

## Research on Equalization Technology of Power Pack with Improved Buck-Boost Topology

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**Abstract**—Aiming at the problems of traditional active equalization circuit, such as long equalization time, slow equalization speed and low control precision, this paper proposes an improved Buck-Boost topology equalization circuit based on the traditional Buck-Boost topology. Layering the battery cells in series to achieve direct equalization between non-adjacent cells, improve equalization speed, and shorten equalization time. At the same time, the fuzzy controller is designed to control the equalization current through the on and off of the MOSFET, thereby further improving the accuracy of the equalization control. The simulation results show that the improved topology and the design of the fuzzy controller make the equalization time shorten by about 40% compared with the traditional structure, and the SOC curve fitting and distribution after the equalization are relatively concentrated to achieve the expected equalization effect.

**Keywords**-Equalization Circuit; Buck-boost Topology; State of Charge; Fuzzy Control; Equilibrium Accuracy

### I. INTRODUCTION

As the core of electric vehicles, the performance of power batteries largely determines the performance of electric vehicles, which has become a major factor restricting the development of electric vehicles. At present, the application of power batteries in electric vehicles is not satisfactory, especially the consistency of batteries. There are generally differences in the consistency of the battery. This difference comes from the difference in the concentration of the battery anode material, the crystal lattice morphology of the battery anode material, the uniform coating difference, the thickness of the membrane, the uniformity of the pores of the membrane[1-3]. Under dynamic conditions, the deterioration of the battery pack consistency is an inevitable process. Eventually, the battery pack is always full of charge when charging, and there is always no way to discharge when discharging. This makes the "effective energy storage" of the battery always lower than the "theoretical maximum

energy storage". It is necessary to promote the residual energy of each unit cell by technical means, so that each unit cell is substantially simultaneously emptied and simultaneously filled to achieve an equalization function[4-6]. Therefore, how to balance the entire power battery pack and make the SOC (State of Charge) of each single battery tend to be consistent maximally, which is the key to prolonging the service life of the battery and is also the focus and difficulty of research.

Active equalization refers to the use of non-energy-consuming components as transit components, which are used to transfer electricity between cells through switch gating. The equalization efficiency is relatively high, energy loss is relatively small, and cost is low, which is an ideal equalization scheme. . Common methods are concentrated capacitive, concentrated inductive, bidirectional flyback transformer and active parallel. Among them, the capacitor-based equalization scheme usually requires more switching devices, the equalization circuit is more complicated, and the equalization ability is affected by the voltage difference between the battery cells; Based on the transformer-based equalization scheme, it can achieve the balance of the monomer to the whole, the whole to the monomers, the monomer to the monomer, etc, and the equalization speed is fast, but the transformer is bulky, and the coaxial multi-winding transformer is difficult to design; inductance-based equalization topology, its equalization ability is not affected by the voltage difference between battery cells, the structure is simple, the cost is reasonable, such as Buck-Boost equalization structure, but the energy can only be transmitted in adjacent cells. If the positions of the cells to be equalized are not adjacent, the equalization time is long and the equalization efficiency is low[7-9]. Although the active equalization methods are various and the performance characteristics are different, the analysis results show that the existing balanced topology cannot achieve balance in terms of equalization efficiency, speed and circuit complexity.

Based on the analysis of the traditional Buck-Boost equalization structure, this paper proposes an equalization circuit of the improved Buck-Boost equalization structure. The equalization method adopts a structure in which the battery cells of the series are layered, so that the battery cells of each layer can not only be equalization within the layer can also be balanced with other layers at the same time, which improves the traditional Buck-Boost circuit can only balance the shortage of adjacent two cells, and the balance speed and efficiency are greatly improved. At the same time, the fuzzy controller based on fuzzy control is used to design the fuzzy controller to further improve the accuracy of the equalization control.

## II. BUCK-BOOST BALANCED EQUALIZATION CIRCUIT

For the problem of inconsistency of single cells in series battery packs, the traditional Buck-Boost equalization circuit uses a bidirectional non-dissipative shunt circuit to control the PWM to transfer energy from higher cells to lower cells in adjacent cells, the two-way transfer of energy is achieved by commutation. The on/off of the switching device is controlled by the PWM pulse output by the controller, and the speed of the energy transfer can be adjusted by adjusting the PWM duty ratio.

Its topology is shown in Figure 1.

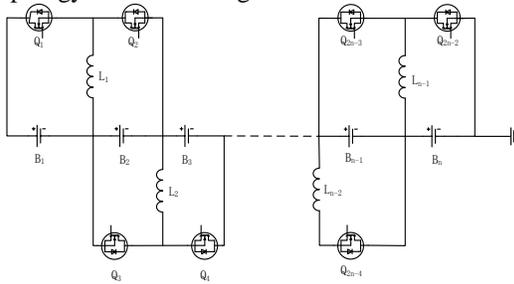


Figure 1. Traditional Buck-Boost equalization topology

When the adjacent single cells need to be balanced, the working process of the traditional Buck-Boost equalization circuit is as follows: Assuming  $SOCB1 > SOCB2$ , the switch  $Q1$  is turned on, and the single battery  $B1$  charges the energy storage inductor  $L1$  to complete part of the energy transfer; when  $Q1$  is turned off,  $Q2$  is turned on, and the inductor  $L1$  acts as a power source to transfer energy to the single battery  $B2$ , to achieve SOC balance. Similarly, the energy of the single battery  $B2$  will be transferred to the single battery  $B1$ .

When the non-adjacent cells need to be balanced, assuming  $SOCB1 > SOCB4$ , the energy needs to be transmitted sequentially through the  $B1, B2, B3, B4$  four-cell battery, that is, three sets of topologies work, and finally achieve equalization, which seriously affects the equalization speed and the switching device's switching and energy storage components will generate losses during the working process, reducing the equalization efficiency and affecting the equalization accuracy.

Therefore, it is necessary to improve the deficiencies of the traditional Buck-Boost topology, improve the equalization accuracy, and reduce the equalization time.

## III. IMPROVED BUCK-BOOST EQUALIZATION TOPOLOGY CIRCUIT

Aiming at the shortcomings of traditional Buck-Boost equalization topology with long working time and insufficient balance accuracy, an improved Buck-Boost equalization topology circuit is proposed. This circuit can realize the simultaneous transfer of energy between adjacent cells and non-adjacent cells and achieve balanced.

### A. Working principle

The equalization method adopts a structure in which a series of battery cells are layered, and adjacent cells form a set of topological structures, and adjacent groups form a new set of structures, as shown in Figure 2,  $B1$  and  $B2$ ,  $B3$  and  $B4$  form a set of equalization structures, respectively, and  $B1+B2$  and  $B3+B4$  form a set of equilibrium structures, and so on. When the number of single cells is large, a ring structure is formed.

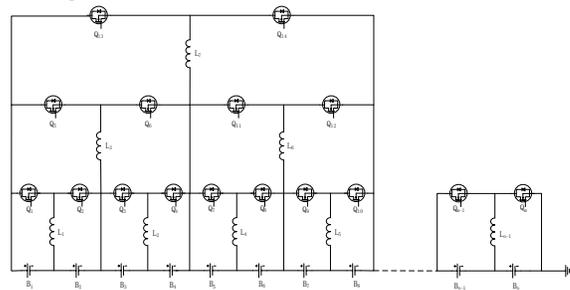


Figure 2. Improved Buck-Boost equalization topology

The improved Buck-Boost topology can realize the independent work of each group structure, that is, the equalization work of any one group structure does not affect the other groups, and the inner ring balance work and the outer ring do not affect each other. For example, when  $B1$  and  $B2$  are equalized,  $B3$  and  $B4$  can be equalized at the same time. In the outer ring,  $B1+B2$  and  $B3+B4$  are simultaneously equalized, and  $B1+B2+B3+B4$  and  $B5+B6+B7+B8$  can also work simultaneously. The structure can simultaneously achieve the equalization between adjacent monomers and non-adjacent monomers, and can simultaneously exchange energy with the "farther" monomers, and the equalization time is significantly shortened, Solved the problem that the traditional battery equalization circuit has a slow balance speed.

### B. Working process

Taking the 4-cell single-cell series as an example, the working process of the improved Buck-Boost equalization structure is as follows: assuming  $SOCB1 > SOCB2$ ,  $SOCB4 > SOCB3$ , and  $SOCB1+SOCB2 > SOCB3+SOCB4$ .

In the inner loop,  $SOCB1 > SOCB2$ , Let  $Q1$  turns on and  $Q2$  turns off. At this time, cell  $B1$  charges inductor  $L1$ ; then  $Q1$  turns off,  $Q2$  turns on, and energy storage inductor  $L1$

charges cell  $B2$ . The two MOSFET driving signals of adjacent cells are complementary, and the dead zone is added at the same time. During the dead time period, the inductor  $L1$  continues to flow through the anti-parallel diodes of  $B2$  and  $Q2$ , and continues to charge  $B2$ , and finally, the SOC balance of the adjacent two-cell cells is achieved. In the same way, the balance between the cells  $B3$  and  $B4$  is achieved.

At the same time, in the outer loop, because  $SOCB1 + SOC B2 > SOC B3 + SOC B4$ , let  $Q5$  turns on,  $Q6$  turns off, then  $Q1$  and  $Q2$  jointly charge inductor  $L3$ ; then  $Q5$  turns off,  $Q6$  is turned on, then inductor  $L3$  charges both  $Q3$  and  $Q4$  simultaneously. The outer loop and the inner loop topology circuit work simultaneously to achieve equalization of four individual cells.

In any loop, when it is detected that the adjacent two sets of battery SOC are equal, the corresponding two switch tubes are disconnected. For example, when  $SOCB1 = SOC B2$  is detected, both  $Q1$  and  $Q2$  are disconnected, and  $B1$  and  $B2$  as a whole balanced with other batteries.

For the traditional structure, only the defects of two adjacent cells can be balanced. The improved Buck-Boost equalization topology achieves the equalization of non-adjacent cells and the equalization speed increases significantly.

#### IV. FUZZY CONTROLLER DESIGN

The battery pack is affected by many factors during the working process, and its parameter changes are characterized by nonlinearity and time-varying. Therefore, this paper uses fuzzy logic reasoning, taking the SOC of the battery as the equilibrium variable, the quantization index is used to determine whether the equalization module needs to be turned on, and the magnitude of the equalization current controls the turn-on and turn-off of the MOSFET, thereby improving the equalization accuracy.

##### A. fuzzy controller

The structure of the fuzzy controller is shown in Figure 3.

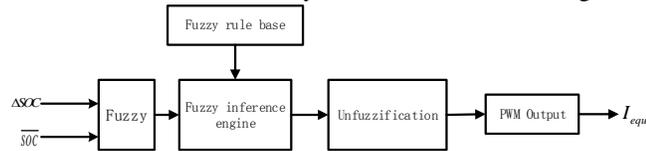


Figure 3. Fuzzy controller structure

The design of the fuzzy controller consists of four parts: the determination of input and output variables, the fuzzification of precise quantities, the establishment of fuzzy rules for fuzzy reasoning, and the anti-fuzzification of output.

1) The fuzzy controller takes the SOC difference  $\Delta SOC$  of the adjacent two batteries and the battery pack equalization target  $\overline{SOC}$  as input variables, and uses the battery equalization current  $I_{equ}$  as an output variable. Among them, the equalization system needs to calculate:

$$\Delta SOC = SOC_i - SOC_{i-1} \quad (1)$$

$$\overline{SOC} = \frac{1}{n} \sum SOC_i \quad (2)$$

The relationship between the output variable and the input variable is as shown in equation (3), and its size directly determines the equalization time and equalization efficiency.

$$I_{equ} = \int (\Delta SOC, \overline{SOC}) \quad (3)$$

2) The actual variation range of the input and output  $\Delta SOC, \overline{SOC}, I_{equ}$  of the fuzzy controller is called the respective basic domain, and their fuzzy domain is  $[0, 0.5], [0, 1], [0, 6]$ . In order to improve the precision of fuzzy control, the basics of  $\Delta SOC$  are divided into five regions of  $\{0, 0.05, 0.1, 0.15, 0.2, 0.5\}$ , and the basic domain of  $\overline{SOC}$  is subdivided into four regions of  $\{0, 0.2, 0.4, 0.6, 1\}$ , the basic domain of  $I_{equ}$  is subdivided into five regions of  $\{0, 1, 2, 3, 4, 6\}$ .

The fuzzy set of the input and output parameter domain is defined as follows:

$$\Delta SOC = \{SS, S, M, B, BB\}$$

$$\overline{SOC} = \{S, M, B\}$$

$$I_{equ} = \{SS, S, M, B, BB\}$$

3) The establishment of fuzzy control rules is determined by the number of subsets of fuzzy sets. The 15 control rules shown in Table 1 indicate that different input variables get different equalization currents.

TABLE I. FUZZY CONTROL RULE TABLE

$\overline{SOC} / \Delta SOC$	SS	S	M	B	BB
S	B	B	B	BB	BB
M	M	M	M	B	B
B	SS	S	S	S	M

4) The fuzzy output is applied to the fuzzy center method [10] to defuzzify, and the expression of the output equalized current  $I_{equ}$  is calculated as shown in equation (4).

$$I_{equ} = \frac{\int z \mu(z) dz}{\int \mu(z) dz} \quad (4)$$

Among them,  $\mu(z)$  is the output result of fuzzy reasoning, which is the membership function of variable  $z$ .

B. Equilibrium strategy based on fuzzy control

The flow chart of the equalization control strategy is shown in Figure 4.

During the operation of the power battery,  $\overline{SOC}$  of the battery pack is from 90% to 30%, the SOC estimation accuracy of the single battery is 5%, and the extreme difference ( $SOC_{max} - SOC_{min}$ ) between the monomers is about 4%, the difference in SOC between them is not large. Since the SOC of the battery cannot be directly measured, it needs to be estimated, and there is a certain error between the calculated value and the true value, and accurate consistency cannot be guaranteed. Considering the equalization accuracy and estimation error, the control accuracy  $\eta$  of the equation (5) is introduced.

$$\eta = \frac{SOC_i(t) - SOC_j(t)}{SOC_i(0) - SOC_j(0)} \quad (5)$$

Where  $\eta$  is the equalization accuracy of the SOC;  $SOC_i(0)$ ,  $SOC_i(t)$  represent the initial SOC and the SOC value at time t of the i-th unit cell, respectively. According to the calculation, the threshold is set to 0.5%. When  $\Delta SOC > 0.5\%$ , the equalization module is turned on, and when  $\Delta SOC < 0.5\%$ , the equalization module is turned off.

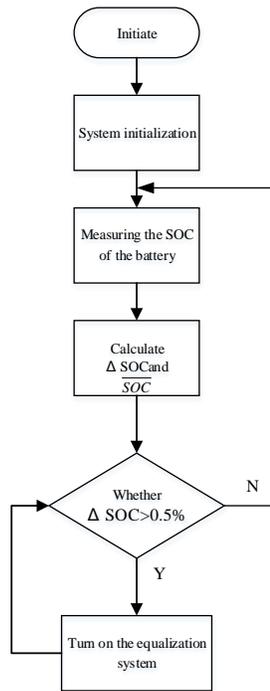


Figure 4. Equilibrium control flow chart

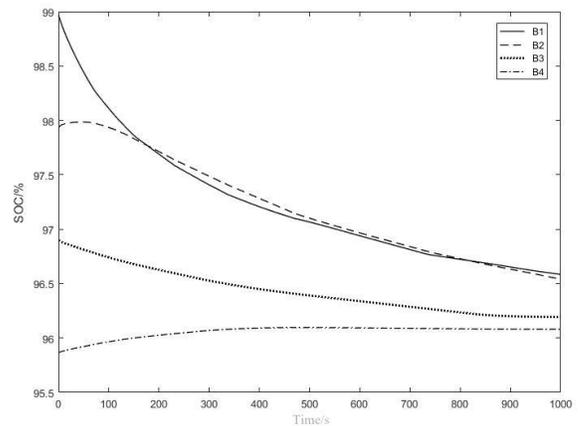
The fuzzy control based equalization algorithm can output different membership functions according to the distribution of SOC of the battery cells, and different input variables produce different output quantities, thereby flexibly adjusting the current of the equalization circuit, effectively

controlling the power battery pack and improving the efficiency of the balance.

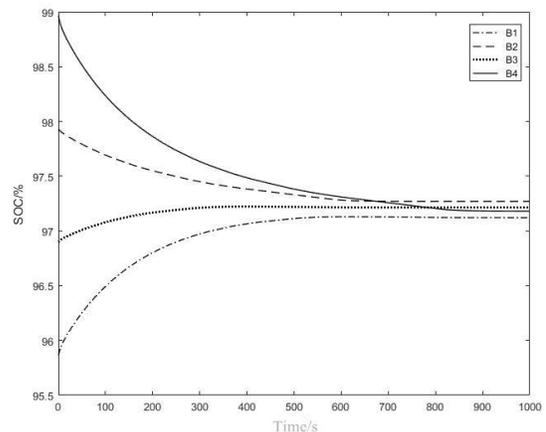
V. SIMULATION RESULTS AND ANALYSIS

In order to verify the balanced structure designed in this paper, a fuzzy controller is built on the MATLAB/simulink platform, and the topology is built and simulated.

Using the lithium battery in the simulink library, the rated voltage is 3.7 V and the nominal capacity is 2 Ah, inductance  $L=100\mu H$ . the SOC is set to 99%, 98%, 97%, 96%. In order to embody the optimal structure of Buck-Boost equalization topology based on fuzzy control, four cell units are connected in series in Buck-Boost equalization topology and improved Buck-Boost equalization topology based on fuzzy controller. Figure 5 is a comparison of the simulation results of the two, in which the abscissa represents the equalization time and the ordinate represents the SOC value of the single cell.



a) Traditional Buck-Boost equalization topology



b) Improved Buck-Boost equalization topology based on fuzzy control

Figure 5. Simulation results of four cell units in two structures

From the simulation time analysis, when  $T=1000$ , the equilibrium time is 50 min. Figure a) continues to equalize and has not yet reached the expected target. In Figure b),

when  $T=600$ , the equilibrium time is 30 min, achieve balanced expectations.

From the simulation effect analysis, since the improved Buck-Boost balanced topology output based on fuzzy control changes the frequency of the MOSFET, the accuracy of the equalization is significantly improved, and the equilibrium curve fitting is good, which is more suitable for the actual working process.

The results show that the improved Buck-Boost equalization topology can simultaneously balance four cells and solve the problem that the traditional Buck-Boost equalization topology can only balance the adjacent two cells, improve the equalization speed and shorten the equalization time about 20 minutes, it is shortened by about 40% before the improvement; on the other hand, the equilibrium curve has less fluctuation, better stability and good balance effect.

## VI. CONCLUSIONS

This paper studies the traditional Buck-Boost equilibrium topology, an improved Buck-Boost equalization topology is proposed for a short board that can only equalize two adjacent single cells. And  $\Delta SOC$  and  $SOC$  are designed as input variables and battery equalization current  $I_{equ}$  is the fuzzy controller of the output variable, which makes it more reasonable to control the on and off of the MOSFET and control the equalization current. The simulation results show that the equalization speed is significantly improved, and the equalization time is reduced by 40% compared with that before the improvement; the equalization accuracy is obviously optimized before the improvement.

Therefore, the equalization circuit based on the fuzzy control can flexibly adjust the current of the equalization circuit according to the distribution of the SOC of the battery unit, achieve effective equalization control of the power battery pack. To some extent, the influence of inconsistency in the battery pack on the battery is reduced, and the structure is simple, the implementation is convenient and effective, and the cost is low, which has high practical value for the electric vehicle battery pack.

## ACKNOWLEDGEMENT

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