Review of Lithium Battery Equalization Control Methods

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Abstract. The high performance of power battery pack is used in the field of electric vehicles widely. With the continuous improvement of the cruising range, the energy imbalance of the power battery has become a limiting factor. This paper analyses and introduces the power battery equalization circuit. According to different circuit topologies, they are divided into two categories: Energy dissipative and non-energy dissipative. We Focused on the analysis of the working principle, advantages and disadvantages of the non-capacity dissipative equalization structure. Finally, this work summarizes the application and development direction of the power battery equalization control in recent years.

1. Introduction

With the improvement of the range of electric vehicles, The performance of the power battery pack will determine the distance between the battery life, At the same time, the performance requirements of the battery are also getting higher and higher [1,2]. Lithium iron phosphate battery as one of the most common types of power batteries. Which has many advantages such as more charging times, higher energy density, more charging and discharging times. Due to the large number of battery cells connected in series and in parallel. During the continuous charging and discharging of the battery, some cells may have an unbalanced discharge condition. If the degree of differentiation is too large, the overall performance of the pack will be limited by the cells with the lowest power. It reduces the battery life of the electric vehicle [3,4]. Equalization technology can greatly suppress the imbalance in the pack and improve the consistency of the battery pack work. So that the battery management system can perform well and protect the safe driving of new energy vehicles [5].

The effective use of energy is becoming more and more strict, so a large number of equalization methods have been proposed [6-10]. Balanced methods are divided into two categories. The energy dissipative type refers to a high-capacity battery cell in the equalization process that converts excess power into heat by parallel resistors. So that the battery power remains consistent. This type of equalization circuit is simple in structure and easy to control, but the heat of the conversion causes the temperature of the entire battery pack to rise, adding extra power to all system. Non-energy dissipative type refers to the use of non-energy storage elements. Transfer excess energy to the low-battery battery cells to complement each other. The energy utilization rate and conversion efficiency are greatly improved, which effectively improves the consistency of the pack [11-12]. This paper focuses on the analysis of the balanced topology of non-energy dissipative types in recent years. For the form of energy conversion, it is divided into cell-to-cell, cell-to-pack, pack-to-cell, and cell-to-pack-to-cell, Each type of equilibrium method is described and analyzed in detail, and its advantages and disadvantages are described.

2. Classification of equilibrium structure

According to the energy conversion method, it is divided into two categories: energy dissipative type and non-energy dissipative type [7,8]. As shown in Figure 1. The energy dissipation type is divided into two types: fixed shunt equalization and switch shunt equalization; Non-energy dissipative types are classified into cell-to-cell, cell-to-pack, cell-to-pack, and cell-to-pack-to-cell. The cell-to-cell, that is, the energy is converted into energy-saving components such as inductors, capacitors, and transformers, and then flows to a cell that needs to be balanced, which reflects point-to-point energy conversion control; The cell to pack, the intermediate energy storage component transfers the higher energy in the monomer to the entire pack, and timely supplement battery cells with lower energy;
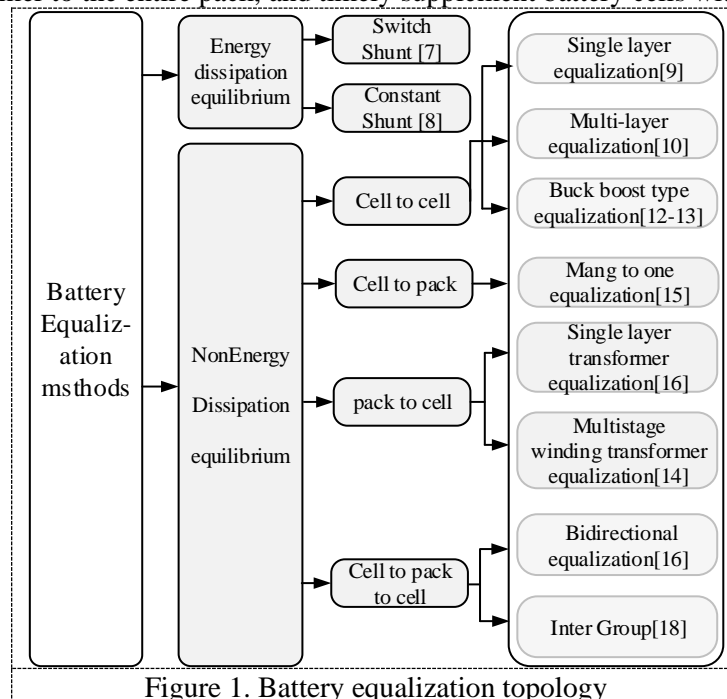

Figure 1. Battery equalization topology

3. Cell to Cell

In a single-layer equalization network topology, the switching network constructs an alternative path between the energy storage component and the battery cell. Directly equalization can be achieved in a targeted manner by energy storage elements. The advantage of this structure is that the control structure of the switch circuit is simple, and the charge and discharge equalization can be realized without closed-loop control. Besides, the battery pack has strong scalability and the disadvantage is that the number of switches is large, the switching frequency is high, which leads to large on-state loss of the switch and the battery pack equalization time is relatively long. Cell to cell equilibrium structures can be divided into three types: transfer equilibrium structure, non-isolated dc-dc equilibrium structure and isolated dc-dc equilibrium structure.

3.1 Transfer Equilibrium Structure

The non-isolated type adopts a buck-boost equalization structure, which can be divided into two categories according to the way of energy flow. The first type is a complete equalization loop between the battery cells and the monomers. The other is to use a DC-DC converter to transfer energy between adjacent cells. This type of structure is to connect an equalization topology between adjacent cells. The equalization process is the transfer of energy from a high-energy cell to an adjacent cell. For example, Boost boost structure, Bidirectional Buck-Boost structure and Cuk structure are non-isolated DC-DC equalization methods [9], which type of balanced topology control is flexible. The voltage difference between the battery cells can be accurately adjusted during the equalization process. The

downside is that the energy is limited to the step-by-step transmission between the cells, and it is impossible to balance the distance and reduce the equalization efficiency.

Figure (2) shows the energy transfer structure of the battery cell. The structure A is a bidirectional Cuk converter, and the energy flows between adjacent cells in both directions. Continuous operation with current. In the same working mode, it can reduce the peak the current requirement of the inductor current and has a higher equalization speed. The difference between the B-type structure and the A-structure in Figure (2) lies in the control mode of the circuit. The control process of the B-type structure is divided into two steps; The switch Q1 is first closed, and the high energy single cells are charged to the energy storage element inductors L1 and L2 and the capacitor C1. Then, the switch Q1 is opened and the switch Q2 is closed, and the capacitor C1 and the inductor L2 form a parallel discharge circuit. Together with the energy storage inductor L1, the battery unit of the low power is replenished.
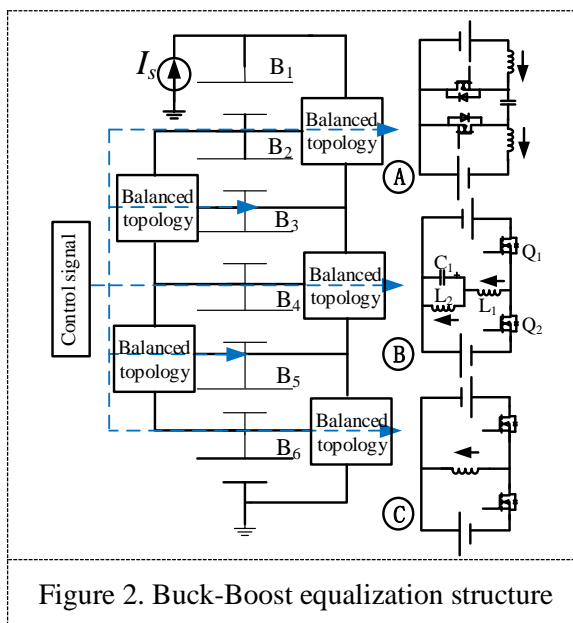

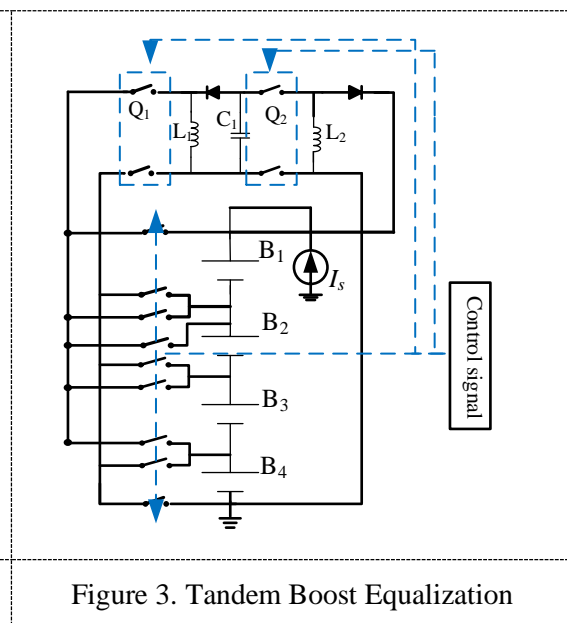| Figure 2. Buck-Boost equalization structure | Figure 3. Tandem Boost Equalization |

The equalization structure is simple and efficient, the system cost is low, and the module is easy to modularize. The class C structure in Figure (2), compared to the A, B two types of equilibrium structure, the single-energy storage energy conversion structure is simple, the space occupancy rate is relatively low, and it is easy to integrate. Based on the buck-boost Buck-Boost equalization structure, Li, Y et al. proposed a boost mode using the new Boost [10]. As shown in Figure 3. In the series-type Boost equalization topology, all single cells are used as boost input, and the latter is used as the output of the previous stage. This equalization structure consists of a large number of discrete components, the overall system cost is low, and the energy loss during the transfer process is small. The downside is that energy is limited to a one-way transmission, and the equalized path is long, making the equalization slow. If a battery circuit fails, the entire battery pack will be paralyzed and will not work properly.

3.2 Isolated DC-DC equalization structure

The isolated equalization structure consists of a small number of peripheral devices and isolation transformers, enabling balanced control between cells [11]. When the voltage of any of the cells exceeds the desired value, the corresponding switch is closed and the excess energy is stored in the primary winding of the transformer. When the switch is turned off, this excess energy is transferred to the entire battery pack. Isolated equalization structures are relatively high in reliability and stability and therefore have a wide range of applications. One of the more classic balanced topologies is a coaxial multi-winding. The secondary windings are connected to a single battery cell for direct energy

conversion. The advantage of this structure is that all cells can be equalized at the same time, without the need to switch switches frequently. The downside is that the number of coaxial windings is too large to be used on a large scale. The battery cells are connected in parallel with a transformer, and the secondary side of the transformer is connected to the entire battery pack. The highest energy cell transfers energy to the battery pack via a flyback transformer. The advantage of this control method is that the circuit structure is simple and the work efficiency is high. The disadvantage is that the leakage inductance of the transformer itself is large, which makes it difficult to achieve a true energy balance in the battery pack.

4. Cell to Pack

The balanced structure of single cell to battery pack adopts single cell as input, and the battery pack as a whole is the receiver of energy, which transfers the surplus energy of high-power battery cells to the whole battery pack to realize the balanced conversion from single cell to whole [12].

In order to solve the problem of low integration of circuit structure. Shang Y proposed an equalization method based on LLC parallel structure [13]. The advantage of this circuit structure is that the circuit structure is simplified and the components are few, which can better realize the miniaturization and light weight of the system. Switching between the left and right switches by the intermediate conversion unit at different times, so that the energy is transferred between the inductor and the capacitor, and finally returned to the entire battery pack. However, the LLC parallel equalization structure also has some defects. The energy storage circuit needs to be switched multiple times, which is slightly complicated in the control timing. In addition, the battery cells that achieve high power during the equalization process are transferred to the battery pack, but the low-power cells cannot be supplemented in a targeted manner so that the equalization efficiency is low.
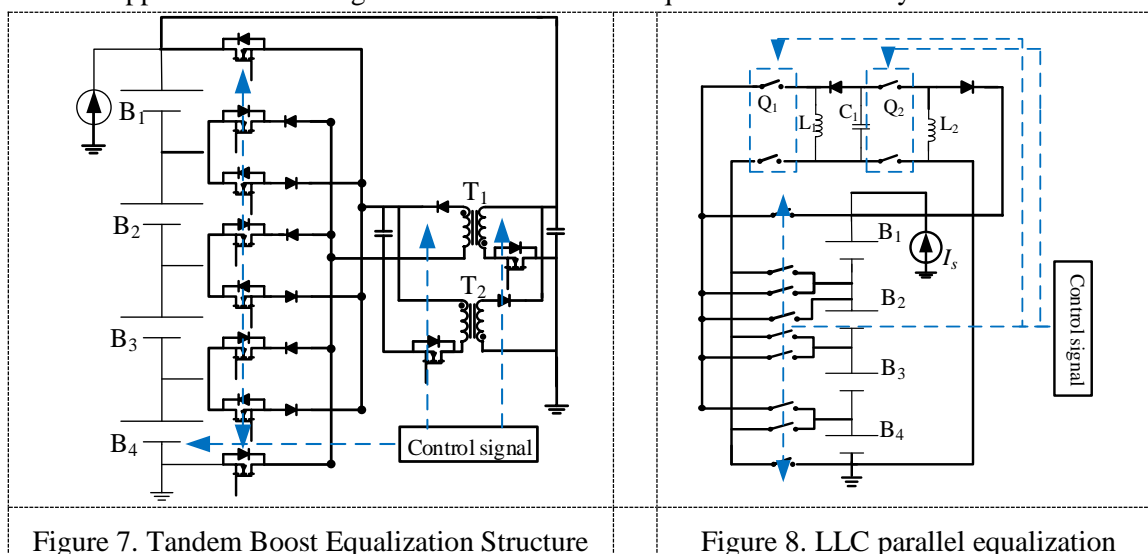

| Figure 7. Tandem Boost Equalization Structure | Figure 8. LLC parallel equalization |

5. Pack to cell

The battery pack as a whole transfers its own energy to the monomers in the group through the peripheral equalization circuit. In this equalization mode, the overall energy will be transferred to the monomers with insufficient energy in an orderly manner, and the control process is simple. The disadvantage is that it is impossible to weaken the high-energy battery cells in a targeted way. Hannan M A et al proposed a lithium-ion battery charging equalization algorithm [16], as shown in figure 8. The balancing method adopts a double transformer structure, switches on a high-energy battery cell and atransformer, transfers excess energy to the whole battery pack, and then uses the whole battery pack as an energy output, a low-power battery cell as an input, The energy of the equalizing circuit structure can flow in two directions, the equalizing voltage difference is relatively high, and the

equalizing efficiency is improved. The disadvantages are that the space occupied by double transformers is large, which makes the EMI performance of the whole system worse.

6. Cell to Pack to cell

Cell-to-pack-to-cell equalization method. When the battery cell power exceeds the expected value, close its corresponding control switch, and supplement the excess energy to the insufficient cells through the flyback transformer. As shown in figure 10, it is a double-layer multi-winding equalization mode [17]. The equalization method is based on the equalization between battery packs, battery packs are respectively connected through two transformers to realize the mutual transfer of redundant energy between the two groups. The battery cell is transferred to the battery pack through the switch, and then to the entire cycle of the monomer. The advantage of the equalization method is that the control method is simple and the energy transfer speed is fast. The disadvantage is that the excess energy is only balanced within the group and the group, and it is difficult to accurately supplement the low-energy single battery. In order to improve the equilibrium efficiency, Shang, Y et al. proposed a modular equalization method for series lithium-ion batteries [18]. As shown in figure 11. A coaxial multi-winding transformer structure is adopted, a plurality of battery cells are inputted The control switch connected to battery pack can accurately supplement and equalize one or several monomers with lower energy at the same time. This structural control method is simple and can realize fast equalization. The disadvantage is that the coaxial multi-winding transformer is adopted and the manufacturing process of the transformer is relatively complicated. Based on the above equilibrium methods, Battery equalization circuit topology modular analysis as shown in Table 1.
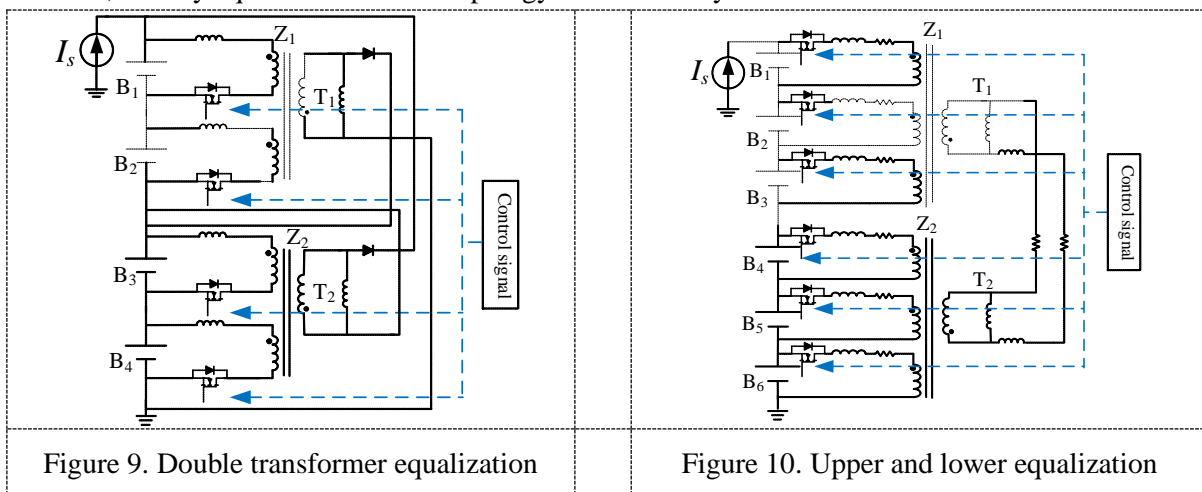

Figure 9. Double transformer equalization   Figure 10. Upper and lower equalization

Table 1. Battery equalization system structure table.

Balanced mode	Energy dissipation type		Non-Energy dissipation type						
			Cell to cell		Cell to pack	Pack to cell		Cell to pack to cell	
Type	Fixed resistor [7]	Shunt resistor [8]	Single layer [9]	buck-boost [12]	Many-to-one [15]	Single winding[16] transformer	Multi-stage winding[14] transformer	Two way [17]	Inter Group [18]
Inductance	0	0	1	N	0	0	0	0	2n+4
Capacitance	0	0	1	2N	0	1	1	0	0
Transformer	0	0	0	0	N	1	2	2	2
Switch	0	N	2N+4	N	N	2N	4	2N	N
Diode	0	0	0	0	N	1	N+1	1	0
Volume	E	E	E	E	P	G	P	P	P
Control method	E	E	P	S	E	P	P	G	G
Equilibrium speed	P	G	G	G	E	G	G	G	G
manufacturing cost	E	E	E	E	P	P	P	P	P

E: excellent, G: good, S: Satisfactory, P: poor

7. Conclusion

This paper has targeted the research status of domestic and foreign equilibrium technology in recent years. It is also expected to focus on the following comprehensive consideration of the performance of the equalization system, including the environmental factors of the battery pack work and the effects of temperature differences. Further research is conducted on the selection of energy storage components and the connection of control switches. The modularized equalization structure can effectively reduce the limitations caused by insufficient single-layer equalization efficiency. the laminated structure has strong anti-interference, which will help to improve the stability of the system.

Acknowledgement

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