Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 10, No. 1, 2024

Research on Active Equalization Circuit of Battery Pack

Xiran Yang

School of Electrical and Information Engineering, Southwest Minzu University, Chengdu, 610225, China

Abstract: For the electric vehicle power battery in the continuous use of the process due to inconsistency caused by the shortening of the life of the problem, put forward a hierarchical through the inductive control of the equalization method, topology using buck-boost equalization circuit hierarchical treatment of the battery pack, through the neighboring average pressure difference method of the control strategy for the overall logic of the operation, after the experimental simulation, the different state of the battery simultaneously After the experimental simulation, the equalization control within and between the battery packs for different states of batteries simultaneously, and finally can realize the power consistency relatively well, which proves that the method is feasible, can effectively improve the inconsistency of battery packs, and is more economical and reliable compared with other control methods.

Keywords: Power battery: active equalization: adjacent pressure difference method: buck-boost.

1. Introduction

As the main body and power source of pure electric vehicles, the performance of the power battery largely determines the performance of the vehicle, and factors such as safety, cost, consistency, fast charging and discharging capability, thermal management, etc. will be considered in the practical application[1] . In order to meet the voltage and capacity requirements of electric vehicles, battery packs are routinely formed by connecting multiple individual cells in series and parallel. Consistency refers to the degree of similarity between the voltage, capacity and other indicators of the individual cells in a battery pack. The manufacturing process will lead to some differences between the cells, and this performance difference will be amplified with constant use, making the overall life of the battery pack much lower than the life of a single cell, and the usable capacity of the battery pack will decline rapidly[2] . To address this inconsistency, battery equalization technology is of great importance.

Equalization topologies are divided into passive and active equalization based on the way of energy conversion. Passive equalization is a balancing method based on energy-consuming circuit components such as resistors to consume the excess energy of the battery pack. Liu Jialin, Luo Dong[3-4] and others use the switching resistance method, which has its own shortcomings, as the efficiency cannot be guaranteed, and it is difficult to install the heat dissipation device. Active equalization is the use of energy storage components as a temporary storage of energy, to achieve the exchange of energy flow between the battery[5] . The most common capacitors, inductors, transformers, etc. can be used as energy storage components for active equalization. Capacitive equalization relies on capacitors to complete the transfer of energy between batteries, its topology is relatively simple, low cost, low loss, the flow of energy relies only on capacitors, the equalization process is slower, the series structure of the batteries farther away from the battery can not be achieved fast equalization[6] . Inductive equalization relies on the inductor as a transit energy storage device, capable of completing the energy exchange between different structures of the monomer and the module. Therefore, the number of switching tubes and reverse parallel diodes will be very high, which will have a great impact on the equalization speed and efficiency[7] . Transformer type equalization circuits, this structure uses one or more circuit components as an energy storage device to complete the equalization energy exchange. The most common is the Buck-Boost converter structure[8-9] , this design can be randomly two batteries can be turned on the energy transfer, equalization operating time will be greatly reduced. However, with the increase of switching devices, it will be difficult to realize precise control, and it will also cause the problem of insufficient development integration space and the difficulty of safe and smooth operation.

In summary, most of the current equalization schemes have poor equalization accuracy, low efficiency and poor results, and the difficulty is because the battery is a nonlinear individual affected by multiple elements. Not only can the voltage be selected as the equalization index, but also other indexes such as charge state, capacity, etc. The selection of equalization variables is not unique. Traditional equalization circuits have many switching devices and are difficult to control accurately, and when applied to battery packs with more monomers, problems such as long operating time, poor scalability, and low reliability occur. For this reason, through the optimization of the topology and the use of appropriate control strategies, this paper implements an inductor-based hierarchical active equalization circuit topology and control strategy. The battery pack is effectively equalized by simultaneous equalization within and between groups.

2. Active Equalization Circuit Topology and Operating Principle

The hierarchical equalization structure is divided into the top layer (inter-group) equalizer and the bottom layer (intra-group) equalizer. Setting up the grouping of series-connected single batteries, taking 9 batteries in series as an example, the circuit topology is shown in Fig. 1, with 3 single batteries connected in series to form a battery pack, and then 3 battery packs connected in series to form a battery block. Relying on the battery management system data acquisition module and related chips, it completes the state calculation of single batteries and battery cells, and realizes the 2-layer energy equalization within and between battery cells through the equalization main controller and driver circuit, and finally realizes the consistency equalization of all single batteries in the series-connected battery pack.

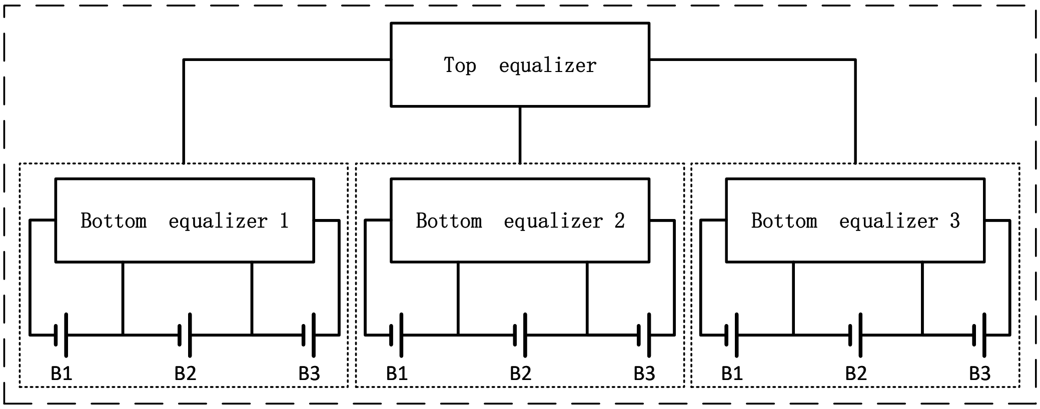

Figure 1. Hierarchical active equalization system structure

2.1. Underlying Equalization Topology and Working Principle

In this paper, three batteries are used to represent each battery subgroup to illustrate the active equalization principle of the circuit, and the equalization topology is shown in Fig. 2:

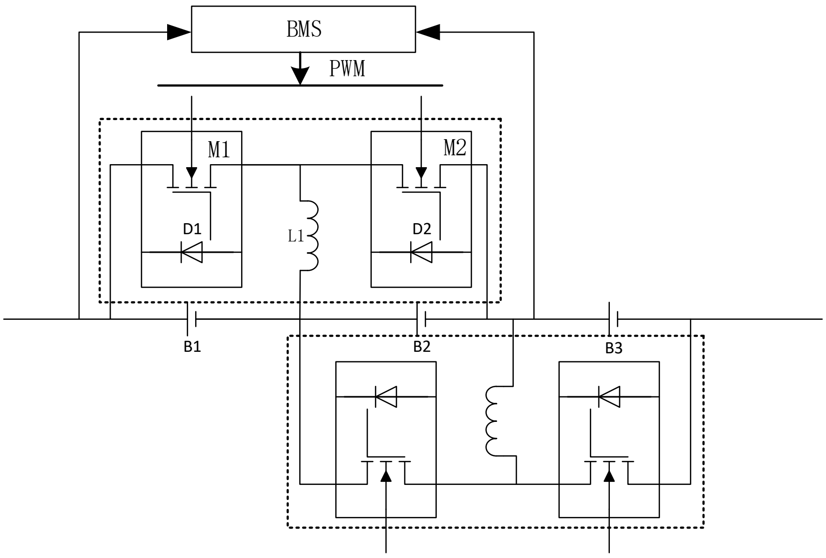

Figure 2. Underlying equalization topology

The current of the battery passes through the inductor and flows in both directions between the battery cells[10] , the terminal voltage of the battery cells is measured by the detection unit in the battery pack, and then it is transmitted to the BMS and it makes the decision of whether or not to carry out the equalization, and then the PWM wave controls the duty cycle of M1 and M2 to turn on the equalization. When the BMS detects$V_{B1} > V_{B2}$ and turns on equalization, when PWM controls M1 to conduct, the current I flows from battery B1 into inductor L1 for storage, at this time, the current is sent from the positive pole of battery B1, due to M1 conduction, D1 diode reverse cutoff, so the current passes through M1 and then passes through inductor L1 and finally enters into the negative pole of battery B1; when the PWM inputs low frequency signal to M1, M1 closes, the inductor L1 generates a reversed electric potential, and the Continuously supply current, diode D2 conduction, inductor L1 will be stored energy to B2 transfer, at this time the direction of the current from the L1 issued to the battery B2 positive through the B2 negative through the positive conduction of the diode D2 flow back to the inductor L1, and finally complete the transfer of energy. Conversely, if you want to make the energy from B2 to B1 transfer, just the same control of M2 can be.

This paper equalization design is mainly by the inductor to achieve the purpose of battery equalization, in this design inductor operation process is the primary consideration. When $0 < t < DT$ When the battery B1 is in the discharge state, that is, M1 conducts, at this time the circuit equation of the loop is:

$$i_{L1}R_{on} + L\frac{di_{L1}}{dt} = U_1 \tag{1}$$

$$i_{L1} = i_0 e^{-\frac{R_{on}t}{L}} + \frac{U_1}{R_{on}}(1 - e^{-\frac{R_{on}t}{L}}) \tag{2}$$

$$i_{L1max} = i_0 e^{-\frac{R_{on}DT}{L}} + \frac{U_1}{R_{on}}(1 - e^{-\frac{R_{on}DT}{L}}) \tag{3}$$

wherei_{L1} is the circuit discharge current, and the voltage of battery B1 can be approximated as a constant valueU_1 is the total equivalent resistance of the discharge circuit.R_{on} is the equivalent total resistance of the discharge circuit.i_0 is the discharge current$0 < t < DT$ is the initial value, when$t = DT$ When, the discharge current reaches the maximumi_{L1max} The

When$DT < t < T$ When the battery B2 is in the charging stage, i.e. M1 is disconnected, the circuit equation of the loop is:

$$i_{L2}R_{off} + L\frac{di_{L1}}{dt} + U_2 + V_D = 0 \quad (4)$$

$$i_{L2} = i_{L1max}e^{-\frac{R_{on}(t-DT)}{L}} + \frac{U_2 + V_D}{R_{off}}(1 - e^{-\frac{R_{on}(t-DT)}{L}}) \quad (5)$$

wherei_{L2} is the circuit charging current, and the voltage of battery B2 can be approximated as a constant valueU_2 is the total equivalent resistance of the charging circuit.R_{off} is the total equivalent resistance of the charging circuit.V_D is the conduction voltage drop of the diode, and considering the magnetic saturation phenomenon during the equalization process, the circuit needs to operate in the discontinuous mode (DCM) during charging and discharging, i.e., the circuit initial current$i_0 = 0$.

2.2. Top equalization topology and working principle

The top inter-battery equalization topology consists of a power inductor and a number of switching tubes, the structure of which is shown in Figure 3. Taking three batteries as an example, the battery subgroup is first taken as a "big battery", so that the overall series-connected battery pack is divided into several "big batteries", which is equivalent to reducing the number of series-connected batteries, and then energy equalization is carried out between any two unbalanced "big batteries" by using an inductive equalization method. Then inductive equalization is used to equalize the energy between any two unbalanced "big batteries". By cooperating with the underlying equalization unit, it changes the shortcomings of single inductive equalization which is not suitable for multi-cell series connection equalization, improves the equalization efficiency and speed, and reduces the control complexity.

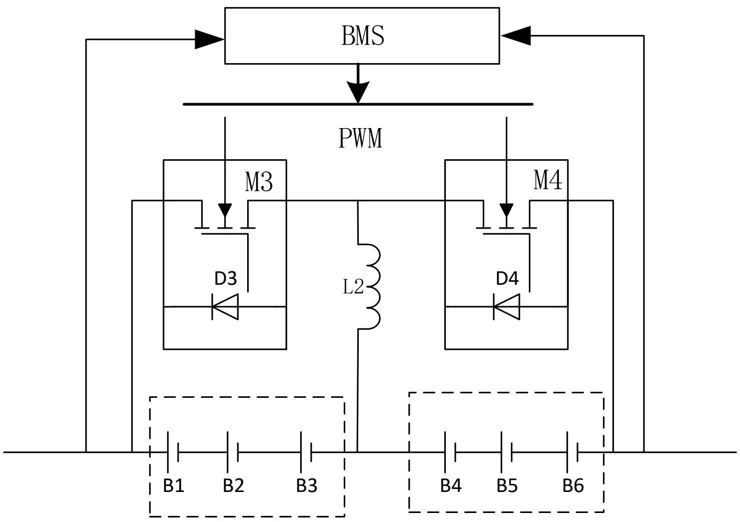

Figure 3. Top equalization topology

Assuming that the cells in the battery pack have been equalized and the $V_{B1} + V_{B2} + V_{B3} > V_{B4} + V_{B5} + V_{B6}$ The topology logic is the same as that of the bottom equalization, and its working process is divided into two stages: when M3 is on, B1, B2 and B3 charge the inductor; when M3 is off and M4 is on, the current is renewed through D4, and at this time the inductor charges B4, B5 and B6. So the control switch off repeatedly, can realize the equalization between the two battery packs. Other battery packs are equalized in this way, and eventually the whole string of batteries can be equalized.

3. Balanced Control Strategy

In this paper, the control strategy is to take the battery end voltage as the condition to trigger the active equalization, and the control strategy mainly adopts the adjacent average voltage difference method, where the BMS detecting module collects each string of single cell end voltage according to a fixed collection period, and sets the threshold between the top adjacent battery packs first, and then sets the threshold between the two adjacent battery cells at the bottom. For example, the trigger threshold for equalization control is set such that the difference of the average value is greater than 20mV to start equalization and less than 5mV to end equalization. The specific trigger conditions are shown below:

$$\left|\left|\frac{V_1 + V_2 + ' + V_k}{k}\right| - \left|\frac{V_{k+1} + V_{k+2} + ' + V_n}{k}\right|\right| > V_T \quad (6)$$

As shown in FIG. 4, using the adjacent average voltage difference method, after detecting the voltage of a single cell through the BMS detection unit, the average voltage of the battery pack is calculated and a threshold value is set for the adjacent battery packs, and at the same time, the single cells within the battery pack are equalized and the judgment threshold is set, and the process is as follows with a battery pack formed by three single cells, for example:

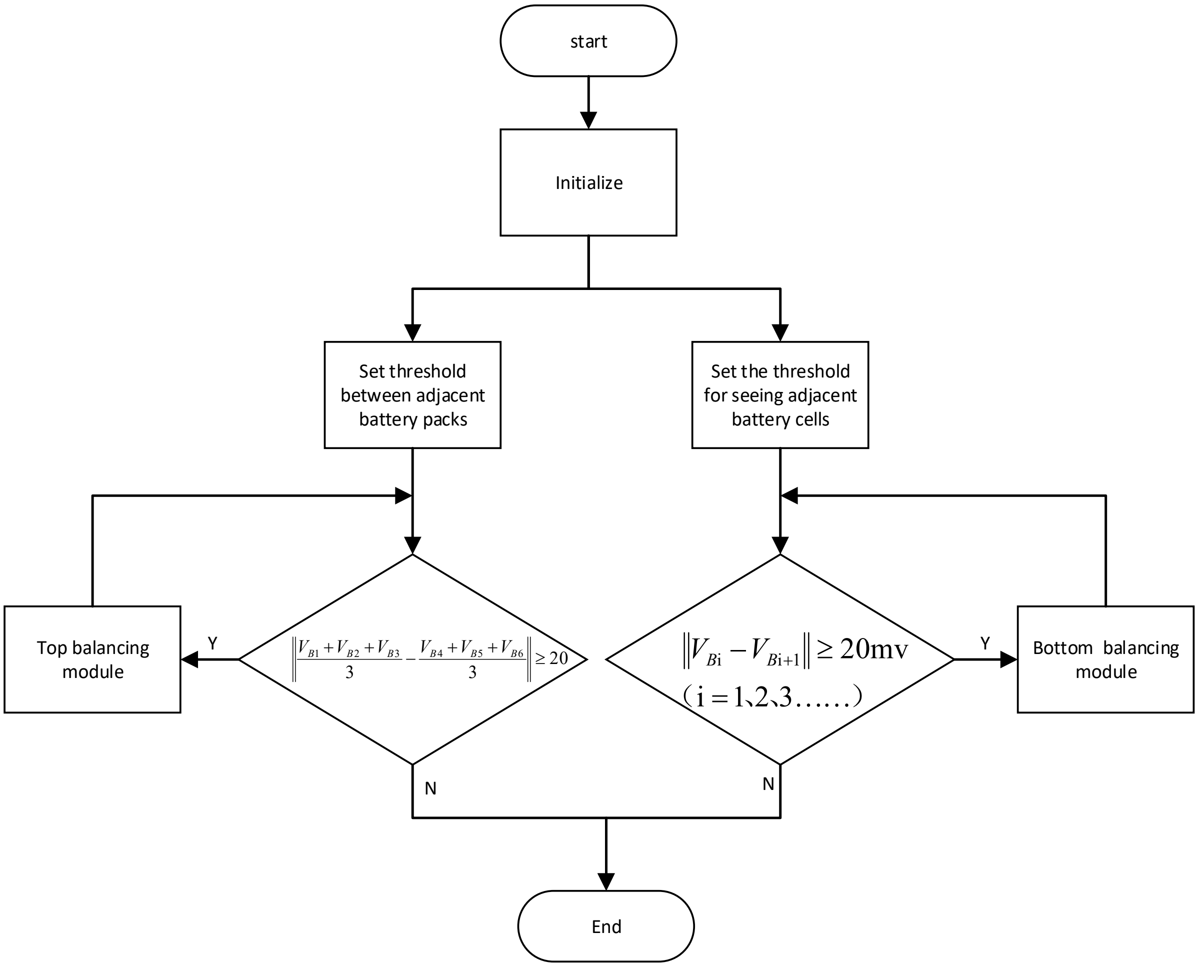

Figure 4. Hierarchical equalization control strategy

According to the flow chart, when the BMS detection unit detects the single cell voltage, the average value of the top battery pack is calculated first, and then the threshold value is compared, and the top equalization is performed after exceeding the threshold range, so as to make the adjacent battery packs keep the same amount of electricity, and at the same time of equalizing the top battery pack, the same equalization is performed for the single cells inside the battery pack, and the above is the equalization strategy designed in this paper. The above is the equalization strategy designed in this paper.

4. Experimental Results and Analysis

The experiment in this paper is to test and view the circuit topology for equalization in the stationary state, the specific method is to use MATLAB to build a simulation model of the equalization circuit of multi-cell batteries, and to verify the feasibility and equalization effect of the hierarchical active equalization scheme based on inductance proposed in this paper by real-time changes in the end voltage of the single cell. In order to facilitate the verification, a six-section series battery pack equalization model is built, with every three single batteries as a battery unit, and the single batteries use the self-contained battery module in the model library, and the four batteries are set to different voltage values and different amounts of power (SOC) before the static equalization experiment. Figure 5 shows the results of the battery pack static equalization experiment.

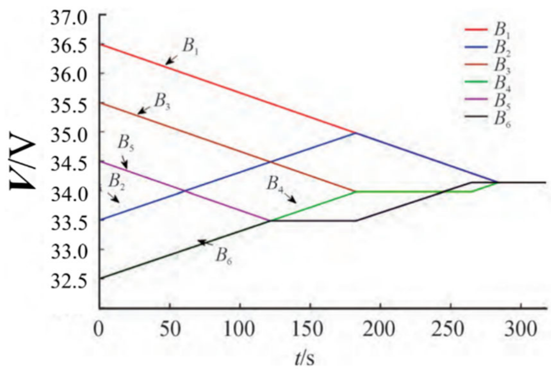

Figure 5. Graph of experimental results

As can be seen in Fig. 5, with different initial data settings for the battery modules in the model, the power of the battery modules with power less than the average value rises significantly, and the power of several modules comes to the same level after 280 seconds, which shows that the equalization scheme proposed in this paper can effectively equalize the batteries.

5. Conclusion

In order to solve the inconsistency caused by electric vehicle batteries in the factory and in the process of constant charging and discharging, an inductance-based hierarchical equalization structure is designed, which can equalize the battery cells within the battery pack and also equalize the battery packs, which significantly improves the efficiency compared to the traditional passive equalization, and the topology is relatively simple, and the application of the electrical components is relatively small, so the inconsistency problem is solved with the consideration of the economic and social factors. The problem of inconsistency is solved while taking into account economic factors.

Acknowledgment

This work was financially supported by the Southwest Minzu University Graduate Innovative Research Project No.(YB2023800) fund.

References

[1] Zhongzhen Sun, Yun Zhao, "Problems in the application of lithium-ion battery packs," Chemical Design Newsletter, vol. 47, no. 1, pp. 82-85, 2021.

[2] Jixiang Du, "Research on passive full equalization technology for battery management system," Master's thesis, Chongqing University of Technology, 2022.

[3] Jialin Liu, "Research on passive equalization strategy and SOC estimation for electric vehicle battery pack," Master's thesis, Kunming University of Science and Technology, 2019.

[4] Luo Dong, "Research and design of centralized battery management system for electric vehicles," Master's thesis, Chongqing University of Posts and Telecommunications, 2018.

[5] Z. Wei, F. Peng, and H. Wang, "An lcc-based string-to-cell battery equalizer with simplified constant current control," IEEE Transactions on Power Electronics, vol. 37, no. 2, pp. 1816-1827, 2022.

[6] Xiangwei Guo, Qi Wu, Cheng Xing, Dongbian Xie, Jun Zhu, "Active equalization method for inductive-capacitive energy storage of series-connected battery packs," Journal of Electrical Machines and Control, vol. 27, no. 5, pp. 128-137, 2023.

[7] Zhengyu Liu, Dengwei Xia, Liyang Yao, Kun Yang, "Research on active equalization scheme of lithium battery bank based on coupled windings," Journal of Electrical Machines and Control, vol. 25, no. 2, pp. 54-64, 2021.

[8] F. Peng, H. Wang, and L. Yu, "Analysis and design considerations of efficiency enhanced hierarchical battery equalizer based on bipolar ccm buck-boost units," IEEE Transactions on Industry Applications, vol. 55, no. 4, pp. 4053-4063, 2019.

[9] K. Liu, Z. Yang, X. Tang, and W. Cao, "Automotive battery equalizers based on joint switched-capacitor and buck-boost converters," IEEE Transactions on Vehicular Technology, vol. 69, no. 11, pp. 12716-12724, 2020. " IEEE Transactions on Vehicular Technology, vol. 69, no. 11, pp. 12716-12724, 2020.

[10] WANG Yu-jie, ZHANG Chen-bin, CHEN Zong-hai, et al. A novel active equalization method for lithium-ion batteries in electric vehicles[J]. Applied energy, 2015, 145: 36-42.