# Soft switching DC/DC converter using auxiliary circuits

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***Abstract*** ***– A novel auxiliary circuit for full-bridge PWM DC/DC converter with controlled secondary side rectifier is presented in this paper. Zero-current turn-on for all power switches of the inverter is achieved for full load range from no-load to short circuit by using controlled rectifier and auxiliary circuit on the secondary side. Modified phase shift PWM control strategy is used for the converter. The principle of operation is explained and analyzed and the simulation results are presented.***

***Keywords:*** ***auxiliary circuit, soft switching, zero voltage zero current switching,***

## I. INTRODUCTION

Phase shifted PWM converters are ofen used in many applications because their topology permits all switching devices to operate under zero-voltage switching by using circuits parasitics like leakage inductance of power transformer and junction capacitances of the power switches.

Circulating current is probably the bigest disadvantage of the phase-shifted PWM converter. This circulating current flows trought the power transformer and switching devices during the freewheeling interval and causes increased conduction losses.

The circulating current can be eliminated by disconnection of the secondary windings, which can be realised by using reverse bias application for the output rectifier or using controlled rectifier.

## II. POWER SCHEME OF THE CONVERTER

The soft switching DC/DC converter using auxiliary circuit is shown in Fig.1. It consists of high-frequency inverter, power transformer, controlled output rectifier and output filter. Secondary switches consist of series connection of diodes and MOSFET transistors to secure reverse capability of the switches. Circuit I. and Circuit II. represent the novel auxiliary circuits that reduce the turn off losses of the secondary transistors, by taking over the current of the transistor at turn off process of the secondary switch. Consequently, the zero voltage turn off of the secondary switches can be achieved.

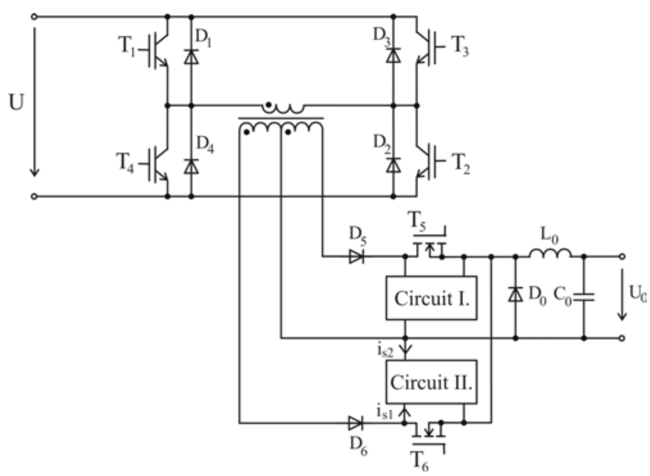


Fig.1 Power scheme of the proposed soft switching DC/DC converter.

## III. OPERATION PRINCIPLE

The converter control diagram and operation waveforms are shown in Fig. 2.

The inverter operates the same way in a range from no load to short circuit. The output power is regulated by secondary controlled rectifier. The rectifier transistors are turned on earlier then inverter transistors ($t_6$). In Fig. 2 there are secondary transistors turned on in a half period earlier then primary transistors. It means that when the primary IGBT transistors turns on the secondary side transistor is already turned on, and the primary so as the secondary current can flow. The rising slope of the primary and secondary currents is slowed down by leakage inductance of the high frequency power transformer, so the inverter transistors turn on at zero current. To achieve negligible turn of losses of the inverter transistors, the secondary transistors are turned of earlier than primary transistors ($t_2$, $t_7$) and consequently the primary current falls to value of magnetizing current which is consecutively turned of by the primary transistors ($t_5$).

Auxiliary circuits shown in Fig. 1 ensure that the secondary switches turn off at soft switching condition (at zero voltage). The auxiliary circuits take over the drain current of the secondary transistors at turn off process ($t_2$), so that the current of the secondary transistors can fall to zero quickly. The energy stored in the auxiliary circuit is at next turn on ($t_6$) of the same transistor forced to the load.

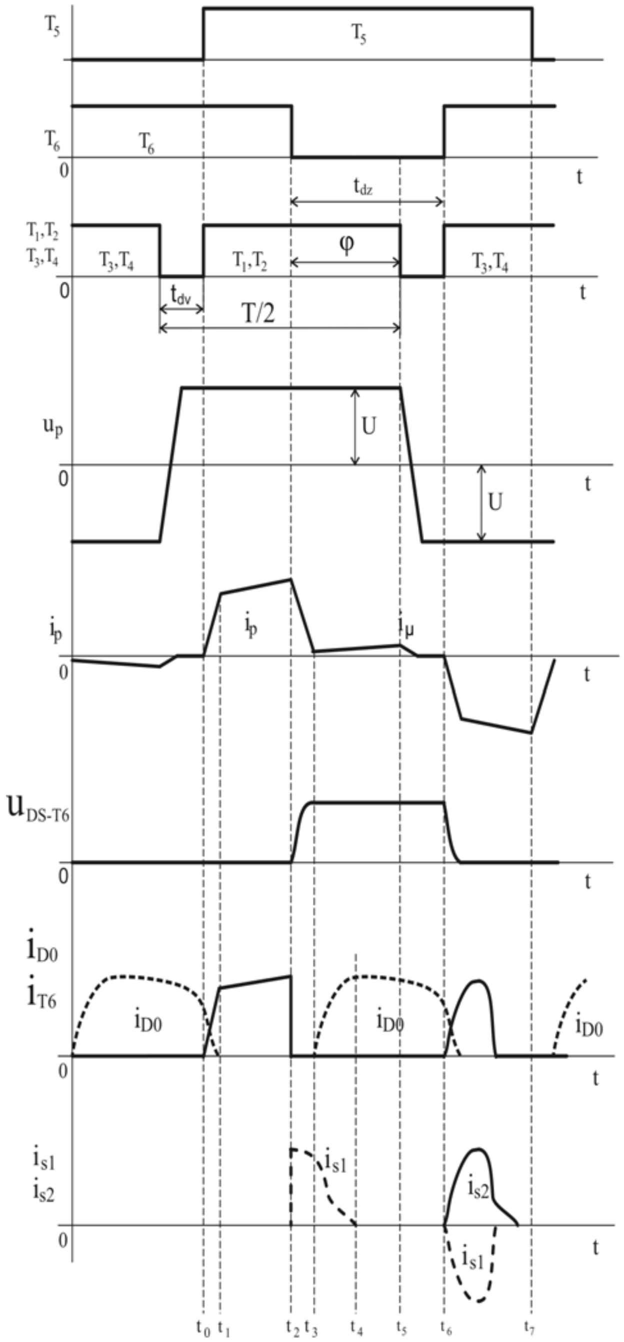


Fig.2 Operation waveforms of the converter

**Interval $t_0$-$t_1$:** Primary IGBT transistor is turned on in the time in that the secondary MOSFET transistor is already turned on. Current of the power transformer primary winding begins to rise. The slope of the primary current rise is slowed down by leakage inductance of the power transformer. The secondary current is commutating from freewheeling diode $D_O$ to transistor $T_6$.

**Interval $t_1$-$t_2$:** Primary current as well as the secondary current is rising with a slope that is given by the output inductance $L_O$.

**Interval $t_2$-$t_3$:** Secondary transistor $T_6$ is turned off. Drain-source voltage of the transistor $T_6$ rises and drain current is simultaneously commutating to the auxiliary circuit. The commutation time depends only on the parasitic inductance of the wires. By using the auxiliary circuit it is achieved that the secondary MOSFET transistor $T_6$ turns off under soft switching conditions (zero voltage).

**Interval $t_3$-$t_4$:** In this interval flows trough primary winding only magnetizing current. The commutation between auxiliary circuit and the freewheeling diode occurs.

**Interval $t_4$-$t_5$:** Only magnetizing current flows trough the primary winding of the power transformer. The output current sinks with slope that is given by inductance of the output filter.

**Interval $t_5$-$t_6$:** At $t_5$ the primary transistors are turned off. Turnoff losses are negligible caused by low magnetizing current that flows trough the transistors at the turn off moment. The magnetizing current falls to zero and stays zero to the time $t_6$. Output current is still flowing trough the freewheeling diode $D_O$.

**Interval $t_6$-$t_7$:** At $t_6$ the secondary transistor $T_6$ is turned on. The leakage inductance energy that was stored in the auxiliary circuit at transistor $T_6$ turn off ($t_2$) is now transferred to the load. The slope of the current rise is given by the inductance of the auxiliary circuit. The same inductance together with the capacitance of the circuit gives the commutation behavior as well as the time of the commutation.

## IV. SIMULATION RESULTS

A PSpice model of the converter was created to verify the properties of the proposed auxiliary circuit. Following waveforms were obtained at resistive load.

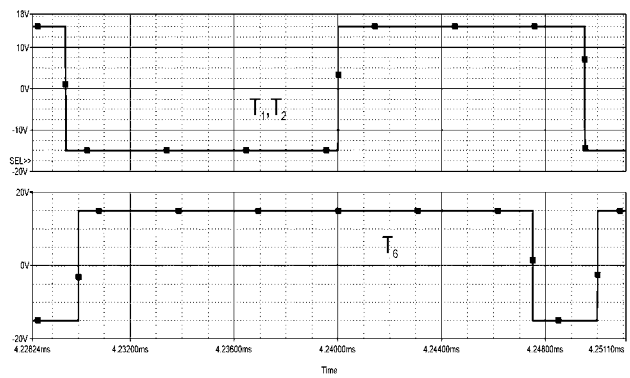


Fig.3 Control pulses of the transistors

Control pulses for the primary and secondary transistors are presented in Fig. 3. Secondary transistor ($T_6$) is earlier turn on and off then the primary one ($T_1$, $T_2$).

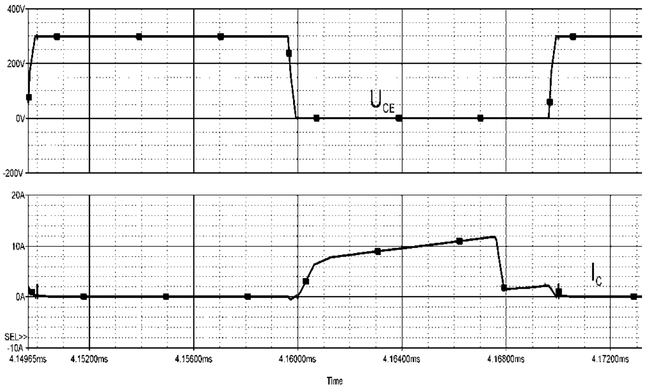


Fig.4 Primary transistor waveforms

In Fig. 4 the primary transistor waveforms (transistor voltage $u_{CE}$ and current $i_C$) are shown. The collector current rate of rise is slowed down by the leakage inductance of the power transformer. Primary current falls down when the secondary transistors are tuned off. IGBT transistor turns off at the instant when only the magnetizing current flows trough primary winding of power transformer. So the primary transistor turn off losses are negligible.

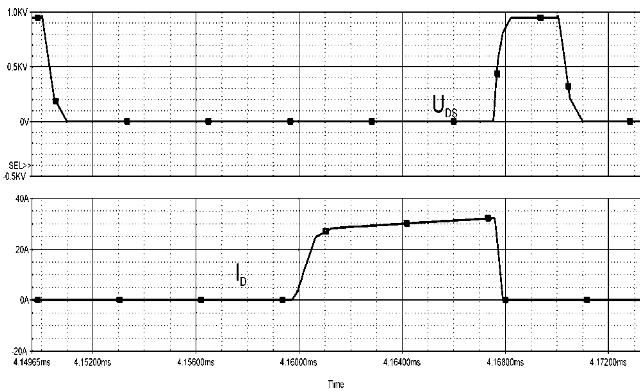


Fig.5 Secondary transistor waveforms

Fig. 5 shows drain-source voltage $u_{DS}$ and drain current $i_D$ of the secondary MOSFET transistor. Without an auxiliary circuit the MOSFET transistor turns off with high turn off losses. The drain-source voltage $u_{DS}$ rises to an excessive value that is given by the leakage inductance energy of the power transformer. This high voltage can be destructive for the MOSFET transistor.

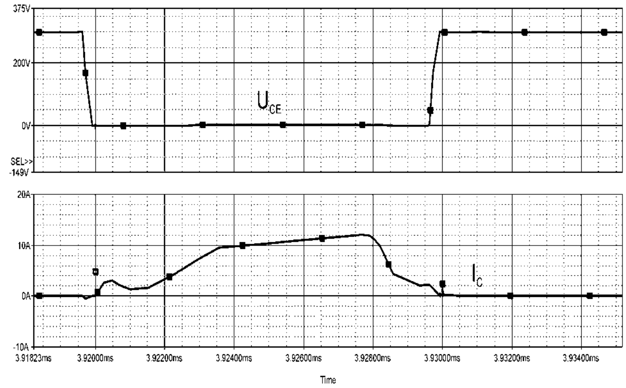


Fig.6 Primary transistor waveforms

The primary transistor waveforms are illustrated in Fig.6. These waveforms were obtained from simulation of the converter with the auxiliary circuits that are shown in power scheme (Fig.1). Transistor voltage $u_{CE}$ and current $i_C$ is similar like the waveforms in Fig. 4. The soft switching of the primary transistors were achieved only with help of the new proposed control mode of the power transistors.

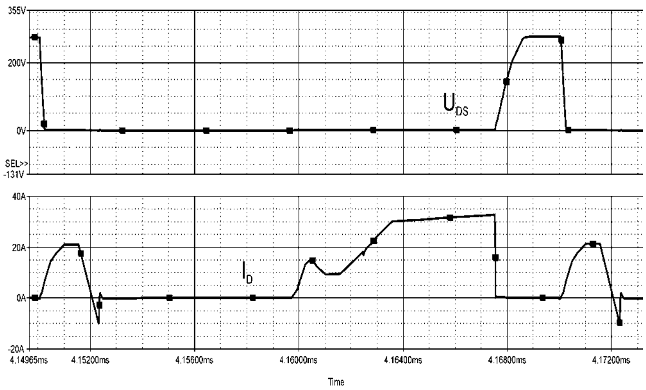


Fig.7 Secondary transistor waveforms

Secondary transistor waveforms (Drain-source voltage $u_{DS}$ and drain current $i_D$) are shown in Fig. 7. Zero current turn on and zero voltage turn off is achieved by using auxiliary circuit. When the secondary transistor turns off, the drain current is taken over by the auxiliary circuit and therefore the transistors can be turned off under soft switching conditions. The leakage inductance energy accumulated at turn off interval is forced to flow to the load at the turn on interval of the secondary transistor. As it was mentioned above the quantity of this energy depends on the value of the leakage inductance of the power transformer and value of the transformer current. The leakage inductance energy is stored in the auxiliary circuit, so that the drain-source voltage would not achieve so high value like in case without auxiliary circuit.

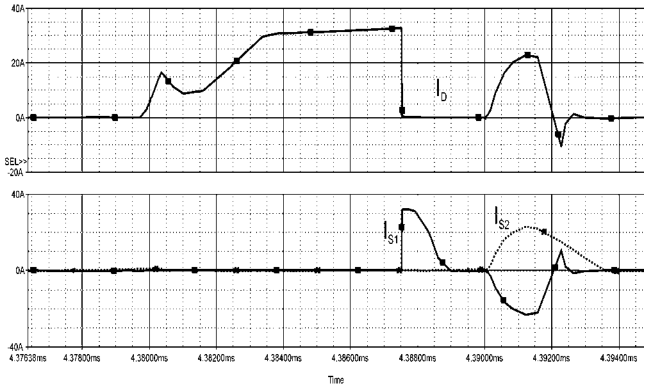


Fig.8 Auxiliary circut and secondary transistor current

Auxiliary circuit currents and the secondary transistor current waveforms are presented in Fig. 8. The commutation from secondary transistor to auxiliary circuit is visible, ass well as the energy that is forced to the load.

## V. CONCLUSION

Operation principle of the DC/DC converter with auxiliary circuit that ensures soft switching of all main converter transistors is presented in the paper. For optimal utilization of the auxiliary circuit it is necessary to use a power transformer whose leakage inductance is minimized (planar transformer or coaxial transformer).

ACKNOWLEDGMENT

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