A NEW SOFT SWITCHING FLYBACK-FORWARD PWM DC-DC CONVERTER

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Abstract- This paper presents a new soft switching flyback-forward PWM converter. The proposed circuit employs an auxiliary circuit to achieve soft switching condition for switches and also absorbs the voltage spikes caused by the leakage inductance of transformers in the converter. In the proposed converter main switch operates at ZVS and the auxiliary switch operates at ZCS. The proposed converter has some advantages such as the low output current ripple, sharing power between the magnetic elements and work at high power levels, soft switching condition in the both turn on and off switch. Soft switching condition is satisfied for both step-up (boost) and step-down (buck) in the proposed converter. Furthermore this converter has a high efficiency and low voltage stress. The converter is controlled by PWM.

Keywords- Zero Current Switching (ZCS), Zero Voltage Switching (ZVS), Soft Switching, and PWM.

I. INTRODUCTION

Isolated DC-DC converters are widely employed in the communication power system and industrial applications, fuel cell systems, etc. Isolation transformer links primary switching circuitry such as flyback, forward, push pull, half bridge or full bridge topologies with secondary rectifiers.

The well- known classical forward converter needs three windings. Two are used to transform the energy and the third one is used to rest the core. So far many of the flyback and forward transformers have been introduced. The new combined forward-flyback converter doesn't need reset windings. The transformer is easier to manufacture, is smaller, has lower weight and is therefore cheaper. In the isolated interleaved ZVS flyback-forward boost type converter, the active clamp circuit is added in the interleaved two phases of the converter to recycle the leakage energy.

There are several ways to control the converters. In the PWM converter, switching frequency is fixed; and output converter controlled by controlling the duty cycle. Therefore PWM soft switching converters more than resonant and quasi-resonant converters are considered. In these converters, an auxiliary circuit is added to the switches of converter, so that converter control remains PWM. This paper describes a new soft switching flyback-forward PWM converter, which absorbed voltage spikes due to the leakage inductance of transformers.

The main switch operates at ZVS and the auxiliary switch operates at ZCS. Soft switching condition is satisfied for both step-up (boost) and step- down (buck) in the converter. In the both turn on and off switch, power is transferred to the output therefore this converter work at high power levels. Furthermore this converter is a high efficiency, low voltage stress and the low output current ripple.

II. PROPOSED CONVERTER AND OPERATIONAL PRINCIPLE

A. Proposed converter

The auxiliary circuit is shown in Fig1. The auxiliary circuit connected in parallel to the main switch. The auxiliary circuit consists of auxiliary switch S_a, series diode D_a, resonant elements L_a and C_a. This circuit when switched properly ensures lossless switching. The proposed flyback-forward converter is illustrated in Fig2; where S_1 is the main switch, C_S is adopted to implement the ZVS soft switching performance, which includes the parasitic capacitance of the main switch. C_b is the block capacitor, C_{O1} and C_{O2} are the output capacitors, V_{in} and V_O are the input and output voltages, D_1, D_2 and D_3 are the proposed converter diodes, and R_O is the load.

There are two transformers in the proposed converter, which are named by flyback (T_1) with 1: n turns ratio and forward (T_2) with 1: m turns ratio and an inductance L_T which is coupled with forward transformer by 1: m turns ratio. L_{m1} and L_{m2} are the magnetizing inductors; L_{K1} and L_{K2} are the leakage inductances of transformers.

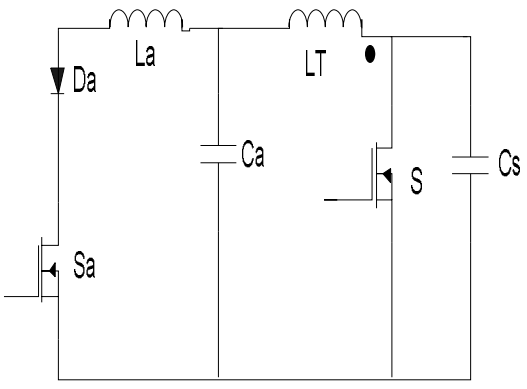


Fig. 1. auxiliary circuit.

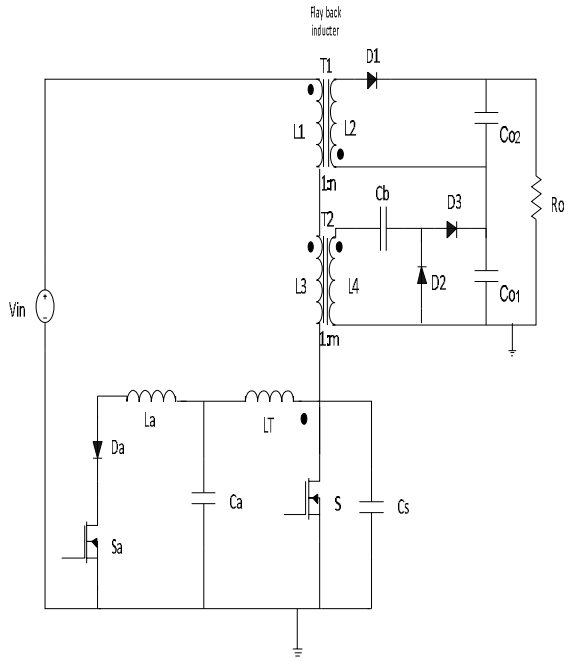


Fig. 2. Proposed flyback-forward PWM converter.

B. Operation of proposed converter

To simplify the analysis of the converter in steady state, these assumptions are considered:

- The parasite elements are ignored.
- The output capacitors (C_{O1}, C_{O2}) are large enough, thus the output voltage (V_O) in one switching cycle is constant.
- The input voltage (V_{in}) in one switching cycle is constant.

Before t_0, the main switch S and the auxiliary switch S_a are in the off-state. The resonant capacitor C_a is charged to V_{ca} by the current of the magnetizing inductors L_{m1} and L_{m2}.(Equation(1)). The secondary side diodes D_1 and D_2 are both reverse-biased and other semiconductor devices are not conducts (see fig 4(a)). Equation (2) and (3) are gives the voltage across the primary of flyback transformer and forward transformer. Equation (4) gives the voltage across the coupled inductor (L_T).

$$V_{ca} = V_{in} + \frac{V_o}{2n} - \frac{2V_{C_b}}{m} \tag{1}$$

$$V_{L_{m1}} = -\frac{V_o}{2n} \tag{2}$$

$$V_{L_{m2}} = -\frac{V_{C_b}}{m} \tag{3}$$

$$V_{L_T} = -\frac{V_{C_b}}{m} \tag{4}$$

Mode1:This interval begins when the auxiliary switch S_a is turned-on with ZCS at $t=t_0$. The equivalent circuit is shown fig4 (b) with $I_{L_a}(t_0) = 0$ as the initial current of resonant inductor L_a. The current in the auxiliary switch S_a increase linearly as in (6).

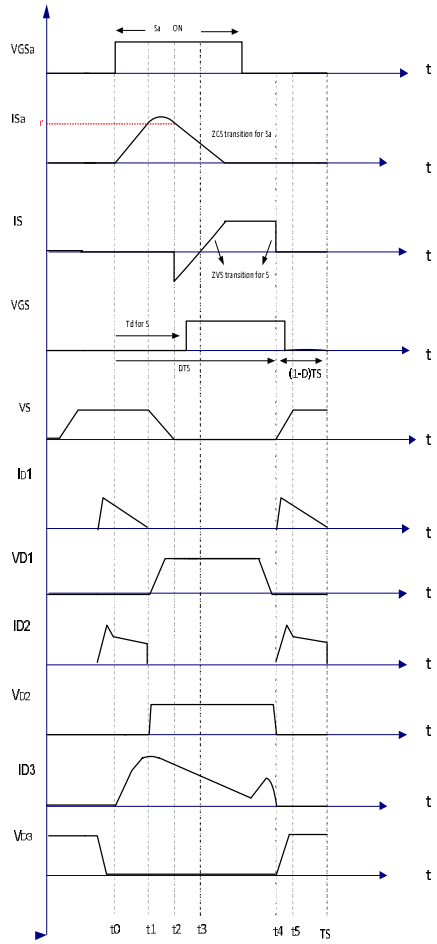


Fig. 3. Key waveforms of proposed flyback-forward PWM converter.

$$I_{S_a}(t) = \frac{V_{C_a}}{L_a}(t - t_0) \tag{5}$$

$$I_{S_a}(t) = \frac{V_{in} + \frac{V_o}{2n} - \frac{2V_{C_b}}{m}}{L_a}(t - t_0) \tag{6}$$

At $t=t_1$, current I_{sa} (t) reaches I'.
During this condition is equivalent to:

$$(t - t_o) = \frac{I'L_a}{V_{in} + \frac{V_o}{2n} - \frac{2V_{C_b}}{m}} \tag{7}$$

Mode2: When the current in the auxiliary switch S_a reaches I', the diode D_1 is turn off with ZCS at $t=t_1$. The resonant elements L_a and C_a are resonating during this interval. The current in the auxiliary switch $I_{S_a}(t)$ will raises sinusoidal as shown in 4(d). Equation (8) and (9) gives the current through the resonant inductor and the voltage across the resonant capacitor respectively. This interval ends, when the voltage across the resonant capacitor $V_{C_a}(t)$ decrease to zero. This forward biases the body diode of the main switch S at time $t=t_2$. Body diode of the main switch s is turns-on and it can be now turned-on with zero voltage

switching (ZVS). The current of the main switch and the voltage of C_a in resonant state are shown in below.

$$I_{S_a}(t) = I' + \frac{V_{C_a}}{z}\sin\left(w_o(t-t_1)\right) \quad (8)$$

$$V_{C_a}(t) = V_{ca}\,COS\left(w_o(t-t_1)\right) \quad (9)$$

$$w_o = \frac{1}{\sqrt{L_a C_a}} \quad (10)$$

$$Z = \sqrt{\frac{L_a}{C_a}} \quad (11)$$

During this condition is equivalent:

$$t_2 - t_1 = \pi/2\sqrt{L_a C_a} \quad (12)$$

Mode3: Body diode of the main switch (S) turns on, therefore main switch (S) can be turn on with zero voltage switching (ZVS). In this interval, the resonant stop and the current of the main switch (S) raise linearly to zero whit slope of $\frac{V_{Cb}}{mL_a}$.

The important equations introduce as following:

$$V_{L_{m1}} = -\frac{V_o}{2n} \quad (13)$$

$$V_{L_{m2}} = \frac{V_{C_b}}{m} + \frac{V_o}{2m} \quad (14)$$

$$V_{L_T} = \frac{V_{C_b}}{m} + \frac{V_o}{2m} \quad (15)$$

$$V_{C_a} = V_{in} + \frac{V_o}{2n} - 2\left(\frac{V_{C_b}}{m} + \frac{V_o}{2m}\right) \quad (16)$$

$$I_{S_a}(t) = -\frac{V_{Cb}}{mL_a}(t-t_2) + I' \quad (17)$$

$$I_S(t) = \frac{V_{Cb}}{mL_a}(t-t_2) - I' \quad (18)$$

Mode4: In this interval, the current of the main switch S is zero, the current of inductor L_T transfer from the body diode S to the main switch S. Therfore diode D_3 turns on by ZVS and diode D_2 turns off by ZCS. During in this interval, the current of auxiliary switch S_a, decrease to zero with the pervious slope. Thus the auxiliary switch S_a is turned off on ZCS. According to KCL equation (17), from the moment, the current of main switch S will be obtained.

$$I - I_{S_a} = I_S \quad (19)$$

$$\Delta T_4 = t_4 - t_3 = \frac{I'L_a}{V_B} \quad (20)$$

$$V_B = \frac{V_{C_b}}{m} \quad (21)$$

The equivalent circuit condition is shown in fig4 (e).

Mode5: At $t=t_4$ i.e., at the end of DTS, the main switch S is switched-off. The turn off of the main switch is at zero voltage (ZVS), because of snubber capacitor across the main switch.

The voltage across the main switch raises slowly thereby the turn off transition losses reduced. In this condition the diodes D_1 and D_2 turn on under ZCS. The voltage across the primary of flyback and forward transformers for this situation is as follows:

$$V_{L_{m1}} = -\frac{V_o}{2n} \quad (22)$$

$$V_{L_{m2}} = \frac{V_{C_b}}{m} \quad (23)$$

$$V_T = \frac{V_{C_b}}{m} \quad (24)$$

This equation circuit is shown in fig4 (f).

It is observed that turn on and turn off of main switch and auxiliary switch by the auxiliary circuit are loss-less.

III. DESIGN GUIDELINES

In this section, guidelines for the design of the proposed flyback-forward PWM converter are presented.

- Selection of resonant inductor L_r and resonant capacitor C_r.
- The slope of current in the auxiliary circuit in T_1 depends on L_r.
- The value of L_r and C_r together decides the resonant interval T_2.The resonant interval should be minimum.

This interval minimizes the conduction losses in the auxiliary switch; maximizes the effective duty cycle as well. The length of the resonant interval is approximately a quarter of the resonant period (Equation (25)).

$$\frac{\pi}{2}\sqrt{L_r C_r} = (5to10)\%ofT_{on}(\max) \quad (25)$$

- Larger values of C_r increase the peak of auxiliary circuit current. Lower values of C_r increases voltage slope of main switch. Value of C_r is so

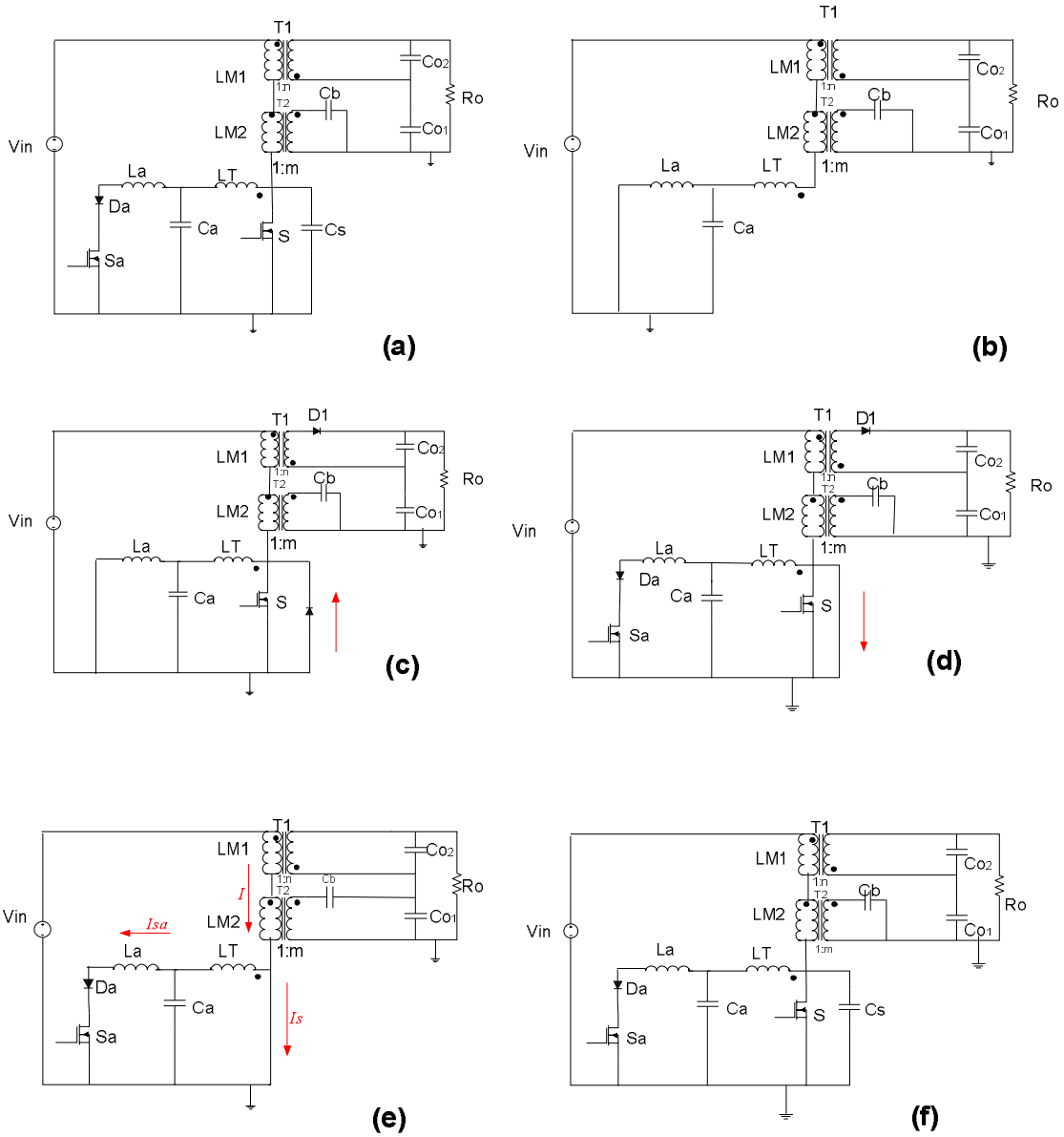


Fig. 4. Operation processes of proposed converter:(a):[t<t0] ,(b):[t0 – t1] ,(c):[t1 – t2] ,(d):[t2 – t3] , (e):[t3 – t4] ,(f):[t4 – t5].

selected that voltage across the main switch does not exceed the specified limit. The C_r value is obtained below.

$$C_r = \frac{It_f}{2V} \tag{26}$$

I is the on-state current, V is the off-state voltage, t_f is the fall time of the main switch.

A. Selection of auxiliary switch Sa, Diodes D and Da

- The device used for the auxiliary switch should has low output capacitance.
- The diodes D and D_a are fast recovery diodes.
- The gating signals to S and S_a are as shown in fig.3 to ensure ZVS and ZCS transitions of the main and auxiliary switch, respectively.
- The turn-on of auxiliary switch is $t=T_1+T_2+T_3$.This ensures that the turn-off transition of the auxiliary switch S_a is at zero current.
- The minimum delay T_d for the turn-on of the main switch S is $t=T_1+T_2$. In several ZVS schemes, the delay is a function of load and other operating conditions.

IV. SIMULATION RESULTS

The flyback-forward PWM converter is simulated shown in fig.5 Fig.6 and Fig.7. The circuit parameters and specifications of proposed converter are summarized in Table.1. As you can see in Fig. 5 the current in turns on instant is negative therefore body diode is on and ZVS condition is provided. Also the voltage at turn off instant raises slowly due to snubber capacitor therefore ZVS condition exists. In Fig. 6 the current of auxiliary switch is zero at turn on and turn off instant therefore ZCS conditions are provided. In Fig. 7

the voltage and current waveforms of D1 is presented. As you can see ZCS condition exists for turn on and off instant.

TABLE 1
Utilized components and parameters in the proposed flyback-forward PWM converter

D	Duty cycle	0.52us
V_{in}	Input voltage	24v
V_{out}	Output voltage	48v
P_o	Output power	50w
f_s	Switching frequency	100KHZ
C_s	Snuber capacitor	4.7nf
C_a	Resonant capacitor	1nF
C_b	Block capacitor	10µf
C_{o1},C_{o2}	Output capacitors	47µF
L_a	Resonant inductor	4 µH
LT	Coupled inductance	30µH
Lm1	magnetizing inductor of fly-back	200 µH
Lm2	magnetizing inductors of	100 µH
N,M	turns ratio	1

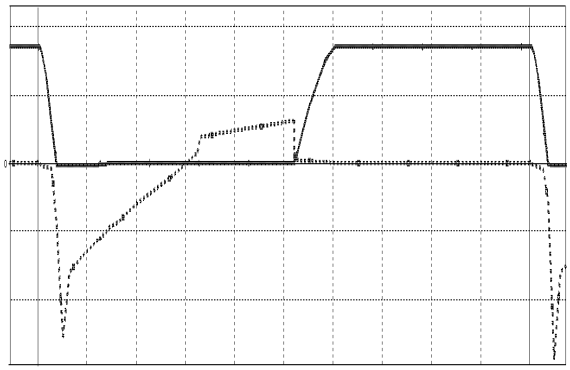


Fig.5. simulated and experimental results ZVS performances of the main switch (S).

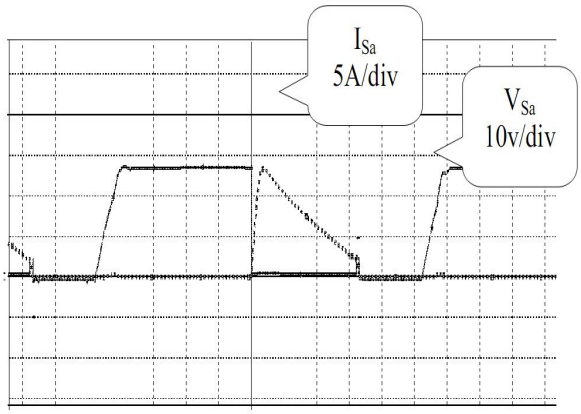


Fig.6. shows the simulated and experimental results ZCS performances of the auxiliary switch (S_a).

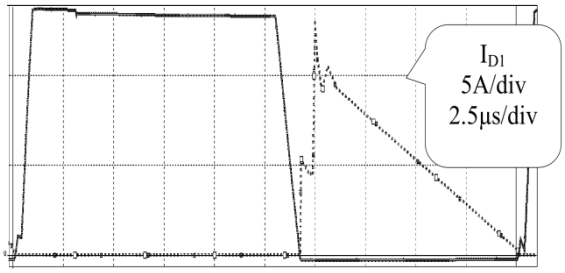


Fig.7. shows the simulated and experimental results the current wave form of (D_1)

CONCLUSION

This paper presents a new soft switching flyback-forward PWM converter. The main switch operates under ZVS condition and the auxiliary switch operates under ZCS condition (turn on and off). Soft switching condition is satisfied for both step-up (boost) and step-down (buck) in the converter. Simulation results are presented for a 50 w, 100KHZ flyback-forward converter.

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