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Research on Fuzzy PID Charging Control of Battery Pack

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Abstract

Battery groups are widely used in production and life. Optimal charging can not only shorten the charge time, but also improve the performance and life of the battery pack. A constant current or constant voltage charging method is commonly used. This type of method cannot adjust the charge capacity in time according to the change of charging capacity of storage battery, and the charge performance is not high. This paper designs a fuzzy PID controller. In the case of variable load and interference, the battery group can still be charged by the optimal charging current. Through the simulation results, the fuzzy PID controller works well and verifies the feasibility of the charging controller.

Keywords

Battery Pack, Charge Management, Fuzzy PID Control

The mobile power system and the UPS (UBS) are widely used. In the event of a power grid failure, the production equipment can be supplied with electricity to make the production normal. The power supply can be provided to residential communities to make the residents' lives unaffected. It is used as a backup power for large weapons in combat to ensure reliable power supply for weapons [1]. The battery is an important part of the mobile power supply system and UPS (UBS). The power supply quality of the power supply system is directly determined by the performance of battery charge.

1. The Chemical Reaction of the Battery Pack Charging

The battery pack can supply power from the power supply system and can also provide buffer for the power grid when it is charged. The total electrochemical reaction equation of the most commonly used lead-acid battery during the charging process is [2]:

$$2P_bSO_4 + 2H_2O \rightarrow P_b + 2H_2SO_4 + P_bO_2$$

During the actual charge, the late charging is often accompanied by a lot of water electrolysis reaction. The reaction equation is:

$$2H_2O \rightarrow 2H_2 \uparrow + O_2 \uparrow$$

The chemical reaction of the lead-acid battery during the charging process is shown in Figure 1.

2 The Main Parameters That Affect Charging of the Battery Pack

1) Charge acceptance

Charge acceptance refers to the maximum charge current the electrolyte can accept under the premise of producing only a small amount of gas [3]. When the battery charge current for the battery pack is greater than its acceptable maximum charging current, it will have intense electric hydrolysis reaction inside, the pressure increase and the temperature rise will accelerate and there will be serious gassing phenomenon.

2) Temperature

The voltage of the battery cell will drop by about 4 mV for every 1˚C increase in temperature [3]. In order to ensure adequate power, the charging voltage must be adjusted with the temperature coefficient of the battery voltage.

3) Battery capacity

The battery capacity represents the ability of the battery to store electricity. During charging, the charging capacity of the battery can be:

$$C = K\int_0^t i dt$$

where i is the charging current (A); t is the charging time (h); K is the charging coefficient of the lead-acid battery.

3. Problems with the Traditional PID Charging Control

The working process of the battery pack is non-linear and its characteristics vary with the working time and the environment. When the battery characteristics change, the charging current must be adjusted in order to get a good control effect. The traditional constant current or constant voltage charging does not

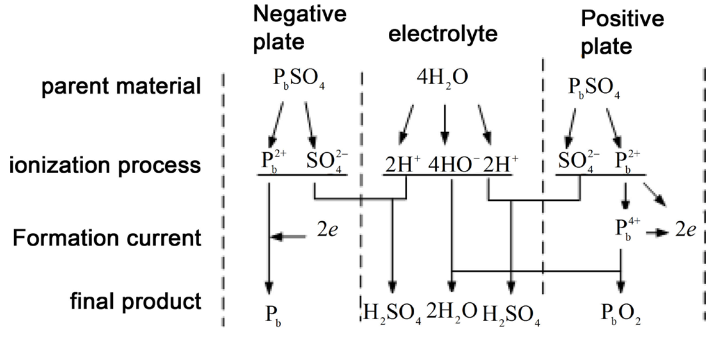

Figure 1. Sketch map of charge chemistry of lead-acid battery.

have this “adaptive” capability, and its parameter setting is dependent on the experience of the technician, making it difficult to guarantee timeliness and continuity [4].

4. Fuzzy PID Charge Control

Battery pack management system is a complex nonlinear time-varying system and can establish a precise mathematical model, making it suitable for fuzzy control [5]. The structure of the fuzzy PID controller is shown in Figure 2. It consists of a fuzzy controller and a traditional PID controller. The input of the fuzzy system is e (the error of the charging voltage) and ec (the error rate of change), the output is the change value of the PID parameter, and the PID parameter is adjusted in real time according to the designed fuzzy control rule to realize the self-tuning of the PID parameters [6].

1) Fuzzification

Take the subordinating degree function of the input (e, ec) and the output (K_P, K_I, K_D) as the triangular function [7].

The variation range of e (the input error) and ec (the error rate of change) is defined as the universe of discourse on the fuzzy set:

$$e, ec = \{-3, -2, -1, 0, 1, 2, 3\}$$

The variation range of the output K_P is defined as the universe of discourse on the fuzzy set:

$$K_P = \{-3, -2, -1, 0, 1, 2, 3\}$$

The variation range of the output K_I is defined as the universe of discourse on the fuzzy set:

$$K_I = \{-0.06, -0.04, -0.02, 0, 0.02, 0.04, 0.06\}$$

The variation range of the output K_D is defined as the universe of discourse on the fuzzy set:

$$K_D = \{-3, -2, -1, 0, 1, 2, 3\}$$

Suppose the fuzzy subsets of e, ec, K_P, K_I and K_D are: {NB, NM, NS, Z, PS, PM, PB}

2) Fuzzy rules

Through repeated experiments and literature review [8], the fuzzy rules are defined as follows. As shown in Tables 1-3.

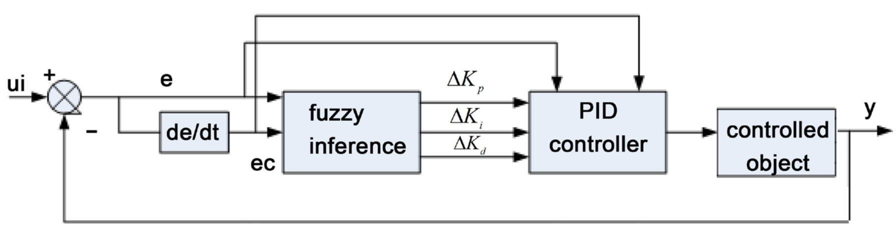

Figure 2. PID controller of fuzzy self-tuning system.

Table 1. Fuzzy control principle of K_P.

e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	PS	PS	PM	PM	PM	PS	PS
NM	PM	PM	PB	PB	PB	PM	PS
NS	PB	PS	NS	NS	NS	NS	Z
Z	PS	PS	NS	Z	NS	NS	Z
PS	PS	PS	NS	NS	NS	NS	Z
PM	PS	PM	PB	PB	PB	PM	PS
PB	PB	PM	PB	PB	PM	PS	PS

Table 2. Fuzzy control principle of K_I.

e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	NB	Z	PB	PB	PB	PS	PS
NM	NB	PS	PB	PB	PS	Z	Z
NS	Z	PS	PS	PM	PM	PS	PS
Z	Z	PM	PS	PM	PM	PS	Z
PS	Z	PS	PS	PM	PM	PM	Z
PM	NS	Z	PM	PS	PS	NS	NS
PB	NS	NS	Z	PS	NS	NS	NS

Table 3. Fuzzy control principle of K_D.

e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	PS	NB	NB	NS	NB	NB	PS
NM	Z	NB	NB	NS	NB	NB	PS
NS	Z	NM	NM	NS	NM	NM	PS
Z	Z	NS	NS	Z	NS	NS	Z
PS	Z	PM	PS	Z	PS	PM	Z
PM	Z	PB	PS	PS	PB	PB	PS
PB	PS	PB	PM	PM	PB	PB	PS

3) Fuzzy reasoning

Take K_P as an example, as calculated by the fuzzy inference synthesis rule:

Fuzzy relations:

$$R = U_{ij}\left(e_i \times ec_j\right) \times K_{Pij}$$

$$K_P = \left(e \times ec\right) \cdot R$$

$$\mu_{K_P}\left(K_P\right) = \vee\left[\mu_R\left(e, ec, K_P\right) \wedge \left(\mu_e\left(e\right) \wedge \mu_{ec}\left(ec\right)\right)\right]$$

4) Defuzzification

The maximum subordinative degree method is adopted for defuzzification.

5) Simulation results

In the simulation of MATLAB, there are dedicated Fuzzy modules, which can be simulated only by inputting the designed parameters. Chart of Fuzzy rule is shown in Figure 3.

Response comparison during the load response is shown in Figure 4.

When the system load suddenly changes under the fuzzy PID control, the overshoot generated is about 12 V and the system transition time is less than 0.1 s; and when the system load suddenly changes under the traditional PID control,

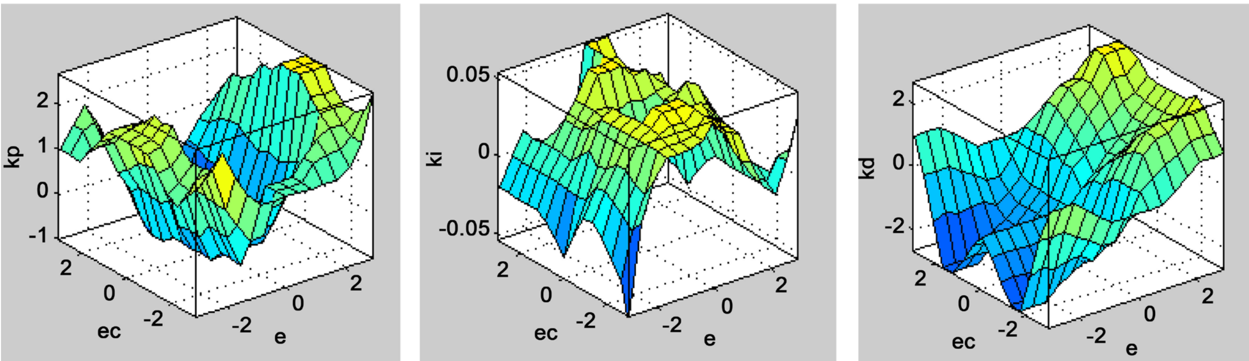

Figure 3. Chart of fuzzy rule.

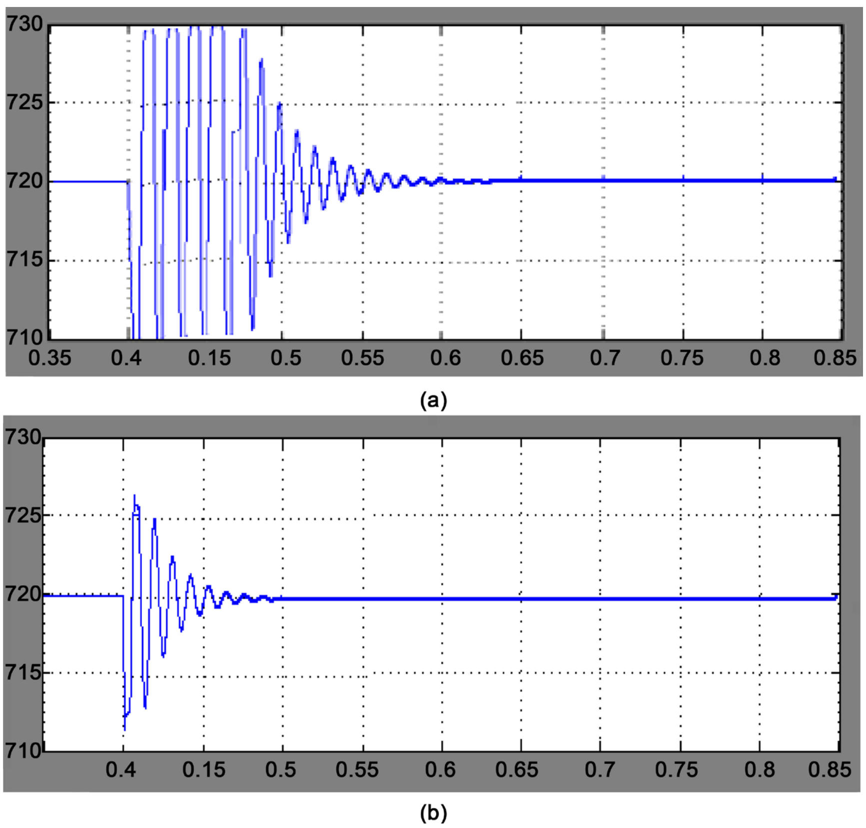

Figure 4. (a) Voltage of PID control with interference; (b) Voltage of Fuzzy-PID control with interference.

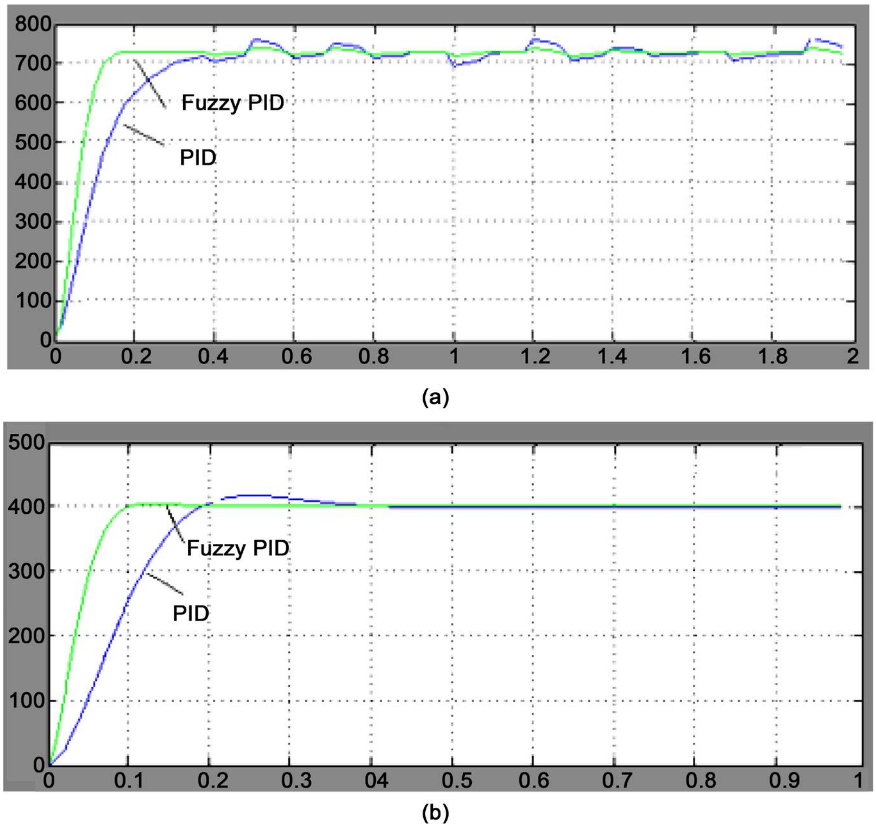

Figure 5. (a) Output voltage with random interference 1; (b) Output voltage with random interference 2.

the overshoot generated is about 20 V and the system transition time is about 0.25 s. It can be seen from the results that when the load suddenly changes, the fuzzy PID control effect is significantly better than the traditional PID control.

When the interference occurs, the fuzzy PID can make quick adjustment to ensure a stable charging voltage. Comparison of the anti-interference capability is shown in Figure 5.

5. Simulation Results and Analysis

The charging process and charging method of the battery are analyzed in this paper, combined with the latest research results and simulation experiments. A fuzzy PID controller is designed to meet the requirement of battery charging control. The simulation results show that the output of the fuzzy PID controller can be quickly returned to the setting value when the setting value changes. The overshoot of fuzzy PID controller is very small, and oscillation phenomenon is rare. The fuzzy PID controller, which has improve rapidity and effectiveness of battery charging, has better control effect than PID control.

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