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Control Strategy for Boost Converter based on Passive Sliding Control Mode

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Abstract—Passive sliding mode control strategy is designed based on passive control with energy-shaping and damping injection for Boost converter. The control structure has double close loops. The expected output current is determined by sliding mode controller in outer voltage loop and the switch function control is determined by passive control in inner current loop. Simulation results reveal that the passive sliding mode control strategy has good dynamic and static performances and anti-disturbance ability.

Keywords—Boost converter; Passive control; Sliding mode control

1. INTRODUCTION

DC/DC converters are widely used in space, communications and other areas for their advantages of small size, low cost, high reliability, etc. Recently, DC/DC converters are used in renewable energy such as photovoltaic generation and wind power generation. As DC/DC converter is a strong nonlinear system, nonlinear control strategy such as sliding mode variable structure method, neural network control method and adaptive control method are suitable to use. Traditional feedback control strategy usually considers the system performances of stability and tracing property but ignores the relativity of the energy and physical characteristics of DC/DC converter [1]. Control system can keep stable if feedback controller constructed according to passivity-based theory which is a nonlinear control system inherent. The passivity-based control strategy has advantages of simple control method, good dynamic performance and lower energy loss [2]. This paper adopts double close loops to control DC/DC boost converter with sliding mode controller as outer voltage loop and passivity-based controller as inner current loop. Simulation results reveal that the system has good dynamic and static performances.

2. DC/DC CONVERTER MODEL

DC/DC boost converter is shown in Fig.1[3]. The converter operates in current continuous mode (CCM) as a switch period includes two switch states for the transistor in on or off state. The boost converter is controlled by adjust duty cycle (*d*) of PWM.

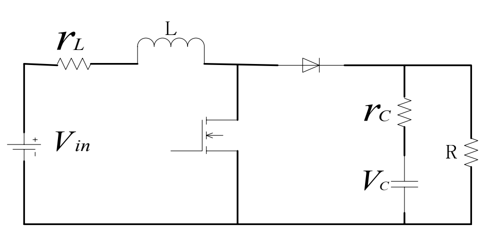

Fig.1 Boost Converter

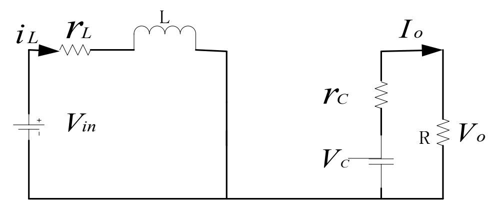

Fig.2 Boost Converter as transistor is on

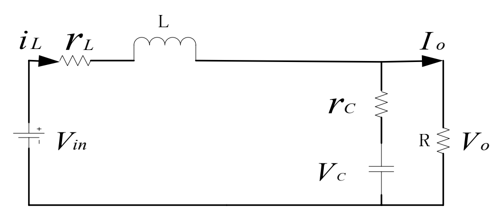

Fig.3 Boost Converter as transistor is off

Fig.2 shows the converter as transistor is on and the corresponding state equations are Equ.(1):

$$\begin{cases} L\dfrac{di_L}{dt} = V_{in} - r_L i_L \\ C\dfrac{dV_C}{dt} = -\dfrac{V_o}{R} \end{cases} \tag{1}$$

Fig.3 shows the converter as transistor is off and the corresponding state equations are as Equ.(2):

$$\begin{cases} L\dfrac{di_L}{dt} = V_{in} - r_L i_L - V_o \\ C\dfrac{dV_C}{dt} = i_L - \dfrac{V_o}{R} \end{cases} \tag{2}$$

Where, i_L is current flow through the inductor. V_C is voltage across the capacitor. V_{in} is input voltage. V_o is output voltage.

According to Equ.(1), Equ.(2) and d, state equation and output equation of boost converter are as Equ. (3) and Equ.(4).

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$$\begin{bmatrix}\dot{i}_L\\ \dot{V}_C\end{bmatrix}=\begin{bmatrix}-[\frac{n}{L}+\frac{r_c}{L(1+\frac{r_c}{R})}(1-d)] & \frac{R}{L(R+r_c)}(1-d)\\ \frac{R}{C(R+r_c)}(1-d) & \frac{1}{C(R+r_c)}\end{bmatrix}\begin{bmatrix}i_L\\ V_C\end{bmatrix}+\begin{bmatrix}\frac{1}{L}\\ 0\end{bmatrix}V_{in} \tag{3}$$

$$V_O=\begin{bmatrix}0 & \frac{R}{R+r_c}\end{bmatrix}\begin{bmatrix}i_L\\ V_C\end{bmatrix} \tag{4}$$

3. PASSIVE SLIDING MODE CONTROLLER DESIGN

Fig.4 is control system structure of passive sliding mode control. The control system is composed of an outer voltage loop and an inner current loop. The outer loop control is employed by sliding mode controller to obtain the expected output current. Passive controller is designed in inner loop to control switch function.

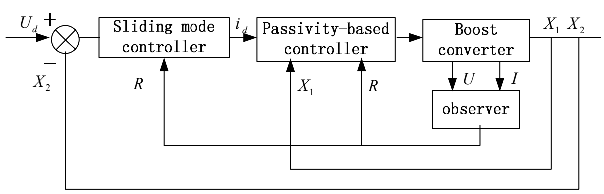

Fig.4 Control system structure of passive sliding mode control

3.1 Design of passive controller

Equ. (3) can be expressed as Equ.(5):

$$D\dot{X}+(1-d)JX+RX=E \tag{5}$$

Where:

$$D=\begin{bmatrix}L & 0\\ 0 & C\end{bmatrix}\ R=\begin{bmatrix}r_L & 0\\ 0 & \frac{1}{R+r_C}\end{bmatrix}\ E=\begin{bmatrix}V_{in}\\ 0\end{bmatrix}\ X=\begin{bmatrix}i_L\\ V_C\end{bmatrix}$$

$$J=\begin{bmatrix}\frac{r_c}{1+\frac{r_c}{R}} & \frac{1}{1+\frac{r_c}{R}}\\ -\frac{r_c}{1+\frac{r_c}{R}} & 0\end{bmatrix}$$

Passive controller is designed by using energy----shaping and damping injection method. Suppose the expected stat variable is $X_d=(I_d\quad U_d)^T$, and the error state variable is $X_e=X-X_d$, then dynamic error equation can be get from Equ. (5) and expressed as Equ. (6).

$$D\dot{X}_e+(1-d)JX_e+RX_e=E-(D\dot{X}_d+(1-d)JX_d+RX_d) \tag{6}$$

Adding damping Equ.(7) into Equ.(6) will get Equ. (8).

$$R_dX_e=(R+R_e)X_e\quad R_e=\begin{bmatrix}R_1 & 0\\ 0 & 0\end{bmatrix}\quad R_1>0 \tag{7}$$

$$\begin{aligned}&D\dot{X}_e+(1-d)JX_e+R_dX_e\\ &=E-(D\dot{X}_d+(1-d)JX_d+RX_d-R_eX_e)\end{aligned} \tag{8}$$

Suppose the right-hand side of Equ.(8) is zero, that means:

$$E=D\dot{X}_d+(1-d)JX_d+RX_d-R_eX_e \tag{9}$$

Then $D\dot{X}_e+(1-d)JX_e+R_dX_e=0$ (10)

Refers to Lyapunov energy function as Equ. (11),

$$V=\frac{1}{2}X_e^{\mathrm{T}}DX_e>0,\ \forall X_e\neq 0,\ D=\begin{bmatrix}L & 0\\ 0 & C\end{bmatrix} \tag{11}$$

Then

$$\dot{V}=X_e^{\mathrm{T}}D\dot{X}_e=X_e^{T}(-(1-d)JX_e-(R+R_e)X_e)<0 \tag{12}$$

From the above deducing, conclusion can be get that the error "zero" is the inherent stable point of the system if the right-hand side of Equ. (8) is zero. Expand Equ. (9) as Equ. (13)and Equ.(14):

$$L\dot{I}_d+\frac{r_c}{1+\frac{r_c}{R}}(1-d)I_d+\frac{1}{1+\frac{r_c}{R}}(1-d)U_d+nI_d-R_1(I-I_d)=V_{in} \tag{13}$$

$$C\dot{U}_d-\frac{r_c}{1+\frac{r_c}{R}}(1-d)I_d+\frac{1}{R+r_c}U_d=0 \tag{14}$$

Control rule d(t) can be get be get from Equ.(13) and Equ.(14).

$$d(t)=1-\frac{V_{in}-r_LI_d+R_e(I-I_d)}{\frac{r_c}{1+\frac{r_c}{R}}I_d+\frac{1}{1+\frac{r_c}{R}}U_d} \tag{15}$$

3.2 Design of sliding mode controller

The outer loop controls output voltage to tend to expected voltage. In order to accelerate the convergence speed of output voltage, proportional integral regulator is used to design sliding surface[4]. Output of the outer loop is current reference of the passive control, so sliding surface is selected as Equ. (16):

$$S=C\beta(u_d-x_2)+x_1+\int(u_d-x_2) \tag{16}$$

If S=0, sliding motion makes output current equal to expected output current as Equ. (17).

$$x_1=C\beta(x_2-u_d)-\int(u_d-x_2) \tag{17}$$

Ignoring resistance of inductance and capacitor, state equation of ideal boost converter Equ.(3) can be written as Equ. (18):

$$\begin{bmatrix}\dot{i}_L\\ \dot{V}_C\end{bmatrix}=\begin{pmatrix}0 & -\frac{1}{L}\\ \frac{1}{C} & -\frac{1}{RC}\end{pmatrix}\begin{pmatrix}i_L\\ V_C\end{pmatrix}+\begin{pmatrix}\frac{V_C}{L}\\ -\frac{i_L}{C}\end{pmatrix}u+\begin{pmatrix}\frac{E}{L}\\ 0\end{pmatrix} \tag{18}$$

Where u is the switch state variables, defined as Equ. (19):