ZERO VOLTAGE SWITCHING OF TWO-SWITCH FLYBACK-FORWARD CONVERTER

Jhao-Cyuan Huang, Yong-seng Wong, Kuo-Bin Liu, NSRRC, Hsinchu, Taiwan

Abstract

The traditional pulse-width-modulated flyback converter power switch has serious electromagnetic interference (EMI) and lower conversion efficiencies problems due to the hard-switching operations. This paper produces a zero voltage switching of flyback-forward converter with an active-clamp circuit, the traditional pulse-width-modulated flyback converter with a active clamp circuit to achieve zero-voltage-switching (ZVS) at both main and auxiliary switches, the active-clamp circuit can reduce most of switching loss and voltage spikes across the switches and improve the overall efficiency of the converter. The theoretical analysis of soft switching flyback-forward converter with an active-clamp circuit is verified exactly by a prototype of 50W with 100V input voltage, 5V output voltage and 30kHz operated frequency.

INTRODUCTION

The first Taiwan synchrotron light source situated at the national synchrotron radiation research center (NSRRC) has been operational for twelve years. Scientists from nationwide and all over the world have been swarming in to conduct pioneering scientific research, with remarkable growth in both research quality and quantity, levelled up to world standard. After Taiwan photon source (TPS) is completed, a bright source of X-rays will be provided to generate an exhilarating vision of our country's scientific and technological development. So NSRRC research high efficiency and small volume power supply. Some scientists present forward-flyback converter[1-3], in order to get high efficiency and reduce high switch voltage stress of main switches, the paper uses active clamp techniques [4-6].

ZERO VOLTAGE SWITCHING OF TWO-SWITCH FLYBACK-FORWARD CONVERTER

Figure 1 shows two-switch active clamp flyback-forward. In the figure, the primary has the transformer magnetizing inductance L_m, the resonant inductor L_r that is the sum of transformer leakage and external inductor, the two main switches S_{m1},$S_{m2}$and auxiliary switch $S_a$are N-channel power MOSFET whose output capacitances are denoted by C_1,C_3 and C_2. The flyback-forward of the active clamp circuit includes a clamp capacitance C_c, and an auxiliary switch S_a is used to achieve ZVS. The isolated forward secondary side has diode D_1 、D_2, output inductor L_1, output capacitor C_o,and transformer winding turn N_2.The isolated flyback secondary side has diode D_3, and transformer winding turn N_3.

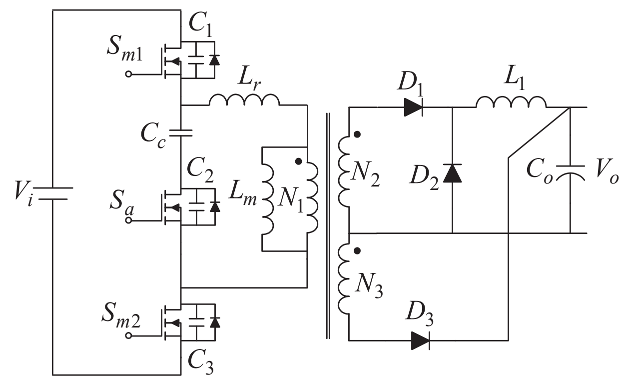

Figure 1: Two-switch active clamp flyback-forward.

OPERATING PRINCIPLES

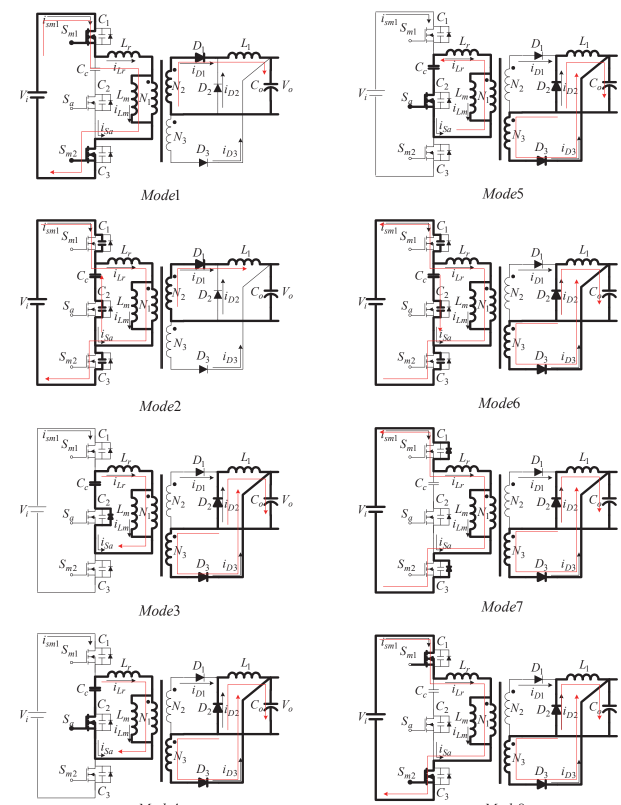

Figure 2: Operation stages of proposed converter.

The proposed converter has eight operating modes as shown in Figure 2.

The two-switch active clamp flyback-forward's features are as follow.

1. The clamp capacitance C_c is larger than resonant capacitance $(C_1//C_3)+C_2$
2. The resonant inductance is less than the magnetizing inductance($L_r \ll L_m$)
3. Both the main switches S_{m1} 、S_{m2} and auxiliary switches S_a operate with ZVS
4. Both the main switches S_{m1} 、S_{m2} and auxiliary switches S_a are ideal

Mode 1: In this mode, the main switches $S_{m1}$and S_{m2} are all turned on, and the auxiliary switch S_a is turned off. The primary winding of transformer is charged by input voltage. The magnetizing inductor voltage $V_{Lm} \approx V_i$, the magnetizing inductor current is equal of the resonant inductor current $i_{Lm}(t) = i_{Lr}(t)$. The primary side and secondary side have some polarities, the input energy is transferred to the output load by the forward converter. The diode D_1 is turned on at the secondary side, the diodes D_2 and D_3 are turned off at the secondary side.

Mode 2: In this mode, the auxiliary switch S_a and the main switches $S_{m1}$and S_{m2} are turned off. The diode D_1 is turned on at the secondary side, the diodes D_2 and D_3 are turned off at the secondary side. The resonant capacitance $(C_1//C_3)$ are charged linearly by the resonant inductor current i_{Lr}, the resonant capacitance $(C_1//C_3)$ voltage are charged from 0V to $\frac{Vin+Vcc}{2}$. The resonant capacitance voltage V_{C2} is discharged from $V_{in}+V_{Cc}$ to 0V.

Mode 3: In this mode, the main switches $S_{m1}$and S_{m2} are all turned off, and the auxiliary switch S_a is turned off. When the resonant capacitance voltage $V_{C2}=0$, the body diode of auxiliary switch is turned on. The clamp capacitance C_c is larger than resonant capacitance of main switches $\frac{C_1+C_2}{2}$, so the clamp capacitance C_c is charged by the stored energy of magnetizing inductor L_m and resonant inductor L_r. The primary side voltage $V_{Lm} \approx V_{Cc}$ so that the diode D_1 of secondary side is turned off, the diodes D_2 and D_3 of secondary side are turned on.

Mode 4: In this mode, the main switches $S_{m1}$and S_{m2} are all turned off. The auxiliary switch S_a is turned on at ZVS when the clamp capacitance current i_{Cc} is positive. If the clamp capacitance current i_{Cc} were negative, the auxiliary switch would achieve ZVS.

Mode 5: In this mode, the main switches $S_{m1}$and S_{m2} are all turned off. The auxiliary switch S_a is turned on. The resonant inductor L_r is charged by stored energy of clamp capacitance C_c when the clamp capacitance current i_{Cc} is negative. This mode ends, when the main switch voltage $V_{C1} \approx \frac{V_{in}+V_{Cc}}{2}$.

Mode 6: In this mode, the auxiliary switch S_a and the main switches $S_{m1}$and S_{m2} are turned off. The resonant capacitance $(C_1//C_3)$ are discharged by magnetizing inductor current i_{Lm}, so the main switches voltage V_{C1} and V_{C3} are discharged from $\frac{Vin+Vcc}{2}$ to 0V. When the main switches voltage $V_{C1}=V_{C2}=0V$, the body diodes of the main switches start conducting the resonant inductor curmet i_{Lr}. The resonant capacitance C_2 is charged by magnetizing inductor current i_{Lm}, so the auxiliary switch voltage is charged from 0V to $V_{in}+V_{Cc}$. The resonant inductor curmet i_{Lr} is linearly increased, the resonant inductor voltage $V_{Lr} \approx V_{in+}V_{Cc}$.The diodes of secondary side D_2 and D_3 are still turned on, the output current $i_{D2}$and i_{D3} decrease.

Mode 7: In this mode, the auxiliary switch S_a and the main switches S_{m1} and S_{m2} are turned off. When the resonant capacitance voltage $V_{C1}=V_{C2}=0V$, the body diode of main switches are turned on. The resonant inductor curmet i_{Lr} is still linearly increased, the resonant inductor voltage $V_{Lr} \approx V_{in+}V_{Cc}$. The output current $i_{D2}$and i_{D3} are still decreased.

Mode 8: In this mode, the main switches $S_{m1}$and S_{m2} are all turned on at the ZVS, when the resonant inductor current i_{Lr} is positive. When the output current $i_{D2}=i_{D3}=0$, this mode ends.

EXPERIMENTAL RESULTS

We do the experiment using the figure 1 circuit for proposed converter. Figure 3 shows the measured results of the proposed converter under rated output load Po=5W. Figure 3(a) shows the gate drive voltage V_{gsm1} and V_{gsa} , the main and auxiliary switch voltage V_{C1} and V_{C2}. The main switch S_{m1} is turned on at the ZVS, when the main switch voltage $V_{C1}=0$. The auxiliary switch S_a is turned on at the ZVS, when the auxiliary switch voltage $V_{C2}=0$.Figure 3(b) shows the resonant inductor current i_{Lr} and the auxiliary switch current i_{Sa}.

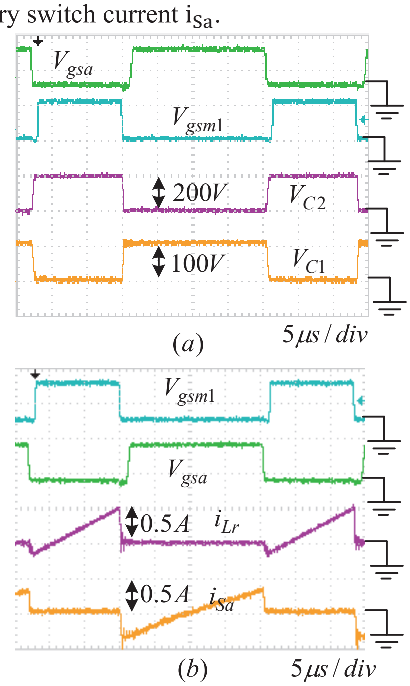

Figure 3: Measured results of the proposed converter under rated output load Po=5W.

Figure 4 shows the measured results of the proposed converter under rated output load Po=50W. Figure 4(a) shows the gate drive voltage V_{gsm1} and V_{gsa} , the main

ISBN 978-3-95450-115-1

and auxiliary switch voltage V_{C1} and V_{C2}. Figure 4(b) shows the resonant inductor current i_{Lr} and the auxiliary switch current i_{Sa}.

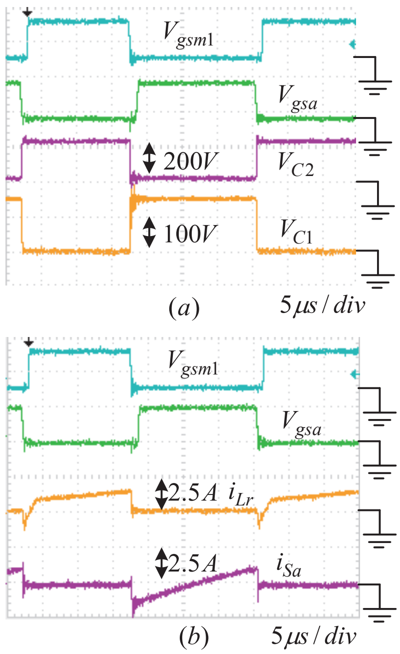

Figure 4: Measured results of the proposed converter under rated output load Po=50W.

Figure 5 shows the efficiency of the flyback-forward converter was measured under different load conditions.

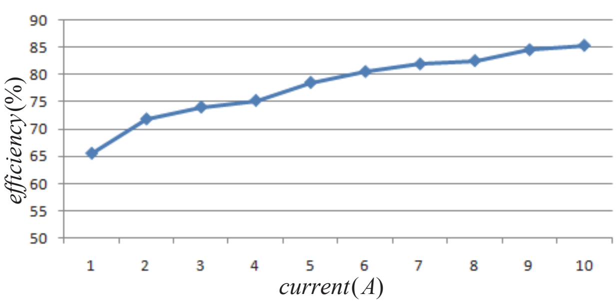

Figure 5: The efficiency of the flyback-forward converter was measured under different load conditions.

CONCLUSION

In this paper, the flyback-forward converter is made of the traditional flyback and forward converters. The flyback-forward converter add a clamp circuit topology. Not only the clamp circuit topology limits the peak voltage stress of main and auxiliary switches devices but also achieves ZVS of the main and auxiliary switches. Based on the experimental results, the flyback-forward converter efficiency is 85% under rated output load Po=50W.

REFERENCES

[1] Yonghan Kang,Byungcho Choi,Wonseok Lim, "Analysis and design of forward-flyback converter employing two transformers", Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual, Volume: 1, pp 357-362, 2001

[2] Murthy-Bellur D., Kazimierczuk M.K., "Two-switch flyback-forward PWM DC-DC converter with reduce switch voltage stress",Circuits and Systems (ISCAS), Proceedings of 2010 IEEE International Symposium on , pp 3705-3708, 2010

[3] Fanghua Zhang, Lan Xiao, Yangguang Yan, "Bi-directional forward-flyback DC-DC converter", Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual, Volume: 5, pp 4058-4061, 2004

[4] Bor-Ren Lin, Huann-Keng Cgiang, Kao-Cheng Chen, Wang D., "Analysis, design and implementation of an active clamp flyback converter," Power Electronics and Drives Systems, 2005. PEDS 2005. Interational conference on, Volume: 1, pp 424-429, 2005.

[5] Murthy-Bellur D., Kazimierczuk M.K., "Active-clamp ZVS two-switch flyback converter", Circuits and Systems (ISCAS), 2011 IEEE International Symposium on , pp 241-244, 2011

[6] Bor-Ren Lin, Fang-Yu Hsieh, "Soft-Switching Zeta-Flyback Converter With a Buck-Boost Type of Active Clamp," Industrial Electronics, IEEE Transactions on , Volume: 54, Issue:5, pp 2813-2822, 2007.