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Analysis of Voltage Mode Buck Converter Based on PID Control Characteristic

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***Abstract*—Aiming at the strongly nonlinear behavior of Buck converter, the state space average method is used to model Buck converter, and the small signal model and open-loop transfer function are obtained. According to the open-loop transfer function, PID controller is designed. For the shortcoming of the traditional PID controller which cannot change the control parameters dynamically according to the change of the system's operating point, the fuzzy algorithm is introduced into the PID controller. To model PID controller and fuzzy PID controller, MATLAB/Simulink is used. It can be shown from simulation results that fuzzy PID control has better dynamic control performance and can be used in other converters.**

Keywords—Buck converter; State space average method; PID controller; Fuzzy algorithm

I. INTRODUCTION

The switching power supply can make the output of the system to be a stable value by controlling the on and off time ratio of the switch. Buck, Boost, Buck-Boost and Cuk are the common structures of DC-DC converters [1,2]. Buck converter is selected as the research object in this paper. Due to the existence of inductance and capacitance inside Buck converter, the circuit produces nonlinear phenomena which affect the power supply performances [3]. In this paper, the state space average method is used to model Buck converter, and the small signal model is obtained [4,5,6]. Traditional PID and fuzzy PID control methods are respectively used to control the nonlinear behaviors.

PID controller is the most common controller which uses traditional linear control method and has simple structure. However, the small signal model of switching converter will change when the operating point changes during working process, so it is difficult to achieve the desired control effect by using traditional PID controller [7,8]. Therefore, a new control method is raised. Fuzzy algorithm does not require precise control parameters and has strong adaptability to the change of converter operating point and good robustness [9,10]. In this paper, fuzzy algorithm and traditional PID control are combined to form the fuzzy PID control. The fuzzy PID controller can adjust PID parameters adaptively to keep the system stable when the load resistance changes.

II. SYSTEM DESCRIPTION MODELING

Buck converter is also known as a step-down converter, and its basic circuit diagram is shown in Fig. 1. Assuming that all the components in the circuit are ideal and no parasitic effects, the converter is in CCM state. According to the states of the switch Q and the diode D , the system can be considered as a variable structure toggles its topology. For each configuration, the corresponding equations can be listed separately. $x(t)$ is the state variable of the system, $u(t)$ is the input variable and $y(t)$ is the output variable.

Configuration 1: S on and D off

$$\begin{cases} \dot{x}(t) = A_1 x(t) + B_1 u(t) \\ y(t) = C_1 x(t) + E_1 u(t) \end{cases}, 0 < t < dTs \tag{1}$$

In the equations, $x(t)=\begin{bmatrix} i_L \\ v_C \end{bmatrix}$, $u(t)=V_{in}$, $A_1=\begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix}$, $B_1=\begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$, $C_1=\begin{bmatrix} 0 & 1 \end{bmatrix}$, $E_1=\begin{bmatrix} 0 \\ 0 \end{bmatrix}$.

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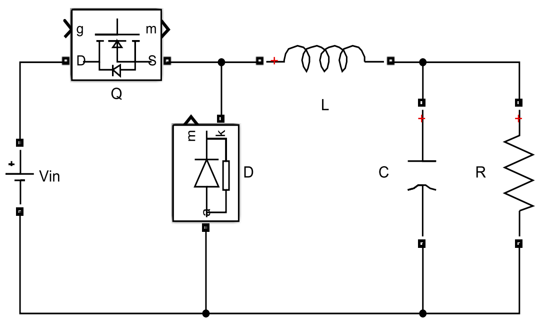

Fig1. Circuit diagram of Buck converter

Configuration 2: S off and D on

$$\begin{cases} \dot{x}(t) = A_2 x(t) + B_2 u(t) \\ y(t) = C_2 x(t) + E_2 u(t) \end{cases}, dTs < t < Ts \tag{2}$$

In the equations, $A_2 = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix}$, $B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$, $C_2 = \begin{bmatrix} 0 & 1 \end{bmatrix}$, $E_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$.

According to the state space average method, the general form of the equations of state during a period of Buck converter can be obtained:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) \\ y(t) = Cx(t) + Eu(t) \end{cases} \tag{3}$$

In the equations, $\begin{cases} A = d_1 A_1 + d_2 A_2 \\ B = d_1 B_1 + d_2 B_2 \\ C = d_1 C_1 + d_2 C_2 \\ E = d_1 E_1 + d_2 E_2 \end{cases}$, $d_1 + d_2 = 1$, d_1 is the duty cycle conducted by the switch, d_2 is the duty cycle conducted by the diode.

By decomposing the state variable into the steady state value and the small perturbation, the static operating point of the converter can be further determined, and the influence of small signal on the steady state operating point can be analyzed. Then, the above variables can be rewritten as: $x(t) = X + \hat{x}(t)$, $u(t) = U + \hat{u}(t)$, $y(t) = Y + \hat{y}(t)$, $d_1 = D_1 + \hat{d}_1(t)$, $d_2 = D_2 + \hat{d}_2(t) = 1 - D_1 - \hat{d}_1(t)$. Substituting into equation (3), the open-loop transfer function of Buck converter under ideal state can be obtained by calculation:

$$G(s) = \left. \frac{v_c(s)}{d(s)} \right|_{v_{in}(s)=0} = \frac{V_{in}}{LCs^2 + \frac{L}{R}s + 1} \tag{4}$$

III. PID CONTROLLER DESIGN OF BUCK CONVERTER

Set the input voltage of Buck converter is $V_{in} = 24V$, the reference voltage is $V_{ref} = 12V$, the inductance is $L = 350\mu H$, the capacitance is $C = 210\mu F$, the resistance is $R = 10\Omega$, the switching frequency is $f = 10kHz$. The transfer equation of the traditional PID controller is:

$$G_C(s) = K_p + K_i \frac{1}{s} + K_d s \tag{5}$$

K_p, K_i and K_d is the control coefficients of proportion, differentiation and integration respectively. The system can be controlled by adjusting these three parameters. According to the open-loop transfer function of Buck converter, these three parameters are set to $K_p = 115, K_i = 7, K_d = 0.03$, and substituted into equation (5) to obtain the transfer function of PID controller. Before adding PID compensation link and after adding PID compensation link, the Bode diagrams of Buck converter are drawn in MATLAB in the same figure. As shown in Fig. 2, PID controller has obvious compensation effect.

IV. FUZZY PID CONTROLLER DESIGN OF BUCK CONVERTER

Uncertain changes will occur in the actual working process of the converter. The control parameters in the traditional PID control method are fixed and cannot be changed adaptively to meet the corresponding circuit conditions, resulting in poor control effect. Aiming at this phenomenon, fuzzy PID controller is proposed. In order to construct fuzzy PID controller, fuzzy algorithm is added to the traditional PID controller. The input of fuzzy PID controller is error signal e and error rate signal, the output is the change of proportional control coefficient ΔK_p, differential control coefficient ΔK_i and integral control coefficient ΔK_d. The basic structure of the fuzzy PID controller is shown in Fig. 3. The principle of the fuzzy algorithm is to detect the error signal and the error rate signal and to output signals by calculating with fuzzy rules. The PID controller coefficients can be dynamically adjusted by output signals.

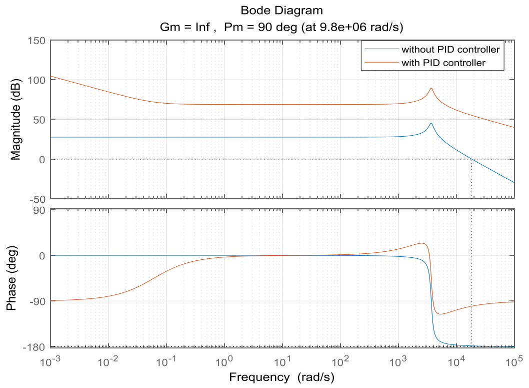

Fig.2 Comparison bode diagram

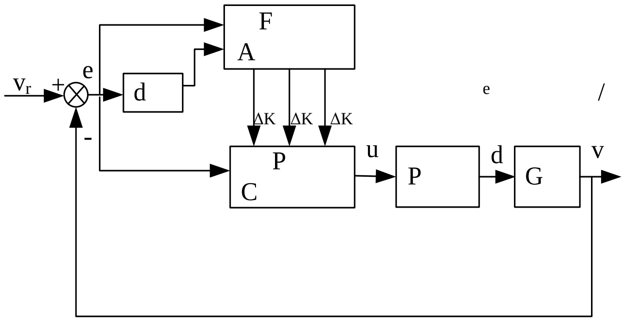

Fig.3 Fuzzy PID controller

In order to prove the superiority of fuzzy PID control method over PID control method, based on MATLAB/Simulink environment, the system simulation schematic diagram was built for verification and comparison. The comparisons of the inductive current and output voltage of Buck converter between PID controller and fuzzy PID controller were shown in Fig. 4 and Fig. 5 respectively. It can be seen from the figures, the overshoot of PID controller is larger than that of fuzzy PID controller, while the response speed is slower and the output voltage and current ripple are larger.

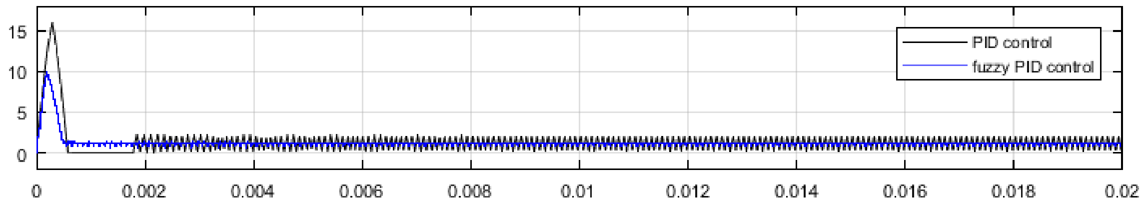

Fig.4 Inductive current comparison graph between PID control and fuzzy PID control

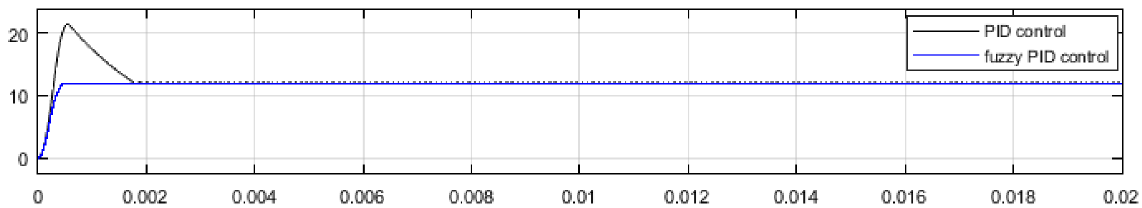

Fig.5 Output voltage comparison graph between PID control and fuzzy PID control

In order to enhance the advantage of the fuzzy PID control method, a resistor $R = 3\Omega$ is connected in parallel to the load resistor when the simulation time is $0.01s$. Fig. 6 and Fig. 7 are drawn in MATLAB by simulation with Simulink. As can be seen from Fig. 6, under the PID control method, the inductance current has a significant mutation, and the ripple of the inductance current becomes significantly larger. However, under the fuzzy PID control method, the inductance current is essentially unchanged, and the output ripple is significantly smaller than the current ripple under the PID control method. As can be seen from Fig. 7, under the fuzzy PID control, the output voltage remains almost unchanged in the process of load resistance value mutation. But under the PID control, at $t = 0.01s$, it is obvious that the output voltage curve generates shake, and it takes a period of time to recover stability. In conclusion, compared with the traditional PID control method, the fuzzy PID control method is more adaptable to the change of load resistance and has better dynamic control effect.

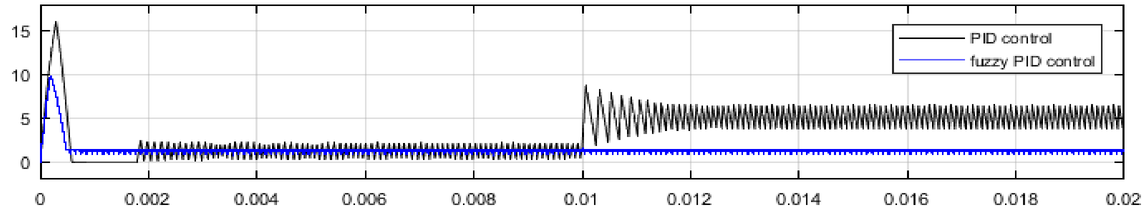

Fig.6 Comparison of inductive currents when load resistance changes

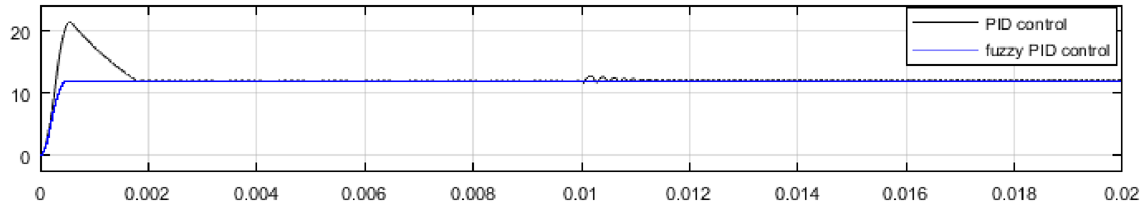

Fig.7 Comparison of output voltages when load resistance changes

V. SUMMARY

Aiming at Buck converter of DC-DC converter, fuzzy algorithm and PID controller were combined in this paper. Fuzzy PID control method can enhance the robustness of the control system for the traditional PID controller cannot flexibly change parameters when the working point of the converter changes. The advantages of fuzzy PID controller that smaller overshoot and stronger robustness are shown in experimental results. When the operating point of the system changes, the output voltage and inductive current of the Buck converter remain basically unchanged under the action of the fuzzy PID controller, indicating that the fuzzy PID control has better dynamic control performance.

REFERENCES

[1] S. Muley, S. Wankhade, Sliding mode controller & conventional controller for boost Converter, IJEDR, Vol. 5 (2017) No.2, p1044-1048.

[2] A.T.L. Lee, J.K.O. Sin, P.C.H. Chan, Adaptive high-bandwidth digitally controlled buck converter with improved line and load transient response, IET Power Electronics, Vol. 7 (2014) No.3, p515-526.

[3] Y.A. Turki, A.E. Aroudi, K. Mandal, D. Giaouris, A. Abusorrah, M.A. Hindawi and S. Banerjee, Non-averaged control-oriented modeling and stability analysis of DC-DC switching converters, International Journal of Circuit Theory and Applications, Vol. 46 (2018) No.3, p565-580.

[4] P. Robert, A. Matteo, U. Christoph, M. Stefano and H. Mario, Modeling, control, and implementation of DC-DC converters for variable frequency operation, IEEE Transactions on Power Electronics, Vol. 29 (2014) No.1, p287-301.

[5] F.Q. Wang, X.K. Ma, Transfer function modeling and analysis of the open-loop Buck converter using the fractional calculus, Chinese Physics B, Vol. 22 (2013) No.3, p236-243.

[6] E. Babaei, H.M. Mahery, Mathematical modeling and analysis of transient and steady states of buck dc-dc converter in DCM, Compel-the International Journal for Computation and Mathematics in Electrical and Electronic Engineering, Vol.32 (2013) No.1, p337-263.

[7] Y.W. Yang, J.L. Liu, Bifurcation of proportion-integration-based voltage-mode Buck converter, Acta Physica Sinica, Vol.63 (2014) No.4, p40502-040502.

[8] M.G. Kim, Proportional-Integral (PI) compensator design of duty-cycle-controlled buck LED driver, IEEE Transactions on Power Electronics, Vol.30 (2015) No.7, p3852-3859.

[9] A.E. Khateb, N.A. Rahim, J.Selvaraj and M.N. Uddin, Maximum power point tracking of single-ended primary-inductor converter employing a novel optimisation technique for proportional integral derivative controller, IET Power Electronics, Vol.6 (2013), No.6, p1111-1121.

[10] M. Condon, B. Hayes, Control of limit cycles in buck converters, Compel-the International Journal for Computation and Mathematics in Electrical and Electronic Engineering, Vol.33 (2014) No.4, p1448-1461.