An Active Clamp based Technique for a High Efficient Flyback Converter

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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 achive soft – switching for the primary and auxillary 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 minimie 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 auxillary switches. ZVS also reduces turn-off di/dtof the output rectifier, thus minimizing rectifier switching losses. The Z-source converter, which is a unque impedance network, is incorporated betweeen 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 auxillary 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, Sa be the primary and auxillary 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.

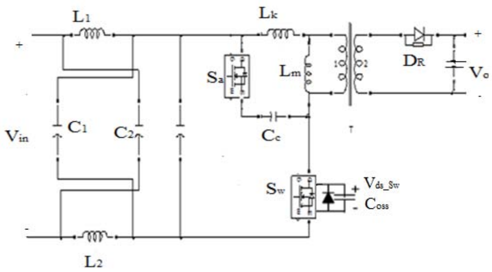

Figure 1: Topology of the active clamp flyback converter

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.

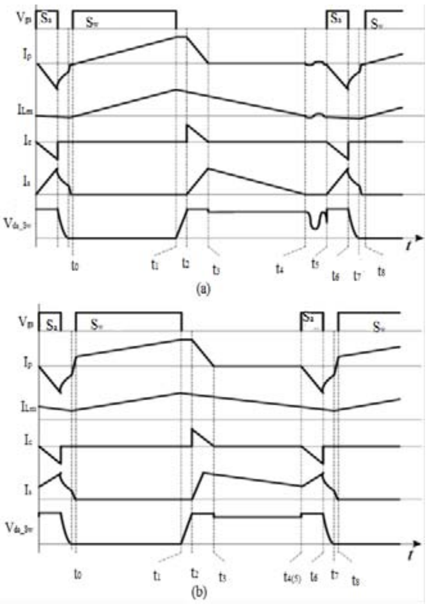

Figure 2: Steady-state operation waveforms with proposed non complementary control method. (a) DCM operation. (b) CCM operation.

There are 8 modes of operation for the circuit:

Mode 1 (t_o-t_1) : At to, the primary switch S_w is ON, and the auxillary 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 Vin 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 Lm and Coss.

Mode 6 (t_5-t_6): At t_5, auxillary switch S_a turns ON. The voltage across leakage inductor L_k and magnetizing inductor Lm 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 auxillary switch ON time determines the clamp voltage.

Mode 7 (t_6-t_7) : At t_6, the auxillary 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_{Coss}, then leakage energy alone will help to achieve ZVS operation of the main switch.

$$E_{Lk} = ½ L_k \, Ip\,neg^2 \geq E_{Coss} = 1/2C_{oss} \, (Vin + NVo)^2$$

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

$$½ L_k \, Ip\,neg^2 + ½ L_m \, Ilm\,neg^2 \geq E_{Coss} = 1/2C_{oss} \, (Vin + NVo)^2$$

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

3. Result

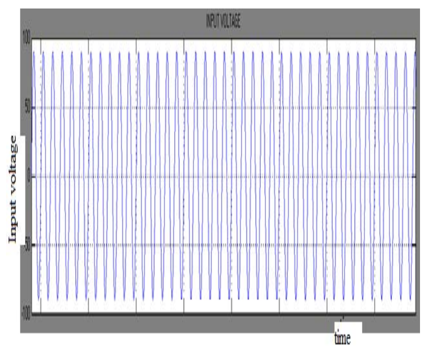

Figure 3: Input voltage of active clamp based flyback converter with feedback

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

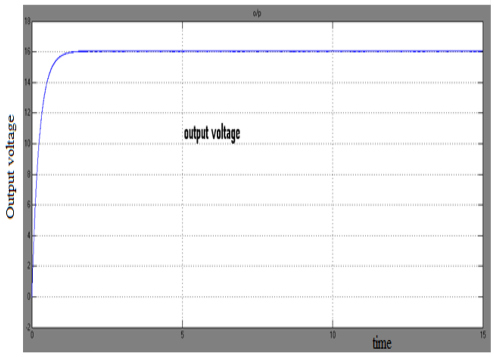

Figure 4: Output voltage of active clamp based flyback converter with feedback

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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