PDM ZCS Resonant High Frequency Inverter for Induction Heated Roller

Shin-Chul Kang, *Member, KIMICS*

***Abstract*—**This paper presents a lossless inductor snubber-assisted series resonant high frequency inverter using the trench gate IGBTs for the electromagnetic induction eddy current-heated fixing roller in copy and printing machines in a new generation. This soft switching high-frequency inverter can completely achieve zero current soft switching (ZCS) commutation mode transitions and wide power regulation under its constant frequency pulse density modulation (PDM) scheme. Its transient and steady state operating principle is originally presented for a constant frequency PDM strategy under a ZCS operation, together with its output power regulation characteristics-based on the pulse density modulation. The effectiveness of this soft switching high-frequency inverter is confirmed for the fixing equipment with the induction-heated fixing roller.

***Index Terms*—**Lossless Inductor Snubber, ZCS, Pulse Density Modulation

I. INTRODUCTION

The authors have been developed a variety of modified circuits and control systems of the voltage source bridge type series resonant zero current soft switching (ZCS) high frequency resonant inverter with lossless inductive snubbers. These are more suitable and acceptable for high frequency series resonant inverter linked high voltage power supply for the power microwave generation, and high frequency series inverter is to drive the silent discharge type exciplex lamp for the UV generation, the silent discharge type ozone tube for the ozone generation and high-intensity ultrasonic generator for ultrasonic cleaning and welding[1-3].

In recent years, the series load resonant high frequency inverter using MOS gate power semiconductor switching devices for the fixing processing in the roller of the copy machine, which makes use of the electromagnetic induction eddy current-based heating (IH) roller. With the great advances on new MOS gate control power semiconductor devices and their driver circuits, sensors interface circuits and control ICs, in addition to the high frequency circuit components, some attractive circuit topologies of the high frequency inverter topologies and so forth. The latest power electronic products on the electromagnetic induction heating applications such as heat treatment and melting processing of the metals and semiconductor materials, food cooking and processing and hot water producer and steam generator as well as the super heated steamer are developed one after another from a practical point of view[4].

Under these technical backgrounds, this paper proposes half bridge ZCS high frequency inverter with lossless inductive snubbers in series with each power semiconductor switch for electromagnetic induction eddy current based heating (IH) roller system for fixing processing in the copy machine[5]. On the other hand, the series resonant inverter using the active power switches is practically difficult to regulate its output power under conditions of a constant frequency specification and ZCS mode transition. The series resonant inverter with a constant frequency phase-shifted PWM strategy cannot achieve the complete ZCS commutation.

In this paper, the ZCS high frequency inverter circuit operation based on the fixed frequency PDM scheme and its power regulation characteristics are presented and discussed from an application point of view.

II. HIGH FREQUENCY ZCS-PDM INVERTER FOR INDUCTION HEATING

A. Induction Heating Load Technology & Circuit Modeling

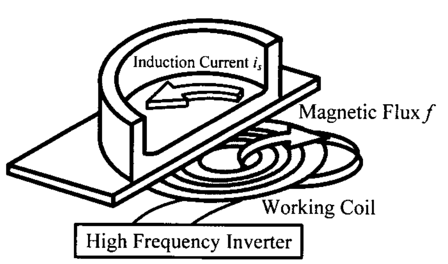
The high-frequency current generated by the voltage-fed series resonant inverter is delivered to the work coil, and the eddy current is induced in the rotating cylindrical material heated directly by Joule's heat based the eddy current on the basis of Faraday's electromagnetic induction law. The induction heating of conductive metal and semiconductor materials is based on non-contact direct heating using the electromagnetic eddy current induction principle.

Fig. 1(a) shows a basic principle of electromagnetic induction heated cooking appliances with a pancake type spiral planer coil as litz wire-based working coil for generating high frequency magnetic flux. The pancake type working coil (see Fig. 1(a)) connected the quasi-resonant ZVS high frequency inverter using $IGBT_S$ generates high frequency magnetic flux. And then, high-frequency magnetic field produced from the working coil makes eddy current in the bottom portion of vessel or pan[4]. The configuration example of electromagnetic IH rolling drum

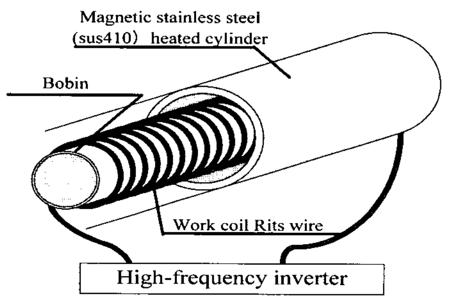
Manuscript received February 10, 2008; revised July 18, 2008. Shin-Chul Kang is with the Department of Electricity , Gyeongnam Provincial Namhae College, Namhae, 668-801, Korea (Tel: +82-55-860-5352, Fax: +82-55-860-5351, Email: kangs@namhae.ac.kr)

for the fixing processing in the copy machine that heats itself directly is schematically shown in Fig. 1 (b).

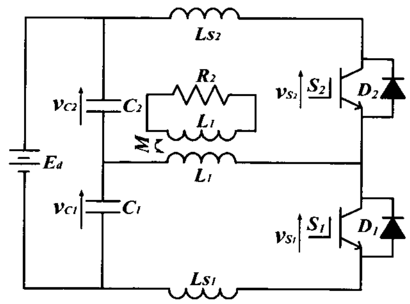
The electromagnetic induction eddy current heated rolling drum structure for a new conceptual copy machine composed of the fixed stationery inner cylindrical work coil assembly connected to a high frequency load resonant inverter and the rolling metal drum (stainless steel titanium alloy metal) to be heated by the electromagnetic induction heated eddy current is schematically illustrated in Fig. 1. The inverter-fed induction heating roller drum load in Fig. 1 is generally represented by using the transformer circuit model circuit depicted in Fig. 2. The divided capacitor voltage source type half bridge series load resonant inverter power supply for the fixing heating processing in the copy machine is demonstrated in Fig. 1(c).



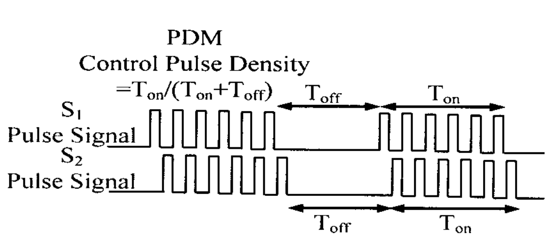
(a) Induction heating principle



(b) Induction heating roller with working coil



(c) High Frequency ZCS-PDM Inverter System



(d) PDM signal

Fig. 1 High frequency ZCS-PDM load resonant inverter.

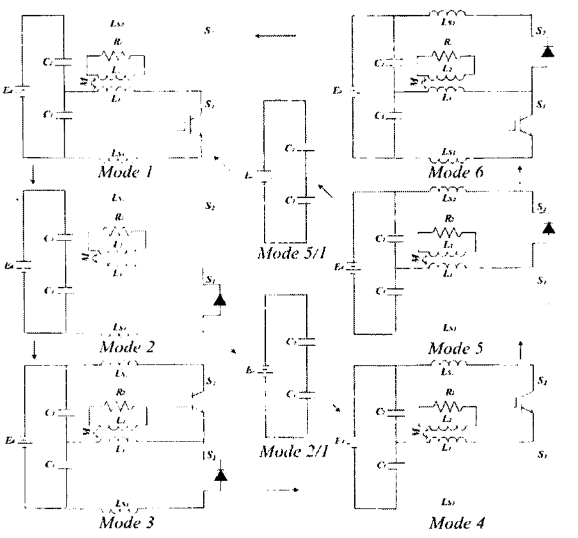
In IH application specific equipment using the series load resonant high frequency inverter, electric power conditioning system by the PFM control scheme in the inverter frequency bands of the frequency domain is lower than a resonant frequency is generally introduced for the fixing heating processing unit in the copy machine. But, the output power regulation characteristics of the series load resonant inverter using IGBTs become the nonlinearity for the PFM strategy. And, there are some problems that interference acoustic sound noise produced by the frequency difference is generated in complex IH systems equipment with the 2 IH inverter units used as a cooking heater.

By introducing the PDM control strategy can regulate the output power of the series load resonant high frequency inverter on the basis of the time ratio control or duty cycle control due to asymmetrical PWM under a soft switching switch principle, the effective power is continuously controlled by varying the time ratio or duty cycle determined by a switching period T_{on}, which injects the high-frequency effective power and non switching period T_{off}, which does not inject the high-frequency effective power, as shown in Fig. 1(d). In particular, the frequency dependence of R_2, in the induction-heated load can minimize by using a constant frequency PDM strategy. The linearity on the effective output power regulation of the voltage-fed series load resonant inverter in the wide power regulation range can be achieved under ZCS transition commutation.

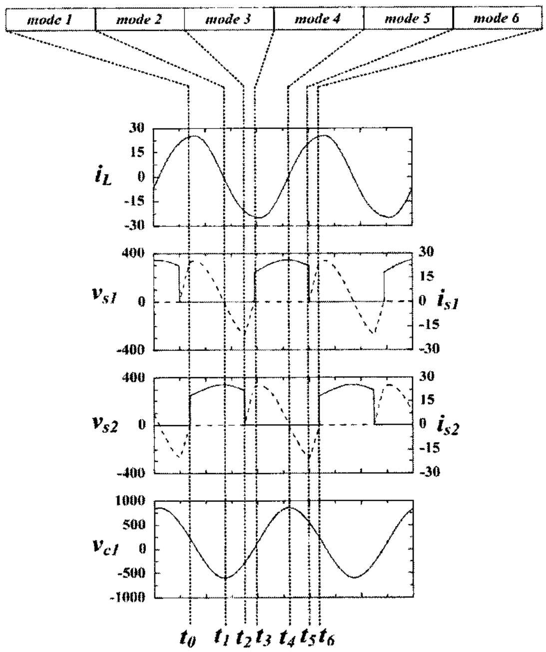
Moreover, the a constant frequency PDM control scheme can regulate the effective power under the ZCS condition which can be implemented by installing the lossless inductors L_{S1}, L_{S2}in series with each active power switch inserted into each bridge arm. The active power switches S_1 and S_2 can be respectively operated with ZCS commutation in all the output power regulation ranges of the high frequency series load resonant inverter using the trench gate IGBTs. Even if the load parameter R_2 might be changed, the ZCS operation of this inverter can be performed completely. And, the constant frequency PDM strategy of this inverter has some unique salient advantages for the reduction of electromagnetic noise and switching power losses. In addition to stabilization of silent discharge sustain voltage.

B. Circuits Features and Operation

The circuit operating mode and equivalent circuits in the voltage-fed half bridge type high frequency inverter treated here (see Fig. 1(d)) are respectively shown Fig. 2. The other types of resonant inverter circuit topologies such as divided voltage half bridge full bridge type, center tapped push pull type, single ended push pull type, boost half bridge type are effectively introduced in place of half bridge type treated here. For high frequency high power applications, the time sharing half bridge load resonant series inverter using the latest IGBTs is effectively applied.



(a) Mode transitions and equivalent circuit



(b) Voltages and currents waveforms in steady state

Fig. 2 Inverter equivalent circuits and steady-state operation waveforms

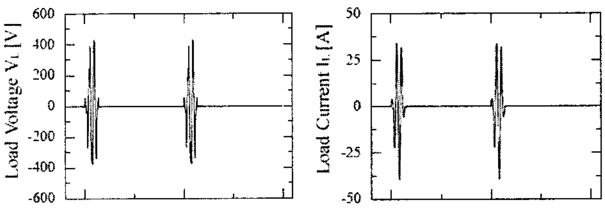
III. SIMULATION AND EXPERIMENTAL RESULT

The practical design specifications and circuit constants of the high frequency series resonant inverter with lossless inductor snubbers for the IH fixing heating processing unit in the copy machine fixing IH roller shown in Fig. 1(b). The design specifications and circuit parameters are indicated in Table 1. The output voltage v_0 and output current i_{Ls}, voltage and current of the active power switches S_1 and S_2 for 10[%], 20[%], 30[%], 40[%], 50[%], 80[%] pulse density time ratio control scheme of this resonant inverter by the PDM control implementation are respectively shown in Fig. 3(a), (b), (c), (d), (e), (f).

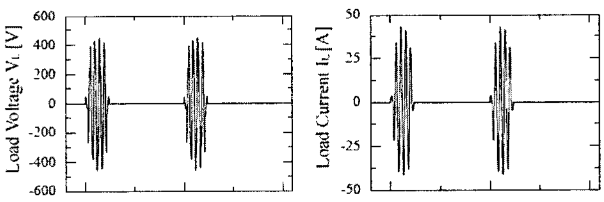
Table 1 Design Specifications and Circuit Parameters

The DC power source voltage(E_d)	282.8[V]
The series resonance capacitor(C_1 =C_2=C_r/2)	0.26[μF]
The inductor(L_{s1} =L_{s2}=L_s)	11.0[μH]
The switching frequency(f_s)	20[kHz]
The load time constant(τ)	5.44[μs]
Electromagnetic coupling coefficient (k)	0.53
Work coil inductance(L_1)	90[μH]

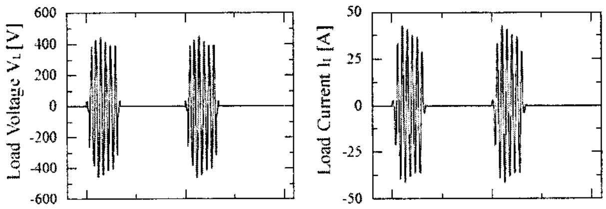
Fig. 4 illustrated the output effective power regulation characteristics. For a time ratio control scheme (see Fig. 1(d)) of the square voltage pulse density modulation, the output power characteristics becomes almost linear in the power regulation in characteristics under the open loop control implementation. Furthermore, it is noted that the ZCS commutation can be achieved for the main switches S_1 and S_2 over all the pulse density control ranges, observing the voltage and current operating waveforms illustrated in Fig. 3(g)



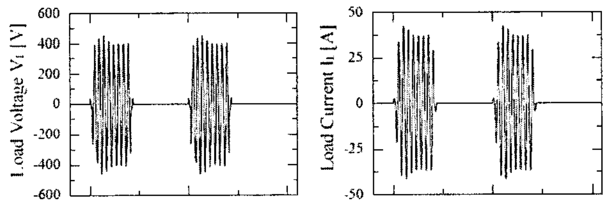
(a) Inverter output voltage v_o and output current i_L of the 10[%] ratio in the pulse density.



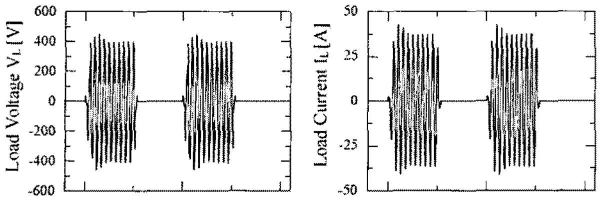
(b) Inverter output voltage v_o and output current i_L of the 20[%] ratio in the pulse density.



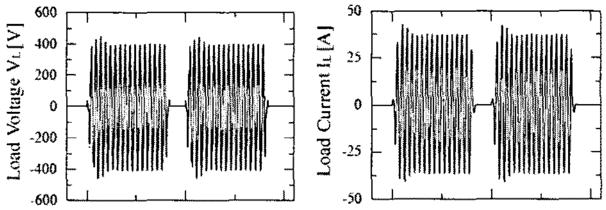
(c) Inverter output voltage v_o and output current i_L of the 30[%] ratio in the pulse density.



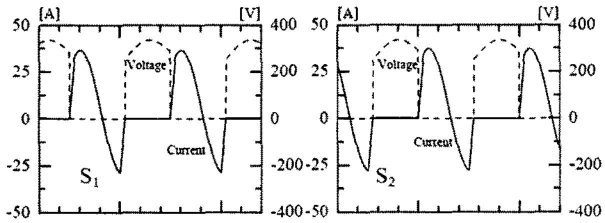
(d) Inverter output voltage v_o and output current i_L of the 40[%] ratio in the pulse density.



(e) Inverter output voltage v_o and output current i_L of the 50[%] ratio in the pulse density.



(f) Inverter output voltage v_o and output current i_L of the 80[%] ratio in the pulse density.



(g) Voltage and current of the switch waveforms in the power injection mode.

Fig. 3 PDM controlled inverter power regulation performance

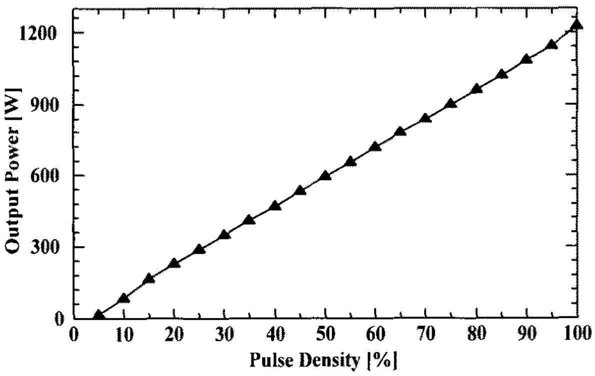


Fig. 4 Power control regulation characteristics.

IV. CONCLUSIONS

In this paper, the transient and steady state circuit operation in a constant high frequency PDM control strategy of the lossless inductive snubbers-assisted high frequency series load resonant inverter using the two in one trench gate IGBT module has been presented, which can operate under ZCS transition and commutation. This soft switching high frequency inverter was effectively applied for the efficient IH rolling drum for the fixing heating processing unit in the new copy machine as the consumer intelligent office automation. As a result, the output effective power of this ZCS inverter using the trench gate controlled IGBTs in new generation was able to be widely regulated from 50[W] to 1200[W] under a fixed frequency PDM control implementation. It was also verified that the output power of this inverter can be controlled continuously and linearly under the condition of complete ZCS principle. A pulse density modulation based on the ZCS high frequency inverter unit will be applied for the silent discharge exciplex lamp type UV generation and ozone generation tube in industry and consumer power application plants.

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Shin-Chul Kang
received the B.S. degree in Electrical Engineering from Pukyong National University, Busan, Korea in 1988. M.S. and Ph. D. degrees in Department of Electronic Engineering from the Dong-A University, Busan, Korea in 1990 and 1995 respectively. From 1978 to 1996, he was a Korea Telecom(KT). And From 1996 to 1997, he was a Chang Won Politechnic College. Since 1997, he has been a faculty member in the Dept. of Electrical at the Gyeong-Nam Provincial Namhae College, where he is currently an associate Professor. His research interests are Control System Analysis, Fuzzy & Artificial Intelligence control etc. He is a member of KIMISC, KMS, KIEE, and KFIS.