PSPICE MODEL OF A SLIDING MODE CONTROLLED DC/DC BUCK CONVERTER

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Abstract: *The control in high performance DC/DC converters requires not only to ensure system stability but also to achieve a rapid response to sudden changes of the load, to achieve good regulation. There are basically two ways to control the switched DC/DC converters - linear and nonlinear control. Nonlinear control often produces better results but sometimes increases the complexity of the practical implementation of the scheme. Switch-mode power supplies represent a particular class of variable structure systems. Thus, they can take advantage of nonlinear control techniques developed for this class of systems. PSpice model of DC/DC buck converter controller is designed, based on the classical sliding mode control (SMC) which is a nonlinear control method.*

Keywords: *buck converter, sliding mode control (SMC), convergence factor*

1. INTRODUCTION

Switched Mode DC/DC converters are essential for efficient conversion of the battery voltage to various supply voltages, needed to perform every function with minimum power drain. With a DC/DC converter a variable battery supply voltage can be converted to an optimal supply voltage for an application.

It is known that the switching DC/DC converters are highly nonlinear plants with uncertain parameters and inevitable and significant perturbations during operation. The control in high performance DC/DC converters requires not only to ensure system stability but also to achieve a rapid response to sudden changes of the load, to achieve good regulation.

In this contribution a DC/DC buck converter controller based on conventional sliding mode control (SMC) is considered [1] – [3].

The paper is organized as follows. The analytical model of buck DC/DC converter is considered in the next section. The basics of the sliding mode control for buck DC/DC converter is considered in section 3. PSpice model of buck DC/DC converter controller based on the classical SMC is presented in section 4.

2. ANALYTICAL MODEL OF THE BUCK CONVERTER

Figure 1 shows a sliding mode controlled buck DC/DC converter [7].

The output voltage v_0 is sensed and multiplied by appropriate coefficient $\beta = R_2/(R_1 + R_2)$ that is subtracted from the reference voltage V_{ref} forms the first state variable x_1 (voltage error).

$$x_1 = V_{ref} - \beta v_0 \tag{1}$$

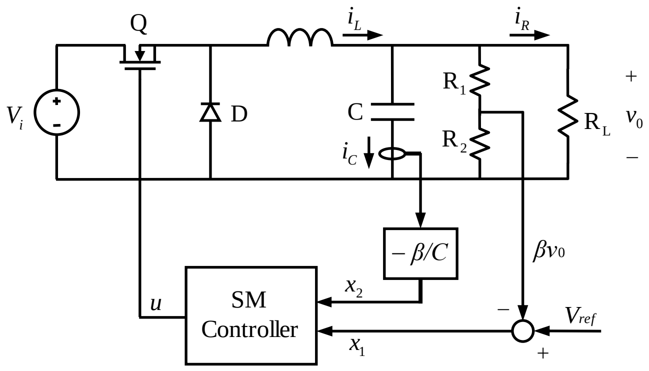

Fig. 1. Sliding Mode Controlled Buck DC/DC Converter

The rate of change of the voltage error x_2 is the second state variable:

$$x_2 = \dot{x}_1 = -\beta \frac{dv_0}{dt} = -\beta \frac{i_C}{C} \tag{2}$$

The differentiation of equation (2) with respect to time gives

$$\dot{x}_2 = -\frac{\beta}{C}\frac{di_L}{dt} + \frac{\beta}{R_L C}\frac{dv_0}{dt} \tag{3}$$

Based on the state space averaging method [4], [5] and [6] it can be written $v_L = uV_i - v_0$. Taking into account $v_L = L(di_L/dt)$, then

$$\frac{di_L}{dt} = \frac{v_L}{L} = \frac{uV_i - v_0}{L} \tag{4}$$

where u is the control input that can be 1 (switch Q is 'ON') or 0 (switch Q is 'OFF').

The substitution of equation (4) in (3) gives

$$\dot{x}_2 = -\frac{\beta}{LC}(uV_i) - \frac{1}{LC}x_1 - \frac{1}{R_L C}x_2 + \frac{V_{ref}}{LC} \tag{5}$$

3. SLIDING MODE CONTROL FOR BUCK DC/DC CONVERTER

In sliding mode control the controller employs a sliding surface or line to decide its control input states u (Figure 2), which corresponds the turning on and off the power converter's switch, to the system

$$S = \alpha x_1 + x_2 \tag{6}$$

where α is a positive quantity in some literature called a convergence factor and is taken to be

$$\alpha = \frac{1}{R_L C} \tag{7}$$

Graphically the sliding line is a straight line on the state plane with gradient α that determines the dynamic response of the system in sliding mode with a first order time constant $\tau = 1/\alpha$.

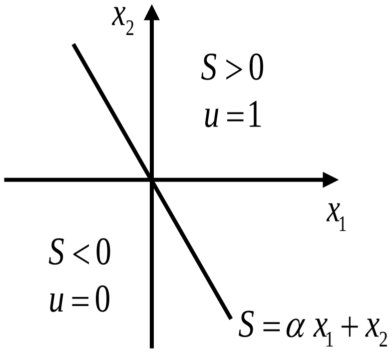

Fig. 2. A diagram of sliding mode control

To ensure that a system follows its sliding surface, a control law must be imposed

$$u = \begin{cases} 1 = 'ON' & when\ S > 0 \\ 0 = 'OFF' & when\ S < 0 \end{cases} \tag{8}$$

The existing condition for sliding mode [2], [6] is

$$\dot{S} = \begin{cases} \dot{S} < 0 & for\ S > 0 \\ \dot{S} > 0 & for\ S < 0 \end{cases} \tag{9}$$

Based on the above the expression for $\dot{S}$ is

$$\dot{S} = \alpha\dot{x}_1 + \dot{x}_2 = \alpha x_2 + \dot{x}_2 = \alpha x_2 - \frac{\beta}{LC}(uV_i) - \frac{1}{LC}x_1 - \frac{1}{R_L C}x_2 + \frac{V_{ref}}{LC} \tag{10}$$

Depending on *S* and u the state space is divided into two regions

region 1: $S > 0$ and $u = 1$

$$\dot{S}_1 = \left(\alpha - \frac{1}{R_L C}\right)x_2 - \frac{\beta}{LC}(uV_i) - \frac{1}{LC}x_1 + \frac{V_{ref}}{LC} < 0 \tag{11}$$

region 2: $S < 0$ and $u = 0$

$$\dot{S}_2 = \left(\alpha - \frac{1}{R_L C}\right)x_2 - \frac{1}{LC}x_1 + \frac{V_{ref}}{LC} > 0 \tag{12}$$

Sliding mode will only exist on the portion of the sliding line that covers both of the region 1 ($\dot{S}_1 < 0$) and region 2 ($\dot{S}_2 > 0$) [6].

From one side the speed of the system increases with increasing of α, but from other side the existing region of the sliding mode decreases that can cause an overshoot in the voltage response ($\alpha >> 1/R_L C$) [6].

4. PSPICE MODEL OF A SLIDING MODE CONTROLLED BUCK DC/DC CONVERTER

Based on the classical sliding mode control, on the above calculations and on the Simulink model of a buck DC/DC converter controller shown in Figure 3 [7], a PSpice model of the converter controller is designed and presented in Figure 4. The parameters of the converter are: V_i = 3.7V; L = 10µH; C = 50µF; R_L = 10Ω.

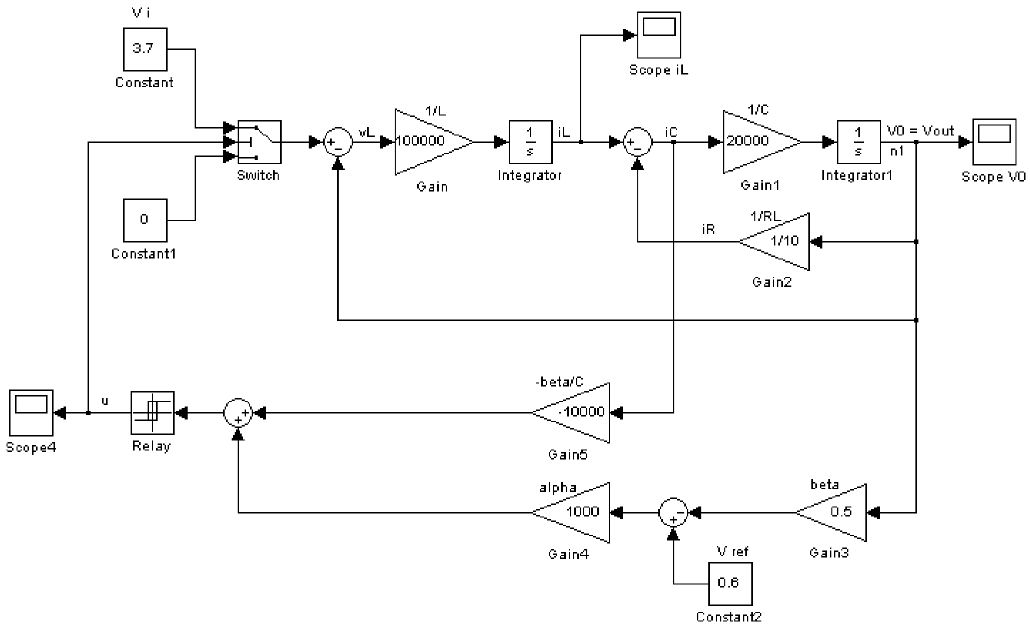

Fig.3. Simulink model of a buck DC/DC converter controller

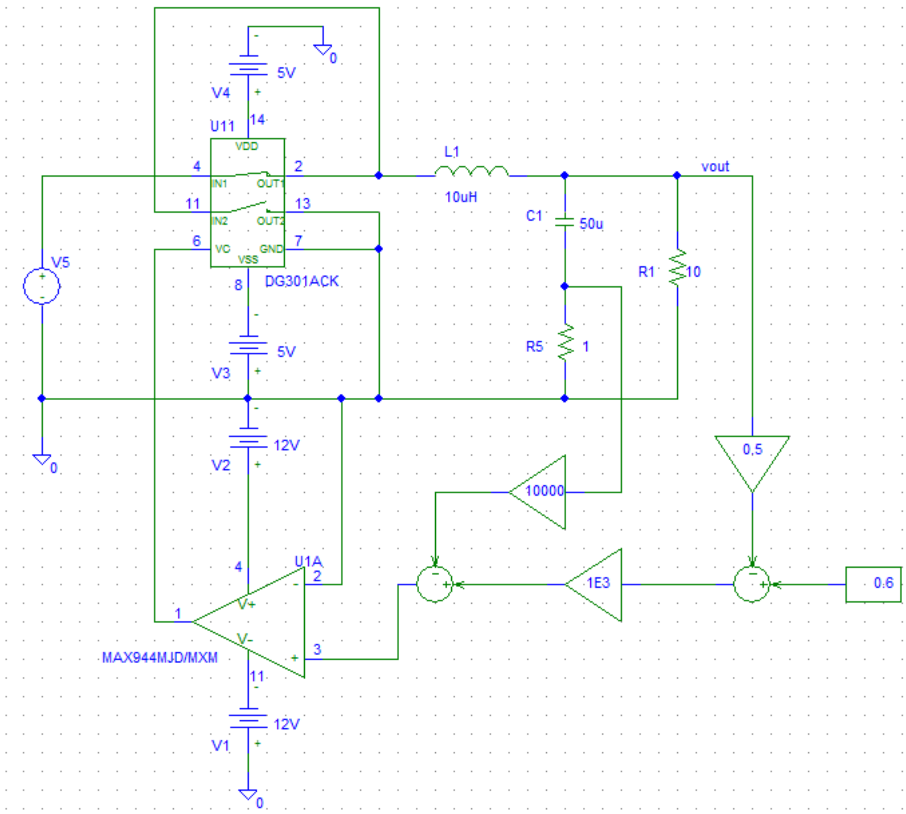

Fig. 4. PSpice model of the converter controller

5. SIMULATION RESULTS

The Simulink simulations are made for two different cases: when α=6000 and α=1000. The other parameters of the controller are: V_{ref} = 0.6V, β=0.5.

The output voltage response in the case when α=6000 is shown on Figure 5.

The simulation starts with a nominal load of 10Ω, than apply a step load change to 2Ω at time t = 3 ms and step load change to 20Ω at time t = 5 ms.

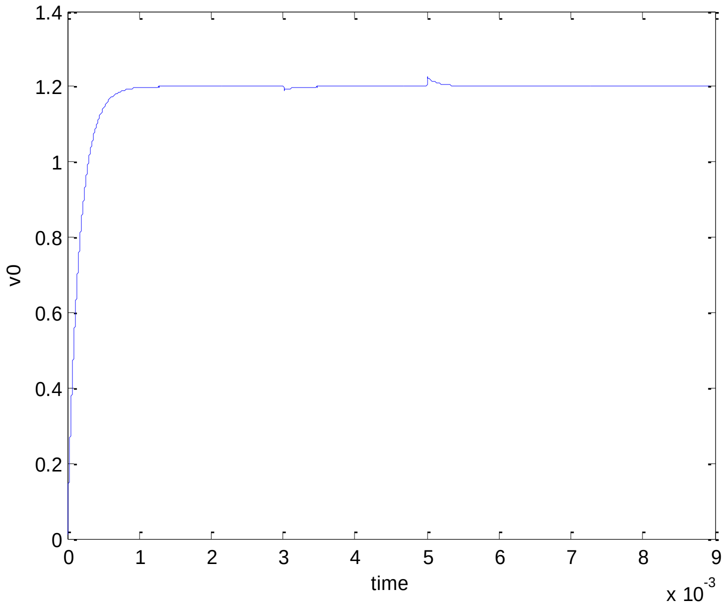

Fig. 5. Output voltage response in the case when α = 6000

The output voltage response in the case when α=1000 is shown on Figure 6. The simulation starts with a nominal load of 10Ω, than apply a step load change to 2Ω (over-loaded condition) at time t=2 ms and step load change to 20Ω (under-loaded condition) at time t=4 ms.

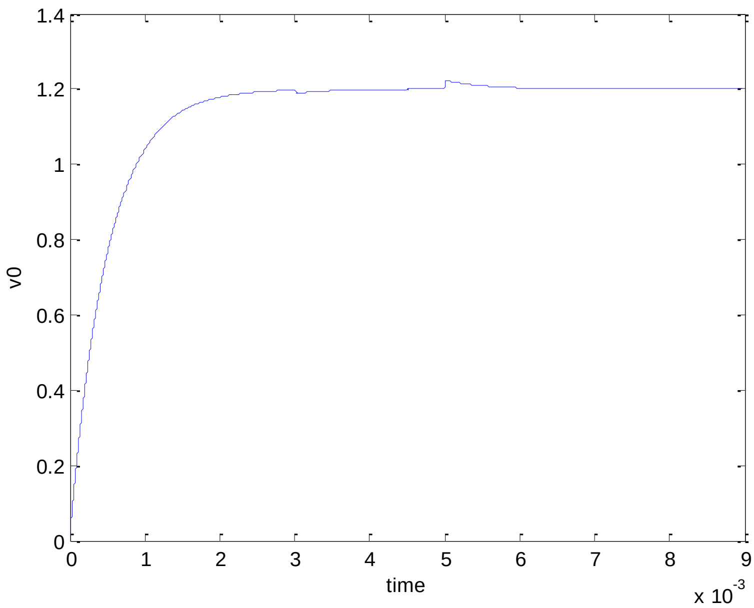

Fig. 6. Output voltage response in the case when α=1000

6. CONCLUSIONS

Simulation results show that the controller with higher α has faster dynamic response at over-loaded and at under-loaded conditions. The results in Simulink and PSpice are similar.

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