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Series Load Resonant Soft-Switching PWM High Frequency Inverter with Auxiliary Active Edge-Resonant Snubber

Bishwajit Saha, Hun Ho Kim, Ho Dong Han*, Soon Kurl Kwon,
Hyun Woo Lee and Mutsuo Nakaoka

The Graduate School of Electrical and Electronics Engineering
Kyungnam University, Masan, Republic of Korea
* Hansung Engineering Company.
Email: bshwajit_bd@yahoo.com

Abstract - In this paper, a novel type of auxiliary active snubbingcircuit assisted quasi-resonant soft-switching pulse width modulation inverter is proposed for consumer induction heating equipments. The operation principle of this high frequency inverter is described using switching modes and equivalent circuits. This newly developed series resonant high frequency inverter can regulate its high frequency output AC power under a principle of constant frequency active edge resonant soft- switching commutation by asymmetrical PWM control system. The high frequency power regulation and actual power conversion efficiency characteristics of consumer induction heating (IH) products using the proposed soft-switching pulse width modulation (PWM) series load resonant high frequency inverter evaluated. The practical effectiveness and operating performance of high frequency inverter are discussion on the basis of simulation and experimental results as compared with the conventional soft-switching high frequency inverter.

Index terms- High frequency inverter, Series tuned resonant load, Auxiliary edge resonant snubber, IH appliances, Asymmetrical PWM.

I. INTRODUCTION

In recent years, the power electronics relating to high frequency electromagnetic based induction heating (IH) have become more suitable and acceptable for food cooking andprocessing appliances, hot water producer, super heated steamer and fixing roller in copy machines and printers [1-2]. The consumer high frequency IH appliances are based upon the eddy current joules heat on Faraday's electromagnetic induction law. The IHloads may consist of planner (pancake), cylindrical and parabolic type air cooled working coil with electromagnetic eddy current based heating materials. The high frequency soft switching edge resonant inverters have the advantages of simple configuration, high efficiency and wide soft commutation operating ranges, high reliability which is indispensable for high frequency high power operation. However, most of ZCS load resonant high frequency inverters with PWM control scheme could not able to regulate its AC output power under constant frequency PWM control. In this paper, a circuit topology of voltage source edge-resonant ZCS high frequency inverter with constant frequency PWM control strategy using active auxiliary quasi-resonant loss less inductor sunbber and switched capacitor snubber is proposed for new generation consumer IH appliances.

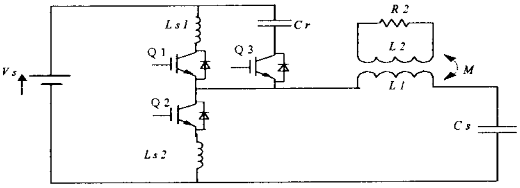
II. High Frequency Inverter

A. Circuit Description:

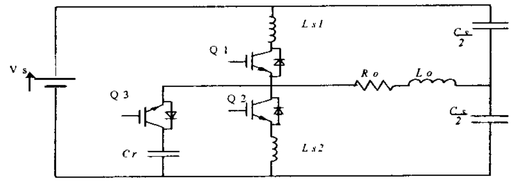
Figure 1 shows the newly developed edge-resonant ZCS- PWM high-frequency inverter using the trench gate IGBTs that canoperate under constant frequency PWM control strategy. This voltage-fed ZCS PWM high frequency edge-resonant inverter circuit consists of two main switches Q_1 and Q_2, an auxiliary switch Q_3 in series with auxiliary edge-resonant switched capacitor C_r as an active snubber in parallel with Q_1 and L_{S1}, ZCS-assisted loss less inductor snubbers L_{S1} and L_{S2} connected in series with Q_1 and Q_2, power factor compensated series load resonant capacitor C_S, and highly inductive IH load represented by its equivalent R_o and L_o series circuit model.

B. Gate Pulse Timing Scheme

The gate voltage pulse timing signal sequences for Q_1, Q_2, and Q_3 are shown schematically in Fig. 2. Q_1 is firstly switched on during a period T_{on1} and before Q_1 is turned off by a time of T_o, Q_3 is turned on for a period T_{on3}. Inserting an overlapping time of T_o between Q_1 and Q_3. Then, Q_2 is turned on after turning off Q_3 by a dead time of T_{d1}. Again Q_1 is switched on



a) Single-end half bridge topology



b) Divided Capacitor Double Ended half bridge Topology

Fig. 1. Edge-resonant ZCS-PWM high frequency inverter

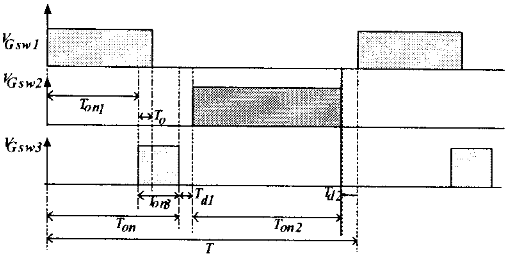


Fig. 2. Proposed PWM gate pulse timing sequences.

after a dead time T_{d2} as another period starts as depicted in Fig. 2. By adjusting the constant frequency asymmetrical PWM control duty cycle, which is defined as the sum of the conduction time T_{on1} of Q_1 and conduction time T_{on3} of Q_3 to the total switching period T. The conduction time T_{on1} of Q_1 can be controlled while keeping T_{on3} of Q_3, the overlapping time T_0 and the dead time T_{d1} constants. As a control variable, the duty cycle D is defined as

$$D = (T_{on} + T_{d1})/T \qquad (1)$$

The proposed edge-resonant ZCS-PWM high frequency inverter with two loss less inductor snubbers ($L_{s1}>0$, $L_{s2}>0$), ($L_{s1}>0$, $L_{s2}=0$) and a single switched capacitor can not only be controlled by the constant frequency asymmetrical PWM for high power settings but also it can be controlled by a constant high frequency pulse density modulation (PDM) for low power settings.

III. Principle of Operation

The switching current commutation transitions and their corresponding operating current and voltage waveforms and the operating modes of this inverter are illustrated in Fig. 4 for a duty cycle D = 0.34. The operation principle of the inverter is explained in the following by using the corresponding switching mode waveforms, ZCS for two main switches and the auxiliary switch in this inverter can be achieved under the PWM gate pulse timing sequences shown in Fig. 2. At the beginning of each switching cycle, the high side of Q_1 is now conducting and high frequency power is supplied to the IH load. After i_{SW1} through of Q_1 naturally commutates by quasi-resonance due to ZCS-assisted high side inductor snubber L_{S1}, in series with the switch Q_1, together with the series inductive load resonant tuned capacitor C_S, switch Q_3 is turned on and switch Q_1 is turned off. As a result, a ZCS at a turn-off switching mode transition can be achieved by the arbitrarily timing processing when turning off the switch. At this mode, since an auxiliary resonant current i_{SW3} flow through the switch Q_3 and increase softly, a ZCS at a turn-on switching transition can be achieved for Q_3. Then, after i_{SW3} is commutated to the anti-parallel diode D_3 of Q_3 by theresonance formed by C_r, R_o-L_o load in series with C_S, a ZCS soft switching commutation at a turn-off switching mode transition can be performed by turning off Q_3. While Q_3 is conducting, V_{Q2} across the low side of main switch Q_2 decreases toward zero. Before the low side of Q_2 is turned on as soon as D_2 of Q_2 becomes reverse biasing state and begins to conduct naturally. While the diode D_2 continues conducting, the current flowing through D_2 of Q_2 is naturally commutated to Q_2. Therefore, a complete ZVS and ZCS (ZVZCS) hybrid commutation can be achieved for Q_2. On the other hand, after i_{sw2} through the low side of Q_2 is naturally commutated to D_2 of Q_2 with the aid of low side ZCS-assisted inductor snubber L_{S2}, the induction heating load R_o-L_o and load power factor compensation series load resonant tuned capacitor C_s, ZCS commutation at a turn-off switching mode transition can be performed by turning off the Q_2 While D_2 of Q_2 is conducting, i_{D2} flowing through D_2 is commutated to the switch Q_1 by turning on Q_1 when a second switching cycle starts. At this mode, a ZCS can be realized with the aid of ZCS-assisted inductor snubber L_{S1}. The multi-resonant ZCS PWM inverter offers a complete ZCS for all the main and auxiliary switches and achieves ZVZCS at turn-on switching transition for Q_2.

IV. Experimental Evaluations

A. . *Design Specifications and results*

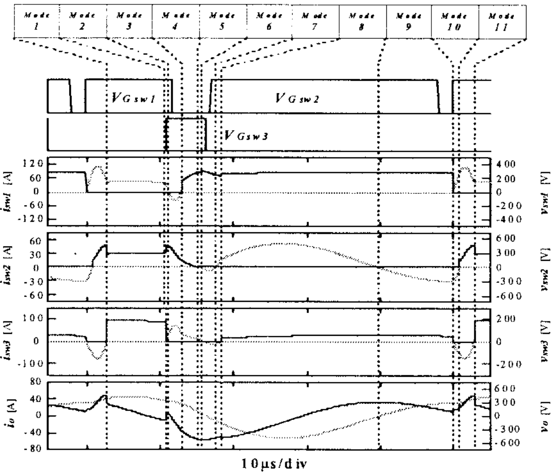


Fig. 3. Voltage and current waveforms during one switching cycle in case of a duty factor of 0.34.

Table 1: Design specifications and circuit parameters

Item		Symbol	Value
DC source voltage		V_S	282.2v
Switching frequency		f_{SW}	20kHz
Inductance of ZCS assisted inductor		L_{S1}	2.09μH
		L_{S2}	2.01μH
Capacitance of quasi-resonant capacitor		C_r	324nF
Capacitance of power factor compensation series tuned capacitor		C_S	0.802μF
Induction heating load	Load resistance	R_0	2.54Ω
	Load inductance	L_0	57.96μH

An experimental setup of this high frequency inverter by using trench gate reverse conducting IGBTs with low saturation voltage is implemented to validate its performance evaluations. The design specifications and circuit parameters used in the experimental breadboard setup are respectively indicated in Table1. An enamel pan has a bottom diameter of 18 cm is used for the IH load. The high frequency IH load consists of enamel pan, ceramic spacer as top plate and a planner pancake type working coil composed of litz wire assembly. The output voltage and current waveforms have shown in fig. 4.

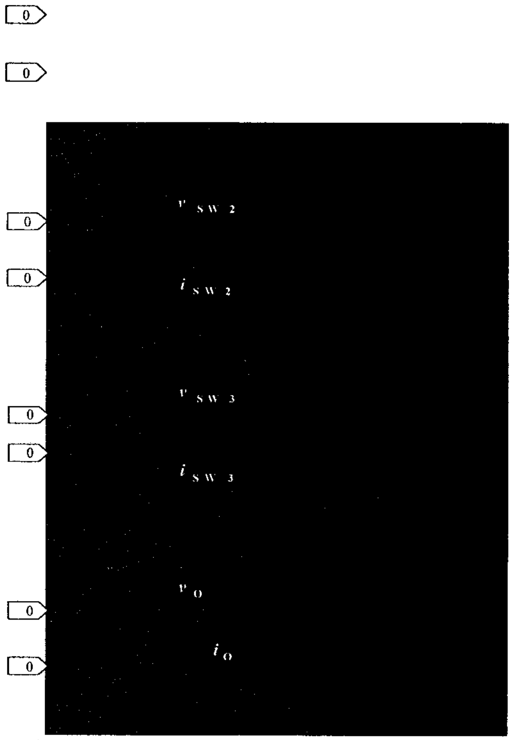


Fig. 4. Measured voltage and current waveforms in case of D=0.34.

B. Power Regulation Characteristics

The input power or high frequency AC output power vs. duty cycle characteristic for the proposed ZCS-PWM inverter, which is based on duty cycle PWM control scheme, is depicted Fig. 5. The solid line shows the simulation results and the dotted line gives the measured experimental ones. In the proposed inverter circuit, its input power or the high frequency AC output power could be regulated approximately from 0.4 kW to 2.6 kW.

C.Comparative Actual Efficiency Characteristics

The actual efficiency vs. the input AC power regulation characteristics of the proposed ZCS-PWM and ZVS-PWM type high frequency inverters are comparatively illustrated in Fig. 6. The actual efficiency of the newly proposed inverter is much higher than that of the previously developed one for lower input or output power setting ranges and the actual efficiency is almost the same for higher input power or higher output power ranges. This is due to the reason of the conduction power loss of the added auxiliary switch Q_3.

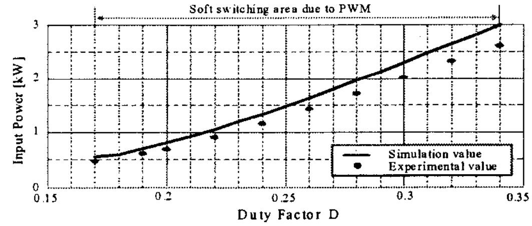


Fig. 5. Input power vs. duty factor characteristics.

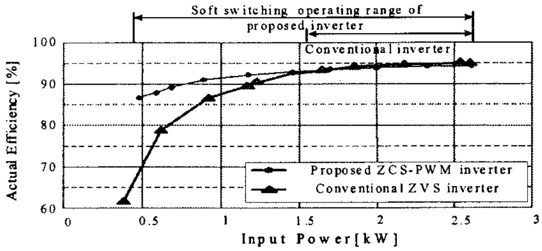


Fig. 6. Actual power conversion characteristics.

V. CONCLUSIONS

In this paper, a new topology of active auxiliary edge-resonant snubber-assisted voltage source ZCS-PWM high frequency inverter using trench gate IGBTs, which developed for consumer and IH super fixing roller. It's operating principle, for switching mode transitions and its operating characteristics have been illustrated and evaluated on the basis of simulation and experimental results. The practical effectiveness of the newly-proposed voltage source ZCS-PWM high frequency edge resonant inverter using the latest trench gate IGBTs have been proved on the basis of the experimental results by producing an actual breadboard prototype. A wider soft switching operating range of this inverter has been obtained as compared with the previous developed voltage source ZVS-PWM one. Therefore, the newly proposed high frequency inverter could actually achieve higher efficiency, high performance and wider soft switching operating ranges.

Acknowledgment

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REFERENCES

[1]. B. K. Lee, J. W. Jung, B. S. Suh, and D. S. Hyun, "A New Half-Bridge Inverter Topology with Active Auxiliary Resonant Circuit Using Insulated Gate Bipolar Transistors for Induction Heating Appliances," *Proceedings of IEEE Power Electronics Specialists Conference (PESC)*, Vol.2, pp. 1232-1237, June, 1999.

[2]. H. Terai, T. Miyauchi, I. Hirota, H. Omori, Mamun A. Al, and M. Nakaoka, "A Novel Time Ratio Controlled High Frequency Soft Switching Inverter using 4th Generation IGBTs," *Proceedings of IEEE Power Electronics Specialists Conference, (PESC)*, Vol. 4, pp. 1868-1873, Vancouver, Canada, June, 2001..