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Simulation of Flyback Converter with Peak Current Mode Control

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Abstract: The most of the analogue and digital electronic systems requires a DC power supplies, many of the system would expect that these power supplies should be of high efficiency, smaller size and weight. The low cost high efficiency flyback converter is most widely used in a DC power supplies. This paper presents the analysis and simulation of a flyback converter in a peak current mode control.

Keywords: Flyback converter, DC power supply, peak current mode, Sub harmonic oscillation.

I. INTRODUCTION

The power converters are broadly classified as non-isolated converter and isolated converter. Non-isolated converter such as buck, boost, and buck-boost converters, can be easily built at lower cost. But they do not provide any protection to the load or to the source when subjected to the high current or voltage. Whereas isolated converters such as flyback, push-pull, forward which are derived from the basic non-isolated converters provides isolation and protection for the source as well as to the load.

To provide a stable DC supply, the regulation of DC output voltage is necessary. The output voltage is regulated using a feedback loop in the system [4]; voltage mode control and current mode control methods are available to control the output voltage. Traditionally voltage mode control technique which is a single loop control method is used in which the output voltage is regulated by direct controlling the duty cycle of the switch. The drawback of this method is poor dynamic performance and prone to input voltage variations [5]. The current mode control is a two loop system with inner current loop and outer voltage loop, the output voltage is not directly controlled by the duty cycle but it will depend on the inductor current.

Current Mode Controls are classified as a peak current mode control and average current mode control. In average current mode control, average value of the inductor current is controlled and in peak current mode control, the peak of the inductor current is sensed and controlled. The power switch is turned on by the fixed frequency clock and tuned off when the peak of the inductor current reaches the threshold level set by the outer voltage loop. Peak current mode control is a widely used method because of its inherent cycle by cycle current limiting to protect the inductor from the over current. For the continuous current conduction mode the peak current mode control suffer from the problem of sub harmonic oscillation for the duty cycle above 50%.This problem is avoided by a slope compensation method.

This paper presents the analysis of peak current mode control for the flyback converter. Section II describes the basic principle of operation of flyback converter. Output voltage regulation by voltage mode control and current mode control is analyzed in section III. Section IV presents the MATLAB/Simulink model of flyback converter and results of the current mode controlled flyback converter.

II. PRINCIPLE OF OPERATION OF FLYBACK CONVERTER

Flyback converter is basically derived from the non-isolated buck-boost converter; fig 1 below shows the circuit diagram of the basic flyback converter.

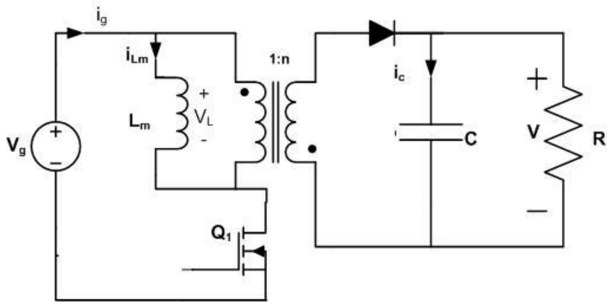

Fig 1 Flyback converter circuit

The fig 1 represents the transformer equivalent circuit model of flyback converter, where the magnetizing inductor L_m functions similar to the inductor of the buck-

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boost converter. With the fixed frequency of the PWM, the input voltage is chopped at desired on and off time. The average output voltage V obtained will depend on the on-off duration of the switch. Basic principle of operation of flyback converter is similar to the buck-boost converter. The energy is stored in the primary magnetizing inductance when the switch is closed initially the energy will not be transferred to the secondary because diode is reverse biased due to winding polarity. This energy stored in the primary magnetizing inductor is transferred to the secondary winding when switch is opened. The flyback transformer performs two functions, it behaves as an inductor while storing the energy and it also behaves as a transformer by transferring the energy from primary to the secondary. The average output voltage of the converter is given by an equation

$$V = \left(\frac{N_2}{N_1}\right)\left(\frac{D}{1-D}\right)V_g \qquad (1)$$

Where N_1 and N_2 is the number of turns in the primary and secondary winding respectively, D is the duty cycle of the switch the output voltage is controlled by regulating the duty cycle and turns ratio of the flyback transformer.

III. OUTPUT VOLTAGE REGULATION

In switched mode power converter operating with fixed frequency pulse width modulation technique, the regulation of output voltage is done by controlling the on-off duration of the power switch. For a power converter output voltage regulation achieved is through the feedback, which is necessary to provide a stabilized DC voltage.

A. Voltage mode control

Voltage mode control is a direct duty cycle control method, the output voltage of the converter is sensed and it compared with the required reference voltage to generate the error signal. The error signal is then given to the controller circuit. The output of the controller is compared with the fixed ramp wave to generate the PWM pulse for the switch.

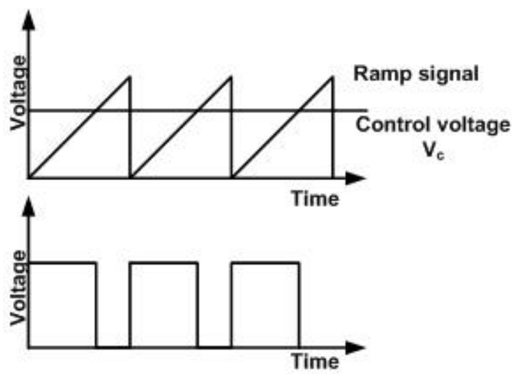

Fig. 2.Voltage mode control pulse width modulation

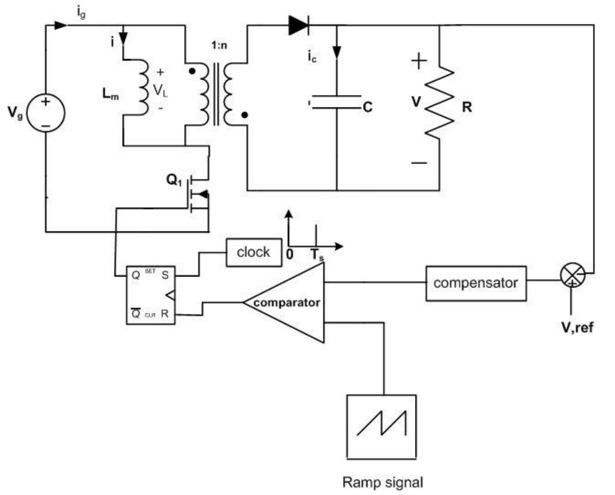

Fig 3 voltage mode controlled flyback converter

B. Current mode control

Current mode control is a two loop system with outer voltage loop and inner current loop. The outer voltage loop will sense DC output voltage of the power circuit and then generates the control signal through the compensator circuit. The control signal from the outer voltage loop is compared with the current sensed by the inner current loop.

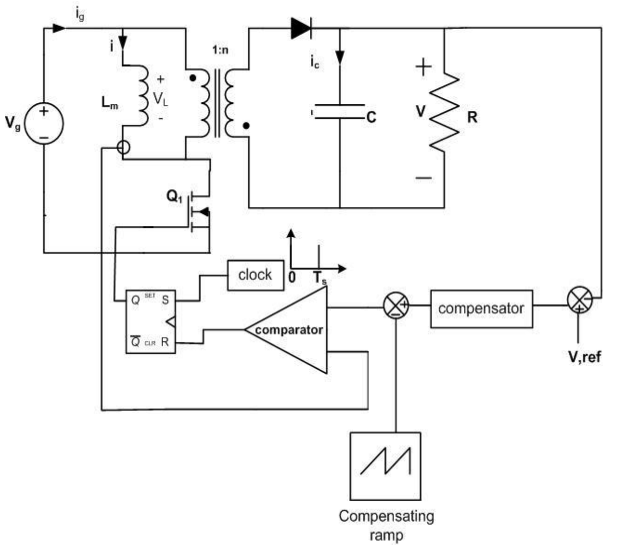

Fig 4 Current mode controlled flyback converter

Fig 4 shows the circuit of peak current mode control for the flyback converter. The switch is initially closed by the fixed frequency clock signal. During this duration the inductor current increases with the slope of m_1. Turn off of the switch is controlled by the control signal V_C. Whenever the peak of the inductor current reaches the control signal the switch is turned off. At this duration the inductor current decreases with a slope of m_2, as shown in the fig 5 below

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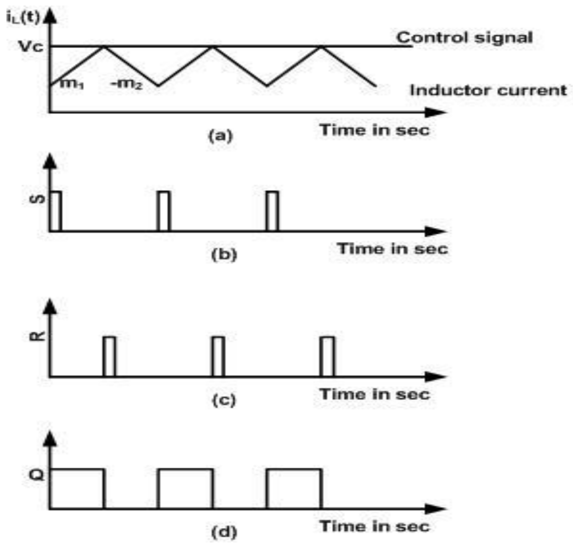

Fig 5 (a) Inductor current and control voltage (b) Initial clock set signal to turn on the switch (c) Reset signal to rest the latch (d)PWM signal given to the switch

The method can be considered as Current programmed controller since the slope of the current is continuously monitored and controlled actions are initiated accordingly.
Current programmed controller suffers from the problem of sub harmonic oscillation for the duty cycle exceeding the 50%. Fig 6 below shows the steady state inductor current and perturbed inductor current. The initial perturbation in the inductor current will decay after several cycle of operation for the duty cycle less than the 50% but this initial perturbation will go on increases for the duty cycle more than the 50%.Δi_{Lo} is the initial perturbation in the inductor current when the switch is closed, Δi_{L1} is the perturbation at the end of one switching cycle.
Perturbation in the inductor current for one switching cycle is given by

$$\Delta i_{L1} = -\left(\frac{m_2}{m_1}\right)\Delta i_{L0} \qquad (2)$$

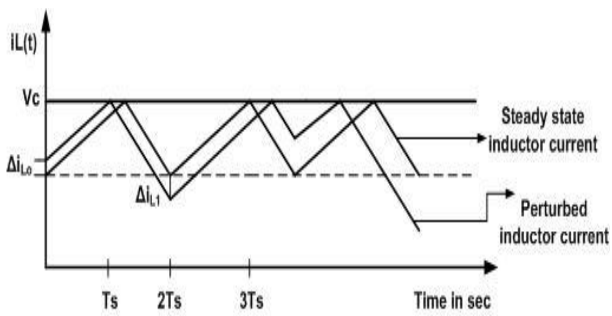

Fig. 6.Sub harmonic oscillation in the inductor current

C. slope compensation
Sub harmonic oscillation in the peak current mode control is damped by adding compensating ramp signal with a slope m_a to the control voltage V_C

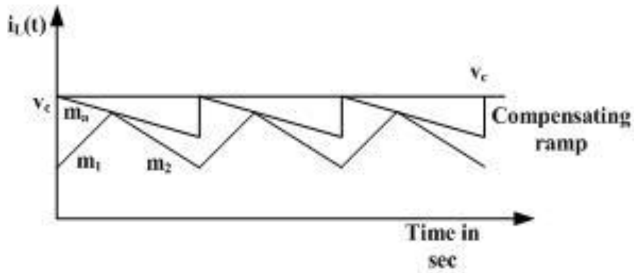

Fig. 7. Addition of the artificial ramp on the control signal

By considering the n switching cycle perturbation in the inductor current at n[th] switching cycle is given by

$$\Delta i_{Ln} = -\left(\frac{m_2 - m_a}{m_1 + m_a}\right)^n \Delta i_{L0} \qquad (3)$$

To ensure stable operation under current mode control the term $(m_2\text{-}m_a)/(m_1\text{+}m_a)$ should be maintained less than unity.

IV.MATLAB /SIMULINK SIMULATION RESULTS AND ANALYSIS

D. Simulation parameters of flyback converter

TABLE I SIMULATION PARAMETERS

Circuit Parameter	Value
Input voltage	325V
Output Voltage	30V
Duty cycle	40%
Output current	8A
Switching frequency	40KHz

E. Open loop simulation of flyback converter
MATLAB simulation model of flyback converter is shown in Fig 8. The 230V 50Hz AC supply is taken as input and then converted into DC which is an input V_g for the flyback converter (Fig 9).This unregulated DC input voltage is converted into the regulated DC voltage through the flyback converter.

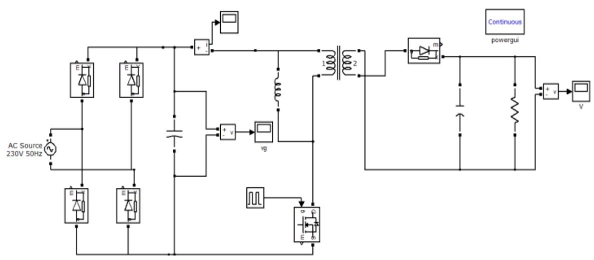

Fig 8.Open loop simulation model of flyback converter

In the open loop simulation circuit a fixed frequency and duty cycle pulse is given to the switch to convert the unregulated DC voltage to a 30V regulated DC voltage. Fig 10 shows the waveform of inductor current with

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maximum value 3A and minimum value of 0.27A. Fig 11 shows the output voltage waveform with the maximum value of 28V.

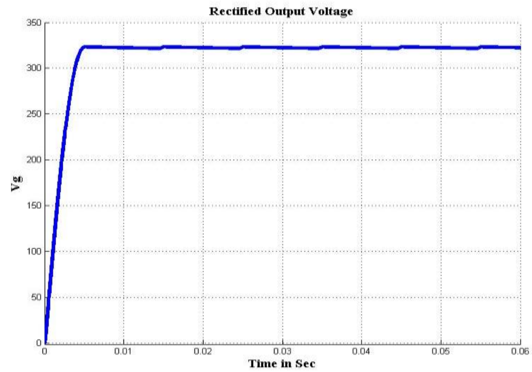

Fig. 9. DC voltage V_g obtained from the rectifier circuit

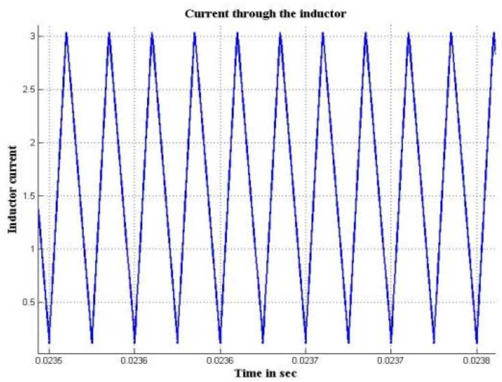

Fig. 10. Current through the inductor with continuous current conduction mode

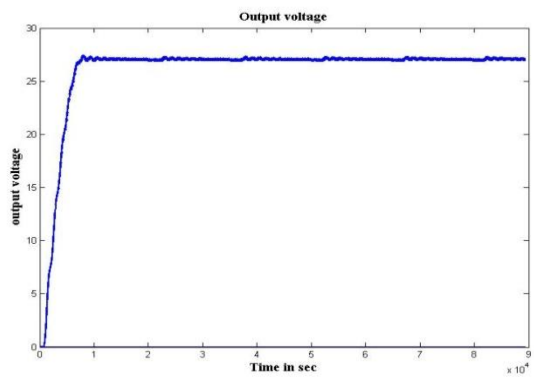

Fig. 11. Regulated DC output voltage of the flyback converter

F. closed loop simulation of flyback converter without slope compensation

Inorder to analyse the effect of subharmonic oscillation for the duty cycle graeter than 50% flyback converter model is simulated for the output voltage V of 50V reference.

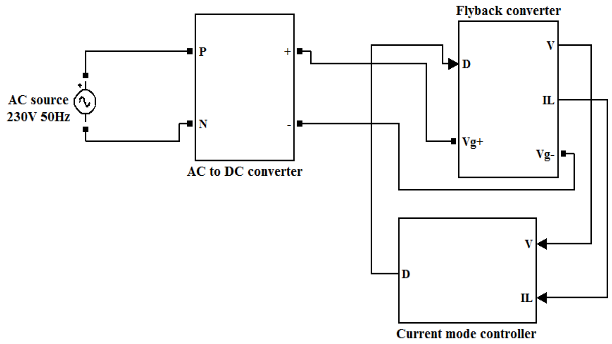

Fig. 12. MATLAB simulation model of the current mode controlled flyback converter

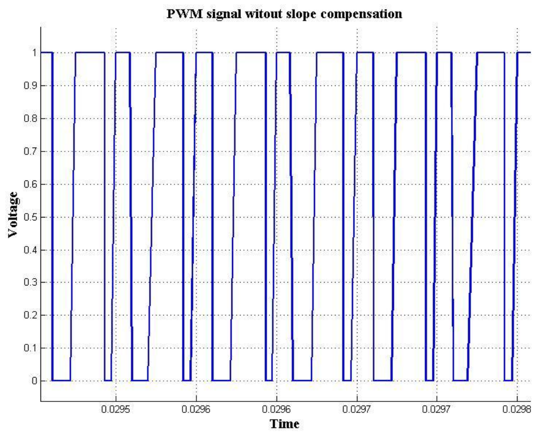

Fig. 13. PWM pulse without slope compensation

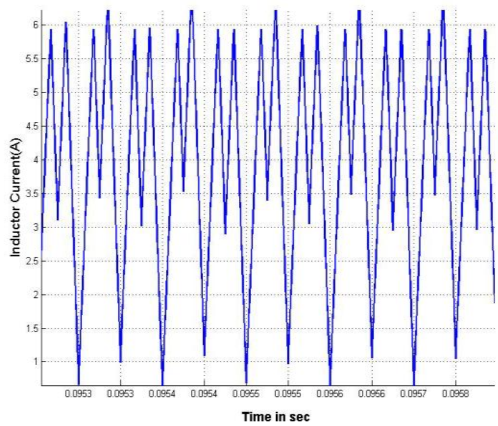

Fig. 14.Current through the magnetizing inductor without slope compensation

Sub harmonic oscillation in the inductor current for the duty cycle greater than the 50% is shown in the fig. 14. Fig. 15 shows the DC output voltage with the maximum voltage of 50V with the sub harmonic oscillation. Fig. 16 shows the output current of the flyback converter with average value of 13A.

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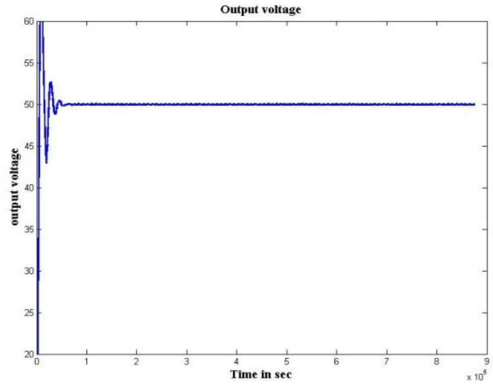

Fig. 15. DC regulated output voltage obtained from the flyback converter

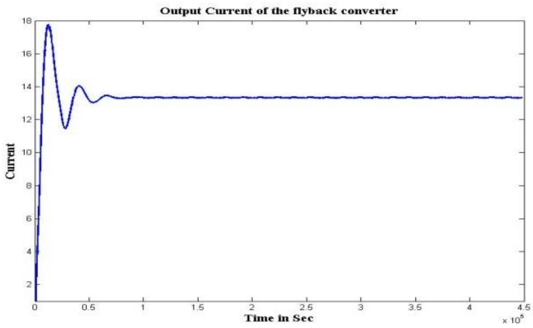

Fig. 16. Output current obtained from the flyback converter

G. closed loop simulation of flyback converter with slope compensation

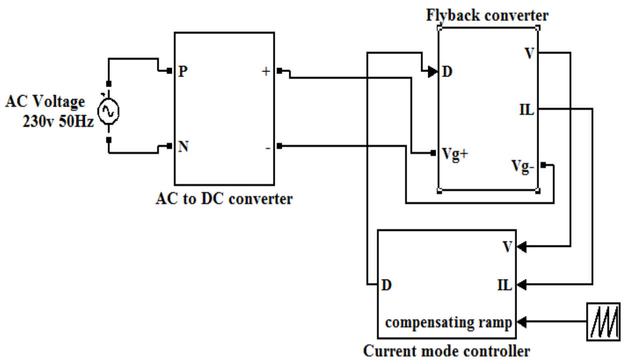

Fig. 17. MATLAB simulink model of current mode controlled flyback converter with the slope compensation

MATLAB simulink model of the current mode controlled flyback converter with slope compensation is shown in fig.17.Fig.18 shows the external ramp added to the control signal to provide the slope compensation. Inductor current waveform with elimination of sub harmonic oscillation is shown in fig.19.Output voltage of flyback converter with average value of 50V is shown in the fig.20.

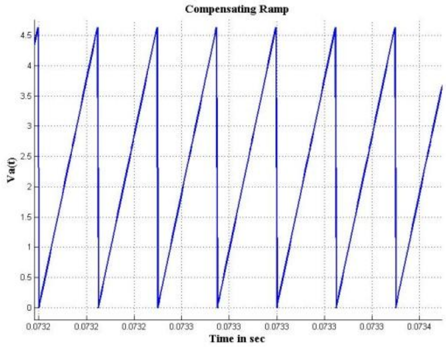

Fig. 18.Compensating ramp signal added to the control voltage

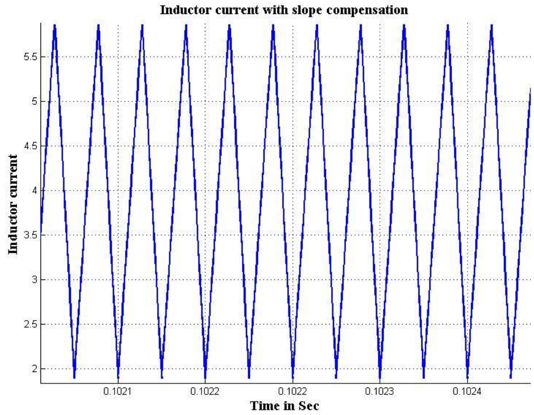

Fig. 19. Current through the magnetizing inductor with slope compensation

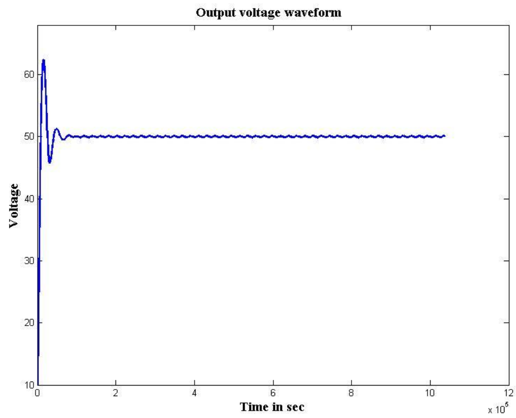

Fig. 20. Output voltage of flyback converter with slope compensation

V. CONCLUSION

In this paper simulation of flyback converter with peak current mode control is analyzed using a MATLAB/ Simulink. Effect of the sub harmonic oscillation for the duty cycle more than the 50% is observed through the simulation. Effect of slope compensation on the sub harmonic oscillation is also observed by the result obtained from the simulation.

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