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Development of Hybrid Induction Heating System for Laser Printer

Young-Min Chae†, Joong-Gi Kwon*, Sang-Yong Han* and Hwan-Ho Sung**

†*Digital Printing Division, R&D Group 2, Samsung Electronics Co., Suwon, Korea
**PSTEK Co., Ansan, Korea

ABSTRACT

Recently, the demand for the development of high quality and high-speed laser printers and efficient power utilization has required. Among complicated electro-mechanic devices in laser printers, the toner-fusing unit consumes above 90[%] of all electrical energy needed for printing devices. Therefore, the development of a more effective energy-saving toner fusing process becomes a significant task in great demand. Generally, there are several ways to implement a fusing unit. Among them this paper presents a new induction heating method. The proposed induction heating method enables the increase of coupling coefficient between heating coil and heat roller which also increases total energy transfer efficiency. Therefore, the proposed IH (Induction Heating) inverter system provides very fast W.U.T. (Warm UP Time) as well as higher efficiency. Through experimental results, the proposed control system is verified.

Keywords: Laser Printer, Fusing System, Induction Heating, Half-Bridge Inverter, Resonant Converter

1. Introduction

Recently, according to the development of SOHO (Small Office Home Office) businesses and the surge in population of personal computers, a demand for the development of high quality and high speed laser printers has increased. In addition, in terms of energy conservation, efficient power utilization related to the laser printer has become more significant.

Normally, a laser printer translates the image data to visible paper through the electro-photograph process. This main electro-photograph process consists of the five following processes: charging, exposing, developing, transfer, and fusing, which are shown in Fig. 1. Through the charging to transfer process, the visible image formed on the OPC drum will transfer to the paper by using a toner particle. Finally the fusing unit, which consists of a high temperature heat roller and pressure roller, melts the toner and attaches the final image to the paper.

Normally, the halogen lamp based fusing unit is used because of low cost and its simple structure. The halogen lamp is placed in the center of the heat roller and generates the radiant energy. This radiant energy is transferred to the heat roller. In consideration of this, the toner fusing unit consumes more than 90% of all electrical energy needed for the printer. The development of a more effective energy-saving toner fusing process becomes a significant task in great demand.

Several heat control methods are being developed to reduce the electrical energy consumption based on the halogen lamp method. However, this heating method has many inherent drawbacks because it uses an indirect

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†Corresponding Author: ym.chae@samsung.com
Tel: +82-11-9170-5564, Fax: +81-31-277-8290,
*Dept. of Digital Printing Division, Samsung Electronics Co.
**PSTEK Co.

heating process, which can cause radiant heat loss. To overcome this, the resistive heating method is proposed. This method enables the warming of the heat roller directly using ohmic heat energy of the heat wire which is attached inside of the heat roller. AC source voltage is applied to the heat wire as shown in Fig. 2. This direct resistive heating method also has some drawbacks because it connects directly to the AC source and requires high electrical insulation between the heat roller and heat coil for safety reasons. To solve this problem, the direct heating method of the heating roller by the induction heating method can be an attractive solution. However, only a few publications and research issues on this development have been presented.

Generally, the eddy current based induction heating method has the following merits: safety, reliability, higher efficiency, faster heating time and simpler and more precise temperature control[1-7].

Therefore, in high quality laser printer applications, the development of a high frequency power supply for the induction heating in the fusing unit necessitates an important and timely task. For small power based industrial IH power applications, the voltage-fed inverter with series resonant load is widely applied because of its reliability and simple structure. Therefore in this paper, a new high efficiency half-bridge inverter with a series resonant circuit for induction heating is proposed.

2. Induction Heating Method and System Configuration

The induction heating method uses the magnetic field energy, which is induced in the coil in AC voltage and then causes the eddy current to occur. This eddy current generates a joule heat as following Eq. 1. The generated joule heat caused by eddy current is normally concentrated in a peripheral layer of skin depth δ shown in Eq. 2. Where μ and ρ are relative magnetic permeability and electrical resistance of the material, and f means the operating frequency of induction coil respectively. Therefore, by increasing the operating frequency the skin depth can be reduced, which means by increasing the operating frequency, it is possible to generate heat directly at the surface of the heat roller with the same power output[1-7].

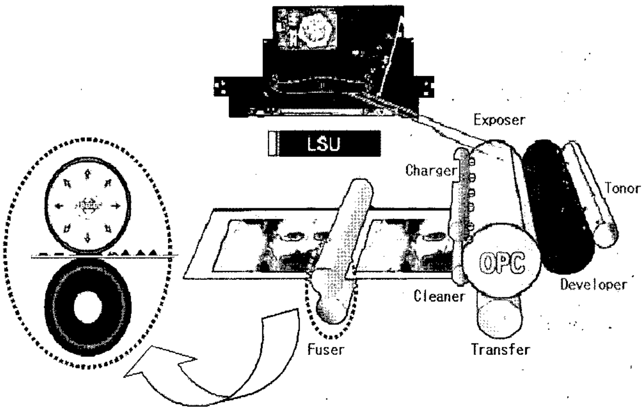
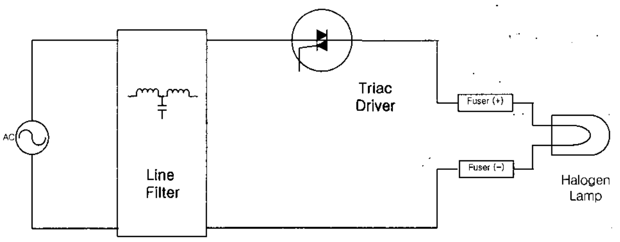
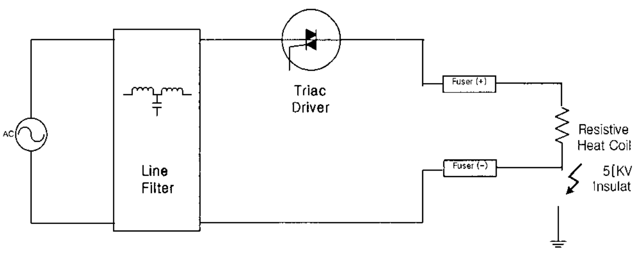


Fig. 1 Electro Photograph Process in Laser Printer



(a) Halogen Lamp Fusing System



(b) Resistive Heating Fusing System

Fig. 2 Conventional Fusing System for Laser Printer

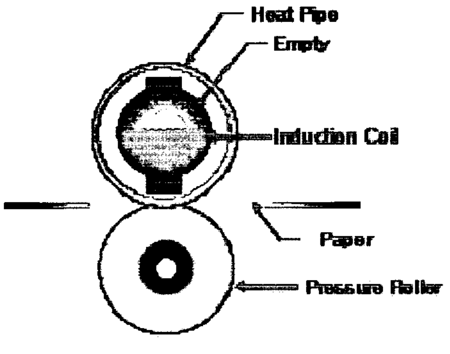
$$P = i_{eddy}^{2} R \tag{1}$$

$$\underline{\delta} = \sqrt{\frac{\Upsilon}{\Phi_0 \Phi_r f}} \tag{2}$$

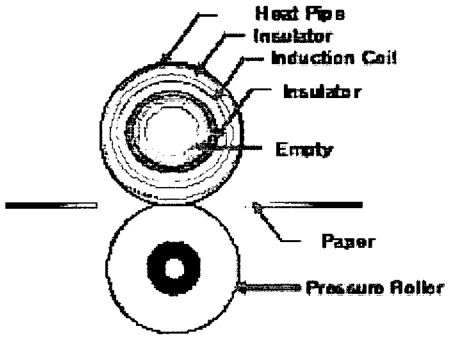
The physical structure of the conventional IH fusing unit is shown in Fig. 3(a). It mainly consists of a heat roller, induction coil and pressure roller. Normally, when the paper is transferred to the fusing unit, the heat roller and pressure roller circulate together and transfer the accumulated heat energy onto the paper to melt the toner particle.

The induction coil is placed in the center of the heat roller with a fixed position. It is therefore essential to maintain some gap between the heat roller and bobbin of induction coil. This structure reduces the coupling coefficient between the heat roller and induction coil. To improve this drawback, this paper proposes a new IH method by increasing the coupling coefficient between the heat roller and induction coil. As shown in Fig. 3(b), the proposed IH method tightly couples the induction coil to the heat roller. To prevent the electrical shortage an insulator is used between the heat roller and induction coil. The use of this physical structure enables the coupling coefficient to improve and ultimately reduces the warm up time of the heat roller, which will be shown in the experimental results.

Fig. 4 shows the proposed heat roller and IH inverter system. As explained, the proposed IH coil can consist of a single cooper layer placed beneath the heat roller, and for the purpose of isolation and impedance matching high frequency transformer connected HB invert system is implemented.



(a) Conventional IH Fusing Unit

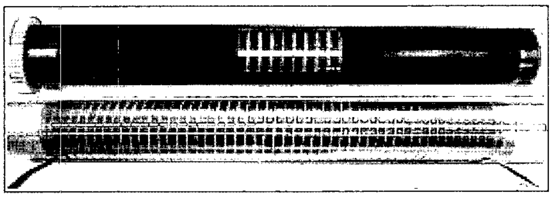


(b) Proposed IH Fusing Unit

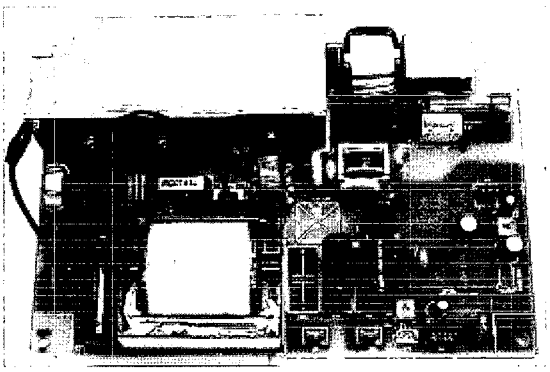
Fig. 3 Physical Structure of Conventional and Proposed IH Fusing Unit

Fig. 5(a) shows the circuit structure of the IH inverter which mainly consists of a diode rectifier, DC link capacitor, MOSFET, transformer, resonant capacitor and IH coil. The rectified DC voltage will be chopped with a high switching frequency (90-180[KHz]) by the HB inverter, and this chopped high frequency AC voltage will be transferred to the second side of the transformer connected with a series resonant capacitor and induction coil. This applied high frequency AC voltage enables the operate resonant circuit mode and achieves the ZVS (Zero Voltage Switching) operation in the main MOSFET switches which will be explained in detail.

Fig. 5(b) shows the overall control block diagram of the proposed IH inverter system, and the main CPU decides the heater ON/OFF state through the temperature sensor (Thermistor). During the ON period the main CPU generates the output power reference signal with digital value or PWM duty. Based on this power reference signal and sensed real power signal, the inverter controller calculates the required output power. To generate the adequate real power, the switching frequency of the inverter changes through the PFM modulator with PLL loop.

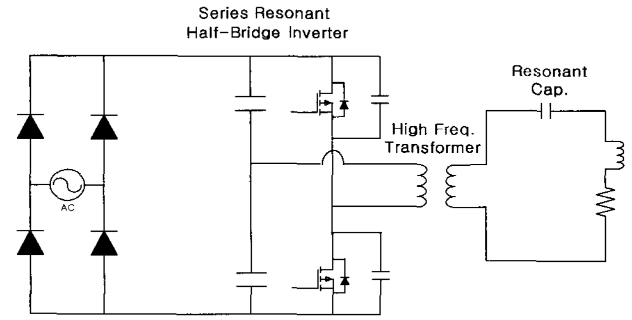


(a) Proposed IH Coil Structure

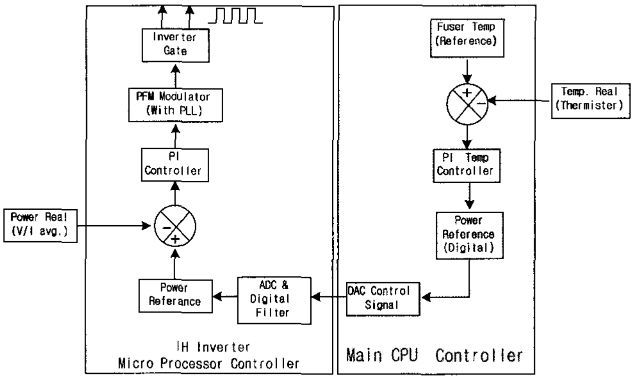


(b) Proposed IH inverter System

Fig. 4 Figure of Proposed IH Fusing System



(a) Circuit structure of Proposed IH system



(b) Control block diagram of Proposed IH system

Fig. 5 System Structure of Proposed IH Fusing Unit

3. Circuit Operation of IH Series Resonant Half-bridge Inverter

The circuit topology of a half-bridge series resonant inverter with zero-voltage switching operation is shown in Fig. 6. It consists of two bidirectional switches Q_1, Q_2 and the series-resonant circuit L_{eq}, R_{eq}, C_r. Each of these switches is composed of a transistor, an intrinsic anti-parallel diode and the output capacitance which is embedded between the drain and source terminal in MOSFET. The principle operation for the ZVS HB inverter is explained by the waveform sketched in Fig. 7. The voltage at the input of the series-resonant circuit is a square wave. If the load quality factor Q_L of the resonant circuit is high enough, the current i_L through this circuit is nearly sinusoidal. For $f_s > f_{resonant}$, the series-resonant circuit represents an inductive load and the current i_L lags behind the inverter voltage V_S by the phase angle ψ ($\psi>0$). Hence, the switch current is always negative before the transistor is turned on. The proposed ZVS HB inverter has six operation states during one-cycle shown in Fig. 7, whose operation states will be explained as follows [3-6]:

3.1 State 1 [$t_0 \le t_1$]

At $t=t_0$, the switch Q_2 is turned off. The load current i_L flows through the series resonant circuit and the parasitic capacitance of the MOSFET is in the negative direction. Therefore, capacitor C_2 is charged and C_1 is discharged by the primary current.

As a result, the voltage V_{c1} decreases linearly from $V_d/2$ to zero, while the voltage V_{C2} increases linearly from zero to $V_d/2$. The result is the inverter output voltage V_s is changed from $-V_d/2$ to $V_d/2$.

3.2 State 2 [$t_1 \le t_2$]

When the voltage V_{c1} becomes zero, the anti-parallel diode D_1 of switch Q_1 begins to conduct. During this time interval, the switch current increases with series-resonant characteristics, before this current reaches zero.

3.3 State 3 [$t_2 \le t_3$]

At $t=t_2$, the switch current reaches zero. Q_1 is turned on with ZVS. At this point, the series-resonant current i_L, flows in a positive direction. In this state, the active power flows through the impedance matching transformer with constant power. During this state, input power is transferred to the series-resonant load until $t=t_3$.

3.4 State4 [$t_3 \le t_4$]

Unlikely state 1 interval, at $t=t_3$, the switch Q_1 is turned off. The load current i_L flows through series-resonant circuit in a positive direction. Therefore, capacitor C_1 is charged and C_2 is discharged.

As a result, the voltage V_{c2} decreases linearly from $V_d/2$ to zero, while the voltage V_{c1} increases linearly from zero to $V_d/2$.

3.5 State5 [$t_4 \le t_5$]

When the voltage V_{c2} becomes zero, the anti-parallel diode D_2 of switch Q_2 begins to conduct. The switch current flows through diode D_2, before this current reaches zero. In fact, there is a small negative voltage of the anti-parallel diode, but this voltage can be negligible in comparison to the input DC voltage V_d.

3.6 State6 $[t_5 \le t_6]$

At $t=t_5$, the switch current reaches zero. Q_2 is turned on with ZVS. After that, the series-resonant current i_L flows in a negative direction. As a result, the conduction sequence of semiconductor devices is D_1-Q_1-D_2-Q_2. This means the HB inverter operates in an inductive resonant mode, while the turn-on switching loss becomes zero.

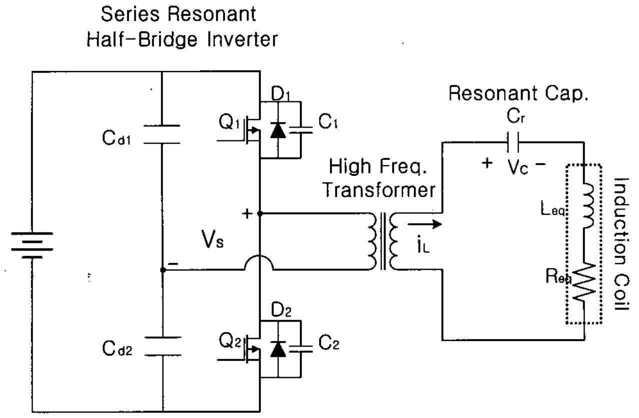


Fig. 6 Simplified Circuit of IH Half-Bridge Inverter

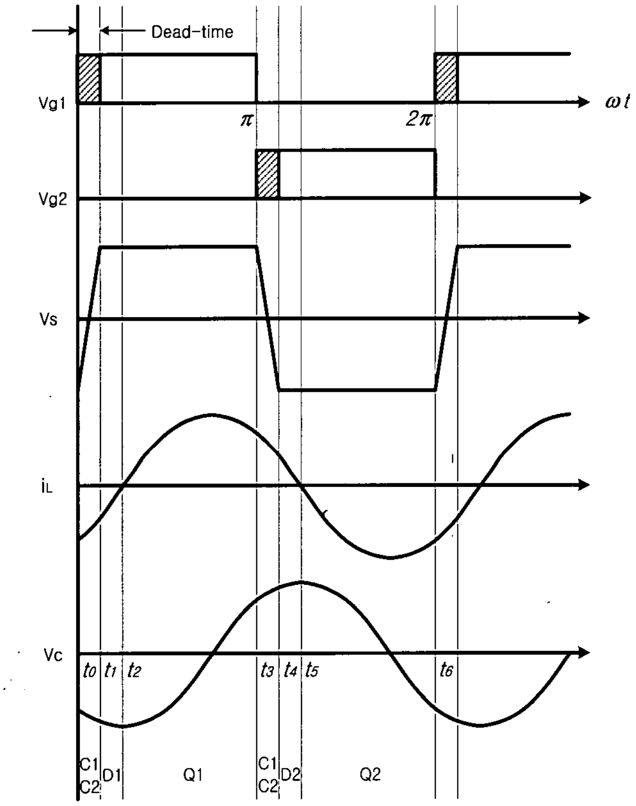


Fig. 7 Key Waveform of HB ZVS Inverter

In particular, there is no reverse recovery current spike of the anti-parallel diode for the opposite switch and also the total switch turn on loss is decreased nearly to zero. Compared with the capacitive load operation, the inductive load operation shows better switching loss and noise characteristics.

4. Experimental Results

The proposed new IH inverter generates 1.5[KW] maximum power, under 220[V]±20[%] input voltage conditions. As explained above, the whole power control is performed by the digital controller based on temperature sensing. The following Table 1 shows the major design specifications and parameters for the new IH inverter fusing system.

To control the real power of the IH inverter system, the PFM (Pulse Frequency Control Method) is used with PLL (Phase Lock Loop) control, so the switching frequency varies depending on load requirements. As shown in Fig.3, the proposed IH coil is placed beneath the heat roller with a single layer, therefore the inductance of the heat roller is of small size 6-12[uH] and is optimized considering the resonant capacitor and switching frequency.

Figure 8 shows the voltage and current waveform of input and output power. The input current is sinusoidal compared to input voltage with the unity power factor. The output voltage and current shows a highly chopped waveform for input voltage and current. In addition, the dependence on load power input current and output power varies linearly.

Table 1 Design Specifications and Parameter

ITEM	Specification
Input Voltage	220 [V] ± 20 [%]
Max. Power	1.5 [KW]
Switching Frequency	90 ~ 180 [KHz]
Resonant Capacitor	150 [uF]
IH Coil Inductance	8 [uH]
Transformer	16T/16T (EER4954 Core)
Control Method	Digital Control

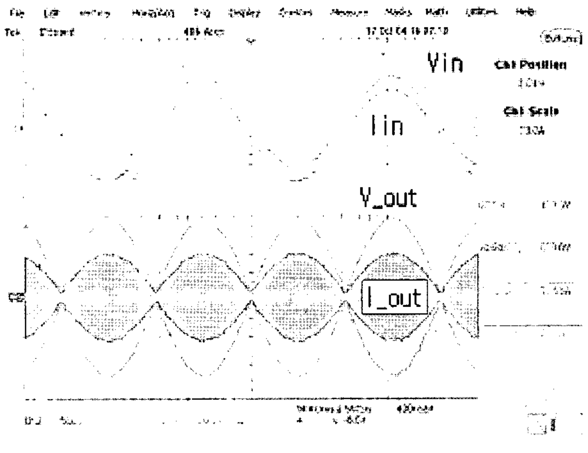
As explained in section 3, the proposed ZVS IH inverter operates in a series-resonant circuit mode, so the inductive load current i_L always lags behind the Vs by the phase angle ψ, and the current is always negative before the transistor is turned on. Figure 9 (a) and (b) show the inverter output voltage, load current and resonant capacitor voltage. Compared with waveform Fig. 7, the experimental waveform exactly coincided.

As power decreases from full to minimum, the load current and capacitor voltage decreased linearly.

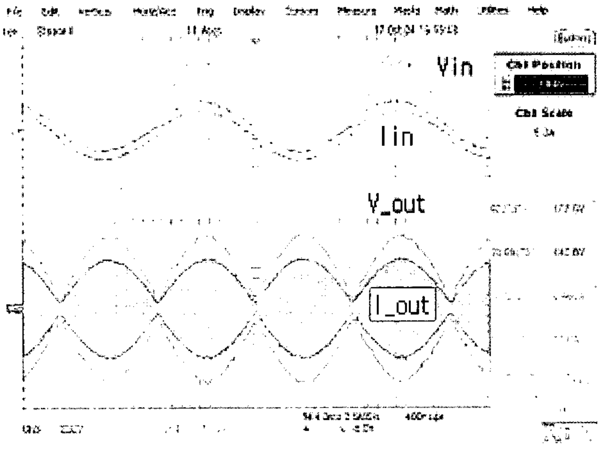
Fig. 10 represents the generated output power according to DAC output value. From this figure, it is shown that the linearly controllable output power is a recorded minimum 240[W] and maximum 1.5[KW]. Within this area, the output power of the proposed system is proportional to the DAC value control signal.

In Fig. 11, the apparent power Q is measured according to the real input power. From this, it is possible to observe that the phase angle ψ maintains a constant level by using a PLL control algorithm. Fig. 12 shows the results of power factor characteristics according to the load changes. From this figure, it shows near unity in the power factor regardless of load changes.

By comparison the W.U.T. characteristics between a conventional halogen ramp and the proposed IH fusing unit, it is possible to reduce the time from 90[sec] to 23[sec] drastically based on 180[°C] heat roller temperature.

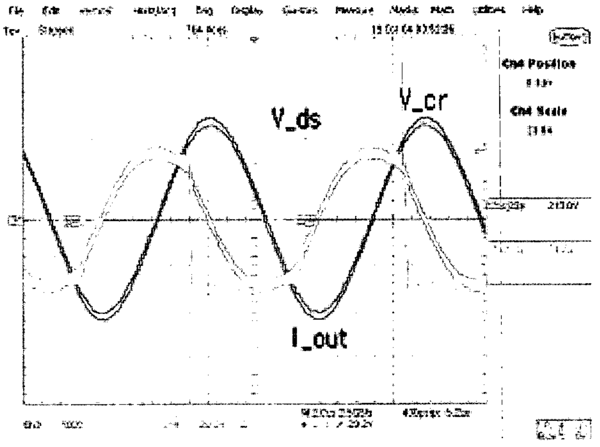


(a) Maximum load condition 1.4[KW]

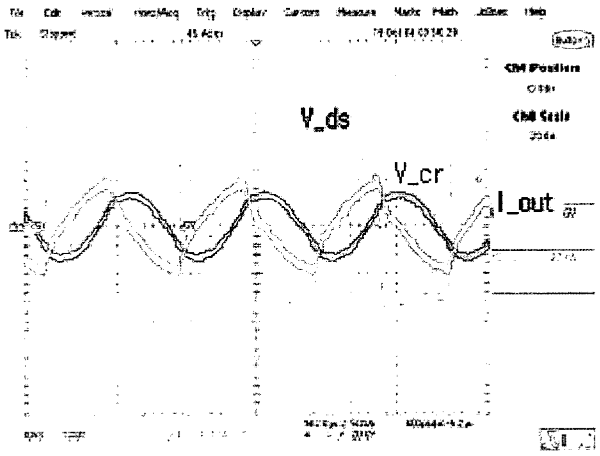


(b) Minimum load condition 300[W]

Fig. 8 Input and Output Power Waveform of Proposed IH Inverter System



(a) Maximum load condition 1.4[KW]



(b) Minimum load condition 300[W]

Fig. 9 Output Voltage and Current Waveform of Proposed IH Inverter System

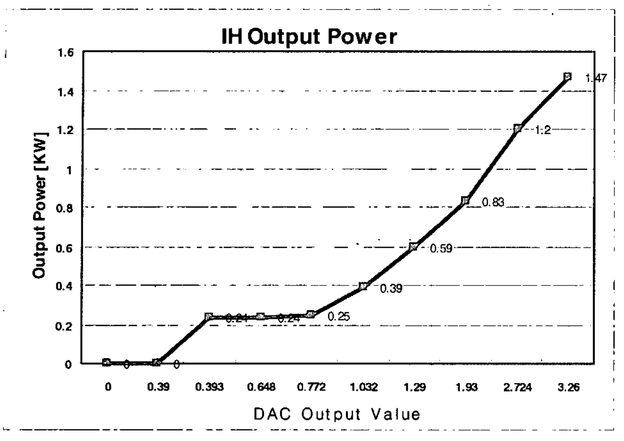


Fig. 10 Output Power Control Characteristics of Proposed IH Fusing Unit

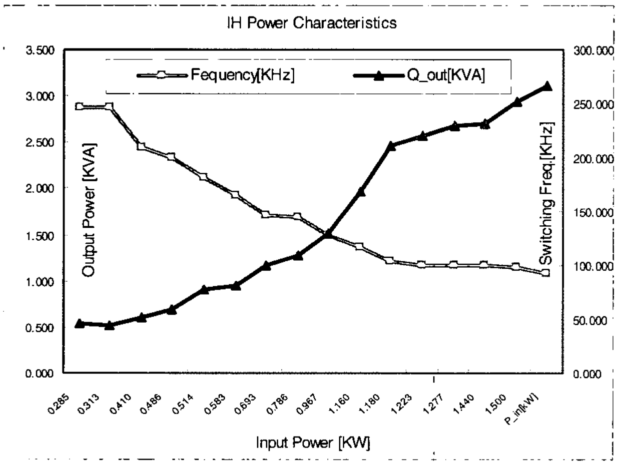


Fig. 11 Characteristics of Apparent Output Power & Switching Frequency

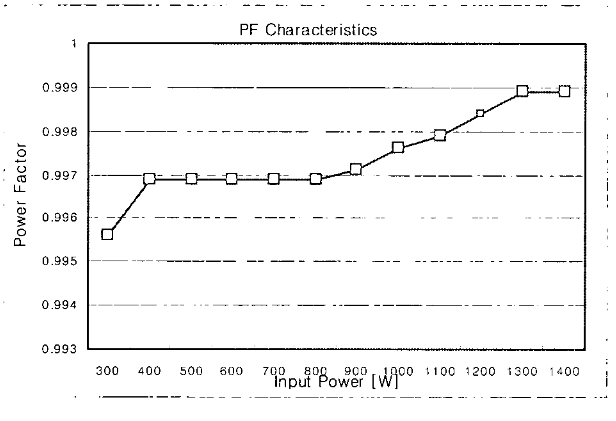


Fig. 12 Power Factor Comparison Results

5. Conclusion

In this paper, a new IH method to reduce the W.U.T. of laser printers is proposed, made possible by increasing the coupling coefficient between the heating coil and heat roller which also increases total energy transfer efficiency. To achieve these performance enhancements, this paper proposes a new physical structure of the IH fusing unit and ZVS switched inverter with resonant operation. To verify the proposed control method, various experiments and performance evaluations are performed.

References

[1] Nakaoka M. "High Efficient Series Resonant High Frequency Inverter with ZCS-Pulse Density Modulation for Copy Machine Fixing Roller in Office Information and Automation Applications," in Proc of PEDS, Vol.1, pp. 114-119, Nov., 2003.

[2] Yong-Chae Jung “High Power Factor Dual Half Bridge Series Resonant Inverter for an Induction Heating Appliance with Multiple,” KIPE Trans., Vol. 3, No. 4, pp. 307~314, 1998.

[3] Dae-Cheul Shin, Hyuk-Min Kwon. etc “A Study on the Development of Superheater Using High-Frequency Resonant Inverter for Induction Heating,” KIPE Trans., Vol. 9, No. 2, pp. 119~125, 2004.

[4] Arcero J. etc " A Comparative Study of Resonant Inverter Topologies Used in Induction Cookers," in Proc. of APEC (Applied Power Electronics Conference), Vol.2, pp. 1168-1174, March, 2002.

[5] Hyun D. S. etc " Half-Bridge Series Resonant Inverter for Induction Heating Applications with Load-Adaptive PFM Control Strategy," in Proc. of APEC (Applied Power Electronics Conference), Vol.1, pp. 575-581, March, 1999.

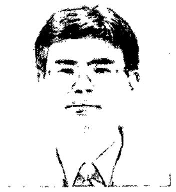
[6] Matsuse K. etc "Analysis of High-Frequency Induction Cooker with Variable Frequency Power Control," in Proc. of Power Conversion Conference, Vol.3, pp.1502-1507, April, 2002.

[7] Yongmin Chae, etc “IH Techniques Usable in Laser Printer,” KIPE Journal., Vol. 10, No. 4, pp. 15~19, 2005.

[8] Marian K. K. "Resonant Power Converters," Wiley-Interscience, 1995.

Youngmin Chae was born in Seoul, Korea in 1967. He received the B.S., M.S. and Ph.D. degrees in electrical engineering from University of the Konkuk, Korea, in 1993, 1995 and 1999, respectively. Since 1999, he has been senior electrical engineer, in Delta Power Electronics Lab, North Carolina, U.S.A. Since 2002, he is currently a senior electrical engineer in Samsung Electronics Co. His research interests are in the areas of Power Factor Correction, SMPS and High Frequency Inverter system. Dr. Chae is a Member of the Korean Institute of Power Electronics, Korea, and reviewer of PESC and APEC of IEEE.

Joonggi Kwon was born in Andong, Korea, in 1960. He received the B.S. degrees in electrical engineering from the University of the Soongsil, Korea, in 1986. Since 1989, he has been a principle electrical engineer in Samsung Electronics Co. His research interests are SMPS and HVPS. Mr. Kwon is a Member of the Korean Institute of Power Electronics, Korea.



Sangyong Han was born in Daegoo, Korea, in 1958. He received the M.S. degrees in electrical engineering from the University of the Kyungpook, Korea, in 1994. Since 1981, he has been a principle electrical engineer in Samsung Electronics Co. His research interests are SMPS and communication network. Mr. Han is a Member of the Korean Institute of Power Electronics, Korea.

Hwanho Sung was born in Changyoung, Korea in 1964. He received the B.S., degrees in electrical engineering from the Seoul National University, Korea, in 1987, and M.S. and Ph.D. degrees in electrical engineering from KAIST, Korea, in 1990 and 1994, respectively. From 1991 to 1998, he has been senior electrical engineer, power electronic division in Samsung Semiconductor, Korea. Since 1998, he is currently a present of PSTEK Co. His research interests are in the areas of SMPS, high frequency inverter system and induction heating system. Dr. Sung is a Member of the Korean Institute of Power Electronics, Korea.