Simulation of Fly Back Converter for Continuous and Discontinuous Mode of Operation

Irfan Khan(1)
(1)M.E. Scholar, Electrical Engineering Department
UIT RGPV, Bhopal, India
Email: (1) irfan.khan5489@gmail.com

Bhoopendra Singh(2), Toshi Sharma(3), Jayadeep Srikakolapu(4)
(2)Asst. Professor, (3), (4) Contract Asst. Professor
Electrical Engineering Department
University Institute of Technology, RGPV, Bhopa,l India

***Abstract*- This paper explains the mathematical modeling and simulation of fly back converter for continuous and discontinuous mode of operation for low power application. The simulation model of the flyback converter is developed to support and enhance the Power Electronics course at the under graduate level. Input to the fly-back converter is the unregulated supply which is obtained by rectifying AC supply. In the proposed model, DC battery fictitiously represents the unregulated supply. All the results are observed and compared when coupled inductor in the fly back circuit is replaced by a linear transformer.**

Index Terms— *Coupled Inductor, flyback converter, Linear Transformer, Power Electronics,*

I. INTRODUCTION

The dc-dc converter converts a fixed dc to variable dc. DC-DC converters can be classified as isolated and non-isolated type converters. Flyback converter is one of the simple topology in isolated converter. For simplicity and economic considerations now a days the flyback converter is widely used [1-2]. Classification of various types of DC-DC converter is shown in fig 1. The basic topology of a flyback converter is presented in fig 2.

The use of transistor switch with primary winding means that the transformer can only be driven only in one direction, this results in large core size [5]. Hence, in the proposed model the topology used for flyback comprises a coupled inductor in place of transformer.

The flyback primary inductance has to be significantly lower than required for a true transformer, since high peak currents are needed. This is normally achieved by gapping the core [4]. The gap reduces the inductance, and most of the high peak energy is then stored in gap. In the flyback converter, the secondary inductance is in series with the output diode and a filter capacitor across the load. When the transistor is turned on, current builds up in the primary and energy is stored in the core, this energy is then released to the output circuit through the secondary when the switch is turn off.

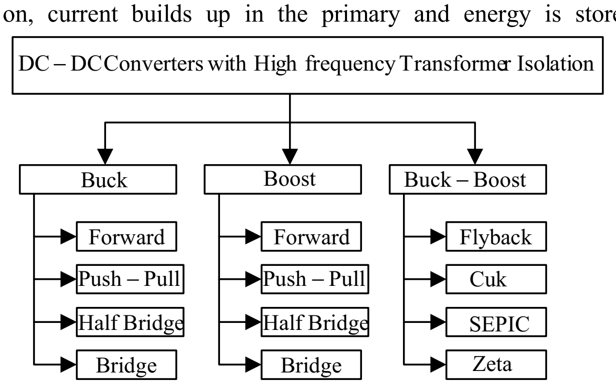

Fig.1. Classification of DC – DC Converter

Applications of flyback converters-

- In Photocopy machines and Xenon flash lamps
- In Switch mode power supply (SMPS)
- In high voltage production in CRTs
- Isolated gate driver circuits
- High Voltage generation (e.g. for Xenon flash lamp laser copier etc.)
- Low cost multiple output power supplier(e.g. main PC supply < 250W)
- Plasma lamp, Voltage multiplier

There are two possible modes of conduction available for the analysis of a Flyback Converter, they are: Discontinuous mode of Conduction and Continuous mode of Conduction [7]. This paper mainly focuses on the technique to explain the working of a flyback converter in the two aforementioned modes of conduction to the undergraduate students at UIT RGPV. The study and simulation implementation of the flyback converter is done in both the modes. In the proposed model, comparison of primary voltage, secondary voltage and secondary current and output power is done by simulating flyback model once by connecting the coupled (mutual) inductor and then the linear transformer. Improvement in the primary voltage, secondary voltage & current and output power is observed when flyback converter is simulated using a coupled inductor instead of a linear transformer. Also, with the use of mutual inductor transient & study state performance is improved. In this paper, a control of the fly-back converter is developed for closed loop operation as well.

II. CONFIGURATION OF FLYBACK CONVERTER

The fly back converter topology basically consists of a coupled inductor, a PWM switch on the primary side and a diode on the secondary side of the coupled inductor. Fig.2 shows the basic configuration of a fly back converter. The flyback converter can be fed with a constant dc input or a variable dc input. The diode direction will be varied according to the winding connection of the coupled inductor. The number of windings on the secondary side of the coupled inductor can be increased according to the application. To avoid complexity in the circuit the circuit has been operated with constant dc source. A high switching frequency device ("Q_1") can be used as a switch. MOSFET has been used to get fast dynamic control over duty ratio. The coupled inductor has been used for voltage isolation.

978-1-4799-6876-3/14/$31.00 ©2014 IEEE

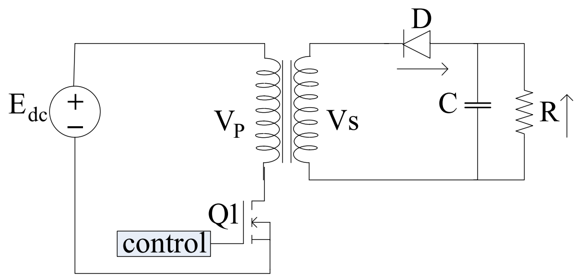

Fig.2. Flyback Converter Topology

III.PRINCIPLE OF OPERATION

The Principle of operation of a flyback converter has been explained for Continuous and Discontinuous mode of operation.

A. *Continuous Mode of Operation*

For continuous mode of operation flyback converter has two modes of operation:

Mode1: When switch Q_1 is turned on

Mode2**:** When switch Q_1 is turned off

a) *MODE 1:* This mode starts when the switch Q_1 has been turned on and valid for $0 < t \leq kT$, where k is the duty cycle ratio, T is the switching period and kT is ON time of the switch. Let The voltage across the primary winding of the inductor be V_p then the primary current I_p starts build up the energy and stores energy in the primary winding. Diode D_1 is reverse biased due to the emf induced in the secondary winding with opposite polarity. Thus, energy transfer from input source to output connected load has been blocked. The output filter capacitor C maintains the output voltage and supplies the load current I_L. The mode -1 equivalent circuit of the configuration has been shown in Fig.2.

The linear increase in the primary current I_P has been given by:

$$I_p = \frac{V_p}{L_p} t \tag{1}$$

Where, L_P is the primary magnetizing inductance
At the end of this mode, at $t = kT$, the peak primary current reaches a value equal to $I_{p(peak)}$ as given by:

$$I_{p(peak)} = I_{p(peak)}|(t = kT) = \frac{V_s}{L_p} kT \tag{2}$$

The peak value of the secondary current is given by:

$$I_{se(peak)} = \left(\frac{N_p}{N_s}\right) I_{p(peak)} \tag{3}$$

In this mode there has been a linear increase in the primary current since the supply voltage appears across the primary winding inductance. The mathematical relation for the linear rise the primary current and the supply voltage is

$$E_{DC} = L_p \ \frac{d}{dt} I_p \tag{4}$$

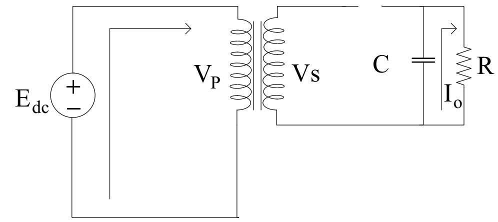

Fig.3. Equivalent circuit in mode – 1

Where, E_{DC} is the input DC voltage, L_p is inductance of the primary winding, I_p is the instantaneous current through primary winding. In this mode the capacitor is assumed to be fully charged so the secondary winding voltage remains almost constant and is equal to:

$$V_s = E_{DC} \frac{N_2}{N_1} \tag{5}$$

The linear rise of primary winding current during this mode has been shown in fig. 6(a) & 6(b) for continuous and discontinuous modes respectively. In case, when the circuit works in continuous mode of operation, the magnetic flux in the inductor core is not zero before the next cyclic turning ON of switch Q1. At the end of switch conduction the energy stored in the magnetic field of the fly back inductor is equal to

$$\text{Stored Energy} = \frac{1}{2} L_p I_p^2 \tag{6}$$

Due to the previous stored charge in the output capacitor, the load connected will get uninterrupted current, although secondary winding does not conduct.

b) *MODE 2:* This mode starts with turn off of switch Q1. Although the winding polarities has been reversed the primary current $I_p$does not change instantaneously This causes diode D1 to turn on and charges the output capacitor C and also delivers current to the resistive load R. The secondary winding side current that decreases linearly and is given by:

$$I_s = I_{s(peak)} - \frac{V_o}{L_s} t \tag{7}$$

Where, L_s is the magnetizing inductance of the secondary side. Before the start of the next cycle, I_{se} secondary winding current decreases linearly to zero in discontinuous mode of operation. Because energy is transferred from the sources to the output during the time interval 0 to kT only, the input power is given by:

$$P_i = \frac{1}{2} \frac{L_p}{T} I_{p(peak)}^2 = \frac{(kV_p)^2}{2fL_p} \tag{8}$$

For an efficiency of η, the output power P_o can be found from:

$$P_o = \eta P_i = \eta \frac{(V_p k)^2}{2fL_p} \tag{9}$$

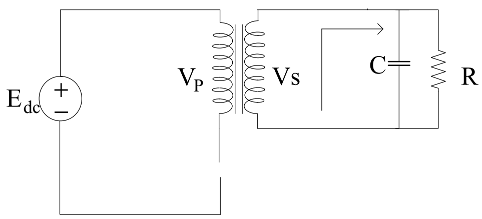

Fig.4. Equivalent circuit in mode – 2

Equating output power, $P_o = \frac{V_o^2}{R_L}$ the output voltage V_o can be obtained as:

$$V_o = V_p k \sqrt{\frac{\eta R_L}{2fL_p}} \quad (10)$$

The allowable duty ratio or maximum duty ratio, K_{max} for the discontinuous mode can be given by:

$$K_{max} = \frac{V_o}{V_{p(min)}} \sqrt{\frac{2fL_p}{\eta R_L}} \quad (11)$$

Therefore, the average output voltage V_o at K_{max} can be given by:

$$V_o = V_{p(min)} k_{max} \sqrt{\frac{\eta R_L}{2fL_p}} \quad (12)$$

The functional equivalent circuit of the configuration in this mode has been shown in fig. 2. The secondary winding current has been indicated in the circuit. The diode D1 connected in the secondary circuit is now forward biased and is conducting as shown in Fig.3. It can be seen that the magnitude and current direction in the secondary winding is such that the mmf produced by the two winding does not have any abrupt changes. The output capacitor is usually sufficiently large such that its voltage does not change appreciable in a single switching cycle but over a period of several cycles the capacitor voltages builds up to its steady state values. Magnitude of the output capacitor voltage depends on various factors, like, input DC supply, fly-back mutual inductors parameters, switching frequency, switch duty ratio and the load at the output. The secondary winding current decay linearly as it flow against the constant output voltage (V_o). The linear decay of the secondary current can be expressed as follows:

$$L_s \frac{dI_s}{dt} = -V_o \quad (13)$$

Where L_s & I_s are secondary winding inductance and current respectively. V_o is the stabilized magnitude of output voltage.

B. Discontinuous Mode of Operation

For discontinuous mode of operation flyback converter operates in following three modes:

Mode1: When switch Q_1 is turned on
Mode2: When switch Q_1 is turned off
Mode3: When switch Q_1 & D_1 is off

Working of modes 1 and 2 are same in both continuous and discontinuous mode of operation. Mode 3 for discontinuous mode of operation has been explained below.
During discontinuous mode, the diode stops conducting after the winding emf as well as current falls to zero due to complete transfer of the magnetic field energy to the output.

a) *MODE 3:* The functional equivalent circuit of the configuration in this mode has been shown in fig. 5. The output capacitor however continues to supply uninterrupted voltage to the load. This part of the circuit operation has been referred to as mode-3 of the circuit operation. This mode is present only in the discontinuous mode of operation.

The Turn ON of Switch Q1 ends this mode and circuit goes again to mode -1.

To ensure the discontinuous conduction over the entire low frequency period, the time constant of the snubber circuit and switching time of circuit must check the following relation [3].

- $RC >$ Switching time of circuit (0.5m sec)
- If, $(RC - T_{ON})$ is positive then it is discontinuous mode of operation

Where, R & C are the snubber resistance & capacitor respectively. Since the snubber capacitor voltage is kept higher than the reflected secondary voltage. "f" is the switching frequency. Moreover, to ensure the continuous conduction over all the network period[6].

- $RC >$ Switching time of circuit (0.5m sec)
- If, $(RC - T_{ON})$ is negative than it is continuous mode of operation

NOTE:-

- If RC is greater than 0.5 m sec than wave forms are discontinuous
- If RC is less than 0.5 m sec than wave forms are continuous
- If difference between RC and T_{on} is positive than waveforms are discontinuous
- If difference between RC and T_{on} is Negative than waveforms are continuous

Fig.6 (a) and 6(b) shows, the voltage and current waveforms of the winding for a complete cycle.
Continuous versus discontinuous mode of operation: In continuous mode of operation switch Q1 is turn on before the secondary current falls to zero. The continuous mode can provide higher power capability for the same value of peak current $I_{p(peak)}$. It means that, for the same output power, the peak current in the discontinuous mode are much higher than those in continuous mode. As a result, more expansive power transistor with higher current rating is needed than those in continuous mode.

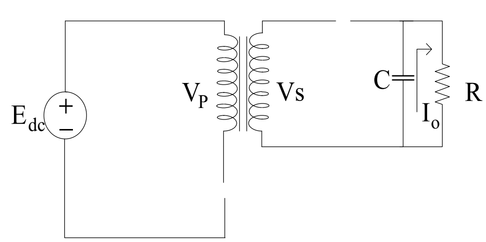

Fig.5. Equivalent circuit in mode – 3

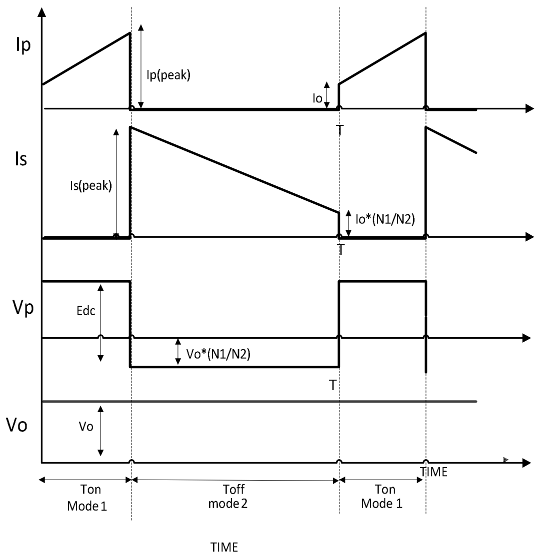

Fig.6. (a) Flyback circuit waveform under continuous mode

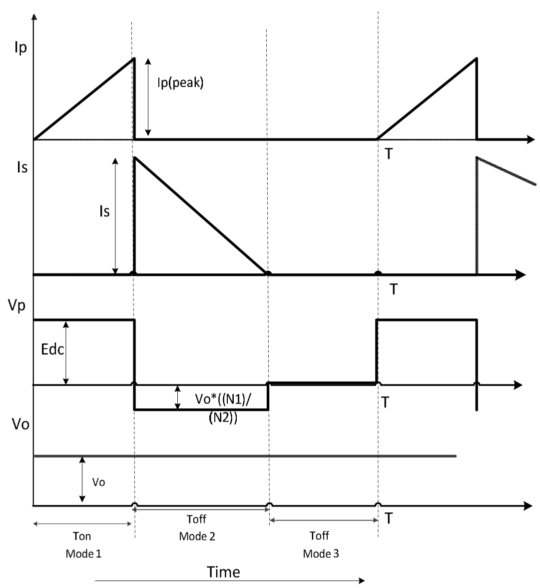

Fig.6. (b) Flyback circuit waveform under discontinuous mode

Moreover, the higher secondary peak currents in the discontinuous mode have a large transient spike at the instant of turn off. However, despite all these problems the discontinuous mode is still more preferred than the continuous mode [7].

IV.SIMULATION IMPLEMENTATION

Fig.7 represents the simulation of the fly-back converter for continuous and discontinuous mode. Before implementation of hardware it is usually advised to simulate the circuit because of the following reasons. Simulation saves a lot of human efforts we can make changes in the circuitry and observe the results thus obtained. It saves time since simulation is more flexible compared to hardware.

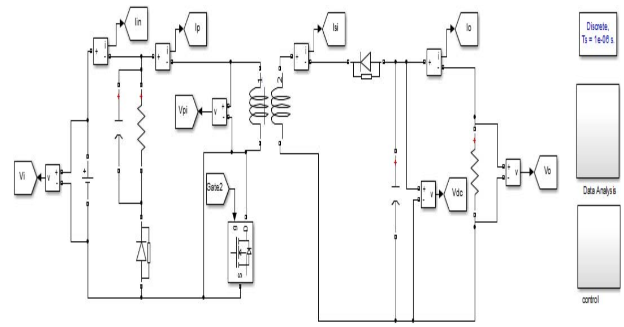

Fig.7. Simulation model of fly-back converter in a open loop and closed loop

V.CONTROL SCHEME

A. *Open Loop*: Firing of switch is controlled by pulse generator; switch is fired at fixed duty ratio. Duty ratio is calculated as-

$$\alpha = \frac{T_{on}}{T} \tag{14}$$

Where, $T_{on}$the on time of cycle and T is the total time.

B. *Closed loop*: Fig.8 show the block diagram of closed loop control scheme. Firing of switch is controlled by the output voltage and inner current loop. The output voltage is sensed and is compared with a reference values .The error generated is passed through a PI controller now the output of PI controller is compared with the input current, the error then generated is fed as an input to the PWM generator and output is given to the switch.

VI.RESULTS

The results obtained are as follows: Fig.9 (a) and (b) shows the waveforms of primary current, secondary current, input voltage, output voltage, output current and primary voltage in continuous and discontinuous mode of operation in open loop control of flyback respectively.

Fig.10 shows the waveforms of primary current, secondary current, input voltage, output voltage, output current and primary voltage in continuous and discontinuous mode of operation in closed loop control of flyback respectively.

Fig.11 (a) and (b) shows the waveforms of primary current, secondary current, input voltage, output voltage, output current and primary voltage in continuous and discontinuous mode of operation in open loop control of flyback with three windings at the secondary side respectively.

Fig.12 shows the waveforms of primary current, secondary current, input voltage, output voltage, output current and primary voltage in continuous mode of operation in close loop control of flyback with three windings at the secondary side respectively.

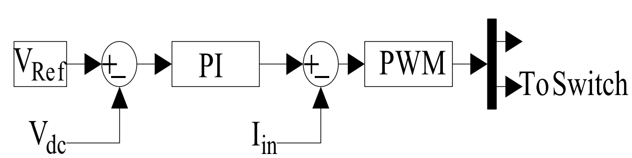

Fig.8. Block diagram for closed loop control

Fig.13 (a) and (b) shows the primary current, secondary current, input voltage, output voltage, output current and primary voltage in continuous and discontinuous mode of operation in open loop control of flyback converter implementing linear transformer.

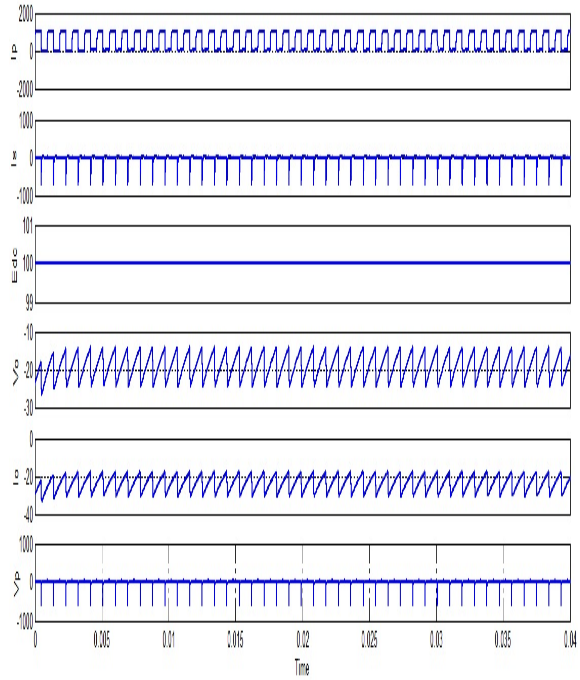

Fig.9. (a) Continuous Mode of Conduction in Open loop control of Flyback

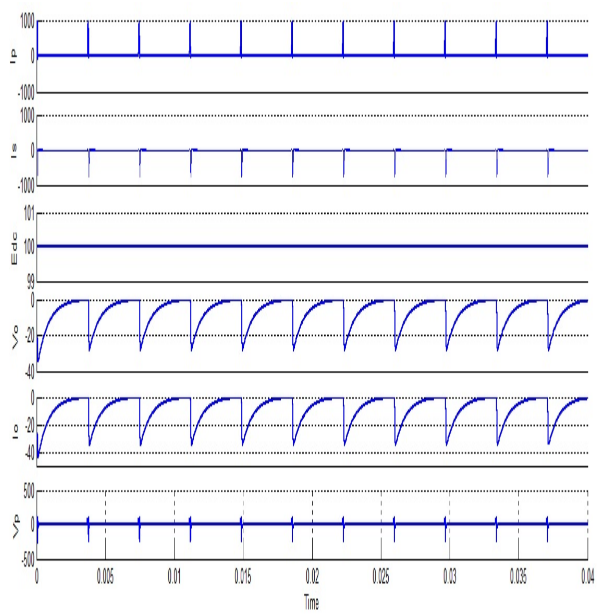

Fig.9. (b) Discontinuous Mode of Conduction in Open loop control of Flyback

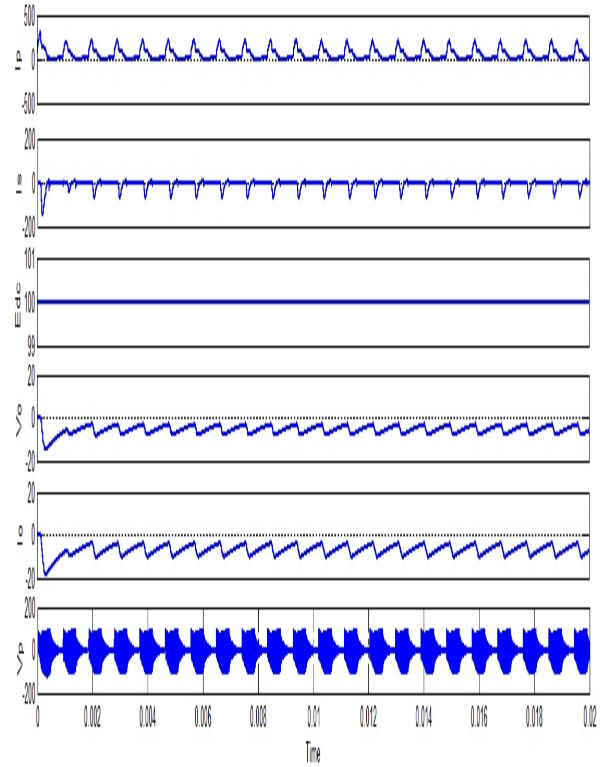

Fig.10. Continuous Mode of Conduction in Closed loop control of Flyback

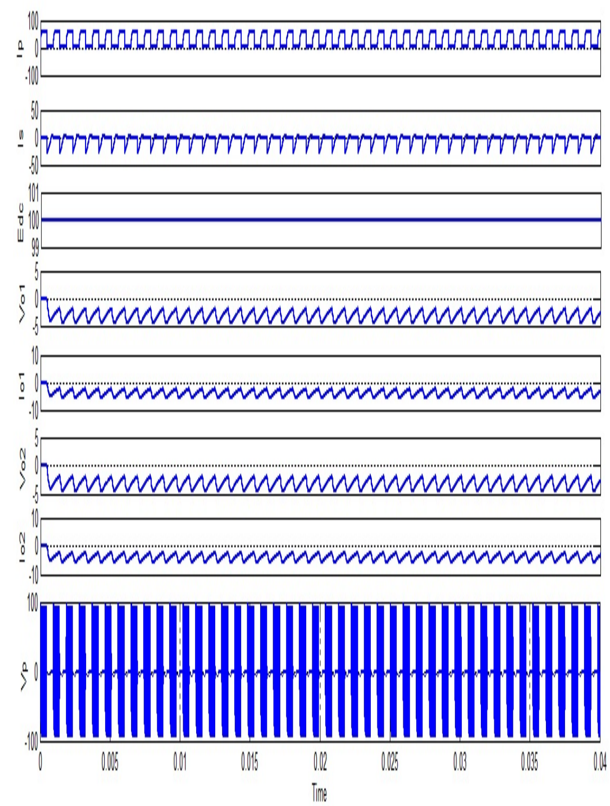

Fig.11. (a) Continuous Mode of Conduction in Open loop control of Flyback with three winding

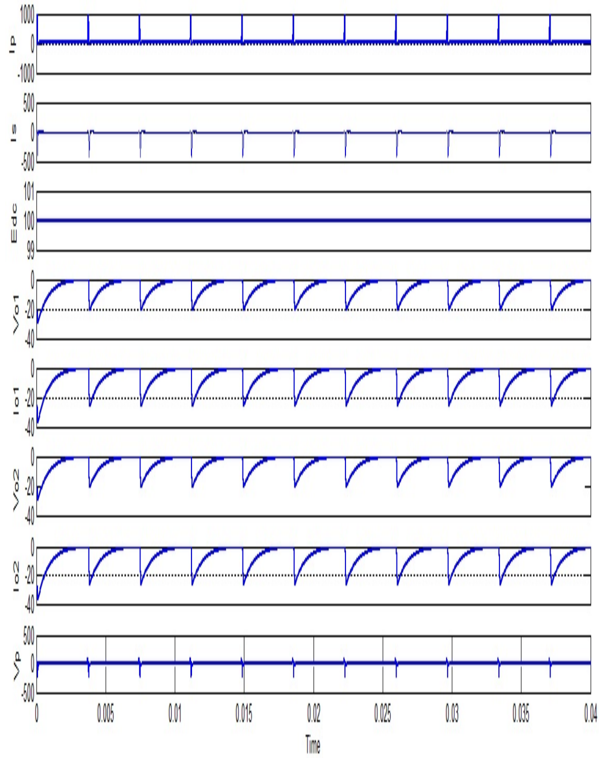

Fig.11. (b) Discontinuous Mode of Conduction in Open loop control of Flyback with three winding

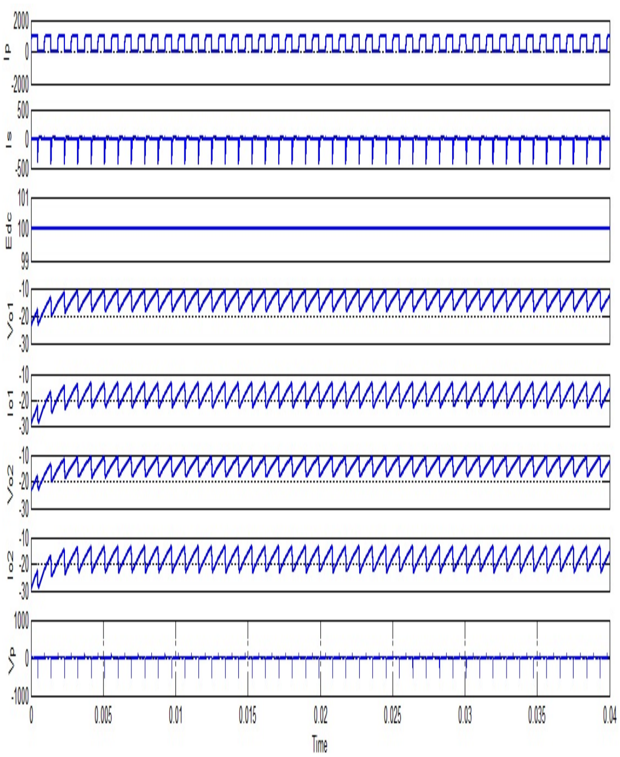

Fig.12. Continuous Mode of Conduction in Close loop control of Flyback with three winding

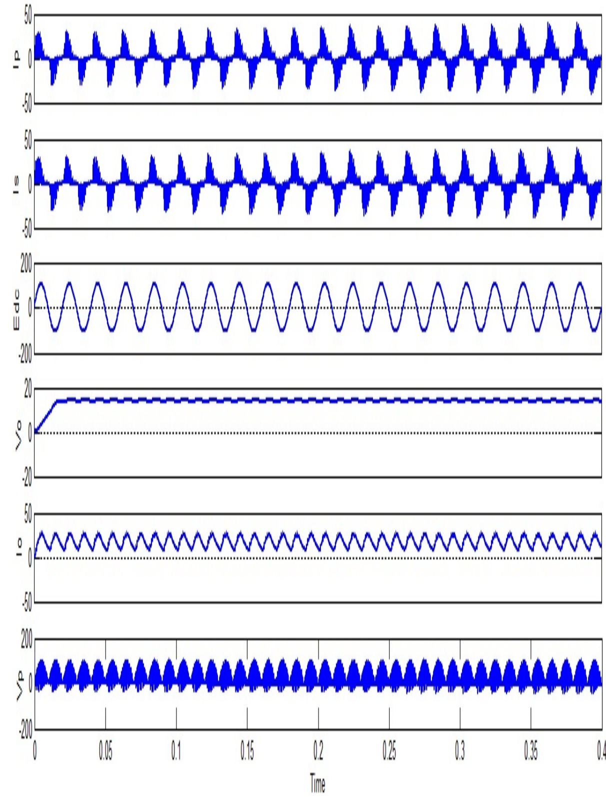

Fig.13. (a) Continuous Mode of Conduction in open loop control of Flyback using linear transformer

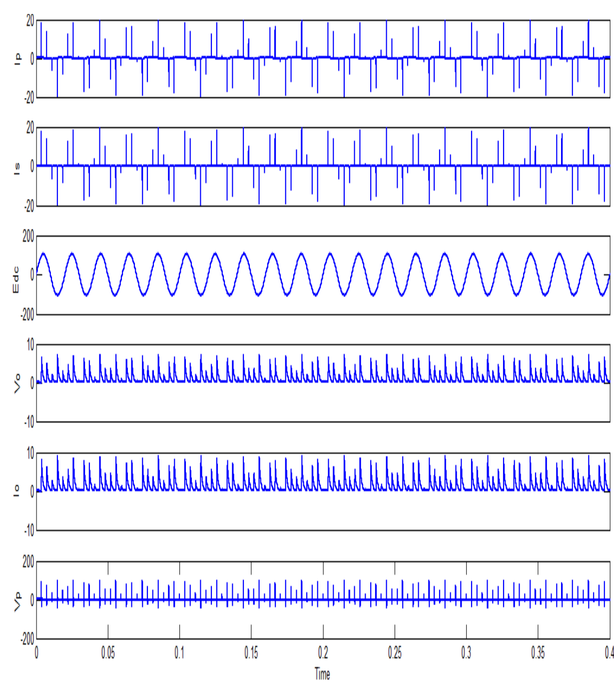

Fig.13. (b) Continuous Mode of Conduction in open loop control of Flyback using linear transformer

VII. CONCLUSION

The simulation of the fly back converter open loop operation in continuous mode and discontinuous mode has been implemented. Along with this a closed loop operation in continuous mode has been implemented. Flyback circuit operation in continuous and discontinuous mode of conduction has been compared using linear transformer and coupled inductor. The simulation of open loop fly back converter with two windings in secondary side has been carried out and results have been plotted.

ACKNOWLEDGMENT

The proposed work has been carried out in the Power Electronics laboratory of the UIT RGPV, Bhopal. Also, the grant for registration of conference is issued under TEQIP – II.

REFERENCES

[1] T-Y Ho, M-S chen, C-Hsien Lin D & A , C-W chang, “The design of a flyback converter based on simulation” IEEE on Power Electronics , 2011

[2] M. H. Rashid, Power Electronics: Circuits, Devices, and Applications , 3rd Edition, Pearson Education, Inc. 2004.

[3] M F , Ali Emadi, M Telefus , and C Davis, “Pulse regulation control technique for flyback converter,” IEEE Transaction on Power Electronics , vol. 20 , no. 4, July 2005.

[4] C H, Hui S.Y.R, Wang W. H, “An Isolated Fully Soft-Switched Flyback Converter with Low Voltage Stress”, Power Electronics Specialists Conference, 1997. PESC 97 Record, 28th annual IEEE Volume 2, 222-27 June 1997.

[5] H S.H. Chung, W-l, Cheung, K-S Tang, “A ZCS Bidirectional Flyback Converter “, Power Electronics Specialists Conference, 2004. PESC 04. IEEE 35th Annual , 20-25 June 2004.

[6] “Snubber circuits suppress voltages transient spikes in multiple output DC-DC Flyback converter power supplies” Application note 848 Maxim Nov. 2001.

[7] S. H; C. Bunlaksananusorn, “Performance comparison of continuous conduction mode(CCM) and discontinuous conduction mode (DCM) flyback converter,” inProc. IEEE Power Electronics and Drive System Conf., 2003, vol.2.s