Single-Inductor Dual-Output Soft-Switching Converter with Voltage-mode Resonant Switch

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Abstract: This paper presents our study on the soft-switching converters with voltage-mode. The switching converters are well-known to obtain high efficiency, but their resonant voltages of the voltage-mode converters go very high. We propose here a soft-switching converter with the clamp circuit in order to reduce the peak voltages. We have investigated the difference of the characteristics with/without the clamp circuit for both half/full-wave converters in simulation. Further, we have investigated a single-inductor dual-output converter in order to reduce the number of the resonant parts.

1. Introduction

The efficiency is a very important item for the switching converter. Recently, the switching frequency has become higher and higher and then the switching loss of the switching MOSFET has increased more and more. In order to increase the efficiency of the switching converter, the reduction of this switching loss is the efficient way. There are two modes of the resonant converters [1)] (the voltage-mode and the current-mode), and here we have investigated the voltage-mode resonant converter. In the voltage-mode, there are two types; the half-wave and the full-wave. We have investigated these two-type converters in simulation where SIMPLIS was used as simulator.

These resonant converters need two inductors and two capacitors. In order to reduce the number of the inductors, we have developed the Single-Inductor Dual-Output (SIDO) converter for the resonant converter.

2. Voltage-mode Resonant Converters

2.1 Full/Half-wave type resonant converter

Figure 1 shows the full-wave resonant converter with voltage-mode. In Fig. 1, the power-stage consists of the main switch SW (usually MOSFET) with the body diode Db, the free-wheel diode Do, the main inductance Lo, the main capacitance Co and the resonant elements which are denoted as Lr, Cr and Dr.

The output voltage Vo is compared with the reference voltage Vref and the voltage error is amplified to be compared with the saw-tooth signal SAW. This SAW signal is generated by the trigger which is supplied from the comparator 2 as the comparison result between the resonant voltage Vr and the diode voltage Vd. So when Vr goes across Vd, the SAW signal starts to rise up.

In order to change the full-wave converter to the half-wave one, the resonant diode Dr should be removed.

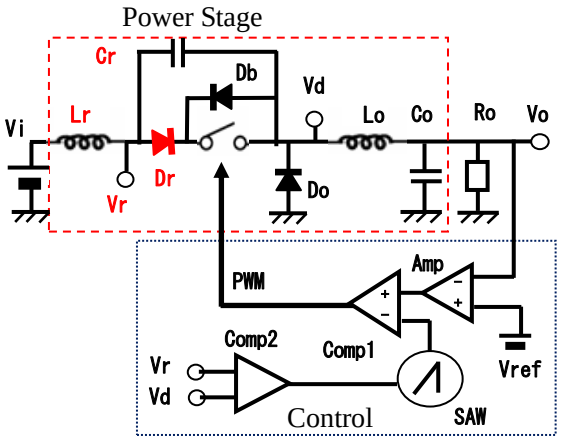

Fig. 1. Resonant converter with full-wave

2.2 Simulation results of the resonant converters

Figure 2 shows the major signals of the resonant converter. First, in the full-wave converter, when SW turns OFF, (1) Vd goes to 0V from Vi and Cr is charged. Then (2) Lr･Cr goes resonant and Vr rises up and down. (3) After Vr goes down under Vd which is about 0V, SW turns ON, but Dr blocks the forward current through SW. (4) So Vr goes the negative voltage and returns to higher than Vd. (5) Then SW flows the current through Dr. (6) Vd rises up and Do turns OFF.

Next in the half-wave converter, (3) when Vr goes down under Vd, then the comparator 2 detects it to reset and start the SAW generator. (4) Then the PWM signal turns “High” to make SW ON immediately. (5) So SW can flow the current because there is no Dr.

In Fig. 2, the output voltage is Vo=0.70V in full-wave converter and Vo-5.00V in half-wave converter. The operational periods To in full/half-wave converters are different, whereas their output currents are Io=0.25A. Note that the peak values Vp of the resonant voltage Vr are the same and they are higher than 100V at Io=0.25 A.

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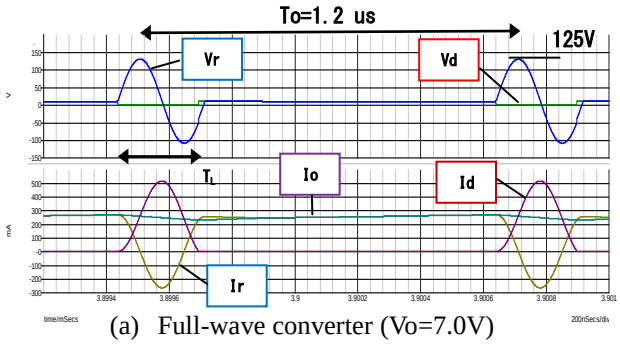
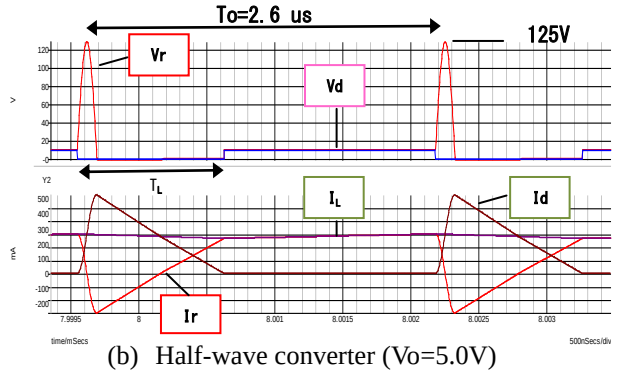


(a) Full-wave converter (Vo=7.0V)



(b) Half-wave converter (Vo=5.0V)

Fig. 2. Simulation results of the resonant converters

3. Proposed Voltage-mode Resonant Converters

3.1 The clamp circuit with the Zener diode

In order to reduce the peak voltage Vp of the resonant voltage Vr, we propose the clamp circuit with the Zener diode which is very effective to compress Vp less than 50V. Figure 3 shows the clamp circuit connected between Vr and GND. Figure 4 shows the simulation results of the resonant voltage Vr of both type converters with the clamp circuits, in which the peak voltage of Vr is compressed from 125V to 42V.which equals to the Zener voltage.

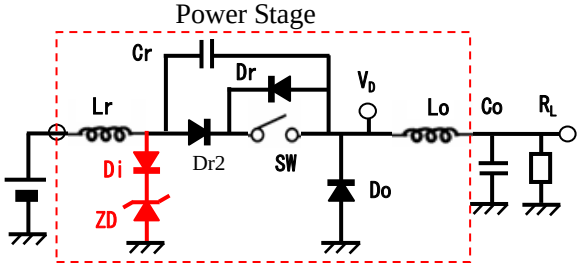
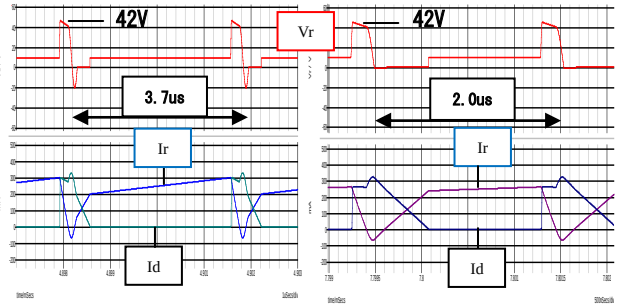


Fig. 3. The clamp circuit with the Zener diode

3.2 Resonant frequency w/wo the clamp circuit

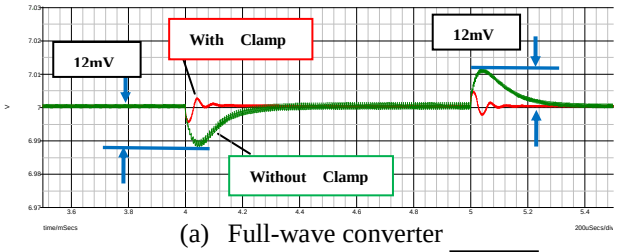
Figure 5 shows the output voltage ripple and the step response of the resonant converters with/without the clamp circuit when the output current changes at the step of 0.25A. The over/under-shoot voltage is less than 15 mV and the steady ripple is about 1 mVpp. With respect to the over/under-shoot, there is a little bit difference with/without the clamp circuit in the full-wave converter. With the clamp circuit, the operational period To shown in Fig. 4 is a little bit changed from that of Fig. 2 which is without the clamp circuit. Figure 6 shows the relationship between the operational period To versus the output current Io. Here, "TH" means the half-wave and "TF" does the full-wave. "THw or TFw" means with the clamp circuit and "THo or TFo" does without one.

In Fig. 6, The difference between THo and THw is about 3us but that of full-wave converter is very large, about 12us which will be a problem of TFw..

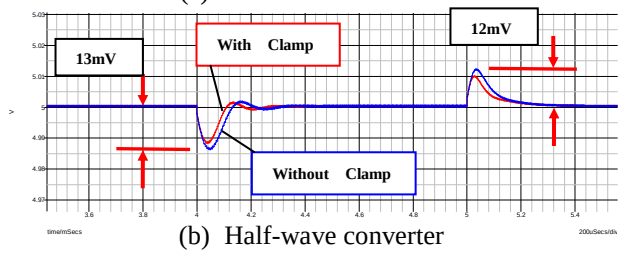


(a) Full-wave (b) Half-wave

Fig. 4. Simulation results with the clamp circuit



(a) Full-wave converter



(b) Half-wave converter

Fig. 5. Step response w/wo the clamp circuit

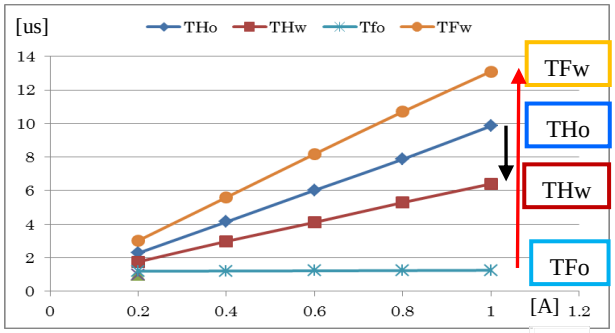


Fig. 6. To vs Io w/wo the clamp circuit

4. Voltage-mode SIDO Resonant Converters

4.1 SIDO resonant converter with clamp circuit

Figure 7 shows the Single-Inductor Dual-Output (SIDO) resonant converter with voltage-mode. The power stage is the same circuit as Fig.3 and the SIDO control part uses the exclusive control method[2]. The select signal SEL is decided by comparing the amplified error voltages and SEL selects the sub-converter V1 or V2 which is supplied the power in the next period. Table 1 shows the parameters. The simulation parameters are shown in Table 1.

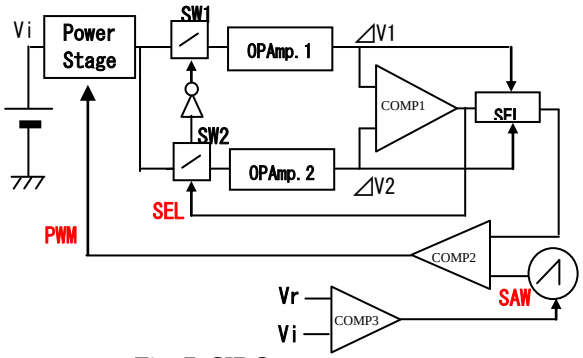


Fig. 7. SIDO resonant converter

4.2 Simulation results of SIDO converter

Figures 8 and 10 show the simulated signals of the SIDO resonant converters with the clamp circuit and Figs. 9 and 11 show the output ripples and the step responses when the current step of 0.25A. In this case, the steady output currents are set at I1=0.50A, I2=0.25A in Fif.9 and I1=0.25A and I2=0.50A in Fig.11. When the SEL signal is High, V1 is selected to be served. The voltages of the over/under-shoots are about 12mV and the ripples are less than 10 mVpp when the total current is 1.0A.

Table 1. Parameters of SIDO resonant converter

Vi	10 V	Lo	50 uH
V1	6.0 V	Co	220 uF
V2	5.0 V	Lr	20 uH
Io	0.50 / 0.25 A	Cr	100 pF

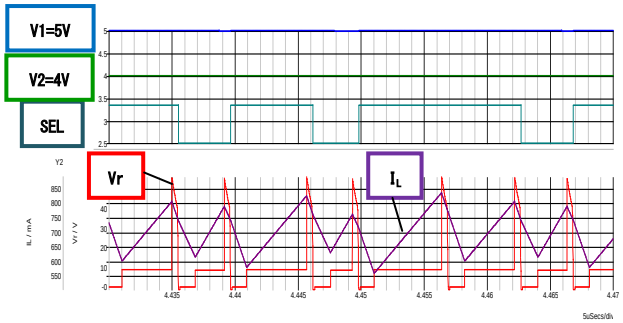


Fig. 8. Simulation results of SIDO half-wave converter

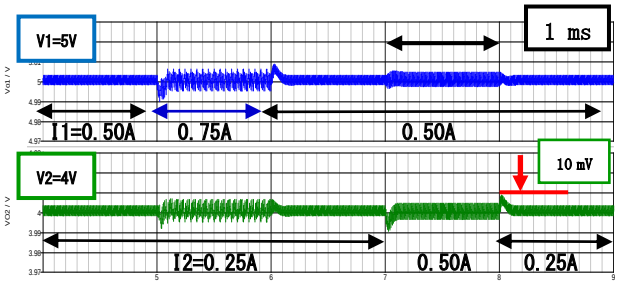


Fig. 9. Step response of SIDO half-wave converter

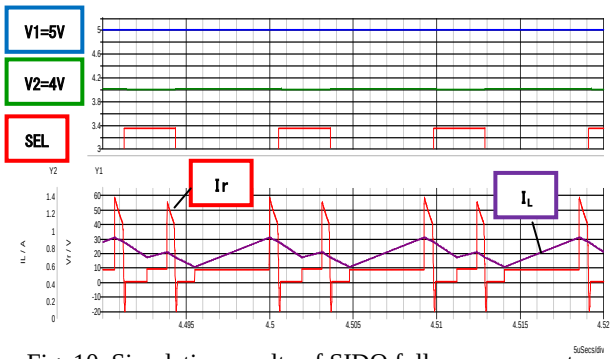


Fig. 10. Simulation results of SIDO full-wave converter

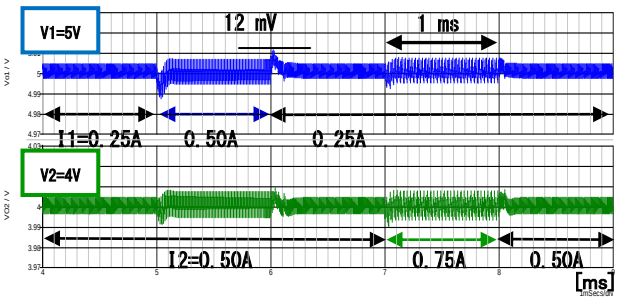


Fig. 11. Step response of SIDO full-wave converter

5. Summary

The voltage-mode resonant converters with the clamp circuit are proposed. The peak voltage is clamped to about 40V and there is a little difference of the characteristics between with/without the clamp circuit using the Zener diode. Furthermore the SIDO resonant converters are proposed in order to reduce the number of the resonant Lr, Cr. In the simulation results, the output voltage ripple or the over/under-shoot is less than 15mV.

References

[1] K. Harada, T. Ninomiya, B. Ko,"Fundamental of Switching Converter", Corona (1992) [in Japanese]

[2] Y. Kobori, N. Tsukiji, N. Takai, H. Kobayashi, "High Speed Response Single-Inductor Dual-Output DC-DC Converter with Hysteretic Control", ICPEIE, Venice, Italy (May. 2014)