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A Comparison of Ideal and Non Ideal Model of DC-DC Buck Converter with PI Controller Using MATLAB Simulation

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Abstract

This paper presents the comparison between the ideal and non ideal model of DC/DC Buck Converter with PI controller. DC/DC converter is extensively analyzed by the researchers because DC/DC converter is the most widely used converter topology. To implement the controller we need a circuit model of the Buck converter. Non ideal model of Buck converter is different from the ideal one in the sense that non ideal model includes the parasitic resistances in its different elements such as inductor capacitor diode and switch. In this paper a SIMULINK model is created for both and their behavior are tested.

Keywords:— *PI Controller, Buck converter, ideal and Non-ideal model, SIMULINK*

I. Introduction

DC/DC Buck converter is used extensively in DC motor drives, renewable energy system, electric vehicle, medical equipments and many more. Buck converter is basically used where we need to lower the input DC voltage. This converter converts the high level DC voltage signal to low level stabilized DC voltage signal. Mathematical modeling of DC/DC Buck converter is an important aspect. There are various techniques available for modeling of DC/DC converter such as state space averaging method (SSA method), signal flow graph technique (SFG), circuit averaging technique etc. State space averaging method is used here to get the transfer function of both the model. State space averaging method is widely used due to its ease of implementation. Further a suitable PI controller is implemented in both the model and their performance is tested.

Different elements of a Buck converter such as inductor, capacitor, diode and switch have internal resistances with them, which make the Buck converter a non-ideal one. These resistances have been included in modeling of a non ideal Buck converter.

The organization of this paper is as follows. In section II mathematical model of ideal and non ideal buck converter is obtained followed by SIMULINK model in section III. Thereafter comparison of both ideal and non ideal model in section IV followed by references.

II. Mathematical Model of Ideal and Non Ideal DC-DC Buck Converter

Figure 1 illustrates the basic circuit diagram of an ideal converter and Figure 2 shows the circuit diagram of a Non-ideal DC-DC Buck converter. Both the circuits have a power MOSFET switch S, diode D_d, inductor *L*, capacitor *C,* and load resistance *R*. This is to be noted that in place of MOSFET as a switch, GTO, IGBT, BJT can be substituted, if desired. Non idealities of Buck converter, i.e. equivalent series resistance of inductor, equivalent series resistance of capacitor, resistance of switch in ON condition, forward resistance and forward voltage drop of diode, have been considered in the non ideal model.

The state space averaging technique, used here for modeling of DC/DC converter, is simple but computationally complex. For this we need state space model of converter each of its operating mode. These models are then averaged over one switching period. This gives non linear large signal averaged model. This large signal model is linearized around an operating point using small signal perturbations which gives small signal transfer function.

Both the converter is operating in continuous conduction mode. Duty cycle is D and switching frequency is f. In continuous conduction mode, a DC/DC converter operates in two modes. First when switch is on (time interval $0 < t \leq DT$) and secondly when switch is off (time interval $DT < t \leq T$).

A .For ideal model of Buck converter-

When the MOSFET is ON, the KVL and KCL equations are given as-

$$V_{in}(t) = V_o(t) + L\frac{di_L(t)}{dt} \quad ....(1)$$

$$i_L = i_C + i_o \quad ....(2)$$

$$i_L(t) = \frac{V_{in}(t) - V_o(t)}{L}t + i_L \quad ....(3)$$

When the MOSFET is off, the KVL and KCL equations are given as-

$$V_o(t) + L\frac{di_L(t)}{dt} = 0 \quad (4)$$

$$i_L = i_C + i_o \quad (5)$$

$$i_L(t) = \frac{-V_o(t)}{L}(t - \propto t) + i_L(\propto t) \quad (6)$$

Where

$$i_L(\propto t) = I_{0\,max} = \frac{V_{in}(t) - V_o(t)}{L} \propto t + I_{0\,min}$$

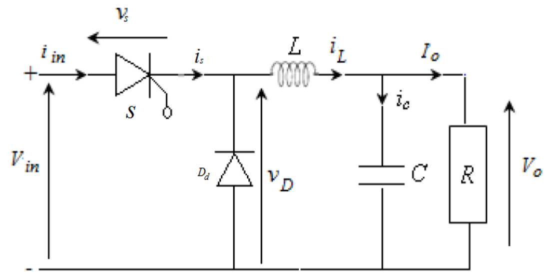

Figure 1: Circuit of ideal DC/DC Buck converter

B. For non ideal model of Buck converter-

When the MOSFET is ON, the KVL and KCL equations are given as-

$$L\frac{di_L(t)}{dt} = -(r_{sw} + r_L + \frac{r_c R}{R + r_c})\, i_L(t) - \frac{R}{R + r_c}v_c(t) + v_g(t) \quad (7)$$

$$C\frac{dv_c(t)}{dt} = \frac{R}{R + r_c}i_L(t) - \frac{1}{R + r_c}v_c(t) \quad (8)$$

$$v_0(t) = \frac{r_c R}{R + r_c}i_L(t) + \frac{R}{R + r_c}v_c(t) \quad (9)$$

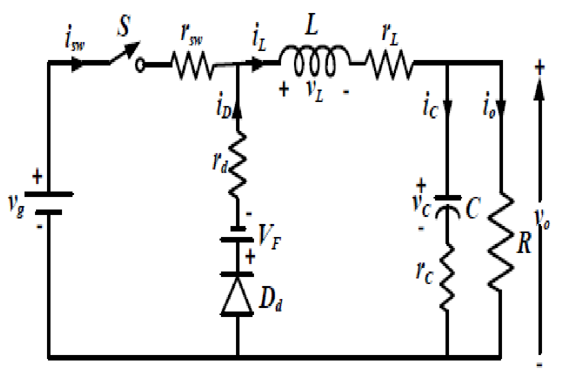

Figure: 2 Circuit of Non Ideal DC/DC Buck Converter

When the MOSFET is off, the KVL and KCL equations are given as-

$$L\frac{di_L(t)}{dt} = -\left(r_d + r_L + \frac{r_c R}{R+r_c}\right) i_L(t) - \frac{R}{R+r_c} v_c(t) + v_F \quad (10)$$

$$C\frac{dv_c(t)}{dt} = \frac{R}{R+r_c} i_L(t) - \frac{1}{R+r_c} v_c(t) \quad (11)$$

$$v_o(t) = \frac{r_c R}{R+r_c} i_L(t) + \frac{R}{R+r_c} v_c(t) \quad (12)$$

Here i_L, v_c, v_o and v_g have their standard meaning as shown in the figure 2.

Now, the transfer function of ideal and non ideal models are obtained using state space modeling technique as discussed in [2]. Due to space constraint detailed description is omitted here.

The small signal, control to output voltage i.e. duty cycle to output voltage transfer function of a ideal DC/DC Buck converter is obtained as –

$$\frac{\tilde{v}_o(s)}{\tilde{d}(s)} = \frac{\frac{V_{in}}{LC}}{s^2 + \left(\frac{1}{RC} + \frac{r_L}{L}\right)s + \left(\frac{1}{LC} + \frac{r_L}{RLC}\right)} \quad .... (13)$$

The small signal, duty cycle to output voltage transfer function of a non ideal DC/ DC Buck converter is obtained as –

$$G_{vd}(s) = \frac{\tilde{v}_o(s)}{\tilde{d}(s)} = \frac{\frac{R(V_g + V_F - (r_{sw} - r_d) I_L)}{LC(R+r_c)}(r_c Cs + 1)}{s^2 + \left(\frac{1}{L}\left(r_x + r_L + \frac{r_c R}{R+r_c}\right) + \frac{1}{C}\left(\frac{1}{R+r_c}\right)\right)s + \frac{r_x + r_L + R}{LC(R+r_c)}} \quad .....(14)$$

A suitable controller is now designed and simulated based on the above transfer function.

III. Simulink Model of Ideal and Non Ideal DC/DC Buck Converter

Based on the transfer function obtained by state space averaging technique, simulation model is created in MATLAB.

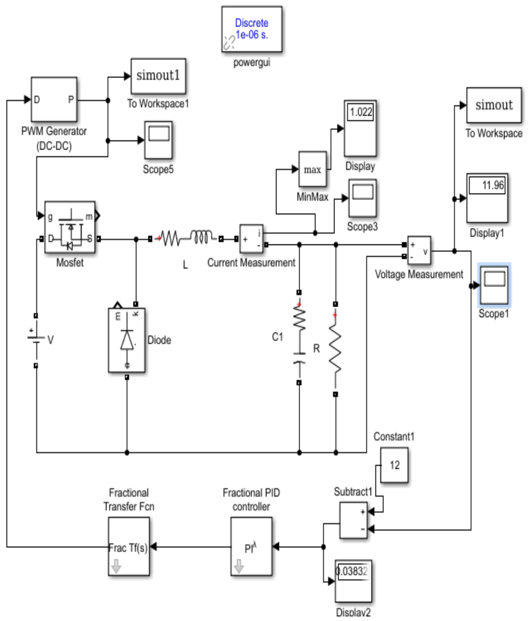

Figure 4: Model of non ideal DC/DC

Buck converter IV. Comparison of Ideal and Non Ideal DC/DC Buck Converter

Frequency response of both the model is shown below. Figure 5 shows the frequency response of ideal model while that of non ideal model is shown in Figure 6.

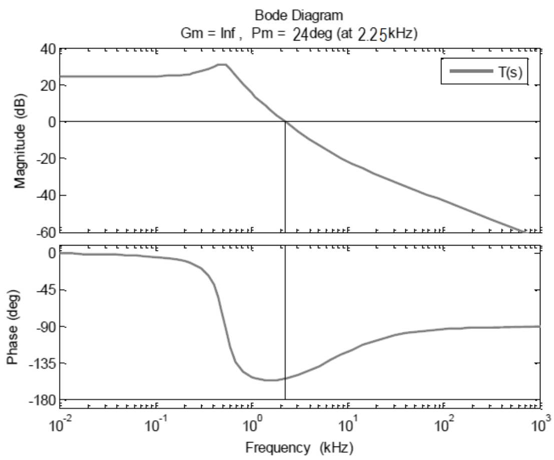

Figure 5: Frequency Response of Ideal DC/DC Buck Converter

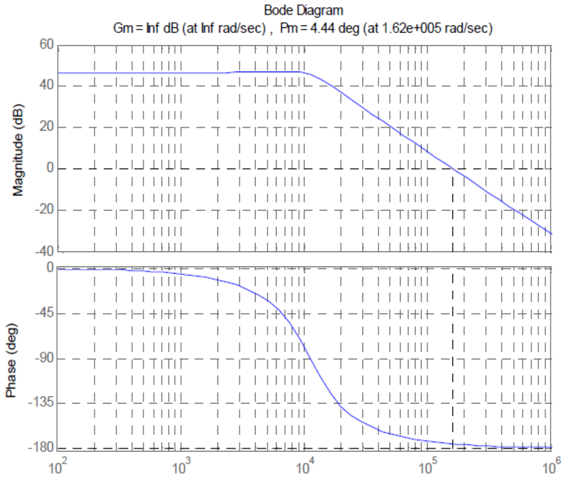

Figure 6: Frequency Response of non ideal DC/DC Buck converter

Table 1. Table of Comparison of Step Response Characteristics of DC/DC Buck Converter

S.No.	Parameters	Values of ideal Buck converter	Values of non ideal Buck converter
1	Rise time	0.06 ms	0.09 ms
2	Settling time	0.98 ms	1.02 ms
3	Peak time	0.11 ms	0.23 ms
4	Overshoot	12.59 v	13.04 v

Frequency response of ideal and non ideal Buck converter clearly shows that the gain margin in both the cases is infinite while the phase margin is 4.44 degree for ideal converter and 24 degree for non ideal converter.

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