Pulse Density Modulation Controlled Series Load Resonant Zero Current Soft Switching High Frequency Inverter for Induction-Heated Fixing Roller

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Abstract –This paper presents the two lossless auxiliary inducors-assisted voltage source type half bridge(single ended push pull:SEPP) series resonant high frequency inverter for induction heated fixing roller in copy and printing machines. The simple high-frequency inverter treated here can completely achieve stable zero current soft switching (ZCS) commutation forwide its output power regulation ranges and load variations under constant high frequency pulse density modulation (PDM) scheme. Its transient and steady state operatprinciple is originally described and discussed for a constant high-frequency PDM control strategy under a stable ZCS operation commutation, together with its output effective power regulation charactertics-based on the high frequency PDM strategy. The experimenoperating performances of this voltage source SEPP ZCS-PDM series resonant high frequency inverter using IGBTs are illustrated as compared with computer simulation results and experimenones. Its power losses analysis and actual efficiency are evaluated and discussed on the basis of simulation andexperimental results. The feasible effectiveness of this high frequency inverter appliimplemented here is proved from the practical point of view.
Keyword s- Series load resonant circuit topology, Lossless inductive snubbers, Zero current soft switching, discrete pulse density modulation, Induction heated roller, Cylindrical working coil stator

1. INTRODUCTION

For industrial and consumer IH power applications in next generathe voltage-fed high frequency inverter with series capaciresonant tank circuitry has been widely applied so far. The general method of output power regulation in this kind of high frequency inverter is based on pulse frequency modulation (PFM) scheme of its inverter frequency. The PFM strategy implies changthe working frequency of the inverter that has essentially some drawbacks for IH applications. That is to say, the high freAC effective output power in case of PFM control strategy delinearly to square root of the series load resonant inverter workfrequency and inverter system efficiency decreases signififor light load in copy machine, facsimile, scanner, data recorder and printer in stand-by mode. In adto this, when two or more invertare assembled in a set of equipment, the actual problem of acoustic noise due to the difoperating frequency of the invertmay occurs. Furtherthe skin effect resistance of the IH fixing roller as well as the depth of the inducededdy current penetration depend on inverter working frequency have much worse influence on the temdistribution characteristics of the IH fixing drum roller.

In this paper, the voltage source type half-bridge series resonant voltage-fed series load resonant inverter with two lossless inductor snubbers in series with each active switch is introduced, which can operate under a high frequency PDM-ZCS operation conditions. The high frequency power regulation characteristics of the developed high frequency series load resonant inverter which is based on a constant high frequency PDM-ZCS are presented in this paper, together with the performance evaluations of the power losses analysis or efficharacteristics on the basis of thesimulation.

2. Induction-heated Fixing Roller Equipment

Presently, the main electric heating method for the fusing roller as light radiant heated roller in the copy and printing machines is introduced which can be heated directly by light emission from the halogen lamp. This scheme has some disadvantages such as relatively low efficiency, required maintenance, easy to temperature, non-recycle, quicker temperature response and short life. On the other hand, the fusing heat roller with an inducworking coil inserted inside the rolling drum made of stainless steel plate is depicted schematically in Fig.1. The titanium alloy and the carbonceramic are effectively applied for the

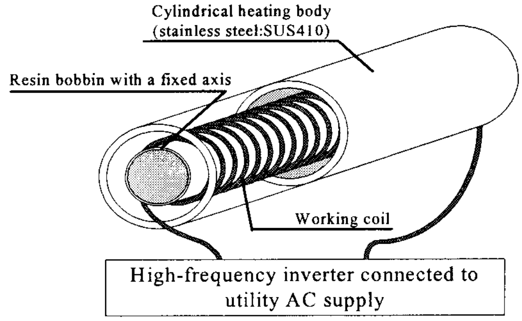


Fig.1 Induction heating fusing roller

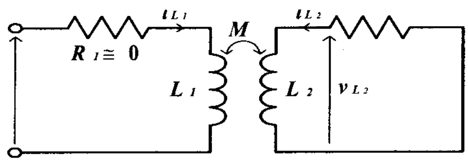


Fig.2 Transformer model of induction heating load

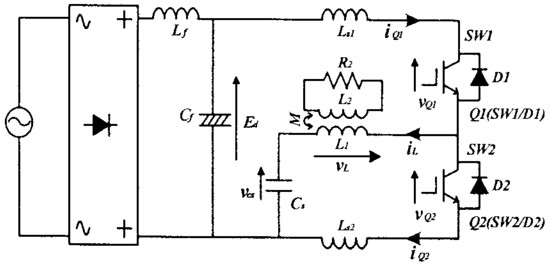


Fig.3 Voltage source ZCS-PDM high frequency inverter system for induction heated fusing roller

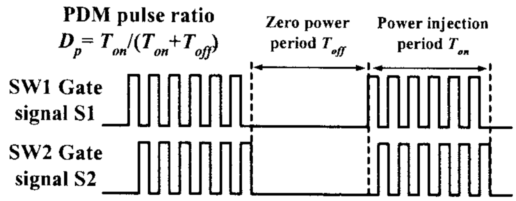


Fig.4 Principle of high frequency PDM time ratio control for series resonant inverter

Table 1 Design specifications and circuit parameters

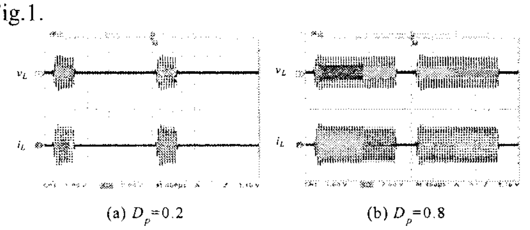
Quantity	Symbol	Value
Input DC voltage	E_d	280V
Series resonant capacitance	C_r	0.49μF
ZCS inductive snubber value	L_s	12.0μH
Self inductance of work coil	L_1	90.0μH
Time constant of the load	τ	9.23μsec
Electro Magnetic coupling co-efficient	k	0.48
IGBT(TO-3P)	V_{CE}	600V
	I_C	75A
Antiparallel diode (TO-3P)	V_{RM}	600V
	I_0	30A

induction heated fusing heat roller in the copy machine and so forth.

3. PDM Controlled Series Load Resonant High Frequency ZCS Inverter

3.1 Main Circuit Description

The overall high frequency power conversion syscomposed of the voltage-fed half bridge series load resonant ZCS-PDM controlled high frequency inverter using IGBTs is dein Fig.3. A DC voltage E_d is applied to the voltage source-fed high frequency inverter via single phase capacitor input type diode full bridge rectificaof 200V/60Hz utility AC power source grid. The single phase PFC converter with boost chopper can be conveniently used in place of diode rectifier. For cost effective appliance design, a diode rectifier with non-smoothing filter is connected in the input side of high frequency ZCS-PDM inverter. This high frequency inverter consists of the active power switches Q_1 and Q_2 the reverse conducting switches due to the power semiconductor switches (IGBTs); SW1 and SW2 with antiparallel diodes; D_1 and D_2 C_r as a tuned resocapacitor in series with IH load. L_{s1} and L_{s2} as auxiliary ZCS-assisted inductive losssnubbers connected in series with Q_1 and Q_2 and the indution-heated fusing heat drum roller represented by the transformer circuit modeling. In this high frequency series load resonant inverter circuit, the active power switches Q_1 and Q_2 can operate completely under ZCS principle and its high frequency AC power regulation based on a variable pulse frequency modulafor both turn-on and turn-off mode zero current soft switching commutations. The effective AC output power of the high frequency inverter in Fig.3 can be newly regulated by a constant high frePDM control strategy on the basis of the pulse group modulation principle in Fig.4. The IH load surrounded by the dotted line is the transformer model parameters represented by the circuit parameters; four unmeasur values (M, L_2, k, R_2) or two measurable values (L_1, $k = M/\sqrt{L_1 L_2}$, $\tau = L_2/R_2$)of the IH load comprised of the cylindrical working coil and inducheated fusing roller load disin Fig.1.



v_L:500[V/div], i_L:40[A/div], t: 400[μsec/div]

Fig.5 Experimental waveforms of v_L and i_L for PDM duty cycle

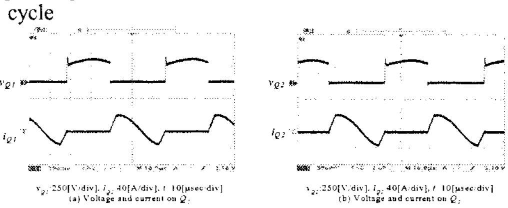


Fig.6 Experimental waveforms of switch voltage and currentfor steady state injection mode

3.2 Pulse density modulation controlled high frequency AC power regulation

As shown in Fig.4, the high frequency AC power regulation can be achieved by varythe pulse density modulation under time ratio during T_{on} period, when the AC output power is injected into the induction heated load and a period T_{off}, on the other hand, when the AC output power is non-injected into the inducon heated load. With the changing the PDM time ratio, the applied pulse density ratio is taking place while the working freof the high frequency inverter is kept constant under a condiof zero current soft switching transition commutation.The auxiliary inductive snubbers; L_{s1} and L_{s2} (L_{s1}= L_{s2}=L_s) in series with the active switches provide ZCS commutation operation for Q_1 and Q_2 in the continuous load current mode which is based on the overlapping current in (SW_1, D_2) and (SW_2, D_1).

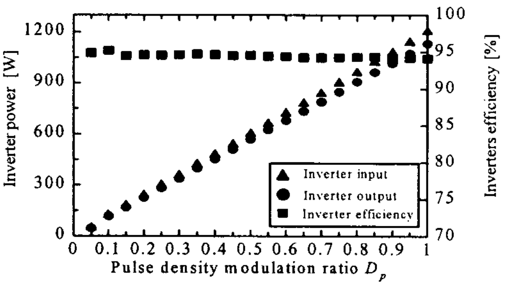


Fig.7 High frequency AC power regulation characteristics in experimence

4. Experimental Results and Evaluations

4.1 Pulse density modulated output voltage and current

The developed voltage source high-frequency series resonant ZCS-PDM inverter uses IGBTs (Mitsubishi Electric Co.,Ltd., CT75AM-12) with soft recovery fast switching diodes (Origin Electric Co.,Ltd, US30P) as the antiparallel fast recovery diodes. For pulse density modulation ratio D_p=0.2 and D_p=0.8 in a PDM control scheme, the measured operatwaveforms of load current i_L and load voltage v_L are depicted in Fig.5. Observed voltage and current waveforms v_{Q1} & i_{Q1}, v_{Q1} & i_{Q1} for the active power switches Q_1 and Q_2 in switching arms of a voltage source type series resonant ZCS-PDM inverter are shown in Fig.6.

The validity of the transformer type circuit models parameters of the induction heated type fusing heat roller load in Fig.1 is proven on the basis of these experimental results.

4.2 Output high frequency AC power regulation and efficiency characteristics

Figure 7 illustrates the pulse density modulation ratio D_p vs. output power characteristics and pulse density modulation ratio D_p vs. power conversion efficiency characteristics for voltage source type series resonant high frequency ZCS-PDM inverter in Fig.4. The high frequency AC output effective power of the high frequency inverter treated here can be regulated and linearly by changthe pulse density modulation ratio D_p. For output power regulation ranges from 5% to 100% of the maximum output power, the actual AC power conversion efficiency more than 94% can be obby the breadboard setup implementation. Especially, it is more important that actual efficiency more than 94% is able to be achieved even for both D_p =1.0 in copy machine printing mode and D_p =0.05 in its stand-by mode, which make the proposed voltage source series resonant ZCS-PDM conhigh-frequency inverter more effective for the induction heating type fusing heat roller applications in copy and printing machines.

5. Conclusions

In this paper, the voltage-fed high-frequency half-bridge (single ended push-pull; SEPP) type series load resonant zero current soft switching inverter topology with ZCS-assisted two auxiliary inductive snubhas been introduced for the induction-heated fusing roller in the copy and printing machines. Its steady state inverter operation under PDM control scheme has been evaluated and discussed on the basis of simulation and experimental data.

The high frequency AC power regulating characteristics and operating performances of this simple voltage source SEPP series resonant high frequency ZCS-PDM inverter using IGBT modules in steady state operation has been qualitatively evaluated in simulation and experiment. For the power loss estimations of this high freinverter, the transformer type circuit model of the inducfusing roller in copy and printing machines has been used from a practical point of view.

The actual high efficiency more than 94% of the series load resonant ZCS-PDM high frequency inverter for IH roller in copy and printing machines has been observed for all the output AC power regulation ranges from 50W to 1200W with stable zero current soft switching operation processing and linear output power control characunder a condition of ZCS commutation. The voltage source SEPP type high frequency series resonant ZCS inverter with lossless inductive snubbers, which is based on a constant frequency PDM control scheme, has provided its practical effectiveness for the stand-by mode and printing mode. Furthermore, rising time and power consumption characteristics of copy machine system have been compared halogen heater type fusing roller with IH type one. As a result, IH fusing roller is effective than halogen heater type fusing roller for copy machine.

Acknowledgment

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