

# An Active Clamp based Technique for a High Efficient Flyback Converter

Chama R Chandran<sup>1</sup>, T Jothi<sup>2</sup>

<sup>1</sup>M E Student, PITAM, Chennai, TamilNadu, India

<sup>2</sup>Senior Lecturer, Department of Electrical and Electronics Engineering, PITAM, Chennai, TamilNadu, India

**Abstract:** This paper proposes a Z-source converter based flyback converter with a new active clamp control method. With this control methodology, the energy in the leakage inductance can be fully recycled. The absorbed leakage energy transferred to the output and input side will achieve zero voltage switching for the main switch. Thus, switching loss can be reduced. A Z-source converter network is incorporated between the power source and converter main circuit to achieve high efficiency. Compared to the conventional methods, this technique can achieve high efficiency at any condition, where the efficiency is not affected by the leakage inductance.

**Keywords:** Active clamp, Flyback, High efficiency, Z-source.

## 1. Introduction

A flyback converter due to minimum number of semiconductor and magnetic components, are widely adopted for offline low-cost power supplies. Another feature which makes it very attractive is its simplicity and low cost. The soft turn-on of the switch is highly desirable, as the voltage across the switch at the instant of turn-on is high. Soft switching is also useful as it minimizes the size and loss of the EMI filter.

When the switch is OFF, an RCD clamp circuit is usually used to dissipate the leakage energy. The transformer used should be associated with minimized leakage inductance to reduce the voltage spikes across the switch, and hence achieve high efficiency. The power supply designers still faces the problem on how to further improve the efficiency of the flyback converter.

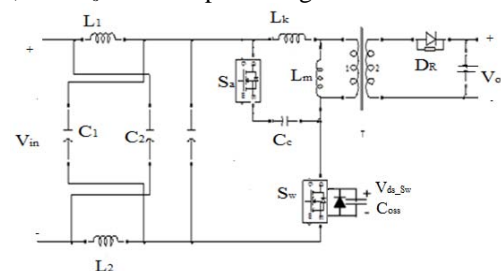
A solution to the problem of improving efficiency is reducing the leakage inductance energy loss. The absorbed leakage energy in the conventional RCD clamp circuit is dissipated in the snubber resistor. If the leakage inductance is large, the energy dissipated in the snubber resistor will be large, which in turn deteriorate the efficiency. The active clamp technology used on flyback converter will recycle the energy in the leakage inductor and can achieve soft – switching for the primary and auxiliary switches. Hence, high efficiency can be achieved, but it is sensitive to parameters variations. Control schemes used to improve efficiency of the conventional flyback converter are mainly focussed on how to minimize the switching loss. The conventional constant frequency control methodology on flyback converter has low efficiency due to high switching loss. This is mainly caused by the high drain-to-source voltage across the switch. Hence, many variable frequency control schemes are developed to improve the performance compared to the conventional constant frequency control.

This paper presents a Z-source converter based flyback converter with a new active clamp technique, to minimize the leakage energy and achieve soft switching for the main switch. The power stage is same as conventional active clamp circuit, but the control methodology and principle of operation will be different. Flyback derived topologies are

widely adopted for low power application due to its relative simplicity compared to other topologies. Active clamp based flyback topology is used to recycle transformer leakage energy while attaining minimum switch voltage stress. The incorporation of active clamp flyback circuit also serves to attain zero voltage switching for both primary and auxiliary switches. ZVS also reduces turn-off di/dtof the output rectifier, thus minimizing rectifier switching losses. The Z-source converter, which is a unique impedance network, is incorporated between the converter main circuit and power source to achieve high efficiency. The Z-source converter is actually a buck-boost converter that has wide obtainable voltage. In this proposed method, the auxiliary switch is turned ON for a short time before the primary switch is turned ON. And recycled leakage energy will achieve soft switching of the main switch. This reduces the circulating energy and thus the circuit can achieve high efficiency at any condition.

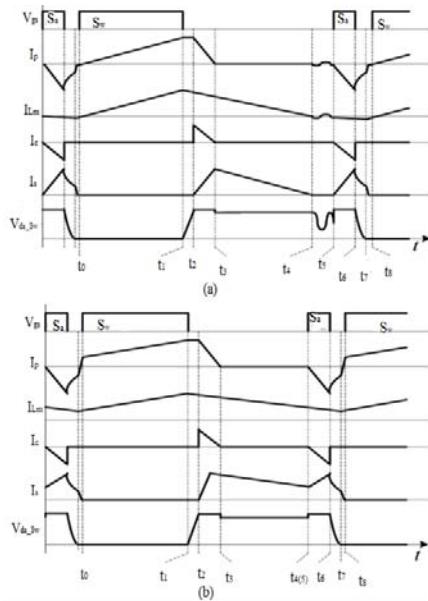
## 2. Principle of Operation

Figure 1 shows the circuit diagram of the proposed z-source converter based active clamp flyback converter. In the figure,  $L_m$  is the transformer magnetizing inductance,  $L_k$  is the transformer leakage inductance. Let  $D_R$  be the output diode rectifier and  $S_w$ ,  $S_a$  be the primary and auxiliary switches.  $S_a$  can be NMOS or PMOS. The equivalent parasitic capacitance of  $S_w$ ,  $S_a$  and the parasitic winding capacitance of the transformer is represented by  $C_{oss}$ .  $N$  is the transformer turns ratio, and  $V_o$  is the output voltage.



**Figure 1:** Topology of the active clamp flyback converter

For simplifying analysis in steady state circuit operation, the clamp voltage is assumed to be constant. The waveforms of DCM and CCM operation are shown in Figure 2.



**Figure 2:** Steady-state operation waveforms with proposed non complementary control method. (a) DCM operation. (b) CCM operation.

There are 8 modes of operation for the circuit:

**Mode 1 ( $t_0-t_1$ ):** At  $t_0$ , the primary switch  $S_w$  is ON, and the auxiliary switch  $S_a$  is OFF. In this mode, the primary side current  $I_p$  increases linearly, and the energy is stored in the magnetizing inductor.

**Mode 2 ( $t_1-t_2$ ):** At  $t_1$ ,  $S_w$  is turned OFF, and  $C_{oss}$  is charged up by the magnetizing current. The drain-source voltage  $V_{ds\_Sw}$  of main switch  $S_w$  increases linearly, due to relative large magnetizing inductance. The end of this mode happens when the drain-source voltage  $V_{ds\_Sw}$  reaches the input voltage  $V_{in}$  plus the clamp voltage  $V_c$ , ie,  $V_{in} + V_c$ .

In this mode, the turn-on of output diode rectifier  $D_R$  depends on the clamp voltage  $V_c$  and the ratio of leakage inductance and magnetizing inductance, ie,  $L_k/L_m$ . The secondary – side rectifier  $D_R$  turns ON once the  $V_c$  reaches  $(1+m)NV_o$ . Then, once  $V_{ds\_Sw}$  reaches  $V_{in} + V_c$ , and the secondary – side rectifier  $D_R$  also turns ON.

**Mode 3 ( $t_2-t_3$ ):** At  $t_2$ , when the voltage  $V_{ds\_Sw}$  reaches  $V_{in}+V_c$ , the antiparallel diode of  $S_a$  turns ON and the output diode rectifier  $D_R$  also turns ON. The energy stored in the magnetizing inductor is delivered to the output, and the energy in the leakage inductor is absorbed by the clamp capacitor.

The leakage inductor current  $I_p$  decreases linearly when the clamp capacitor is large and the circuit is lossless, ie, during this mode, the difference between the primary and magnetizing current is delivered to secondary side. This mode ends as soon as the current in the leakage inductor reaches zero. Then all the magnetizing current is transferred to secondary side.

**Mode 4 ( $t_3-t_4$ ):** At  $t_3$ , as the current through leakage inductance reaches zero, the antiparallel diode of  $S_a$  is OFF.

Now the magnetizing current delivered to the load decreases linearly.

**Mode 5 ( $t_4-t_5$ ):** At  $t_4$ , as the magnetizing current reaches zero,  $D_R$  turns OFF. Then a parasitic resonance occurs between  $L_m$  and  $C_{oss}$ .

**Mode 6 ( $t_5-t_6$ ):** At  $t_5$ , auxiliary switch  $S_a$  turns ON. The voltage across leakage inductor  $L_k$  and magnetizing inductor  $L_m$  is clamped to  $V_c$  and  $D_R$  turns ON. Then current through  $L_k$  increases reversely and the magnetizing current  $I_{Lm}$  also increases reversely, but the magnitude will be smaller than leakage current. These negative current will achieve ZVS of main switch  $S_w$ . The absorbed leakage energy in Mode 3 will be transferred to output side and leakage inductor again. The auxiliary switch ON time determines the clamp voltage.

**Mode 7 ( $t_6-t_7$ ):** At  $t_6$ , the auxiliary switch  $S_a$  is turned OFF and the negative current  $I_p$  discharges parasitic capacitor loss. If the leakage energy is larger than the parasitic capacitor energy the secondary  $D_R$  keeps ON, and the difference between  $I_p$  and  $I_{Lm}$  is fed to secondary side. Once the leakage energy becomes smaller than that of parasitic capacitor, the magnetizing inductance also helps to achieve soft switching. As soon as the leakage inductor current  $I_p$  reaches magnetizing inductor current  $I_{Lm}$ , the  $D_R$  is OFF and then both the magnetizing inductance and leakage inductance discharge  $C_{oss}$ .

**Mode 8 ( $t_7-t_8$ ):** At  $t_7$ , the output capacitor  $C_{oss}$  voltage is decreased to zero and then the antiparalleled diode of main switch  $S_w$  turns ON. Here, the primary-side switch  $S_w$  should be turned ON before the primary current  $I_p$  changes the polarity. If the leakage energy  $E_{Lk}$  is larger than parasitic capacitor energy  $E_{C_{oss}}$ , then leakage energy alone will help to achieve ZVS operation of the main switch.

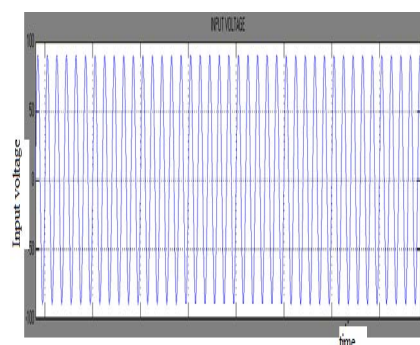
$$E_{Lk} = \frac{1}{2} L_k I_p^2 \geq E_{C_{oss}} = \frac{1}{2} C_{oss} (V_{in} + NV_o)^2$$

If the leakage energy is smaller than parasitic capacitor energy, then the magnetizing energy  $E_{Lm}$  is also used to realize ZVS operation.

$$\frac{1}{2} L_k I_p^2 + \frac{1}{2} L_m I_{Lm}^2 \geq E_{C_{oss}} = \frac{1}{2} C_{oss} (V_{in} + NV_o)^2$$

For CCM condition, Mode 5 does not exist and only the leakage energy can be used to achieve ZVS.

### 3. Result



**Figure 3:** Input voltage of active clamp based flyback converter with feedback

The input voltage applied to the converter circuit is 90V and the output voltage obtained is 16V.

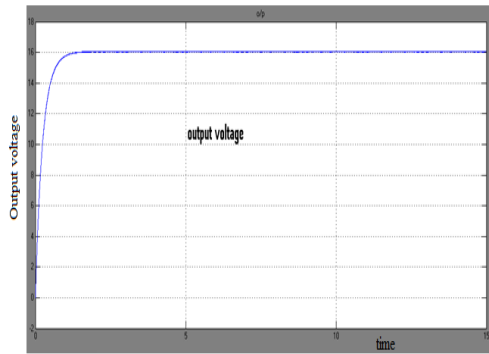


Figure 4: Output voltage of active clamp based flyback converter with feedback

#### 4. Conclusion

This paper proposes a Z-source converter based flyback converter with an active clamp control method. The Z-source converter is a unique impedance network providing unique features that cannot be obtained in the traditional voltage source and current source converters, where a capacitor and inductor are used, respectively. The proposed circuit has some attractive features such as low device stress, soft switching operation, and high efficiency at all conditions. It can be adopted to various control schemes, such as VF and CF. All the advantages makes it suitable for low power offline application with strict efficiency.

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#### Author Profile

**Chama R Chandran** received the B.Tech degree in Electrical and Electronics Engineering from Sree Buddha College of Engineering, Pattoor, Allapetty District, Kerala in 2010 and doing final year M.E. degree in Power Electronics and Drives from Prathyusha Institute of Technology and Management, Thiruvallur, Chennai, respectively. During Dec. 2010 - Aug. 2011, she worked as lecturer in Sree Buddha College of Engineering, Kerala.