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# Researching on Discharge Efficiency of Battery Pack with Redundant Cells

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**Abstract:** Redundant Balancing Method Is An Efficient Battery Management System (BMS) Strategy, Which Can Make The Effective Capacity Of The Battery Group Close To The Sum Of Battery Capacity. In This Paper, The Discharge Switching Strategy Of The Battery Pack With Redundant Equalization Is Analyzed, And The Effect Of The Strategy On The Discharge Efficiency Of The Battery Pack Is Analyzed In Detail From Three Angles Such As Number Of Redundant, Switching Duration And Battery Initial Capacity Variance. Finally, The Simulation Results Are Verified By Experiments. The Results Show That The Simulation Data Is Consistent With The Actual Situation.

**Keywords:** Redundant Cell; Management Strategy; Battery Management System (BMS)

## I. INTRODUCTION

For high energy, high specific power, small size, long cycling life, and wide working temperature range, etc. [1], lithium ion battery has become main energy storage for carrying new energy. Due to the differences among production materials, manufacturing process, and working environment, single lithium ion battery usually shows non-uniformity in internal resistance, voltage and capacity. In order to overcome "short board effect" caused by Non-uniformity, batteries in series generally have to be equipped with battery management system (BMS).

At present, there are several typical strategies for battery management system, such as active equalization, passive equalization, redundancy equalization and so on. The strategy of redundant equalization is a kind of management method that can maximizes the effective capacity of the battery pack to the amount that close to the total capacity summed up by each unit.

In 2004, Li Hongyan [2] put forward a strategy adding more than one redundant battery cell to a lithium ion battery pack, which only works when non standby batteries depleted or damaged. It has nothing to do with the improvement in energy utilization of the battery pack. In 2007, Xu Jianming [3] also mentioned the redundant backup and equal time interval switching algorithm to make the battery pack to achieve a balanced discharging. In 2010,Yu Wei[4] [5] [6] team at the Suzhou Institute of Nano-Tech and Nano-Bionics(SINANO),Chinese Academy of Sciences, brought the concept of redundant backup into the field of power battery. Instead of using relay switch, they achieved redundancy by using semiconductor device, which created a new digitized era in power battery field. In 2011, Antonio Manenti[7] and his group came up with the idea of redundant equalization and carried out experimental verification. It is proved that this method can greatly improve the Balancing efficiency. In 2012, an algorithm to minimize the switching times in completing equalization was given by Fang Binyun and Xu Luxiong [8].

In this paper, the strategy applied to the process of discharge by switch shifting for the battery pack with redundant batteries is analyzed, and from multiple perspectives such as the number of redundant batteries and switches, the standard deviation of the initial battery capacity, the paper analysis the effect of the strategy on discharging efficiency of the battery pack in detail by numerical simulation method and the results will be testified by experiments at the end of this paper.

## II. REDUNDANT EQUALIZATION METHOD

Non-uniformity of the power batteries consists of non-uniformity of voltage, non-uniformity of resistance and non-uniformity of capacity. Therefore, in order to get a better performance with the battery pack, a battery management system (BMS) needs to be built based on the control of voltage and capacity of the battery pack. A lot of experiments showed that the failure of the battery pack is usually caused by only one or two batteries within it. And the inconsistency of the battery ( $SoC$ ) is a major cause which can lead to sever damage to the whole battery pack. Thus, the intelligent charge and discharge management strategy based on the structure with redundant unit can effectively solve the problems above and increase the effective capacity of the battery pack. Figure 1 is a schematic diagram of a typical redundant balancing battery management system, the number of batteries "*n*" in a general group will be more than the actual requirement number "*m*", The system can independently control the usage of each battery in the pack, the specific switching control strategy affects the performance of the pack. At present, there are three kinds of common methods, which are as follows: simple switching method, Numerical optimization method, and equal energy change / time switching method.

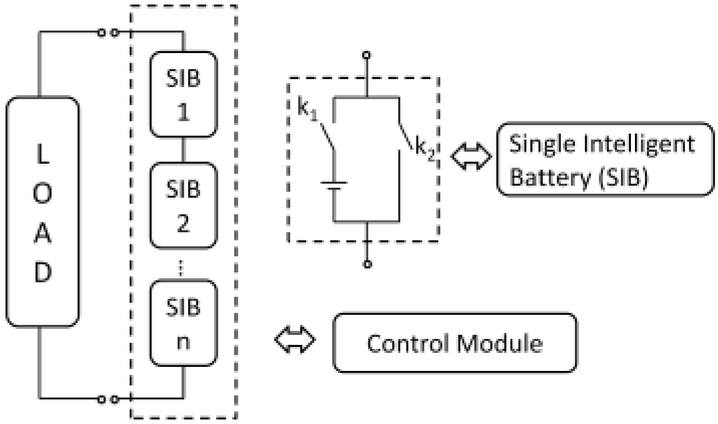



**Figure 1.** Schematic diagram of a typical redundant balance battery management system (BMS)

**1. Simple Switching Method**

The method is applied in the discharging process, the backup battery works only when the non-standby battery depletion or damage happens. So the efficiency is not high.

**2 Numerical Optimization Method**

This method can optimize the switching times according to the initial state of battery. However, for there is no steady initial stat due to the changing working conditions, the calculation will get complicated, and the initial state given by this method can be very different form the reality.

**3 Equal Energy Change / Time Switching Method**

The method is in constant change of energy or time redundancy cell switching, the method in the discharge process try to keep the battery optimization combination discharge, is the best way to deal with the discharge process may occur at any time of emergency situations. The specific switching energy or time interval is related to the maximum energy and discharge current of the battery pack.

## III. EQUAL ENERGY CHANGE/TIME SWITCHING METHOD

Assuming there are *n* cells, the subscript "*i*" in $SoC_{i0}$ stands for the battery under working condition, we define the situation with switch $K_1$ closed and $K_2$ open as state "1", in contrast of that is state "0". The *r stands for* redundant number, under condition that the discharging current *I is* given, the system will make a reselection after a duration time to sort $SoC$ by size of number.

$$SoC_{\min} \le SoC_1 \le SoC_2 \ldots\ldots SoC_m \le SoC_{m+1} \le \ldots\ldots SoC_n \le SoC_{\max} \quad (1)$$

Set *m* batteries with lowest SOC to state 0 and the other *n-m* batteries to working condition.

Definition: $SoC_{ic}$ stands for the remaining capacity of the battery labeled "*i*".

$$\delta = \frac{\sum_{i=1}^{n} SoC_{i0} - \sum_{i=1}^{n} SoC_{ic}}{\sum_{i=1}^{n} SoC_{i0}} \quad (2)$$

## IV. SIMULATION

Based on the principle above, we developed a simulation software by VB, it studies the effect of three factors (the variance distribution of initial state, number of redundant batteries and switching time / energy) to the efficiency in discharge with the method of redundant balancing. The number of cells in the simulation is

100, the mean value of $SoC$ is 70, and the data in the simulation is generated randomly through the Normal distribution algorithm.

**1 The influence by the number of redundant batteries**

Set variance of the pack to10, switching interval to 10s, discharge rate to C=0.1c. Make the redundant cell number m to m = 0, 1, 2, 3, 4, 5, 10, 20, then simulate the efficiency in discharge of the battery pack.

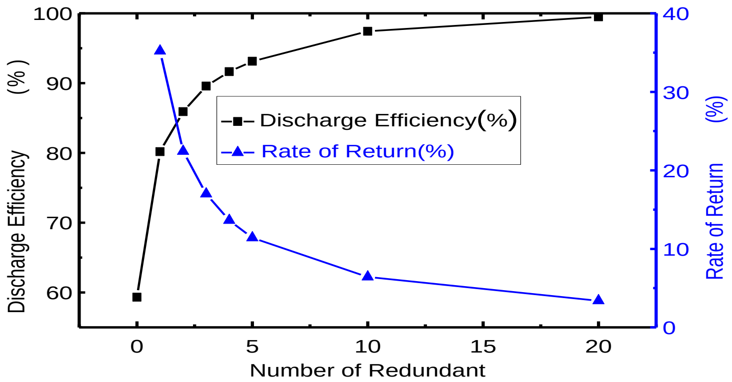



**Figure 2.** Effect of the number of redundant cells on discharge efficiency

Defined rate of return as:

$$\varphi_{r=i} = \frac{\delta_{r=i} - \delta_{r=0}}{\delta_{r=0} * i} \quad (3)$$

We can see from figure 2, the discharge efficiency can be improved significantly by adding the number of redundant battery to the pack. It can be seen, with five redundant batteries, the discharging efficiency can reach 93%; but as the number increases, the improvement of discharging efficiency becomes slow. Therefore, we need to choose the redundancy number rationally in practical application.

**2. The influence of switching time / energy difference**

When switching, set a fixed discharging current value, change the switching time that is to change the shifting energy difference. Set battery $SoC$ to $\sigma$ =10, discharge rate to C=0.1c, back-up number m=5, switching interval to t=10~500s respectively. The simulation is as follow:

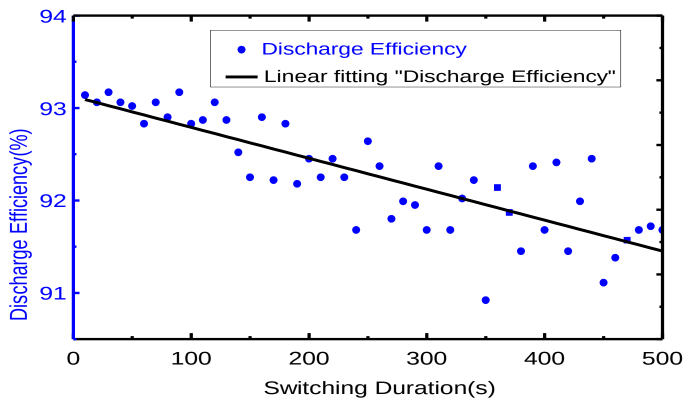



**Figure 3**. Effect of switching interval on effective energy release rate

As can be seen from figure 3, the greater the switching interval, the less times it need to shift and the less the energy that releases. But too high switching frequency will introduce harmonics in the circuit. This will affects the quality of the power supply, and will bring certain switching losses.

**3 The effect of initial variance on discharge efficiency**

Set battery $SoC$ standard variance $\sigma$ =2, 5, 8, 10, the redundant battery number *m*=1, 3, 5, switching interval time for t=100s, discharge rate setting for C=1C, the variance of the initial simulation on discharge efficiency influence.

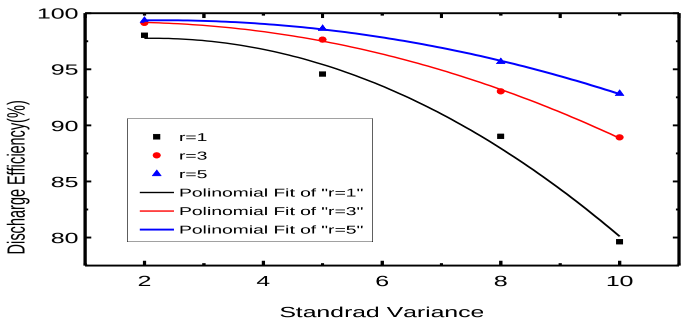



**Figure 4.** Sigma factors influencing the release rate of available energy

As can be seen from figure 4, the greater the initial standard variance of the battery pack to achieve the same discharge efficiency, the more redundant batteries is needed. It also shows that the redundant battery method can significantly improve the discharge efficiency of the battery pack. But with a given number of redundant battery, simple selection of the initial distribution of the battery pack is necessary. Consistency should not be too large, so as to maximize the efficiency of the battery pack.

## V. EXPERIMENTAL VERIFICATION

In order to verify the simulation data, this paper tries to build an intelligent battery management system contains 18 batteries according to figure 1, as shown in figure 5. The battery capacity in the group were 68, 86, 77, 89, 85, 85, 67, 73, 71, 60, 83, 90, 85, 79, 74, 69, 88, 76.

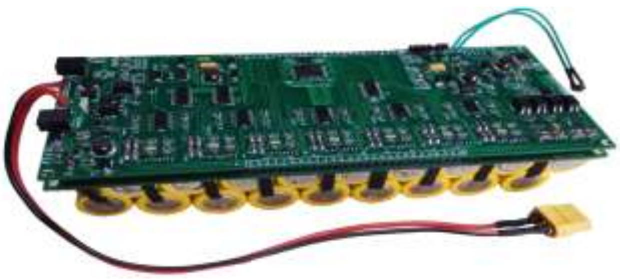
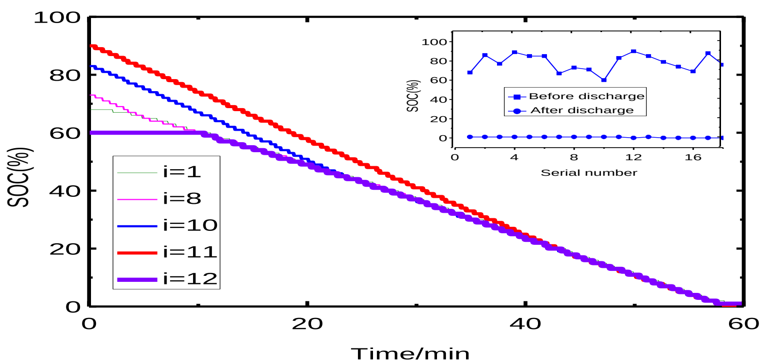


**Figure 5.** Balanced redundant module

Battery discharge parameters are as follows: discharge cut-off voltage: 2.0V, discharge rate: 0.5 c, the number of redundant batteries is seven. That is to say, discharge voltage is 36V. In the discharge process, the $SoC$ change of the serial number for the four section of the "1, 8, 10, 11, 12" is shown in figure 6.




Embedded image is the initial capacity compared with the after discharge of the battery diagram.
**Figure 6.** Discharge of SOC changes before and after

Among them,

$$\delta = \frac{\sum_{i=1}^{n} SoC_{i0} - \sum_{i=1}^{n} SoC_{ic}}{\sum_{i=1}^{n} SoC_{i0}} = \frac{\sum_{i=1}^{18} SoC_{i0} - \sum_{i=1}^{18} SoC_{ic}}{\sum_{i=1}^{18} SoC_{i0}} = (1405-12)/1405 = 99.15\% \qquad (4)$$

As shown in figure 6, with the discharge, the serial number for the four section of the "1, 8, 10, 11, 12" battery $SoC$ gradually tend to be consistent. Discharge capacity of the initial inconsistency has been greatly improved after discharging. By calculation, the discharge efficiency of the battery is 99.35%, so the full discharge of the battery is achieved. Therefore, the redundant battery can effectively improve the discharge efficiency of the battery pack.

## VI. CONCLUTION

In this paper, the battery discharge switching strategy with redundant balancing method is analyzed from three respects, redundant number, switching time interval and initial capacity battery standard variance. This paper studies the influence of the strategy on the battery discharge efficiency by numerical simulation method. The results are as follows:

First of all, increasing the number of redundant batteries can improve the discharge efficiency of the battery pack, but there is an optimal value.

Second, increasing the switching interval times can increase the discharge efficiency of the battery pack, but too high the frequency can lead to harmonic in the circuit, and an increasing switching energy loss.

Finally, the greater the initial standard variance of the battery pack to achieve the same discharge efficiency, the more redundant batteries is needed. Therefore, in practical application, it is recommended that the variance of the group battery should be selected rationally, so as to save the quantity of redundant battery.

At the end of this paper, we built a system with redundant battery units to verify the simulation data. But limited by the experimental conditions and with the difficulty of building an intelligent battery management system contains 100 batteries .The simulation results are simply verified by 18-battery system, which can only prove the rationality and reliability of the redundant simulation data, and the further work is to be carried out in the future.

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