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Soft-Switching PWM Boost Chopper-Fed DC-DC Power Converter with Load Side Auxiliary Passive Resonant Snubber

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ABSTRACT

This paper presents a new circuit topology of high-frequency soft switching commutation boost type PWM chopper-fed DC-DC power converter with a loadside auxiliary passive resonant snubber. In the proposed boost type chopper-fed DC-DC power converter circuit operating under a principle of ZCS turn-on and ZVS turn-off commutation, the capacitor and inductor in the auxiliary passive resonant circuit works as the lossless resonant snubber. In addition to this, the voltage and current peak stresses of the power semiconductor devices as well as their *di/dt* or *dv/dt* dynamic stress can be effectively reduced by the single passive resonant snubber treated here. Moreover, it is proved that chopper-fed DC-DC power converter circuit topology with an auxiliary passive resonant snubber could solve some problems on the conventional boost type hard switching PWM chopper-fed DC-DC power converter. The simulation results of this converter are illustrated and discussed as compared with the experimental ones. The feasible effectiveness of this soft switching DC-DC power converter with a single passive resonant snubber is verified by the 5kW, 20kHz experimental breadboard set up to be built and tested for new energy utilization such as solar photovoltaic generators and fuel sell generators.

Keywords: DC-DC converter, Boost chopper, Auxiliary passive resonant snubber, Soft switching, PWM

1. Introduction

In recent years, semiconductor switched-mode DC-DC power conversion circuits and systems have begun to show effectiveness for the power conditioners in new energy applications such as solar photovoltaic generation, fuel cell generation, micro gas turbine generation and new type 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 MOS-FETs, IGBTs, SITs and MCTs are generally introduced for high performance DC-DC power converter circuits with PWM control scheme. However in high frequency PWM applications, their dynamic and static performances are not as suitable and acceptable for high power DC-DC converter operating under a principle of the hard switching PWM scheme. Because their transient switching operation in turn-on and turn-off modes cause high *di/dt* and high *dv/dt* electrical dynamic stresses, the power semiconductor devices have high peak voltage stress or peak current stress due to parasitic

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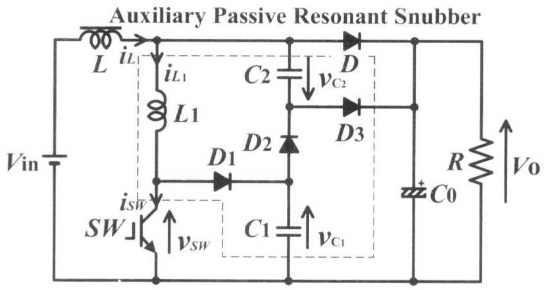
parameters related to switching surges. On the other hand, soft switching PWM techniques have been introduced for the converter or the inverter in order to solve these significant problems, which are based on the switching commutation operating schemes to turn-on and turn-off under zero current switching (ZCS) or zero voltage switching (ZVS). To improve and alleviate these semiconductor power device related switching problems, a variety of circuit topologies of soft switching PWM chopper-fed DC-DC converters have been proposed on the basis of passive resonant snubbers[1]-[5] and active resonant snubbers[6]-[11].

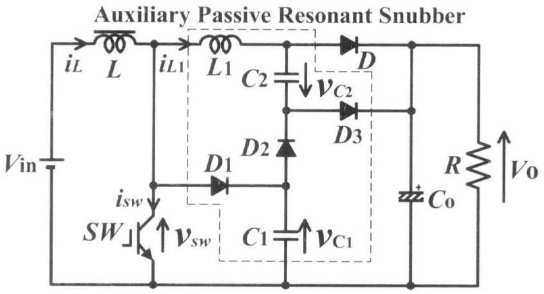
In this paper, a new single-switch auxiliary passive resonant snubber PWM boost chopper-fed DC-DC power converter, together with its extended buck type and buck-boost type chopper-fed DC-DC power converter circuit topologies are introduced, which can operate in a single passive resonant snubber without using the auxiliary active power switch is proposed for high power applications. At this point, the operation principle and performance evaluations on the basis of computer simulation results are basically presented along with the extended converter circuit topologies. A 5kW 20kHz experimental breadboard setup using a single-switch auxiliary passive resonant snubber assisted soft switching boost chopper-fed DC-DC power converter is built and tested as compared with a conventional hard switching PWM DC-DC power converter. Feasible experimental operating performances are illustrated and evaluated herein.

2. Circuit Description

A practical passive soft switching circuit topology designed for a PWM boost chopper-fed DC-DC power converter with a single auxiliary passive resonant snubber is shown in Fig. 1(a), (b). This boost chopper-fed DC-DC power converter using a single IGBT, which can achieve a soft switching commutation mode is composed of a auxiliary passive resonant snubber in DC load side with passive power switches (D_1, D_2, D_3) and passive resonant inductor (L_1) and resonant capacitors (C_1, C_2). The PWM active power switch SW with a single passive resonant snubber can completely achieve soft switching commutation at turn-on and turn-off in spite of the constant duty cycle control based on PWM, which is based on ZCS turn-on due to the resonant inductor L_1 and ZVS turn-off due to the resonant capacitor C_1. The generic passive snubber assisted soft switching commutation approach uses all three types of conventional PWM chopper type DC-DC power converters here. Since two resonant capacitors (C_1, C_2) of the resonant snubber circuit act as the lossless snubbers, power losses and EMI noises in the soft commutation of soft switching PWM boost chopper-fed DC-DC power converter circuit can actually show a reduction including peak voltage and peak current stresses related ratings.



(a) Topology I



(b) Topology II

Fig. 1. Two types of proposed single-switch soft switching PWM boost chopper-fed DC-DC converters with auxiliary passive resonant snubber.

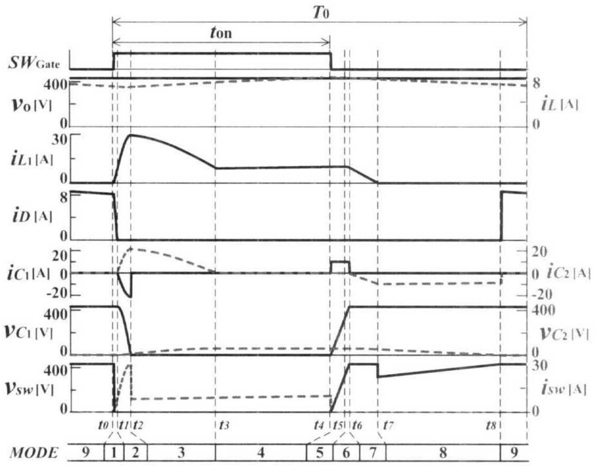
3. Principle of Operation

The soft switching PWM boost chopper-fed DC-DC power converter with a single passive resonant snubber in Fig. 1(a) which includes energy storage boost inductor *L*, the main switch *SW*, the blocking diode *D* and the DC smoothing filter capacitor C. The auxiliary passive resonant snubber circuit includes two resonant capacitor C_1, C_2, the resonant inductor L_1, the auxiliary diode D_1, D_2 and D_3. Since the output capacitor C for the output voltage smoothing as well as the boost inductor L for input current smoothing are too large as constants when compared with L-C active auxiliary resonant snubber constants, soft commutation time is extremely short. Therefore it is assumed that the current flowing through boost inductor L and the output voltage V_o are considered as a constant value under the soft switching transition. In order to describe the operating principle in Fig. 1(a), (b), the operating voltage and current waveforms in a steady state are depicted in Fig. 2. Fig. 3 shows the equivalent circuits of this soft switching boost chopper-fed DC-DC power converter. The operation of this DC-DC power converter with an auxiliary passive resonant snubber is described below.

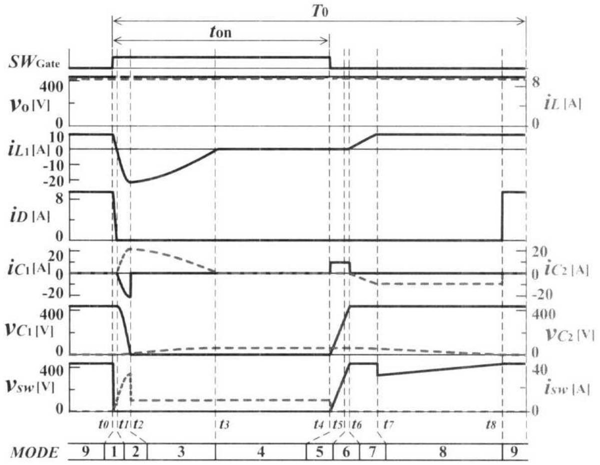
Mode 1 ($t_0<t<t_1$) When the main active power switch SW in the soft switching PWM boost chopper-fed DC-DC power converter is off-state, the stored energy during the previous conduction interval in the boost inductor L is transferred to the load side flowing through the blocking diode D. At that point, the resonant capacitor C is charged with the polarity depicted in Fig. 1 up to the output DC voltage V_o, but the resonant capacitor C_2 is not charged. When the switch SW is turned on at time t_0, the current of the blocking diode D is linearly decreased by the boost inductor L. On the other hand, the current flowing through the resonant inductor L increases linearly from zero.

Mode 2 ($t_1<t<t_2$) When the current flowing through the blocking diode D becomes to zero, auxiliary diode D_2 is turned on. The resonant inductor L_1 and the resonant capacitors C_1 and C_2 start to resonate, and the energy stored into C_1 is discharged flowing through the C_1-C_2-L_1-SW loop as shown in Fig. 3, producing a sinusoidal resonant current.

Mode 3 ($t_2<t<t_3$) When the voltage across the resonant capacitor C_1 is equal to zero, the diode D_1 is turned on with the composed resonant circuit L_1, C_2 and D_2. The voltage across the resonant capacitor C_2 still increases in accordance with the decrease of the current of resonant inductor L_1. When the resonant circuit is completed, the energy stored into the resonant capacitor C_1 is transferred to the resonant capacitor C_2.



(a) Topology I



(b) Topology II

Fig. 2. Voltage and current operating waveforms.

Mode 4 ($t_3<t<t_4$) When the current flowing through the resonant inductor L_1 is equal to the boost inductor L, the turn-on commutation process is completed and the voltages across the C_1 and C_2 are kept constant. This converter circuit works as a conventional boost chopper-fed DC-DC power converter circuit.

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

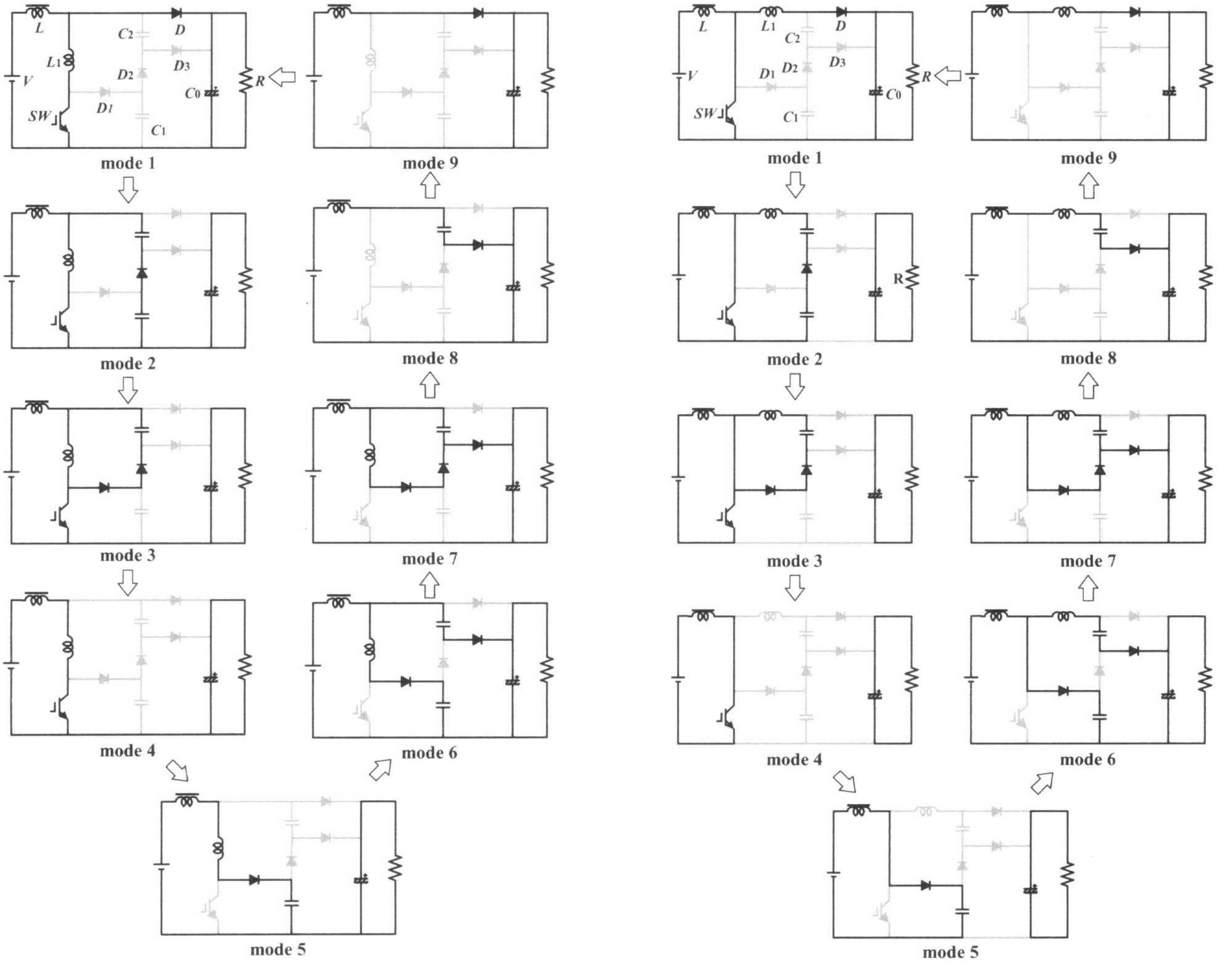
Mode 6 ($t_5<t<t_6$) When the diode D_3 is turned on at time t_5, the energy stored into the resonant capacitor C_2 is discharged through the diode D_3.

Mode 7 ($t_6<t<t_7$) When the voltage across the resonant capacitor C_1 reaches the output voltage V_o of this DC-DC power converter, the diode D_2 is turned on at time t_6. In addition, the current flowing through the resonant inductor L_1 is transferred to the load through the diode D_2 and D_3. Therefore, the current flowing through L_1 decreases continuously.

Mode 8 ($t_7<t<t_8$) When the current flowing through the resonant inductor L_1 becomes zero, the current flowing through L_1 is kept constant to zero until the main active power switch *SW* is turned on.

Mode 9 ($t_8<t<t_0$) When the voltage across the resonant capacitor C_2 goes to zero at time t_8, the other operation mode starts. The current flowing through the capacitor C_2 is commutated to the diode D_o.

The *di/dt* stress at turn-on and *dv/dt* stress at turn-off are both limited to the circuit constants L_1 and C_1, respectively. The switching power loss of the IGBT is greatly reduced due to a soft commutation PWM strategy. At the turn-on commutation switching process, the energy stored into the resonant capacitor C_1 is transferred to the resonant capacitor C_2. At the turn-off commutation switching process, the energy stored into the resonant capacitor C_2 and L_1 are transferred to the load. This kind of a load side single passive resonant lossless snubber assisted soft



(a) Topology I

(b) Topology II

Fig. 3. The operating modes of soft switching PWM boost chopper-fed DC-DC converters.

switching PWM boost chopper-fed DC-DC power converter circuit demonstrates high efficiency in operation under a stable soft commutation strategy. The actual efficiency of this converter results in a high value in spite of constant switching frequency PWM-based voltage regulation.

Table 1. Design specifications and experimental parameters.

Passive snubber circuit parameters	$L_1 = 3\,\mu H$
	$C_1 = 47$ nF
	$C_2 = 47$ nF
Input DC voltage	$V_{in} = 200$ V
Output DC voltage	$V_{out} = 400$ V
Switching frequency	$f_{sw} = 16$ kHz
Duty cycle	$D = 0.5$
Load resistor	$R_o = 33\,\Omega$
Boost inductor	$L_o = 5$ mH
DC filter capacitor	$C_o = 2{,}000\,\mu F$

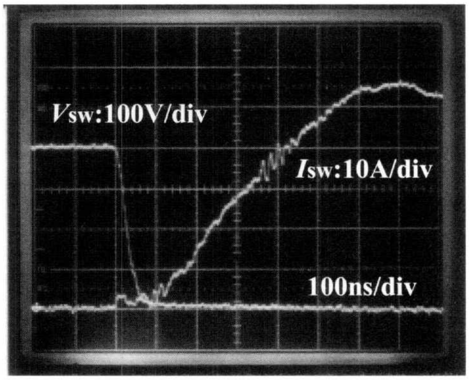


Fig. 4. Voltage and current waveforms of the active power switch *SW* at turn-on (under 5kW output).

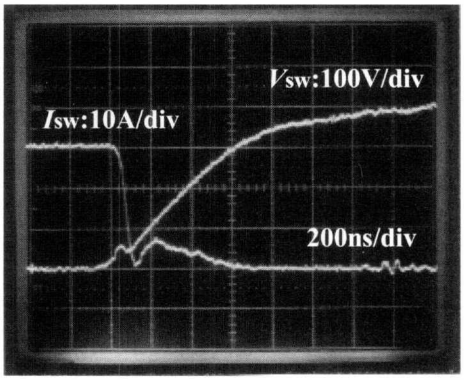


Fig. 5. Voltage and current waveforms of the active power switch *SW* at turn-off (under 5kW output).

4. Experimental Results and Discussions

The soft switching PWM boost chopper-fed DC-DC power converter with auxiliary passive resonant snubber is designed and simulated for high power applications. The design circuit parameters and specifications of this DC-DC power converter are indicated in Table 1. When the duty cycle D as a control variable is specified to 0.5, the voltage and current switching waveforms of this soft switching DC-DC power converter are respectively illustrated in Fig. 4 and Fig. 5. The soft-switching operation in each mode transition can be achieved at both ZCS turn-on and ZVS turn-off commutation processes. Fig. 6 shows comparative output power vs. actual efficiency characteristics for the hard switching and soft switching DC-DC power converter.

5. Simulation Results and Discussions

The relation between the duty cycle vs. output voltage characteristics are depicted in Fig. 7. In addition to this, the peak voltage across the active power switch *SW* of this soft switching PWM chopper-fed DC-DC power converter is represented in Fig. 7. In this case, the peak voltage is equal to the output voltage V_o. Under the duty cycle as a control variable, *dv/dt* and *di/dt* dynamic stress characteristics are illustrated in Fig. 8 and Fig. 9.

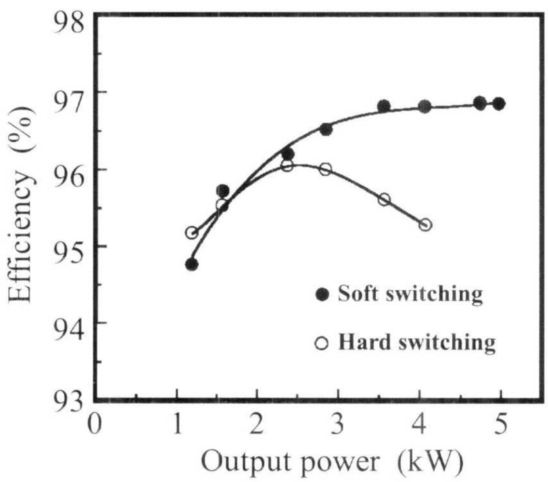


Fig. 6 Output power vs. efficiency characteristics.

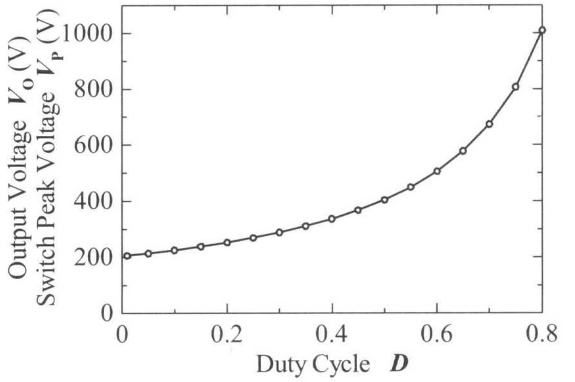


Fig. 7. Duty cycle vs. output voltage and switch peak voltage characteristics.

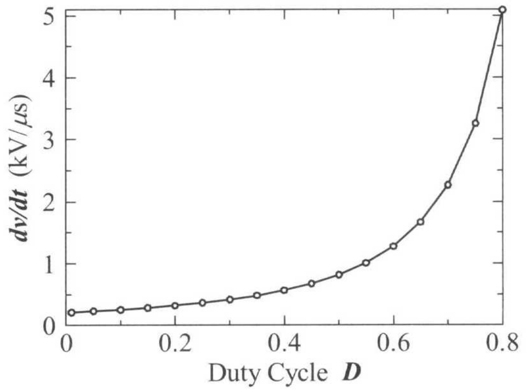


Fig. 8. *dv/dt* characteristics at turn-off.

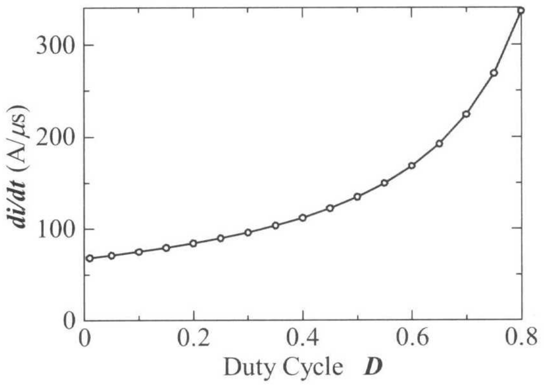
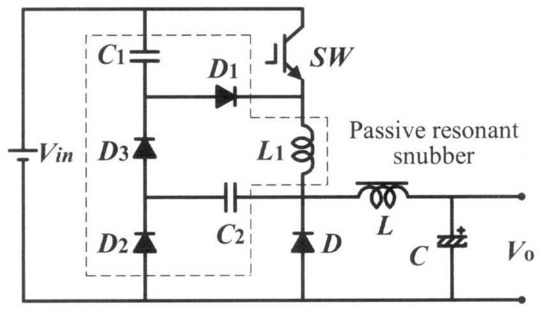


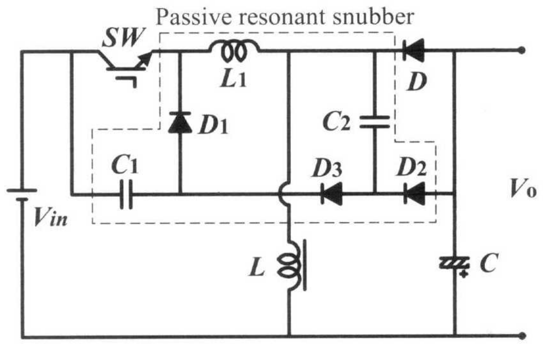
Fig. 9. *di/dt* characteristics at turn-on.

6. Extended DC-DC Power Converter Topologies with Passive Resonant Snubber

The passive resonant snubber assisted boost chopper type DC-DC converter circuits using a single active power switch have two different soft switching operation modes for turn-on and turn-off commutation schemes. Both of them have a current loop to transfer the energy stored into the inductor or capacitor in the passive resonant snubber. At the turn-on point, a resonant inductor L_1 in series with active power switch *SW* effectively limits the turn-on related *di/dt* stress and the capacitor C_2 parallel with the resonant inductor L_1 in the energy transfer. At the turn-off transition, the resonant capacitor C_1 in parallel with the active power switch *SW* restrains the turn-off related *dv/dt* stress and the resonant capacitor C_2 in series with the resonant capacitor C_1 to transfer the energy. Illustrating the general principle mentioned above, Fig. 10 shows the load side energy recovery-based passive resonant snubber circuit assisted buck, or boost-buck soft switching DC-DC power converter topologies of non-isolated configuration respectively. The basic operating principle of these chopper mentioned above is similar to the principle of passive resonant snubber-assisted the boost power converter discussed above.



(a) Buck type



(b) Buck-boost type

Fig. 10. Extended converter family.

7. Conclusions

In this paper, the 5kW 20Hz auxiliary edge-resonant snubber assisted soft switching PWM boost chopper-fed DC-DC power converter using a single IGBT was proposed for new energy interfaced power conditioner of high power applications. Its steady-state operation principle was described on the basis of the equivalent circuits of this soft switching DC-DC power converter and steady-state performance evaluations were illustrated and discussed on the basis of the simulation and experimental results as a function of duty cycle variable. The soft switching PWM boost chopper-fed DC-DC power converter topology with a single passive resonant snubber could be expected to reduce the switching power losses, or the switching surge. The operating characteristics of this soft switching PWM chopper-fed DC-DC power converter were practically verified on the basis of experimental and simulation results. The proposed DC-DC power converter has the following salient unique features as well as its extended DC-DC power converter.

(i) The active power switch operation can completely achieve ZCS turn-on and ZVS turn-off commutation schemes.

(ii) This boost converter with lossless resonant snubber can operate under wide soft switching commutation ranges in duty cycle control ranges.

(iii) The power conversion actual efficiency of this DC-DC power converter can be effectively increased in comparison with conventional hard switching DC-DC power converter in the high power ranges.

(iv) This passive resonant snubber can be applied to buck type and boost-buck type DC-DC power converter for soft switching commutation.

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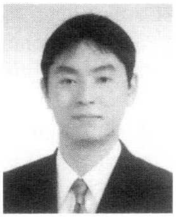

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