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A new soft switching flyback-forward converter with high power density

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Abstract: In this paper, a new soft switching flyback-forward converter with high power density is proposed. The active clamp circuit provides soft switching conditions for auxiliary and main switches. The proposed Zero-voltage switching flyback-forward converter is analyzed and also a prototype of this converter is presented to verify theoretical analysis.

Key words: Soft switching; Flyback-Forward; Zero Voltage Switching (ZVS)

1. Introduction

DC-DC converters are widely used in audio systems, telecommunications equipment, computers and many other commercial and industrial components. Typical dc-dc converters consist of active switch MOSFET or IGBT, diodes, inductors and capacitors. Transistor switching resources work in the area off and saturation. Thus, they have greater efficiency, less size and weight, quick response and easy control. This type of resources possesses varieties topologies such as buck, boost, forward, flyback. The switching converters are generally divided into hard and soft switching converters. The hard switching has power losses and Electro Magnetic Interference (EMI) due to voltage and the current overlapping at the time of switching. Therefore, soft switching converters are introduced (Park et al., 2010; Mousavi et al., 2011). In these converters, switching frequency and the power density can be increased. This condition is usually obtained by zero voltage switching (ZVS) and zero current switching (ZCS). One of the switching power supplies is flyback-forward converters (Cao t al., 2010; Mao et al., 2006).These converters consist of two flyback and forwards transformer.

In this paper introduce a ZVS flyback-forward converter with the minimum element and low stress on semiconductor devices. Furthermore, power density of the converter increase due to forward-flyback structure.

2. Description and Operation of the proposed Flyback-Forward Converter

The proposed flyback-forward converter with active clamp circuit is shown in Fig.1. The active clamp circuit includes C_4 and S_2. In flyback-forward converter in both of switch turning on and off , the energy is transferred, thus power density of theses converters is high.

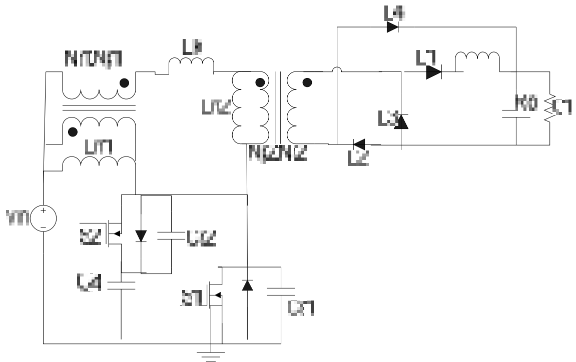

Fig. 1: The proposed flyback-forward converter

In order to simplify the steady state analysis, the following assumptions are made:
- Power switching devices are ideal.
- L_{m1} and L_{m2} are much large.
- The output capacitor is large enough, so output voltage is constant in a switching cycle.
- Both turns ratios of the two transformers are identical.(n=Ns1/Np1=Ns2/Np2).

The switching period can be divided into 7 operating modes. The equivalent circuit for each operating mode of the proposed converter is shown in Fig.2.

Mode 1 [t_0-t_1]: This mode begins with the auxiliary switch S_2 turning off and output capacitor of S_2 is charged. At the same time the drain source voltage of S_1 has decreased to zero voltage.

Mode 2[t_1-t_2]: At time t_1 $Vds_{S1}=0$ and I_{S1} is negative. Thus, the body diode of S_1 conducts. In the secondary side, D_6 and D_8 turn on. The value of the magnetizing currents and the input current can be written as follows:

$$I_{in} = I_{lm1} + I_{lm2} + nI_s \quad (1)$$

$$I_{m1} = I_{m1}(t_1) + \left(\frac{V_{in}}{L_{m1}}\right)(t - t_1) \quad (2)$$

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$$I_{m2} = I_{m2}(t1) + \left(\frac{(1+n)V_{in}}{L_{m2}}\right)(t - t1) \quad (3)$$

$$\frac{dIs}{dt} = \frac{nV_{in}-V_O}{L} \quad (4)$$

$$I_{in} = I_{S1} \quad (5)$$

Mode 3 [t_2-t_3]: The main switch can be turned on under ZVS condition. In this mode the circuit operation is like the circuit operation in mode 2.

Mode 4[t_3-t_4]: This mode begins when D_6 turns off and at time t_4, S_1 is turned off. . The value of the main switch current is:

$$I_{S1} = I_{Lm1} + I_{Lm2} \quad (6)$$

Mode 5 [t_4-t_5]: Input current I_{in} charges the output capacitor C_{S1} and discharges C_{S2}.At time t_5, the drain-to-source voltage of S_2 is zero.

Mode 6 [t_5-t_6]: This mode starts, when I_{s2} is negative. Thus, the body diode of S_2 is conducting. In the secondary side, D_3 and D_4 turn on. The value of the magnetizing currents and the input current are :

$$I_{Lm1} = I_{Lm1}(t5) - \frac{V_{C4}(t5)-V_{in}}{L_{m1}}(t - t5) I_{Lm2} = I_{Lm2}(t_5) - (1 + n)\frac{V_{C4}(t5)-V_{in}}{L_{m2}}(t - t_5) I_{in} = Ilm1 + Ilm2 + nIs \quad (7)$$

$$I_{in} = -I_{S2} \quad (8)$$

Mode 7 [t_6-t_7]: The auxiliary switch can be turned on under ZVS condition. In this mode the circuit operation is like the circuit operation in mode 2.When the transformer is demagnetized and the current through L is still not zero, the inductor current still decreases.

Mode8 [t_7-t_8]: This mode begins when the diode D_1 turns off. At the end of this mode the auxiliary switch, D_3 and D_4 turning off.

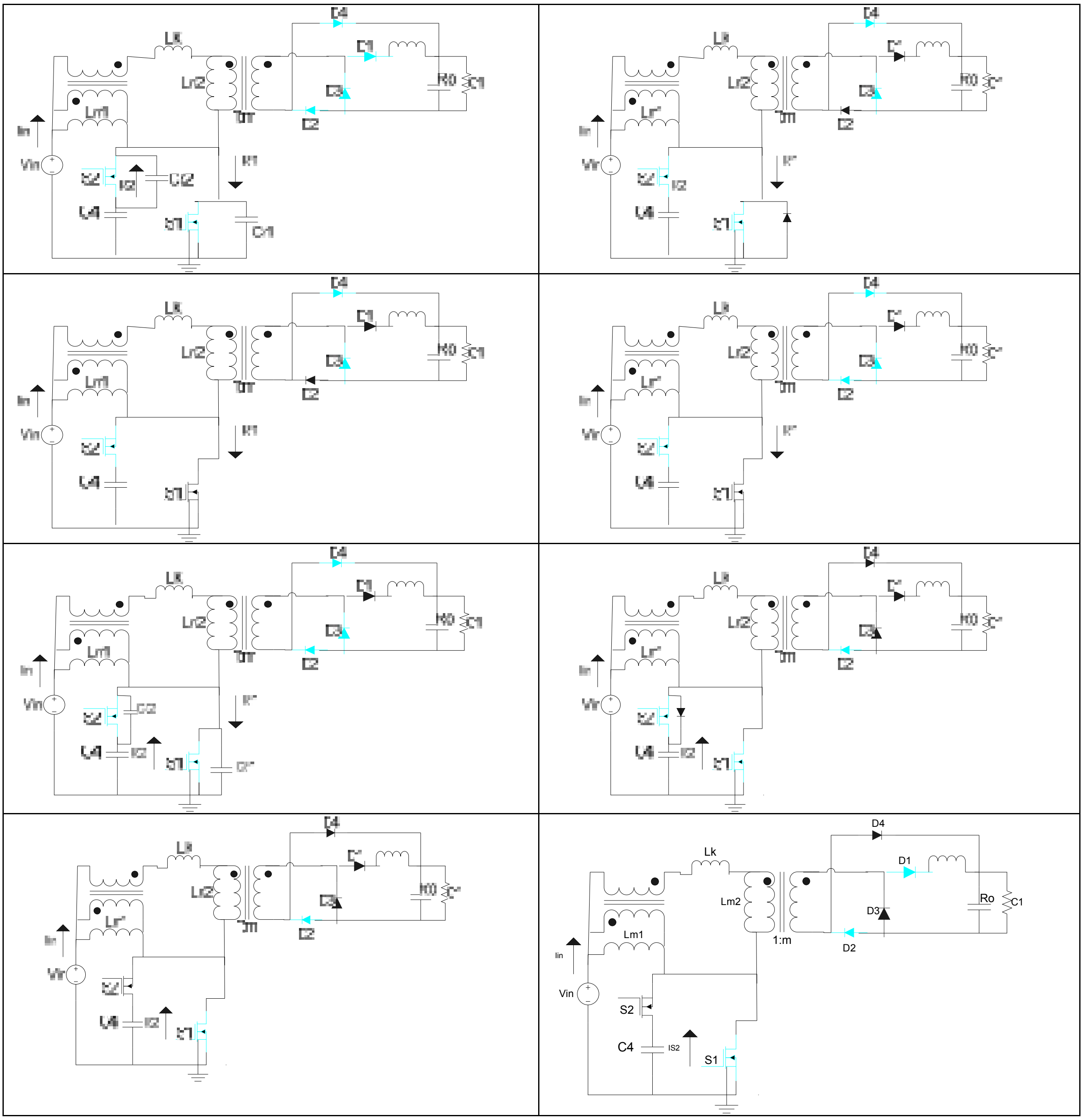

Fig. 2: The equivalent circuit for each operating mode of the proposed converter

3. The simulation and experimental results

In this section a prototype of proposed flyback-forward converter at frequency 100 kHz was simulated by PSPICE and Implemented. Elements and specific values of the proposed flyback-forward converter are presented in table I. The key waveforms of proposed converter are shown in Fig. 3. Fig. 4 and Fig 5 show the drain-source voltage and current of main and auxiliary switches respectively. As you can see the both switches, turn on under ZVS conditions because current is negative in turn on instant and therefore body diode of switches conduct. The efficiency of the proposed converter is shown in Fig. 6.

Table 1: Power stage Components

COMPONENTS	PARTNAME/VALUE
S1,S2	IRF640
L1	100UH
D1-D4	MUR860
N,m	**1:1**
L_k	4.5UH
C_O	100UF

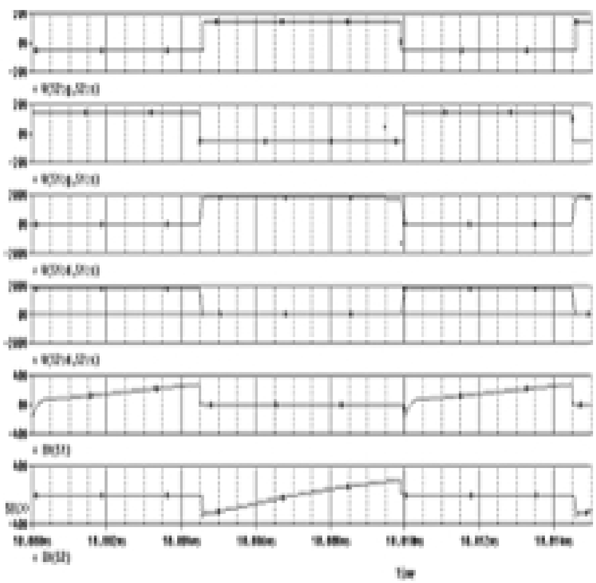

Fig.3: The simulated waveforms of drain-source voltage and current of S_1 and S_2

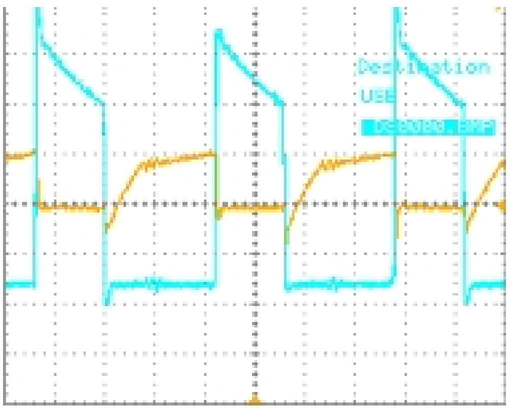

Fig. 4: Measured drain-source voltage (blue) and current (yellow) waveforms of main switch

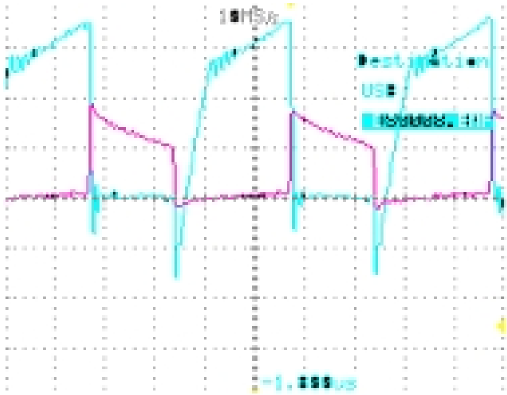

Fig. 5: Measured drain-source voltage (red) and current (blue) waveforms of auxiliary switch

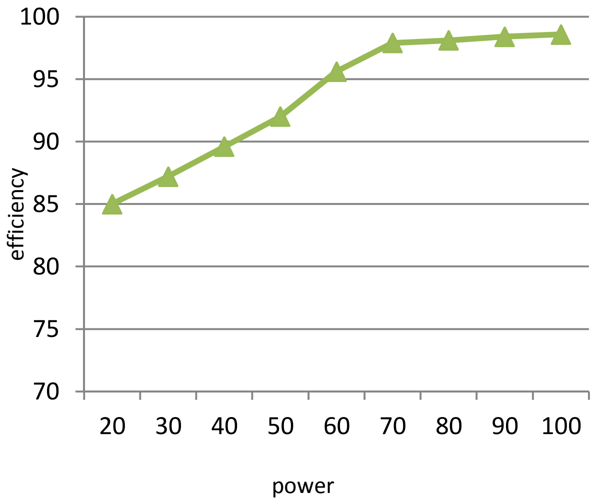

Fig.6: The efficiency of the proposed converter versus the output power

4. Conclusion

In this paper, a flyback-forward converter with active clamp is presented. A ZV condition is provided for turning on and off of the main and auxiliary switches by auxiliary circuit. The coupled inductor in input increase voltage gain and clamp capacitor absorb voltage spike due to leakage inductance of transformer. Also power density of converter is high because the power transfers to the output in on and off state of main switch.

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