Soft Switching Full-Bridge PWM DC/DC Converter Using Secondary Snubber

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Abstract ***- A novel full-bridge PWM DC/DC converter with controlled secondary side rectifier using secondary snubber is presented in this paper. Limitation of the circulating current as well as soft switching for all power switches of the inverter is achieved for full load range from no-load to short circuit by using controlled rectifier and snubber on the secondary side. Phase shift PWM control strategy is used for the converter. The principle of operation is explained and analyzed and the experimental results on a 1kW, 50 kHz laboratory model of the converter are presented.***

Keywords ***– Secondary snubber, soft switching, zero voltage switching, zero current switching.***

I. INTRODUCTION

The conventional phase shifted PWM converters are often used in many applications because their topology permits all switching devices to operate under zero-voltage switching by using circuit parasitics such as power transformer leakage inductance and devices junction capacitance. However, because of phase-shifted PWM control, the converter has a disadvantage that circulating current flows through the power transformer and switching devices during freewheeling intervals. This circulating current can be eliminated by disconnection of the secondary winding, which can be realized either by controlled rectifier [1] – [4] or reverse bias application for the output diode rectifier [6] – [19].

Many various active [5] – [9] or passive [10] – [19] snubbers, auxiliary circuits and clamps were developed to solve the problem with circulating current and elimination of switching losses.

Preferred solutions are those with non-dissipative circuits and energy recovery possibility. New non-dissipative energy recovery snubber on the secondary side of the full-bridge PWM converter is proposed in the paper. The energy of the power transformer leakage inductance is transferred to the load where is utilized.

II. POWER CIRCUITS OF THE PROPOSED CONVERTER

To improve the properties of the existing converters, the new topology of the following full-bridge DC/DC converter was proposed.

The proposed DC/DC converter shown in Fig. 1 consists of high-frequency full bridge inverter, center tapped power transformer, controlled output rectifier, output filter and novel type of secondary energy recovery snubber.

The converter is controlled by modified pulse-width modulation (Fig.2), and consequently the zero-voltage turn-on and zero-current turn-off all of the transistors T_1-T_4 in the inverter are reached.

The new snubber circuit eliminates the turn off losses of the secondary transistors because they turn off under zero voltage. The semiconductor switches T_5, T_6 in the secondary side are used to reset secondary and simultaneously also primary circulating current

III. OPERATION PRINCIPLE

The switching diagram and operation waveforms are shown in Fig. 2. The basic operation of the proposed soft switching converter has six operating modes (intervals) within each half cycle. The switching diagram and operation waveforms are shown in Fig. 6. The DC/DC converter is controlled by modified pulse width modulation with phase shift between primary and secondary switches.

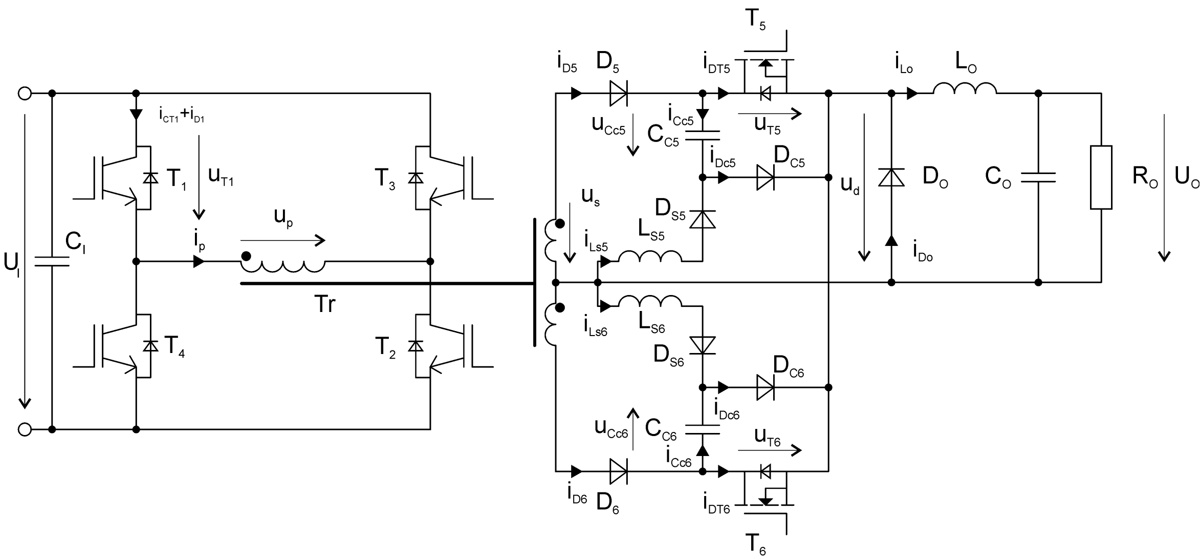

Fig. 1 Scheme of the proposed PWM DC/DC converter

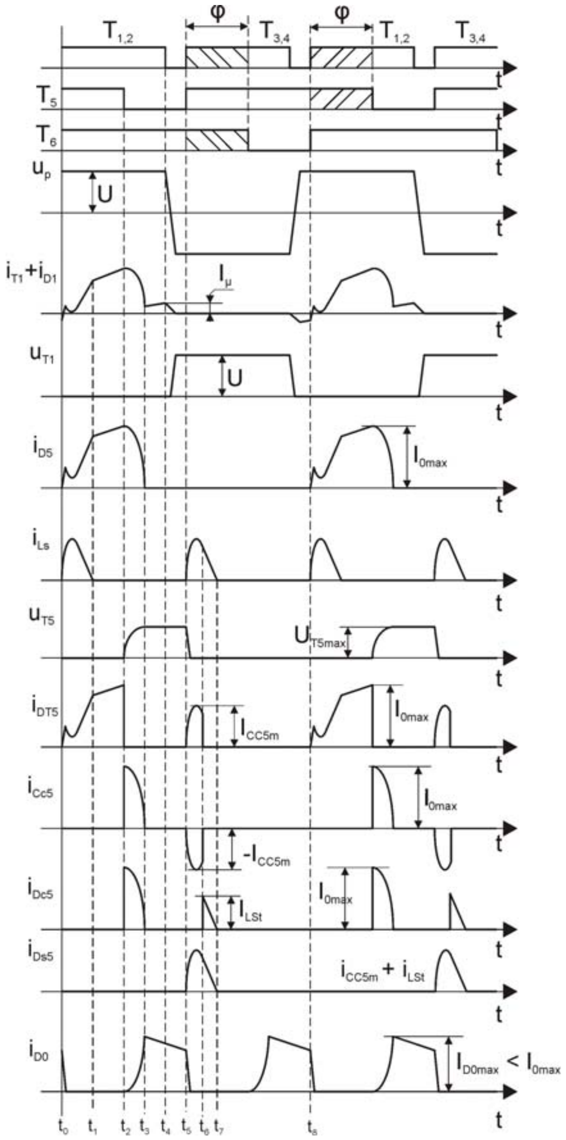

Fig. 2 Operation waveforms of the converter

Interval (t_0-t_1): At the time t_0 the primary transistors T_1, T_2 are turned on. The leakage inductance of the power transformer ensures that the emitter current of these transistors rises with a reduced di/dt, so the IGBT switches are turned on under zero current conditions. The rectifier switch T_6 is turned on in the same interval and the capacitor C_{C6} is discharging to load through smoothing choke. At the end of this interval is the capacitor C_{C6} fully discharged.

Interval (t_1-t_2): During this period the secondary current rises with a slope that depends on the output filter inductance L_0.

Interval (t_2-t_3): At the time t_2 the secondary transistor T_5 is turned off. The transistor current is commutated to the snubber capacitor C_{C5}. The rise of drain-source voltage U_{T5} is slowed by down capacitor C_{C5}.and thus the zero voltage turn off of the secondary MOSFET is ensured. The maximum value of the voltage U_{T5} depends on the load current, leakage inductance and the secondary voltage of the high frequency power transformer. While the capacitor C_{C5} is charging, the capacitor current commutates to the freewheeling diode D_0.

Interval (t_3-t_4): Only negligible magnetizing current flows through primary winding of the transformer. The load current starts to flow through the freewheeling diode D_0.

Interval (t_3-t_5): The load current continues to flow through the freewheeling diode D_0 during this period.

Interval (t_5-t_6): The secondary transistor T_5 is turned on at t_5 a half period earlier then primary transistors T_1 and T_2. The capacitor C_{C5} starts discharging through T_5, L_0, R_0, L_S, and D_{S5}. The rate of rise of discharging current of this capacitor C_{C5} is limited by the snubber circuit inductance L_S, and thus zero current conditions of the MOSFET transistor T_5 is achieved. Also the primary transistors T_3, T_4 are turned on at the beginning of this interval and the energy from the input source U is transferred to the load. But on the beginning of this transfer the power is supplied also from the snubber circuit capacitance C_{C5}. The waveforms of the primary and secondary currents are exactly the same like the current waveforms of the opposite transistors only with a half period phase shift. At the time t_6 the discharge current stops to flow through the T_5 transistor.

Interval (t_6-t_7): The energy stored in snubber inductance L_S is now flowing through D_{S5}, D_{C5}, L_0, R_0, L_S. At the time t_7 the whole load current flows through the transistor T_6.

Interval (t_7-t_8): At the time t_8 ends one period of the DC/DC converter operation and another period starts with the turning on of the transistors T_1, T_2.

IV. EXPERIMENTAL RESULTS

The experimental results were obtained on the laboratory model of the proposed converter to verify its function and features.

Converter parameters:
Output power P = 1 kW,
Input voltage U = 300V,
Switching frequency f_S = 50 kHz.

The following waveforms were obtained at resistive load.

Fig. 3 shows the waveforms of the primary IGBT transistor (transistor voltage u_{CET1} and current i_{CT1}), where the rate of collector current rise is limited by the leakage inductance of the power transformer. The transistor is turned on under zero voltage. Primary current falls down when the secondary transistors are turned off. IGBT transistor turns off at the time when only small magnetizing current flows through primary winding of the power transformer and thus zero current turn off is achieved.

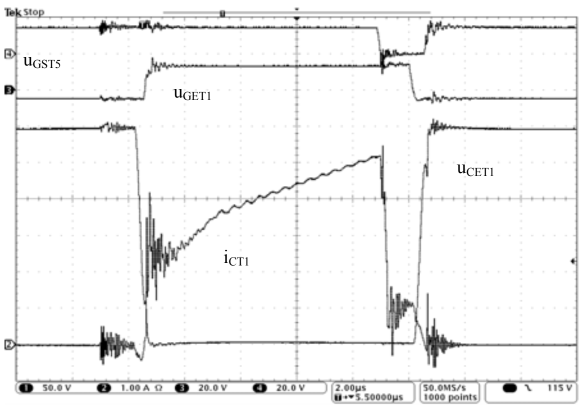

Fig. 3 Switch voltage u_{CET1} and switch current i_{CT1} of the primary transistor at turn-on and turn-off

In Fig. 4 the collector-emitter voltage u_{DS} and collector current i_{DT5} of the secondary MOSFET transistor are shown. The secondary transistor is turned on under zero voltage and zero current. The energy recovery snubber causes a zero voltage turn off of the transistor. The leakage inductance energy of the power transformer is forced to flow through the load at the turn on interval of this transistor. The value of this energy, which should be as low as possible depends on the leakage inductance value and mainly on the transformer current.

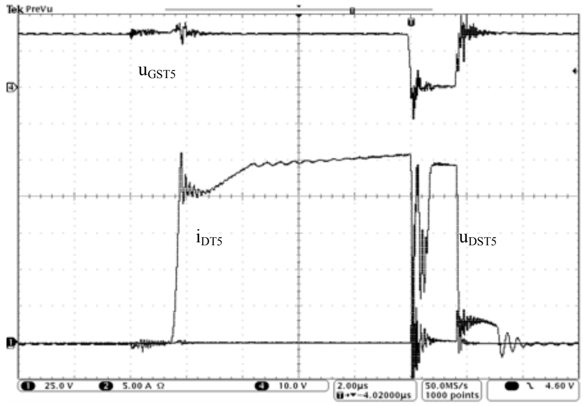

Fig. 4 Collector voltage u_{DS} and collector current i_D of the secondary transistor at turn-on and turn-off

V. CONCLUSION

Operation principle of the novel full-bridge PWM DC/DC converter with secondary energy recovery snubber is presented in the paper. Soft switching all of the power switches and reduction of circulating currents are achieved for full load range in the proposed converter.

At proper design it is possible to utilize the magnetizing current of power transformer for charging or discharging output capacitances of the IGBT switches and thus zero-voltage turn-on of the IGBTs to achieve. The IGBT transistors are turned off almost under zero current. Only small magnetizing current of the power transformer is turned off by IGBT transistors, so the turn off losses are minimized.

One of the main tasks of the proposed secondary snubber is transfer of the leakage inductance energy to the load at turn-off of the secondary switch.

Moreover it ensures zero current turn-on and zero voltage turn-off of the secondary switch.

For optimal utilization of the snubber circuit it is necessary to use a power transformer whose leakage inductance is minimized (planar transformer or coaxial transformer). A laboratory model of this converter is being developed to verify the theoretical and simulation analysis.

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