Design of 90W CCM Multi Output Flyback Converter

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Abstract—This paper describes design of Multi output flyback converter operating in continuous conduction mode (CCM). The proposed converter generates five outputs with a single input source. This paper covers operation of flyback converter with wide input range of (16 V - 29 V). Converter along with power circuit, control circuit, input filter and snubber circuit is discussed in this paper. The power circuit is energized from a dc input voltage and flyback converter with switching element MOSFET is switched ON and OFF using PWM controller UC28025 with switching frequency of 100 kHz. Simulation is carried out using ORCAD and testing results are tabulated in this paper.

Key words: Continuous Conduction Mode, Multi Output, Wide Input Range

I. INTRODUCTION

Modern electronic systems require high-quality, small, lightweight, reliable, and efficient power supplies. Linear power regulators are limited to output voltages smaller than the input voltage and also their power density is low because they require low frequency (50 or 60 Hz) line transformers and filters. Linear regulator is confined to produce only a lower regulated output from higher non-regulated input. Regulation efficiency of linear regulator is low, resulting in power loss. To overcome the limitations of linear regulator, switched mode power supplies are used as alternative in most of modern electronic applications. Switching regulators use transistor switch to generate square waveform from a non-regulated DC input voltage. This square wave with adjustable duty cycle is applied to low pass output filter to obtain regulated DC output. They generate buck, boost and inverted outputs. Isolated and non-isolated converters are two types of switched mode power supplies among which buck, boost and buck-boost are non-isolated converters, where as flyback, push-pull, full-bridge and half-bridge are isolated converters. For applications requiring multiple outputs isolated converters are employed. Design of multi-output converters is a remarkable challenge. Among various switched mode power supply topologies, flyback is the easiest implementation to obtain multiple outputs from single input source. Flyback topology is widely used in low power applications. The transformer in flyback converter (Usually known as coupled inductor) is used to achieve electrical isolation and energy storage. High switching devices such as MOSFET/IGBT is used as switching device and hard switching is employed, due to which voltage and current stress suffered from transformer leakage is high. This results in low efficiency and high switching losses.

II. FLYBACK CONVERTER

Fig. 1: Flyback Converter

Flyback converter is shown in fig 1. The transformer in flyback converter acts as coupled inductor and is different from conventional transformer. Primary side is energized by input supply and generally MOSFET/IGBT is used as switching device to turn on and turn off.

There are 2 modes of operation in which flyback converter operates.

A. Modes of Operation:

1) Mode 1: When switch is Turned ON:

when switch ‘S’ is on, the primary winding of the transformer gets connected to the input supply with its dotted end connected to the positive side. At this time the diode ‘D’ connected in series with the secondary winding gets reverse biased due to the induced voltage in the secondary (dotted end potential being higher). Thus with the turning on of switch ‘S’, primary winding is able to carry current but current in the secondary winding is blocked due to the reverse biased diode. The flux established in the transformer core and linking the windings is entirely due to the primary winding current. The following mathematical relation gives an expression for current rise through the primary winding:

\[
E_{dc} = L_{pri} \times \frac{dI_{pri}}{dt}
\]  

(1)

And secondary voltage equals to

\[
V_{sec} = E_{dc} \times N_2/N_1
\]  

(2)
B. Mode 2: When switch is Turned OFF:

![Fig 2 (B): Equivalent Circuit during Mode-2](image)

Mode-2 of circuit operation starts when switch ‘S’ is turned off after conducting for some time. The primary winding current path is broken and according to laws of magnetic induction, the voltage polarities across the windings reverse. Reversal of voltage polarities makes the diode in the secondary circuit forward biased. Though primary winding current is interrupted due to turning off of the switch ‘S’, the secondary winding immediately starts conducting such that the net MMF (Magneto motive force) produced by the windings do not change abruptly. MMF in this case, is the algebraic sum of the ampere-turns of the two windings.

Primary voltage in this case is:

\[ V_{pri} = \frac{V_o \times N_1}{N_2} \]  

(3)

And linear decay of secondary current is expressed as:

\[ I_{sec} = \frac{d}{dt} I_{sec} = -\frac{V_o}{L_p} \]  

(4)

III. CIRCUIT DIAGRAM AND DESCRIPTION

![Fig. 3: Circuit Diagram of Multi-Output Flyback Converter](image)

The proposed converter generates five different outputs with single input source. Primary side of transformer is energized from input DC source (16 V-29 V). MOSFET is used as switching device operating at 100 KHz switching frequency. Maximum duty cycle at which converter operates is 0.45 and ripple voltage is kept below 100 mV. Five secondaries produce five different outputs viz \( V_{o1} = 15 \) V, 2 A, \( V_{o2} = 15 \) V, 0.9 A, \( V_{o3} = 30 \) V, 1.2 A, \( V_{o4} = 5 \) V, 0.9 A, \( V_{o5} = -15 \) V, 0.44 A. Converter is operating in continuous conduction mode ( \( L_p > L_{min} \)). Large spikes which appear across switch due to presence of leakage inductance is suppressed by RCD snubber connected across MOSFET. Input filter is used to prevent input source from being corrupted and to reduce EMI.

IV. DESIGN STEPS

A. Specifications:

1) Input specification:

\[ V_{in}^{\text{Nominal}} = 28 \text{ V} \]
\[ V_{in}^{\text{min}} = 16 \text{ V}, V_{in}^{\text{max}} = 29 \text{ V} \]

Emergency operation: DC steady state voltage shall be between 16-29 V and is taken care by design.

2) Output Specifications:

- \( V_{o1} = 15 \) V, 2 A
- \( V_{o2} = 30 \) V, 1.2 A
- \( V_{o3} = 15 \) V, 0.9 A
- \( V_{o4} = -15 \) V, 0.44 A
- \( V_{o5} = 5 \) V, 0.9 A

3) \( D_{max} \) limited to 0.44 at 16 V

4) Efficiency = 70%

5) Switching frequency, \( f_s = 100 \) KHz

6) Ripple voltage = 100 mV

7) Output power = 90.6 W

8) Input power = 129.43 W

B. Turns Ratio:

\[ n = \frac{V_o \times d_{max}}{(1-D_{min}) \times V_{in}} \]

For \( V_o = 15 \) V: \( n = 0.7 \times 0.44 \)

\( n_1 = 0.61 \)

C. Minimum Primary Inductance:

\[ L_{min} = \frac{2f_s I_{rms}^2 (1-K^2)}{K_{rms}^2} \]

\[ L_{min} = 0.61^2 \times 2.5 \times (1-0.311)^2 \]

\( L_{min} = 2.21 \mu \text{H} \)

D. Primary Inductance:

\[ L_p = \frac{(2+\sqrt{2})^2}{K_{rms}} \]

\( L_p = \frac{2+129.43^2+100^2+0.25}{2+129.43^2+100^2+0.25} \]

\( L_p = 7.65 \mu \text{H} \)

To keep the \( \Delta I \) minimum, selected \( L_p = 32.8 \mu \text{H} \)

E. Transformer Design:

1) Area Product Calculation:

\[ A_p = \frac{I_p \times I_{rms}}{K_{rms} \times B_m} \]

Where \( I_p \) is primary peak current, \( I_{rms} \) is primary rms current,
\( K_w \) is winding factor = 0.3, \( J_i \) is current density = \( 4 \times 10^6 \) A/m,
\( B_m \) is maximum flux density = 0.2 T.

\[ A_p = \frac{32.8 \times 16.32 \times 10.73}{0.3 \times 0.2 + 10^6} \]

\( A_p = 23006.13 \text{ mm}^4 \)

Select a core having area product greater than \( 23006.13 \text{ mm}^4 \)

2) Selection of Core:

Selected core EE55/25/21 N87

Area product \( A_p = A_{p,T} \times A_{w} \)

\( A_{p,T} = 354 \text{ mm}^2 \times 234.3 \text{ mm}^2 \)

\( A_p = 82942.2 \text{ mm}^4 \)

3) Calculation Of Number Of Primary Turns:

\[ N_p = \frac{I_p + I_{rms}}{B_m \times 4C} \]
4) **Calculation of Number of Secondary Turns:**

\[ N_s = \frac{N_p \cdot V_o (1 - D)}{V_m/n + D} \]

\[ = 9 \times 15 \left(1 - 0.44\right) \]

\[ = 16 + 0.44 \]

\[ = 10 \text{ turns} \]

5) **Calculation of Secondary Inductance:**

\[ L_s = \frac{N_p^2 \cdot 32.8 \mu}{n^2 \cdot (0.61)^2} \]

\[ = 88.15 \mu \text{H} \]

6) **Calculation of Output Capacitance:**

\[ C_{o1} = \frac{(60 \text{ m})}{[2 \times 4.5 \mu]} \]

\[ = 150 \mu \text{F} \]

7) **Voltage across Switch:**

\[ V_{sw} = V_{in} + \left(\frac{V_o \cdot (N_1)}{N_2}\right) \]

\[ = 16 + 15 \left(\frac{8}{17}\right) \]

\[ V_{sw} = 26 \text{ V} \]

MOSFET selected is IRFP150A

\[ V_{ds} = 100 \text{ V} \]

\[ I_d = 40 \text{ A} \]

V. SIMULATION CIRCUIT AND WAVEFORMS

VI. CONCLUSION

The flyback converter is designed and implemented for the given specifications. The converter was designed for input range of 16 V to 29 V AC input voltage range, with 5 multiple outputs, 90.6 W full load output power and output voltage ripple less than 100 mV. The converter designed is shown to work satisfactorily within given limits maintaining constant regulated output with minimal ripple. The load regulation is shown to be very low, hence demonstrating the converter’s ability to account for variations in supply voltage and load to maintain constant (regulated) output. The circuit is simulated using ORCAD and the relevant waveforms are obtained.

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