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RESEARCH ON EQUILIBRIUM STRATEGY FOR LITHIUM-ION BATTERY PACK

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ABSTRACT

In order to meet the performance of PEV demand, the car's energy was provided by series of power batteries. This paper points out the significance of the balance management. As the lack of traditional evaluation system of consistency which based on the battery voltage difference, this paper expounds on consistency problem of battery from DC internal resistance, polarization voltage, SOC and capacity. According to the target of increasing battery capacity utilization, balance strategy is proposed based on the capacity and SOC. Finally, According to the on-board and online balance requirements, algorithm has been embedded into the circuit which based on the SOC strategy. An experiment platform has been put up to test the strategy. And the effectiveness of strategies has been verified.

KEYWORDS: Pure Electric Vehicles; Lithium Batteries; Balance management; SOC

INTRODUCTION

In the battery current technical level, pure electric vehicles must be dozens or hundreds of section of the power battery to provide energy, but due to the consistency problem of battery, each battery there is a big difference in voltage, resistance and capacity, the actual battery usage is more complex than that single cell, which also has a serious impact on its application in the field of pure electric vehicles. Therefore, the consistency of batteries as the core problem of battery group, has become a bottleneck of power battery group applications. Balance strategy is the basis of balanced judgment. Different balance strategies are used to balance the battery, and the results will be quite different.

STUDY ON BALANCE STRATEGY

- Balance strategy based on the external voltage

Understanding the consistency problem of the traditional way of balancing the battery is not thorough enough, at the same time, the state of the battery identification method is relatively single, so the consistency of battery voltage, the external voltage as control objects to achieve balance. Based on the external voltage balance strategy, the content of judgment is that during the charging and discharging process, the external voltage of battery is always taken as the balance control object, and the battery with high voltage in the group is discharged, and the battery with low voltage is charged, so the voltage of the battery pack is adjusted to the same. When the battery is balanced, the average voltage of the battery pack is calculated first, then the equalization control band is determined, and the discharge balance of the battery is higher than that of the control band.

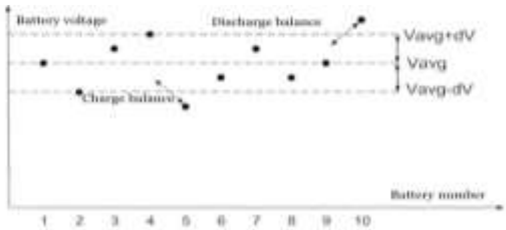

Fig1. The scheme of voltage balance

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This equalization strategy is very simple to be realized. It only needs to determine the balance of the battery's external voltage. But it has some drawbacks, and it is easily affected by the parameters of the battery and the working condition, and the problem of the balance judgment is unstable.’=

- Balance strategy based on the capacity

The capacity balancing strategy is based on the capacity utilization ratio to evaluate battery consistency. The goal of equalization is to increase the capacity utilization of battery pack, so that the maximum capacity of battery pack can be increased to the minimum capacity of battery, and the maximum available capacity of battery. The contents of judgment based on balance strategy: each cell maximum available capacity and the battery pack in the maximum available capacity and SOC, one of the largest available capacity in a single battery charge discharge cycle remained unchanged, adjust the battery through a certain way to achieve the SOC battery equalization, since the SOC representative the ratio between the remaining battery capacity and the maximum available capacity, so also can adjust the capacity to achieve balance. According to the theory of battery consistency based on capacity utilization, the balance of battery is the minimum capacity. The single cell meets the full charge and full discharge simultaneously, so we can get the balanced capacity of each battery according to this standard. According to the definition of capacity and SOC of N series battery in the consistency evaluation based on the above mentioned capacity utilization, there are several situations in the actual application of battery state:

1) When the battery m is full and full discharge, that is $Q_{ch\_max}[m]=Q^{B}_{ch\_max}$ and $Q_{dch\_max}[m]=Q^{B}_{dch\_max}$, the capacity utilization of the battery group at this time: $\eta_C=\dfrac{Q^{B}_{max}}{Q_{max}[m]}=1$, so it doesn't need to be balanced.

2) When the battery m is first filled with electricity, and is not the first to finish the electricity，that is $Q_{ch\_max}[m]=Q^{B}_{ch\_max}$ and $Q_{dch\_max}[m]>Q^{B}_{dch\_max}$, $\eta_C<1$,So for any battery K, it is assumed that its charge balance capacity is $Q^{eq}[k]$:

a) To make the battery m first full of electricity:

$$Q^{eq}[k]\le Q_{ch\_max}[k]-Q_{ch\_max}[m] \tag{1}$$

b) To make the battery m first discharge:

$$Q^{eq}[k]\ge Q_{dch\_max}[m]-Q_{dch\_max}[k] \tag{2}$$

So we should satisfy:

$$Q_{ch\_max}[k]-Q_{ch\_max}[m]\ge Q^{eq}[k]\ge Q_{dch\_max}[m]-Q_{dch\_max}[k] \tag{3}$$

After the balance, the battery packs meets the condition 1).The capacity utilization η_C of the battery pack is maximized at this time.

c) When the battery m is not first filled with electricity, that is $Q_{ch\_max}[m]\ne Q^{B}_{ch\_max}$, it is the battery l, who make $Q_{ch\_max}[l]=Q^{B}_{ch\_max}$.

First, we need to balance the battery m to satisfy the condition that the battery is first full of electricity. The balance capacity $Q^{eq}[m]$ of the battery m needs to be satisfied:

$$Q_{dch\_max}[l]-Q_{dch\_max}[m]\ge Q^{eq}[m]\ge Q_{ch\_max}[m]-Q_{ch\_max}[l] \tag{4}$$

On this basis, the battery m has been satisfied with the condition (2), so for the other battery k in the battery group, the balance capacity relationship required by the formula 3 is calculated.

$$Q_{ch\_max}[k]+Q^{eq}[m]-Q_{ch\_max}[m]\ge Q^{eq}[k]\ge Q^{eq}[m]+Q_{dch\_max}[m]-Q_{dch\_max}[k] \tag{5}$$

According to the above deduction, the judgment process based on the capacity balancing strategy is shown in Figure.2.

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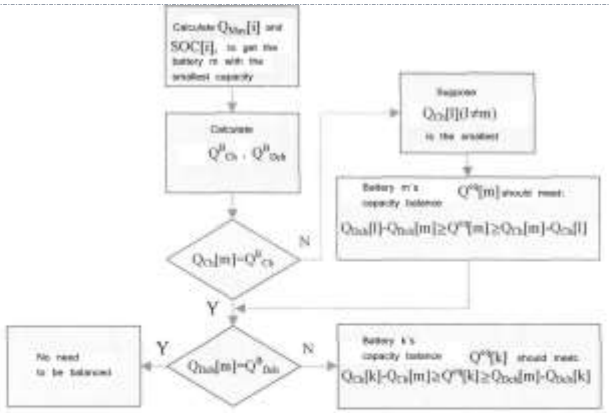

Fig2. Capacity balance judgment process

The capacity balancing strategy is based on the single battery with the smallest battery capacity as the reference standard. Based on the full charge and full discharge of the battery, the range of the required balance capacity of each battery is calculated, which provides effective data support for the balanced implementation. After the battery capacity is balanced, the capacity utilization of the whole battery has been maximized. It can be considered that the battery pack has achieved a good consistency.

3) Balance strategy based on SOC

According to the analysis of the consistency of the battery pack, the consistency problem of the battery pack is mainly reflected in four aspects: SOC, DC internal resistance, polarization voltage and the maximum available = capacit. Because the DC internal resistance, the polarization voltage and the maximum available capacity of the battery are basically unchanged during a charge and discharge process, the equalization of the battery pack can only be achieved by adjusting the SOC of each single cell. After research, SOC is used as a balanced reference object, and the balance circuit has a higher efficiency [1]. SOC balance strategy mainly through the difference between reducing the battery SOC to realize battery equalization based on target, according to the judgment content capacity based on balance strategy, improve the requirements can determine the battery capacity utilization rate can also SOC balance based on verification as follows:

According to the different battery status divided by the capacity balance, we make the analysis.In the first case, when the SOC of each battery in the battery group tends to be consistent at a certain time, that is:

$$SOC[1]=SOC[2]=\ldots=SOC[n]=SOC'$$

According to the definition of the maximum available capacity of the battery group, it is obvious that there are:

$$Q^{B}_{ch\_max}=\min\{Q_{\max}[i]\times SOC'\}=Q_{ch\_\max}[m](i=1,\ldots,n.)$$

$$Q^{B}_{dch\_max}=\min\{Q_{\max}[i]\times(1-SOC')\}=Q_{dch\_\max}[m](j=1,\ldots,n.)$$

The capacity utilization η_C of the whole battery has reached the maximum, and the battery pack does not need to be balanced. In the second case, an arbitrary battery k, if it is balanced to the same SOC level as m, needs the balanced capacity :

$$\eta_C=\frac{Q^{B}_{\max}}{Q_{\max}[m]}=1$$

$$Q_S^{eq}[k]=Q_{\max}[k](SOC[m]-SOC[k]) \qquad (6)$$

We replace it in formula 1 and 2:

$$\begin{cases} Q_{\max}[k](SOC[m]-SOC[k])\le Q_{\max}[k](1-SOC[k])-Q_{\max}[m](1-SOC[m]) \\ Q_{\max}[k](SOC[m]-SOC[k])\ge Q_{\max}[m]\cdot SOC[m]-Q_{\max}[k]\cdot SOC[k] \end{cases}$$

Because $Q_{\max}[k]\ge Q_{\max}[m]$, the above inequalities are always set up. That is $Q_S^{eq}[k]$, which meets the formula3. In the case of case three, it can also be proved to be satisfied with the relationship type 5.

The judgment content based on the SOC balance strategy: using the battery SOC as the control object, the difference between the SOC of the battery is reduced by charging and discharging the cell of the single cell. First, we need to identify the SOC of each single cell in the battery pack, and select one of the battery's SOC as

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the balance target. Usually, in order to improve the efficiency of the equalization and give full play to the advantage of charge and discharge equalization, we set the target as the SOC average($\overline{SOC}$) of the battery pack. The balance control belt $(dSOC)$ is also set to prevent the balance fluctuation, and the discharge balance of the high SOC monomers is carried out, and the charge balance is carried out on the contrary.

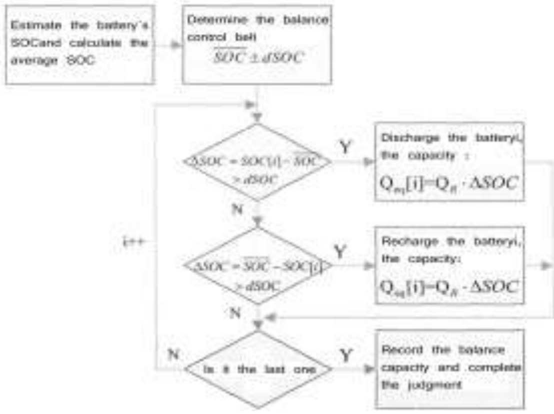

Fig3. SOC balance judgment process

Then the balance capacity of each battery can be calculated by the difference (ΔSOC) between the average value of SOC and SOC and the rated capacity (Q_R), the balance can be achieved by measuring the capacity. The balance policy judgment process is shown in Figur4. Based on the SOC balance strategy, we only need to recognize the SOC of the battery, do not require the identification of the maximum available capacity, and do not need to determine the location of the smallest battery capacity. So that is different from the previous capacity balancing strategy. Because the maximum available capacity of battery is different, it is unrealistic to ensure that the SOC of battery is always in a consistent state, so the requirement for equalizer is also very demanding. Based on the SOC balance judgment process, we only need to determine the SOC of all batteries at a certain time, and then balance the static SOC. But if the choice in the different charge and discharge cycle in SOC determine the time difference between the larger, may cause different balanced cycle judgment result is not the same, the battery group repeated switching between different balance state, this will result in an invalid state equalizer. So it is necessary to make a balanced judgment at a certain moment in the process of charging or discharging, such as the starting time of the charging or the end of the charging. Based on the SOC balance strategy, we can not only improve the utilization of battery capacity, but also solve the problem of consistency effect on battery state recognition. Since the SOC of each battery tends to be consistent after the equalization, the SOC of the battery pack is equal to the SOC of the single cell. Modifying the SOC by this way can greatly reduce the complexity of the battery group SOC estimation. Using the SOC balance strategy based on the balance of the battery pack, need at a time in the group every battery SOC estimation, SOC estimation methods at present are: open circuit voltage method, current time integral method [2], fuzzy logic method [3], Calman filtering method and Electrochemical methods[4], and so on.

SUMMARY

On the basis of introducing the cause of battery conformance problem, this chapter analyses the effect of consistency on the performance of battery pack. Aiming at the shortcomings of the traditional consistency evaluation method based on the voltage difference outside the battery, the consistency problem of the battery is studied from four aspects of the DC resistance, the polarization voltage, the capacity and the SOC of the battery, and the influence of the above four aspects on the external voltage difference of the battery is analyzed. On this basis, according to the influence of consistency on the available capacity of battery pack, the concept of capacity utilization of battery pack is introduced, and the consistency of battery pack is evaluated by using it. In addition, this chapter also introduces the judgment method based on the external voltage equilibrium strategy and its existing problems in detail. In order to improve the capacity utilization of battery pack, a capacity based equalization strategy and a SOC based equalization strategy are proposed. Two kinds of equilibrium strategies are introduced, and it is pointed out that the capacity balancing strategy is not suitable for online balancing schemes.

EXPERIMENTS DESIGN AND DATE ANALYSIS

The experimental platform of battery equalization is shown in Figure4. The experimental platform is mainly used for the verification of battery balance strategy and the test of balance circuit. It consists of three parts: charge and discharge motor, battery pack and PC monitor system.

The charging and discharging motor mainly realizes the charging and discharging function of the battery group, and completes the two-way flow of energy between the battery group and the power grid. Charge discharge in the work process through the CAN bus to accept balanced module to send battery information, battery voltage control method using the monomer of the battery pack constant current constant voltage charge and constant current discharge, the main technical indicators are: the rated power of 10kW; the output voltage is DC 30 ~ 150V; the output current is -100A ~+100A. The test battery is divided into two groups, all of which are lithium iron phosphate batteries and 11 batteries in series. The rated capacity of the single cell is 20 Ah and 60 Ah, respectively. The charging and discharging parameters of the battery group are as follows: the charge discharge current is 0.5C, the charging cut-off voltage is 3.65V, and the discharge cut-off voltage is 2.5V.

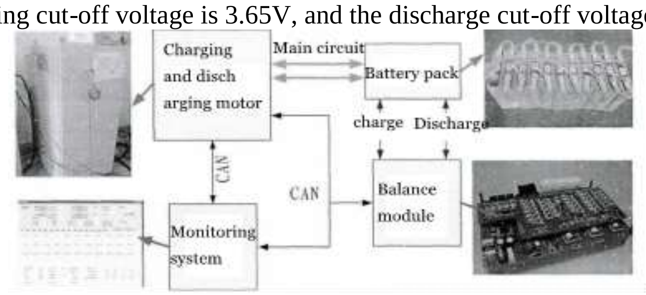

Fig4. Experimental platform

The first experiment is set for the power lithium batteries with the rated capacity of 20 Ah. The balance strategy is based on the battery SOC. There is a more obvious problem of disagreement.

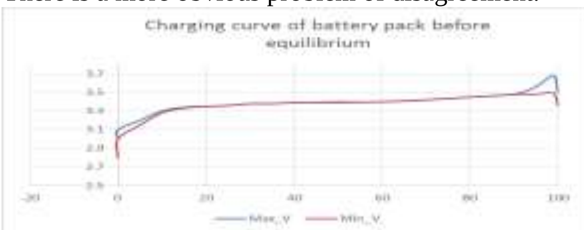

Fig5. Batteries curve before balance

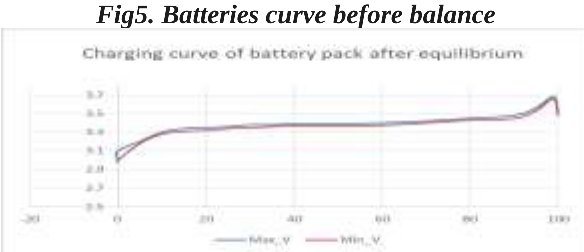

Fig6. Batteries curve after balance

We also compared the battery capacity in the balancing process of the charge and discharge as shown in Table.1.

Table1. Changes in battery capacity

Cycle times	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
Charge capacity	18.1Ah	18.2Ah	18.6Ah	18.7Ah	18.7Ah	18.9Ah
Discharge capacity	18Ah	17.9Ah	18.4Ah	18.5Ah	18.5Ah	18.6Ah

At the same time, a battery group with a rated capacity of 60Ah is tested based on the balance strategy of the battery voltage, and only discharge balance is included.

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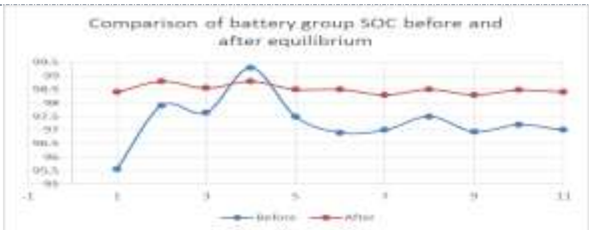

Fig7. SOC contrast

Figure8, 9 show the highest voltage charging curve and voltage minimum battery before and after the balance experiments, after 100 balance cycles.

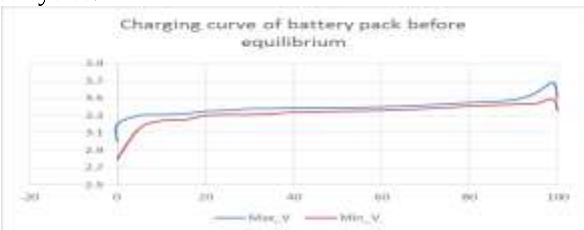

Fig8. Batteries curve before balance

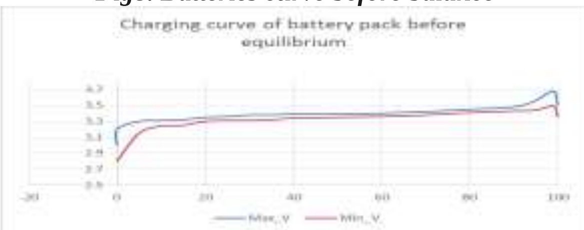

Fig9. Batteries curve after balance

RESULTS AND DISCUSSION

- Figure5 shows that the lowest battery charging curve of the battery before balancing the voltage and electricity in the front battery pack five. The balance module is used to balance the battery pack.
- After 6 charging and discharging cycles, the charging curve of the battery is shown in Figure6, and the difference of the voltage between the single cells is obviously reduced.
- The relationship between each single cell battery within the SOC equilibrium and changes, as shown in Fig7, the balance before the maximum difference between batteries SOC close to 5%, then into the differences between SOC has balanced battery control within the visible.
- Table1 shows that the battery capacity attenuation and consistency problems led to the available capacity of the battery is balanced before the rated capacity decreased by 9% after the available capacity of the battery after balance gradually increased by 4%. It can be seen that the goal of improving the battery capacity utilization based on SOC balance strategy is achieved.
- Figure8 and 9 shows the highest voltage charging curve and voltage minimum battery before and after the balance experiments, after 100 balance cycles, the difference between the highest voltage of the battery in the battery and the lowest voltage of the situation has not improved, while the battery maximum available capacity has not increased, but also reduce the balance than before by 3%, thus balancing system in the traditional systems depends on battery voltages is not ideal.
- The above experiments show that the equalization system based on SOC equilibrium strategy achieves the equalization of battery pack, and it can rapidly and effectively improves the maximum capacity of battery pack, and the maximum available capacity of battery pack is increased by 4% in the 6 cycle of equalization. The traditional balance strategy based on external voltage cannot effectively achieve the balance of the battery group.
- At the same time, the experiment also verified that the hardware of the equalization system works normally, and the measurement accuracy of voltage, current and temperature reaches a predetermined goal. The charge and discharge equilibrium can be judged and executed correctly, which fully shows that the design of the system meets the actual requirements.

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CONCLUSION

In this paper, we studied the balance strategy based on the different consistency evaluation system. Firstly, the strategy based on external voltage balance and its existing problems are studied. According to the capacity utilization rate of the consistency of the evaluation system is put forward based on capacity equilibrium strategy and balance strategy based on SOC, discussed the method to judge the two equilibrium strategies, pointed out that the use of capacity balancing strategy is not suitable for online condition based on SOC based balancing strategy has good practicability. The software part is embedded in the implementation algorithm based on the SOC equilibrium strategy and completes the programming of various functional modules. The experimental platform is built to test the balance system, and the reliability of the balanced circuit and the efficiency of the SOC balance strategy.

DISCUSSION

Due to the complexity of this topic and the limitation of research time, the balance technology of lithium battery still needs further improvement.

- This paper aims to improve battery capacity utilization and solve the problem of consistency effect on battery capacity. But the battery management during the actual use often pay more attention to the battery characteristics of energy and power, improves the capacity is to improve battery energy and power output characteristics of the utilization rate, and also did not establish optimal equalization scheme based on power and energy [5].
- The current application of the balanced circuit energy consumption is relatively large. The commonly used electric resistance discharge balance circuit not only consumes a lot of energy, but also produces heat to affect the reliability of the circuit and the distribution of the heat field of the battery box.
- At the same time, the existing lossless balance circuit often has many shortcomings, such as complex control, high cost, large volume and no support for modular design, so it is difficult to be applied in the field of electric vehicle.
- In this paper, a new modular charging equalization circuit is designed, which improves the energy utilization rate under the condition of using the vehicle, but the effect is still limited. Therefore, it is urgent to study the new nondestructive balance circuit to meet the balanced demand of the vehicle battery pack.

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