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A PATH FOR HORIZING YOUR INNOVATIVE WORK

MULTIPLE-OUTPUT ISOLATED FLY-BACK DC-DC CONVERTER

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Abstract

This paper presents a multiple output isolated fly back DC-DC converter that regulates the output voltages at fixed switching frequency. The three output converter is simulated at operating frequency of 400 kHz. The converter output power is nearly 20W and the output voltages are 5V, 12V and -12V. The fly back topology reduces the no. of passive components. The use of higher switching frequency comparatively reduces the size of magnetic components.

I. INTRODUCTION

Fly-back converter is the most commonly used SMPS circuit for low output power applications [1] where the output voltage needs to be isolated from the input main supply. The output power of fly-back type SMPS circuits may vary from few watts to less than 150 watts. The overall circuit topology of this converter is considerably simpler than other SMPS circuits. Input to the circuit is generally unregulated dc voltage obtained by rectifying the utility ac voltage followed by simple capacitor filter. The circuit can offer single or multiple isolated output voltages and can operate over wide range of input voltage variation. In respect of energy-efficiency, fly-back power supplies are inferior to many other SMPS circuits but it's simple topology and low cost makes it popular in low output power range.

The commonly used fly-back converter requires a single controllable switch like MOSFET and the usual switching frequency is in the range of 500 kHz. Computer simulation plays a vital role in the design and analysis of power electronic converters and their controllers. Designing Power electronic systems without computer simulation is extremely laborious, time consuming, error-prone and expensive. In the industry, computer simulation of power electronic converters is carried out to shorten the overall design process.

II. CIRCUIT OPERATION

In figure 1 [2] when power switch S1 is 'on' with the application of 'on' pulse from the control circuit, the current flows through the primary winding and energy is stored within the core. Note that no current can flow through the secondary because of opposite dot polarity and hence diode D1 is reversed bias.

When power switch driving pulse from the control circuit is removed (during 'off' time), the polarity reverses and the current flows in the secondary winding.

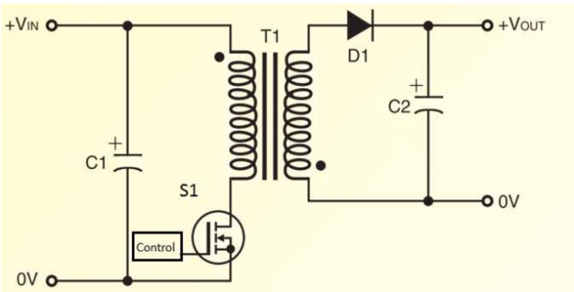

Figure 1: Flyback topology

The current flows in either the primary or secondary winding but never in both the windings at the same time. Thus the so called fly back transformer is not a transformer but a coupled inductor.

Discontinuous and continuous modes of operation

A fly back converter, just like any other topology has two different modes of operation, discontinuous mode and continuous mode [2]. A circuit that has been designed for discontinuous mode will move into continuous mode when the output current is increased beyond a certain value. The waveforms of primary and secondary currents through the transformer are shown in figure 2. In the discontinuous mode all the energy stored in the primary during the power switch 'on' time is completely delivered to the secondary and to the load before the next cycle, and there is also a dead time between the instant the secondary current reaches zero and the start of the next cycle.

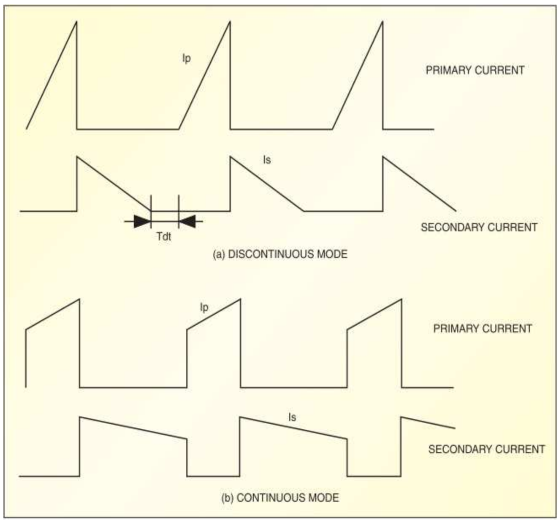

Figure 2: Primary and secondary currents in (a) discontinuous and (b) continuous mode

In the continuous mode there is still some energy left in the secondary at the beginning of the next cycle. The flyback can operate in both modes, but it has different characteristics. The discontinuous mode has higher peak currents, and therefore it has higher output voltage spikes during the turn-off. On the other hand, it has faster load transient response, lower primary inductance, and therefore the transformer can be smaller in size. The reverse recovery time of the diode is not critical because the forward current is zero before the reverse voltage is applied. Conducted EMI noise is reduced in discontinuous mode because transistor turn-on occurs with zero collector current. The continuous mode has lower peak currents and, therefore, lower output voltage spikes. Therefore DCM is usually recommended for high voltage and low current output applications. Meanwhile, CCM is preferred for low voltage and high current output applications.

A change in load resistance means changes in output currents. Hence, the duty cycle (D) has to be changed to maintain the desired output power.

III. Design Procedure

The design procedure will be explained briefly for a three output isolated flyback dc-dc converter with specifications given in Table I:

TABLE I. CONVERTER SPECIFICATIONS

Parameter	Symbol	Value
Input Voltage	Vin	18-72 VDC
Output Voltage 1	Vout1	5 VDC
Output Current 1	Iout1	2.8 A
Output Voltage 2	Vout2	12 VDC
Output Current 2	Iout2	100 mA
Output Voltage 3	Vout3	-12 VDC
Output Current 3	Iout3	100 mA
Output Power	PO	16.7 W
Switching Frequency	fs	400 kHz

The design of the converter is conducted using various steps.

Step 1.Determine system requirements

- Set minimum DC input voltage, V_{dcmin},
- Set maximum DC input voltage, V_{dcmax},
- Switching frequency, f_S 400kHz
- Output voltage, V_O in Volts
- Output power, PO in Watts
- Power supply efficiency, η: 0.8 if no better reference data available (0.75 to 0.85)
- Loss allocation factor, Z: 0.5 if no better reference data available (0.4 to 0.6)

f_s is the switching frequency of switcher IC.

Step 2. Determine primary waveform parameters

The average current is calculated using "Eq. 1" [1].

$$Iavg = \frac{PO}{\eta \times Vdcmin} \quad (1)$$

Peak primary current I_p "Eq. 2" [1] is calculated from average current I_{avg}, ripple to peak current ratio K_p, and maximum duty cycle D_{max}.

$$Ip = \frac{Iavg}{(1 - {}^{Kp}/_{2}) \times Dmax} \quad (2)$$

Where K_p is less than 1.0 for continuous mode. K_p is equal to 1.0 for Discontinuous mode, D_{max} is 60%. The ripple current I_r "Eq.3" is calculated from average current I_{avg}, peak primary current I_p, and maximum duty cycle D_{max}.

$$Ir = 2 \times (Ip - \frac{Iavg}{Dmax}) \quad (3)$$

IV. Design Of Magnetics

The design of the transformer is critical for the desirable operation of the converter.

Step 4. Determine primary inductance L_P

The primary inductance of the transformer is calculated by using the "Eq.4" [1].

$$Lp = \frac{10^6 \times PO}{Ip^2 \times Kp \times (1 - \frac{Kp}{2}) \times fs} \times \frac{Z \times (1-\eta) + \eta}{\eta} \quad (4)$$

where units are µH, watts, amps and Hz.

Choose the proper core

Ferrite is the most widely used core material for commercial SMPS applications. Soft ferrites like NiZn and MnZn are available. There high resistivity prevents eddy current losses at high frequency. The type of the core should be chosen with regard to system requirements including number of outputs, physical height, cost and switching frequency [4]. A flyback transformer designed for DCM operation requires a smaller inductance value than one designed for CCM operation, since the current ripple (I_r) is much higher. In some applications, lower inductance may result in a physically smaller transformer; assuming the efficiency and thermal performance remain acceptable.

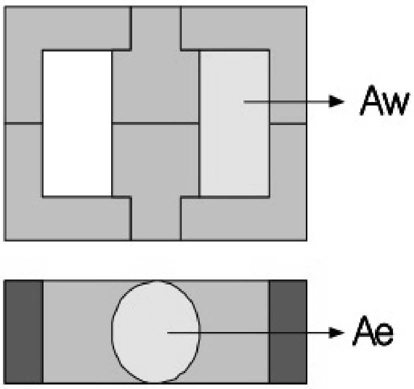

Figure 3: Window area and cross sectional area

The core type used depends mainly on size restraints. EFD and EPC cores are used when a low profile is required [3]. E, EE and EF are good general cores and can usually be used with either vertical or horizontal bobbins. ETD and EER cores are usually larger, but have a wide winding area, which makes them particularly good for higher power designs or multiple output designs.

Once the core type and size are determined, the following variables are obtained from the core data sheet. **A_e**: The cross sectional area of the core (mm^2), **A_w**: Winding window area (mm^2), **B_{sat}**: Core saturation flux density (tesla). Figure 3 shows the A_e and A_w of a core. The typical B-H characteristics of ferrite core are obtained from the datasheets. Since the saturation flux density (B_{sat}) decreases as the temperature increases, the high temperature characteristics should be considered. If there is no reference data, use B_{sat} = 0.3~0.35T[3]. Minimum no. of primary winding to avoid core saturation is found out using "Eq.5" [3].

$$\mathrm{Npmin} = \frac{\mathrm{Lp \times Ilimitmax}}{\mathrm{Bsat \times Ae}} 10^6 \qquad (5)$$

where $I_{limitmax}$ is the maximum current limit of the switching device.

Reflected output voltage

This parameter is the secondary winding voltage during diode conduction, reflected back to the primary through the turn's ratio of the transformer. "Eq. 6" [1] is used to calculate the V_{or}.

$$\mathrm{Dmax} = \frac{\mathrm{Vor}}{\mathrm{Vor + (Vdcmin - Vds)}} \qquad (6)$$

V_{ds} is the average Drain to Source voltage during Switch ON time which can be obtained from the datasheet of the switching IC. The primary number of turns

N_p is related to the secondary number of turns N_s by the ratio between V_{or} and $V_o + V_d$ .Thus the no. of secondary can be obtained by using “Eq. 7” [1].

$$Np = Ns \times \frac{Vor}{Vo+Vd} \qquad (7)$$

Step 5. Determine maximum peak inverse voltages PIV_S

The peak inverse voltage across the secondary rectifier diode is given by “Eq.8”.

$$PIVs = Vo + (Vdcmax \times \frac{Ns}{Np}) \qquad (8)$$

Additional or auxiliary output winding number of turns N_x “Eq. 9” and rectifier diode peak inverse voltage PIV_x “Eq. 8” can be determined from the desired value for auxiliary output voltage V_x, auxiliary rectifier diode forward voltage drop V_{dx}, output voltage V_o, output rectifier diode forward voltage drop V_d, and number of secondary turns N_s.

$$Nx = \frac{Vx+Vdx}{Vo+Vd} \times Ns \qquad (9)$$

V. SIMULATION RESULTS

The three output isolated flyback dc-dc converter was simulated in LTspice IV circuit simulator using the elements designed in the previous section. The equivalent electrical circuit model for the transformer is obtained by calculating the inductance of secondary windings by using the relation “Eq.10”. Table II gives converter component values which are used in the simulation.

$$\frac{Lp}{Ls} = (\frac{Np}{Ns})^2 \qquad (10)$$

Spice equivalent model of the switching IC was unavailable; hence alternately a pulse source generating a switching frequency of 400 kHz is used. The voltage controlled switch along with pulse source is modeled as PWM. The converter designed using LTspice IV is shown in figure 4.

TABLE II. CONVERTER COMPONENT VALUES

Component	Symbol	Values
Primary Winding	L1	20µH
Output winding for 5V	L3	2.15µH
Output winding for 12V	L2	4.26µH
Output winding for 12V	L4	10.8µH
Output capacitor for 5V	C2	2700µF
Output capacitor for 12V	C1	47µF
Output capacitor for -12V	C4	47µF

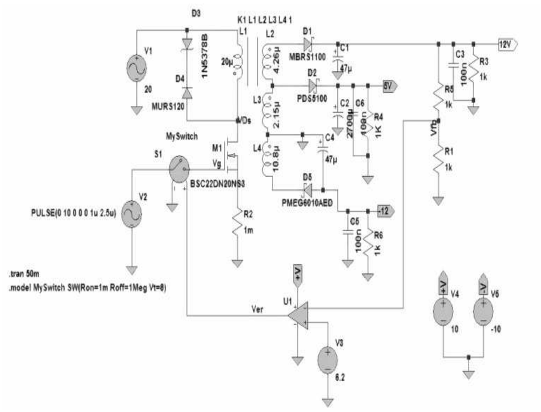

Figure 4. Schematic of converter designed using LTspice IV.

A voltage mode feedback without compensation network is used. The output of error amplifier drives the voltage controlled switch. Thus the gate to source voltage V_g is shown in figure 5 and the result of simulation i.e. the output voltages are shown in figure 6.

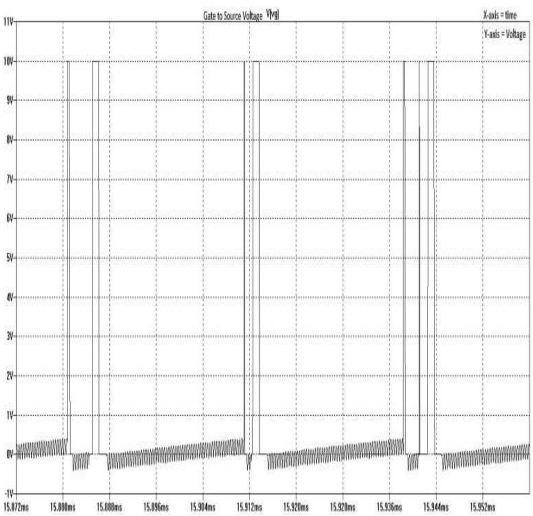

Figure 5. Gate to source voltage Vg.

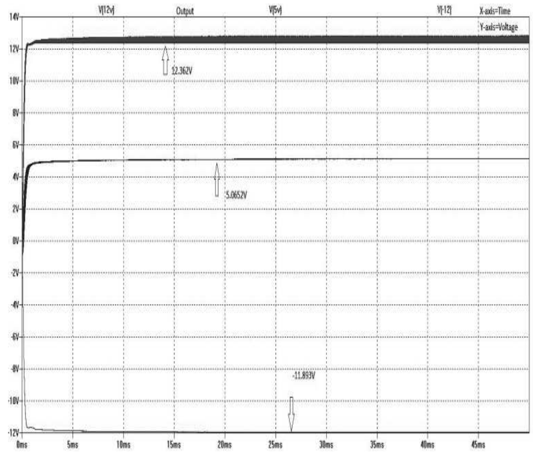

Figure 6. Output voltage waveforms.

VI. CONCLUSION

The multiple output isolated flyback dc-dc converter with three outputs is analyzed in this paper. The advantage of this topology is the circuit is simpler and requires less no of components. The flyback converter can be operated in CCM or DCM depending on the load conditions. Hence the duty cycle is varied to maintain the desired output. The simulator allows the designer to determine the correctness and efficiency of a design before the system is actually constructed. The calculated values of converter component differ from the actual values used in the simulation design. Consider the output winding for 5V; the actual value of the inductor calculated from using “Eq.5, 7, 10" gives output voltage less than 5V when used in simulation. Hence the value of inductor L3 is changed to 2.15µH in the simulation design. The reasons for doing this might be that we are not actually using the spice model of switcher IC and the simulation is done just to verify if the design will work or not. When actual prototype is generated the results will nearly match with the calculated values.

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