Design, Modelling and Simulation of a PID Controller for Buck Boostand Cuk Converter

Priyadarshini [1], Dr. Shantharam Rai [2]

[1]M-Tech, Department of ECE, Canara Engineering College, Mangalore, Karnataka, India

[2]Professor, Deparment of ECE, Canara Engineering College, Mangalore, Karnataka, India

Abstract: ***This paper first presents open loop behavior of buck boost and cuk dc-dc converter operated under Continuous conduction mode (CCM). This is achieved withthe help of state equations and MATLAB/SIMULINK tool for simulation of those state equations. Using the knowledge of open loop converter behavior, a closed loop converter is designed. DC-DC converter will be designed for specific line and load conditions. But in practice there is deviation of the circuit operation from the desired nominal behavior due to changes in the source, load and circuit parameters. So we need to design a proper controller or compensator to overcome this situation of the circuit operation. This paper presents PID controller designed such that any input variations produces a constant output voltage.***

Keywords: Switching converter, MATLAB/SIMULINK, System modeling, PID controller.

1. Introduction

Controller design for any system needs knowledge about system behavior. This involves a mathematical relation between inputs to the system, state variables, and output called modeling of the system. This study aims at development of the models for buck boost and cuk converters and studying its open loop response, so these models can be directly used in case of close loop system. Then PID controller is used to form closed loop converter. The State variable approach is a power technique for analysis of switching converters. The state model of a system consists of the state equation and output equation.

1.1 Modeling Construction

The steps to obtain a state space modeling and simulation of Model Construction of DC-DC Switching power electronic converters are

1) Determine the state variables in the power converter e.g. inductor current and capacitor voltage.
2) Determine the modes of operation governing the states of the power semiconductors (Switch ON & OFF states)
3) Assume the main operating modes of the converter (continuous or discontinuous conduction)
4) Apply Kirchhoff's laws and combine together to form state-space model
5) Implement the derived equations with "SIMULINK" blocks (open loop system simulation is then possible to check the obtained model).
6) Design a proper controller or compensator to overcome the deviation of the circuit operation from the desired nominal behavior.

2. Buck Boost Converter

Fig. 1 shows DC-DC buck-boost converter with switching period T and the dutycycle D. Consider continuous conduction mode of operation, when the switch is ON and OFF, the state space equations are as follows

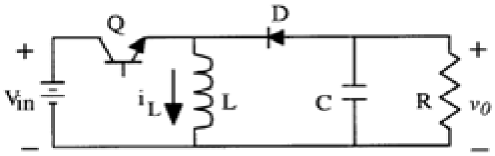

Figure 1: Buck Boost converter

When switch is ON:

$$\frac{di(t)}{dt} = \frac{V_i}{L} \quad \text{...1}$$

$$X_1'(t) = \frac{1}{L}U(t) \quad \text{... 2}$$

$$\frac{dv_C}{dt} = -\frac{V_C}{RC} \quad \text{...3}$$

$$X2'(t) = -\frac{V_C}{RC} \quad \text{...4}$$

When switch is OFF:

$$\frac{di(t)}{dt} = \frac{V}{L} \quad \text{...5}$$

$$X1'(t) = \frac{V}{L} \quad \text{... 6}$$

$$\frac{dV}{dt} = -\frac{i1}{C} - \frac{V}{CR} \quad \text{...7}$$

$$X2'(t) = -\frac{i}{C} - \frac{V}{CR} \quad \text{... 8}$$

These equations are implemented in Simulink as shown in Fig. 3 to obtain the states $i_L(t)$ and $v_C(t)$

$$\begin{bmatrix} x1'(t) \\ x2'(t) \end{bmatrix} = \begin{bmatrix} 0 & D'/L \\ -D'/C & -1/RC \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} (U(t))$$

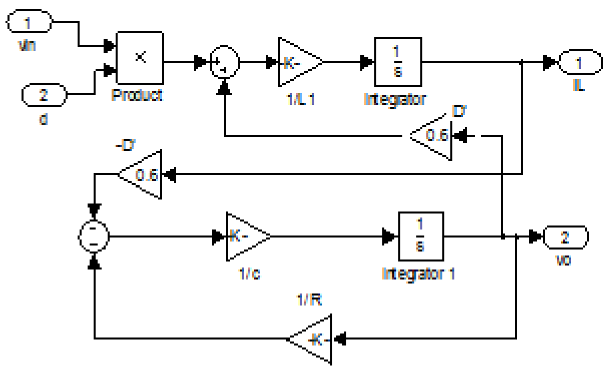

Figure 2: Open loop modelling of buck boost converter

3. Cuk dc-dc converter

Fig 3. shows the Cuk converter with switching period T and duty cycle D. During the continuous conduction mode of operation, the state space equations are as follows,

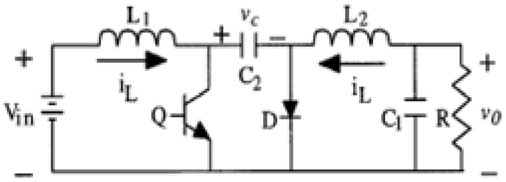

Figure 3: Cuk converter

When Switch is ON:

$$\frac{d_{i1}}{dt} = \frac{Vg}{L1} \qquad ...9$$

$$X1'(t) = \frac{1}{L}U(t) \qquad ...10$$

$$\frac{d_{i2}}{dt} = \frac{V1}{L2} - \frac{V2}{L2} \qquad ...11$$

$$X2'(t) = \frac{V1}{L2} - \frac{V2}{L2} \qquad ...12$$

$$\frac{d_{V1}}{dt} = -\frac{i2}{C1} \qquad ...13$$

$$X3'(t) = -\frac{i2}{C1} \qquad ...14$$

$$\frac{d_{V2}}{dt} = \frac{i2}{C2} - \frac{V2}{RC2} \qquad ...15$$

$$X'_4(t) = \frac{i2}{C2} - \frac{V2}{RC2} \qquad ...16$$

When Switch is OFF:

$$\frac{d_{i1}}{dt} = -\frac{V1}{L1} + \frac{U(t)}{L1} \qquad ...17$$

$$X1'(t) = -\frac{V1}{L1} + \frac{U(t)}{L1} \qquad ...18$$

$$\frac{d_{i2}}{dt} = -\frac{V2}{L2} \qquad ...19$$

$$X'_2(t) = -\frac{V2}{L2} \qquad ...20$$

$$\frac{d_{V1}}{dt} = -\frac{i1}{C1} \qquad ...21$$

$$X'_3(t) = -\frac{i2}{C1} \qquad ...22$$

$$\frac{d_{V2}}{dt} = \frac{i2}{C2} - \frac{V2}{RC2} \qquad ...23$$

$$X'_4(t) = \frac{i2}{C2} - \frac{V2}{RC2} \qquad ...24$$

These equations are implemented in simulink in order to obtain $i_{L1(t)}, i_{L2(t)}, v_{C1(t)}, v_{C2(t)}$

$$\begin{bmatrix} \dot{x_1}(t) \\ \dot{x_2}(t) \\ \dot{x_3}(t) \\ \dot{x_4}(t) \end{bmatrix} = \begin{bmatrix} 0 & 0 & -D'/L1 & 0 \\ 0 & 0 & D'/L2 & -1/L2 \\ D'/C1 & -D'/C1 & 0 & 0 \\ 0 & 1/C2 & 0 & -1/RC2 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix} + \begin{bmatrix} 1/L1 \\ 0 \\ 0 \\ 0 \end{bmatrix} (U(t))$$

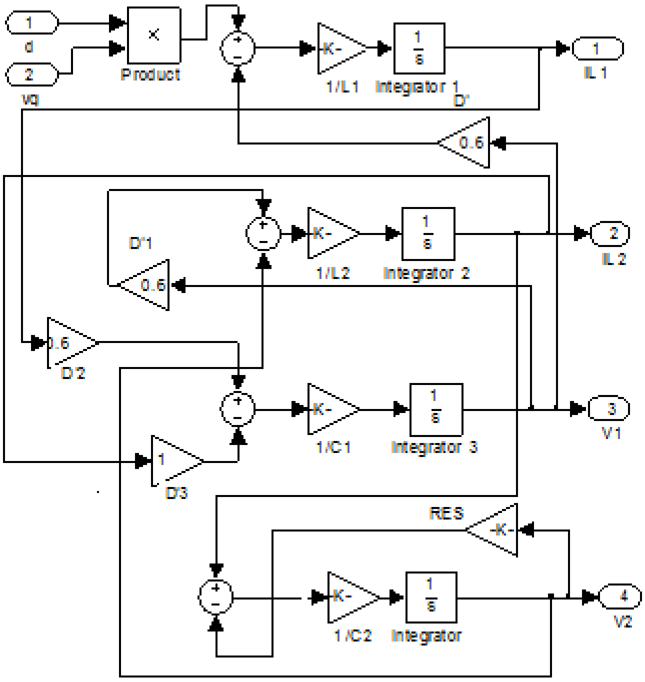

Figure 4: Open loop modelling of cuk converter

Design consideration of Buck Boost converter
Vg=12, Vo= -24, fs=25KZ, Δv=0.5%, $\Delta I = 10\% Idc$
L=586μH, C=660μF, $R_{L=}4\Omega$

Design consideration of cuk converter
Vg=12, Vo= 24, fs=25KZ, L1=180μH, L2=150μH
C1=200μF, C2=220μF, R_L=4Ω

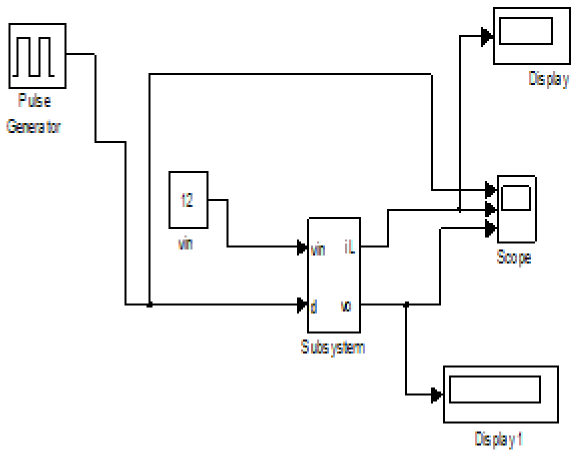

Figure 5: Subsystem of open loop Buck Boost converter

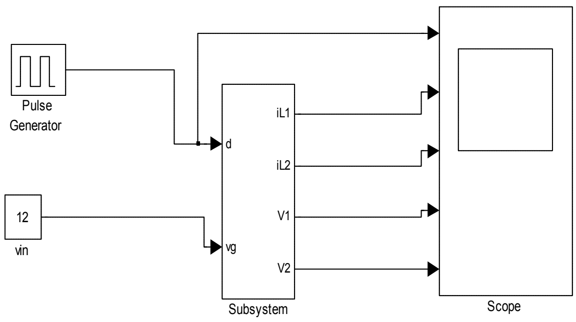

Figure 6: Subsystem of open loop cuk converter

4. Proportional Integral Derivatives

A PID controller is feedback loop controlling mechanism. A PID controller corrects the error between a measured process value and a desired set point by calculating and then a corrective action adjust the process as per the requirement .

The PID controller calculation involves three separate parameters, The Proportional value(P) determines the reaction to the current error, the Integral(I) determines the reaction based on the sum of recent errors and the Derivative (D) determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element. By "tuning" the three constants in the PID controller the PID can provide control action designed for specific requirements. DC converters are modeled using state space analysis which directly determines state variables like inductor current and capacitor voltage. Requirement is to obtain a constant output voltage for input disturbance and this can be achieved by directly tuning the I value.

Table1: Effects of increasing parameters

parameter	*Rise time*	*Overshoot*	*Settling time*	*S.S error*
Kp	Decrease	Increase	Small change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small change	Decrease	Decrease	None

5. Ziegler-Nichols Method

John G. Ziegler and Nathaniel B. Nichols introduced Ziegler-Nichols method. In this method, the I and D gains are first set to zero. The "P" gain is increased until it reaches the "critical gain (Kc)" at which the output of the loop starts to oscillate. Kc and Pc (oscillation period) are used to set the gains as shown

Table 2: Ziegler-nichols method

Control type	*Kp*	*Ki*	*Kd*
P	0.5.kc	-	-
PI	0.45.kc	1.2kp/pc	-
PID	0.6.Kc	2Kp/pc	Kp.pc/8

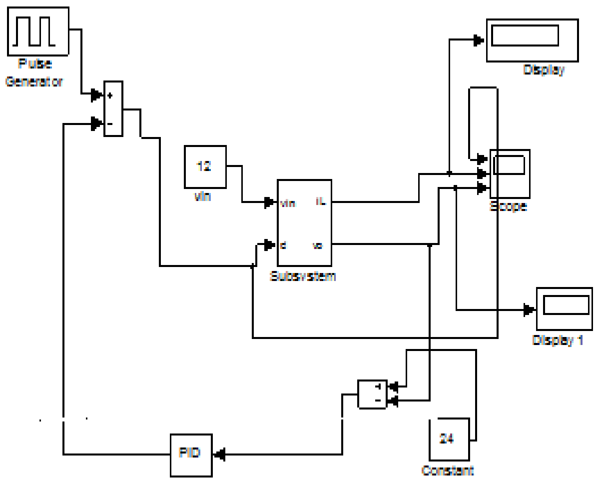

Figure 7: Closed loop buck boost converter with PID controller

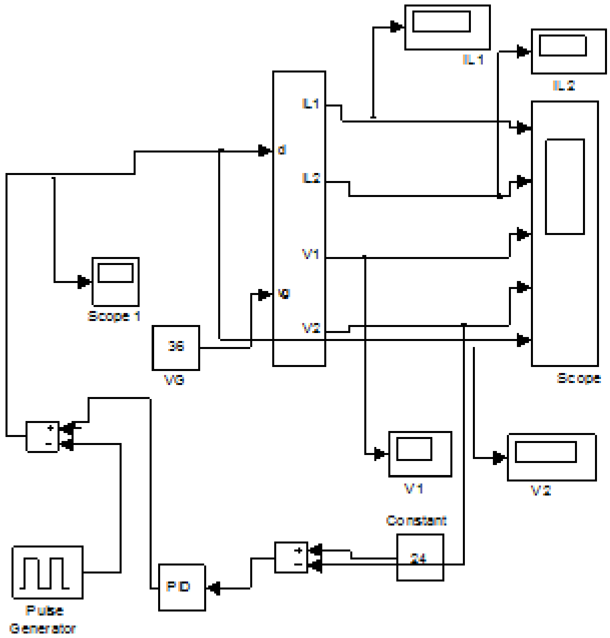

Figure 8: Closed loop Cuk converter with PID controller

6. Results

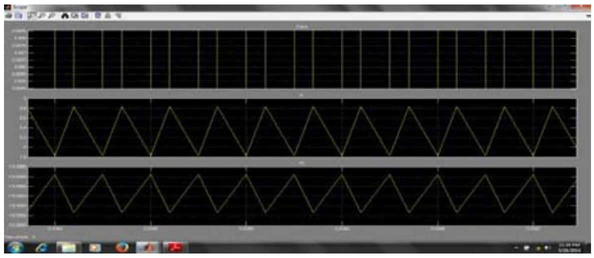

Figure 9: Results of open loop buck boost converter

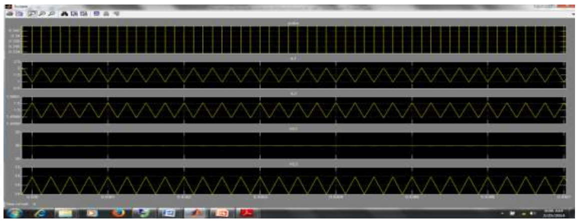

Figure 10: Results of open loop Cuk converter

Figure 11: closed loop buck boost converter with PID Controller

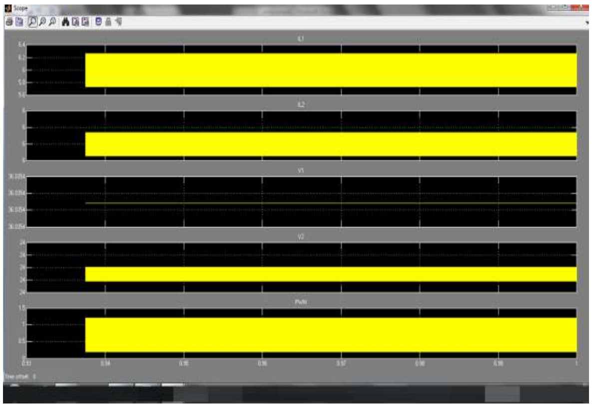

Figure 12: Results of closed loop Cuk converter with PID controller

7. Conclusion

This paper presents the state-space model implementation of buck-boost and Cuk converters. Result obtained from both the converter provides the dynamic behaviour in open loop. DC-DC converter will be designed for specific line and load conditions. But in practice due to changes in the source, load and circuit parameters ,there is deviation of the circuit operation from the desired nominal behavior. To overcome this problem a proper controller or compensator needs to be designed. Hence PID controller is designed and modelled for (1-36V) input variation to get constant output 24V, such that non linearity and un-stability of power converters can be improved.

8. Future Work

The Future work of this paper is design a closed loop PID controller for both buck boost and cuk converter using systematic ziegler-nichols method and a comparative study of buck boost and cuk converter can be performed.

Reference

[1] M.H.Rashid,"PowerElectronics:circuits,devicesandapplications",PearsonEduation,2004
[2] Vitor Femao Pires, Jose Fernando A. Silva, Teaching Nonlinear Modeling, Simulation, and Control of Electronic Power Converters Using MATLAB/SIMULINK, IEEE Transactions on Education, vol. 45, no. 3, August 2002
[3] M Gopal ,"Digital control and state variable methods", Tata McGraw-Hill
[4] J. Clerk Maxwell, *Control Design Techniques in Power Electronics Devices,* Springer, 2006
[5] Su.J.H., J.J. Chen and D.S. Wu. "Learning feedback controller design of switching converters via MATLAB/SIMULINK", *IEEE Transactions on Education*, Vol. 45, 2002, pp. 307-315.

Author Profile

Ms. Priyadarshini was born in sakleshpur, India. She received the Diploma (Electronics and communication) from the S.N Moodbidri College. She received the B.E (Electronics and Communication Engineering) degree from the sahyadri college of Engineering and Management, Mangalore in 2012. Currently perusing M.Tech (Electronics), in Canara Engineering College, Mangalore.

Dr. Shantharam Rai was born in Mangalore, India. He received the B.E (Electronics and Electrical Engineering) degree from the Mangalore University, in 1998. M.Tech (Power Electronics) from the NITK, in 2003. He is currently an H.O.D of the Dept .of E&C Engineering, CEC, Mangalore. His area of interest is Power Electronics and Control systems. He has guided number of projects for both UG and PG students.