PHASE SHIFT CONTROL AND SWITCHING LOSS INVESTIGATION OF RESONANT DC-DC CONVERTER

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This paper presents the phase-shifted pulse modulation (PSPM) of DC-DC resonant converter. The converter employs an IGBT full bridge inverter, resonant tank, high frequency transformer, and output rectifier. The implementation of the PSPM control and switching conditions of the power switches are discussed and verified by Saber simulator. The switching losses of the IGBT's switches are analyzed and calculated analytically and by Saber simulation. The switching losses are measured and verified by an experimental prototype of 10kW.

Keywords: DC-DC converters, resonant tank, distribution systems

1. INTRODUCTION

Nowadays, the use of power electronic converters in power distribution system becomes applicable thanks to the advanced techniques applied to the design and development of DC/DC, DC/AC and AC/DC converters. Many of these power electronic converter systems are associated with multi-level converter structure for energy conversion at high voltage levels (kV and MV).

These new circuits allow economical replacement of conventional power distribution transformer with high frequency (HF) DC-DC converter and HF transformer. This converter structure, also called 'DC-DC electronic transformer' [4] is used as the central component of the AC/AC converter system. As well known, increasing the switching frequency leads to reduce the size and weight of the transformers which helps the whole system to be easily transported with low expenses, important for fast replacement. The disadvantage of increasing switching frequency is high switching losses. Many authors present resonant supply topology in order to achieve low losses through "soft-switching" commutation[1], [2], [3].

Figure 1 gives an overview of the proposed system structure of one cell from multilevel systems. The described system employs an input rectifier, IGBTs full bridge, LCL resonant tank, low profile high frequency transformer, and output rectifier.

Phase shifted pulse modulation (PSPM) is proposed for output voltage control.

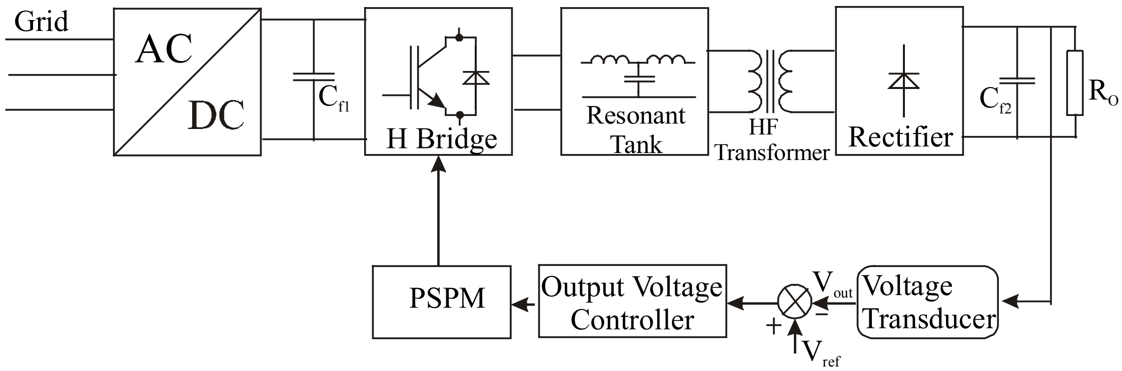

Fig.1. Block diagram of the proposed system.

2. Principle of Phase Shift Control

The DC-DC resonant LCL converter (LCL-RC) is derived by adding an inductor L_2 in series of the conventional parallel resonant converter, as shown in Fig.2 [4]. It consists of a feeding bridge (S_1–S_4 and D_1–D_4), resonant LCL tank, insulation HF transformer and rectifying bridge (D_5–D_8).

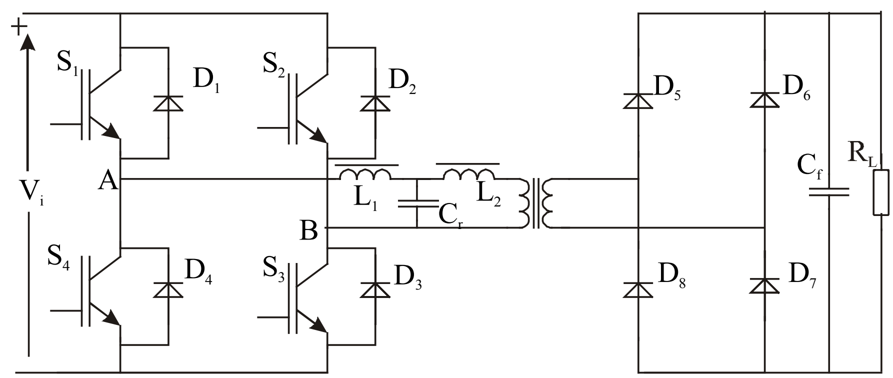

Fig.2. Considered DC-DC resonant converter.

The phase shift control of the DC-DC resonant converter proposed in this paper is aimed in minimization of switching losses in the converter switches.

Figure 3 illustrates the operation circuits (conducting and non-conducting branches) of the considered converter for the time intervals $t_1 \div t_7$. The rectifier of the DC-DC converter in Fig.2 is presented as an effective resistive load R_e in Fig. 3. It is assumed that all circuit components and power devices are ideal.

In Figure 2 the simulation results (Saber) explaining the PSPM control.

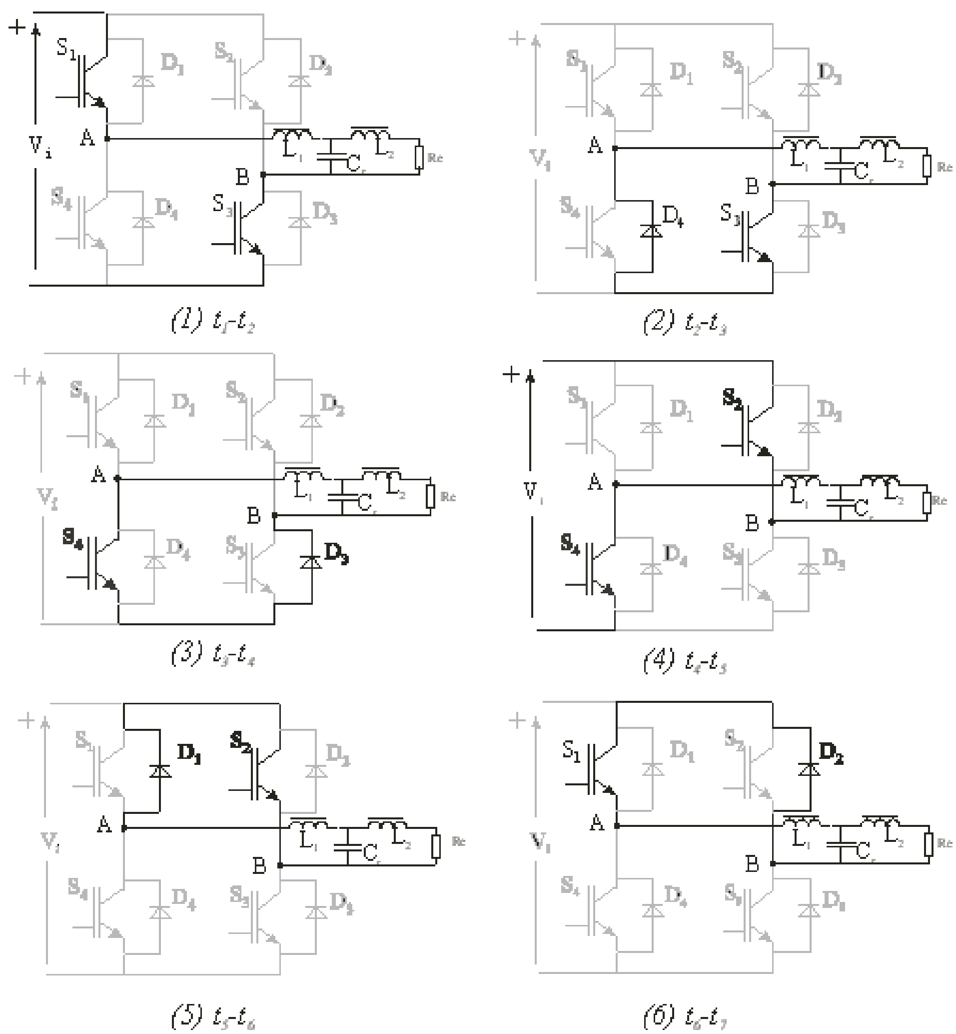

Fig.3 Equivalent circuits for time intervals $t_1 \div t_7$

Switching operation modes and time intervals are:

1) time interval t_1 - t_2: During this time interval switches S_1 and S_2 are turned on and the power from the input voltage source V_i the is supplied to load R_e.

2) time interval $t_2 – t_3$: At the instant t_2 the switch S_1 is turned off and the anti-parallel diode D_4 starts to conduct.

3) time interval $t_3 – t_4$: At the instant t_3 the current i_{l1} changes its direction, S_3 is turned off under zero-voltage, zero-current switching condition (ZVZCS) and S_4 completes ZVZCS turn on.

4) time interval $t_4 – t_5$: During this time interval the switches S_2 and S_4 are turned on and the power is supplied to the load R_e from the voltage source V_i.

5) time interval $t_5 – t_6$: During the interval $t_5 – t_6$ the current flows trough S_2 и D_1.

6) time interval $t_6 – t_7$: At the instant t_6 the current i_{l1} changes again its direction, S_2 is turned off under ZVZCS and S_1 completes ZVZCS turn on.

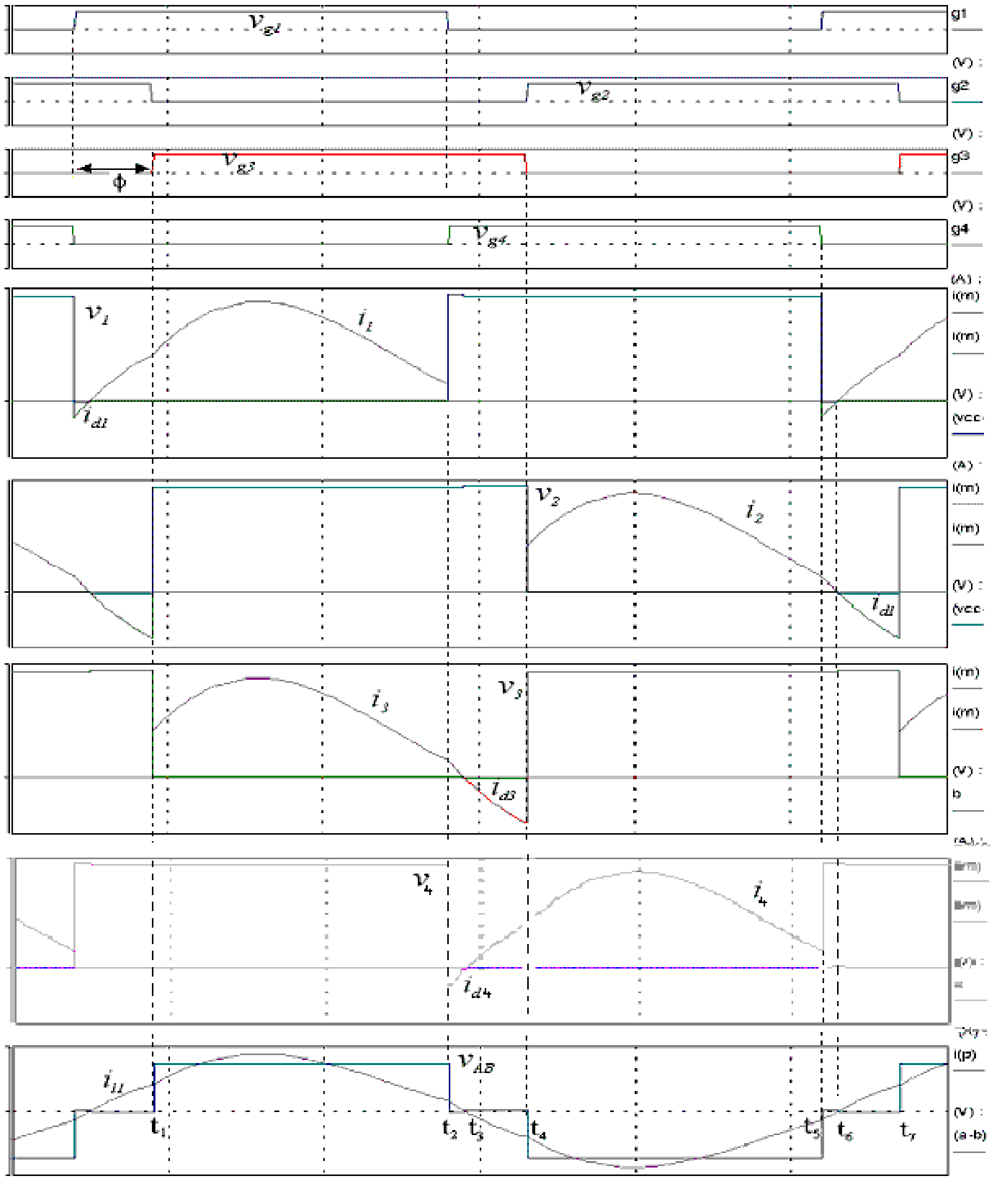

Fig.4 Simulation waveforms of the proposed PSM resonat DC-DC converter (SABER)
v_{g1}-v_{g4}- gate voltages ; v_1-v_4 voltages across S_1-S_4; i_1-i_4 currents trough S_1-S_4.,
i_{d1}-i_{d4} currents trough D_1-D_4.

3. Analyses of Total Losses in the Switches

The switching loss can be separated in the following groups [1]:

- power loss induced by the diode reverse-recovery mechanism,
- power loss during IGBT turn-off time, owing to current tail,
- power loss during IGBT turn-on transition,
- power loss induced in IGBT by semiconductor output capacitances.

The losses of the output capacitances and diode reverse-recovery are not significant therefore they can be neglect [1].

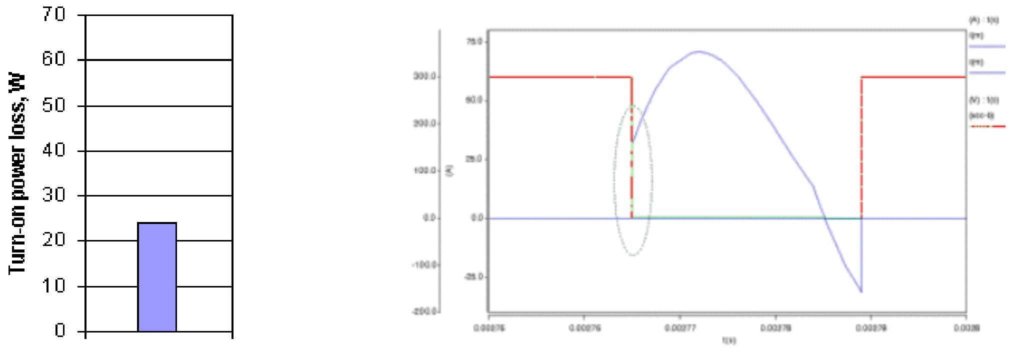

Fig.5 Switching losses of S2 and S3 (soft turn-off, hard turn-on)

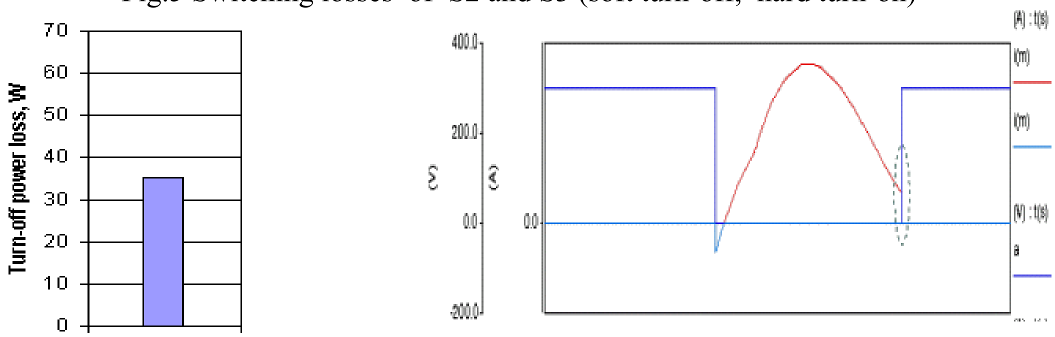

Fig.6 Switching losses of S1 and S4 (soft turn-on, hard turn-off)

The switches S2 and S3 commutate at "hard" turn-off, and S1 and S4 commutate at "hard" turn-on. However, we present the approach for calculation of the switching losses in the PSPM controlled converter:

$$E_{S1,S4} = E_{CON,LOS} + E_{SW,TURN-ON} \tag{1}$$

$$E_{S2,S3} = E_{CON,LOS} + E_{SW,TURN-OFF} \tag{2}$$

$$P_{CON,LOS} = f\, E_{CON,LOS}\ ; \qquad P_{SW} = f\, E_{SW,LOS} \tag{3}$$

Here $E_{S1,S4}$ and $E_{S2,S3}$ are the energy losses for one commutation period (the turn off losses of S1,S4 and losses of S2,S3 are neglected because the soft switching commutation). $E_{CON,LOS}$ is calculated using the manufacture data of the used switch.

In Fig.5 and Fig.6 the switching losses of S1 - S4 are shown. The switching loss at hard turn-off is 24W and the switching loss at turn-off is 35W (at phase-shift ϕ=30^o). As a result from (1), (2) ,(3) the total losses per switch (S1,S4) and (S2,S3) for applying the proposed PSPM control are 104W and 93W respectively .

For comparison, in hard switching operation the total losses are 184 W for each IGBT switch.

4. EXPERIMENTAL RESULTS

A prototype of the proposed unidirectional LCL-RC converter was built and tested. Switching losses were measured using oscilloscope waveforms observed by a digital scope. The prototype has the following specifications: input voltage U_{in}=300V; output voltage U_{out}=300V; output power P_{out}=10kW; operating frequency f_o=20kHz.

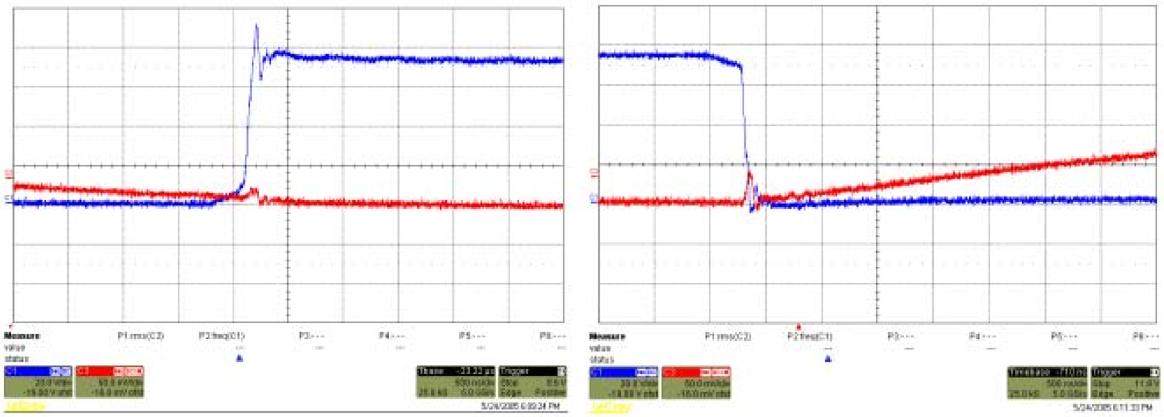

Fig.7 Soft switching, voltage and current. a) turn off, b) turn on.

The considered converter was realized with two types power switches 100A, 1200V IGBTs – Mitsubishi CM100TU-24H and Semikron SKM 100GB123D.

5. CONCLUSION

In this paper a phase shift control of the DC-DC resonant converter is proposed aimed in minimization of switching losses in the converter IGBT switches. An analytical approach for calculation of switching and conduction losses in this DC-DC resonant converter has been presented. This approach allows prediction of the total losses in the DC-DC resonant converter with PSPM control.

A good matching between the analytical and experimental results was obtained.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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