Linear Control Analysis of Closed Loop Switch Mode Flyback Converter

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***Abstract* - This paper presents the application of the linear PID controller in the switch mode flyback converter with voltage mode control. The flyback DC-DC converter is operating at ~170V 50Hz ac supply providing regulated output voltage 42V DC. The controller is used to change the duty cycle of the converter and in that way the output voltage is regulated. This paper also evaluates the dynamic response and transient behavior of the systems. The simulation results confirm in the flyback converter doesn't need any type of slope compensation, which is an advantage of the voltage mode control in converter. The linear PID controller has good dynamic and steady state response for switched mode flyback converter. The output of linear PID controller has evaluated by software simulation using MATLAB version R2010a.**

Keywords — component: Flyback converter, voltage mode control, Proportional Integral and Derivative controller (PID).

I. INTRODUCTION

Recently, SMPS (switching mode power supply) has been widely used in consumer market. Task of power electronics is to process and control the flow of electrical energy by supplying voltages and currents that is suited for optimally load's user as shown by the fig.1. The DC-DC converter has characterized a high efficiency and a high electric power in the field of electric power conversion [1]. The feedback controller compares the output of the system with the reference value, and minimise the error. Controller output's is the control signal (duty cycle) which control the switch in a power processor units [2].

A DC-DC flyback converter is a switching power supply topology widely used in applications that require power below 2OOW. Due to its low part count and electrical isolation between input and output, the flyback converter is compact and suitable for off-the-line operation. Flyback power supplies are ubiquitous in modem low-power office equipment, such as computer monitors, printers, AC/DC adapters, etc. DC-DC flyback converters exhibit nonlinear characteristics [3] [4]. The causes of nonlinearity in the power converters include a variable structure with in a single switching period, saturating inductances, voltage clamping etc. The flyback converter controller is based on voltage mode control scheme; there is, its single voltage feedback path where in the duty ratio (or switching period) is controlled by comparing the waveform obtained from the resulting error voltage from the operational amplifier with an external ramp which is fixed signal value[5].

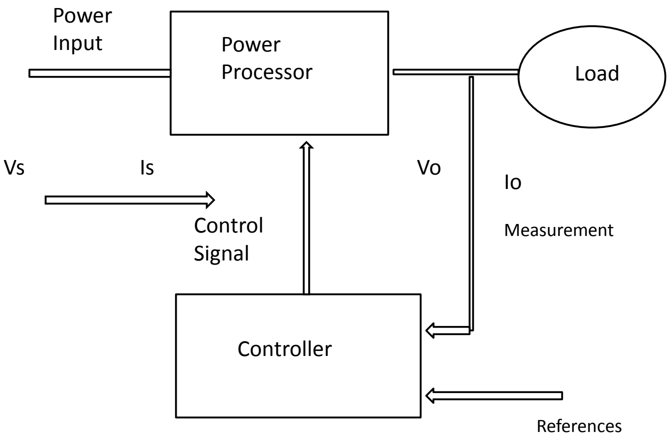

Fig.1.Block diagram of power electronics system

So whenever there is any change in system, any parameter variations or even load disturbances PID controller works, as an error amplifier which gives the control voltage signal for switching the switch [6].

In this present work, the dynamic and transient response of voltage mode controlled flyback converter with linear controller PID is analyzed. MATLAB/ SIMULINK 2010a software is adopted to simulate the behaviours of the flyback converter.

II. BASIC TOPOLOGY OF FLYBACK CONVERTER

Basic topology for any switching mode power supply (SMPS) DC-DC flyback converter system input to the circuit is generally unregulated dc voltage obtained by rectifying the utility ac voltage followed by a simple inductor capacitor filter [7]. The circuit can offer single or multiple isolated output voltages and can operate over wide range of input voltage variation. A fast switching device (‘Switch’), like a MOSFET, is used with fast dynamic control over switch duty ratio (ratio of ON time to switching time-period) to maintain the desired output voltage. The transformer in fig.2 is used for voltage isolation as well as for better matching between input and output voltage and current requirements.In this type of power supply converter, a transformer is used to store energy, rather than a single inductor. Primary and secondary windings of the transformer are wound to have good coupling so that they are linked by nearly same magnetic flux [8] [9]. A simplified equivalent circuit diagram of a switched mode flyback converter supply is shown in fig.2.

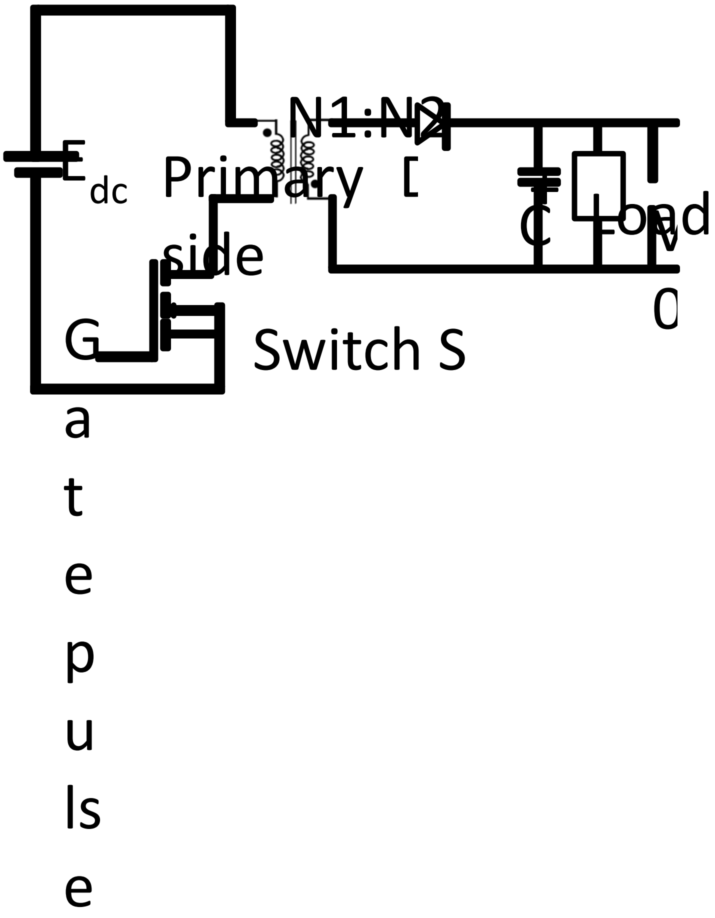

Fig.2.Equivalent circuit diagram of flyback converter

MODES OF CIRCUIT OPERATION

Mode-1

Figure 3 show the equivalent circuit diagram for mode 1.When the MOSFET is turned on, the primary current i_1 flows, while the diode is reverse biased preventing a flow of secondary current i_2. During this MOSFET’s turn on period, energy is stored in the transformer with a load current being supplied by the output capacitor.

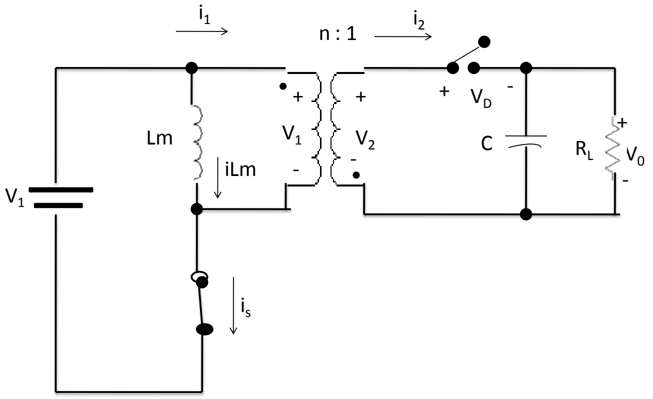

Fig.3.Equivalent circuit diagram of flyback converter for Mode 1

The diode current $i_{D,}$

$$i_D = i_2 = 0 \qquad (1)$$

$$i_1 = i_2 / -n = 0 \qquad (2)$$

The voltage across the magnetizing inductance L_m

$$V_{Lm} = V_1 = L_m.\left(\frac{d}{dt} iLm\right) \qquad (3)$$

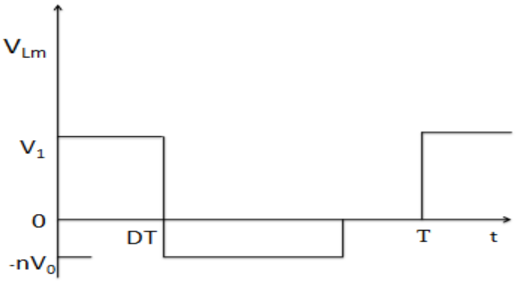

Fig.4. Voltage across the switch

The switch current

$$i_s = I_{LM} = (V_1 /Lm).t + I_{LM}(0) \qquad (4)$$

At time t = 0, $I_{LM}(0)$ is the initial current in the magnetizing inductance .The peak-to peak value of the ripple current through the magnetizing inductance L_m is shown in fig.5

$$\Delta I_{LM} = \frac{V1DT}{Lm} = \frac{V1D}{fs.Lm} \qquad (5)$$

the transfer function of the flyback converter is

$$Mv_{DC} = \frac{V0}{V1} = \frac{I0}{I1} = \frac{D}{n(1-D)} \qquad (6)$$

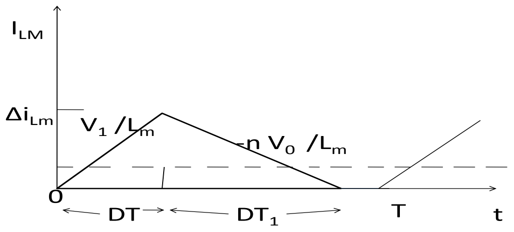

Fig.5. Current through magnetizing inductance

Mode 2

Figure 6 show the equivalent circuit diagram for Mode-2.Controlling the charging time duration (known as duty cycle) in a cycle can control the amount of energy stored during each cycle. When the MOSFET is tuned off, the primary current cease to conduct. The collapsing magnetic field in the transformer causes a polarity of the secondary voltage to reverse. The diode is now forward biased enabling a flow of secondary current. During this turn off period, energy stored in the transformer is released to the output capacitor and load.

The secondary voltage

$$v_2 = V_O \qquad (7)$$

$$V_1 = -n\, v_2 = -nV_0 \qquad (8)$$

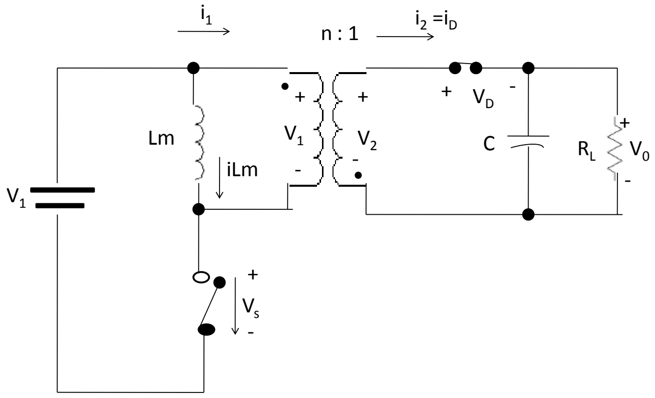

Fig.6. Equivalent circuit of flyback converter in mode2

The current through the magnetizing inductance

$$I_{LM} = - n\,\frac{V0}{Lm}(t\text{-}DT) + \frac{V1D}{fsLm} + i_{LM}(0) \qquad (9)$$

Switch voltage

$$V_{s\,max} = V_{1max} + n\,Vo = \frac{nVo}{Dmin} \qquad (10)$$

The converter’s main energy storage inductor may operate in two modes: DCM and CCM.

At CCM/ DCM boundary the minimum value of the magnetizing inductance

$$L_m(min) = \frac{(1-Dmin)^2 n^2 RLmax}{2fs} \qquad (11)$$

$$Lm(min) = \frac{n^2 Vo(1-Dmin)^2}{2fs.Iomin} \qquad (12)$$

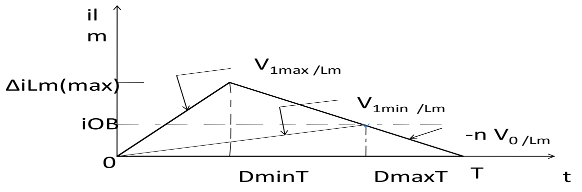

Fig.7. Waveform of the current through the magnetizing inductance

The minimum value of the magnetizing inductance peak current at the CCM/ DCM boundary occurs at

$D=D_{BMmax}$

$$\Delta iLm(min) = \frac{nVo(1-DBmax)}{fsLm(max)} \qquad (13)$$

The energy transferred from the input dc voltage source V_1 to the magnetizing inductance during one cycle for the boundary case is

$$W_{OB} = \frac{Lm(max)\Delta iLm(max)2}{2} \qquad (14)$$

The total power output at the boundary

$$P_{OB} = \frac{WoB}{T} = f_s W_{OB} = \frac{fs.Lmmax\Delta i2Lm(min)}{2} \qquad (15)$$

VOLTAGE MODE CONTROLLER

The controller section in the flyback converter has two PWM methods for controlling the output voltage. This two standard PWM control techniques are voltage mode control and current mode control. Figure 8 shows the basic main rule of voltage mode control. In the basic principle of voltage mode control an error amplifier amplifies the difference between a reference voltage and output voltage. The resulting error voltage is the control voltage and it’s compared with saw-tooth signal in comparator section. Comparator gives a PWM signal to drive the switch (MOSFET) in the converter to maintain the constant output voltage. The whole process is repeated for the next error or control signal [10].

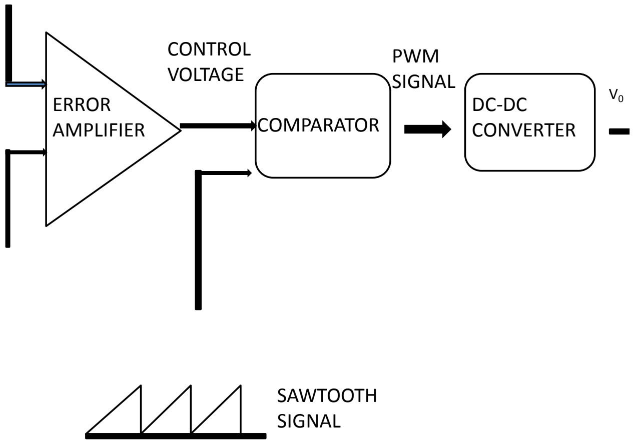

Fig.8.closed loop feedback for voltage mode control (VMC)

This control mechanism allows a pulse width of the gate drive signal. The duty ratio of the PWM signal depends on the value of the control voltage. The frequency of the PWM signal is the same as the frequency of the saw-tooth waveform. The control of the Switch duty ratio adjusts the voltage across the inductor and hence the inductor current brings the output voltage to its reference value.

III. PID CONTROLLER

PID (proportional-integral and derivative) controller is a special case of the linear controller [8]. Fig.9 shows the equivalent model of the PID controller. The control signal is a sum of three terms

a) the P-term constant K_P (which is proportional to the error),
b) the I-terms constant K_I (which is proportional to the integral of the error),
c) the D- terms constant K_D (which is proportional to the derivative of the error).

PID controller parameters are chosen as by hit and trial methods and it's not being exactly accurate, because K_P, K_I and K_D are dependent on each other. In fact, changing one of these variables can change the effect of the other two [11] [12]. The PI compensator is used to reduce the steady state error. The PD compensator is used to increase the bandwidth of the feedback loop and compensate the overshoots of the system. PID controllers are more sensitive to operating point and parameters variation and its region is small operating regions. The controller can also be parameterized as control signal

$$u(t) = K_p e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{d}{dt} e(t) \qquad (17)$$

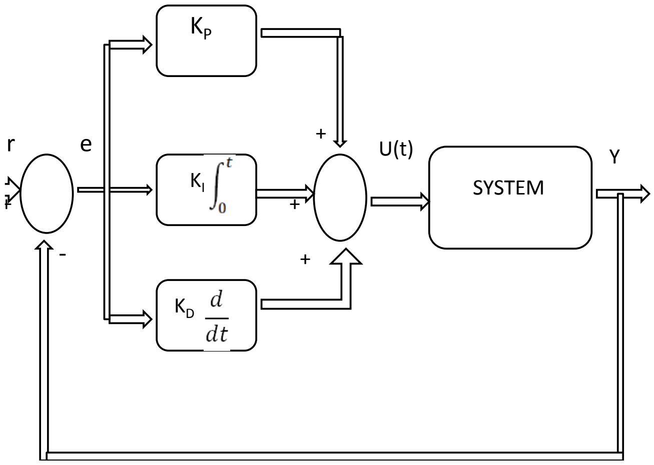

Fig.9. Equivalent model of the proportional-Integral and Derivative (PID) controller

Some initial values for the controller parameters are listed in Table (). The discrete PID controller is used as the error amplifier in the developed model to generate the controllable duty cycle of the switch.

S.NO.	Controller parameter	Range
i.	Proportional constant K_P	70.09
ii.	Integral constant K_I	9.008
iii.	Derivative constant K_D	0.045

IV. CONTROL METHODOLOGY

In the proposed model linear PID controlled switch mode flyback converter with voltage mode control run with the computer simulation. The linear PID controller works as an error amplifier. The output of the error amplifier generates the control voltage, which is compare with the external saw-tooth signal in a comparator and generates a controlled duty cycle. The converter switch (MOSFET) is controlled with duty cycle and gives the suitable output waveform. The analysis of the flyback converter has done with the simulation run with 3.5 sec.

For the simulation design purpose the model parameters are given in Table ().

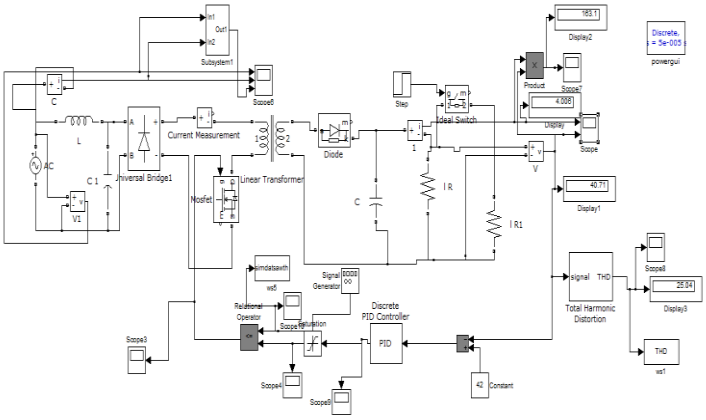

Fig.10. Simulation diagram for flyback converter with PID controller

TABLE 1 : SIMULATED CIRCUIT PARAMETER

S. No.	Parameter	Ranges
1.	Input voltage	90-230 V
2.	Output voltage	41V
3.	Load resistance	10.595 ohms
4.	Line frequency	50 Hz
5.	Total output power	160W(<200W)
6.	Switching frequency	250 KHz

The stable waveform verifies that the voltage mode control maintains the stable operation under a large duty cycle without the need of slope compensation.

V. SIMULATED RESULTS

(1)-Simulation response for power factor control

From equation (4, 5), obviously, the sinusoidal input current i_s is inherently generated, and its current amplitude I_s =Vs/WL is proportional to the controllable phase (φ) without sensing current and current loop. Additionally, the sinusoidal input current i_S is in phase with the input voltage V_s. The input parameters are given in Table. The result shown by the simulated fig. 11, the input current and voltage waveform and its related input power factor waveform, where the sinusoidal current i_S is in phase with the input voltage V_s. The input power factor of the switch mode flyback converter is 0.998.

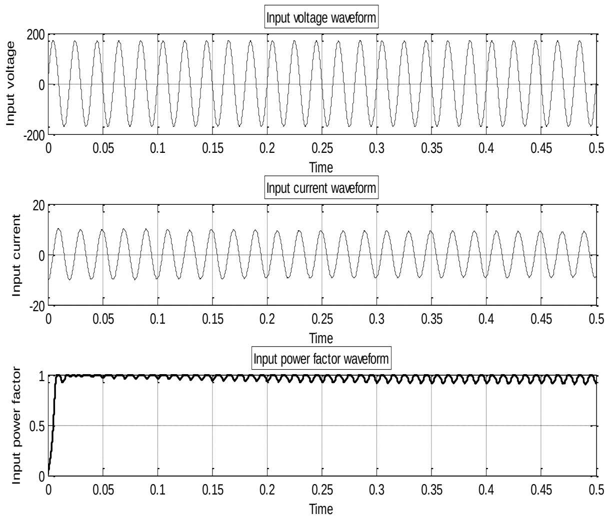

Fig.11. Input waveform for power factor control

(2)-Simulation response for transient condition of PID controlled flyback converter

For the circuit parameters in Table() the simulated waveforms are plot in fig.12 the output voltage and current waveform respectively. The output voltage and output current of the system are 41V and 3.9A respectively given by the PID controlled flyback converter. The transient parameters are listed in Table(2) .

TABLE 2

S.No.	Parameter	Value
1	Rise time	0.68 sec.
2	Peak time	0.9 sec.
3	Overshoot	0.21%
4	Settling time	1.2 sec.

(3)-Simulation response for Dynamic condition of the PID controlled to flyback converter
To verify the dynamic performance of the proposed linear PID controller some simulated results are shown in the Fig.13, where the load resistance is suddenly changed from 10.5 Ω to10.5||200 Ω at t= 0.8 second.

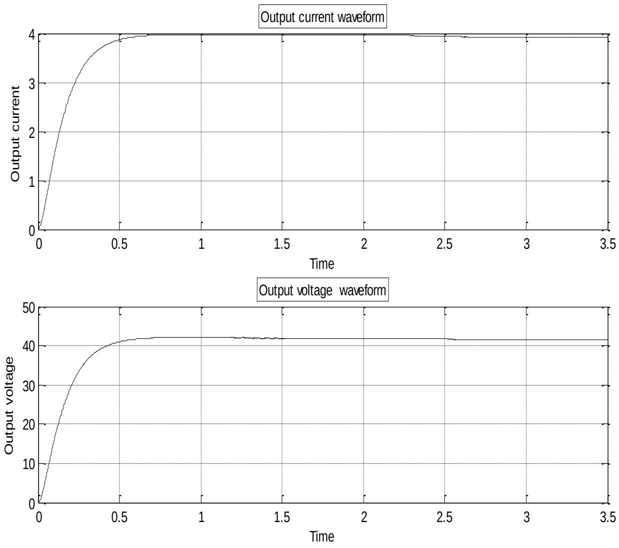

Fig.12.Output current and voltage waveform of PID controlled flyback converter.

In order to support sufficient power to regulate the output voltage, the input current magnitude is increased from 3.8A to near 4.2A by the controller. From this case, we can find that the input current i_s is always in phase with the input voltage v_s under transient response. Consequently, the controller can keep good performance under the condition of load change. During this test the reference voltage of the converter is 42V.

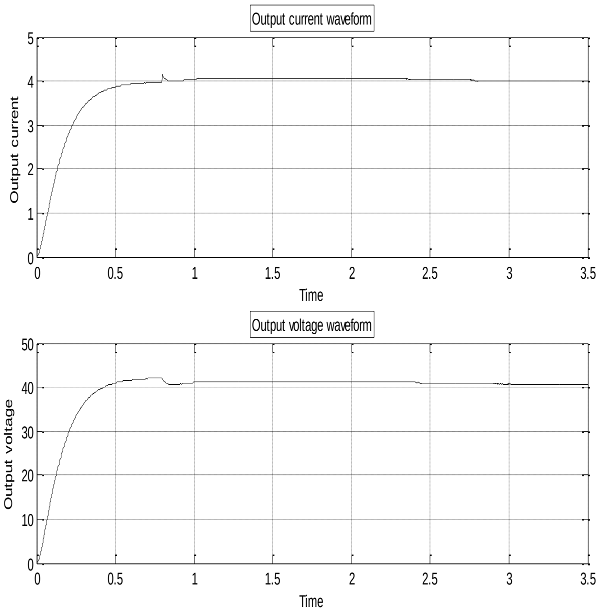

Fig.13.Output current and voltage waveform during dynamic condition of PID controlled flyback converter

VI. CONCLUSION

This paper has presented the application of voltage mode control in a flyback converter with linear PID controller. The use of voltage mode control eliminates the need of slope compensation and alleviates the noise immunity issue in the current mode control. All the advantages make it suitable for low power off-line application with strict efficiency. This system shows the input power factor is 0.998.

The performance of the closed loop flyback converter with PID controller is analysed using MATLAB/ simulation and found that the performance of the dynamic and transient behaviour of the controller gives satisfactory responses.

In future it can be extended to study the performance of intelligent controller

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