Designing and Tuning of PI Controller for Flyback Converter

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***Abstract*— This paper aims at designing of an optimized controller for isolated DC-DC Flyback converter for constant voltage applications. The Flyback converter can both step up and step-down the input voltage, while maintaining the same polarity and the same ground reference for the input and output. MOSFETs are used as a switching device in low power and high frequency switching applications. It may be noted that, as the turn-on and turn-off time of MOSFETs are lower as compared to other switching devices, which reduces the switching losses. High frequency operation of MOSFET reduced size of filters components. These converters are now being used for various applications, such as Switched Mode Power Supply (SMPS) etc. The paper attempts to present designing and tuning of Flyback converters for constant voltage output.**

***Keywords*— Flyback converter, PI Controller, Duty cycle, PWM, Ziegler Nicholas Method**

I. INTRODUCTION

The DC converter 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 converters are widely used for the control of motor voltage in electric cars, ceiling elevators, mine excavation etc. Their specific features are the precise control of acceleration with high efficiency and fast dynamic response.

This paper discusses the design of an optimized controller and a buck-boost DC-DC converter, while presenting the result of analysis. In modeling area of DC-DC converters, a variety of models are presented which comprises desirable responses by administration of control methods. Most of the articles have concentrated on controlling designs of PI controller. In this paper PI controller is tune with Ziegler Nicholas (ZN) method.

II. OPERATION CIRCUIT MODEL FOR FLYBACK CONVERTER

In Flyback converter power transformer is used for isolation between a primary side and a secondary side.

Mode 1 (Switch is closed): When switch 'S' is on, the primary winding of the transformer gets connected to the input supply with its dotted end connected to the positive side. At this time the diode 'D' connected in series with the secondary winding gets reverse biased due to the induced voltage in the secondary (dotted end potential being higher). Thus with the turning on of switch 'S', primary winding is able to carry current but current in the secondary winding is blocked due to the reverse biased diode. The flux established in the transformer core and linking the windings is entirely due to the primary winding current.

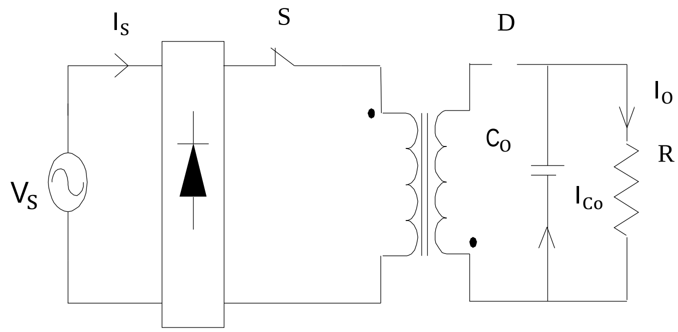

Figure 1. Mode:1 when switch is closed

Mode 2 (Switch is open): When the switch is opened the primary current and magnetic flux drops. The secondary voltage is positive, forward-biasing the diode, allowing current to flow from the transformer. The energy from the transformer core recharges the capacitor and supplies the load.

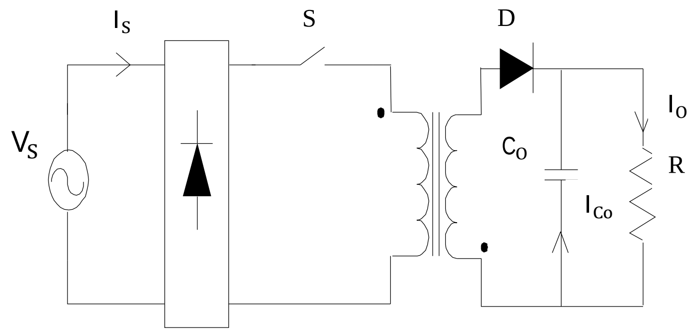

Figure 2. Mode:2 When switch is open

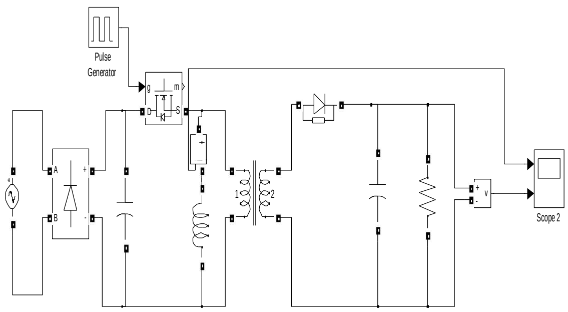

Figure 3. Simulation model of flyback converter for open loop control

A. Design parameter and equations for flyback converter:

$V_O = D(N_2/N_1)V_{in}/(1-D)$

$L_m = DV_{in}/(\Delta I_{Li}) f_s$

$C_O = V_o D/(f_s R \Delta V_{co})$

Where

f_s = switching frequency

ΔI_{Li} = peak to peak ripple current I_{Li} (assuming 10% of I_{Li})

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

N_2/N_1 = Transformer turn ratio.

B. The calculated value of flyback converter:

Input voltage (V_{in}) = 220 volts

Output voltage (V_O) = 400 volts

Duty cycle (D) = 38.18%

Switching frequency (f) = 25 kHz

Magnetizing inductor (L_m) = 37 mH

Filter capacitor (C_O) = 0.252 µF

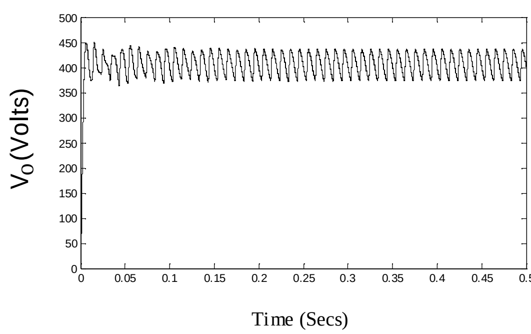

Figure 4. Open loop response of flyback converter

The results of open loop flyback converter is shown in figure 5, which depicts peak to peak ripple voltage (ΔVo) is 53 Volt and maximum overshoot of 12%. 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 flyback converter give design equations:

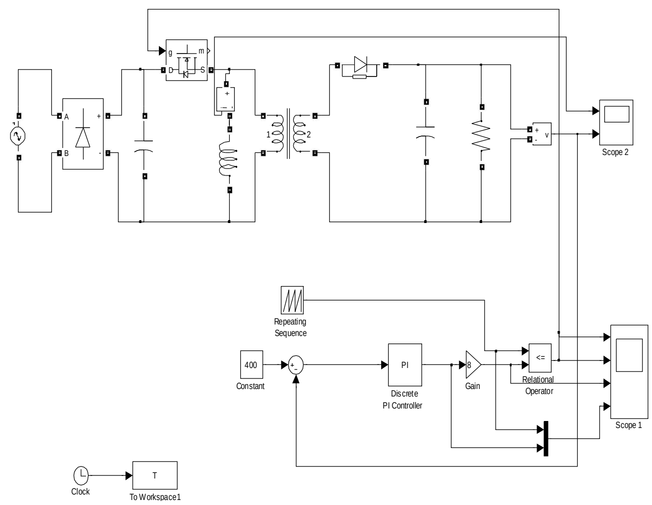

Figure 5. Simulation model of flyback converter for closed loop control

The Simulink Schematic of flyback converter with analog PI controller is shown in figure 5.

The output voltage is sensed V_{out} and compared with the input voltage V_{ref} .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.

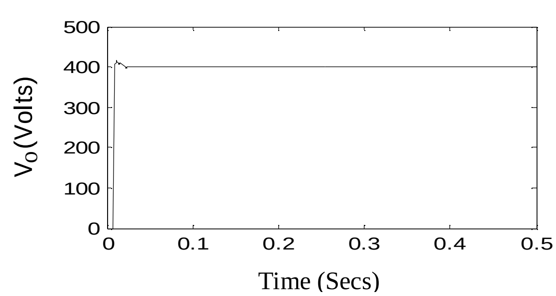

Figure. 6 Closed loop response of Output voltage Vs Time

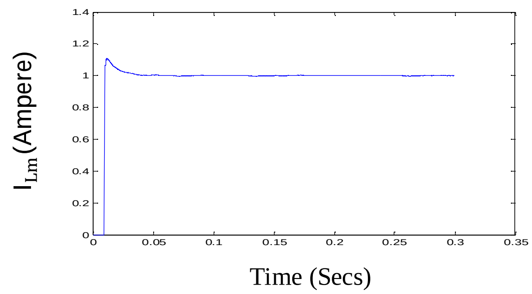

Figure 7. Closed loop response of Magnetization current (I_{Lm}) Vs Time

The results of closed loop flyback converter is shown in fig.7 which has maximum overshoot of 3.82%, settling time 0.01sec and rise time 0.01 sec.

D. Tuning of PI controller by Ziegler-Nicholas Method:

Ziegler-Nicholas is one of the oldest methods of tuning of PID controller. Remove integral and derivative action. Set integral time (*Ti*) to 999 or its largest value and set the derivative controller (*Td*) to zero. Create a small disturbance in the loop by changing the set point. Adjust the proportional, increasing and/or decreasing, the gain until the oscillations have constant amplitude. Record the gain value (*Ku*) and period of oscillation (*Pu*).

Closed-Loop Calculations of *Kc*, *Ti*, *Td*

TABLE I

	K_c	T_i	T_d
P	$K_u/2$	-	-
PI	$K_u/2.2$	$P_u/1.2$	-
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

III. EFFECT DUE TO VARIATION PI CONTROLLER PARAMETERS K_P AND K_I ON OUTPUT VOLTAGE AND INDUCTOR CURRENT

TABLE II. Performance parameters when L_m=47.60 mH, C_O = 0.7656 μF, K_I= 0.019 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
0.000019	1.3	0.01	0.01	2.3	0.01	0.01
0.0001	1.3	0.01	0.01	2.41	0.01	0.01
0.00011	3.82	0.01	0.01	7.62	0.01	0.01
0.00012	18.9	0.0162	0.01	41.42	0.0151	0.01
0.00013	20.5	0.0184	0.01	45.47	0.0177	0.01
0.00014	20.5	0.0186	0.01	47.49	0.0177	0.01

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

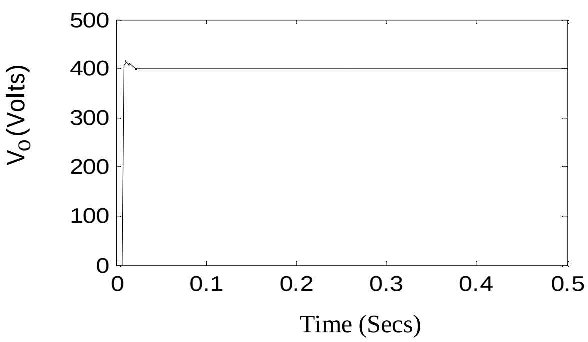

Figure 8. Output voltage Vs time with K_P = 0.00011

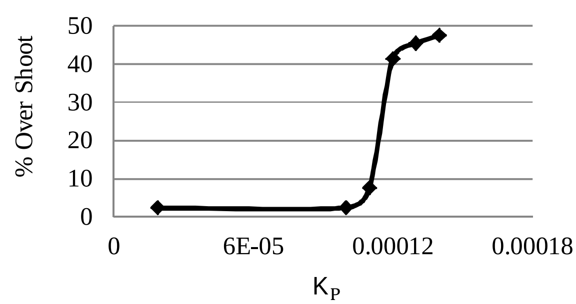

Figure 9. Effect on overshoot due to variation in K_P

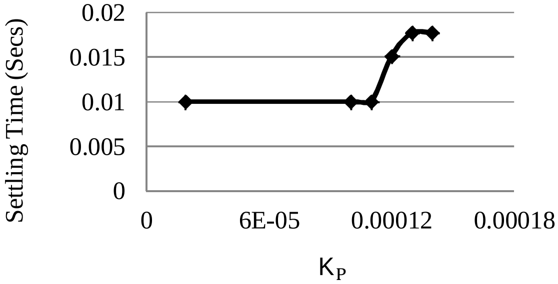

Figure 10. Effect on settling time due to variation in K_P

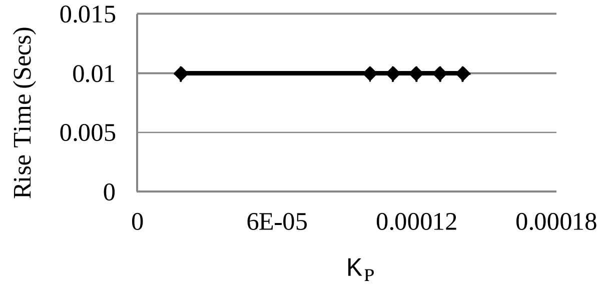

Figure 11. Effect on rise time due to variation in K_P

(b) Performance of magnetization current (I_{Lm}) Vs time graph for flyback converter when K_p value is varied.

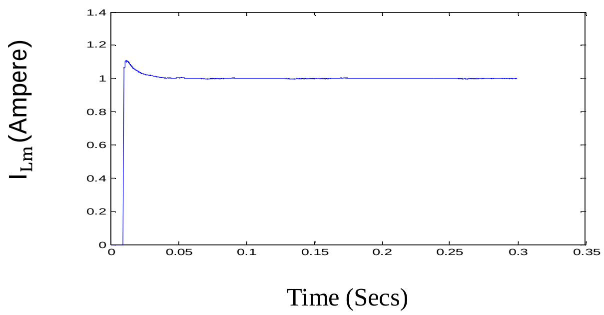

Figure 12. Magnetization current (I_{Lm}) Vs time with K_P = 0.00011

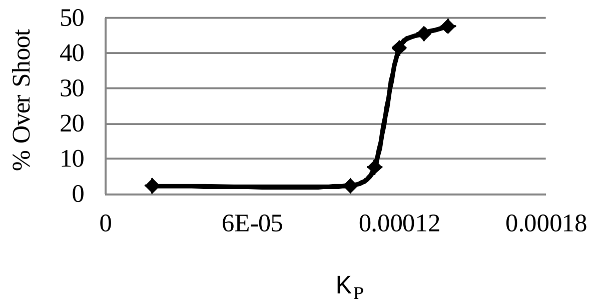

Figure 13. Effect on overshoot due to variation in K_P

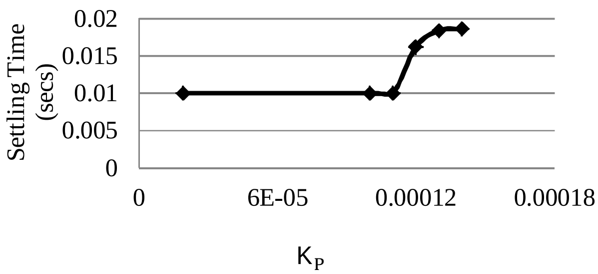

Figure 14. Effect on settling time due to variation in K_P

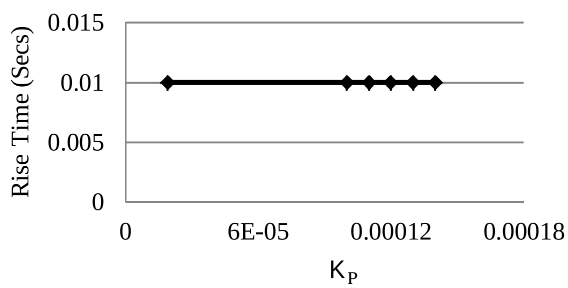

Figure 15. Effect on rise time due to variation in K_P

TABLE III. Performance parameters when L_m= 47.60 mH, C_O = 0.7656 µF, K_P= 0.00011, 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
0.0016	1.5	0.01	0.01	2.76	0.01	0.01
0.0017	1.95	0.01	0.01	3.8	0.01	0.01
0.0018	2.87	0.01	0.01	5.71	0.01	0.01
0.0019	3.82	0.01	0.01	7.62	0.01	0.01
0.002	5	0.01	0.01	10.19	0.0112	0.01
0.0021	6	0.0127	0.01	12.38	0.0121	0.01

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

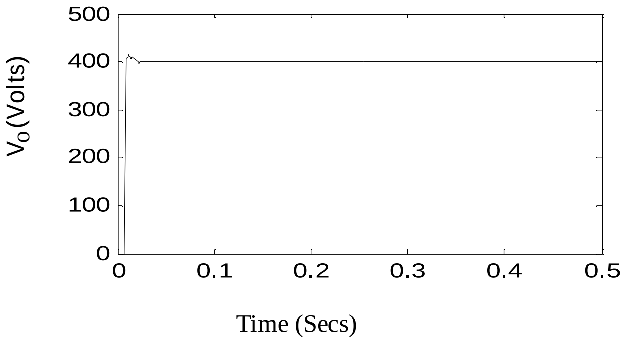

Figure 16. Output voltage Vs time with $K_I = 0.0019$

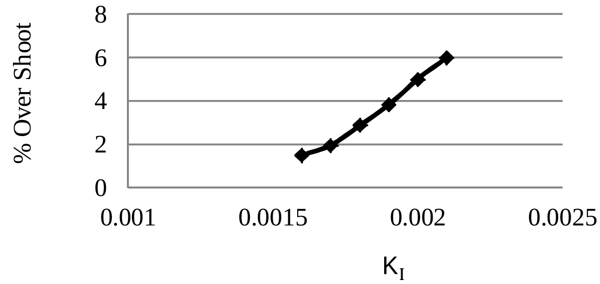

Figure 17. Effect on overshoot due to variation in K_I

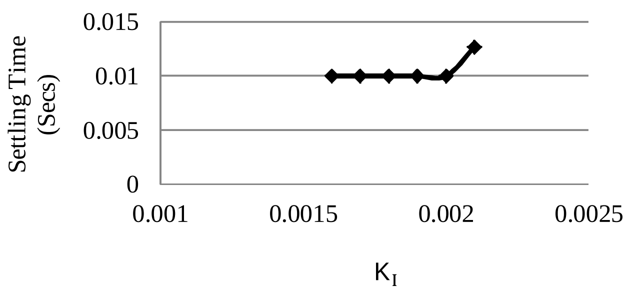

Figure 18. Effect on settling time due to variation in K_I

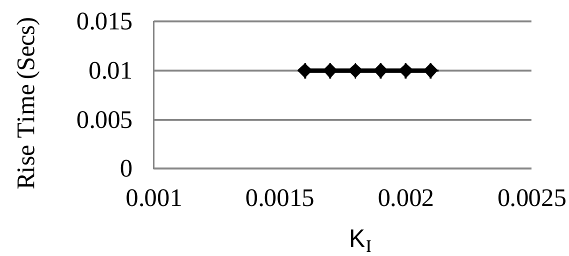

Figure 19. Effect on rise time due to variation in K_I

(b) Performance of magnetization current (I_{Lm}) Vs time graph for flyback converter when K_I value is varied.

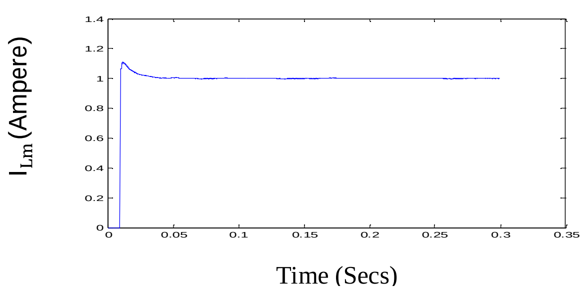

Figure 20. Magnetization current (I_{Lm}) Vs time with $K_I = 0.0019$

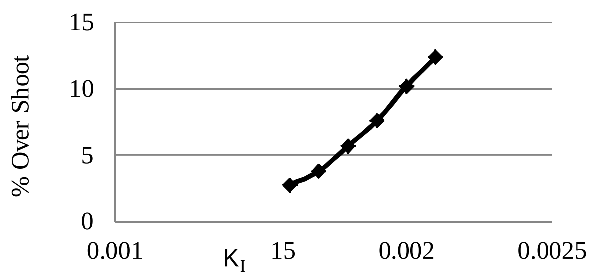

Figure 21. Effect on overshoot due to variation in K_I

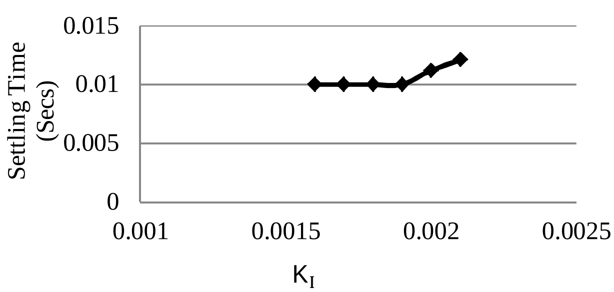

Figure 22. Effect on settling time due to variation in K_I

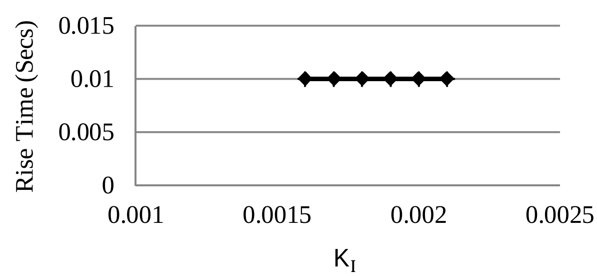

Figure 23. Effect on rise time due to variation in K_I

IV. CONCLUSION

The designing of flyback converters has been carried out for constant voltage applications considering inductor and capacitor as performance parameters. Flyback converter has been designed to deliver 400 volts DC to a 400 watt load. Performance and applicability of this converter is presented on the basis of simulation in MATLAB SIMULINK. Flyback converters are employed for LOW POWER applications below 150 W and with voltages below 500V. Note that the core with an air gap doubles as a transformer and an output choke— saving one heavy and costly component. Now cut the electrical connection between the two parallel inductors and use only magnetic coupling between the two L's by purposefully winding them on the same magnetic core. This makes for a two winding inductor--each separately wound and isolated electrically from each other except for the common magnetic core coupling . We now lose the common ground. Current no longer flows simultaneously in the two electrically isolated inductor windings due to the core coupling alone because the primary and the secondary have their own seriesswitches. Moreover, these switches can act in a complementary fashion so that when one is on the other is off.

The design concepts are validated through simulation and results obtained show that a closed loop system using flyback 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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