전력전자학술대회 논문집 2000. 7.19-22

개선된 소프트 스위칭 Two-transistor forward converter

An Improved Soft Switching Two-transistor Forward Converter

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ABSTRACT

This paper proposes an improved soft switching two-transistor forward converter which uses a novel lossless snubber circuit to effectively control the turn-off dv/dt rate of the main transistors. In the proposed soft switching implementation, the turn-off voltage traces across the main two transistors are almost the same, contributing to reduce the total capacitive turn-on loss, and the snubber current is divided into the two transistors, resulting in distributed thermal stresses.

I. Introduction

Snubbers are required to control di/dt and dv/dt in a switching device, keep the device within its safe operating area, and limit the switching loss in the device. Resitive snubbers, which discharge via resistors, are simple to design and use, but the energy dissipated in the resistors is proportional to the switching frequency. Therefore, these snubbers are not practical· at the high switching frequencies encountered in the modern power electronics system. In high frequency applications, it is necessary to use an energy recovery snubber to keep losses to a minimum, by regenerating the energy trapped in the snubber circuit to the load or back to the input source [1]-[4].

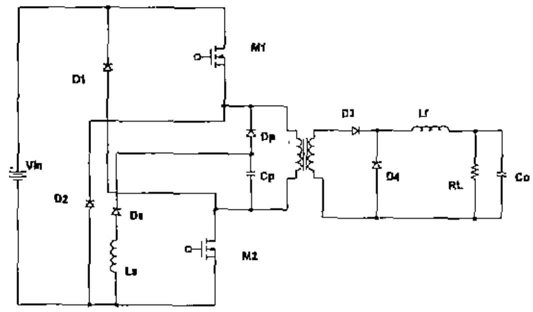
For the two-transistor forward converter, which has been widely employed in telecommunications power supplies due to high reliability[5], [3] and [4] have proposed similar techniques to reduce switching losses as shown in Fig. 1(a). The conventional soft switching two-transistor forward converter, however, presents the differences between the upper and the lower transistors in their power losses and thermal stresses, contributing to degrade the overall reliability of the power supplies. To distribute the power losses and thermal stresses through the two transistors, an improved soft switching two-transistor forward converter is proposed in Fig. 1(b).

In this paper, the operation analyses for the two soft switching two-transistor forward converters are performed, particularly over the turn-off period. The operation of the conventional soft switching two-transistor forward converter is well understood [4], but the operation during the period after the transformer magnetizing current is reseted has never been presented. The analytical results are verified through experiment and the advantages of the proposed converter are discussed.

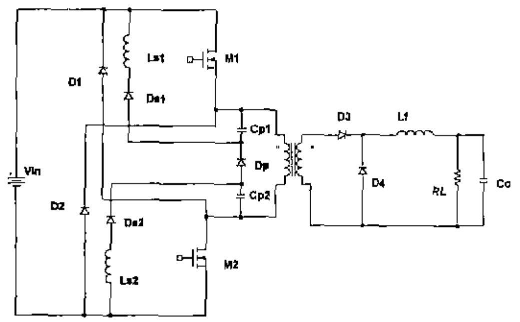
II. Analysis of operation of soft switching two-transistor forward converters

A. Conventional converter

The switches M1 and M2 are turned on in a zero-current-switching form because the transformer leakage inductor L1k limits the short circuit current. The Cp voltage is reversely biased by resonating between Cp and Ls. The snubber current flows through the lower switch M2. After the switches M1 and M2 are turned off in a zero-voltage-switching form by the snubber capacitor Cp, the capacitors Cp,



(a)



(b)

Fig. 1 (a) Conventional soft switching two-transistor forward converter. (b) Proposed soft switching two-transistor forward converter with equalized transistor stresses.

Cds1, and Cds2 are charged by the sum of the magnetizing current and the reflected Lf current. When the Cp voltage ramps up to zero, the Lf current commutates from D3 to D4. Then, the magnetizing current decreases due to the positive Cp voltage, and the capacitors Cp, Cds1, and Cds2 are charged only by the magnetizing current because the Lf current flows through D4. When the Cp voltage increases to Vin, the resetting diodes D1 and D2 are turned on. When the magnetizing current is decreased to zero, both D1 and D2 are turned off simultaneously.

The equivalent circuit of the conventional converter for the period after D1 and D2 are turned off is shown in Fig. 2(a). In this figure, the initial voltages of Vcp, Vds1, and Vds2 are Vins. The transformer resetting current flows through Lm, L1k, Cds1, Vin, and Cds2 in parallel with Ls, Ds, and Cp as indicated in the figure. In the steady state, the capacitor voltages become

$$V_{ds1} = \frac{C_{ds1}}{C_p + C_{ds1} + C_{ds2}} \text{ Vin} \quad (1)$$

and

$$V_{ds2} = V_{cp} = \frac{C_p + C_{ds2}}{C_p + C_{ds1} + C_{ds2}} \text{ Vin} \quad (2)$$

where Cp is the snubber capacitor, and the capacitors Cds1 and Cds2 are the switch output capacitances.

Comparing (1) and (2), it can be seen that the steady-state turn-off voltage difference between the two switches exists. The total capacitive turn-on switching loss occurred in the switches is proportional to the sum of the square of Vds1 and the square of Vds2. As a result, the capacitive turn-on switching loss of conventional soft switching converter may be increased due to the voltage difference. Furthermore, the snubber current of the conventional converter flows through only one switch. These loss inequalities between the two switches contribute to hot spots and degrade the reliability of this converter.

B. Proposed converter

The above analysis of the operation of the conventional converter can be directly extended to the proposed converter. In fact, the only difference between the two converters is the lossless snubber. When the switches M1 and M2 are turned on, the snubber Ls1 current forced by the Cp1 voltage and the snubber Ls2 current forced by the Cp2 voltage flow through M1 and M2, respectively. Therefore, the total snubber current is distributed through the two switches. Another difference is seen during the turn-off period of the reseting diodes D1 and D2 when the switches M1 and M2 are turned off.

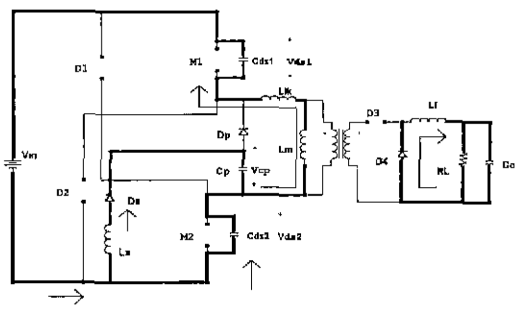
The equivalent circuit of the proposed converter for the period after D1 and D2 are turned off is shown in Fig. 2(b). In this figure, the initial values of Vds1 and Vds2 are Vins and the initial voltages in Cp1 and Cp2 are determined by the capacitance ratio of Cp1 to Cp2. If Cp1 is equal to Cp2, the initial values of Vcp1 and Vcp2 are Vins/2. The transformer resetting current flows through Lm, L1k, Cds1, Vin, and Cds2 because the snubber diodes Ds1 and Ds2 are reverse biased. In the steady state, the capacitor voltages become

$$V_{ds1} = \frac{C_{ds1}}{C_{ds1}+C_{ds2}} \text{ Vin} \fallingdotseq \text{Vin}/2 \qquad (3)$$

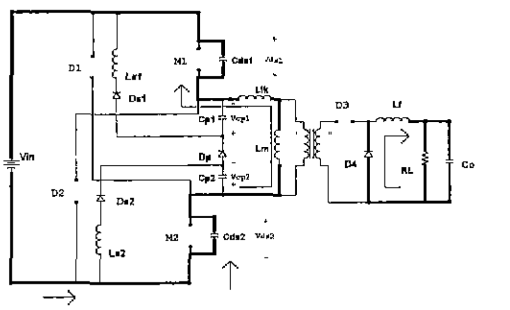
and

$$V_{ds2} = \frac{C_{ds2}}{C_{ds1}+C_{ds2}} \text{ Vin} \fallingdotseq \text{Vin}/2 \qquad (4)$$

where the capacitors Cds1 and Cds2 are the switch output capacitances. From (3) and (4), it can be seen that the capacitive turn-on voltage of the switch M1 is equal to that of M2. As a result, the turn-on switching loss of the proposed converter is lower than that of the conventional converter.



(a)

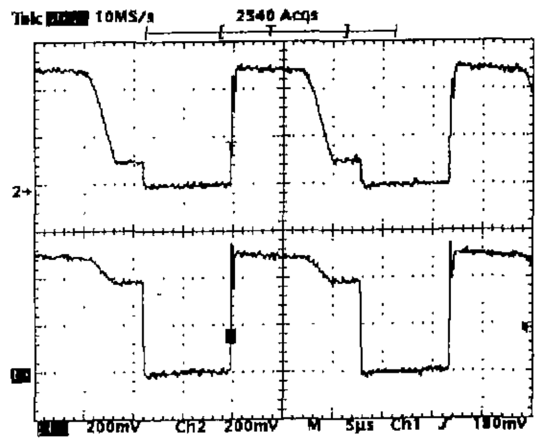


(b)

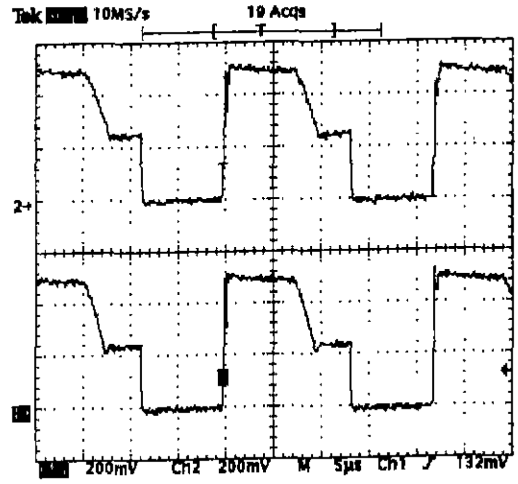
Fig. 2 Equivalent circuits for the period after both resetting diodes D1 and D2 are turned off ; (a) conventional and (b) proposed.

III. Experimental result

Evaluations of the conventional and proposed two-transistor forward converters were performed on 45 kHz 50-V/25-A power stages designed to operate in the 220-280 V dc-input-voltage range. The components and parameters used for the implementations of the power stages are as follows:



(a)



(b)

Fig. 3 Experimental Vds1 (upper trace) and Vds2 (lower trace) waveforms (100 V/div.) ; (a) conventional and (b) proposed.

M1,M2 - IXFN48N50(IXYS), D1,D2,D3,D4 - DSEI 2X30-06C(IXYS), Ds,Ds1,Ds2 - DSEI 30-10A(IXYS), Cp = 2.2 nF, Ls = 18 uH, Cp1,Cp2 = 4.7 nF, Ls1,Ls2 = 17 uH, Lf = 50 uH, Vin = 245 V.

Fig. 3(a) shows the oscillograms of Vds1 and Vds2 for the conventional two-transistor forward converter. As can be seen from this figure, the upper switch voltage Vds1 is much lower than the lower switch voltage Vds2 at the instant of turn-on. As a result, *the turn-on loss of the lower switch is much higher* than that of the upper switch. The typical output capacitance of the employed MOSFET switch is 0.9 nF[7]. Using (1) and (2), the *theoretical turn-on* voltages of Vds1 and Vds2 are 55 V and 190 V, respectively. The experimental results show good agreement with the theoretical ones. Fig. 3(b) shows the oscillograms of Vds1 and Vds2 for the proposed implementation. From this figure, it can be seen that the trace of the upper switch voltage Vds1 is similar to that of the lower switch voltage Vds2. Therefore, the two switches of the proposed implementation undergo the same voltage and thermal stresses.

Ⅳ. Conclusion

This paper presents a new soft switching two-transistor forward converter to improve the reliability of the conventional implementation, by distributing the turn-on voltages and thermal stresses through the two transistors. The key features of the proposed configuration include :

- the turn-on voltages of the main switches are almost the same, contributing to reduce the total turn-on loss,
- the snubber current is divided into the two transistors, resulting in distributed thermal stresses.

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