Comparative Analysis of Analog PI and Discrete PI controller with single switch topology Buck Converter for Improving Percentage Regulation and Accuracy

Harshit Derasari

Department of Instrumentation and Control Engineering, L.D. College of Engineering, Ahmedabad, Gujarat.

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Abstract - *Switch Mode Power Supply (SMPS) plays an important role in miniaturized energy sources. Switching power supplies normally consists of two stages in the power circuit, viz. the input stage and the output dc-dc converter stage. A switch mode power supply contains the power stage and the controlling unit. The power stage includes the mainly power conversion from the input voltage supply to the output voltage supply and also includes switching device and the filter circuits. A major problem associated with this is strong dependency of DC bus voltage stress with the output load and input variance. The main perspective of this paper is to avoid this problem is presented by implementing buck converter with single switch topology and closed loop feedback with PI controller. Controller is design for single switch topology DC-DC Converter. Converter topology is selected in such a way that the input stage is discontinuous current mode (DCM) buck converter and the output stage is continuous mode converter providing wide band width response. Variation into the standard buck power circuitry stage and consideration of power stage component needs are included.*

Key Words: **Buck Converter, PI controller, MATLAB.**

1. INTRODUCTION

The switch mode converters are few of the simple power electronic devices which step down or step up electrical voltage by switching action. These dc-dc converter useful with many area of applications like power supplies for computers, office appliances, appliance control, communication instruments, motor drives, automobile applications, aircraft modules, etc.

Controlling and stabilization of dc-dc converters are the main parts that need to be analyzed. Many control methods are available for control of switching device operation in dc-dc converter but the easy working and low cost controller always will be in demand for most of the industrial application as well as high performance appliances. Each different controlling method have its own pro and cons due to which that particular control methods considered as suitable control method under static and dynamic conditions, compared to other controlling methods.

2. INTRODUCTION TO DC-DC BUCK CONVERTER WITH FEEDBACK CONTROL LOOP

The semi-conductor components are used as switching device through which converter is operate at high switching frequencies. The different design of inductor and capacitor in buck converter uses as filter circuitry. The resisting device act as load in buck converter which can be change to analyses the behavior in light resistive load and heavy resistive load. The various input sources utilizes like battery, renewable energy sources etc.

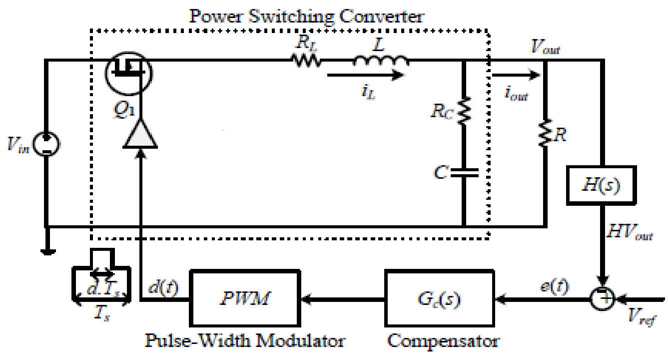

Fig. 1 [3] Block diagram of PID controller

The need or duty of compensating circuit/network is to settle the system as rapid as possible after change in normalized operating conditions occur. This compensating circuit/network is the controlling network for converter. This controlling network consider a portion of output and compares it with reference input. Further signal conditioning and amplification of error is done, and according to error corrective action is taken. The controlling action consists of opposing the variation observed in output.

3. DESIGN AND SIMULATION OF PI CONTROLLER

Here it is assume that the dc-dc buck converter is in continuous conduction mode. It includes linear time invariant components like resistor, inductor and capacitor together with switches like MOS and diodes, whose operation is controlled to maintain the desired conversion.

Therefore, equation for inductor voltage and capacitor current two circuits are considered, one in the on time and other in the off time of the converter.

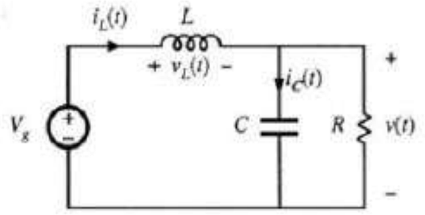

Fig. 2 [1] Buck converter circuit when switch turns on

So for on time our equation for inductor voltage and capacitor current are,

$$Vl(t) = Vg(t) - Vc(t)$$

$$Ic(t) = Il(t) - Io(t)$$

By expanding above equations we get,

$$\frac{dIl}{dt} = \frac{Vg(t)-Vc(t)}{L}$$

$$\frac{dVc}{dt} = \frac{Il(t)}{C} - \frac{Io(t)}{RC}$$

Now the above equations can be written as,

$$\begin{bmatrix} \frac{dIl}{dx} \\ \frac{dVc}{dx} \end{bmatrix} = \begin{bmatrix} 0 & -1/L \\ -1/C & -1/RC \end{bmatrix} \begin{bmatrix} Il \\ Vc \end{bmatrix} + \begin{bmatrix} -1/L \\ 0 \end{bmatrix} [Vg]$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} Il \\ Vc \end{bmatrix}$$

They may be written as,

$$\dot{x} = Aon\, x + Bon\, u$$

$$y = Con\, x + Don\, u$$

Here, Don = 0.

Now, when switch is off,

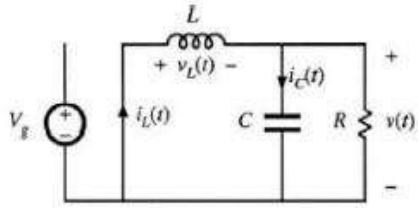

Fig. 3 [1] Buck converter circuit when switch turns off

So for off time our equation for inductor voltage and capacitor current are,

$$\frac{dIl}{dt} = \frac{-Vc(t)}{L}$$

$$\frac{dVc}{dt} = \frac{Il(t)}{C} - \frac{Vc(t)}{RC}$$

These can also be written as,

$$\begin{bmatrix} \frac{dIl}{dx} \\ \frac{dVc}{dx} \end{bmatrix} = \begin{bmatrix} 0 & -1/L \\ -1/C & -1/RC \end{bmatrix} \begin{bmatrix} Il(t) \\ Vc(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} [Vg]$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} Il(t) \\ Vc(t) \end{bmatrix}$$

Above equations can be rewritten as,

$$\dot{x} = Aoff\ x + Boff\ u$$

$$y = Coff\ x + Doff\ u$$

Here Doff = 0.

From above equations we can see that A on = A off and B off= 0. For State Space Averaging given that, $A = dA_1 + (1\text{-}d)\,A2$ where, A1 = A2. So that, A = A1 = A2 and B = dB1 + (1-d) B2.

$$B = d \begin{bmatrix} 1/L \\ 0 \end{bmatrix} + (1-d) \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$B = d \begin{bmatrix} 1/L \\ 0 \end{bmatrix}$$

Where, d= Duty cycle

$$B = \begin{bmatrix} d/L \\ 0 \end{bmatrix}$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} I_l \\ V_c \end{bmatrix}$$

So,

$$A = \begin{bmatrix} 0 & -1/L \\ -1/C & -1/RC \end{bmatrix}, \quad B = \begin{bmatrix} d/L \\ 0 \end{bmatrix}, C = [0 \quad 1], D = 0$$

The line-to-output transfer function is H(s)= $\frac{Vo(s)}{Vin(s)}$. Its expression based on average model is

$$Havg(s) = \frac{d}{1+s\frac{L}{R}+s^2 LC}$$

In the transfer functions, *Vin* and *Vo* are the input and output voltages respectively. $\widetilde{Vo}(s), \widetilde{Vin}(s)$ and $\hat{d}(s)$ Are the small variations of the output voltage, input voltage and duty cycle respectively. d is the duty cycle, C is the output capacitance, L is the inductance, and R is the load resistance.

The parameter values of this system are as follows:

Input Voltage, Vin	12V
Output voltage, Vo	6 V
Duty Cycle, D	50%
Capacitance, C	220 uF
Inductor	10 mH
Load resistance, R	10 ohms

Now, putting all these values in equation we can derive the system transfer function as follows,

$$\frac{\widetilde{Vo}(s)}{\hat{d}(s)} = \frac{0.5}{0.0000022\ s^2 + 0.001\ s+1}$$

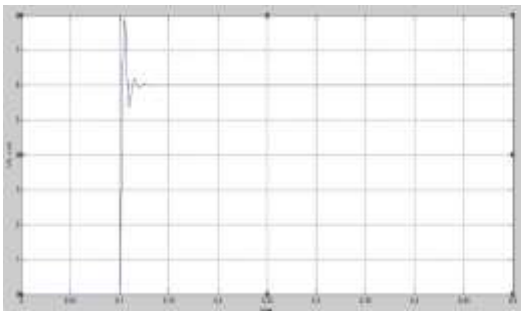

Fig. 4 Step response of state- space average model of the system

- **Simulation of PI Controllers in continuous time domain**

Closed loop implementation PI controller with the circuit of Buck converter were implemented using MATLAB Simulink

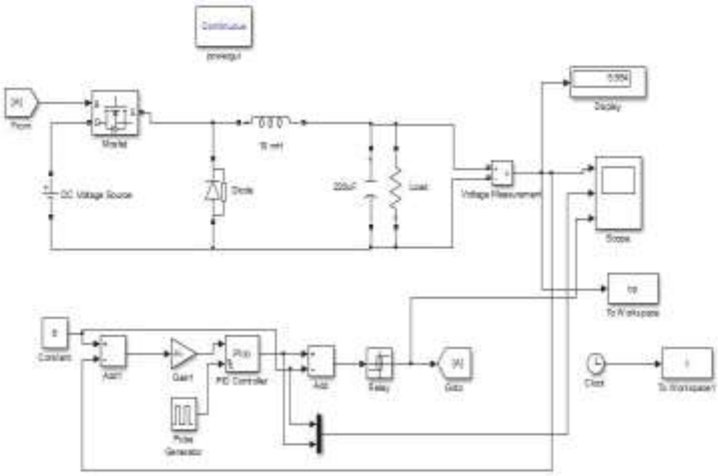

Fig. 5 closed loop Continuous PI controller implementation for buck converter

Simulation of closed loop Continuous PI controller implementation continuously track the desired output voltage which is given as reference and error is given to the PI controller. PI controller gives controller action according to error and PWM is generated which changes the duty cycle for operating the switching device.

- **Simulation of PI Controllers in Discrete time domain**

Closed loop implementation Discrete PI controller with the circuit of Buck converter were implemented using MATLAB Simulink.

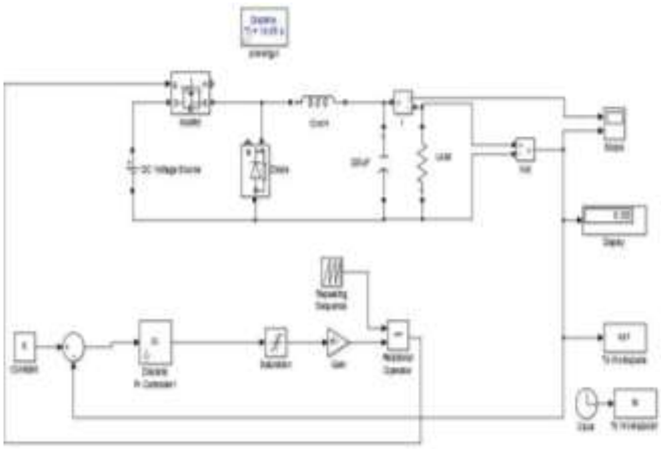

Fig. 6 closed loop Discrete PI controller implementation for buck converter

Simulation closed loop Discrete PI controller implementation continuously track the desired output voltage which is given as reference and error is given to the PI controller. PI controller gives controller action according to error and PWM is generated with the help of repeating triangular waves which changes the duty cycle according to error and the switching device operated accordingly.

4. SIMULATION RESULT AND HARDWARE IMPLEMENTATION

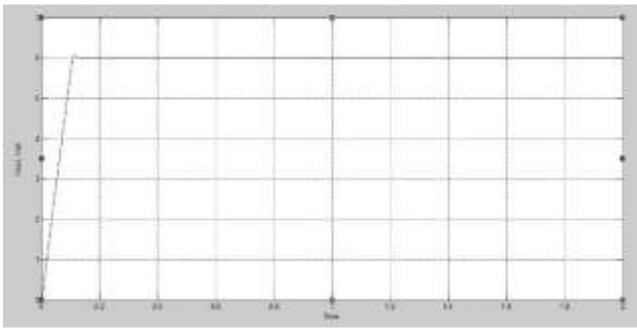

Fig. 7 Output response of Continuous PI controller for buck converter

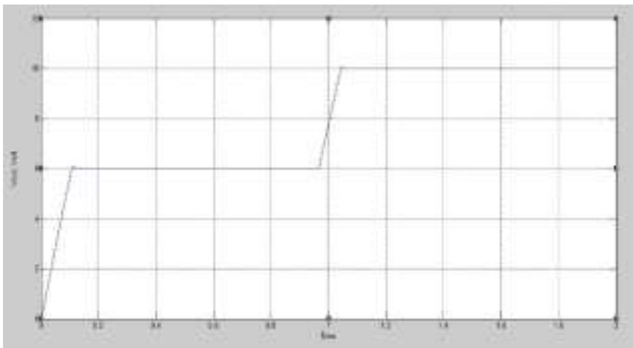

Fig. 8 Output response of Continuous PI controller for buck converter with change in reference voltage

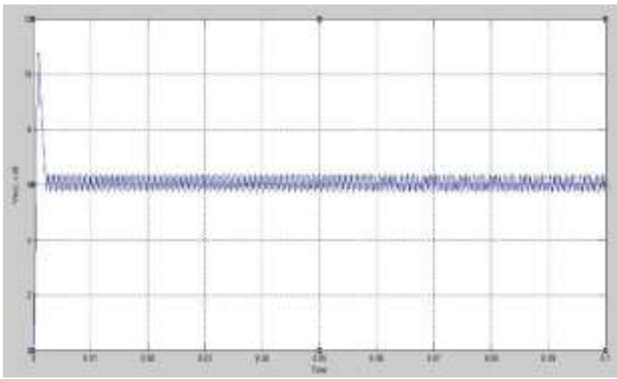

Fig. 9 Output response of Discrete PI controller for buck converter

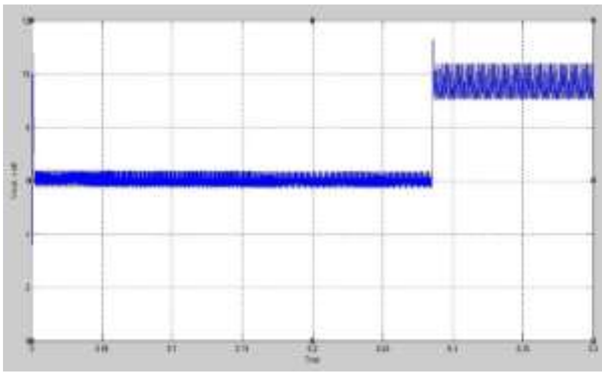

Fig. 10 Output response of Discrete PI controller for buck converter with change in reference voltage

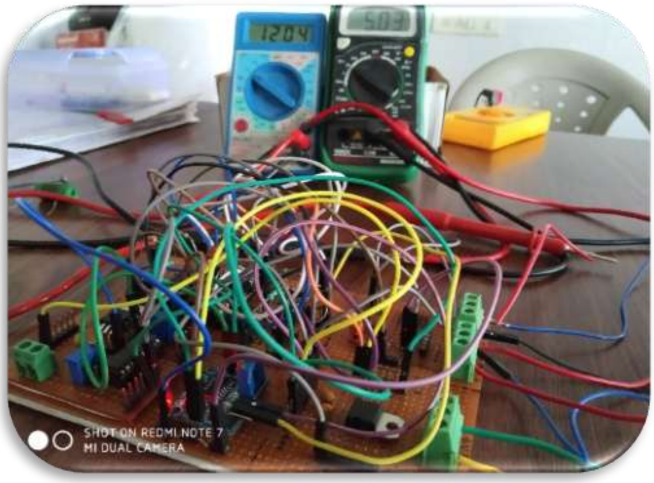

Fig. 11 Buck converter with Analog PI controller without load

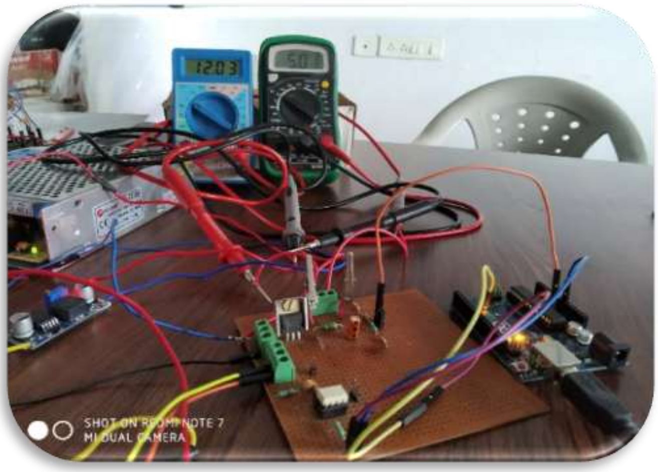

Fig. 12 Buck converter with Discrete PI controller without load

Here, the effect of PI controller for rapid transient response is discuss through the simulation results. Mainly the problem associate with this controlling technique for converter is variable switching frequency operation with jitter. Therefore, switching frequency must be maintain constant. Both different domain of controller have their own pro and cons.

5. COMPARATIVE ANALYSIS OF PI CONTROLLER IN TWO DIFFERENT DOMAIN

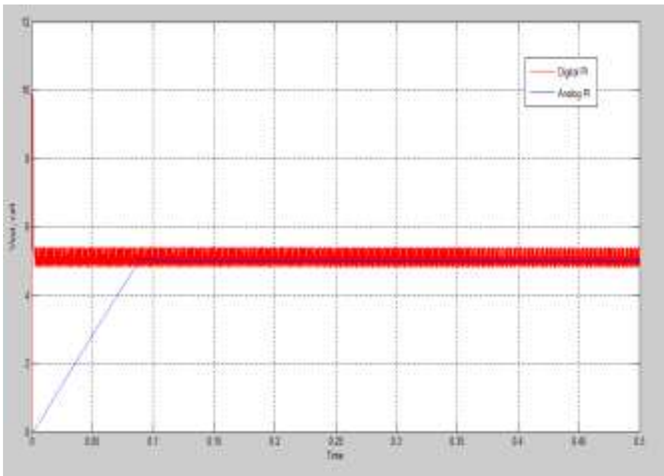

Fig. 13 Comparison of resultant output voltages of buck converter using analog and Discrete PI controller

Specifications	Analog PI	Discrete PI
Rise time (sec.)	0.0694	0.00030
Settling time (sec.)	0.0869	0.9802
Overshoot (%)	1.6568	85.7375
Peak (v)	5.0804	9.8924
Peak time (sec.)	0.0934	0.0009
Voltage Variation (%)	±3	±5
Jitter present	Low	Comparatively high
System's Flexibility	Low	High
Design Complexity	More Complex	Comparatively Simple

Table.1 Comparative analysis of PI controller using hardware configuration in both domain

6. CONCLUSION

The main aim of this paper is to implement the action agenda for new technique. Here, two realizations for buck converter based on PI controller are considered, the comparison between analog PI and discrete PI controllers is described. The Implementation results observed from no load to full load condition and ±20% Input variation in both controller.

The technology uses in digital controlling scheme is new era for power management but on other side analogous control scheme gives more accurate results than other. So, the implementation and observational results show that each of them has its pro and cons as well weaknesses and strengths. So, the application field can be determine which method will suitable and can be employee.

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