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ZVS-PWM Boost Chopper-Fed DC-DC Converter with Load-Side Auxiliary Edge Resonant Snubber

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Abstract— This paper presents a high-frequency ZVS-PWM boost chopper-fed DC-DC converter with a single active auxiliary edge-resonant snubber which is used for power conditioner such as solar photovoltaic generation and fuel cell generation. The experimental results of boost chopper fed ZVS-PWM DC-DC converter are evaluated. In addition to its switching voltage and current waveforms, and the switching *v-i* trajectory of the power devices are discussed and compared with the conventional hard switching DC-DC converter treated here. The temperature performance of IGBT module, efficiency, and EMI noise characteristics of this ZVS-PWM DC-DC converter using IGBTs are measured and evaluated from an experimental point of view.

Index Terms— DC-DC power converter, Auxiliary edge-resonant snubber, ZVS, PWM, EMI noise evaluations

1. Introduction

In recent years, considerations of higher efficiency, power density of power conversion, energy utilization equipment, and variety of circuit topologies of the soft-switching PWM boost chopper-fed DC-DC power converter are urgently required. The practical developments of isolated or non-isolated DC-DC power converter using power MOS-FETs or IGBTs have attracted special interest in various fields related to the new energy generation and storage power supplies of small-scale distributed type photovoltaic generation system (PVGS), fuel cell generation system (FCGS) for residential power energy applications, information and telecommunication equipment. As for DC-DC power converters, lightening, miniaturization, noise reduction and high performance (high-speed response, and waveform quality) have been strongly demanded, because the high-frequency switching PWM technologies are more acceptable, with great advances of power semiconductor devices such as power MOSFETs, IGBTs, SITs, microprocessor control board and the magnetic circuit components; inductors and transformers.

However, the significant problems for high-frequency switching PWM power conversion technology cause system efficiency reduction due to increased switching losses and snubber circuit losses, high *dv/dt* and *di/dt* electrical stresses, high frequency leak current to the ground and EMI noises; radiated emission and conducted emission. For effective and practical solutions, it is presently necessary to use the principles of soft-switching power conversion PWM technology, which are based on active auxiliary edge resonant snubber in addition to passive edge resonant snubber.

In this paper, described is the circuit topology of the boost type ZVS-PWM chopper type DC-DC power converter with the simple active auxiliary edge-resonant snubber. The experimental results of this soft-switching PWM boost chopper designed for the maximum output power 3kW, and switching frequency 16kHz are described and discussed, together with comparative operating characteristics of the soft-switching PWM boost chopper type DC-DC power converter treated here and conventional hard switching PWM one.

2. Soft-Switching PWM Boost Chopper

Fig. 1 shows the circuit configuration of edge-resonant ZVS-PWM boost chopper type DC-DC power converter using the IGBTs. This power converter circuit is based on the conventional PWM boost chopper type DC-DC power converter, which basically includes an active auxiliary resonant snubber circuit composed of a resonant inductor L_r, a resonant capacitor C_r, a lossless snubbing capacitor C_s, an auxiliary active switch S_2 and an auxiliary diode D_2.

The equivalent circuits are depicted in Fig. 2 for the mode transition of this ZVS-PWM boost chopper-fed DC-DC power converter. The gate voltage pulse sequences of the main active power switch and the auxiliary active power switch are indicated in Fig. 3, and the operating voltage and current waveforms of the ZVS-PWM boost chopper circuit components are shown in Fig. 3. The operating principle in mode transitions of this soft commutation chopper is explained as follows;

[Mode 0] The stored energy into the boost inductor L_m is transferred to the load side. When the auxiliary power switch S_2 is turned on, Mode 0 shifts to Mode 1.

[Mode 1] When the auxiliary power switch S_2 is turned on with ZCS, the current through the diode D_1 begins to flow the active auxiliary resonant circuit. The currents through the resonant inductor L_r, and the resonant capacitor C_r, and the auxiliary power switch S_2 increase sinusoidally.

[Mode 2] When the diode D_1 is turned off, the current through D_1 commutate the active auxiliary resonant circuit. The lossless snubbing capacitor C_s connected to the main power switch S_1 in parallel is in the edge-resonant mode with a resonant inductor L_r and resonant capacitor C_r.

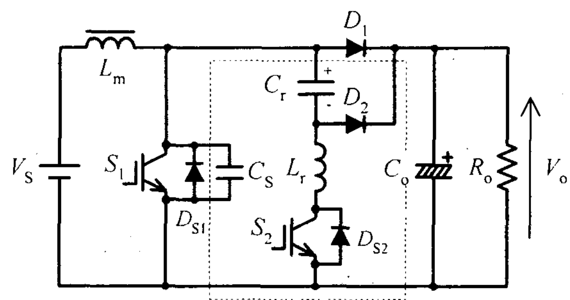


Fig. 1. Zero voltage soft switching boost type PWM chopper using auxiliary edge resonant snubber.

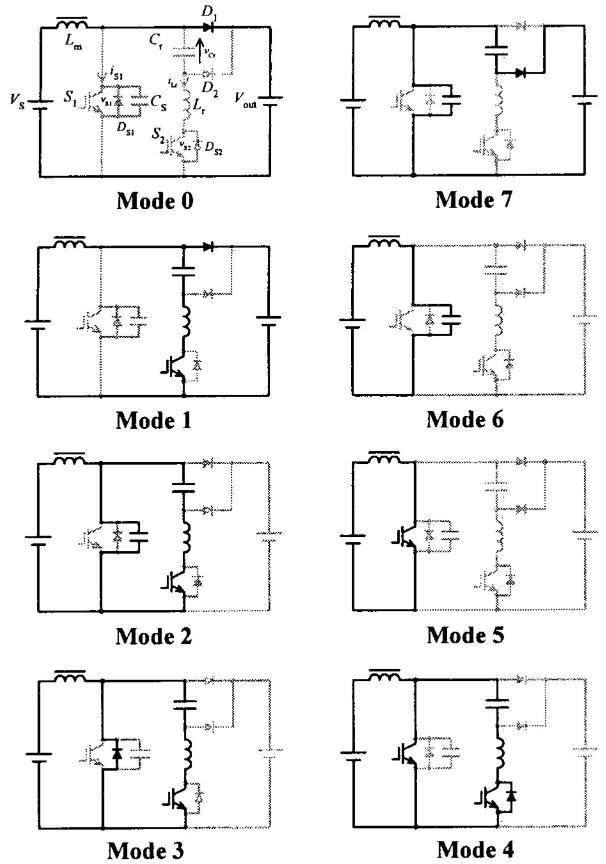


Fig. 2. Mode transition and equivalent circuits.

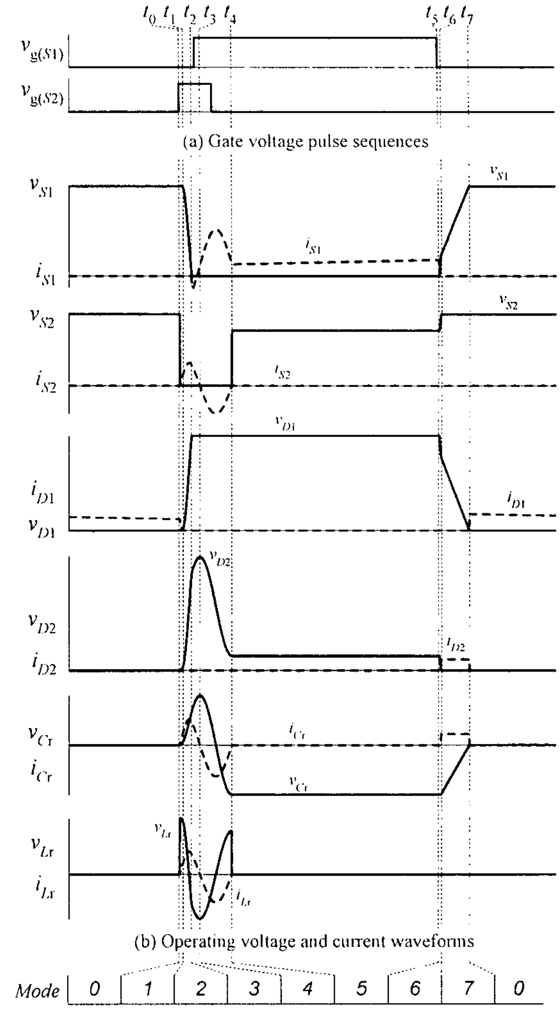


Fig. 3. Gate pulse sequences and typical operating waveforms.

Therefore, the lossless snubbing capacitor C_s becomes the discharging mode, and the voltages across C_s drops gradually.

[Mode 3] When the voltage across the snubbing capacitor C_s becomes zero, the anti-parallel diode D_{S1} of the main power switch S_1 is naturally turned on. As a result, the main power switch S_1 can achieve ZVS and ZCS hybrid commutation in a turn-on transition when current through the anti-parallel diode D_{S1} decreases and naturally shifts to the main power switch S_1 by giving the gate voltage signal of the main power switch S_1 during D_{S1} is turned on.

[Mode 4] When the current of the main power switch S_1 becomes bigger than the current flowing through a boost inductor L_m, the diode D_{S2} in anti-parallel with the auxiliary power switch S_2 is naturally turned on, and the current flowing through S_2 begins to commutate to the anti-parallel diode D_{S2}. By turning the gate voltage pulse signal delivered to the auxiliary power switch S_2 during this period, an auxiliary power switch S_2 can achieve complete ZVS and ZCS hybrid commutation in a turn-off mode transition when the current flowing through the auxiliary power switch S_2 shifts exactly.

[Mode 5] When the auxiliary power switch S_2 is turned off, the resonant current through the inductor L_r and the capacitor C_r becomes zero; all the circuit operations are identical to the conduction state of the conventional PWM boost chopper type DC-DC power converter.

[Mode 6] When the main power switch S_1 is turned off with ZVS, the current through the boost inductor L_m flows through the snubbing capacitor C_s. Therefore, the lossless snubbing capacitor C_s becomes its charging mode, and the voltages across the lossless capacitor C_s increases gradually.

[Mode 7] When the voltage across the lossless snubbing capacitor C_s becomes larger than the sum of the voltage across the resonant capacitor C_r and the output voltage V_o, the auxiliary diode D_2 is turned on. When the voltage across the lossless snubbing capacitor C_s is equal to the output average voltage V_o and the voltage across the auxiliary resonant capacitor C_r becomes zero, the diode D_2 is naturally turned off. At the same time, the diode D_1 is turned on and Mode 7 shifts to Mode 0.

This soft-switching PWM boost chopper type DC-DC power converter circuit repeats cyclically the steady-state operation described above.

3. Experiment results and performance evaluations

3.1 Design specifications and switching waveforms

The experimental design specifications and circuit parameter constants of the high-frequency ZVS-PWM boost chopper controlled DC-DC power converter with a single active auxiliary edge-resonant snubber is listed in Table 1.

Table I. Design specifications and circuit parameters.

DC Input Voltage	V_S	200V	Snubber Capacitor	C_S	33nF
DC Output Voltage	V_0	380V	Resonant Inductor	L_r	7.6μH
Switching Frequency	f_S	16kHz	Resonant Capacitor	C_r	121nF
Output Capacitor	C_0	8,200μF	Boost Inductor	L_b	1.02mH

(Remarks)
Power Switching Devices
· IGBT [S1, S2] -- Mitsubishi CM75DU-24H
· Diode [D1] -- Toshiba 30JL2C41
· Diode [D2] -- Hitachi DFM30F12

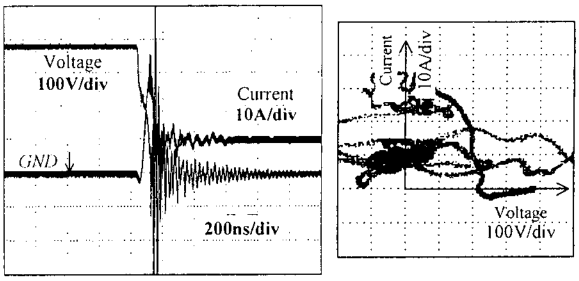
Fig. 4 (a) illustrates the voltage and current waveforms in the hard switching mode transition and its *v-i* trajectory of the power semiconductor device in the case of turn-on transition of the main power switch S_1 of the hard switching PWM boost chopper-fed DC-DC power converter. Fig. 4 (b) illustrates the voltage and current waveforms in a soft-switching PWM boost chopper-fed DC-DC power converter and v-i trajectory in the case of turn-on transition of the main power switch S_1. From voltage and current switching waveforms in Fig. 4 (a) under a condition of a hard switching commutation, it can be observed with the high *dv/dt* and rapid *di/dt* characteristics as well as voltage surge and current surge. Moreover, taking a look at the *v-i* trajectory in Fig. 4 (a), it extends over the first quadrant and the second quadrant largely. Therefore, it is based on the increase of the switching electrical stresses for IGBT used in the converter, and increase of the switching power loss and EMI noises.

However, switching waveforms in Fig. 4 (b) under a condition of soft-switching commutation, it can achieve the softened *dv/dt* and *di/dt* values, and the suppression of the voltage surge and current surge. Observing the *v-i* trajectory in Fig. 4 (b), it goes moving along the voltage axis and current axis of the main power switching device, so the ideal soft switching operation can be achieved without the switching losses at turn-on and turn-off transition. Therefore, under the soft-switching scheme, the switching power losses, voltage surge and current surge don't occur because the switching can be achieved under a condition of zero voltage or zero current soft-switching.

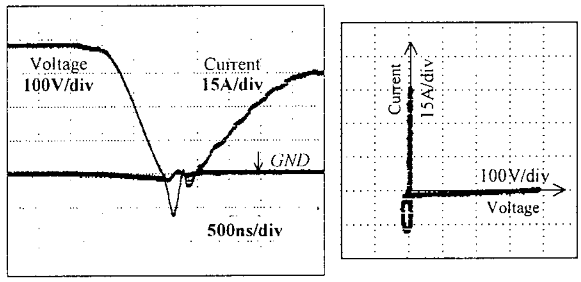
3.2 Temperature characteristics of main power switch

A small pin hole is made from the side in the metal part under a bottom side of IGBT (main switch S_1) power module package, and the tip of the K-type thermocouple probe is tightly inserted into the central part of the IGBT module, and the measured temperature of the two in one IGBT module package under a both operating conditions of the hard switching and soft-switching schemes.

As shown in Fig. 5, the temperature under hard switching scheme(H-SW) becomes 60°C after 80 minutes, but the temperature under soft-switching PWM scheme(S-SW) becomes 48°C. So soft-switching PWM makes suppression of temperature at 12°C as compared with those of hard switching PWM scheme. In these results, the downsizing of the cooling equipment including a fan can be substantially achieved, because the switching power losses of the main power switch S_1 can be sufficiently reduced using the soft-switching PWM scheme.



(a) Hard switching



(b) Soft switching

Fig. 4. Voltage and current waveforms and *v-i* trajectory in case of turn-on transient of S_1.

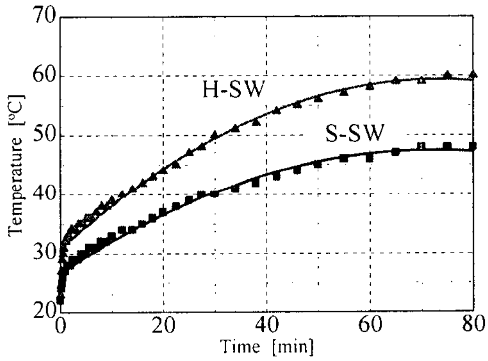


Fig. 5. Temperature measurement of IGBT module.

3.3 Actual power conversion efficiency characteristics

The actual power conversion efficiency of hard switching (H-SW) PWM boost chopper type DC-DC power converter and soft-switching (S-SW) PWM boost chopper type DC-DC power converter can be respectively measured by using the digital power meter. As shown in Fig. 6, actual efficiency of the soft switching PWM boost chopper can be improved as compared with that of hard switching PWM boost chopper scheme for the required output power range. Especially, for 3kW breadboard setup, the actual conversion efficiency of soft-switching PWM scheme can achieve 97.8%. And moreover, for high frequency switching, this power circuit can achieve higher efficiency characteristics.

3.4 EMI testing of radiated emissions

The performance of radiated emission measured by EMC bilog antenna in the shielded anechoic chamber shown in Fig. 7. Observing from the results in Fig. 8, Soft switching PWM boost chopper can be decreased the noise level all

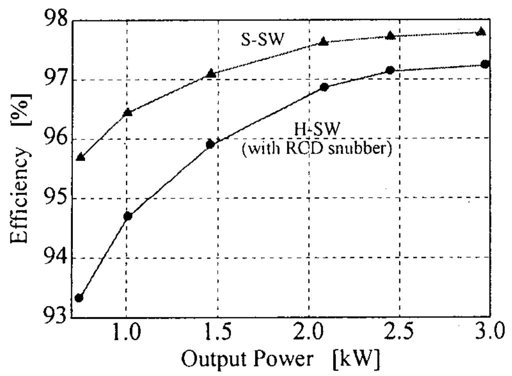


Fig. 6. Output power vs. actual efficiency characteristics.

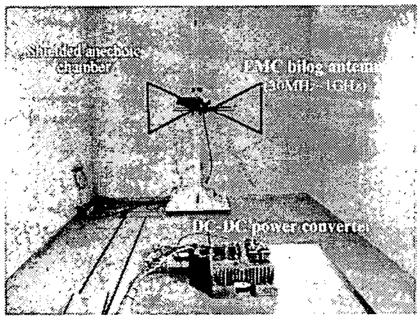


Fig. 7. Facility for measuring radiated emission.

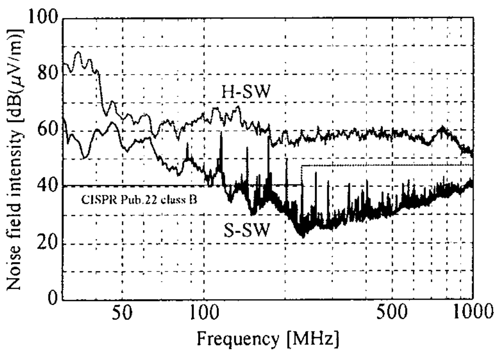


Fig. 8. Noise measurement of radiated EMI.

over the frequency range. Especially, the noise level for the maximum 37.1 [dBμV/m] can be reduced about 230MHz. It is more effective to use a soft-switching PWM scheme of boost chopper-fed DC-DC power converter with active auxiliary resonant snubber to suppress the radiated emission.

3.5 EMI testing of conducted emissions

The measured result of conducted emissions is measured with using the line impedance stabilization network (LISN) illustrated in Fig. 9. According to Fig. 10, the soft switching PWM boost chopper can be decreased the noise level all over the frequency range except for around 1.8MHz, 2.7MHz and 5.5MHz. Especially over 6MHz, can be excellent performance as compared with that of hard switching PWM boost chopper. It is effective to use a soft-switching PWM scheme of the boost chopper-fed DC-DC power converter with active auxiliary resonant snubber to suppress the conducted emission, too.

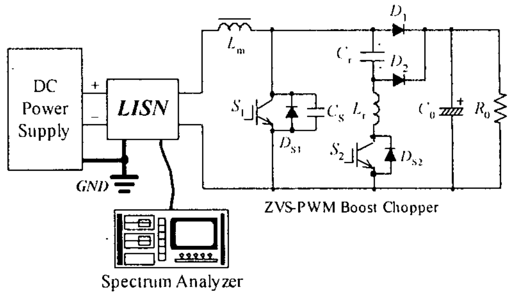


Fig. 9. Measurement of conducted emission.

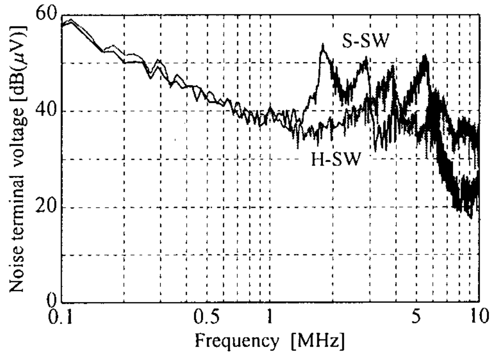


Fig. 10. Noise measurement of conducted EMI.

4. Conclusion

In this paper, ZVS-PWM boost chopper type DC-DC power converter with a single active auxiliary resonant snubber has presented for the power interface of the solar photovoltaic and fuel cell power conditioner. The feasible characteristics of this ZVS-PWM DC-DC power converter using IGBTs is compared with the conventional hard switching PWM one on the basis of the voltage and current waveforms, switching *v-i* trajectory, actual power conversion efficiency, and EMI test.

In the future, considerations of further higher efficiency and higher power density of power conversion and energy utilization equipment, and the comparison and the examination about a variety of circuit topologies of the soft-switching PWM boost chopper-fed DC-DC power converter could be required from an experimental points of view.

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