PDP 유지 전원단에 적합한 새로운 고효율 능동형 클램프 포워드 컨버터

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A new high efficiency active clamp forward converter suitable for the sustaining power module of a plasma display panel

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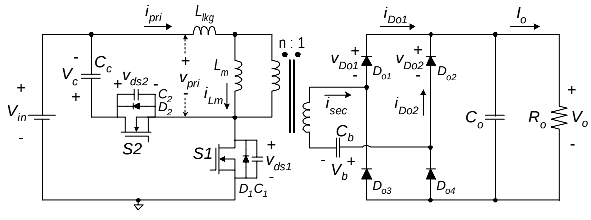
ABSTRACT

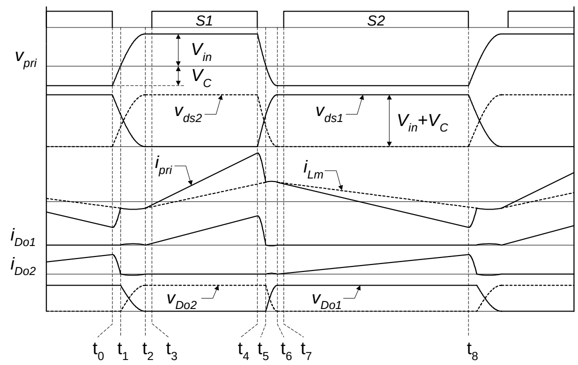
A new high efficiency active clamp forward converter suitable for the sustaining power module (SPM) of a plasma display panel (PDP) is proposed. It has a wide zero voltage switching (ZVS) range without inserting additional resonant inductor. Also, it features simpler structure, lower cost, less mass, and no effective duty loss. Furthermore, voltages across all rectifier diodes are clamped on the output voltage, which results in a higher efficiency.

1. Introduction

Nowadays, the PDP is one of the most leading candidates for the large screen TVs, due to its desirable merits such as the wide view angle, lightness, thinness, long lifetime, high contrast, and large screen[1]. Since the SPM among various power modules used in the PDP handles most of power over 85%, it determines the overall system efficiency. Therefore, it is necessary to increase the efficiency of the SPM in order to improve the overall system efficiency. Since a prior active clamp forward (ACF) converter with a center-tapped transformer (CTT) presented in [2] achieves the ZVS of switches by using the additional resonant inductor, it features the low switching losses, low electromagnetic interference (EMI) noise, and high efficiency. Furthermore, since rectifier diodes have a full rectification configuration, its voltage conversion ratio is higher than that of the traditional single ended ACF converter, resulting in a higher efficiency. Due to these advantages, it is adopted for the SPM of the PDP. However, in high voltage low current applications such as the SPM,



a circuit diagram



b key waveforms

Fig. 1 The proposed converter

since the additional large resonant inductor in series with the leakage inductor L_{lkg} is necessary to achieve the ZVS of all switches over the wide load range, it has several serious problems such as the large effective duty loss, serious voltage ringing in the rectifier diodes, considerable heating, and noisy output voltage. Above all, the dissipative resistor-capacitor (RC) snubber is necessary to absorb the serious ringing voltage across the rectifier diodes, resulting in degrading the overall system efficiency. In this paper, to overcome these problems, a new high efficiency ACF converter suitable for the SPM is proposed as shown in Fig. 1a. In the proposed converter, since the magnetizing inductor L_m is used to achieve the ZVS of all switches, no additional large resonant inductor is required for the wide ZVS range. In addition, since it has no large output filter inductor, it features the simpler structure, lower cost, less mass, and no effective duty loss. Furthermore, since voltages across all rectifier diodes are clamped on the output voltage, there is no need for the RC snubber, resulting in a higher efficiency.

2. The operation of the Proposed Converter

Fig. 1b shows the key waveforms of the proposed converter. It is assumed that all components are ideal except for the output capacitors of switches and L_{lkg}. One operation cycle can be divided into eight modes as follows:

Mode 1(t_0~t_1): When S_2 is turned off at t_0, the output capacitor C_2 of S_2 begins to be charged and the output capacitor C_1 of S_1 discharged by L_{lkg}. The i_{sec} still flows through D_{o2} and D_{o3}.

Mode 2(t_1~t_2): When i_{pri} becomes equal to i_{Lm} at t_1, C_2 begins to be charged and C_1 discharged by L_m together with L_{lkg}. At the same time, the direction of i_{sec} is reversed and the commutation between D_{o1} and D_{o2} begins.

Mode 3(t_2~t_3): At t_2, the discharge of C_1, charge of C_2, and commutation between D_{o1} and D_{o2} are finished completely. i_{pri} flows through the body diode D_1 of S_1 with the slope of $\{V_{in}-n(V_o+V_b)\}/L_{lkg}$, and i_{sec} flows through D_{o1} and D_{o4}.

Mode 4(t_3~t_4): S_1 is turned on with the ZVS at t_3. In this mode, the directions of i_{pri} and i_{Lm} are reversed.

In the prior ACF converter with a CTT, although S_1 is turned on with the ZVS due to the external large inductor, it increases the freewheeling interval when all output rectifier diodes are simultaneously turned on, resulting in a large effective duty loss. However, since there is no output filter inductor in the proposed converter, there are no freewheeling interval and no effective duty loss. The circuit operation of t_4~t_8 is similar to that of t_0~t_4.

3. Design Considerations

For the convenience of the steady state analysis, it is assumed that the dead time between S_1 and S_2 is neglected, and V_c, V_b, and V_o are constant. The voltage V_b can be obtained as $V_b=(1-2D)V_o$ from the voltage second balance rule on L_m. Also, since the average current of D_{o1} is equal to that of D_{o2} from the current second balance rule on C_b, the output current I_o is equal to the sum of the average currents of D_{o1} and D_{o2}. Therefore, the voltage conversion ratio of the proposed circuit can be obtained from the above equation and average current of D_{o1} as follows:

$$\frac{V_o}{V_{in}} = \frac{1}{2n(1-D)(1+L_{lkg}/L_m)+L_{lkg}f_s/(nD^2R_o)} \quad (1)$$

where f_s and D are the switching frequency and duty ratio of S_1, respectively.

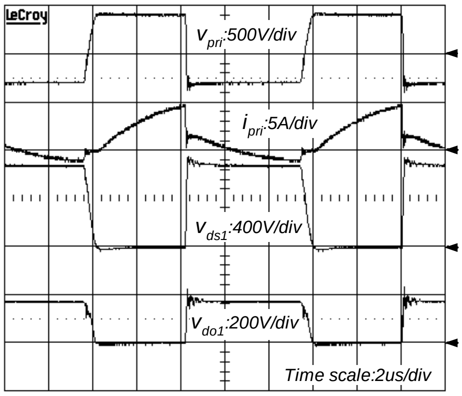
Since the energy stored in both L_m and L_{lkg} at t_4 is larger than that at t_0, it is easier to achieve the ZVS of S_2 than S_1. Therefore, the value of L_m should be carefully chosen to achieve the ZVS of S1over the whole load variations. The ZVS condition of S_1 can be approximately obtained as follows:

$$\frac{1}{2}L_{lkg}i_{pri}^2(t_0)+\frac{1}{2}L_m i_{Lm}^2(t_0) \geq \frac{1}{2}(C_1+C_2)(V_{in}+V_c)^2+\frac{1}{2}\left(\frac{4C_D}{n^2}\right)(nV_o)^2 \quad (2)$$

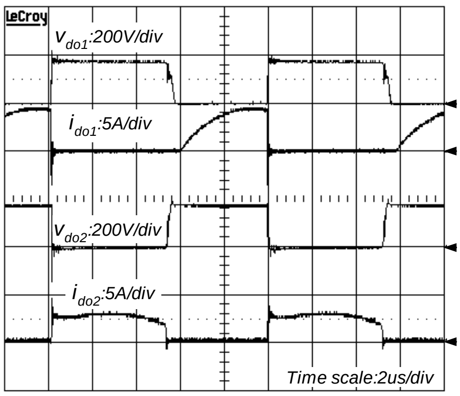
where C_D is the junction capacitor of the rectifier diode. When L_{lkg} is given in manufacturing the transformer, this equation provides the design guideline for L_m ensuring the ZVS of all switches S_1 and S_2 over the whole load ranges.

4. Experimetal Results

To verify the operation and analysis of the proposed converter, the prototype is implemented with specifications of V_{in}=385V, V_o=170V, $P_{o,max}$=425W, f_s=100kHz, L_m=477uH, L_{lkg}=5.2uH, C_c=C_b=4.4uF, n=2, S_1 and S_2=17N80C3, D_{o1}~D_{o4}=15ETH03, C_1=C_2=59pF, and C_D=45pF. Fig. 2a and 2b shows key waveforms at the full load. Since the voltages across rectifier diodes are clamped on the output voltage as shown in these figures, there is no serious voltage ringing across them. Also, since there is no freewheeling interval of rectifier diodes, there is no effective duty loss. The small difference between Fig. 1b and Fig. 2b is caused by the reverse recovery of the rectifier diodes and resonance between L_{lkg} and C_b. Fig. 3a and 3b show the ZVS condition of switches at the full and 10 % load, respectively. As shown in these figures, the ZVS of switches can be ensured over the whole load variations. Fig. 4 shows that the proposed

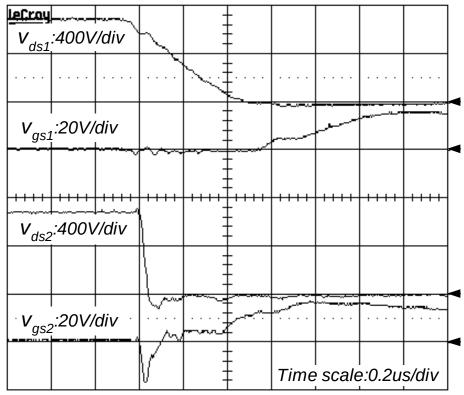


a key waveforms of vpri, ipri, vds1, and vdo1

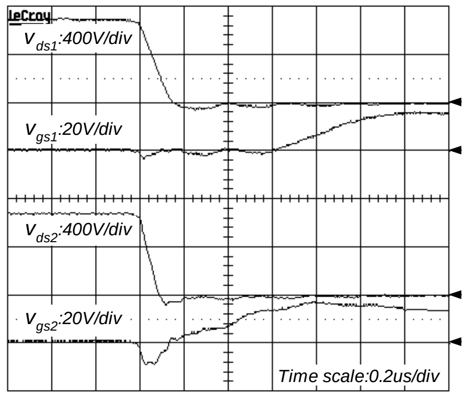


b key waveforms of vdo1, ido1, vdo2, and ido2

Fig. 2 Key waveforms



a at full load



b at 10% load

Fig. 3 ZVS conditions

converter has the maximum efficiency of 97.7 % at a 90 % load. Moreover, the efficiency over a wide load range is as high as above 90 %, which is a very desirable feature for severe load varying applications such as PDPs and digital audio amplifiers.

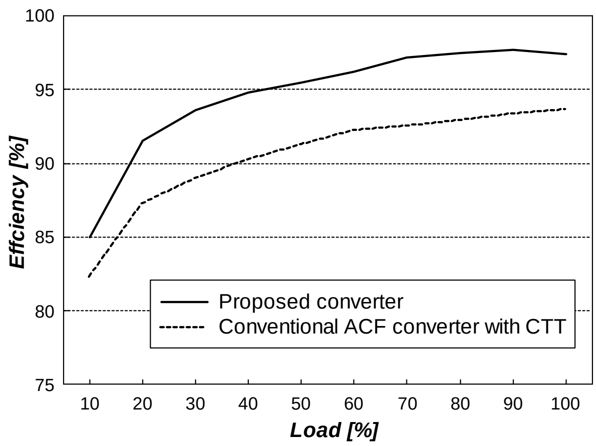


Fig. 4 Measured efficiency

5. Conclusions

A new high efficiency active clamp forward converter for the SPM of the PDP is proposed. It ensures the ZVS operation of all power switches over the whole load variations without the additional resonant inductor. Furthermore, since there is no large output filter inductor, it features the simpler structure, lower cost, less mass, higher efficiency, and no effective duty loss. The efficiency over a wide load range is as high as above 90 %. Therefore, the proposed converter is well suitable for the SPM of the PDP.

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References

[1] Han, S. K., Moon, G. W., and Youn, M. J.: 'High performance sustaining driver for plasma display panel employ gas-discharge current compensation method' Electro. Lett., 2004, 40, (8), pp. 473–474

[2] Mass, G. J., Ferrari de Souza, A., Barbi, I.: 'Analysis and experiment of a forward converter with active clamping and output rectifier using a center tapped transformer', Proc. IEEE PESC 2001, Vol. 4, pp. 1767–1772