Design and Implementation of Flyback Converters

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***Abstract* - In switch mode power supplies(SMPS), flyback converters are very popular because of, design simplicity, low cost, multiple isolated outputs, high output voltages and high efficiency. They are preferred especially for low power applications (150W). In this work, flyback converters are analyzed, mathematical modeled, designed with given parameters, tested with simulation software and practically results.**

Keywords: SMPS, isolated DC-DC converters, flyback converters

I. INTRODUCTION

According to efficiency and power density, SMPSs are more popular than linear power supplies [1]. Most of the advanced communications and computer systems require SMPSs which have high power density, high efficiency and constant operation frequency [2].

At the last decade, a lot of converter topology has been proposed for switch mode power supplies. Flyback converters are the simplest isolated DC-DC converter topology because of absence of inductor at the output filter, only one semiconductor switch and only one magnetic component (transformator or coupled inductor). Besides, obtaining up to 5000V output voltage and having multiple outputs are the superiorities [5-6]. Because of these advantages, flyback converters become the most preferred DC-DC converter topology for switch mode power supplies [3].

Main features of flyback converters;

- High-frequency transformator (coupled inductor) design is simple for low power applications.
- Low cost because of low component number.
- Blocking voltage not occurred on the output diode, thus diode cost reduced.
- There is no additional inductor at the output circuit. This simplifies the usage of multiple outputs.
- Transient response is fast because of output inductor absence.

Flyback converters are preferred mostly for low power applications because of magnetic core limitations (5W-150W).

Application areas of flyback converters;

- Low power SMPS applications: Cell phone charge unit, computer power sources(< 250W),
- To produce high voltage source for CRTs,
- To produce high voltage for Xenon flash lamps, lasers, photocopies,
- Isolated driver circuits

In this paper, first, flyback converter is analyzed and mathematically modeled. Then, simulated and implemented for desired parameters.

II. FLYBACK CONVERTER

Converters can be classified as isolated and non-isolated. Flyback converter is one of the simple topology in isolated converters. Fig.1 shows the typical topology of flyback converters.

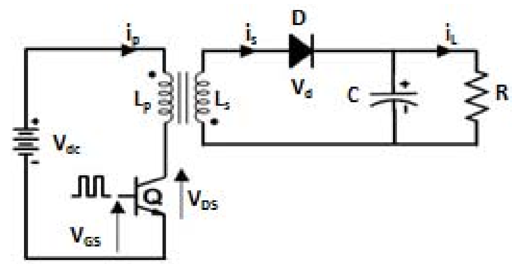
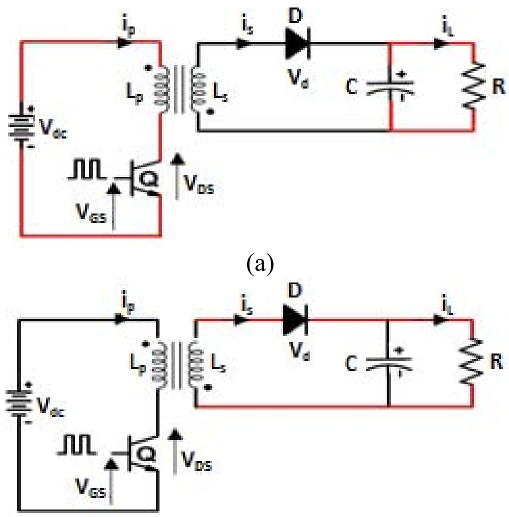


Figure 1. Simplified flyback converter

Dot-ends of the inductors determine the operation of converter. Polarity of primary winding(L_p) and secondary(L_s) are not same. Operation of the converter is very simple; when the switch is turned-on, energy absorbed into the primary winding, then stored energy transferred to the secondary winding after switch turned-off[4]. This means there is no transformator action and L_p-L_s are only coupled- inductors. When switch Q is turned on, V_{dc} applied to primary winding. Because of constant V_{dc}, primary current I_p rise to peak value linearly[6]. At this interval, secondary winding is oppositely polarized to the primary inductor and consequently diode, *D*. Load current is supplied by capacitor, *C*(Fig.2(a)). When switch *Q* is turned-off, stored energy at the air gap and magnetic core are transferred to secondary winding and load is fed by inductor L_s. I_s discharge linearly over resistive load.

Stored energy at the air gap can be obtained from primary inductance and primary current by (1).

$$E = \frac{1}{2} \times L_p \times I_p^2 \tag{1}$$



(a)

(b)

Figure 2. (a) Switch turn-on, (b) Switch turn-off

There are three operation conditions for flyback converter, continuous conduction mode (CCM), discontinuous conduction mode (DCM) and critical operation mode [4]. Secondary current, I_s, defines the operation mode of converter.

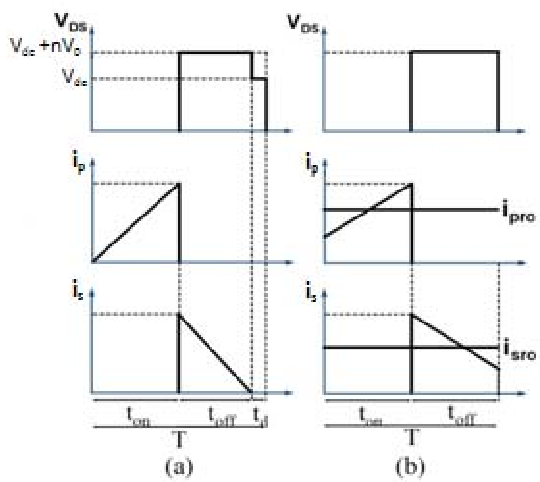


Figure 3. (a) DCM characteristics, (b) CCM characteristics

As shown in Fig.3.a, during the Q on time, there is fixed voltage across L_p and current in it ramps up linearly. The secondary diode is off state. Hence, secondary winding effectively doesn't exist. As a result, there is no transformer action when Q on time. At the end of the on time, primary current ramped up to I_{p_max}.

In Fig.3.b, when Q turns-off, the magnetizing current in the primary winding stops, but the core must return to its previous condition, and the voltage of secondary winding will reverse, to create the flyback action. So that, this brings diode into conduction mode and a decreasing current flows in the secondary winding. During this off period, primary winding is not conducting and does not exist.

In DCM, the secondary current falls to zero before the next Q on time.

In CCM, the secondary current is greater than zero when Q turns-on for the next period. Secondary current couldn't fully discharge and there will be stored energy at the secondary side when the next switch Q turn-on interval starts.

Both operating modes have advantages and disadvantages.

- $d\varphi/dt$ and leakage inductance is high at DCM. High instantaneous rise of primary current cause usage of expensive transistors and high EMI(Electromagnetic Interference) problem.
- Although in the DCM operation, average value of secondary current remains same value, peak of the secondary current is two or three times greater than CCM operation. This current cause high EMI problem. High di/dt causes instantaneous noise problems when switch turning-on.
- In the DCM operation, secondary current ripple is nearly twice than in the CCM operation, that cause more winding turns and larger output capacitor

In spite of disadvantages, DCM preferred rather than CCM because of fast response to load current and input voltage variations.

III. DESIGN

Mean voltage over inductors are zero at steady-state;

$$(V_{dc} - V_{DS}) \times t_{on} = (V_o + V_d) \times t_{off} \times n \tag{2}$$

V_{dc}	: Input voltage,
V_o	: Output voltage,
t_{on}	: Turn-on time,
t_{off}	: Turn-off time,
V_d	: Conduction voltage drop of diode D,
V_{DS}	: Conduction voltage drop of switch Q,
n	: Transformation ratio of inductors.
L_p	: Primary inductance,
L_s	: Secondary inductance.

For CCM, switching period T can be shown as,

$$T = t_{on} + t_{off} \tag{3}$$

In the DCM operation, (4) is derived by adding t_d dead time from (3). To ensure that the circuit remains discontinuous, the maximum on time which will generate the desired maximum output power is established, thus [6]:

$$T=t_{on}+t_{off}+t_d \tag{4}$$

$$0,8\times T=t_{on}+t_{off} \tag{5}$$

Where t_d is the dead time.

If $t_{off}=T-t_{on}$ is placed at (2) , t_{on} will be;

$$t_{on}=\frac{T\times n\times(V_o+V_d)}{(V_{dc}-V_{DS})+n\times(V_o+V_d)} \tag{6}$$

In (6), all magnitudes are constant except input voltage, it can be seen that t_{on_max} occurs at V_{dc_min}.

$$t_{on\_max}=\frac{T\times n\times(V_o+V_d)}{(V_{dc\_min}-V_{DS})+n\times(V_o+V_d)} \tag{7}$$

At conduction mode of switch Q, primary current will rise linearly because of the constant input voltage and reach peak value at t_{on_max} . Note that maximum turn-on time occur at min input voltage. Maximum primary current, i_{p_max},

$$i_{p\_max}=\frac{(V_{dc\_min}-V_{DS})\times t_{on\_max}}{L_p} \tag{8}$$

Stored energy at the primary winding can be obtained by replacing i_{p_max} in (1). Since, an amount of energy in joules delivered in a time in seconds, (9) presents input power in watts,

$$P_i=\frac{1}{2}\times\frac{L_p\times i_{p\_max}^2}{T} \tag{9}$$

Conduction mode voltage drop on the switch is approximately 1V and negligible. If (8) is placed at (9), input power will be,

$$P_i=\frac{\left[V_{dc\_min}\times t_{on\_max}\right]^2}{2\times T\times L_p} \tag{10}$$

Stored energy at the air gap transferred to secondary inductor after the switch Q turns-off. Secondary current I_s, decreases linearly over resistive load.

Flyback converters operate around 80 percent efficiency[7], so;

$$P_i=1,25\times P_o \tag{11}$$

Primary inductance can be obtained by (10) and (11);

$$L_p=\frac{\left[V_{dc\_min}\times t_{on\_max}\right]^2}{2,5\times T\times P_o} \tag{12}$$

Maximum value of secondary current is;

$$i_{s\_max}=i_{p\_max}\times n \tag{13}$$

Flyback converters operation mode is defined by magnetizing inductance and load current. Operation modes of converters can change with load current variations.

In CCM(Fig.3), current and inductance equations will change because of the remaining current at secondary winding. It can be seen from Fig.3, primary and secondary currents are ramp functions. Let i_{pro} is the center of the primary ramp and i_{sro} is the center of the secondary ramp, then output power calculated as;

$$P_o=V_o\times i_{sro}\times\left(\frac{1-t_{on\_max}}{T}\right) \tag{14}$$

From (14), center of the secondary ramp will be;

$$i_{sro}=\frac{P_o}{V_o\times\left(\frac{1-t_{on\_max}}{T}\right)} \tag{15}$$

For %80 efficiency, center of the primary ramp will be;

$$i_{pro}=\frac{1,25\times P_o}{V_{dc\_min}\times\left(\frac{t_{on\_max}}{T}\right)} \tag{16}$$

It is obvious from (16) that, minimum primary current which guarantee CCM operation, can occur at minimum output power. And center of the ramp is also the half of current variation(17)

$$i_{pro}=\frac{di_p}{2} \tag{17}$$

From the terminal equation of primary inductance, L_p is calculated as follows[7],

$$L_p=\frac{\left(V_{dc\_min}-1\right)\times t_{on\_max}}{di_p} \tag{18}$$

If (16) placed in (18), primary inductance will be,

$$L_p=\frac{\left(V_{dc\_min}-1\right)\times V_{dc\_min}\times t_{on\_max}^2}{2,5\times P_{o\_min}\times T} \tag{19}$$

Design parameters of flyback converter for in DCM operation are given at Table 1.

TABLE 1: Design parameters

Input Voltage (V_{dc_max}, V_{dc_min})	: 70V, 50V
Output Voltage (V_o)	: 6V
Load Current	: 0.2A
Switching Frequency (f)	: 65kHz

Transformation ratio;

$$V_{dc\_mean} = \frac{V_{dc\_min} + V_{dc\_max}}{2} = \frac{50+70}{2} = 60$$

$$n = \frac{V_{dc\_mean}}{6+1} = 8.6$$

For DCM;

i. Maximum switching time is derived by (6). Because of dead time at DCM, period will be 0,8xT; $t_{on\_max} = 6.62\mu s$

ii. Primary inductance is derived by (12); $L_p = 2.9\mu H$

iii. Primary peak current is derived by (8); $i_{p\_max} = 111mA$

iv. Secondary peak current; $i_{s\_max} = 111 \times 8.6 = 962mA$

IV. RESULTS

Figure 4-5 and Figure 6-7 shows simulation and implementation results of designed flyback converter, respectively.

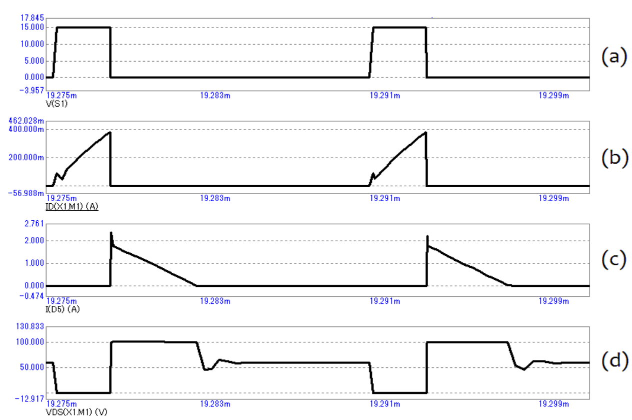


Figure 4. Simulation results, a) Switching signals(Volt/div=5V), b) primary current waveform (Amp/div=0.2A), c) secondary current waveform (Amp/div=0.5A) d) voltage waveform of switch Q (Volt/div=50V)

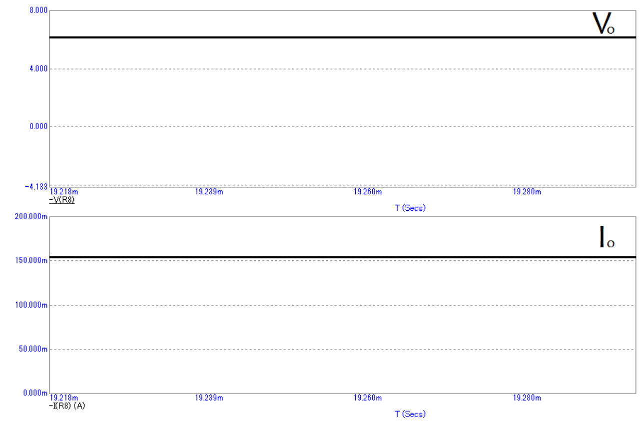


Figure 5. Simulation results, a) Output voltage, b) Output current waveforms (Volt/div=2V and Amp/div=0.1A).

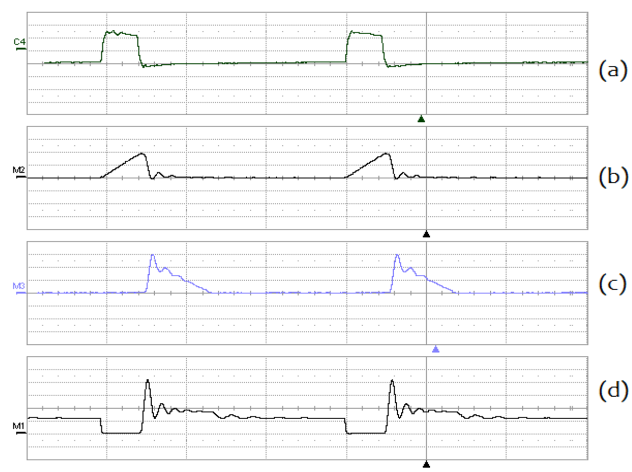


Figure 6. Implementation results, a) Switching signals(Volt/div=5V), b) primary current waveform (Amp/div=0.2A), c) secondary current waveform (Amp/div=0.5A) d) voltage waveform of switch Q (Volt/div=50V).

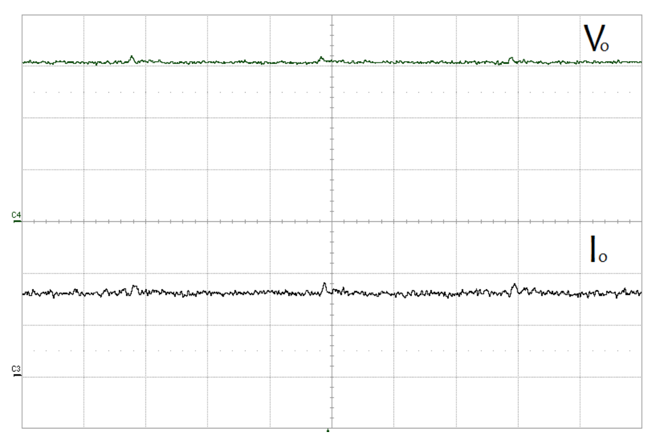


Figure 7. Implementation results, a) Output voltage, b) Output current waveforms (Volt/div=2V and Amp/div=0.1A).

V – CONCLUSION

In this paper, analyze, design and implementation of flyback converters with desired parameters which is used in low power switch mode power supplies achieved. Implementation results are closely-matching with those obtained from the mathematical and simulation calculations. The results present that, proposed flyback converter is an excellent candidate for high-frequency, isolated DC-DC converters with low power applications.

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