Soft-Switching Boost Chopper Type DC-DC Power Converter with a Single Auxiliary Passive Resonant Snubber.

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Abstract - **This paper presents boost and buck and buck-boost DC-DC converter circuit topologies of high-frequency soft switching transition PWM chopper type DC-DC high power converters with a single auxiliary passive resonant snubber. In the proposed boost power converter circuits operating under a principle of ZCS turn-on and ZVS turn-off commutation schemes, the capacitor and inductor in the auxiliary passive resonant circuit works as the lossless resonant snubber. In addition to this, the switching voltage and current peak stresses as well as EMI and RFI noises can be basically reduced by this single passive resonant snubber. Moreover, it is proved that converter circuit topologies with a passive resonant snubber are capable of solving some problems of the conventional hard switching PWM processing based on high-ferquency pulse modulation operation principle. The simulation results of this converter are discussed as compared with the experimental ones. The effectiveness of this power converter with a single passive resonant snubber is verified by the 5 kW experimental breadboad set up.**

Keywords ; **DC-DC Converters, Time ratio controlled chopper, A single passive resonant snubber, Soft switching PWM, Extended converter topologies**

I. INTRODUCTION

In recent years, semiconductor switched-mode power conversion circuits and systems have been begun to be effectively applied for new energy applications such as solar photovoltaic generations, fuel cell generation and secondary battery energy storage and super capacitor energy storage, with the great advances in power semiconductor switching devices and their peripheral technologies. The active high power devices and power modules such as MOSFETs, IGBTs, SITs and MCTs are generally introduced for high performance power conversion circuits with PWM control scheme. However, in high-frequency PWM applications, their dynamic and static performances are not more suitable and acceptable for high power converter operating under a principle hard-switching PWM. Because their transient switching operation in turn-on and off modes causes high di/dt and high dv/dt electrical stresses, the power semiconductor devices have high peak voltage stress or peak current stress due to parasitic parameters related on switching surges. On the other hand, soft-switching PWM techniques have been introduced for chopper and inverter in order to solve these significant problems, which are based upon the switching commutation operating schemes to turn on and off under zero current or zero voltage principle. To improve these semiconductors power devices related switching problems, a variety of circuit topologies of soft-switching PWM chopper type and inverter type DC-DC converters have been proposed on the basis of passive lossless snubber and active resonant snubber. In this paper, in the first place, a new single-switch auxiliary passive resonant snubber-assisted boost PWM chopper type DC-DC converter, together with its extended buck type and buck-boost type converter topologies, which can operate in a single lossless soft-switching PWM scheme without auxiliary resonant active power switches is proposed for high power applications. In the second place, the operation principle and performance evaluations on the basis of computer simulation results are presented along with its concerned converter topologies. A 5 kw experimental breadboad setup circuit using a single-switch auxiliary passive resonant snubber assisted boost chopper DC-DC converter is built and tested and its experimental performances are illustrated here in.

II. CIRCUIT DESCRIPTION

A practical passive soft switching circuit topology of boost PWM chopper type DC-DC converter with a single auxiliary passive resonant snubber is shown in Fig.1. This boost chopper type DC-DC converter circuit using a single IGBT, which can achieve soft switching transition commutation modes, is composed of DC load side energy feed back type resonant lossless snubber with passive power switches and passive resonant components. In this circuit, an inductor L_1 in series with a main active power switch S, two resonant capacitors C_1 and C_2. Because the pulse modulated active power switch S with a single passive resonant lossless snubber can completely achieve soft-switching at high-frequency turn-on and off points in spite of duty cycle control, which is based on zero-current turn-on due to resonant in L_1 and zero-voltage turn-off due to resonant capacitor C_1. In addition, this boost type DC-DC power converter circuit operation is based on soft switched PWM strategy by a single active power switch. This generic soft switching snubber approach is possible to use all types of conventional PWM chopper type DC-DC converters.

Since two capacitors of the resonant snubber circuit act as lossless snubbers, power losses and EMI noise in the soft commutation of non isolation link PWM boost converter circuit can be actually reduced including peak voltage and peak current stress related ratings.

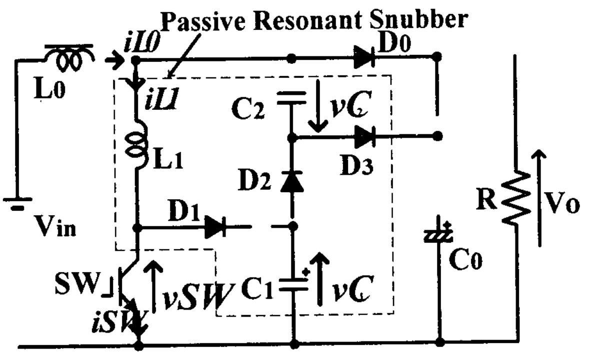


Fig.1. A proposed single-switch PWM boost DC-DC converter with passive resonant snubber.

III. PRINCIPLE OF OPERATION

The boost soft switching PWM chopper type DC-DC power converter with a single passive resonant snubber which includes L_0, SW, D_0 and C_0. Auxiliary passive resonant snubber circuit includes C_1, C_2, L_1, D_1, D_2 and D_3. Because the capacitor C_0 for the output voltage smoothing as well as the inductor L_0 for input current smoothing are too large constants as compared with resonant LC constants and soft commutation time is extremely short, it is assumed that the current flowing through L_0 and the output voltage Vo are considered as a constant value during the soft commutation transition processing process. In order to describe the working principle, the operating voltage and current waveforms in steady state are depicted in Fig.2 and Fig.3, shows the equivalent circuits of this converter. The operation of this converter is described below for its equivalent circuits show in Fig.3.

Mode 1: At mode 1($t_0<t<t_1$), when the active power switch SW in the boost PWM DC-DC power converter shown in Fig.1 is in off-state, stored energy during the previous conduction interval in the boost DC inductor L_0 is transferred to the load through the blocking diode D_0. Then, the capacitor C_1 is charged with the polarity depicted in Fig.1 up to the output charged to the output DC voltage Vo, but the capacitor C_2 is not charged.When the active power switch SW is turned on at time t_0, the current of the blocking diode D_0 is linearly decreased by the inductor L_1. On the other hand, the current flowing through the inductor L_1 increases linearly from zero.

Mode 2: At mode 2($t_1<t<t_2$), when the current of the diode D_0 becomes zero, D_2 begins to conduct. The resonant inductor L_1 and the capacitors C_1 and C_2, start to resonate, and the energy stored in C_1 is discharged through C_1-C_2-L_1-SW loop as shown in Fig.3, producing a sinusoidal resonant current. As a result, the current through the inductor L_1 contains both the current of the inductor L_0 and the resonant current.

Mode 3: At mode 3($t_2<t<t_3$), when the voltage across the capacitor C_1 is equal to zero, the diode D_1 begins to conducts so L_1 and C_2 resonate through D_1 and D_2. The voltage across the capacitor C_2 still increase in accordance with the decrease of the inductor L_1 current. When the resonant current is completed, the energy stored into the capacitor C_1 is transferred to the capacitor C_2.

Mode 4: At mode 4($t_3<t<t_4$), when current through the inductor L_1 is equal to the energy storage inductor L_0, the turn-on commutation process is completed and the voltages across the C_1 and C_2 are kept constant. The converter circuit works as a conventional boost chopper type converter circuit.

Mode 5: At mode 5($t_4<t<t_5$), as soon as the active power switch SW is turned off at time t_4, the current through the main power switch is completely commutated to C_1 through D_1. As the voltage across the capacitor C_1 increases to the output voltage Vo due to this charging current.

Mode 6: At mode 6($t_5<t<t_6$), when the diode D_3 is turned on, at time t_5, the energy stored into C_2 is discharged through the diode D_3.

Mode 7: At mode 7($t_6<t<t_7$), when the voltage across C_1 reaches the output voltage Vo of this power converter, the diode D_2 is turned on at time t_6. In addition, the current flowing through the inductor L_1 is transferred to the load through D_2 and D_3. Thus, the current through L_1 decreases continuously.

Mode 8: At mode 8($t_7<t<t_8$), when the current flowing through the inductor L_1 becomes zero, the current through the inductor L_1 is kept constant to zero, until the active power switch SW is turned on.

Mode 9: At mode 9($t_8<t$), when the voltage across the capacitor C_2 goes to zero at time t_8, another operation mode starts. The current flowing through in the capacitor C_2 is commutated to the diode D_0.

The turn-on di/dt stress and turn-off dv/dt stress are both limited by the circuit constant L_1 and C_1, respectively. The switching power loss of the power device:IGBT and EMI noise are greatly reduced due to a soft commutation PWM strategy. At the turn-on commutation switching process, the energy stored into C_1 is transferred to C_2. At the turn-off switching process, the energy stored into C_2 and L_1 are transferred to the load. This kind of a single passive resonant lossless snubber assisted-converter circuit has a high efficient operation under a stable soft commutation strategy, and the actual efficiency converter results in a high value in spite of PWM-based voltage regulation.

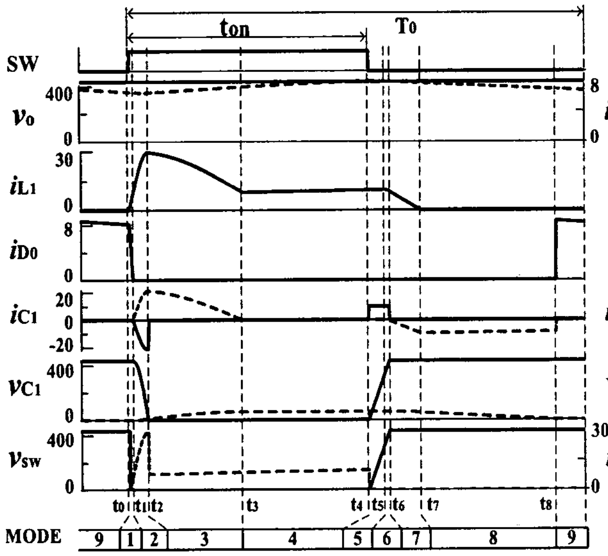


Fig.2 Voltage and current operating waveforms

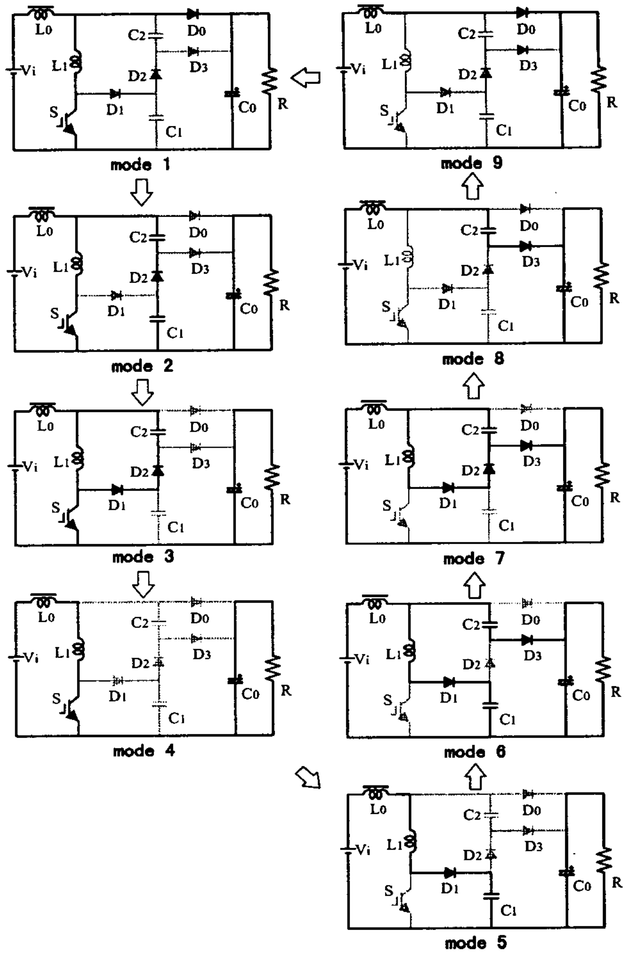


Fig.3 The operating modes of soft switching PWM DC-DC converter with a single passive resonant snubber and equivalent circuits.

IV. Experimental Results And Discussions

The soft switching boost PWM chopper type DC-DC power converter with auxiliary passive resonant snubber using IGBT is designed and simulated. The design circuit parameters and specifications of this converter shown in Table 1. When the duty cycle D as a control variable is 0.5, voltage and current switching waveforms of this power converter are respectively illustrated in Fig.4 and Fig.5. The soft-switching operation of the boost PWM completely converter with a single passive resonant snubber is able to be achieved at both ZCS turn on and ZVS turn off. Fig.6 shows comparative output power vs. efficiency characteristics for hard switching and soft switching.

Table.1 Design specifications and Experimental Parameters.

Circuit parameters	L_1 = 3 μH
	C_1 = 10 nF
	C_2 = 500 nF
Input voltage	V_{in} = 200 V
Switching frequency	f = 20 kHz
Duty cycle	D = 0.5
Load resistor	R = 33Ω
Boost inductor	Lo = 500 μH
DC filter capacitor	Co = 2000 μF

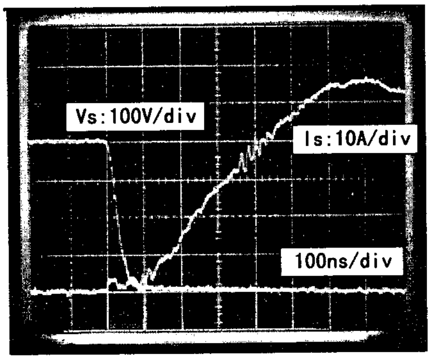


Fig.4 Experimental switching voltage and current waveforms of the active power switch S at turned on (under 5 kW output).

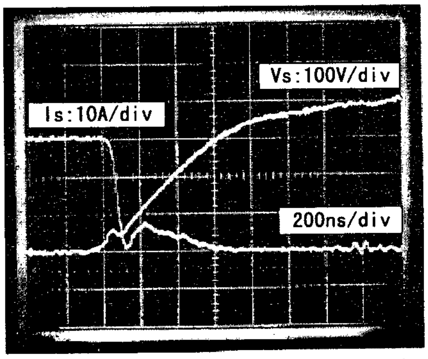


Fig.5 Experimental switching voltage and current waveforms of the active power switch S at turned off (under 5 kW output).

V. Simulation Results

The relation between the duty cycle vs. output voltage characteristics show in Fig.7. In addition, in Fig.7, peak voltage across switch SW is represented because peak voltage is equal to output voltage. Under control variable duty cycle, dv/dt and di/dt dynamic stress characteristics are shown in Fig.8 and Fig.9.

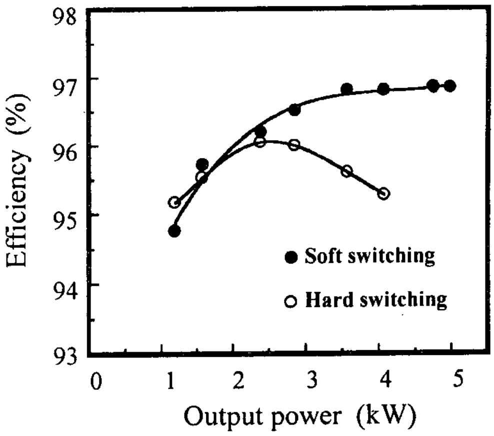


Fig. 6 Output power vs. Efficiency characteristics.

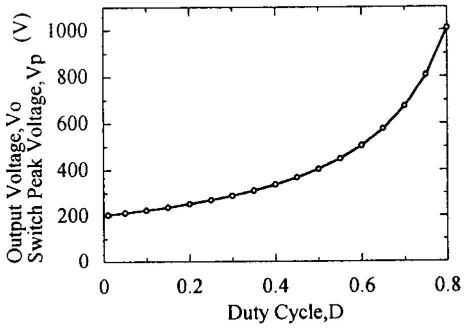


Fig.7 Output voltage Vo and Switch peak voltage Vp, Duty cycle characteristics

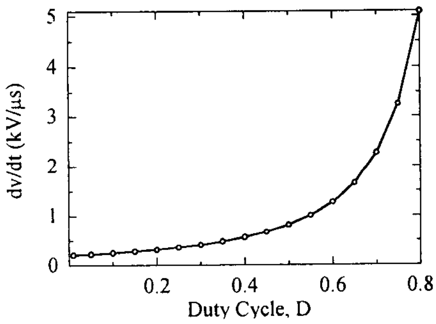


Fig.8. dv/dt characteristics at turn off.

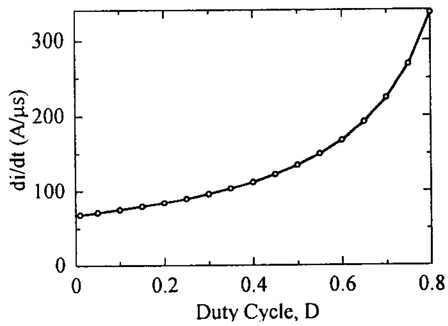
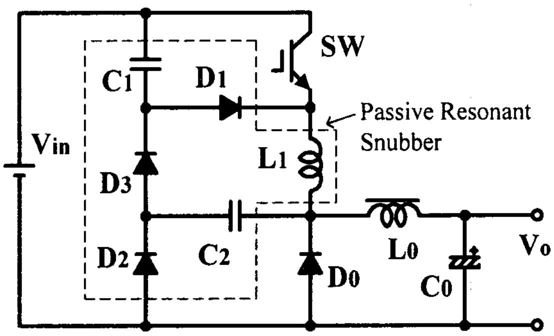


Fig.9. di/dt characteristics at turn on.

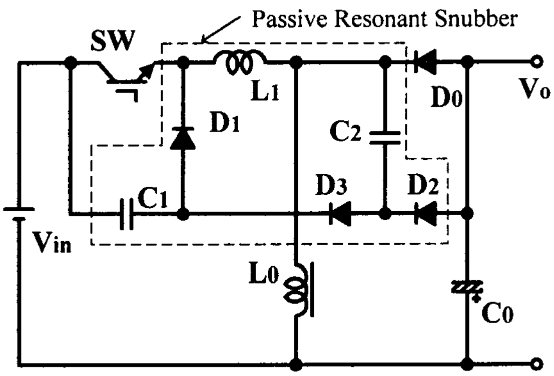
VI. EXTENDED CONVERTER TOPOLOGY

The passive resonant lossless snubber-assisted boost chopper type DC-DC converter circuit using a single active power switch have two different soft switching operation modes; turn-on and turn-off commutation schemes. Both of them have a current loop to transfer the energy stored in the inductor or capacitor in the resonant snubber. In the turn-on point, an inductor in series with power switching device limits effectively the turn-on related di/dt stress and a capacitor in parallel with the inductor to transfer the energy. In the turn-off instant, a capacitor in parallel with switching device restrains the turn-off related dv/dt stress and a capacitor in series with the capacitor to transfer the energy.

Using the general principle mentioned above, the energy recovery-based passive resonant lossless snubber circuit assisted buck and boost-buck DC-DC power converter topologies are respectively shown in Fig.10, and the basic principle of operation is similar to the principle of passive resonant snubber-assisted the boost power converter discussed above.



(a) buck type



(b) boost-buck type

Fig.10 Extended converter family.

VII. CONCLUSIONS

In this paper, 10kW soft switching auxiliary resonant snubber assisted PWM chopper type boost DC-DC power converter using a single IGBT was proposed for new energy interfaced power conditioner. Its steady-state operation principle was deseriked on the basis of the equivalent circuits of this DC-DC converter and steady-state performance evaluations of the proposed power converter circuit illustrated and discussed on the basis of the simulation and practical experiment as a function of duty cycle variable. The soft switching PWM power converter topology with a single passive resonant snubber can be expected to reduce the switching power losses, switching surge related EMI noise. The operating characteristics of this soft switching PWM chopper type in spite of duty cycle control scheme power converters are practically verified on the basis of experimental and simulation results. The proposed power converters have the following salient unique features.

(i). This boost converter with lossless resonant snubber can operate at a soft switching commutation without auxiliary active switches.

(ii). The active power switch operation can completely achieve zero-current turn-on and zero-volt turn-off schemes.

(iii). The capacitors for the passive resonant circuit act as lossless snubbers.

(iv). This power converter can operate under constant switching frequency.

REFERENCES

[1] X. WU, X. JIN, L. HUANG and G. FENG, "A Lossless Snubber for DC-DC Converters and Its Application in PFC," Proceedings of IPEMC 2000, Vol.3, pp.1144-1149. 2000

[2] M. Shimada and M. Nakamura, "Single-Switch Auxiliary Resonant Converters," Proceedings of PCC-Nagaoka,Japan ,pp.811-814. 1997

[3] L. R. Brbosa, E. A.A. coelho, J. B. Vieira, L. C. de Freitas, V. J. Farias, "PWM soft-switched Converters with A Single Active Switch," The on IEEE Industry Applications Society Vol.11,pp.1305-1310. 1997

[4] M. Nakamura, M. Shimada, T. Myoui, H. Sadakata, S. Moisseev, M. Nakaoka, "Performance Evaluations on Soft-Switching Boost Power Converter with a Single Auxiliary Passive Resonant Snubber," Proceeding of PESC 2001, Vol. 2, pp 1057-1062.