Designing and Parametric Variation of PI Controller for Buck Converter for Constant Voltage Applications

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***Abstract*- In this paper, we study on buck dc/dc converter of high efficiency by soft switching technique. The paper will focus on modeling, analysis, and design and simulation buck converter architecture. The converter is designed in CCM (continuous conduction mode). The voltage mode control strategy is proposed by using pulse width modulation (PWM) with a proportional-integral (PI). The effectiveness of the step down converter is verified through simulation results using control oriented simulator like MATLAB/Simulink tools. The circuit operation, designs and simulation results are mentioned in this paper.**

Keywords*—Buck Converter, Total Harmonic Distortion, Pulse width modulation and PI control.

I. INTRODUCTION

DC-DC converters are some of the simplest power circuit. It is a device which transforms AC to DC. This device is also known as an AC to DC converter. A Chopper can be considered as a DC equivalent of an AC transformer with a convertible constant convertible in a continuous form. Like a transformer, the converter can be employed for stepwise increase or reduction of DC source voltage.

The name Buck Converter most probably evolves from the fact that the input voltage is bucked/chopped or attenuated, in amplitude and a lower amplitude voltage appears at the output. This paper discusses the design of an optimized controller and a buck converter, while presenting the result of analysis.

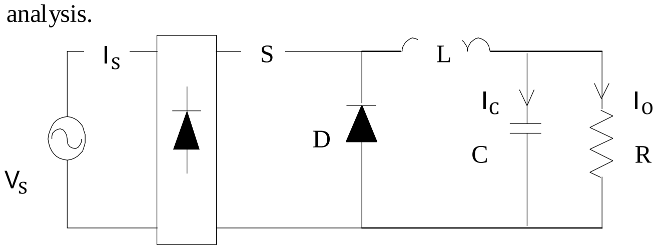

Figure 1. DC-DC Buck converter

II. OPERATION CIRCUIT MODEL FOR BUCK CONVERTER

Figure 1 shows the DC-DC Buck Converter circuit topology. The circuit operation can be divided into two modes.

Mode 1 (Switch is closed):

When the controlled switch (e.g. MOSFET) ‘S’ is on by by pulse width modulation (PWM), then input voltage appears across the inductor L, filter capacitor, C and load resistor R and current in inductor L increases linearly. In the same cycle the capacitor C is charged. During mode 1, the diode reversed biased and resulted from flowing current, the input provides energy to the load as well as to the inductor.

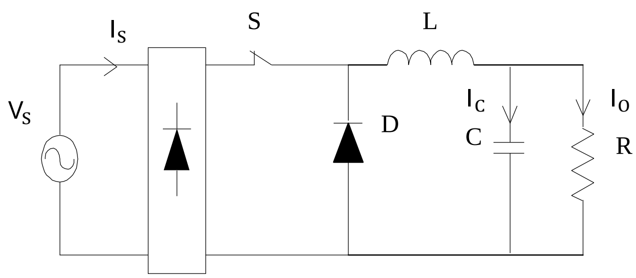

Figure 2. Mode:1 When switch is closed

Mode 2 (Switch is open):

When the controlled switch i.e MOSFET is switch off. The voltage across the inductor L is reversed. However, current in the inductor L cannot change instantaneously and the current starts decreasing linearly through inductor L capacitor C, load R and diode D. In this cycle the capacitor is also charged with the energy stored in the inductor.

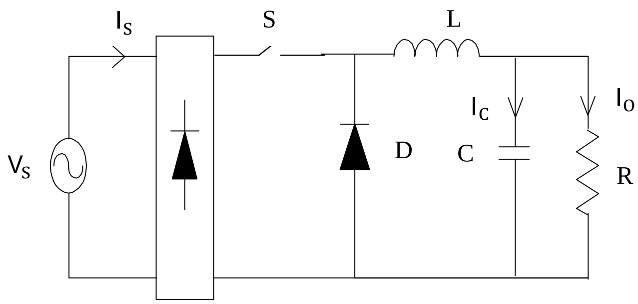

Figure 3. Mode:2 When switch is open

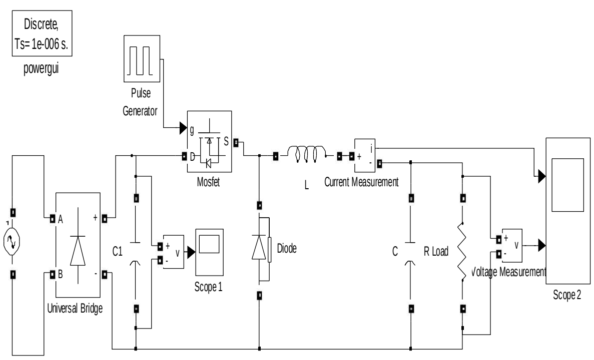

Figure 4. Simulation model of buck converter for open loop control

A. *Design parameter and equations for buck converter:*

$V_O = DV_{in}$

$L = V_O(1-D)/(\Delta I_L) f_S$

$C_O = (1\text{-}D)/(8L_O f_S^2)(\Delta V_{CO}/V_O)$

Where

f_s = switching frequency

ΔI_L = Peak to Peak ripple current I_L (assuming 10% of I_L)

ΔV_{Co} = voltage ripple (assuming 5% of V_O)

D = Duty cycle.

B. *The calculated value of Buck converter:*

Input voltage (V_S) = 220 volts

Output voltage (V_O) = 48 volts

Duty cycle (D) = 21.81%

Switching frequency (f_s) = 25 kHz

Inductor (L) = 7.8 mH

Capacitor (C) = 0.434 μF

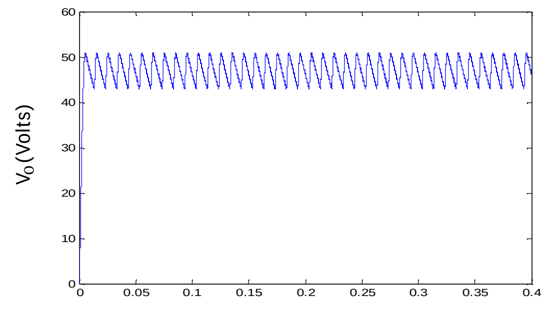

Figure 5. Open loop response of flyback converter

The results of open loop buck converter is shown in figure 5, which depicts peak to peak ripple voltage (ΔVo) is 8.6 Volt and maximum overshoot of 17.3%. Since the design equations assume constant input voltage and constant load under steady state conditions, the variation of input voltage shall result in fluctuation in output Therefore, a closed loop controller is required with optimized parameters to suit the constant voltage output as per requirement of load.

C. *Controller for closed loop buck converter give design equations:*

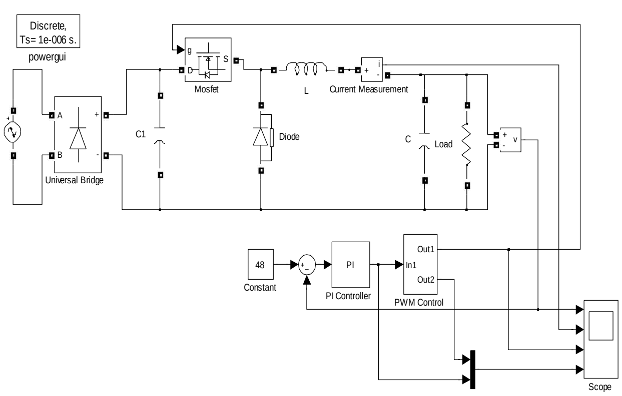

Figure 6. Simulation model of buck converter for closed loop control

The Simulink Schematic of buck converter with analog PI controller is shown in figure 6.

The output voltage is sensed V_{out} and compared with the input voltage V_{ref} then an error signal is produced which is processed through PI controller to generate a control voltage. The control voltage is used to feed to the PWM generator for control of switch. The PI controller has two parameters namely K_P and K_I.

PI controller has transfer function: $C(s) = K_P + \frac{K_i}{s}$

Where, K_P=Proportional gain and K_i= Integral gain.

The results of closed loop flyback converter is shown in fig.7

which has maximum overshoot of 12.72%, settling time 0.01sec and rise time 0.01 sec.

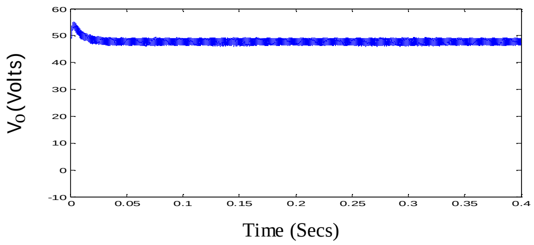

Figure 7. Closed loop response of Output voltage Vs Time

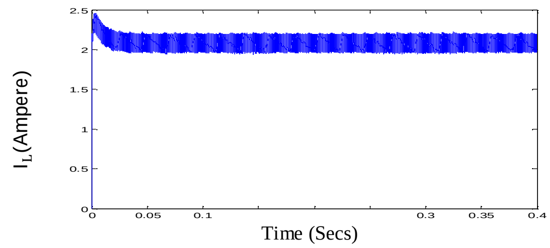

Figure 8. Closed loop response of Inductor current (I_L) Vs Time

III. EFFECT DUE TO VARIATION OF K_P AND K_I ON OUTPUT VOLTAGE AND INDUCTOR CURRENT

TABLE I Performance parameters when L=7.8 mH, C= 0.434 µF, K_I= 20 and value of K_P is varied

K_P	Voltage(V_O)			Current (I_{Lm})		
	O.S (%)	Settling Time	Rise Time	O.S (%)	Settling Time	Rise Time
0.04	32.08	0.01	0.01	32.29	0.01	0.01
0.10	19.79	0.01	0.01	21.42	0.01	0.01
0.16	12.72	0.01	0.01	13.89	0.01	0.01
0.22	14.58	0.01	0.01	14.28	0.01	0.01
0.28	12.5	0.01	0.01	14.28	0.01	0.01

(a) Performance of output voltage (V_O) Vs time graph for flyback converter when K_p value is varied.

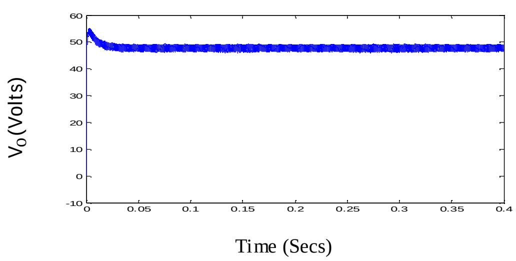

Figure 9. Output voltage Vs time with K_P = 0.16

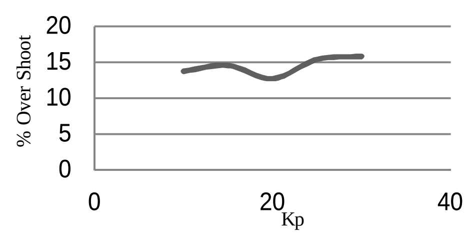

Figure 10. Effect on overshoot due to variation in K_P

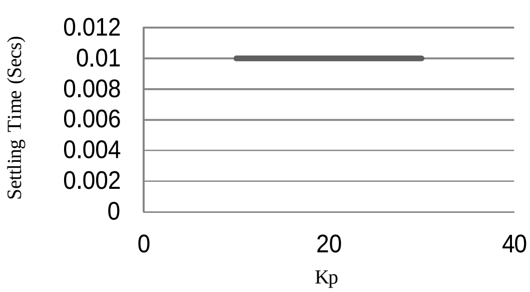

Figure 11. Effect on settling time due to variation in K_P

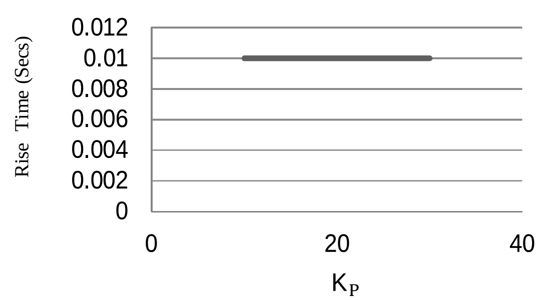

Figure 12. Effect on rise time due to variation in K_P

(b) Performance of magnetization current (I_L) Vs time graph for buck converter when K_p value is varied.

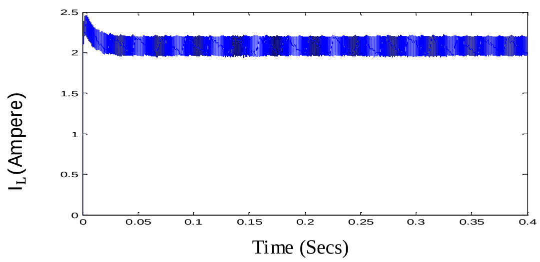

Figure 13. Magnetization current (I_{Lm}) Vs time with K_P = 0.16

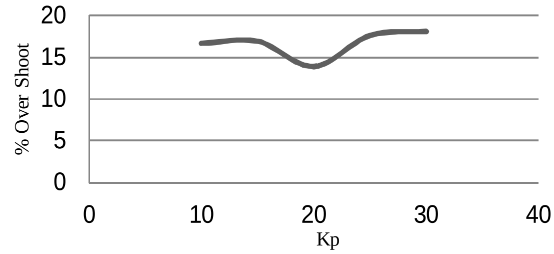

Figure 14. Effect on overshoot due to variation in K_P

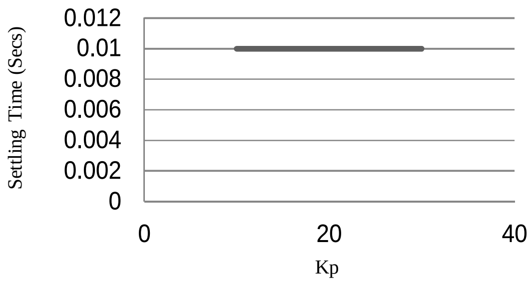

Figure 15. Effect on settling time due to variation in K_P

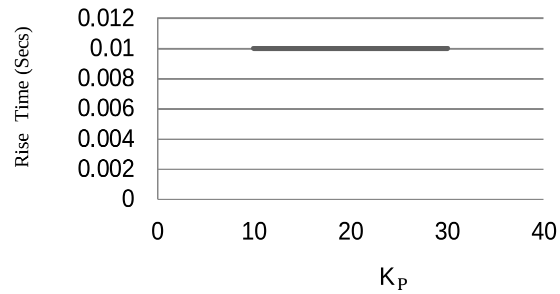

Figure 16. Effect on rise time due to variation in K_P

TABLE II Performance parameters when L= 7.8 mH, C = 0.434 μF, K_P= 0.16, K_I value is varied .

K_I	Voltage(V_O)			Current (I_{Lm})		
	O.S (%)	Settling Time	Rise Time	O.S (%)	Settling Time	Rise Time
10	13.75	0.01	0.01	16.66	0.01	0.01
15	14.58	0.01	0.01	16.91	0.01	0.01
20	12.72	0.01	0.01	13.89	0.01	0.01
25	15.41	0.01	0.01	17.61	0.01	0.01
30	15.83	0.01	0.01	18.09	0.01	0.01

(a) Performance of output voltage (V_O) Vs time graph for buck converter when K_I value is varied.

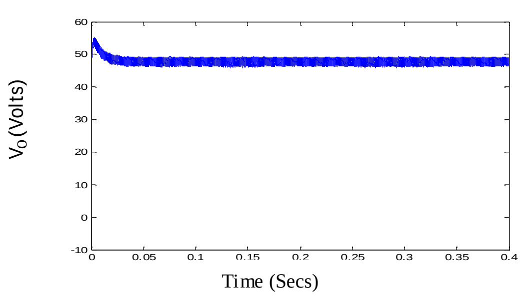

Figure 17. Output voltage Vs time with K_I = 20

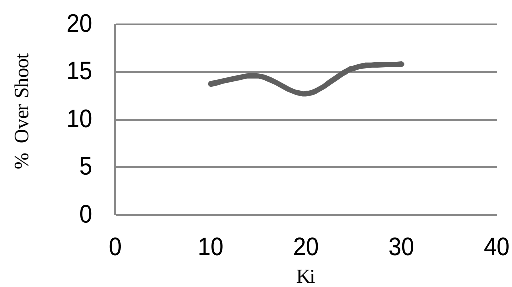

Figure 18. Effect on overshoot due to variation in K_I

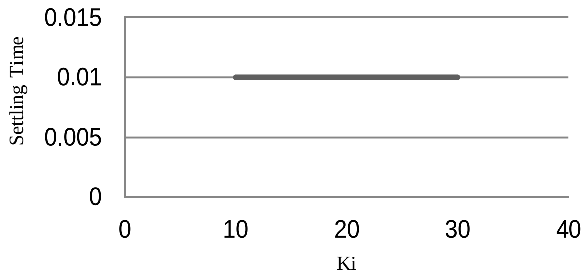

Figure 19. Effect on settling time due to variation in K_I

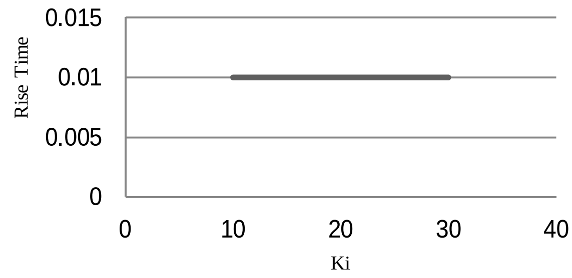

Figure 20. Effect on rise time due to variation in K_I

(b) Performance of inductor current (I_L) Vs time graph for buck converter when K_I value is varied.

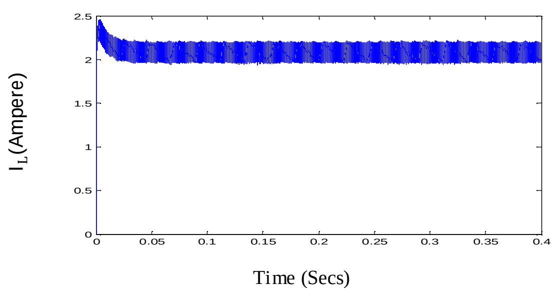

Figure 21. Magnetization current (I_{Lm}) Vs time with K_I = 20

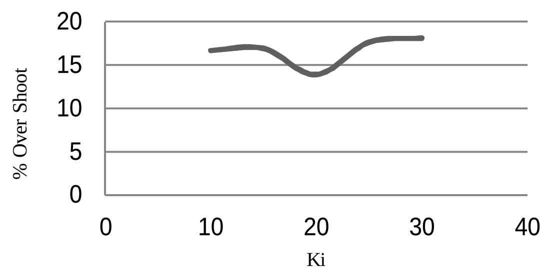

Figure 22. Effect on overshoot due to variation in K_I

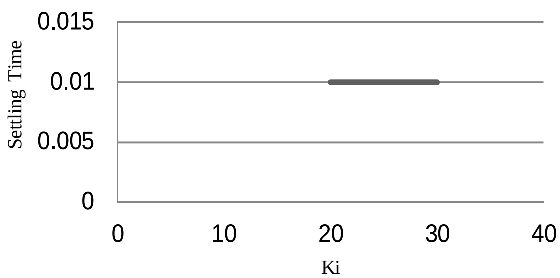

Figure 23. Effect on settling time due to variation in K_I

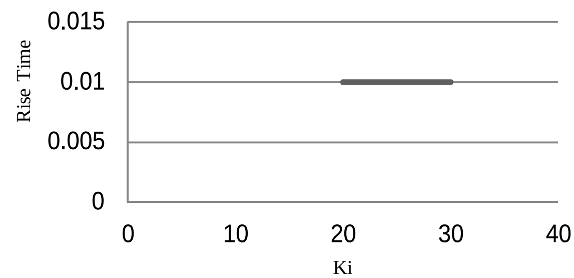

Figure 24. Effect on rise time due to variation in K_I

IV. CONCLUSION

Step down switching regulators are the backbone of electronic equipments. The designing of buck converters has been carried out for constant voltage applications considering K_P and K_I are the performance parameter for PI controller. Buck converter has been designed to deliver 48 volts DC to a 100 watt load. Performance and applicability of this converter is presented on the basis of simulation in MATLAB SIMULINK. Buck converters are employed for low power applications below 150 W and with voltages below 230V. The parametric variation analysis of buck converter have been carried out for constant voltage applications considering

The design concepts are validated through simulation and results obtained show that a closed loop system using buck converter will be highly stable with high efficiency. Better efficiency due to: moderate duty cycles, lower voltage MOSFETs and rectifiers, and reduced switching losses due to reduced peak-to-peak voltage swing.

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