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DC Rail Side Series Switch and Parallel Capacitor Snubber-Assisted Edge Resonant Soft-Switching PWM DC-DC Converter with High-Frequency Transformer Link

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ABSTRACT

This paper presents a novel circuit topology of a DC busline series switch and parallel snubbing capacitor-assisted soft-switching PWM full-bridge inverter type DC-DC power converter with a high frequency planar transformer link, which is newly developed for high performance arc welding machines in industry. The proposed DC-DC power converter circuit is based upon a voltage source-fed H type full-bridge soft-switching PWM inverter with a high frequency transformer. This DC-DC power converter has a single power semiconductor switching device in series with an input DC low side rail and lossless snubbing capacitor in parallel with the inverter bridge legs. All the active power switches in the full-bridge arms and DC busline can achieve ZCS turn-on and ZVS turn-off transition commutation. Consequently, the total switching power losses occurred at turn-off switching transition of these power semiconductor devices; IGBTs can be reduced even in higher switching frequency bands ranging from 20 kHz to 100 kHz. The switching frequency of this DC-DC power converter using IGBT power modules can be realized at 60 kHz. It is proved experimentally by power loss analysis that the more the switching frequency increases, the more the proposed DC-DC power converter can achieve a higher control response performance and size miniaturization. The practical and inherent effectiveness of the new DC-DC converter topology proposed here is actually confirmed for low voltage and large current DC-DC power supplies (32V, 300A) for TIG arc welding applications in industry.

Keywords: DC-DC power converter, high frequency transformer link, input DC side active edge resonant snubber, soft switching PWM, low voltage and large current DC power supply, arc welding machines

1. Introduction

1.1 Research Background

The high performance isolated switching DC-DC power conditioning processing converter type semiconductor switching mode power supplies ranging from a few kW to about 30 kW or more have been required for TIG and MIG arc welding applications in industry. Many downsized arc welding applications, high frequency switching mode DC power supplies using the latest power MOSFETs and IGBTs with the aid of high frequency transformer parasitic resonant circuit topologies

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have been developed and used for low voltage and large current DC output applications.

However, most high frequency resonant DC-DC power converter topologies based on series resonant, parallel resonant, series/parallel resonant tank circuits have not always been adopted for arc welding power supplies rating more than 10kW. It is difficult to condition the DC output voltage under conditions of constant frequency switching with high power conversion efficiency, except in a variety of resonant tank high frequency inverters for induction heating and melting uses. Therefore, voltage source-fed hard-switching high frequency switching mode PWM DC-DC power converters with high frequency transformer links have been widely used for switching DC power supplies designed for low voltage and large current output applications as TIG/MIG arc welding machines in industry. These voltage source-fed hard-switching PWM inverter type DC-DC power converters operate in switching frequency bands ranging from 10 kHz to 20 kHz.

In comparison, saturable reactor switch assisted zero voltage switching (ZVS) PWM voltage source full-bridge high-frequency inverter linked DC-DC converters[1], lossless capacitors and transformer parasitic inductive component assisted soft-switching high frequency inverter type DC-DC converters with a phase-shifted modulation control scheme in secondary side active switches of high frequency transformers [2][3] have also been developed and evaluated from a practical point of view.

The soft switching DC-DC power converter circuit topologies mentioned above are more suitable and acceptable for medium/high voltage and low/medium current output applications[4][5]. However, magnetic saturable switches or high frequency transformer secondary side active power semiconductor switches in these converter topologies cause relatively large conduction losses when they are selected for low voltage and large current usages. Therefore, to accommodate for low voltage and large current DC applications requiring high performance, high power density and high efficiency as industrial arc welding power supplies, a new isolated voltage source-fed edge resonant soft switching PWM DC-DC power converter circuit topology with active power switches allocated in the primary side of high frequency transformer was developed and evaluated from a practical point of view [6].

1.2 Research Objective

This paper presents a novel circuit topology for a voltage source-fed full-bridge type edge resonant soft-switching PWM DC-DC power converter with a specially-designed high frequency planar transformer. This converter is composed of a conventional voltage source-fed full-bridge hard switching PWM inverter type, a high frequency transformer as well as an additional power semiconductor switching device (IGBTs) in series with an input DC busline low side and only one lossless capacitive snubber in parallel with two inverter H bridge legs. Under the newly-proposed full bridge soft switching PWM DC-DC power converter circuit with active edge resonant snubber assisted by high frequency transformer parasitic components, all the active power switches in inverter bridge arms and the active power switch in series with the input DC busline low side can achieve a complete ZVS/ZVT and ZCS hybrid soft switching commutation.

The steady-state operating principle of the DC busline series low side switch and lossless edge-resonant capacitor snubber-assisted soft switching PWM DC-DC power converter with a thinner high frequency planer transformer link is described using a switch-mode equivalent circuit with notes on its remarkable operating features. Moreover, the experimental performances using the latest IGBT power modules under a designed switching frequency of 60 kHz are illustrated. Additionally, a power loss analysis is made with a comparison of the conventional high frequency transformer isolated link voltage source hard-switching PWM DC-DC power converter used commonly. It is confirmed that the proposed DC-DC converter is practically more effective for high performance arc welding power supplies in industry.

2. New Soft Switching DC-DC Converter

Fig. 1 shows the newly-proposed high performance TIG/MIG arc welding power supply using a novel type full-bridge soft-switching PWM IGBT inverter circuit with a high frequency planar transformer link. This converter is composed of an H-shaped voltage source single-phase full-bridge high frequency inverter, active edge resonant snubber, high frequency transformer, center-tapped FRD rectifier, reactor filter and arc welding load represented by an equivalent resistive circuit. A single active PWM switch Q5(S5/D5); reverse conducting IGBT type (RC-IGBT); is additionally inserted in series with the input side DC power busline connected to the source voltage E and to the inverter bridge legs and a single lossless snubbing capacitor C is additionally inserted in parallel with input side DC busline ports.

The main active power switches $Q_1(S_1/D_1)$ and $Q_4(S_4/D_4)$ in a diagonal bridge arm or $Q_2(S_2/D_2)$ and $Q_3(S_3/D_3)$ in an another diagonal bridge arm of the H configuration voltage source type high frequency inverter stage can be turned on and off in accordance with a specifically modified PWM control processing circuit similar to a conventional H configuration full-bridge type hard-switching PWM high frequency inverter. However, under the newly-proposed soft switching DC-DC power converter with a high frequency transformer link, the active power switches Q_1 ~ Q_4 in the full-bridge type inverter arms can perform a ZVS turn-off transition due to the presence of the active PWM switch Q_5 as well as the lossless snubbing capacitor C in parallel with the DC busline and a high frequency transformer parasitic inductive leakage component. This capacitor snubber is completely discharged before the active power switches Q_1 and Q_4 or Q_2 and Q_3 are turned off, respectively. In addition, the inverter bridge arm side switches can also perform ZCS at a turn-on switching transition with the aid of inductance L_l as the parasitic leakage inductive component of specially-designed high frequency transformer T. The switch Q_5 can achieve ZVS/ZVT at a turn-off mode transition due to the presence of the single lossless snubbing capacitor C. This switch Q_5 can also achieve ZVS at a turn-on mode transition due to the use of the lossless snubbing capacitor C as an edge resonant snubber assisted by a leakage component. The lossless snubbing capacitor C is charged up to the same voltage as the source of DC busline by the energy stored in the leakage inductance L_l after the diagonal bridge arm switches are turned off completely with ZVS. The conduction power loss due to the additional power switch may make the total conduction power loss increase a little. However, in considering the whole DC-DC power converter treated here, its total turn-off switching power losses can be substantially decreased on the basis of the active edge resonant snubber under optimum soft switching operation conditions.

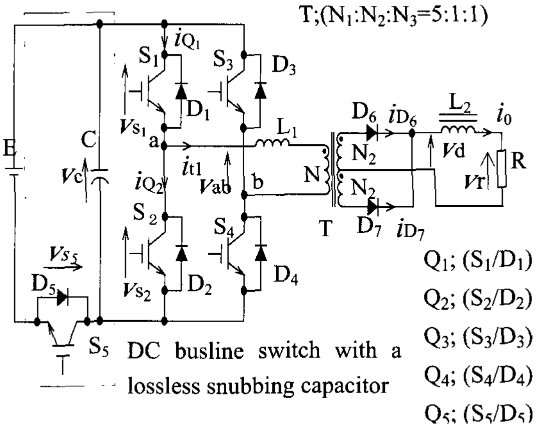


Fig. 1 Proposed soft-switching PWM DC-DC converter

3. Principle of Operation

3.1 New Gate Voltage Timing Sequences

Fig. 2 shows the timing sequences of the switching gate driving pulse trains of the switches Q_1 ~ Q_5. The gate voltage pulse signals for the switches Q_1 and Q_4 or Q_2 and Q_3 are basically the same as the signal timing sequences with a dead time of the conventional full-bridge PWM inverter type DC-DC converter. The turn-on gate voltage pulse signal of the DC busline low side series active switch Q_5 is synchronized with the same timing as the turn-on signals applied to Q_1 and Q_4 or Q_2 and Q_3.

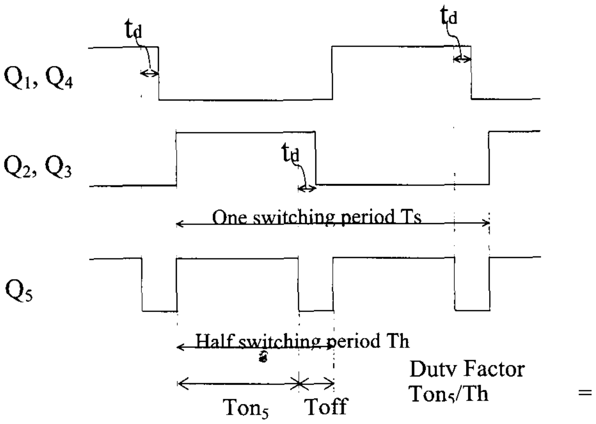


Fig. 2 Timing sequences of switching gate driving pulses

As for the turn-off gate pulse signal, the pulse train signal is delivered to Q_5 before the predetermined length of time td on the basis of the time when the turn-off signals are diagonally applied to the inverter arms. The pulse pattern control processing circuit can be easily implemented by modifying the conventional PWM signal processing circuit using commercially based standard PWM control IC(μ PC494).

3.2 Switching Operation Modes and Their Equivalent Circuits

Fig. 3 illustrates the relevant operating voltage and current waveforms during a complete switching period for the pulse pattern of the gate drive timing sequences depicted in Fig. 2. The switching operation circuit modes of this converter during a half switching cycle are divided into seven steady-state operation modes from mode 0 to mode 6 in accordance with an operation timing process from t_0 to t_6. The switching equivalent circuits corresponding to these operation modes are demonstrated in Fig.4. The operation principle in each mode is described in the following:

Mode 0 (~t_0): Before time t0, the active power switches Q1, Q4 and Q5 are turned on simultaneously. The transformer primary current it1 flows through the primary-side winding of the high frequency transformer. The current is1 flows through the diagonal switches; Q1, Q4 and the current is5 flows through the series switch Q5. During this period, all the currents it1, is1 and is5 are respectively equal. The capacitor voltage vc across the lossless snubbing capacitor C is completely the same as the DC busline voltage E. The high speed diode rectifier D6 is turned on and the transformer primary side energy is conveniently supplied to the equivalent arc welding load R through the loop of the rectifier diode D6 → DC smoothing filter reactor L2 → load R→ the secondary winding of high frequency transformer T.

Mode 1 (t_0 ~ t_1): At time t_0, the turn-off gate pulse signal is applied to the DC rail series switch Q_5, which can be turned off with ZVS, because the current i_{s5} through the series switch Q_5 is immediately cut off due to the lossless snubbing capacitor C. After time t_0, the voltage v_c across the lossless snubbing capacitor C decreases gradually toward zero voltage. In the circuit connected to the high frequency transformer secondary-side, the diode rectifier D_6 is still turned on. As a result, the transformer primary side energy is supplied to the transformer secondary circuit until the rectifier output voltage v_d across the rectifier diodes D_6 and D_7 terminals becomes equal to the DC output voltage v_o across the equivalent load R. When the rectifier DC output voltage v_d (See Fig.3) becomes equal to the v_o, the fly-wheeling operating mode begins to appear and the DC filter reactor L_2 supplies energy to load R as well as the high frequency transformer with the center-tapped secondary winding. When the rectifier voltage v_d becomes zero, the other rectifier diode D_7 is turned on in addition to rectifier diode D_6 and only filter reactor L_2 circulates the energy stored in itself to the load resistance R. Observing the equivalent circuit in mode1, the voltage v_c across the lossless snubbing capacitor C is estimated as,

$$v_c(t) = (E - i_{t1} / C)t \tag{1}$$

From Eq. (1), the discharging time t_x of the lossless snubbing capacitor C is given by below until its voltage v_c becomes zero.

$$t_x = CE / i_{t1} \tag{2}$$

From Eq. (2), the higher current i_{t1} flows through the transformer primary side winding, the discharging time t_x for the lossless snubbing capacitor C becomes shorter.

The delay time t_d indicated in Fig. 2 is designed to be longer than time t_x, which is calculated from Eq. (2) under a condition of maximum output current i_{t1}. In this case, the diagonal switches (Q_1, Q_4) or (Q_2, Q_3) in H configuration bridge arms can achieve ZVS mode transition completely. For a wider complete ZVS operation range at the turn-off switching commutation for the diagonal bridge arm switches (Q_1, Q_4) or (Q_2, Q_3), the delay time t_d(see Fig.2) should be varied in accordance with a value of the high frequency transformer primary winding current i_{t1}.

Mode 2 (t_1 ~ t_2): At time t_1, the voltage v_c across the lossless snubbing capacitor C becomes zero. In the interval from t_1 to t_2, the anti-parallel diodes D_2 of Q_2 and D_3 of Q_3 are turned on respectively, the current i_{t1} through the transformer primary winding flows through two circulation loops; $L_1 \rightarrow D_3 \rightarrow S_1 \rightarrow L_1$ and $L_1 \rightarrow S_4 \rightarrow D_2 \rightarrow L_1$. In the DC-DC power converter circuit connected to the transformer secondary side winding, the rectifier diodes D_6 and D_7 are still turned on simultaneously and the fly-wheeling operating mode continues.

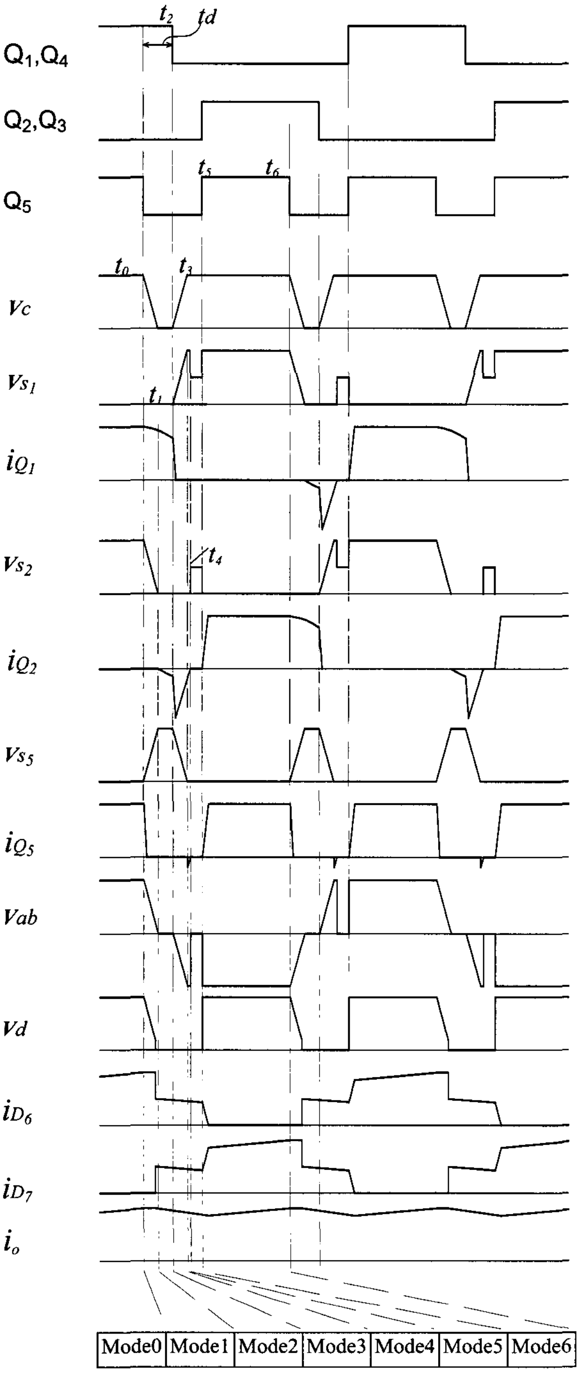
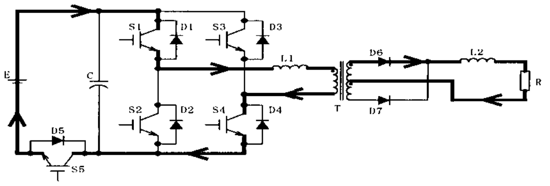
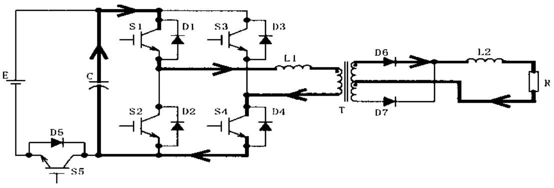


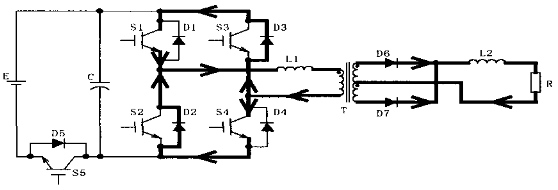
Fig. 3 Operating voltage and current waveforms during one switching cycle



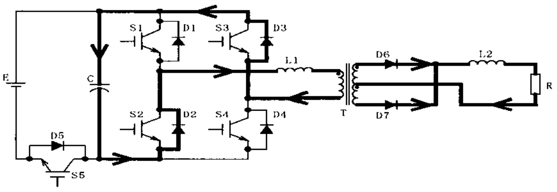
(a) Mode0 (~t_0): Energy transfer to secondary during turn-on of Q_1,Q_4 and Q_5



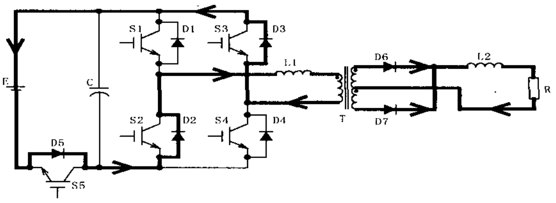
(b) Mode1 (t_0~t_1): Discharge of C after Q_5 is turned off



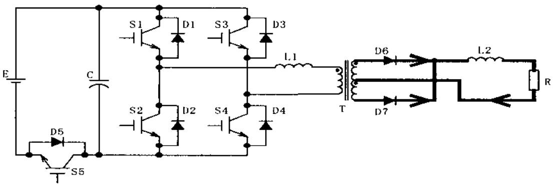
(c) Mode2 (t_1 ~t_2): Current circulation after discharge of C



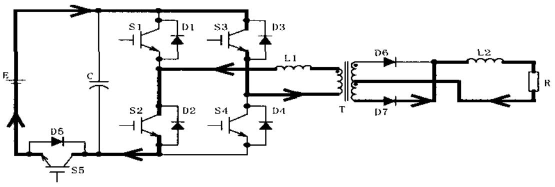
(d) Mode3 (t_2~t_3): Charge of C after Q_1, Q_4 are turned off



(e) Mode4 (t_3~t_4): v_C is clamped by E



(f) Mode5 (t_4~t_5): No operation in primary circuit



(g) Mode6 (t_5~t_6): Energy transfer to secondary during turn-on of Q_2,Q_3 and Q_5

Fig. 4 Equivalent circuits for seven operational modes

Mode 3 (t_2 ~ t_3): At time t_2, the turn-off gate pulse signals are applied to the diagonal bridge arm switches Q_1 and Q_4. These active switches can be turned off with ZVS because the voltage v_c has already reached zero and the energy stored in leakage inductive component L_1 is returned back to the lossless snubbing capacitor immediately through the anti-parallel diodes D_2 of Q_2 and D_3 of Q_3. After this, the lossless snubbing capacitor C can be charged up to the same voltage as the DC busline voltage source E. In the DC-DC power converter circuit connected to the transformer secondary side, the rectifier diodes D_6 and D_7 are still turned on and the fly-wheeling operating mode still continues. The condition that the lossless snubbing capacitor C is charged up to the same voltage as the DC busline voltage source E can be given by Eq. (3).

$$(1/2)CE^2 = (1/2)L_1(i_{t1})^2 \tag{3}$$

However, as described later in mode 6, the circuit constant parameters in mode 6 should be designed to meet the condition of $(1/2)CE^2 \leqq (1/2)L_1(i_{t1})^2$ in order to achieve a ZVS or soft commutation at turn-on switching transition of the DC rail series switch Q_5.

Mode 4 (t_3 ~ t_4): Under a condition of $(1/2)CE^2 < (1/2)L_1(i_{t1})^2$, the voltage v_c across the lossless snubbing capacitor C is clamped to the DC busline voltage E after the voltage v_c reaches the DC busline voltage source E, because the anti-parallel diode D_5 of the DC rail series switch Q_5 is turned on naturally and the energy stored in the leakage inductive component L_1 of the high frequency transformer is returned back to the DC busline voltage source E. In the DC-DC power converter circuit connected to the transformer secondary side, the rectifier diodes D_6 and D_7 are still conducting and the fly-wheeling operating mode continues.

Mode 5 (t_4 ~ t_5): In this operating mode, all the switching mode operations are stopped in the circuit including the primary side winding circuit of the transformer, except the voltages across the diagonal power switches Q_1 and Q_4 decrease down to (1/2)E and the voltages across the other diagonal switches Q_2 and Q_3 increase up to (1/2)E due to the parasitic circuit parameters of the switches Q_1, Q_2, Q_3, and Q_4 in the inverter bridge arms. In the DC-DC power converter circuit connected to the transformer secondary side center-tapped windings, the rectifier diodes D_6 and D_7 are still conducting and the fly-wheeling operation mode continues.

Mode 6 (t_5 ~ t_6): At time t_5, the turn-on gate pulses indicated in Fig. 2 are applied to the switches Q_2, Q_3 and Q_5. At this time, the second diagonal switches Q_2 and Q_3 can be turned on with ZCS due to the parasitic leakage inductance L_1 of the high frequency transformer. The DC rail series switch Q_5 in the busline achieves a complete soft switching commutation of ZVS/ZCS at a turn-on switching transition, since the voltage v_c has the same value as the DC busline voltage source E. In the power converter circuit connected to the transformer secondary side, only rectifier diode D_7 is turned on and the transformer primary side energy is supplied to the load R through the loop of the rectifier diode D_7 → DC smoothing filter reactor L_2 → load R → the secondary side center-tapped windings of the transformer.

Thereafter, the operation processes for the second switches Q_2, Q_3 and Q5 become the same as that for the first switches Q_1, Q_4 and Q5, as described before. The succeeding operation processes for the switches Q_1, Q_4, Q5 and the switches Q_2, Q_3, Q5 will be repeated in periodic sequence.

4. Experimental Results and Discussions

4.1 Experimental Setup Implementations

The experimental setup of the proposed soft switching PWM DC-DC converter with 60 kHz planar transformer and secondary center-tapped windings, as shown in Fig. 5, is experimentally demonstrated with 32V, 300A output voltage and current ratings. The design specifications and circuit constant parameters are indicated in Table 1.

The two in one IGBT power module CM100DUS-12Fs produced by Mitsubishi Electric Co. Ltd. are used for the active switches Q_1 ~ Q_4 in the inverter bridge arms. In addition, the two in one IGBT power module CM75DU-12Hs are actually used for two active PWM switches Q_5 and Q_6 in parallel instead of one switch in series with the DC busline. The input side DC rail switches Q_5 and Q_6 in parallel are effectively necessary for realizing the same operating switching frequency as the high frequency full bridge inverter frequency. The series switch Q_5 in the input side DC rail is switched during the operation of the first diagonal switches Q_1 and Q_4 and the input side DC rail series switch Q_6 is also switched during the operation period of the second diagonal switches Q_2 and Q_3 as shown in Fig. 6.

The overall appearance of the experimental setup of the TIG arc welding power supply using the newly-developed soft switching PWM DC-DC power converter using IGBT power modules is demonstrated in Fig. 7. Under the TIG arc welding soft switching PWM power supply used in industry, as shown in Fig. 7, the diametric size or physical size is substantially 50% less and its weight is substantially 48% less than conventional hard switching PWM full bridge inverters with DC-DC converter type power supply which have been developed previously for TIG arc welders in industry.

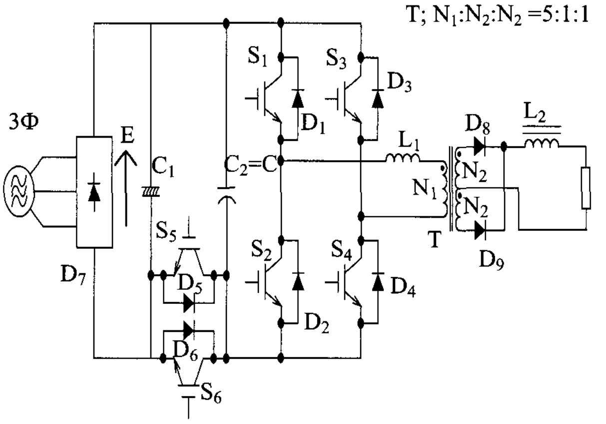


Fig. 5 Experimental setup circuit implementation

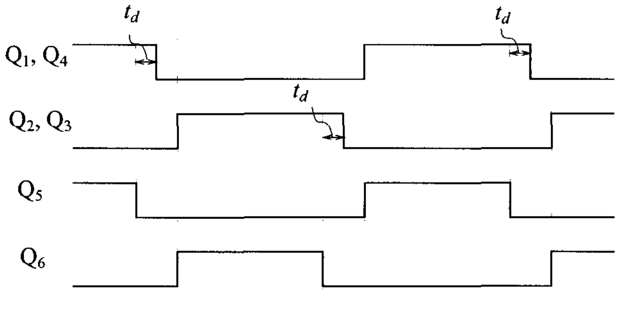


Fig. 6 Switching gate driving pulses for experimental setup circuit

Table 1 Design specifications and circuit parameters

Item	Symbol	Value
DC Busline Voltage	E	280[V]
Inverter Switching Frequency	fs	60[kHz]
Switching Period	Ts	16.7[μS]
Leakage Inductance of High Frequency Transformer	L_1	2[μH]
Capacitance of Quasi Resonance Capacitor	C_2	0.1[μF]
Inductance of DC Reactor in load side	L_2	100[μH]
Load Resistance	R	0.07[Ω]
Maximum Load Current	Io	300[A]
Turns Ratio of High Frequency Transformer	N_1:N_2:N_2	5:1:1

Remarks

IGBTs Diodes	S_1-S_4 D_1-D_4	CM100DUS-12F Vces=600V,Ic=100A(Tc=25℃)
	S_5-S_6 D_5-D_6	CM75DU-12H Vces=600V,Ic=75A(Tc=25℃)

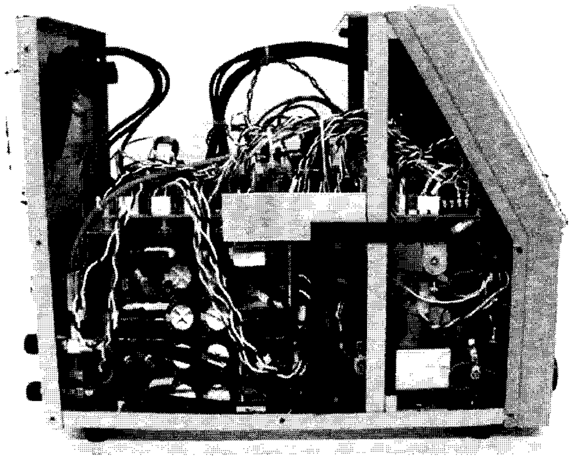


Fig. 7 Overall Appearance of TIG arc welding power supply

Fig. 8 represents the assembled appearance of the proposed DC-DC power converter board in the primary side circuit of the high frequency transformer. Four IGBT modules are mounted on one heat sink (Length: 240mm, Width: 150mm) with a forced air cooling fan and are connected by the printed circuit board. The DC smoothing electrolytic capacitors C_1 and the lossless snubbing capacitor C_2=C are mounted on this printed circuit board. The connecting IGBTs, DC smoothing capacitor C_1 and the lossless snubbing capacitor C_2 on the printed circuit board enables a minimization of the wiring stray inductance due to the laminated busbar arrangement assembled connections among the IGBTs, C_1 and C_2.

Fig. 9 shows the exterior appearance for the planar type high frequency transformer used for the TIG arc welding power supply displayed in Fig. 7. This high frequency transformer is extremely small and thin because of the 60 kHz switching frequency operation design and cupper plates used for its primary and secondary side center-tapped windings. The windings are punched through by a molding designed and manufactured specially for this high frequency (60 kHz) transformer.

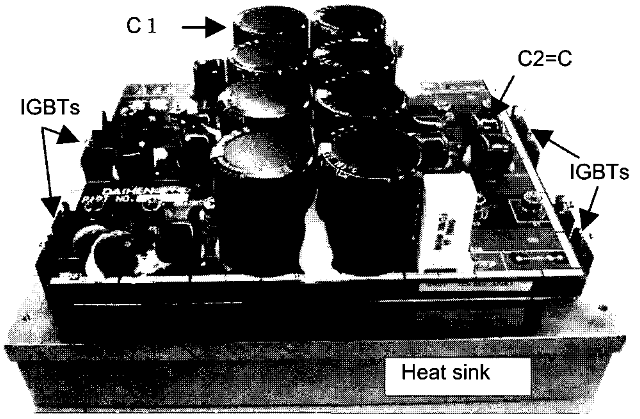


Fig. 8 Assembled component appearance in high frequency transformer primary side circuit

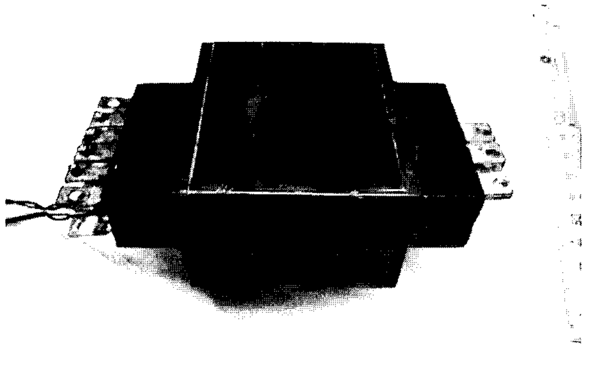
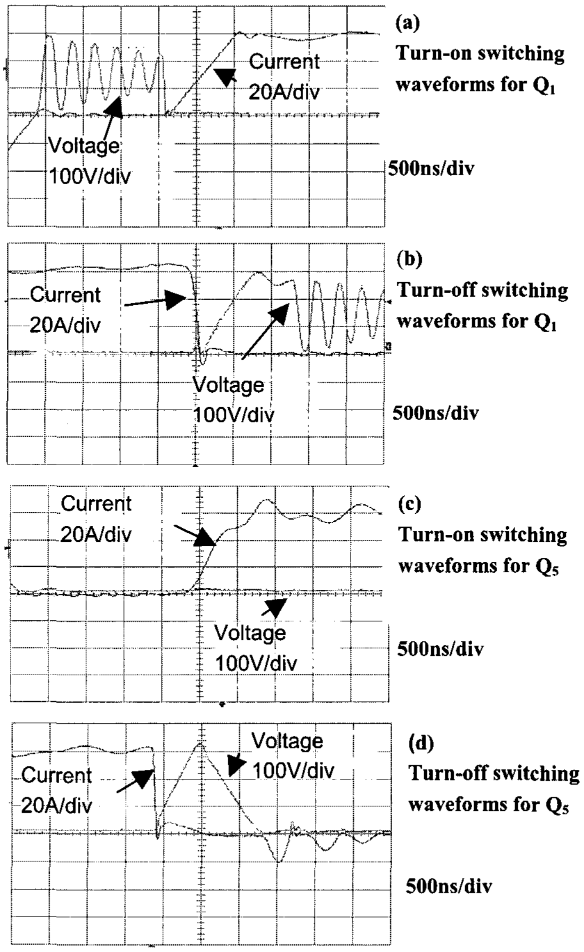


Fig. 9 Appearance for planer high frequency transformer

4.2 Switching Voltage and Current Waveforms

The measured relevant switching voltage and current waveforms in a steady state operation of the proposed DC-DC power converter operation are shown in Fig. 10 (a) and (b), when the inverter bridge arm switch Q_1 is turned on and turned off, periodically. While observing these switching waveforms, it was found that switch Q_1 is turned on with ZCS and is completely turned off with ZVS. The other switching waveforms for the measured voltage and current are respectively shown in Fig. 10 (c) and (d), when input side DC rail switch Q_5 is turned on and turned off, periodically. From the operating waveforms shown in Fig. 10 (c) and (d), it is understood that switch Q_5 is ideally turned on with ZVS/ZCS and is turned off with ZVS. However, at the turn-off switching transition for switches Q_1 and Q_5, some switching power losses at turn off transition still exist due to the inherent tail current characteristics of the IGBT power modules.



(a) **Turn-on switching waveforms for Q_1**

(b) **Turn-off switching waveforms for Q_1**

(c) **Turn-on switching waveforms for Q_5**

(d) **Turn-off switching waveforms for Q_5**

Fig. 10 Measured switching voltage and current waveforms

4.3 Comparative Power Loss Analysis

According to the power loss analysis and the proposed DC-DC converter evaluations, observed in Fig. 11, there is a total power loss in all of the active power switches including the input side DC rail switches Q_5 and Q_6 which is compared with the total power loss of all the switches in a conventional hard-switching power converter. When the switching frequency is 10 kHz, the total power losses for both proposed and conventional converters are almost equal each other. From an acoustic noise point of view, the switching frequency of high frequency inverter power IGBTs must be designed at a switching frequency of more than 18 kHz, therefore the proposed soft switching DC-DC converter is designed for 60 kHz under the condition of 32V and 300A DC output. The more the switching frequency of the high frequency inverter stage increases, the more this newly-developed soft switching PWM DC-DC power converter can realize improvements in power conversion efficiency, power density and volumetric downsizing as compared with the use of conventional hard-switching type DC-DC power converters.

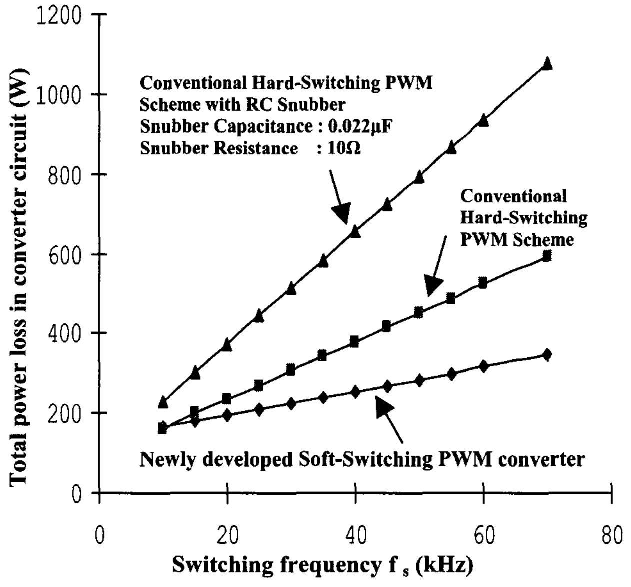


Fig. 11 Comparative power loss analysis

Thus, in case the switching frequency of the soft switching inverter stage with a high frequency transformer is profitably selected to be designed for 60 kHz, the total power loss in the proposed DC-DC converter can be estimated as only 280W while the power loss of the conventional hard-switching type becomes 520W. Furthermore, the R-C snubber circuits to block voltage and current switching surges or spikes should be mounted for each of the IGBTs in the inverter full bridge arms for conventional hard-switching full bridge inverter types.

Therefore, the total system power loss for the conventional hard-switching DC-DC power converter circuit including the power losses of the RC snubber circuit could be actually estimated to be about 900W, which is three times more than the total power loss of the newly-developed soft switching PWM DC-DC power converter with a high frequency transformer.

5. Conclusions

In this paper, a novel circuit topology of an input side DC rail active edge resonant snubber-assisted 60 kHz soft-switching PWM DC-DC power converter with a high frequency transformer link was presented. This converter, with a switching frequency designed for 60 kHz even in IGBTs, is suitable for low voltage and large currents such as 32V and 300A DC output specifications for high performance TIG arc welding equipment in industry. The operating principle of this DC-DC power converter was described by using the switching mode equivalent circuits, along with its unique features. The practical effectiveness of the newly-proposed DC-DC power converter operating under a condition of stable soft-switching PWM control scheme were substantially proved from an experimental point of view. Based on the operated voltage and current waveforms, all the active switching devices in this DC-DC power converter could achieve soft switching commutation of ZVS/ZVT turn-off and ZCS/ZCT turn-on switching mode transitions. The power loss analysis of the newly-proposed soft switching PWM DC-DC power converter was evaluated for high performance arc welding power supplies and discussed in comparison to conventional hard switching PWM DC-DC power converters with high frequency transformer links. The more the switching frequency increases, the more the proposed DC-DC power converter demonstrates remarkable advantageous points such as high power conversion efficiency, high power density and high performance and electrical energy savings as compared with conventional full bridge DC-DC converters.

Therefore, downsized and lighter weighted TIG/MIG arc welding power supplies using this newly-developed power converter have been tested and already been put into practical use in industry.

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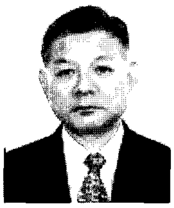

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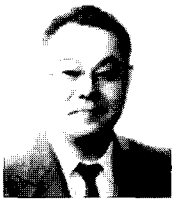

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