Universe Scientific Publishing

Research on Active Balance Control Strategy for Electric Vehicle Power Battery Pack

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Abstract: The battery pack of a pure electric vehicle is composed of multiple battery cells connected in series and parallel, and in the process of battery charging and discharging and long-term use, it will cause an imbalance between the battery cells or battery packs, which affects the capacity utilization and service life of the battery. This paper analyzes the electric vehicle lithium-ion battery pack as a study of equalization control, and analyzes the equalization variables used for the battery pack, the battery model, the external characteristics of the battery, and the SOC estimation based on the extended Kalman filter algorithm. The SOC is used as the equalization variable, so that all the battery cells are basically at the same charging and discharging depth, which makes full use of the power of the battery pack, and improves the safety performance of the battery pack when it is working, and an equalization control simulation model is constructed in Matlab/Simulink software, and the equalization method and the system of this paper for the battery cluster are simulated and researched.

Keywords: Pure Battery Vehicles; Equalization Control; Cuk Equalization Circuit; SOC

1. Introduction

Active equalization is non-energy consuming equalization where excess battery energy can be stored in the energy storage element. According to the different energy transfer elements, active equalization can be divided into switched capacitor equalization, inductive equalization, transformer equalization and converter equalization.

The equalization effect is closely related to the equalization variables. In the case of imbalance in the battery pack, the equalization variables, such as operating voltage, SOC, and residual capacity, will have different degrees of inconsistency, and at the same time, the temperature, operating conditions, etc., will also produce a certain degree of interference. Therefore, when the inconsistency phenomenon is formed among individual battery cells, the characteristics presented by each equalization variable determines whether it can be used as an equalization control quantity.

2. Power Battery SOC Estimation Analysis

2.1 Lithium-ion battery inconsistency

The inconsistency of the battery's individual parameters leads to the fact that the usable capacity of a conventional power battery pack is often lower than that of a battery pack composed of a certain number of cells, and at the same time, the service life is not long. This variability is mainly caused by two factors.

First, because it is difficult to ensure that the process of each battery is the same when the battery is manufactured, this will prompt some differences in the pole plate and core of each battery, which will cause the capacity and internal resistance of each battery to differ.

Second, in the actual application of the situation, the application environment is different, which causes the degree of weakness of each battery performance differences, at the same time, when the longer the use of the case, the attenuation of this difference is more prominent, which will lead to the capacity of the battery, the internal resistance of the battery to show a clear difference.

2.2 Battery SOC Estimation

2.2.1 Simulation verification based on Kalman filter method

(1) Design of experimental conditions for battery HPPC characterization test

Conducting dynamic performance tests on batteries requires the design of test experiments, and generally commonly used is The Hybrid Pulse Power Characterization (HPPC). The main objective of this test is to determine the following parameters as a function of discharge depth, (a) V feedback pulse capability at the end of the 10s discharge pulse and (b) V feedback pulse power capability at the end of the 10s feedback charging pulse. These power capabilities are then used for other performance tests such as effective energy and effective power. Another purpose of this test is to determine the voltage characteristic curves for the voltage sampling time of a single cell during discharge, holdover, and feedback charging operation with due consideration to reliability, and to derive the fixed internal resistance of the cell and the polarized internal resistance of the cell as a function of state of charge (SOC) (i.e., derive the internal resistance versus SOC primarily from the voltage curves).

HPPC process:

A HPPC test small and medium cycle is basically composed of these 60s, 10s pulse discharge, 40s rest, 10s pulse charging, the whole test process is composed of one HPPC test for every 10% DOD, from high SOC to low SOC, the specific process is as follows:

Note: Charging method: charging method specified by the raw manufacturer;

Discharge current: 5C or 25% discharge current of the maximum discharge multiplier specified by the raw manufacturer;

Full charge battery, discharge according to 1C to 10% DOD, dormant for one hour, then discharge at 5C for 10s, dormant for 40s, and charge for 10s.

Full charge battery, discharge to 20% DOD at 1C, hibernate for one hour, then discharge at 5C for 10s, hibernate for 40s, charge for 10s.

Fully charged battery, discharge at 1C to 30% DOD, hibernate for one hour, then discharge at 5C for 10s, hibernate for 40s, charge for 10s.

Fully charged battery, discharge at 1C to 40% DOD, hibernate for one hour, then discharge at 5C for 10s, hibernate for 40s, charge for 10s.

Fully charged battery, discharged at 1C to 50% DOD, hibernated for one hour, then discharged at 5C for 10s, hibernated for 40s, recharged for 10s.

Fully charged battery, discharge to 60% DOD at 1C, hibernate for one hour, then discharge at 5C for 10s, hibernate for 40s, charge for 10s.

Fully charged battery, discharge at 1C to 70% DOD, hibernate for one hour, then discharge at 5C for 10s, hibernate for 40s, charge for 10s.

Fully charged battery, discharge at 1C to 80% DOD, hibernate for one hour, then discharge at 5C for 10s, hibernate for 40s, charge for 10s.

Fully charged battery, discharge at 1C to 90% DOD, hibernate for one hour, then discharge at 5C for 10s, hibernate for 40s, charge for 10s.

(2) Internal resistance characteristics

The internal resistance of a battery refers to the resistance of the current flowing through the interior of the battery during operation. The main factors affecting the internal resistance of a battery are the state of charge of the battery and the magnitude of the charging and discharging current.

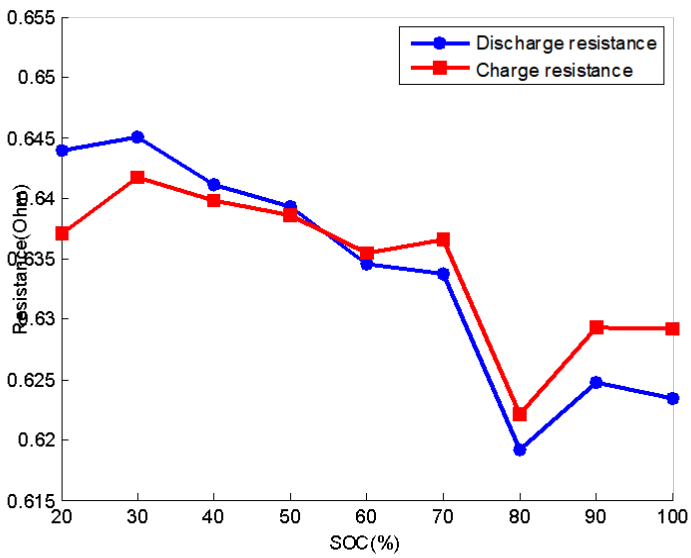


Fig. 1 Charge/discharge internal resistance of battery corresponding to different SOCs

(3) Identification of lithium-ion battery model parameters

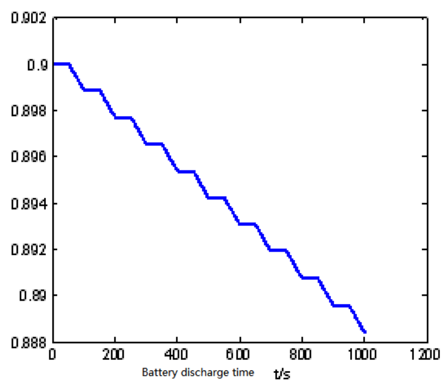
Since the electrical parameters of the model components can not be measured directly by multimeter, and each parameter shows nonlinear characteristics with the changes of temperature, degree of charging and discharging, life span, remaining capacity and other external factors, it is necessary to obtain the identification of different charging states of the working conditions, the identification of the parameters of the electrical components of the equivalent circuit can be based on the standard identification method and the specific process, in the identification, this paper, according to the battery and the In the identification, this paper makes corresponding improvements to the test experiment according to the needs of the actual situation such as battery and model characteristics, and only considers the influence of SOC on the model parameters. The internal parameters of the battery model (open-circuit voltage U_{oc}, capacitance C_b, ohmic internal resistance R_0 and polarization internal resistance R_p) need to be obtained by the method of parameter identification, while the external parameters can be obtained only by measurement.

In this paper, HPPC test is used to identify the battery model parameters.

Table 1 Identification parameters

batteriesSOC （%）	polarization time constant τ /s	open circuit voltage U_{oc} /V	capacitors C_b /F	ohmic resistance R_0 /Ω	Polarization Resistance R_P /Ω
20	11	258.0961	1111.9	0.1187	0.0359
30	15	263.3882	1792.8	0.1177	0.0328
40	13	269.1555	1591.6	0.1115	0.0351
50	17	274.7639	1801.9	0.1139	0.0363
60	15	278.3264	2040.9	0.1094	0.0354
70	16	281.2472	2347.3	0.1116	0.0359
80	16	284.2707	2429.9	0.0975	0.0343
90	17	291.3226	1969.3	0.1072	0.0333
100	13	295.5347	1751.3	0.1043	0.0398

The algorithmic control strategy is built in Simulink, the rated capacity of the battery is 60Ah, the rated voltage is 291.3V, the initial value of SOC is 0.9, and the battery is subjected to the discharge test under the constant speed driving condition at the constant temperature, and the discharge time is 1000s.



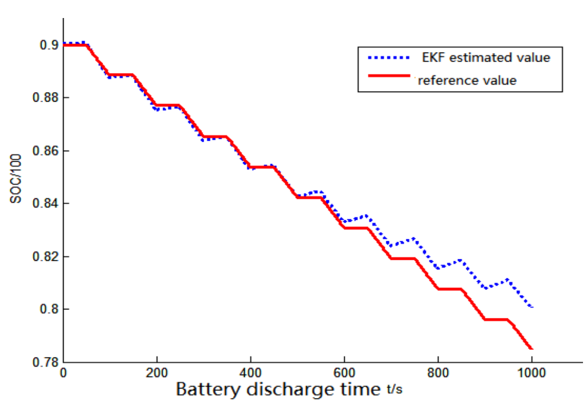


Fig. 2 SOC estimation based on EKF Fig. 3 SOC estimation based on EKF algorithm

From Fig. 2, it can be seen that the extended Kalman filter can accurately estimate the charge state of the battery in the first 600s of the battery discharge, and with the increase of the discharge time, the estimation accuracy of the extended Kalman filter decreases, which is due to the fact that the charge state of the battery is affected by the temperature, the manufacturing accuracy and many other factors. In this paper, the influence of these factors is no longer considered, and the extended Kalman filter can meet the requirements.

3. Power battery pack equalization research

3.1 SOC-based equalization control strategy

3.1.1 Input and output variables

FLC based on SOC to achieve equalization, the focus of the equalization strategy is to use the FLC algorithm to dynamically adjust the equalization current in the group to achieve fast equalization of the equalization circuits in the group and shorten the equalization time.

The input variables based on the FLC algorithm are SOC_{dif} and ΔSOC, and the output variable is the balanced current I_{equ}. $u(x)$. $u(y)$ and $u(z)$ correspond to the membership functions of SOC_{dif} , ΔSOC and I_{equ}. Firstly, the input variables SOC_{dif} and ΔSOC are fuzzified and converted into fuzzy variables, respectively μ (x) And μ (y) Then these fuzzy variables are input into the inference machine and processed by a pre built rule library composed of practical experience and knowledge to obtain the fuzzy variables μ (z) . Finally, after deblurring, it is converted into the corresponding current output value I_{equ} .

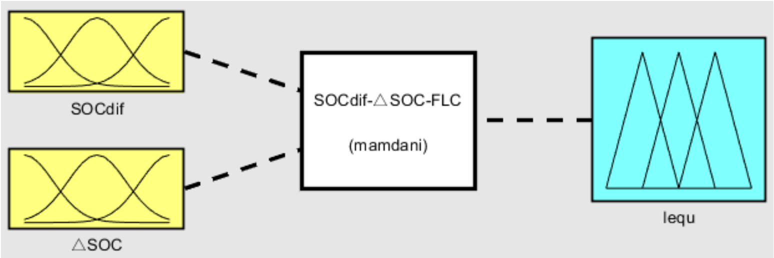


Fig. 4 Block diagram of fuzzy logic control

3.1.2 Fuzzy control rules

In the equalization process, the fuzzy rule table shown in Table 2 is established through the experience accumulated based on expert knowledge about battery pack equalization:

(1) If SOC_{dif} is larger, the value of the balancing current should also be larger, in order to reduce the balancing time and improve the balancing speed.

（2）If ΔSOC is large and SOC_{dif} is small, the value of the balanced current should be reduced to prevent overcharging of the battery.

（3）If ΔSOC is small and SOC_{dif} is also small, the value of the equilibrium current should also be small to prevent the battery from over discharging;

（4）If ΔSOC and SOC_{dif} are in the middle range, the value of the equilibrium current should also be in the middle range to improve the equilibrium speed and safety.

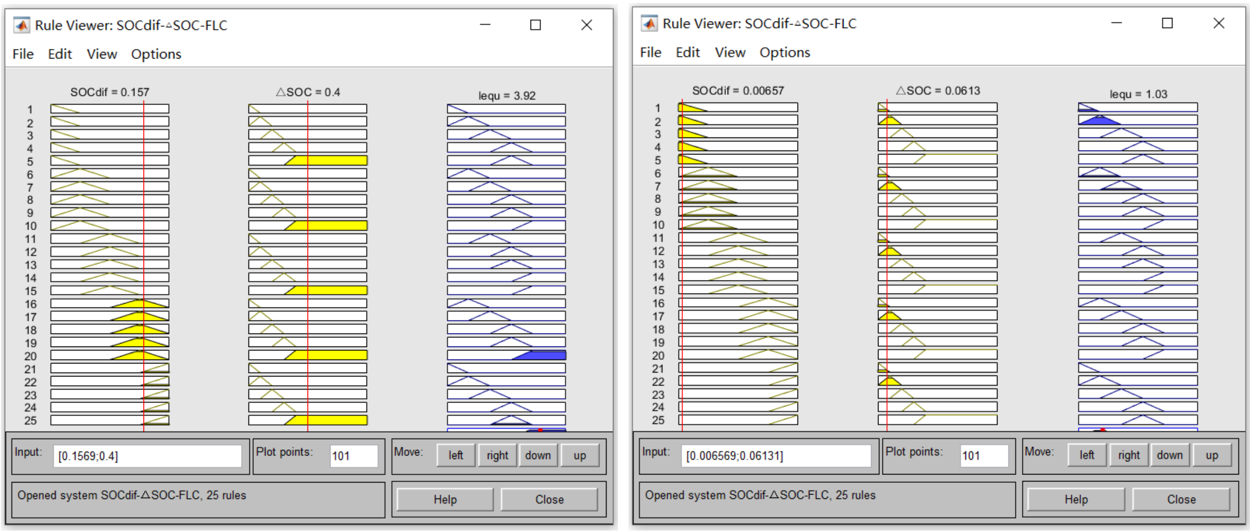
Table 2 Table of fuzzy rules

I_{equ}		ΔSOC				
		VS	S	M	L	VL
SOC_{dif}	VS	VS	S	M	L	L
	S	S	M	L	L	VL
	M	M	L	L	VL	VL
	L	S	M	L	L	VL
	VL	VS	S	M	L	L

In this paper, the control rules of the dual-input single-output fuzzy controller are in the form of if A and B then C. Each of the two inputs has five fuzzy subsets and hence the total number of fuzzy control rules based on permutations and combinations consists of 25 if-then statements. The logical relationship between the inputs and outputs is established in the software and the corresponding fuzzy rule formulation is given here in terms of SOC based fuzzy control.

3.1.3 Fuzzy reasoning and defuzzification

In order to quantitatively analyze the states of the input and output quantities of the fuzzy inference process, two states are analyzed: SOC_{dif} is larger、 SOC_{dif} is lesser, The relationship between the input and output quantities in the two states is shown in Fig. 5 (a) and (b), respectively.：



(a) SOC_{dif} is is large (b) SOC_{dif} is lesser

Fig. 5 Relationship between input and output quantities in two states

3.2 Simulation analysis

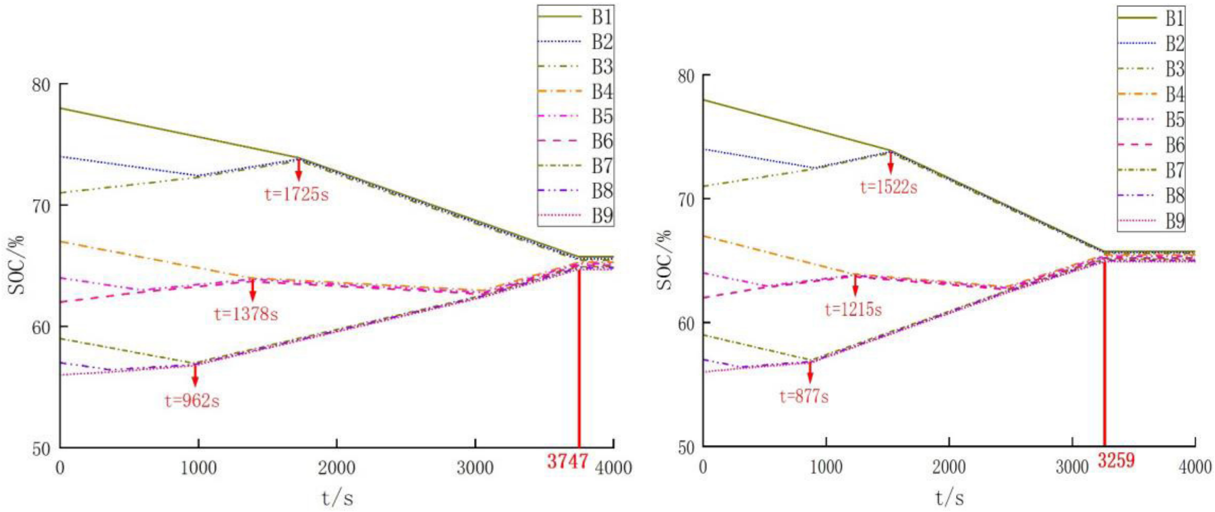
3.2.1 Main parameters of simulation

This paper uses Matlab/Simulink software for modeling and simulation, the parameters of the lithium-ion battery are 4.2V/3.2AH, and the nine series-connected lithium-ion batteries are divided into three modules, with three single batteries in each module. The numbering of each single cell is recorded as B1, B2, B3, B4, B5, B6, B7, B8, B9 in order, and the initial SOC values are 78%, 74%, 71%, 67%, 64%, 62%, 59%, 57%, 56%, respectively. The balanced simulation model consists of battery module, oscilloscope, double layer selector switch, Cuk module, Buck-Boost module, switching control module, current control module and PWM output module.

3.2.2 Analysis of equalization simulation results

In order to verify the superiority of the fuzzy logic control (FLC) algorithm proposed in this paper, comparison experiments are conducted with the most value method, and the experiments are divided into static equalization and charging equalization for comparison.

(1) Static equalization

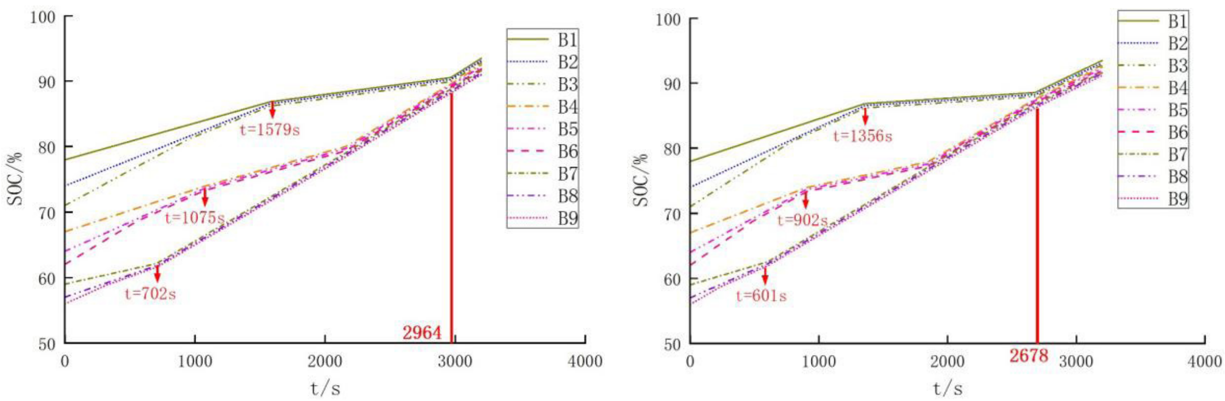


(a) Based on the most value method (b) Based on FLC

Fig. 6 Variation of cell SOC under static equalization

The SOC variation curves for static equalization based on the most value method and fuzzy logic control algorithm are shown in Fig. 6(a) and Fig. 6(b), respectively. The time required to equalize the battery pack by the two methods is 3747 s and 3259 s. The time efficiency of the fuzzy logic control algorithm is improved by about 13%, which results in faster equalization.

(2) Charge equalization



(a) Based on the most value method (b) Based on FLC

Fig. 7 Variation of battery SOC under charging equalization

The SOC variation curves for charging equalization based on the most value method and fuzzy logic control algorithm are shown in Fig. 7(a) and Fig. 7(b), respectively. The time required to equalize the battery pack by the two methods is 2964 s and 2678 s. Therefore, the time efficiency of the fuzzy logic control algorithm is improved by about 9%, which results in faster equalization.

4. Conclusion

In this paper, the control method is analyzed according to the demand of power battery pack equalization for pure battery vehicles. The equalization control strategy using SOC as the input variable of the fuzzy controller is studied. With SOC as the equalization variable, the fuzzy logic control (FLC) algorithm is designed to dynamically adjust the equalization current. Finally, simulation experiments are carried out to prove the significance and effectiveness of this paper.

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