ZVZCS PWM DC-DC CONVERTER WITH ENERGY RECOVERY CLAMP

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Summary A novel zero-voltage zero-current switching full-bridge PWM DC-DC converter with controlled secondary side rectifier is presented in this paper. Zero-voltage turn-on and zero-current turn-off for all power switches of the inverter is achieved for full load range from no-load to short circuit by using turn-off snubber and secondary energy recovery clamp. Modified PWM control strategy is used for the converter. The principle of operation is explained and analysed and simulation results are presented.

1. 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.
To decrease the circulating current to zero and thus to achieve zero-current switching, various snubbers, auxiliary circuits and/or clamps connected mostly at the secondary side of power transformer are applied [1] – [10].
The disconnection of the secondary windings is usually achieved by application of the reverse bias for the output rectifier or using controlled rectifier.
The optimal switching for IGBTs is zero-voltage turn-on and mainly zero-current turn-off due to elimination of the current tail influence, which has considerable high involvement in creation of the IGBT turn-off losses.

2. POWER CIRCUITS OF THE PROPOSED CONVERTER

To achieve the aims mentioned above, the topology of the following ZVZCS converter was designed.
The DC-DC converter shown in Fig.1 consists of high-frequency inverter, power transformer, output rectifier, output secondary switch and output filter.
The main part of the converter includes high frequency full-bridge inverter consisting of the four ultrafast IGBT´s T_1-T_4 and freewheeling diodes D_1-D_4. The secondary winding of the high-frequency step-down power transformer TR is connected through a fast recovery rectifier D_5, D_6 and secondary switch T_5 to output filter consisting of smoothing choke L_0 and capacitor C_0.
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.

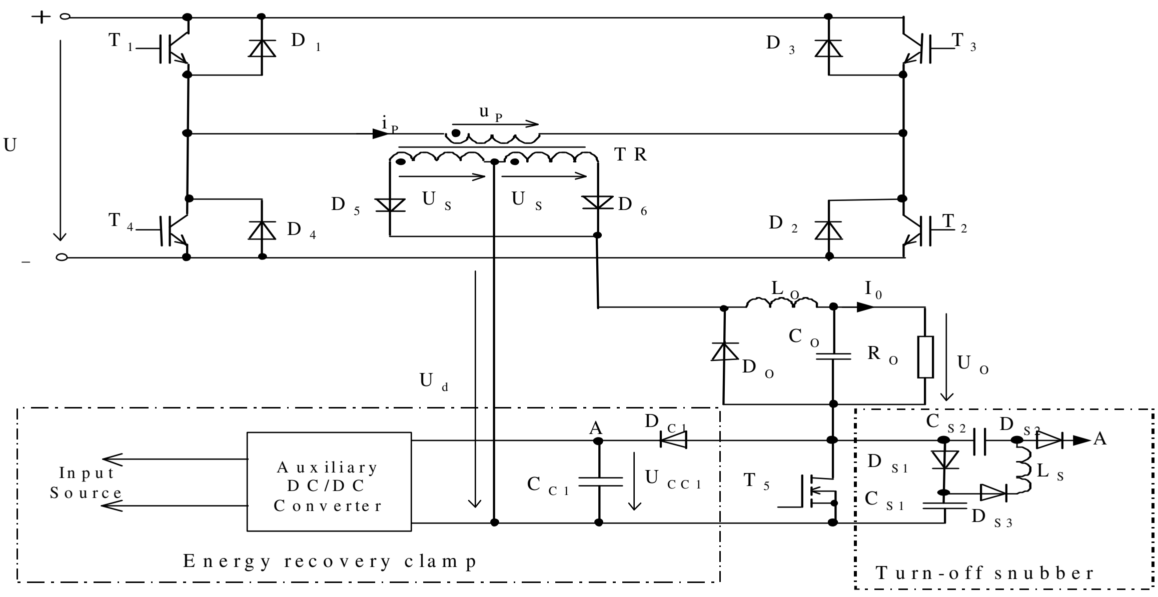

Fig.1. Scheme of the proposed ZVZCS PWM DC-DC converter

The semiconductor switch T_5 in the secondary side is used to reset secondary and consequently also primary current. The transistor T_5 operates with double switching frequency. At turn-off of the switch T_5 the energy stored in leakage inductance is clamped by D_{C1} and C_{C1} and then transferred trough auxiliary dc-dc converter to the input source. By using non-dissipative snubber to reduce turn-off losses of the transistor T_5, the overall efficiency is increased.

3. OPERATION PRINCIPLE

The basic operation of the proposed soft switching converter has eight operating modes (intervals) within each half cycle. The switching diagram and operation waveforms are shown in Fig. 2.

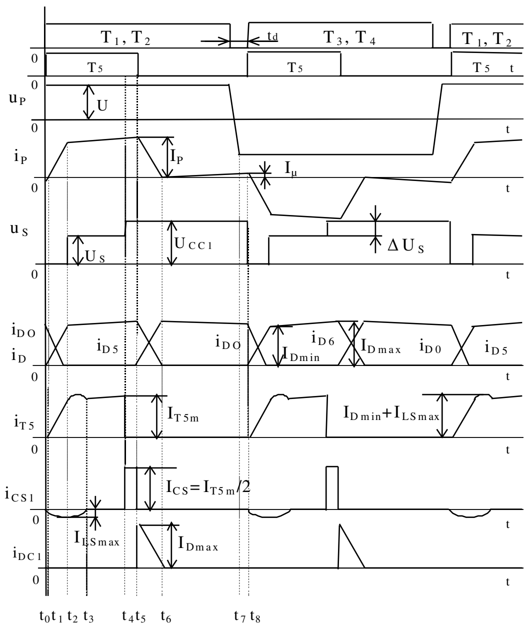

Fig. 2 Operation waveforms of the converter

4. SIMULATION RESULTS

A simulation model in programme Orcad was created to verify the properties of the proposed converter. The simulations were made at input voltage U = 320V.

Parameters:

Transformer TR parameters:

Turns ratio n = 6,

Magnetizing inductance L_m = 800 μH,

Leakage inductance L_{LP} = 7 μH.

Snubber circuit parameters:

Snubber capacitors $C_{S1} = C_{S2}$= 56 nF,

Snubber inductance L_S = 5 μH.

Set value of clamp voltage U_{CC1} = 80 V

The following waveforms were obtained at resistive load.

Fig.3 shows switch voltage u_{CE4} and switch current $i_{C4}+i_{D4}$ during turn-on and turn-off of the transistor T_4 in the converter. The switch (transistor T_4 including diode D_4) is turned-on under zero-voltage because at turn-on of the transistor T_4 its freewheeling diode D_4 is in on state. Moreover the rate of rise of the collector current is limited by the leakage inductance L_{LP} of the transformer.

The transistor turn-off losses are negligible because transistor T_4 turns-off only small magnetizing current (about 1.5 Amp in this case) as can be seen in the Fig.3.

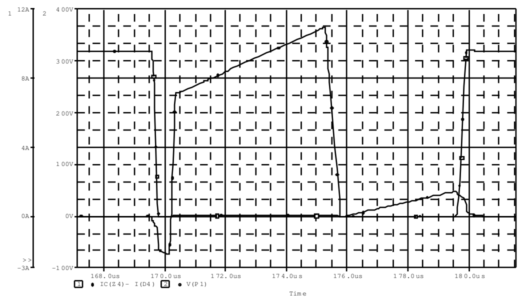

Fig. 3. Switch (transistor T_4 + diode D_4) voltage u_{CE4} and switch current $i_{C4}+i_{D4}$.

Collector-emitter voltage u_{DS} and collector current i_D of the secondary transistor T_5 (bottom waveforms) is shown in Fig. 4. The secondary switch (transistor T_5) is turned-on under zero-current due to influence of the leakage inductance of the transformer L_{LS} reflected to the secondary side and snubber inductance L_S.

The turn-off loss is reduced by snubber capacitors C_{S1} and C_{S1} acting as the non-dissipative snubber as it is evident in Fig. 4.

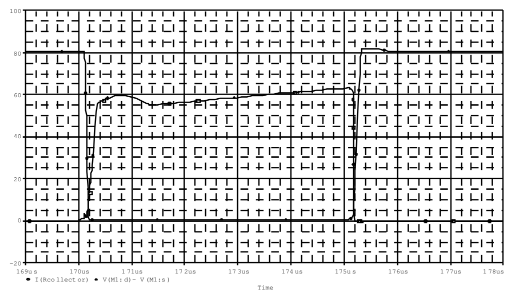

Fig. 4. Collector-emitter voltage u_{DS} and collector current i_D of the secondary transistor T_5

Rectified voltage u_d and output diode current i_{D5} is shown in Fig. 5.

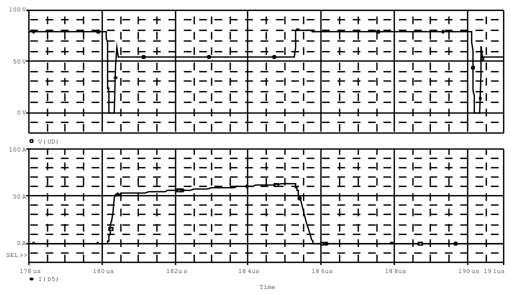

Fig. 5. Rectified voltage u_d (upper waveform) Output diode current i_{D5} (bottom waveform)

During commutation between secondary diode and output freewheeling diode the secondary voltage and accordingly rectified secondary voltage is zero.
At turn-off of the secondary switch T_5 the secondary and also rectified voltage rises as a result of energy stored in leakage inductance. The over-voltage ΔU_S can be maintained on acceptable value by proper design of the auxiliary dc-dc converter.
Fig. 6 shows the snubber capacitor current at turn-on and turn-off of the secondary switch T_5 (bottom waveform).

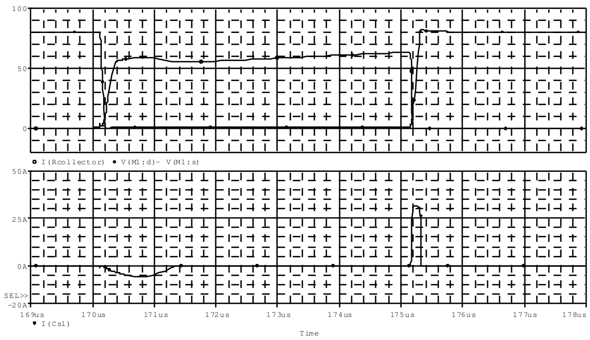

Fig. 6. Collector voltage u_{DS} and collector current i_D of the secondary transistor T_5 (upper waveforms) Snubber capacitor current i_{CS1} (bottom waveform)

5. CONCLUSION

Soft switching and reduction of circulating currents in the proposed converter are achieved for full load range using the secondary side turn-off and energy recovery clamp in combination with modified PWM control.
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 negligible magnetizing current of the power transformer is turned-off by IGBT transistors.
The main task of the proposed secondary energy recovery clamp is the transfer the leakage inductance energy to the input source at turn-off of the secondary switch.
Turn-off snubber is employed to improve turn-off process of the secondary switch. Using leakage inductance of the power transformer working as a turn-on snubber it is ensured zero current turn-on process of the secondary switch.
Finally, it is possible to say, that IGBTs in the full bridge inverter operate at almost ideal switching conditions – ZV turn-on and ZC turn-off.
Soft switching of the secondary switch and leakage inductance energy transfer to the input source is ensured by turn-off snubber and energy recovery clamp containing only non-dissipative components.

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