BIDIRECTIONAL DC-DC CONVERTER WITH OUTER LOOP VOLTAGE BASED ON FUZZY PID CONTROL

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ABSTRACT

This paper introduces the Bidirectional DC-DC Converter with Outer Loop Voltage Based on Fuzzy PID Control. Since the traditional PID controller cannot better balance the dynamic and static performance problems, we took Boost converter as an example and proposed a double closed-loop control system with the outer voltage loop based on fuzzy PID control and the inner voltage loop using PI control in view of the fact that in fuzzy control, it is unnecessary to establish the accurate mathematical model of the controlled object. And then we designed a bidirectional DC-DC converter with the outer loop voltage using fuzzy PID control. A Boost simulation model was established in Matlab/Simulink. The contrastive simulation experiments show that compared with the traditional PID control methods, the response speed and the output voltage ripple of the bidirectional DC-DC converter are greatly reduced. It means that the proposed fuzzy PID control on the outer loop voltage can solve the nonlinear problems of the bidirectional DC-DC converter, and represents an emerging trend in physical sciences and applied sciences as well.

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INTRODUCTION

In recent years, with the rapid development of new energy technology, bidirectional DC-DC converter has been widely used in the new energy vehicles. bidirectional DC-DC converter is a kind of strongly nonlinear system. How to make the converter system work steadily and fast is a hot research area[1-3].

With the development of modern control theory, nonlinear control has been widely used in the control of power electronic converters, such as the sliding mode control, feedback linearization, passive control, neural network control and fuzzy control. Literature [4] analyzes the nonlinear characteristics of traditional converter and bidirectional DC-DC converter, puts forward the feedback linearization and high-order sliding mode control to solve the nonlinear problems of bidirectional DC-DC converters and traditional converters. Literature [5] is a nonlinear problem for the bidirectional DC-DC converter, combined with the advantages of sliding mode control and sliding mode variable structure controller, using both switch control method, obtained the good robustness and rapidity.

Although the above methods can better solve the problem of nonlinear system, the structure of controller is too complex, difficult to practice. Based on the advantages of fuzzy control in solving nonlinear problems, the system uses fuzzy PID control voltage outer loop and PI control current inner loop, which constitutes voltage and current double closed loop control. Voltage loop control keeps the output voltage in a timely manner to track the given value, current loop control can effectively reduce the peak and ripple of the output current, improve the response speed.

TOPOLOGICAL STRUCTUREAND WORKING PRINCIPLE

The topology of the bidirectional DC-DC converter has a lot of kinds, compared with other bidirectional DC-DC converter, bidirectional half-bridge DC-DC converter has small voltage and current stress, and use less number of inductance, so as to reduce the cost and volume. After using the method of multiple technology, it can effectively reduce the input and output current ripple, thereby reduce the design difficulty of inductance. The most important is that the multiple design can achieve a wide voltage output, this is a big advantage for the charging and discharging performance of hybrid electric vehicle[6-7],so this article using the two phase interleaved bidirectional DC-DC converter to meet the requirements of the hybrid power conversion device. Figure 1 is the topology of the two phase interleaved bidirectional DC-DC converter.
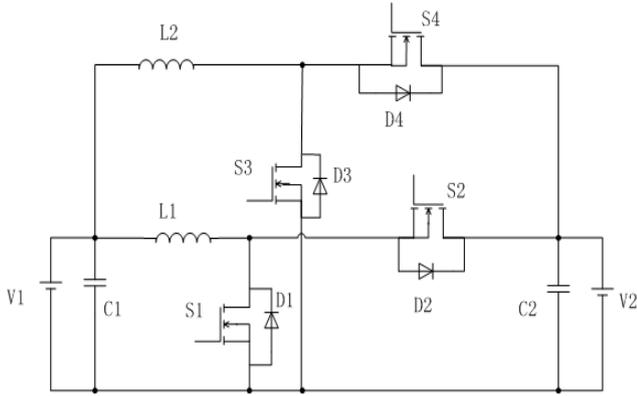
Fig. 1 Topology of the two phase interleaved bidirectional DC-DC converter

When the hybrid electric vehicle starts or accelerates, the two phase interleaved bidirectional DC-DC converter works in Boost mode, the energy flows from V_1 to V_2, switch tube S_1, S_3 stagger work, switch tube S_2, S_4 does not work, and its reverse parallel diode D_2, D_4 are the fly-wheel diode.

When the hybrid electric vehicle stops or slows down, the two phase interleaved bidirectional DC-DC converter works in Buck mode, the energy flows from V_2 to V_1, switch tube S_2, S_4 stagger work, switch tube S_1, S_3 does not work, and its reverse parallel diode D_1, D_3 are the fly-wheel diode.

SYSTEM STRUCTUREAND CONTROLLER DESIGN

Control System Structure

The two phase interleaved bidirectional DC-DC converter uses voltage and current double closed loop control structure. According to the deviation between the voltage setting and the output voltage, the voltage controller adjusts the current setting in real time, the current controller controls PWM signal and the output is always followed by a given, stable output voltage and current[8-9]. In the process of booster, the dc voltage ripple can be reduced effectively, ensure that drive performance; in the process of decompression, the voltage output of the converter is steady, and the effect of the current ripple on the battery charging performance is reduced.

The traditional double closed loop control uses the PI controller to adjust the switch device. However, due to the nonlinear characteristics of the bidirectional DC-DC converter, control often can not reach the expected effect. he voltage outer loop uses fuzzy PID control to modify the parameters of the controller, which can improve the adaptive ability of the nonlinear system. The block diagram of the control structure is shown in figure 2.
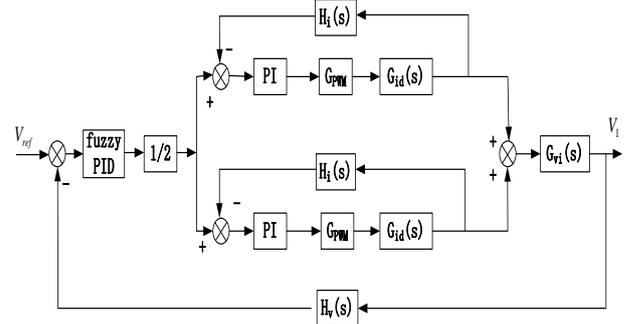

Fig. 2 Control block diagram of the system

Design of Fuzzy PID Controller

Fuzzy PID control is a kind of intelligent control method, using the basic theory and method of fuzzy mathematics, the rules of the condition and operation represented by fuzzy sets, and the fuzzy control rules of the relevant information is stored into the computer knowledge base, then according to the actual situation of the control system, the computer uses fuzzy inference to set of PID control parameters online, so as to achieve the best adjustment of PID parameters[10]. The input of the fuzzy controller is error e and error change ec, to achieve the purpose of real-time correction K_P, K_I, K_D, make the PID parameter can be adjusted continuously with the change of system structure and the actual situation. Figure 3 is a block diagram of fuzzy PID.
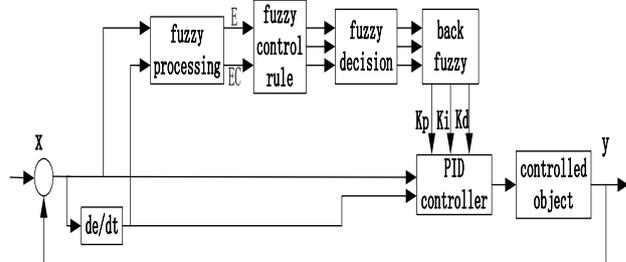

Fig. 3. Block diagram of fuzzy PID

1) Selection of Input and Output Variables

Output voltage deviation and deviation change rate of the bidirectional DC-DC converter is used as the input variable of the fuzzy controller, the parameters of the PID controller K_P, K_I, K_D are modified by the fuzzy controller in real time. The correction formula is as follows:

$$\begin{cases} K_P = K_P^{'} + \Delta K_P \\ K_I = K_I^{'} + \Delta K_I \\ K_D = K_D^{'} + \Delta K_D \end{cases} \quad (1)$$

2) Determination of Fuzzy Rules

The fuzzy subset of fuzzy controller input error e and error change rate ec is:{NB, NM, NS, ZO, PS, PM, PB}, the domain is defined as {-3, -2, -1, 0, 1, 2, 3}; Output variable fuzzy subset of ΔK_P, ΔK_I, ΔK_D are as

follows:{NB, NM, NS, ZO, PS, PM, PB}, respectively defined the domain ΔK_P={-0.3, -0.2, -0.1, 0, 0.1, 0.2, 0.3}, ΔK_I={-0.06, -0.04, -0.02, 0, 0.02, 0.04, 0.06}, ΔK_D={-3, -2, -1, 0, 1, 2, 3}. In order to facilitate the design, take the input e, ec and the output K_P, K_I, K_D membership functions are based on triangle function[11]. Fuzzy rule is "if… then…" conditional statement[12]. The specific fuzzy control rules table is shown in table 1, table 2, table 3.

Tab. 1 fuzzy rule table of ΔK_P

ΔK_P e \ ec	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	ZO
NM	PB	PB	PM	PM	PS	ZO	ZO
NS	PM	PM	PM	PS	ZO	NS	NM
ZO	PM	PS	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	ZO	ZO	NS	NM	NM	NM	NB
PB	ZO	NS	NS	NM	NM	NB	NB

Tab. 2 fuzzy rule table of ΔK_I

ΔK_I e \ ec	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NM	NM	ZO	ZO
NM	NB	NB	BM	NM	NS	ZO	ZO
NS	NM	NM	NS	NS	ZO	PS	PS
ZO	NM	NS	NS	ZO	PS	PS	PM
PS	NS	NS	ZO	PS	PS	PM	PM
PM	ZO	ZO	PS	PM	PM	PB	PB
PB	ZO	ZO	PS	PM	PB	PB	PB

Tab. 3 fuzzy rule table of ΔK_D

ΔK_D e \ ec	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	ZO
NM	PB	PB	PM	PM	PS	ZO	ZO
NS	PM	PM	PM	PS	ZO	NS	NM
ZO	PM	PS	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	ZO	ZO	NS	NM	NM	NM	NB
PB	ZO	NS	NS	NM	NM	NB	NB

SIMULATION RESULTS ANALYSIS In order to verify the effectiveness of the controller, the boost model of two phase interleaved bidirectional DC-DC converter is established by using Fuzzytoolbox and "SimPowerSystems"toolbox in Matlab/simulink. Figure 4 is the Boost model simulation model.
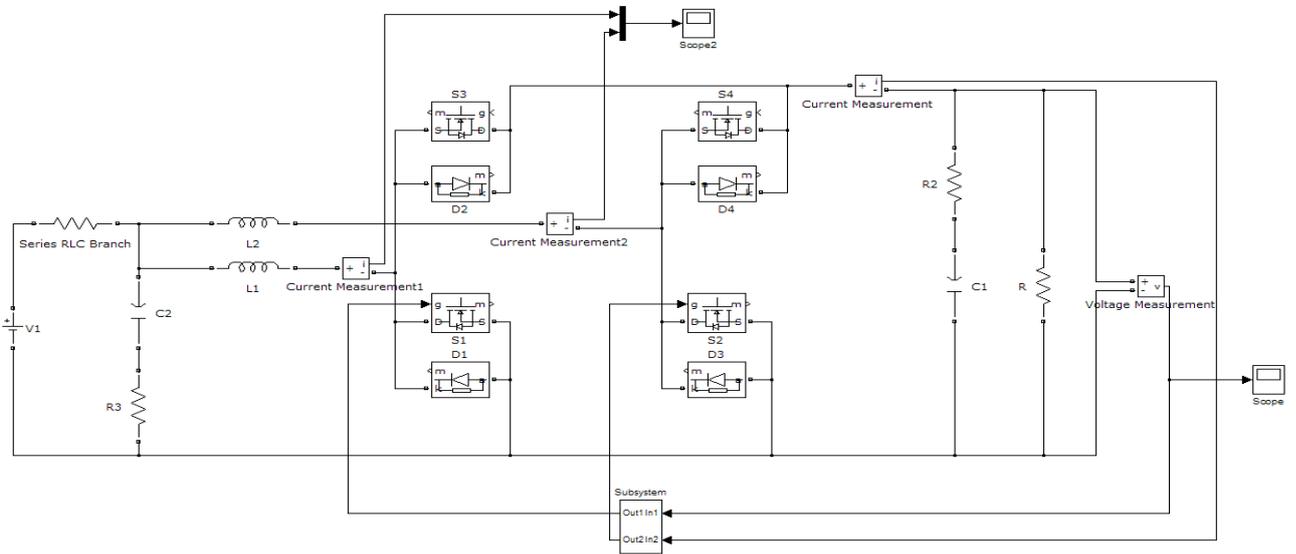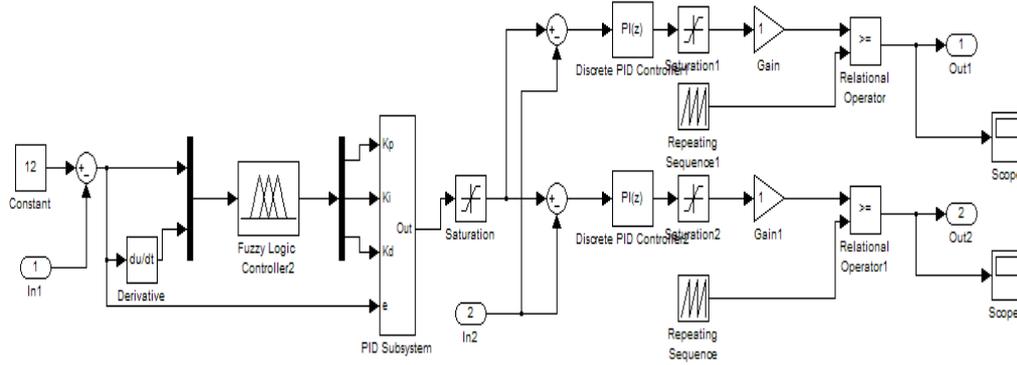

Fig. 4 Boost simulation model

Fig. 5 Control subsystem simulation model

In figure 5, the control subsystem will use a fuzzy PID control voltage loop and two PI control current loop structure. After regulator adjusting voltage outer loop, the output voltage will be the current inner ring of the given value compared with the inductance of the converter current value, so as to control the output voltage pulse.
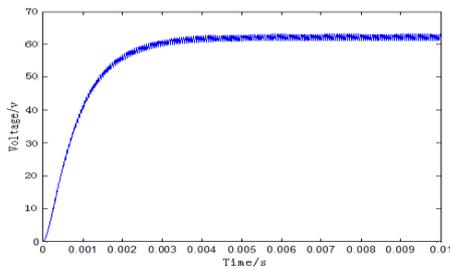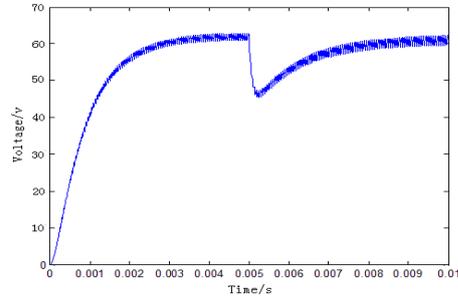

(a) PI control
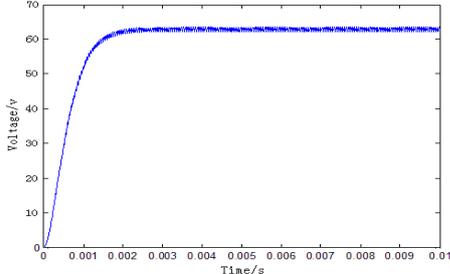
(b) fuzzy PID control
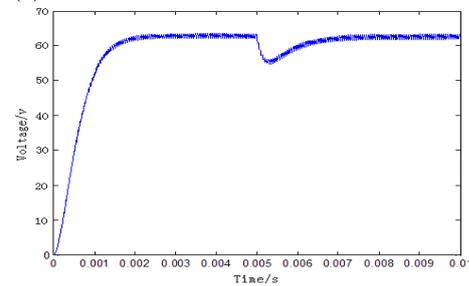Fig. 6 Voltage output waveform under Boost mode

Figure 6 is the simulation output voltage oscillogram of PI control and fuzzy PID control in Boost mode. It can be seen that the output voltage ripple of the bidirectional DC-DC converter is improved after fuzzy PID compensation, and the output voltage response speed is improved, the steady-state error is negligible.

In order to simulate the case of sudden start and acceleration of hybrid electric vehicle, it can be realized by using the load. t=0.005s, suddenly reduce load, used to simulate the vehicle speed running. The simulation results as shown in figure 7, when the system uses fuzzy PID control, the amplitude change

of the output voltage is small, and equilibrium is reached within a relatively short time, shows that the fuzzy PID control system has the characteristics of stability and fast dynamic response.

(a) PI control

(b) fuzzy PID control
Fig. 7 Output voltage waveform when the load is reduced under Boost mode

CONCLUSION
The paper takes the Boost converter as an example , achieves the design of a fuzzy PID controller, and accomplishes matlab simulation verification experiment. Experimental results shows: outer voltage loop adopts fuzzy PID control have solved the problem of nonlinear system. Compared with the traditional PI control, the fuzzy PID control of the outer voltage loop can effectively improve the response speed of the two phase interleaved bidirectional DC-DC converter, and reduce the output voltage ripple.

ACKNOWLEDGMENTS

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