A New High Frequency Linked Soft-Switching PWM DC-DC Converter with High and Low Side DC Rail Active Edge Resonant Snubbers for High Performance Arc Welder

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Abstract –This paper presents two new circuit topologies of DC bus lineside active edge resonant snubber assisted soft-switching PWM full-bridge DC-DC converter acceptable for either utility AC 200V-rms or AC 400V-rms input voltage source. All the active power switches in the full-bridge arms and DC busline can achieve ZCS turn-on and ZVS turn-off commutations and the total turn-off switchingpower losses of all active switches can be reduced for high-frequency switching action. The effectiveness of these new DC-DC converters topologies is proved for low voltage and large current high efficiency DC-DC power supplies as TIG arc welding machine from a practical point of view.

I. INTRODUCTION

This paper presents two novel circuit topologies of voltage source full-bridge soft-switching PWM inverters suitable for either utility AC 200V-rms or AC 400V-rms input line, which are composed of full-bridge inverter and additional DC busline PWM series switches with the aid of a DC busline parallel lossless capacitive snubber. Under the newly proposed soft-switching PWM full-bridge DC-DC converters with high frequency transformer, all the active switches in the full-bridge arms and DC busline can actively achieve ZVS/ZVT turn-off commutation operation. These circuit topologies are adopted for low voltage and large current applications as electro-plating, automotive DC feeding and arc welding power supplies. Therefore, for the low voltage and large current applications, a soft-switching DC-DC converters with active main and auxiliary switches in the primary side of the high frequency transformer is considered to be more suitable and cost effective.

II. DC-DC Converter for Utility AC 200V-rms

A. Circuit Description:

Fig. 1 shows a novel high frequency transformer linked soft-switching PWM DC-DC converter acceptable for utility AC 200V-rms. This converter is composed of voltage source full-bridge inverter with active switches in series with DC busline and a single lossless snubbing capacitor in parallel with DC busline, a high frequency transformer with secondary side center-taped windings, DC reactor filter and DC load as arc welder and electroplater. In the newly-developed DC-DC converter, the active edge resonant PWM switches; reverse conducting IGBT $Q_5(S_5/D_5)$ and $Q_6(S_6/D_6)$ in series with DC busline and a lossless capacitor in paralleled with DC busline are added in series with the DC power busline connected to the voltage source full-bridge high frequency inverter composed of the bridge arm switches $Q_1(S_1/D_1)$, $Q_2(S_2/D_2)$, $Q_3(S_3/D_3)$ and $Q_4(S_4/D_4)$. In particular, it is noted that a single small lossless snubbing capacitor C in DC input busline is inserted between active switches Q_5, Q_6 and the full-bridge type inverter in order to achieve ZVS.

B. Gate Pulse Timing Sequences

Fig. 2 depicts pattern-timing sequences of the switching gate driving pulses to be provided to the semiconductor switching devices; IGBTs;Q_1-Q_4, Q_5, Q_6. The gate voltage pulse signals with a certain dead time, which are delivered to Q_1 and Q_4 or Q_2 and Q_3 in the diagonal bridge arms of the voltage source full-bridge inverter arms, are the same as signal sequences of conventional full-bridge inverter.

C. Operation Principle of Converter Topology

Fig. 3 illustrates the relevant voltage operating waveforms the DC-DC converter circuit for utility

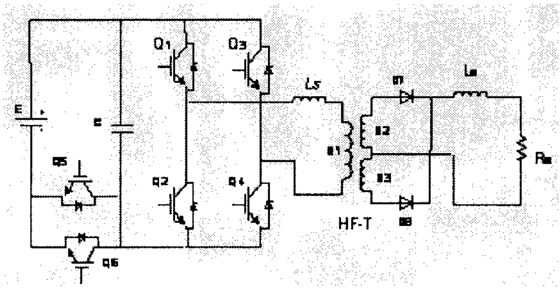

Fig. 1 Soft-switching PWM DC-DC power converter with high frequency transformer link for utility AC 200V-rms input

AC 200V-rms input in a complete switching period specified bythe pulse pattern of gate drive timing sequences shown in Fig. 2. The operation modes of the converter circuit for the utility AC 200V-rms input are divided into seven operation modes from mode 0 to mode 6 are shown in Fig.4.

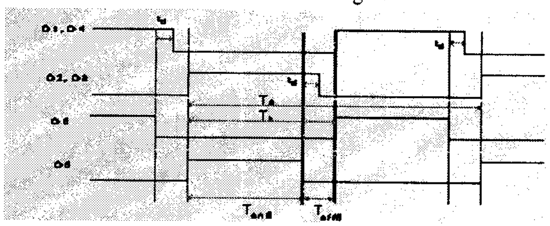

Fig. 2 Pattern sequences of switching gate driving pulses

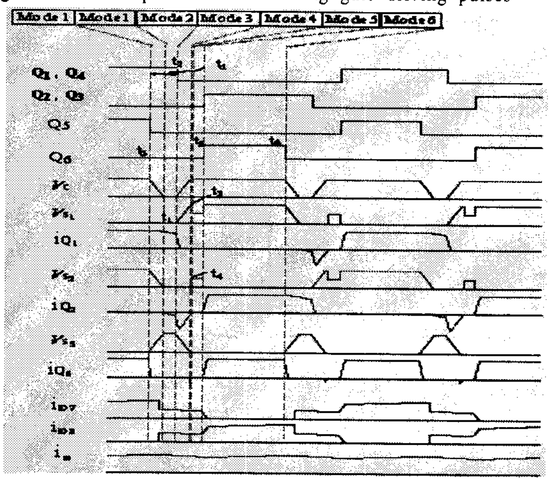

Fig. 3 Operating waveforms for AC 200V-rms input during one switching period

III. New Soft Switching PWM DC-DC Converter for Utility AC 400V-rms Grid

Fig. 5 shows a planner type high frequency transformer linked soft-switching PWM DC-DC converter topology acceptable for utility AC 400V-rms input. Under the DC-DC converter used for utility AC 400V input, the DC busline voltage source is selectively operated by divided voltage sources E_1 and E_2. The voltages E_1 and E_2 ($E_1 = E_2$) are designed so as to be equal to E. The switch Q_5 in Fig. 1 is moved to the high side of DC busline in Fig. 5. The diodes D_9 and D_{10}in series are also inserted in parallel with the DC busline between Q_5 or Q_6 and full-bridge inverter arms. And the center point between E_1 and E_2 is directly connected to the mid point between the diodes D_9 and D_{10}.The timing pattern sequences of switching gate driving pulses for the utility AC 400V-rms input grid are exactly the same as that for the utility AC200V-rms input shown in Fig. 2.The operating waveforms of the converter circuit topology II for the AC 400V-rms input grid are almost the same as that of the converter circuit topology I for the AC 200V-rms input grid. The main differencebetween circuit operation with AC 200V and circuit operation with AC 400V is that the voltage v_C across the capacitor C is not clamped to DC busline voltage in case of the circuit for AC 400V-rms input.

IV. Experimental Results and Discussions

A. System Implementations for 200V and 400V Utility AC grids

The experimental setups for the soft-switching PWM DC-DC power converter circuits I and II with high frequency transformers applied for either the utility AC 400V-rms dual inputs are implemented in Fig. 6, represents the assembled component appearance in the transformer primary side of the main power converter circuit used in the experimental setup.

B. Measured Switching Voltage and Current Waveforms

The switching operating voltage and current waveforms under maximum output power (36V, 350A) for utility AC 400V-rms input when the switch Q_1 is turned on and turned off are depicted in Fig. 8 (a) and (b), respectively, the switch Q_1 is turned on with ZCS and turned off with ZVS. The switch Q_5 is turned on and turned off., the switch Q_5 is completely turned on with ZVS/ZCS and is turned off with ZVS. However, at the turn-off mode transition processing for switches falling current and Q_1

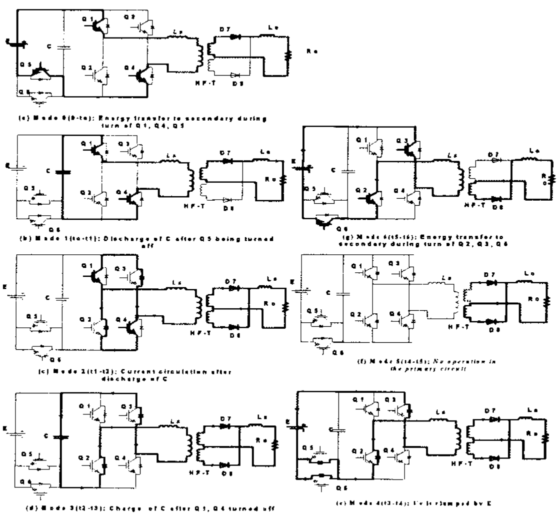

Fig. 4 Equivalent circuits for seven switching operation modes

and Q_5, some power losses still exists due to inherent tail current of the used IGBTs.

C. Power Loss Analysis

Considering power loss analysis in Fig. 9, the total power losses of all the active switches in the full-bridge arms including Q_5 and Q_6 in DC busline for the newly-developed soft-switching PWM DC-DC power converter circuits I, II for utility AC 200V-rms and AC 400V-rms input shown in Fig. 6 are compared with those of all the switches in conventional hard-switching PWM inverter type

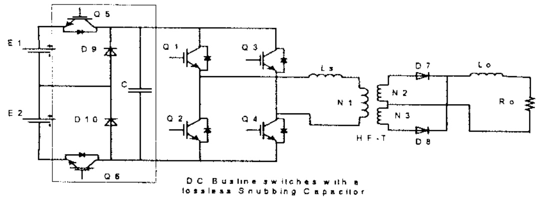

Fig. 5 Soft-switching PWM DC-DC power converter with a high frequency transformer link for utility AC 400V-rms input

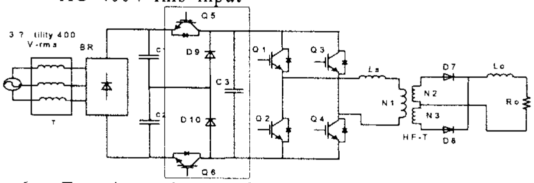

Fig. 6 Experimental setup for utility AC 400V-rms input grid

DC-DC converters with a high frequency DC link. When the switching frequency is about 20 kHz, the total power losses for soft-switching PWM DC-DC inverter type power converter and hard-switching PWM inverter type DC-DC converter are almost equal. The more the switching frequency of full-bridge high frequency inverter increases, the more two newly-developed DC-DC power converter circuits I, II can have remarkable advantages.

Fig. 7 Assembled component appearance in transformer primary side circuit of soft-switching PWM DC-DC power converter

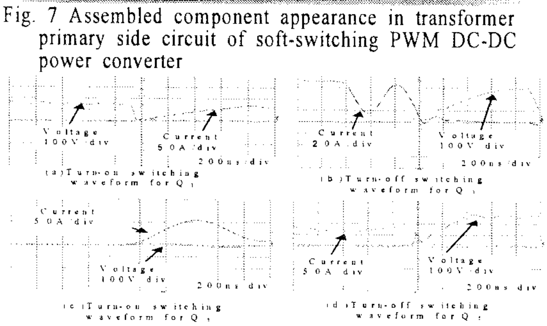

Fig. 8 Measured switching voltage and current waveforms for the switches Q_1, Q_5 under the circuit for utility AC 400V-rms input

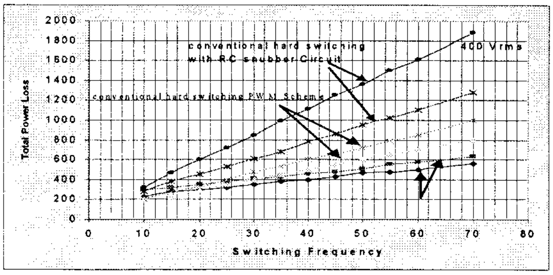

Fig. 9 Comparative power loss analysis between newly -developed soft-switching PWM and conventional hard-switching PWM DC-DC power converters

V. CONCLUSIONS

In this paper, two new circuit topologies of soft-switching PWM DC-DC power converters I, II with planner type high frequency transformer suitable and acceptable for the utility AC 200V-rms or 400V-rms selective dual voltage input specifications have been presented, The power loss analysis of soft-switching PWM DC-DC power converters with a high frequency transformer link have been discussed and evaluated as compared with that of hard-switching PWM DC-DC power converter with a high frequency transformer link. The practical effectiveness of the proposed two DC-DC power converter topologies operating under a principle of soft-switching PWM scheme have been actually proved from a practical point of view for the utility AC 200V and the AC 400V and the high efficiency and high power density of two types of DC-DC power converters could be achieved on the basis of the experimental results for the latest CO2/MAG arc welder put into practice.

Acknowledgment

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