Research in Equalizing Charging Control Strategy in Li-ion Power Battery

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Abstract

Immanent problem existed in equalizing charging process may induce performance recession of power battery, and a new method raised in this paper, combining fuzzy strategy, is put forward in dealing with the problem. It is functioned with established mathematical model, closed-loop energy controlled digital pulse-width modulation power source on the foundation of element simulation in Simulink. The method can conduct simulation experiments on system response with and without static load-balance, as well as prompt load-balance respectively. It is shown in the results that, the sever coupling occurred between internal error voltage and external load current, can be escaped by applying the fuzzy controller based on closed- loop energy control model. The results also embrace real-time control output under any error voltage input signal and load current, which improves the adaptability and robustness of the system.

Keywords: *Li-ion Power battery; Energy closed-loop; Simulink; Fuzzy control*

1. Introduction

Li-ion power battery has achieved an increasing attention among researchers with its high energy density, high reliability, and environment-friendly quality in recent years [1]. However, because of the discrepancy caused by manufacturing process, battery material, resistance and ambient temperature, it may occur that the voltage of the single battery string in a battery pack is imbalanced, which may reduce or cause a fatal damage to the life of the battery pack in use. So the balance control is of great significance and it has practical applications in extending the life of the battery pack as well [2, 3].

An inverter equilibrium charger based on MOSFET is a severe non-linear and complicated system determined by its topology structure, which deduced that the establishment of mathematical model of the system is difficult [4]. It may cost time and is low in profit if the experiment to test the electrical parameters of the system is conducted directly on the device [5, 6]. In view of this, this paper has proposed an equilibrium control strategy, which deals the complicated equilibrium control problem of the battery pack as the fuzzy control of energy closed-loop control model.

2. Design of equilibrium controller

The complicated equilibrium control problem of the battery pack can be simplified to a dual-input and single-output control [7]. This paper has introduced the energy closed-loop control model based on fuzzy control strategy controller. The structure of the controller is shown in Figure 1.

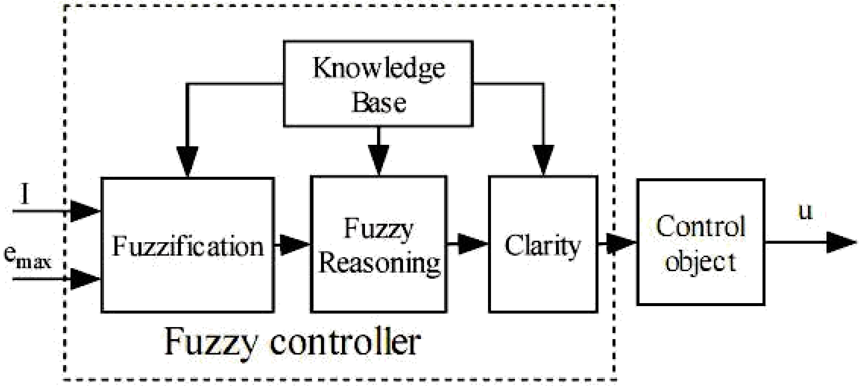

Figure 1. Structure of Fuzzy Controller

For the practical application of the battery pack, the input of an equilibrium controller is the max disequilibrium degree parameter e_{max} between voltage Vi (i =1, 2,⋯, 8)of eight batteries in the battery pack and the given voltage V (average voltage) of the system. So in order to obtain e_{max}, eight sets of voltage difference e_i(i =1, 2,⋯, 8) are needed. V_i (i =1, 2,⋯, 8) can be obtained by the isolation voltage acquisition circuit and the average voltage can be obtained using equation 1:

$$\bar{V} = \frac{\sum_{i=1}^{8} V_i}{8} \tag{1}$$

Equation 2 is applied to get as fuzzy controller input value:

$$e_{\max} = aMAX\left|V_i - \bar{V}\right| \tag{2}$$

Where, a is the symbolic coefficient of e_{max}, and $e_i = V_i - \bar{V}$. When the collected voltage is higher than the average value a=1, when the collected voltage value is lower than the average value a=-1. The max disequilibrium degree parameter e_{max} and load current is used as the input of designed fuzzy controller. After quantizing with fuzzy controller, conducting fuzzy decision according to the fuzzy reasoning rules, calculating the fuzzy control unit, and obtaining accurate digital control unit with clarity processing, the input was sent into the execution unit for accurate equilibrium control [8].

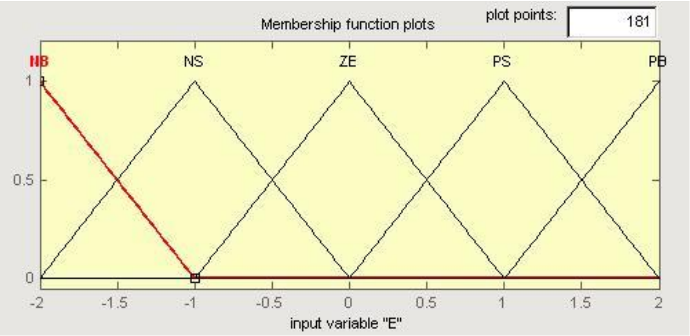

Figure 2. Membership Function of Input Value E

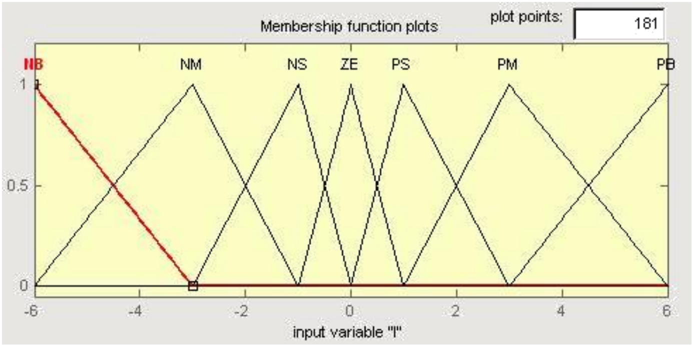

Figure 3. Membership Function of Input Value I

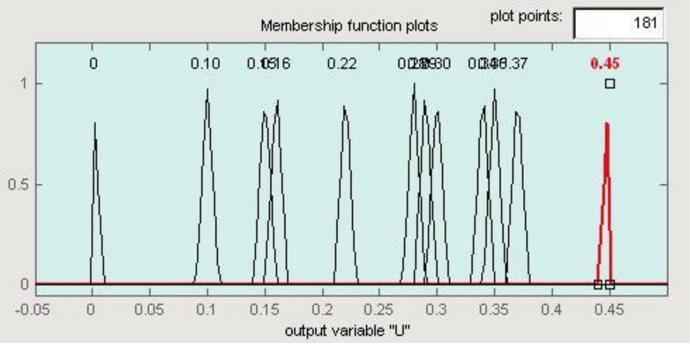

Figure 4. Membership Function of Output Value U

Discrete domain of fuzzy inputs E, I and the output U is taken as E NB, NS, ZE, PS, PB,, I NB, NM, NS, ZE, PS, PM, PB, and U of NB , NM, NS, ZE, PS, PM, of PB. The membership function of the input parameters are selected graphics of the triangular membership functions shown in figure above [9].

Here, T-S deterministic fuzzy reasoning is applied, the rule of which is: If E is E_i and I is I_j then U is U_{ij} .

Where, U_{ij} is the function determined or real numbers determined, rather than fuzzy sets. Fuzzy control rules are set which refers to the actual equilibrium data, and duty cycle of power-switch drive signal can be obtained according to the reference voltage error value and load current. In the representation of the load current fuzzy domain, N represents that the battery pack is charging; P represents that the battery pack is discharging.

Table 1. The Output Rule of Fuzzy Controller

U	I						
E_{max}	NB	NM	NS	ZE	PS	PM	PB
NB	0.45	0.37	0.29	0.15	0.22	0.30	0.34
NS	0.35	0.28	0.22	0.10	0.16	0.22	0.30
ZE	0	0	0	0	0	0	0
PS	0.35	0.28	0.22	0.10	0.16	0.22	0.30
PB	0.45	0.37	0.29	0.15	0.22	0.30	0.34

Table 1 has indicated the Li-ion power battery fuzzy control output with and without loads. The output is the specific duty cycle value within the range [0, 0.45], the duty of which can be directly used to control the power switch pipe of half-bridge circuit after the traditional PID controller conditioning [10]. The fuzzy controller applies two-dimensional input structure, which indicates the max disequilibrium degree parameter E and load current I, and duty cycle of power switch signal U respectively. Exact measure domain of max equilibrium degree of single batteries is [-0.5, 0.5], the exact measure domain of load current is [-45, 45], and the exact measure duty cycle domain is [0, 0.45]. Enter the corresponding rules of the fuzzy control input and output fuzzy rules in the fuzzy rule editor.

To test the effect of the established equilibrium controller, this paper has established a simulation environment based on MATLAB7.0, SIMULINK and a simulation model. The general equilibrium controller simulation model is shown in Figure 5.

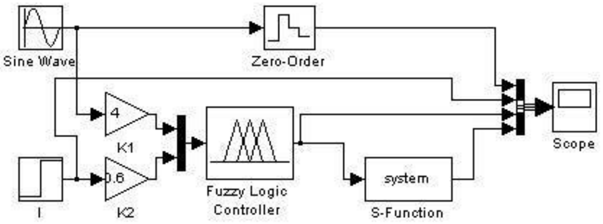

Figure 5. Simulation Model of Equilibrium Controller

The input signals of the model is phase-shift Sine function and step function. Where, Phase-shift Sine function is used for simulating the changes of error voltage in the battery pack, and the step function is used for simulating the prompt load signal added to equilibrium system. Quantization coefficients K1, K2 are applied to conduct fuzzification of max disequilibrium degree of input error voltage and load current. The fuzzy language with fuzzification is entered in the fuzzy logic rule base to conduct fuzzy reasoning and fuzzy output.

3. Design of simulation model

3.1. The model of main equilibrium circuit model

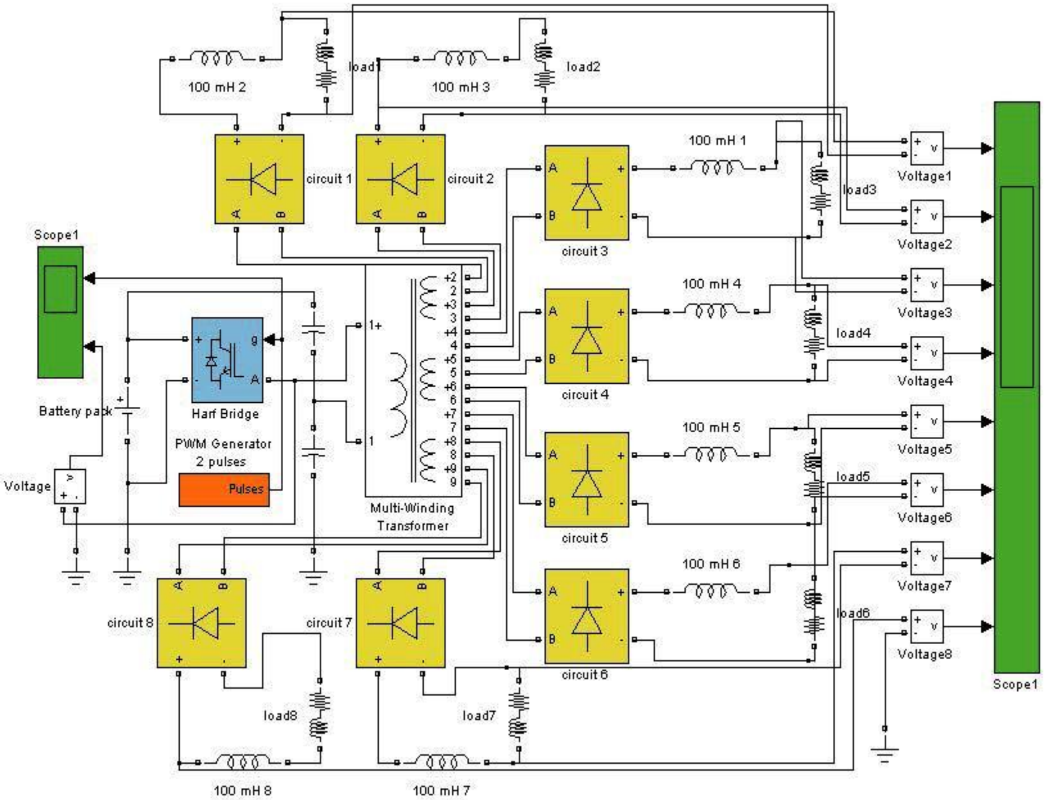

Figure 6. Simulation Model of Equilibrium Circuit

The equilibrium circuit simulation model is established with the function components modules in Sim Power System libraries of SIMULINK with MATLAB7.0, as is shown in Figure 6. Battery equilibrium circuit is powered by the equilibrium battery pack itself. The initial DC source can be transformed into required voltage and current through the half-bridge inverter circuit and multi-output transformer for isolation voltage transformation, into eight-way electrical isolation side-way circuit for secondary rectification, filtering.

3.2. Simulation mode of power battery pack

Li-ion power battery pack is composed of many single batteries through the series, and the parallel combination. The internal electrical characteristics are extremely complex, which cannot be completely described for all of its electrical accurately with existing simulation module in SIMULINK. Thus, according to the charging and discharging curves of the known Li-ion battery pack, through the preparation of the S function modules, to simulate battery charging and discharging characteristics of the pack, in order to achieve the simulation of the Li-ion battery pack.

Charging and discharging curves of Li-ion battery pack are shown in Figure 7 and 8.

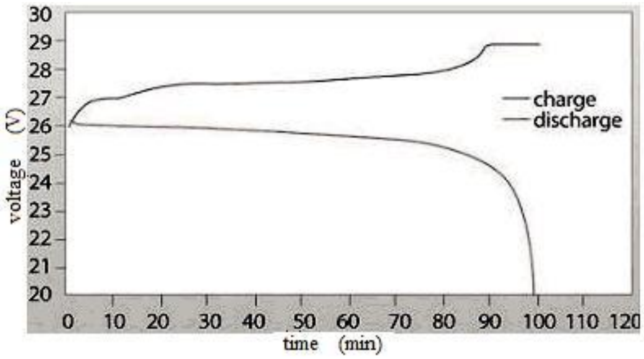

Figure 7. Charging Curves of Li-ion Power Battery Pack

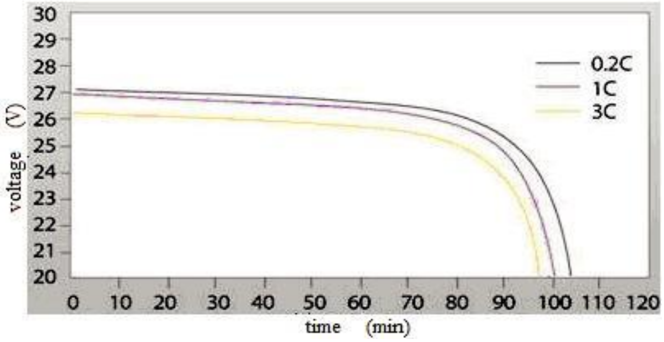

Figure 8. Discharging Curves of Li-ion Power Battery Pack

4. Analysis and simulation experiment

During the simulation, first the paper conducted experiment of fuzzy controller for simulation response under static, non-load and variable voltage error control situation. Voltage error output curve of fuzzy controller in real-time control of the no-load condition is shown in Figure 9. The simulation interval is selected for 30min, and use phase-shift Sine function to simulate the max equilibrium degree parameter E. The sine function parameters are set as: amplitude is 0.4, frequency is 0.07rad/min, and the phase angle is 45 degrees, the control output is the duty cycle signal.

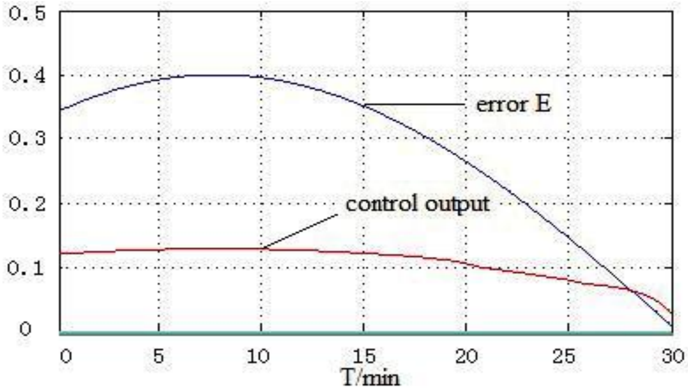

Figure 9. Control Output under No-Load Condition

Figure 9 has indicated that, in initial phase of equilibrium control, for a given E, the duty cycle signal will be instantaneous given by fuzzy controller. When E gradually increased, the output duty cycle signal value from the fuzzy controller increased as well. When E gradually decreased, the duty cycle signal gradually decreased, and finally it reached 0 with E. The results have shown that voltage error value of the specific time, the fuzzy controller would output real-time control unit to track the changes, which reflects the real-time fuzzy controller controlling.

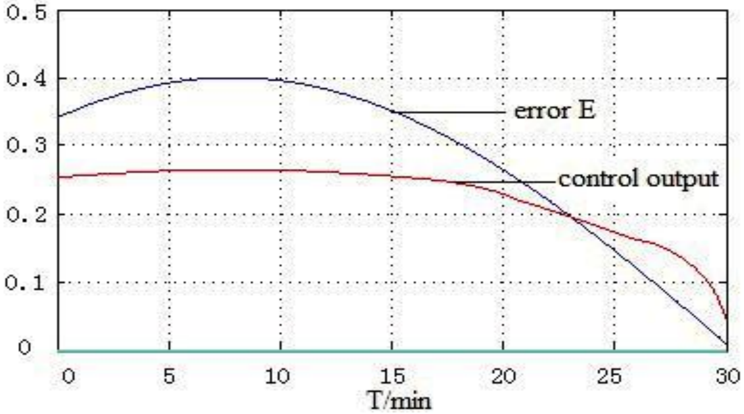

Figure 10. Control Output of the System under External Load Condition

Taking the actual equilibrium process into account, a fuzzy controller should be able to meet the static, non-load equilibrium, but also to meet the dynamic loading equilibrium of the system. Therefore, the simulation of the control output from the fuzzy controller with load is carried out; the control output is shown in Figure 10.

Figure 11 indicates the output response of the equilibrium control system under non-load state. It can be seen from the figure that the system response can reflect the response curve and real-time track output of fuzzy controller fast and accurately.

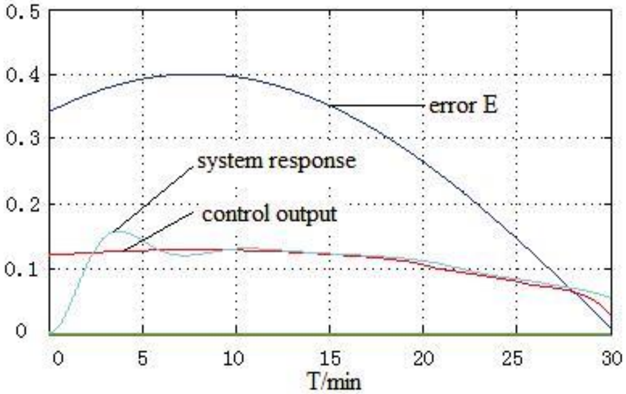

Figure 11. Output Response of the System under No-Load Condition

When compared with Figure 10 and Figure 12, a conclusion can be draw that control output of fuzzy controller with load is much larger than the one without load under the same max disequilib-rium degree parameter. It indicates that the depth of equalizing control is determined by the fuzzy controller upon both the max disequilibrium degree parameter as well as the load current value, which satisfies the fuzzy rules of fuzzy controller's internal design.

In order to prove the robust stability of the fuzzy controller, as well as adding prompt load in the static, non-load balance control process. The fuzzy controller output and system response is shown in Figure 12.

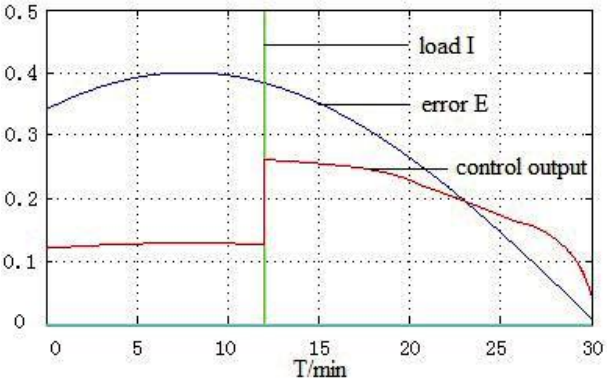

Figure 12. Control Output of the System under External Load Condition

It can be seen in the initial stage of the simulation system without load, real-time control unit of the fuzzy controller is small, and it may change the output followed by max disequilibrium degree parameter. At 12min, prompt load is added in the system, and the output of fuzzy controller instantaneous increased and followed the max disequilibrium degree parameter and the load current until the max disequilibrium degree parameter equals to zero.

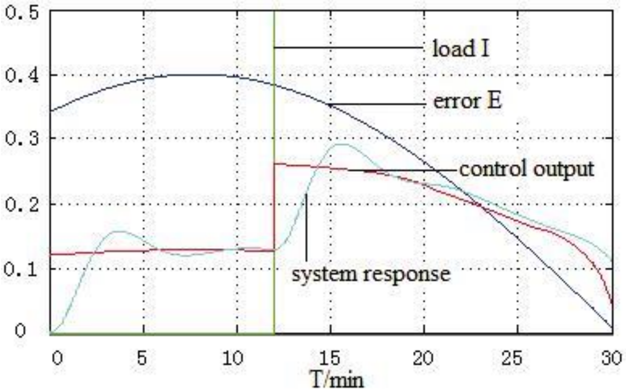

Figure 13. Output Response of the System under Prompt Load Condition

Figure 13 indicates the response of the system output of control system with a prompt load. As for prompt load applied, the system has a quick response and the output response of the system come to become stable gradually after the load is stable, showing that the fuzzy controller has robust stability.

5. Conclusion

Aiming at the severe non-linear complex system of inverter battery equilibrium controller, this paper has applied the half-bridge inverter topology as object, fuzzy control strategy, and Matlab soft-ware, Simulink, PowerSystem Blochset to provide the basic modules to establish a simulation model, experiments of static, non-load equilibrium simulation, dynamic, loading, equilibrium simulation, and prompt load equilibrium simulation. The results obtained through simulation experiments have indicated that the modulation of the fuzzy controller has a certain stability and anti-disturbance ability. The proposed energy closed-loop control model principle and the established fuzzy controller is correct, effective, and they can be well applied to a equilibrium control of the Li-ion battery pack.

Acknowledgements

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