International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 2, February- 2013

Comparative Evaluation of Performance of a Sliding Mode Controller and a Conventional Controller on a DC-DC Boost Converter

Monisha Mohan
Assistant Professor
Department of AEI
MBC college of Engineering
Peermade, India

Binson V. A.
Assistant Professor
Department of AEI
Saintgits college of Engineering
Kottayam, India

Arun P.
Assistant Professor
Department of EEE
MES college of Engineering
Kunnukara, India

Abstract

This paper presents State-space averaged modeling and control of a DC-DC boost converter. DC state and small signal AC state modeling of the converter was derived and the control-to-output transfer function was determined. Inherent time-varying nature and heavy nonlinearity make the power electronic converter have many difficulties in control. Classical control approach cannot attain ideal control effect. Hence, nonlinear controllers such as sliding mode controllers (SMC) have been applied to boost converters. In this paper a SMC controller is proposed to control boost converters. A comparison of experimental results indicates that the performance of the SMC is superior to that of a conventional controller (PI).

1. Introduction

In recent years, there has been increasing interest in the development of efficient control strategies to improve dynamic behavior of DC-DC converters. For some applications, the DC-DC converters must provide a regulated output voltage with low ripple rate. Thus, for such case the regulation of the output voltage must be performed in a closed loop control mode. Proportional Integral and hysteretic control are the most used closed loop control solutions of DC-DC converters since these control techniques are not complicated and can be easily implemented on electronic circuit devices. The design of the linear controller is based on the linearized converter model around an equilibrium point near which the controller gives good results.

However this control approach is not so efficient since these converters are highly nonlinear and thus have constantly changing operating points.
Therefore, a PI or PID controller may not respond well to significant changes in operating points.

Many nonlinear controllers are applied to boost converters to solve this problem. Among them are sliding mode controllers. Sliding mode control is a powerful method that is able to yield a very robust closed-loop system under plant uncertainties and external disturbances. The objective of the project is to design a sliding mode controller (SMC) to control a boost converter.

2. State space averaged model

Modeling of a system may be described as a process of formulating a mathematical description of the system [1]. It involves the establishment of a mathematical input-output model which best approximates the physical reality of a system.

The nonlinearity of switching converters makes it desirable that small-signal linearized models be constructed. An advantage of such linearized model is that for constant duty cycle, it is time invariant: there is no switching or switching ripple to deal with, and only the important DC components of the waveforms are modeled.

The state-space averaging method, different from the circuit averaging technique, is a mainstay of modern control theory. The state-space averaging method makes use of the state-space description of dynamical systems to derive the small-signal averaged equations of PWM switching converters. A benefit of the state-space averaging procedure is the generality of its result: a small-signal averaged model can always be obtained, provided that state equations of the original converter can be written.

Consider the boost converter of Figure 1. The physical state variables are the independent inductor current i(t) and the capacitor voltage v(t), thus we define the state vector x(t) as,

$$x(t)=\begin{vmatrix} i(t) \\ v(t) \end{vmatrix}$$

In modeling the non-ideal boost converter, the conduction loss of MOSFET, Q (represented by switch S in Figure 1), is modeled by ON resistance R_{ON}, while the forward voltage drop of diode D is modeled by an independent voltage source of value V_D.

The input voltage $V_r(t)$ is an independent source which should be placed in the input vector u(t). In addition, the modeled diode forward voltage drop V_D is also included in the input vector u(t). Thus, we define the input vector as

$$u(t)=\begin{vmatrix} V_r(t) \\ V_D \end{vmatrix} \tag{1}$$

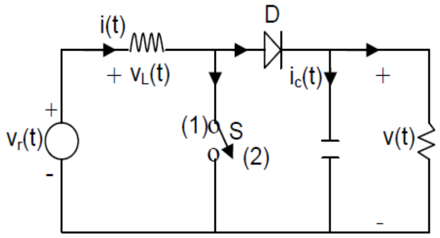

Figure1. Boost Converter Circuit

The converter system has to be represented in state equations of the form [1]:

$$K\frac{dx(t)}{dt} = Ax(t) + B \tag{2}$$

$$y(t) = Cx(t) + Eu(t \tag{3}$$

Where, K is a matrix containing the values of capacitance, inductance, and mutual inductance (if any), such that $K\frac{dx(t)}{dt}$ is a vector containing the inductor winding voltages and capacitor currents. The matrices A, B, C, and E contain constants of proportionality.

Now the state equations for each interval of the switching of the converter are written. When the switch is in position (1), the converter circuit of Figure 2 is obtained.

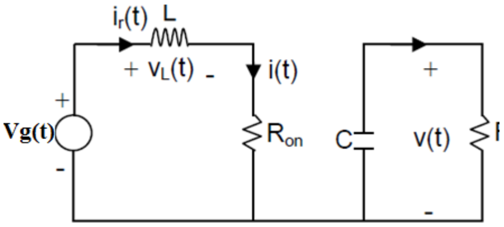

Figure 2. Boost Converter Circuit during On State

The inductor voltage, capacitor current and converter input current are:

$$L\frac{di(t)}{dt} = Vg(t) - i(t)R_{on} \tag{4}$$

$$C\frac{dv(t)}{dt} = \frac{-v(t)}{R} \tag{5}$$

$$i_r(t) = i(t) \tag{6}$$

These equations can be written in the following state-space form:

$$\begin{bmatrix} L & 0 \\ 0 & C \end{bmatrix}\frac{d}{dt}\begin{bmatrix} i(t) \\ v(t) \end{bmatrix} =$$

$$\begin{bmatrix} -R_{on} & 0 \\ 0 & -\frac{1}{R} \end{bmatrix}\begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} Vg(t) \\ V_D \end{bmatrix}$$

$$K\ \frac{dx(t)}{dt} = A_1\ x(t) + B_1 u(t) \tag{7}$$

$$[i_r(t)] = [1 \quad 0]\begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + [0 \quad 0]\begin{bmatrix} Vg(t) \\ V_D \end{bmatrix}$$

$$y(t) = C_1\, x(t) + E_1 u(t) \tag{8}$$

When the switch is in position (2), the converter circuit of Figure 3 is obtained. The inductor voltage, capacitor current and converter input current are:

$$L\frac{di(t)}{dt} = Vg(t) - v(t) - V_D \tag{9}$$

$$C\frac{dv(t)}{dt} = i(t) - \frac{v(t)}{R} \tag{10}$$

$$i_r(t) = i(t) \tag{11}$$

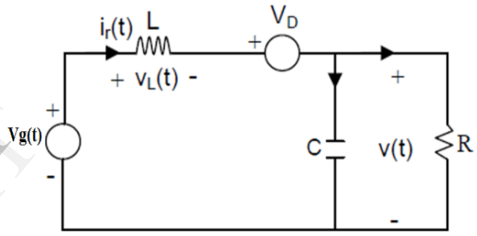

Figure 3. Boost Converter Circuit in Off State

The state-space equation representations of these equations are:

$$\begin{bmatrix} L & 0 \\ 0 & C \end{bmatrix}\frac{d}{dt}\begin{bmatrix} i(t) \\ v(t) \end{bmatrix} =$$

$$\begin{bmatrix} 0 & -1 \\ 1 & -\frac{1}{R} \end{bmatrix}\begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + \begin{bmatrix} 1 & -1 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} Vg(t) \\ V_D \end{bmatrix}$$

$$K\ \frac{dx(t)}{dt} = A_1 x(t) + B_1\, u(t) \tag{12}$$

$$[i_r(t)] = [1 \quad 0]\begin{bmatrix} i(t) \\ v(t) \end{bmatrix} + [0 \quad 0]\begin{bmatrix} Vg(t) \\ V_D \end{bmatrix}$$

$$y(t) = C_1 x(t) + E_1\, u(t) \tag{13}$$

To obtain a linear model that is easier to analyze, we construct a small signal that has been linearized about a quiescent operating point such that the characteristics of the linearized and nonlinear functions are approximately equal for sufficiently small variations in say $\hat{v}(t)$, about V.

Thus, the equations of the small-signal AC model are:

$$K\frac{d\hat{x}}{dt} = A\hat{x}(t) + B\hat{u}(t) +$$

$$\{(A_1 - A_2)X + (B_1 - B_2)U\}\hat{d}(t) \quad (14)$$

$$\hat{y}(t) = C\hat{x}(t) + E\hat{u}(t) +$$

$$\{(C_1 - C_2)X + (E_1 - E_2)U\}\hat{d}(t) \quad (15)$$

The quantities $\hat{x}(t), \hat{u}(t), \hat{y}(t)$ and $\hat{d}(t)$ are small ac variations in state vector, input vector, output vector and duty ratio. The complete small signal equivalent circuit model for boost converter is shown in Figure 4.

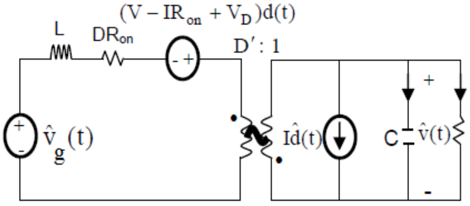

Figure 4. Complete Small-Signal Equivalent Circuit Model of a Nonideal Boost Converter

The control-to-output transfer function of boost converter [1], obtained using standard state space averaging techniques is given by,

$$G_{vd}(s) = \frac{V}{DL_eC}\left(\frac{(1-(\frac{sL_e}{R})}{s^2+b_1s+b_2C}\right) \quad (16)$$

3. Design of sliding mode controller(SMC)

SMC is a variable structure control (VSS). The main objective in the regulation of VSS through sliding mode behavior is to force the system to reach a prescribed surface, known as the sliding surface or sliding manifold, defined in the state space. The sliding surface is made ideally invariant (although, realistically, quasi-invariant due to inescapable small time delays and perturbations) with respect to the high-frequency switch-controlled state trajectories. The switching occurs among available feedback paths which produce system motions locally directed towards the sliding manifold.

The switching function is selected depending upon the order of the system [2] [3] [4]. If n is the order then the order of switching function must me N-1. Since a boost converter's small signal model is second order, a first order switching function S is designed where,

$$S = i_L - iref \quad (17)$$

Switching law or control law is selected to be as [5],

$$u = \frac{1}{2}(1 - \mathrm{sign}(S)) \quad (18)$$

4. Simulation Results

A DC-DC boost converter was designed using Simulink SimPowerSystems toolbox in MATLAB. A block diagram of the proposed SMC is shown in Fig 5 and PI controller is shown in Figure 6. The two responses one using PI controller and other with SMC controller is shown in Figure 7and Figure 8 respectively. For the simulation purpose the input voltage V_{in} = 5V, the output voltage Vo = 12V. The parameters chosen for boost converter are shown in Table I [6].

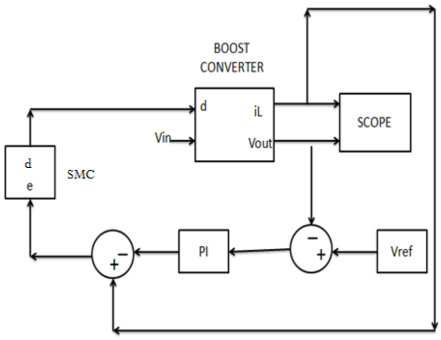

Figure 5. Block Diagram for SMC

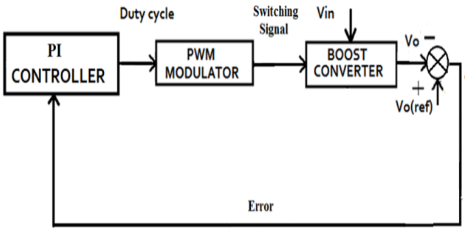

Figure 6. Block diagram for PI controller

Table 1. Circuit Parameters for boost converter

Parameter	Value
Capacitor(µF)	1056
Inductor(µH)	250
Load Resistor(Ω)	25
Equivalent Resistance of Inductor (mΩ)	10
Equivalent Resistance of Capacitor (mΩ)	30

Using SMC it is clear that the response is better than PI controller and settling time is also reduced. The output voltage response is not smooth in PI controller since there is an undershoot present, which increases as the input voltage is varied. In the case of SMC the output response is smoother.

Table II shows the settling time and rise time for PI controller and SMC for the responses shown in Figure 7 and Figure 8. The input voltage was varied in step from 5V to 7V and the response of both controllers was compared. The result is shown in Table III.

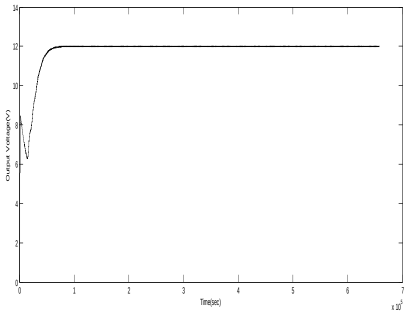

Figure 7. Response of Boost converter with PI controller

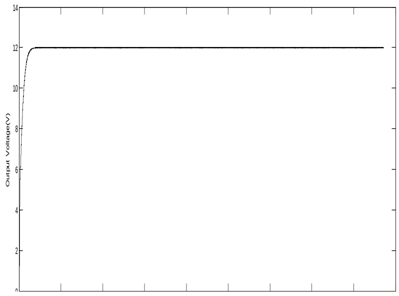

Figure 8. Response of Boost converter with SMC controller

Table 3. Rise time and settling time for different input voltages and a fixed output voltage to boost converter

Input Voltage *(V)*	**Rise Time** *(sec)*		**Settling Time** *(sec)*	
	PI	*SMC*	*PI*	*SMC*
5	0.0285	0.00791	0.0289	0.0086
6	0.0298	0.0713	0.0302	0.0078
7	0.0307	0.0689	0.031	0.0075

Table 2. Comparison of SMC with PI Controller

Controller	**Rise Time***(sec)*	**Settling Time***(sec)*
PI	0.0285	0.0289
SMC	0.0079	0.0086

5. Conclusion and future work

In this paper boost converter is modeled using state space averaging method. SMC is developed in MATLAB and was compared with the conventional PI controller. The response of SMC is better and more robust than the normal PI controller.The future works include implementation of fuzzy sliding mode control (FSMC) to get more accurate results.

6. References

[1] R.W. Erickson, D. Maksimovic, Fundamentals of Power Electronics, Kluwer Academic Publishers, 2001.

[2] G. Spiazzi, P. Mattavelli, L. Rossetto, L. Malesani, Application Of Sliding Mode Control To Switch-Mode Power Supplies, Journal of Circuits, Systems, and Computers (JCSC) 1995.

[3] Mattavelli, L. Rossetto And G. Spiazzi ,Small Signal Analysis Of Dc-Dc Converters With Sliding Mode Control, IEEE Transaction on Power electronics, March 1995.

[4] V. Utkin, Sliding Modes in Control Optimization, Springer-Verlag, 1992.

[5] G. Spiazzi, P. Mattavelli, L. Rossetto, Sliding Mode Control of DC-DC Converters

[6] Liping Guoa, John Y. Hungb, R.M. Nelms, Comparative Evaluation of Sliding Mode Fuzzy Controller and PID Controller for A Boost Converter, Science Direct, July 2010