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Zero Voltage Switching Fly-Back Converter for Power Supply Design

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Abstract***: Fly-back Converters are extensively functionally pertained on electrical power-supply circuits used in low power loads. Thinking towards energy-efficiency, fly-back systems are sub- standard to many other switched supply circuits but it has simple topology and low cost making it popular in low output power range. In this paper, study was performed for interleaved fly-back converter, which is featured with zero-voltage-switched electronic knobs, with lessened reverse-recovery loss on the rectifying diodes. The converter is configured out of two parallel-operated identical fly-back converters and auxiliary inductor connected in parallel between the diodes. This configuration is expected to provide higher efficiency at optimally high power***

Keywords: Fly-back Converter, Power Supply, Efficiency, Switched Mode Power Supply (SMPS)

I. Introduction

For the relevance obligations of low output voltage which is necessitated to be cut off from the input main supply circuit, the use of SMPS circuits in the form of fly-back converter is widely articulated. As compared to the other SMPS circuits, this wholesome circuit topology is noteworthy easier. By renovation of the utility AC voltage tracked by an easier capacitor filter, then the input as an unregulated DC voltage is obtained. The scrupulous circuit can proffer single or multiple output voltages which can be manoeuvred over a broad range of varying input voltages. With reference to performance of fly-back converters, they are poorer in comparison with other SMPS circuits but are pronounced for their easier topology and popularly known for its range of low output power. Regarding energy-efficiency, fly-back power supplies are substandard to scores of other SMPS circuits but it's simple topology and low cost, crafts it acceptable in low output power assortments.

Due to stumpy component counts and the effortless configurations, it demands the electrical segregation to be applied for electrical power circuits with low power prerequisite in fly-back converters. The structure of fly-back converter is simple and it is easy to control the power streaming through it. The fly-back converter is economical and it involves lower number of elements compared to other converters available in the market. This is due to the fact that the inductor is coalesced along with the transformer. But in other converters, the inductor and transformer are take apart elements.

II. Constructional Details & Working Principle

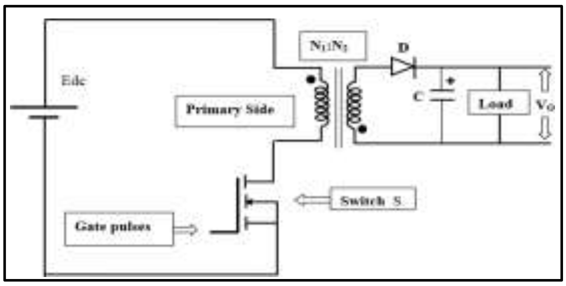


Fig.1- Basic Configuration of Fly-back Converter

The input obtained to the circuit is an unregulated DC voltage originated from a source. Ripples of low frequency may be in attendance to the input. As SMPS circuit functions at frequency range of 100 kHz, unregulated input presumes invariable magnitude during whichever high frequency cycle. A fast toggling device, like MOSFET, is used with fast dynamic control to preserve output voltage The transformer connoted for voltage seclusion plus for enhanced equivalency amid input and output voltage and current desired. The primary and secondary windings of fly- back transformer don't transmit current concurrently, analogous to two magnetically coupled inductors. Design of magnetic circuit is worked out like inductor. The yielding unit of fly-back transformer engrosses voltage rectification and filtering circuit.

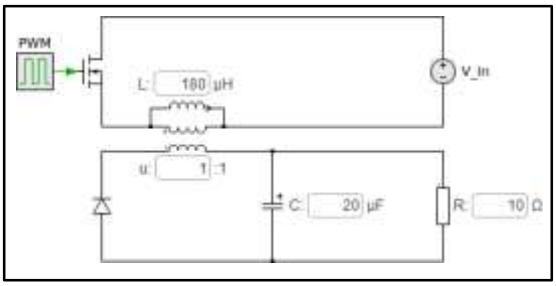


Fig 2- Fly-back Converter design

A fly-back converter renovates a DC voltage at the entrance to a DC voltage at the output. The functional principle is analogous to the buck-boost converter; supplementary transformer is inured to realize galvanic segregation of the input and output. For a fly- back converter in continuous conduction mode, the yielding voltage across resistor R is specified by:

$$V_{out} = -\frac{N2}{N1}\left(\frac{D}{D-1}\right)V_{in}$$

Where,
D is the duty cycle,
N1 is the Turns in Primary Side
N2 is the Turns in Secondary Side

III. MODES OF OPERATION

During its procedures, fly-back converter presumes different circuit-formations. Apiece of these circuit formations have been consigned here as modes of circuit operation.

Mode I: When switch is on, the primary winding of the Transformer gets connected to input with its dotted end connected to positive side. At this time the diode connected in series with the secondary winding gets reverse biased due to the induced voltage in the secondary.

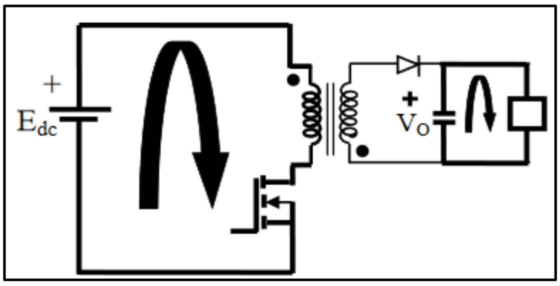


Fig 3- Current Flow in Mode I

With turning on switch, primary winding, is capable to carry current but current in the secondary winding is wedged due to effect of reverse biased diode. The flux instituted in the transformer core and apprehending the windings is completely to primary winding current. The input supply voltage emerges crossways primary winding inductance and primary current escalates linearly. The pursuing mathematical relation gives an expression for current rise through primary winding:

$$E_{dc} = L_p \frac{d}{dt} i_p$$

Mode II: It starts when switch is turned off after conducting for some time. The primary winding current path is broken and, the voltage polarity of the windings reverses. Reversal of voltage polarities makes the diode in the secondary circuit forward biased. As primary winding current is wrecked up due to turning off of switch, the secondary winding immediately starts conducting such that the net MMF formed by the windings do not change abruptly.

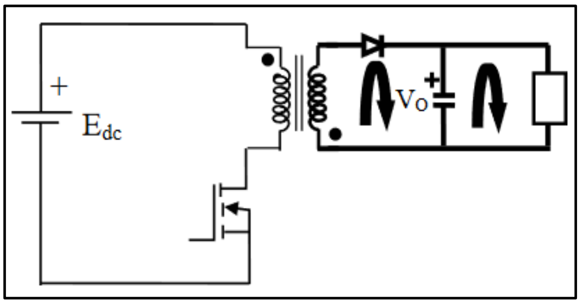


Fig 4- Current Flow in Mode II

Mode III: The secondary winding, whilst charging the output capacitor and provide for the load, transfers energy from the magnetic field of the fly-back transformer to the power supply. As off period of the switch is kept large, secondary current gets adequate time to decay and magnetic field energy is totally transferred to output capacitor and load. In discontinuous mode, after complete transfer of energy, the secondary winding current fall to zero and the diode in series with the winding stops conducting.

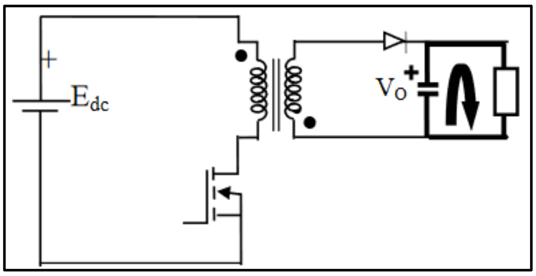


Fig 5 – Current Flow in Mode III

IV. CONFIGURATION UNDER STUDY

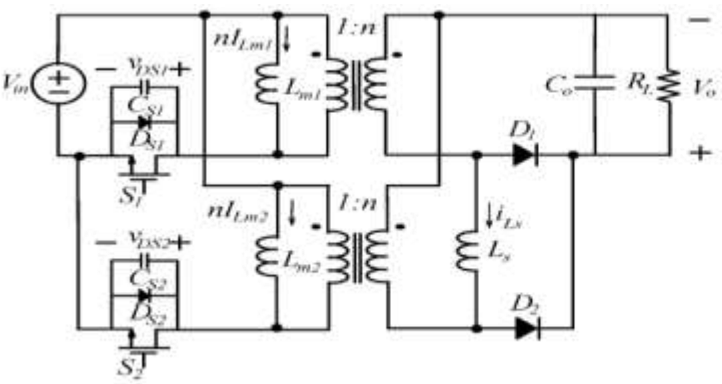


Fig 6 - Interleaved Circuit Under Study

The two fly-back converters are connected in parallel and individually composed of their own MOSFET switches, transformers, and rectifying diodes. To make simpler analysis, the constituents of both the converters are presumed to be identical. In transformer models, magnetizing inductances are explicitly shown, while the leakage inductances are momentarily omitted. Two fly-back converters are inter-leavingly operated to energize the output load. In this configuration, only one extra element, inductor L, is attached to fulfil the ZVS task. The factor of design for this circuit embraces the assessment calculation of Ls, output filtering capacitor, Co, and control algorithm. The equations below provide the values of required circuit parameters:

$$L_s = \frac{(nV_{in} + V_o)(1-D_e)^2 T_s}{I_o} \qquad P_o = V_o I_o = nV_{in}\left(\frac{nV_{in} T_s}{L_s} - I_o\right)$$

$$\frac{\Delta I_{Lm}}{I_{Lm}} = \frac{2L_s V_o}{L_m(nV_{in} + V_o)} \qquad \Delta V_c = \frac{I_o D^2{}_{eff} T_s}{2C_o} = \frac{V_o D^2{}_{eff} T_s}{2R_L C_o}$$

$$\Delta V_c = \frac{I_o D^2{}_{eff} T_s}{2C_o} = \frac{V_o D^2{}_{eff} T_s}{2R_L C_o}$$

The assumptions are made to design the simplified circuit of the converter are given in figure below:

a.	Neglect forward voltage drops on MOSFET S1, S2 and diodes D1,
b.	Output capacitor C_o is large so, neglect the output voltage ripple.
c.	Transformers have large magnetizing inductances L_{m1} and L_{m2}, so, $I_{Lm1} = I_{Lm2} = I_{Lm} =$ constant
d.	Output capacitances of MOSFETs, C_{S1} and C_{S2} are equal $C_{S1} = C_{S2} = C_s$
e.	The gating signals for S1 and S2, noted as v_{GS1} , v_{GS2}, are complementarily operated.

Fig 7- Assumptions in designing

By using these assumptions, and referring the primary side to secondary, the simplified circuit is as follows:

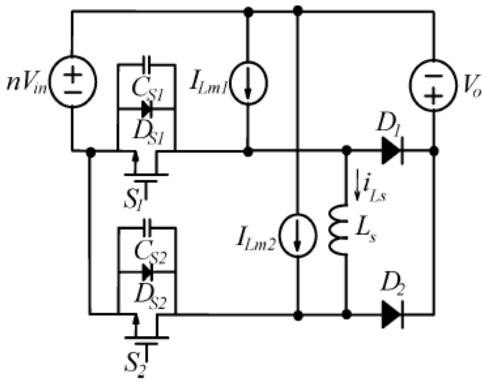
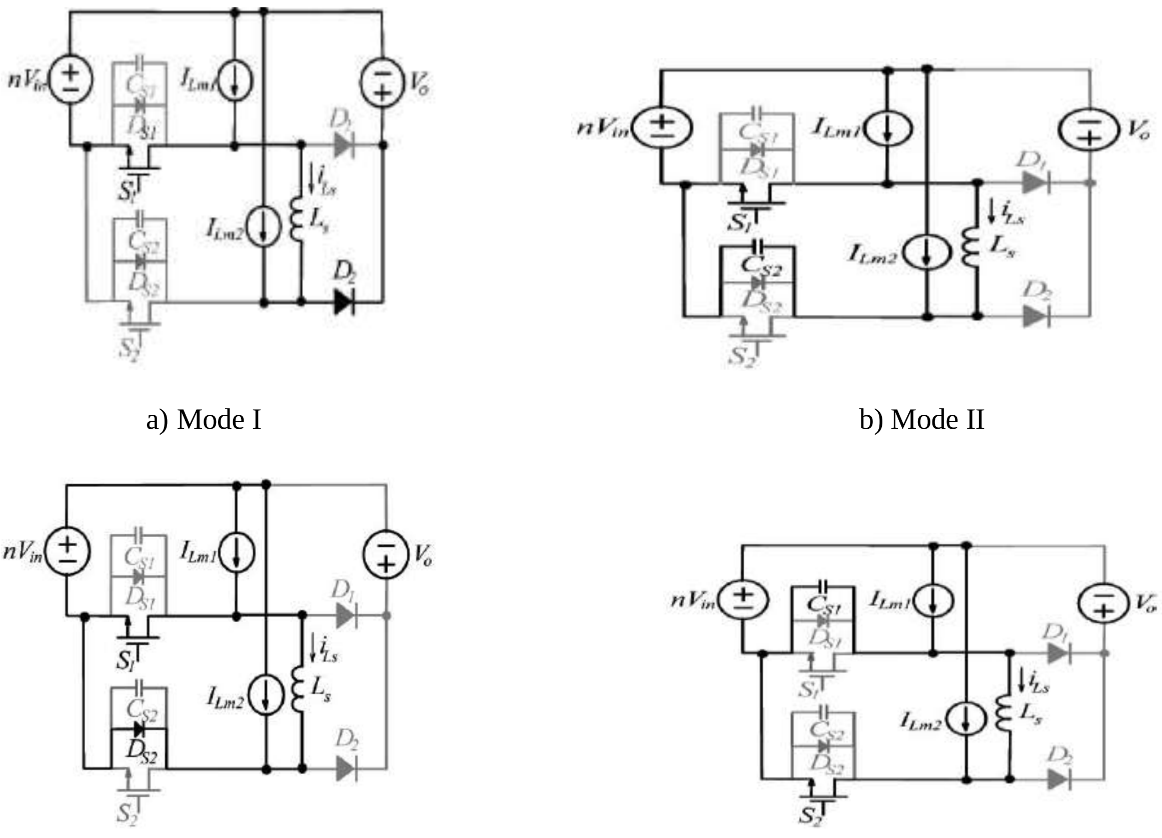


Fig 8- Simplified circuit under study

V. Functionality of Circuit

The circuit under study operates under eight modes. The former four modes characterize the ON state to turn-OFF transient of S_1, while S_2 undergoes OFF-state to zero-voltage turn-ON transition.



a) Mode I

b) Mode II

c) Mode III

d) Mode IV

Fig 9- Modes of operation of Interleaved Circuit

Burst-Mode Operation:

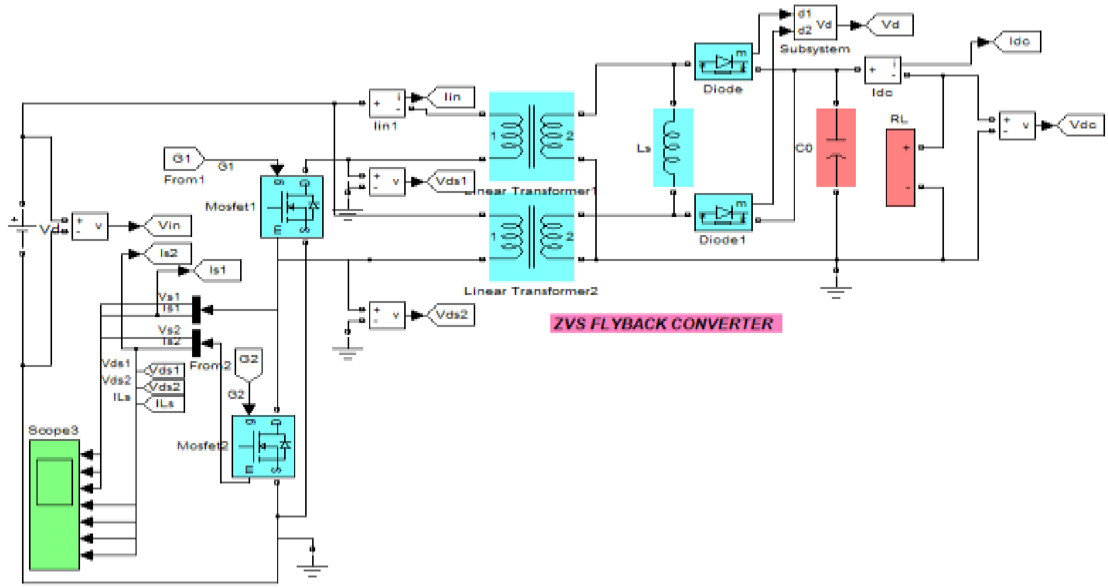


Fig 10- Functional control diagram of ZVS fly-back converter

It is a special operation method for PWM control. PWM gating pulse drives few of the switches, i.e. temporarily power output is reduced. For the control of this circuit, the operating frequency might be very high under light-load condition. Higher frequency implies the rise / fall time of the gating pulses are diminished. In order to endow with lower output power at moderate frequency, burst-mode control is adopted to influence the circuit. If the frequency is under preset, the switching frequency is hoisted to diminish the power output.

Beyond upper limit frequency, controller stops incrementing, but steps away a few cycles to trim down output power.

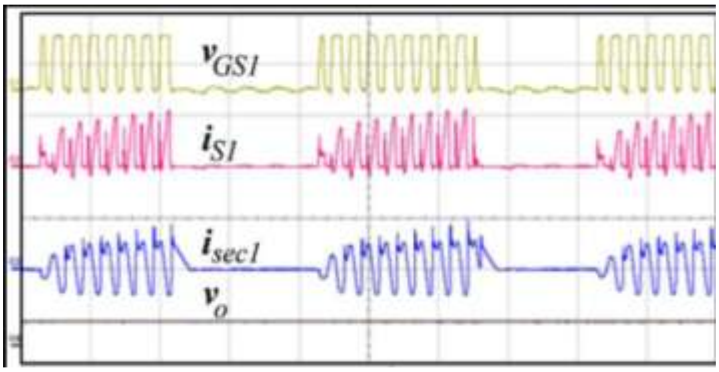


Fig 11- Burst-mode operation

Fig. 11 shows the gate signal, switch, and transfer secondary currents in the system. The switching frequency is maintained at 200 kHz.. It should be noticed that even during burst-mode operation, the output voltage fluctuation is still not appreciable.

Model of Control Algorithm:

The circuit controller: TMS320F2812 Computing speed: 150 MIPS
Feature: Built-in PWM generators, with duty ratio and phase delay adjustment
Voltage Divider Circuit: reduce output voltage
Low-pass filter: Filer output voltage
Filter output compared with the preset V_{ref}
PI Controller: From error v_e we get error-amending control-force signal u_v
Output power ~ switching frequency^{-1}
i_o current ~ load changes
Isolation amplifier: isolate the voltage reference and boost the current-driving capability for MOSFETs.

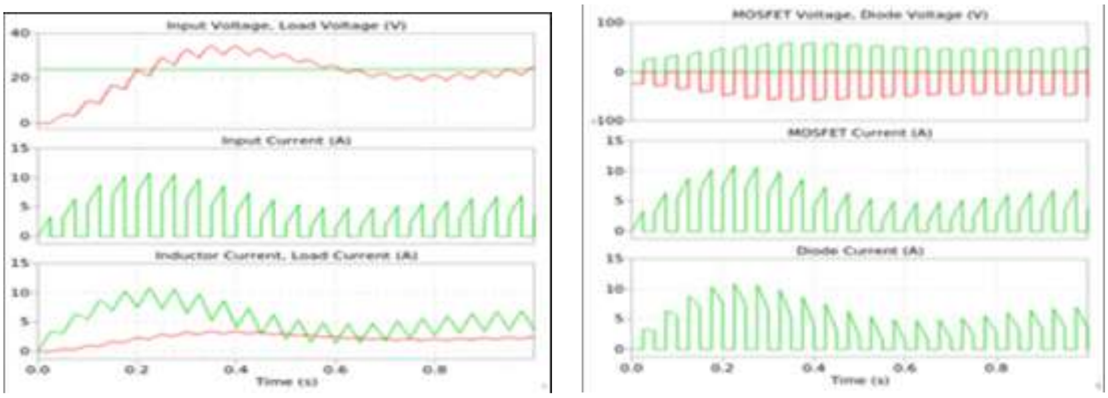


Fig 12- Theoretical waveforms of converter

The functional model of interleaved fly-back converter consists of constant supply, output capacitor, output resistance. The output voltage is passes out through a voltage divider circuit. A low pass filter is used to provide a stable output. The control circuit is adapted with PI control. The controller reduces the error in output voltage and provides feedback through frequency mapping block to the isolation amplifier. The detailed flow of signal is given in the diagram above.

Fig.13. Gating and Switching signals Waveforms

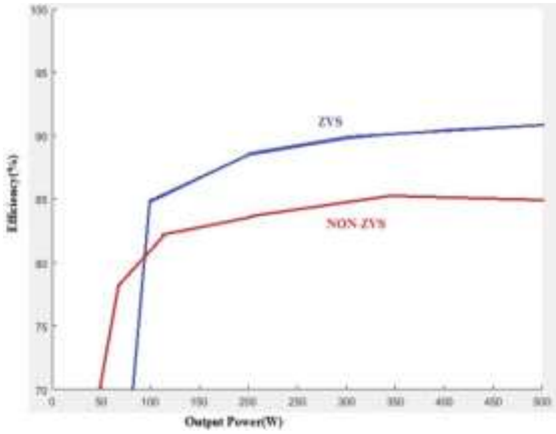


Fig.14. Performance Characteristics of ZVS

CONCLUSION

In this paper, an interleaved fly-back converter with ZVS feature has been studied. Only one additional inductor is obligatory to acquire the ZVS characteristics. The converter is able to provide high efficiency and low ripple output. Intending equations and control algorithm are discussed in the paper. Since circuit is controlled by differing frequency to copy with the output power dissimilarity, burst-mode control scheme has been entrenched into the controller to thwart too high-operation frequency under low-load circumstances. The highest effectualness is 91%. Even the worst efficiency is about 83% at very low-power output.

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