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Research on a new fast charging method for lithium batteries in five phases

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Abstract

The principle of fast charging of lithium batteries was introduced. In order to realize the fast charging of lithium batteries , this paper proposed a fast charging method based on the five phase , which was based on the analys is of the polarization phenome non of lithium batteries in the charging process . By changing the pulse period and pulse a muplitude of each stage , the capacity of lithium batteries to accept the current capacity and the charging efficiency can reach the maximum. A new fast charging method in five stages were simulated and analyzed by using MATLAB/Simulink. The results show that a new fast charging in five stages significantly reduce the charging time,compared with the traditional multi-stage constant current method and multi-stage normal pulsed method.

Keywords

Ithiumion batteries; depolarization; intermittent positive and negative pulse.

1. Introduction

In recent years, the rapid development of electric vehicles has led to an increasing demand for high-capacity power batteries. Lithium-ion batteries are widely used in electric vehicles due to their unique properties such as small size, light weight, long cycle life, high energy density, and the ability to be charged and discharged with high current [1]. For the application of electric vehicles, lithium-ion batteries are required to be charged quickly and efficiently, and at the same time try to ensure that the batteries have a long service life [2-3]. The performance and service life of lithium-ion batteries are closely related to the choice of charging method, and the selection of an efficient charging method is very important for lithium batteries [4].

Currently, power batteries are mainly characterized by long charging and discharging time, short cycle life, poor battery stability and low charging and discharging efficiency. battery's poor stability and low charging and discharging efficiency.A five-stage fast charging method is proposed, which is compared with the traditional multi-stage constant current charging method and multi-stage ordinary pulse charging method.

2. Fast charging principle of operation

2.1. Basic Theory of Fast Charging

In the mid-1960s, the American scientist Maas put forward the curve of acceptable charging current of the battery on the premise of the lowest degassing rate on the basis of experimental proof.

As can be seen from Fig. 1, the maximum charging current that a Li-ion battery can accept is an exponentially decaying curve while maintaining a trace amount of outgassing. Its equation is:

$$i = Ie^{-at} \tag{1}$$

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Where: I is the maximum initial current value at t = 0, I is determined by the state of use of the battery; a is the decay constant.

There are two main reasons why the acceptable current of the battery decreases exponentially: on the one hand, it is because the active substance inside the battery decreases with charging; on the other hand, it is the polarization phenomenon that prevents charging. Maas's law shows that in the charging process, if the battery is discharged or stopped for a short period of time at the right time, it can improve the battery charging acceptance rate, increase the size of the acceptable current of the battery, change the inherent charging curve of the battery, and make the charging speed increase.

2.2. Conventional fast charging methods

In order to effectively accelerate the charging speed of lithium batteries, shorten the charging time, and reduce the polarization phenomenon, so as to comprehensively enhance the efficiency of energy use, domestic and foreign has been continuously strengthening the research and practice of fast charging methods for lithium batteries. At present, the domestic battery fast charging methods are mainly the following:

(1) Multi-stage constant current charging is a fast charging method that is more commonly used today [7]. The so-called constant current charging is a charging method that keeps the current constant during the whole charging process or part of the time period of the battery. Constant-current charging is based on the accurate prediction of SOC, but various algorithms have a certain amount of error accumulation, so the battery is easily overcharged or underfilled.

(2) Multi-stage pulse charging. In the charging process, set the size of the current in each stage, each charging time period is Tc, and then stop charging for Td to ensure that the charging power is greater than the discharging power. As charging proceeds, the current size is reduced step by step. When the voltage reaches the cut-off voltage, charging stops. There is no discharge pulse during the charging process, relying only on stopping charging to recover the polarization effect.

2.3. Fast charging methodology design

In order to eliminate the polarization phenomenon generated during the charging process of lithium batteries, improve the charging acceptance rate and shorten the charging time, this paper designs a new five-stage fast charging method as shown in Fig.1. In the first stage, the initial charge capacity of the battery is low, and the polarization phenomenon is not obvious, at this time, the battery has the strongest charging acceptance current ability, so it adopts the high-current constant-current charging, so that the battery can obtain as much power as possible in a short time. Due to the limited ability of the battery to accept charging, the next four stages of the frequency and amplitude of the intermittent - positive and negative pulse charging, charging current value with the charging process step by step to reduce the length of the stop charging and negative pulse discharge with the charging will also be increased step by step!

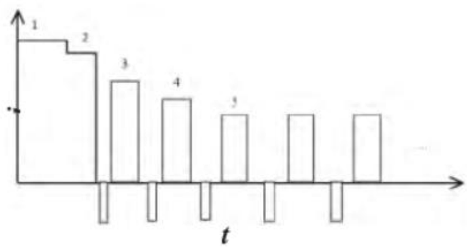

Fig. 1 Five-stage fast charging curve

The five-stage fast-charging method splits the traditional large pulse into multiple positive pulses intermittent - positive and negative pulses, because the alternating frequency of positive and negative pulses is higher than that of conventional positive and negative pulses.The alternating frequency of positive and negative pulses is higher than that of conventional positive and negative pulses, which improves the charging acceptance ability of the battery, and also repairs the Li-ion battery to a certain extent during the whole charging process.During the whole charging process, the lithium battery will be repaired, which belongs to the repair-type fast charging method [8].

An important issue that needs to be addressed with the five-stage fast charging method is the choice of what parameter to use as the basis for the end-of-stage determination. Although the acceptable charging current is decreasing with time, due to the different initial state of the battery, charging parameters, etc., if the selection of time as a judgment parameter is easy to cause the battery overcharge or undercharge. Battery voltage has a close relationship with the energy charged into the battery, so this paper adopts battery voltage as the judgment parameter, when the voltage reaches a certain value it will automatically switch to the next stage or stop charging.

2.4. Determination of fast charging method parameters

As the lithium battery is charged, the polarization inside the battery changes, so the charging frequency of the pulse stage should be changed accordingly, and the pulse frequency size is:

$$f_1 = \frac{1}{2\pi R_1 C_1}\sqrt{T-1} \tag{2}$$

$$T = \frac{\sqrt{2R_S R_1 C_1^2 + 2LR_1^2 C1 + R_1^4 C_1^2}}{L} \tag{3}$$

R_1 and C_1 are the equivalent resistance value and the equivalent capacitance value of the simplified model of Li-ion battery, respectively.capacitance values, whose magnitudes are [9]:

$$R_1 = a_1 e^{a_3 \tau} + a_2 e^{a_4 \tau} (a_3, a_4 < 0) \tag{4}$$

$$C_1 = b_1 e^{b_3 \tau} + b_2 e^{b_4 \tau} (b_3, b_4 < 0) \tag{5}$$

Where: a_1 - a_4 , b_1 - b_4 depend on the specific battery parameters; t is the SOC of the battery.It can be seen from the formula that the resistance and reactance of the battery and the SOC of the battery become a nonlinear relationship, in the charging process, the SOC is constantly changing, and the impedance of the battery also changes accordingly.

According to the specification provided by the manufacturer, the maximum allowable charging current for lithium-ion batteries is 1.5 C. C denotes the ratio of the current size of the battery during charging and discharging, i.e. multiplication, e.g., for a battery with a capacity of 100 Ah, the charging current of 1 C denotes the size of 100 A. In this paper, the maximum value of the charging current is set to 1.5 C. The fast charging method proposed in this paper will carry out pulse discharging and stopping charging during the charging process, which eliminates the polarization generated during the charging process, and the charging current will be reduced. polarization phenomenon generated during the charging process, increase the time of continuous charging with high current, and the charging mode of forward current is 1.5 C, 1.2 C, 1 C, 0.7 C, 0.3 C.

The negative pulse parameters are determined. If the amplitude of the negative pulse is too small, depolarization will not be very effective, and if the amplitude of the negative pulse is too large the battery will be damaged. With different discharge currents, the temperature rise was measured separately and the curves are shown in Fig. 2. The data shows that high current discharge causes a continuous rise in temperature, this is due to the fact that a large discharge current produces more heat on the internal resistance of the battery than the heat absorbed by the chemical reaction, if the battery is discharged with a negative pulse that lasts too long or has too large an amplitude, it will produce a lot of heat and damage the battery life. By summarizing the experience of experts' experiments [10], it was determined that the pulse discharge current is 0.5 C, at which time the positive and negative pulse charging method has the highest efficiency, the shortest charging time, and very little damage to the lithium battery.

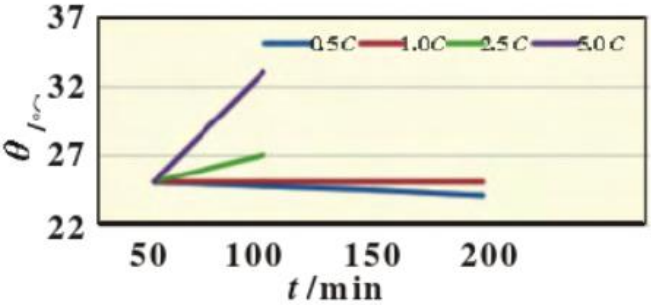

Fig.2 Battery temperature change curve under different discharge current

The negative pulse width is calculated by the formula:

$$a = \frac{K \lg kI_d}{\sqrt{C_d}} \tag{6}$$

Where: a is the battery current acceptance ratio; K is the discharge constant; k is the calculation constant; Id is the size of the negative pulse current; Cd is the discharge capacity, and because there is Iod = aCd, can be obtained:

$$I_{od} = K\sqrt{C_d} \lg kI_d \tag{7}$$

Let the discharge time be dt, then:

$$I_d dt = C_d \tag{8}$$

Different negative pulse widths are determined according to the different states of the battery polarization phenomenon at different stages.

When negative pulse discharge is performed, the ohmic polarization disappears rapidly and the electrochemical polarization can also disappear in microseconds, but the concentration polarization takes longer to eliminate, requiring several seconds or even tens of seconds of stop charging to eliminate. Although the negative pulse discharge accelerates the elimination time of the concentration polarization, it still needs a stop-charging time to eliminate the concentration polarization, so it is designed to pause charging for a few milliseconds before and after the negative pulse discharge, which is used to eliminate the concentration polarization on the one hand, and on the other hand, it is used to provide a buffer time between the positive and negative pulses.

3. Simulation Analysis

According to the design of the battery charging system, the corresponding modules are selected in MATLAB/Simulink for connection, and the overall simulation diagram is built as shown in Fig.3. The five subsystems from top to bottom represent one stage of the charging method in turn, and the lithium battery adopts the battery model that comes with MATLAB/Simulink, which not only sets the rated voltage and rated current of the battery, but also sets and observes the SOC of the battery.The battery parameters are selected as follows: the rated capacity is set to 7.5 Ah, and the rated voltage is set to 12 V. By sampling the voltage of the lithium battery, we can set the rated voltage of the lithium battery according to the different voltages. voltage sampling of the lithium battery, the switching between different subsystems is controlled according to the different voltages, so as to select the appropriate initial stage of charging according to the different remaining capacities of the battery. The SOC of the Li-ion battery can be set from 0 to 100% according to the simulation condition.

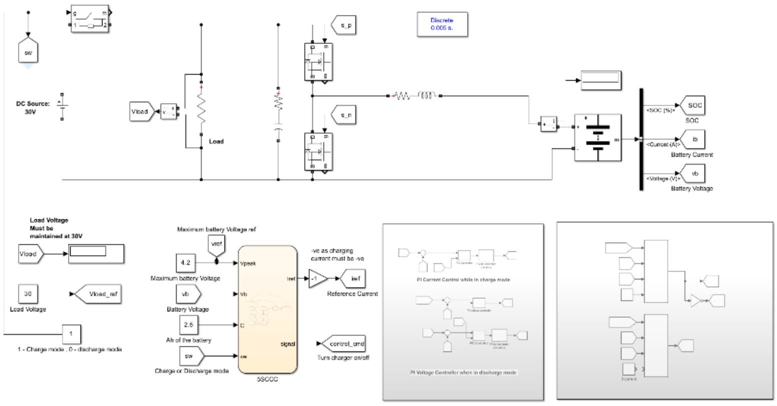

Fig.3 Five-stage fast charging MATLAB/Simulink control block diagram

The internal structure of each stage charging subsystem is shown in Fig.4, which contains a Switch subsystem that generates constant DC current and a Discharge subsystem that discharges it. The timing of the Switch subsystem and the Discharge subsystem is realized by different pulse triggers, which in turn enables constant-current charging (at which time the Discharge subsystem does not operate) or intermittent-positive and negative pulse charging.

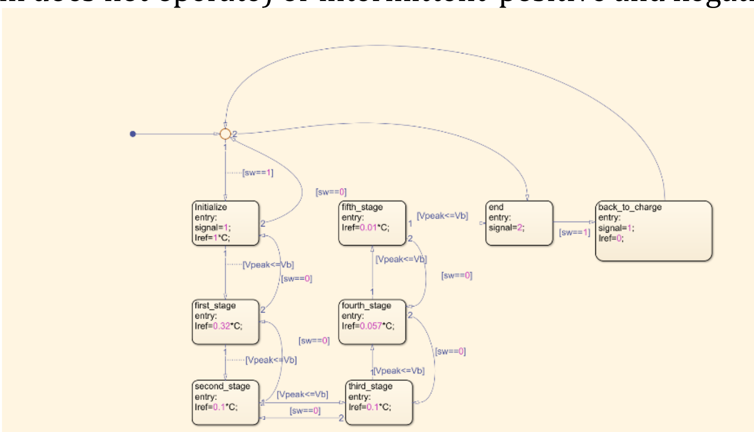

Fig .4 Block diagram of the internal structure of the subsystem

The internal structure of the Switch subsystem is shown in Fig.5, which first inverts the DC current and then rectifies and filters it to achieve a stable and constant DC current output.

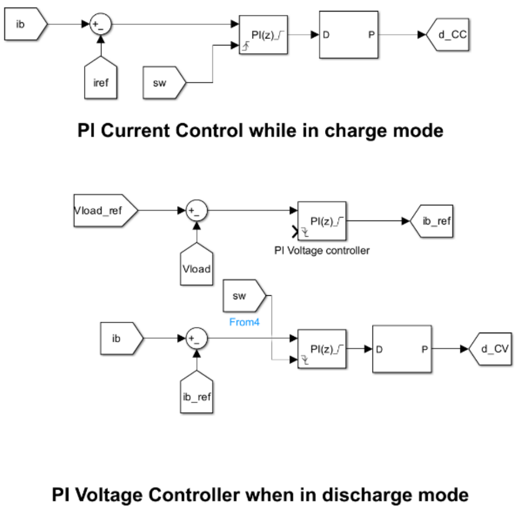

Fig. 5 Internal block diagram of Switch subsystem

The internal structure of the Discharge subsystem is shown in Fig.6, where the switching tube IGBT is turned on during discharge and discharged through a resistor.

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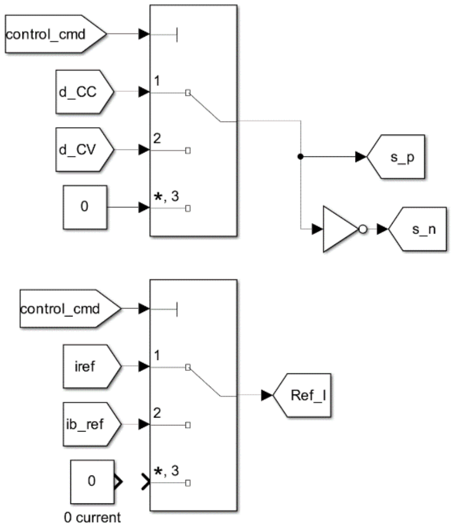

Fig. 6 Internal block diagram of the Discharge subsystem

From Fig. 7, Fig.8, Fig. 9 and Table 1, it is obvious that the fifth-order novel fast charging method significantly shortens the charging time and achieves the purpose of fast charging.

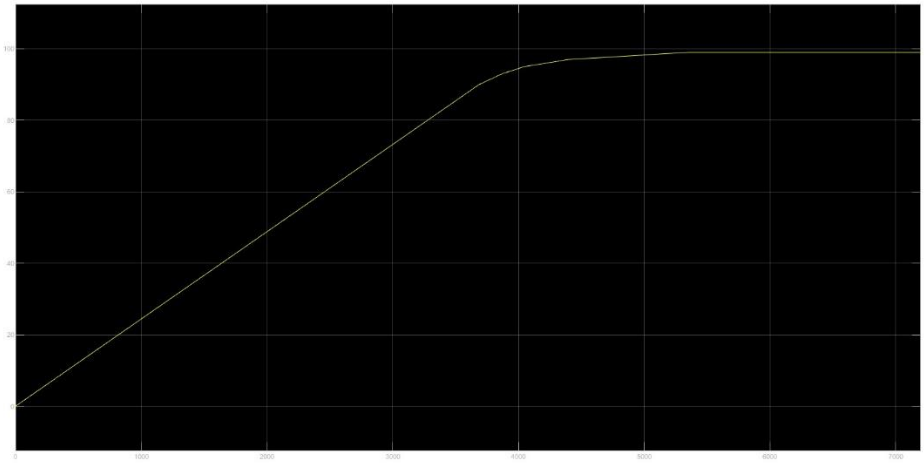

Fig.7 Five-stage constant current charging SOC curve

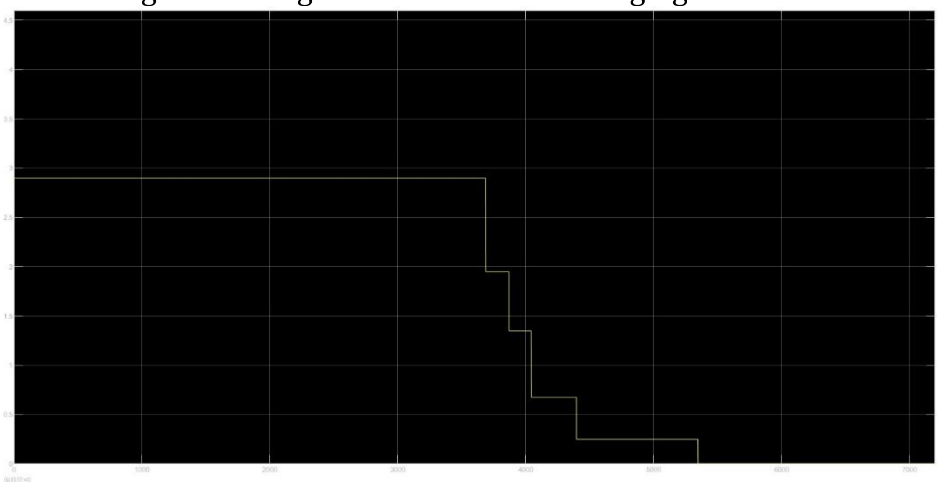

Fig. 8 Fifth order constant current charging current graph

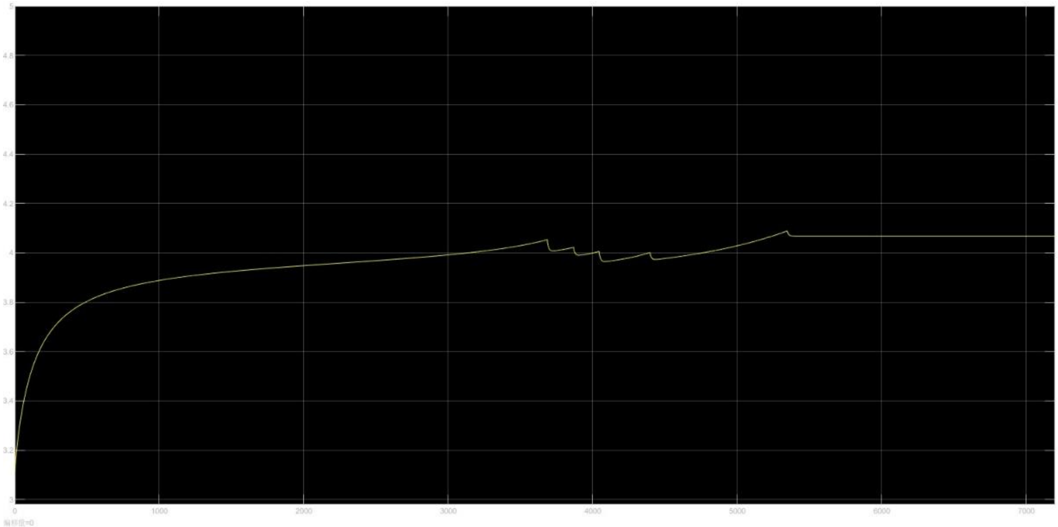

Fig. 9 Five-stage constant current charging voltage curve

Table.1 Comparison results of the fifth-order constant-current charging method with the conventional charging method.

methodologies	charging time/s	battery capacity/%
Five-step constant-current fast charging	5320	99
Constant Current and Constant Voltage Charging	6000	92

4. Reach a verdict

(1) In this paper, the polarization phenomenon and fast charging theory of lithium-ion batteries are analyzed in detail, and for the traditional charging method which can not well remove the polarization in the charging process and the problem of long charging time, the five-phase charging method with discharge pulse and stop charging is designed in the charging process to realize fast charging;

(2) The pulse charging frequency, positive current parameter, negative pulse parameter and stop charging parameter were determined through analysis and comparison;

(3) In this paper, the five-stage fast charging method is simulated and experimented, and the simulation results are compared with the traditional multi-stage constant current method and multi-stage ordinary pulse method, and the results show that the five-stage fast charging method improves the charging speed a lot more than the traditional fast charging method, and realizes the charging idea of high efficiency, rapidity, and non-destructive charging.

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