits should be developed in the direction of small volume, low loss, low cost, easy integration and modularization. At the same time, it is necessary to improve the circuit structure and improve the anti-interference ability of the circuit.

(2) There are many equalization control strategies proposed, but the equalization efficiency is not good. The strategy should monitor and control the charging, discharge and static states of the battery, reasonably estimate the battery state in real time, and select the appropriate equalization reference variable in order to facilitate the implementation of the equalization strategy, and achieve a more accurate and rapid balance.

(3) When the equalization circuit and equalization strategy are applied to different batteries and different situations, the control effect is not satisfactory. It is necessary to improve its adaptability to different environments. Most of the proposed equalization techniques are still in the simulation test stage, there is still some way to go before they can be implemented on the real vehicle.

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