A Study on Constant Power Control of Half Bridge Inverter for Microwave Oven

Min-Ki Lee*, Kang-Hoon Koh and Hyun-Woo Lee****

Abstract - For the global microwave market, high RF power or deluxe model is applying for inverter gradually. In this paper, 120[V]/1200[W] high power inverter is proposed and verified by an optimized design of PFM type. Especially the steady power output control was fulfilling at +/- 10[%] input voltage variation.

Keywords: Half bridge inverter, Microwave oven, IGBT, Constant power control, PFM

1. Introduction

As a power supply system, inverter is applying for the microwave oven increasingly due to following merit [1]~[2]. Firstly, inverter type power supply system can be designed high power easier than LC resonance type power supply system. Secondary, linear power output can be obtained and controlled precisely. Accordingly, cooking and defrost performance for microwave oven function is improved [3]~[6].

In this paper, PFM(Pulse Frequency Modulation) control suitable for the microwave oven inverter is described. A compensation circuit accompanied by input voltage variation and IGBT operating circuit is proposed and major characteristics were tested for the half-wave bridge inverter of designed series resonance type.

2. Inverter system design for microwave oven

2.1 Proposed Inverter

Fig. 1 shows the proposed block diagram that consists of inverter power supply part and Micom controller.

The power output compensation circuit in power supply part of inverter is to detect input voltage variation. The output voltage of DA converter is in inverse proportion as input voltage variation by this output and compensated. Accordingly, this compensation circuit is to function as input voltage variation and compensated DA converter output is connected to the non-inverting terminals of OP AMP. CT(Current Transformer) is inserted in a terminal of power supply and its output is connected to the inverting(-) terminal of OP AMP to be same voltage level as OP AMP output. And, this OP AMP output is flow out the integrator and a basis signal for frequency control of PWM.

PWM signal of micom is an input of Photo Coupler in Fig. 2 and this signal is to be a voltage source using A, flows out DA converter and obtains output B. Table 1 shows voltage of point A for input voltage.

Table 1 Output voltage of negative AMP

Input Volt.	108[V]	120[V]	132[V]
Point A[V]	10.8	9.7	8.6

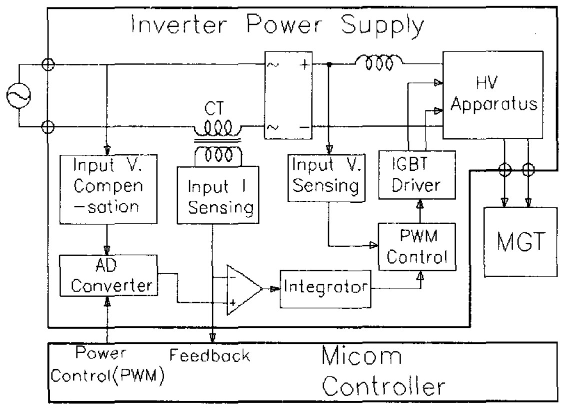

Fig. 1 Proposed inverter block diagram

2.2 Specification of inverter

Table 2 shows each value of inverter for microwave oven.

Table 2 Specification of inverter

ITEM	VALUE
Rated Input	120[V/60Hz]
RF power output	1200[W]
Efficiency	More than 60[%]
Ibm	Less than 1.5[A]
Ebm	Less Than 4.8[kV]

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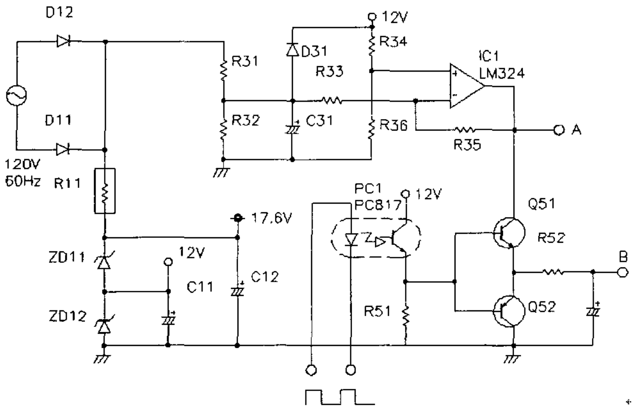

Fig. 2 Circuit diagram of DA converter & power supply

2.3 Proposed PFM Control

The existing method was applied for frequency control according to each power output level. On the other hand, the proposed circuit will be constant frequency for an output power generating.

The fixed frequency control method shows that the range of RF generation stop is very wide as Fig. 3.

When this RF generation stop range is wide, it is not easy to obtain power output and get in fall power factor. On the other hand, PFM method can improve these problems.

PFM has a frequency control according to input voltage phase at the same power output and very wide range of RF generation as shows in Fig. 4.

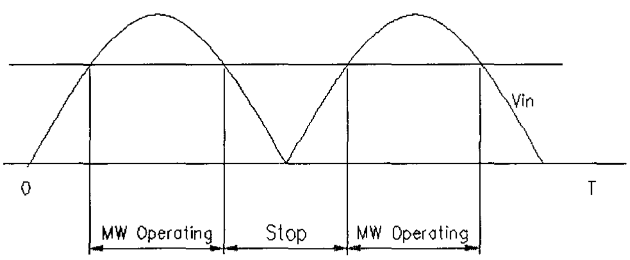

Fig. 3 Area of MWO generation

As it is, lower generation frequency 20[kHz] is used for upward power when the voltage is low.

Higher generation frequency 30[kHz] is to change wave form from sinusoidal wave type output to square wave type when the voltage is high.

If PFM control is apply for a magnetron power supply, RF generation range of magnetron is wider and over current or over voltage is not supply for magnetron input. Fig. 5 shows a circuit to consist PFM control.

Input V_{SEN} is used for frequency variation source as a result of detection for pulsating wave power supply input. This frequency controls transistor Q_3, Q_4 and Q_5 in Fig. 6 and realizes output of PFM. The internal oscillator of KA3525A in Fig. 6 is connected to RT and CT as a current mirror, and the same current amount as RT current will charges and discharges CT.

Consequently, the operating frequency is high when the current flows in RT is high, the operating frequency is high and if the current flow in RT is low, this frequency is low. And, the terminal voltage of RT is constant as 4 Volts. When OFF all of 3 transistors, RT will appear only and it will be operated at minimum frequency. In this time, this frequency should be set up higher than audio frequency. If all of 3 transistors are ON, they are operated at the highest frequency 30[kHz].

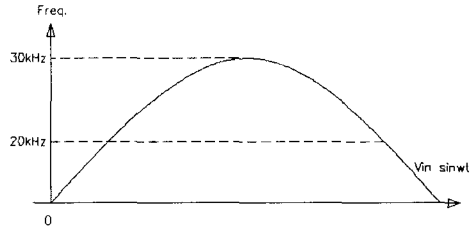

Fig. 4 Input voltages vs. frequency at PFM method

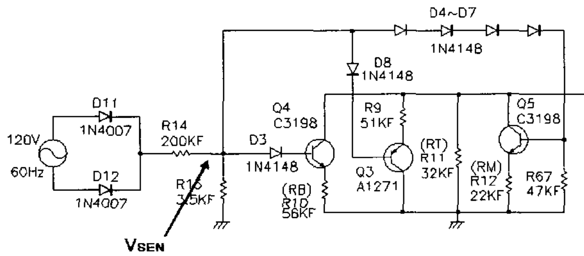

Fig. 5 proposed PFM control circuit

2.4 Frequency generation and IGBT operation part

Fig. 6 shows frequency generation and IGBT operation circuit. To make two waves of alternation switching, common PWM IC of KA3535A is prepared.

KA3535A has a lot of merit because of simple peripheral circuit and easy control of frequency. The base signal of transistor Q_{61} can stop PWM operation.

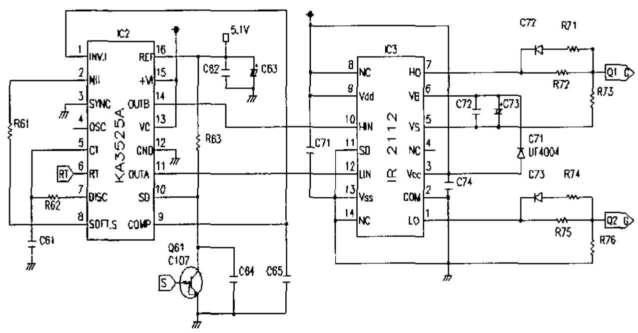

Fig. 6 Circuit diagram of frequency generation & IGBT driver

3. SRHBI(Serial Resonant Half Bridge Inverter) Design

3.1 SRHBI analysis

Fig. 7 shows SRHBI circuit and functional waveform for magnetron operating. It consists of half bridge type using two switches and operates serial resonance between the primary coil of transformer and C_{r1}, C_{r2}. Each of the current waveform shows in Fig. 7.

Current i_{in} that is supplied from input section C_f is correctly a half of transformer primary rectified current i_L. However, a maximum value of switch current is same as transformer primary current i_L.

Fig. 8 shows turn-on current direction when each mode is split a switching period of each switch.

3.1.1 mode 1 (t0 ~ t1) :

This mode is switch S_1 ON period and serial resonance current between transformer primary coil and C_{r1}, C_{r2} is flowed through this switch. So, the current form has similar to sign. Before half period of resonance is completed, switch S_1 will be OFF and transform to ZVS(Zero Voltage Switching) mode.

3.1.2 mode 2 (t1 ~ t2) :

This mode is all switches OFF period and initial voltage of C_{a1} and C_{a2} at t1 is 0[V] and v_{in} of input terminal voltage. These initial voltages will exchange each other though a serial resonance between transformer primary coil inductance and C_{a1}, C_{a2}. So, the voltage of C_{a1} and C_{a2} at t_2 is v_{in} of input terminal voltage and 0V for each. At this time, inverse parallel diode of S_2 will be in forward bias and turn-on, and then this mode will be transformed to next mode.

3.1.3 mode 3 (t2 ~ t3) :

This period is diode turn-on and will proceed so long as transformer primary current is reached up to 0 through resonance. For this period, because switch S_2 has 0 volts, S_2 makes ON in advance. If so, transformer primary current at the moment of zero through main resonance is transform to next mode that is changed current direction.

3.1.4 mode 4 (t3 ~ t4) :

This period is switch S_2 ON and serial resonance current between transformer primary coil and C_{r1}, C_{r2} is flowed through this switch.

So, the current waveform has similar to negative region of sign wave. Before half period of resonance is completed, switch S_2 will be OFF and transform to the second ZVS(Zero Voltage Switching) mode.

3.1.5 mode 5 (t4 ~ t5) :

This period is all switches OFF and initial voltage of C_{a1} and C_{a2} at t_4 is v_{in} of input terminal voltage and 0V for each. These initial voltages will exchange each other though a serial resonance between transformer primary coil inductance and C_{a1}, C_{a2}. So, the voltage of C_{a1} and C_{a2} at t_5

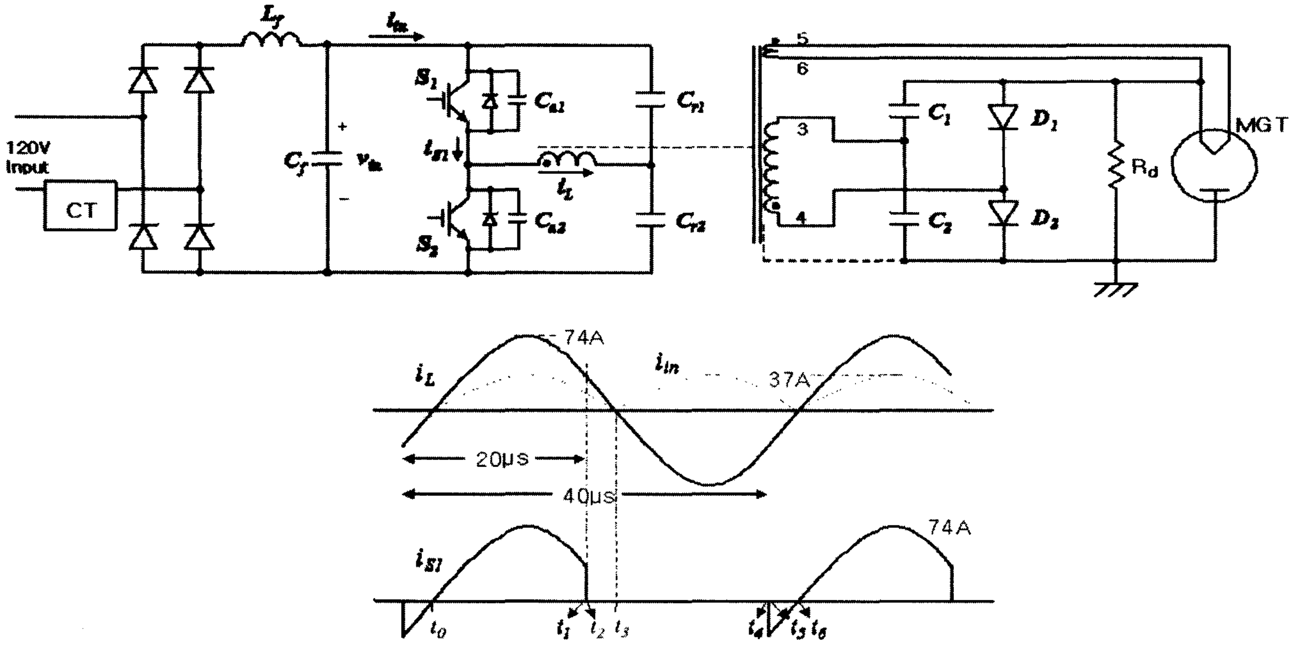

Fig. 7 Circuit Diagram & waveforms of SRHBI

will be 0V and v_{in} of input terminal voltage for each.

At this time, inverse parallel diode of S_1 will be in forward bias and turn-on, and then this mode will be transformed to next mode.

3.1.6 mode 6 (t5 ~ t6) :

This period is diode turn-on and will proceed so long as transformer primary current is reached up to 0 through resonance. For this period, because switch S_1 has 0 Volts, the switch makes ON in advance. If so, transformer primary current at the moment of zero through main resonance is transform to the initial mode and a cycle is completed.

The peak value of this current can be investigated when assuming supply wattage 2[kW] for inverter circuit at input terminal C_f and clearly rectified sign wave to supply input current i_{in}.

When the input current i_{in} and input voltage v_{in} to supply input terminal C_f is described in Fig. 7, the average input power can be calculated using following formula.

$$P_{in} = \frac{2}{T}\int_0^{T/2} v_{in} i_{in} dt = \frac{2}{T}\int_0^{T/2} V_P \sin\omega_s dt \cdot (V_P \sin\omega_s t \cdot I_P)\sin\omega_r t dt \quad (1)$$

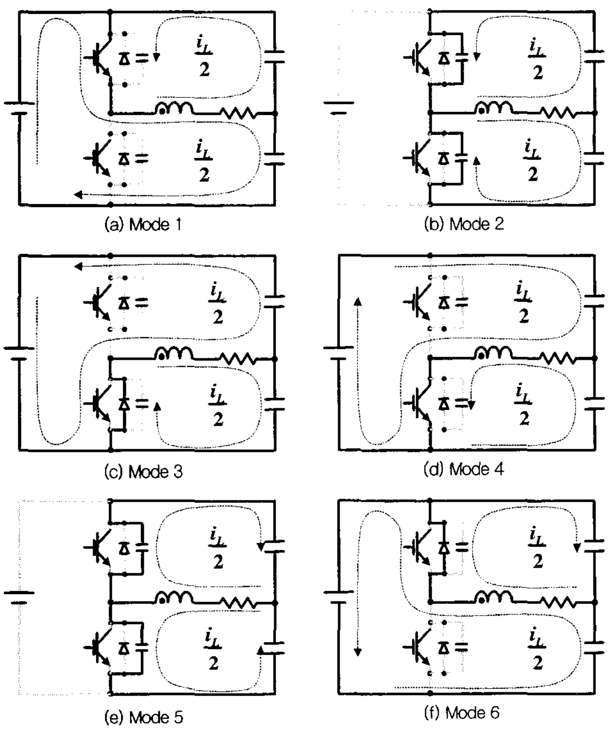

Fig. 8 Current direction of each mode

If so, the calculated maximum peak current Ip to supply input terminal C_f is 37[A]. Because the current of transformer primary coil is double compared to i_{in}, maximum peak current of i_L is 74[A] as described in Fig. 7.

3.2 Design for HV Transformer(HVT)

We are decided to the core spec. is Isu Ceramic's UTV4671B (effective core area: 2.28[㎠]) and MGT is Panasonic's 2M261-M32.

Fig. 9 is showing really modeling circuit of HV Transformer. We called L_M is magnetizing inductance; this inductor supply voltage is transferring the HVT secondary voltage. L_{l1} and L_{l2} is primary and secondary each side inductance. In this paper decided final spec. of turns 1:16:350 and its gap is 2[mm].

The designed HVT each variable value like (2)

$$L_M = 32.83[\mu H] \\ L_{l1} = 2.95[\mu H] \\ L_{l2} = 23.3[\mu H] \quad (2)$$

The filament impedance is

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{0.3^2 + (2\pi(30kHz)\times 1.3\mu H)^2} = 0.387[\Omega] \quad (3)$$

and 1.3μ H inductance is LC filter's L value located in MGT for removing harmonics. The MGT filament current requires 10.4[A] for that the filament voltage is given by the equation (3) and it's calculated 4[Vrms] and the filament coil turn are only one.

$$V_{fil} = Z \cdot I_{fil} = 0.387\Omega \times 10.5A = 4[V]$$

Somewhat, primary coil of HVT supplied about 64[Vrms].

According to we can decide 16 turns of HVT primary coil. Considerations of HVT's secondary coil turns cannot exceed 4.85[kV] peak anode voltage of MGT at the +10[%] input voltage. Way of an experiment, we decided 350 turns of the secondary coil.

Fig. 10 shows the SRHB inverter's circuit diagram designed by this paper.

Fig. 11 shows Photograph of the SRHBI type MWO inverter

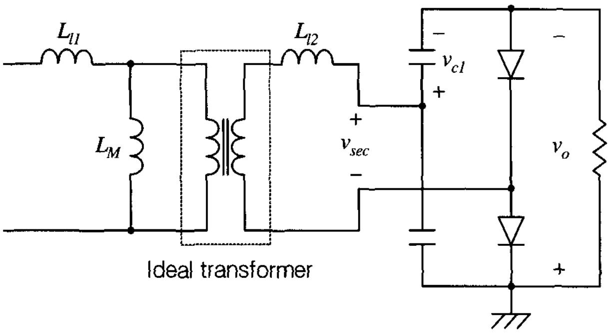

Fig. 9 Modeling of HV Transformer

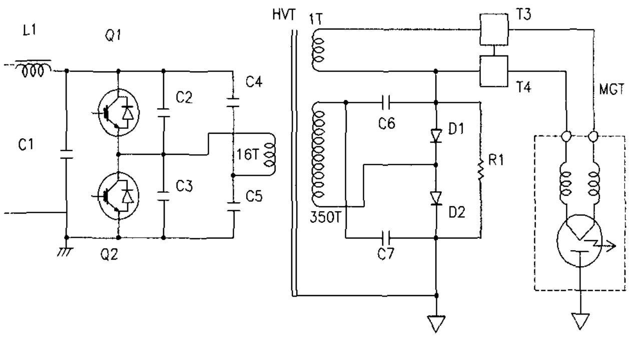

Fig. 10 Designed circuit diagram of SRHBI

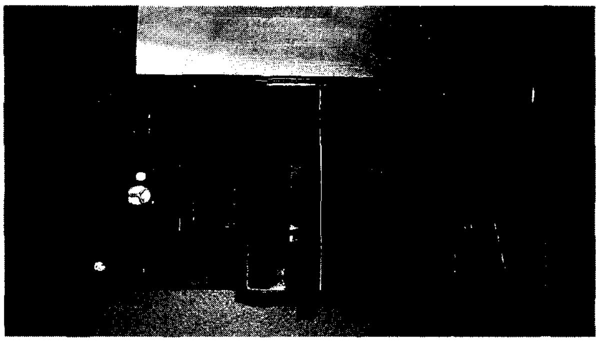

Fig. 11 Photograph of the SRHBI type MWO inverter

4. Experimental Results

A 1.2kW SRHB inverter has been PC board to verify the operation of the proposed inverter. Fig. 12 shows the waveform of the SRHBI at 120[V]/1.2[kW]. Fig 13~14 shows the MW operating range.

Fig. 13 shows that inflection point appears in resonance current while switch on. The reason is phenomenon that all while high voltage part's diode appears becoming off.

Hence, if high voltage diode becomes off, then suddenly resonance frequency becomes low because L_{IO} appears at primary side. According to this phenomenon, can be guarantee enough time to that switch operate zero voltage switching. But, if take out same output; bring up the peak value of MGT's anode current. Because of current does not pass to MGT at secondary resonance phenomenon section.

It can be seen that the SRHB inverter operation time is 6.8[ms], it's a wide range of 120[Hz] phase. Filament current is also suitable measurements 10.42[A] when the MGT generating Microwave.

Where, ice : Flowing current to switch, Vge : Gate signal.

Operating frequency measurements from 22[kHz] to 29.8[kHz] by PFM at the 2[kW]. And average overall efficiency of 60.1[%] is achieved.

Fig. 15 shows variable characteristics of input current according to variations of input voltage. In case of inverter which applied proposed PFM circuit, we find it is inversely proportional to input voltages till 5[%] of input voltage to control used power regularly. Also, in case of iron core LC resonant type, we find current increases by 126[V], then decreases by 132[V]. This results from leakage characteristics of HVT.

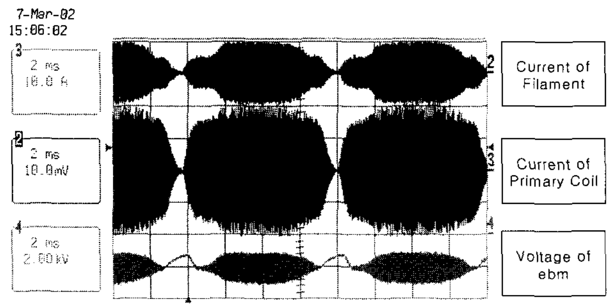

Fig. 12 Waveforms of the SRHBI at the 120V/1.2kW

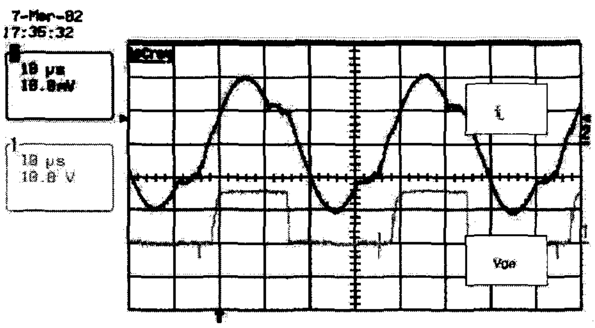

Fig. 13 Volt. waveforms of SW at the low voltage side PFM

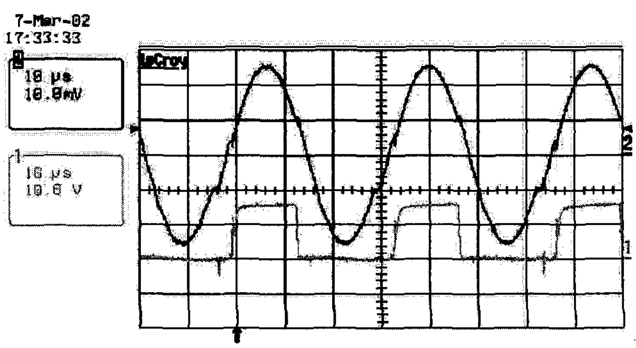

Fig. 14 Volt. waveforms of SW at the high voltage side PFM

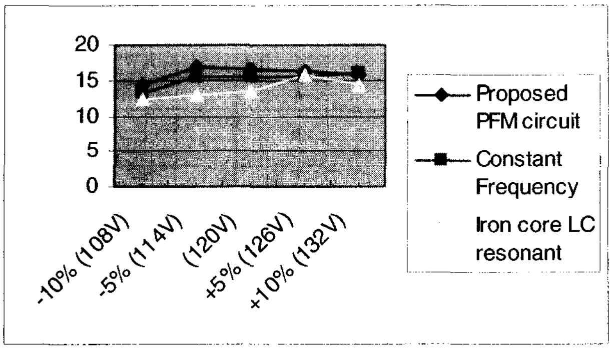

Fig. 15 The input current according to the input voltage variation

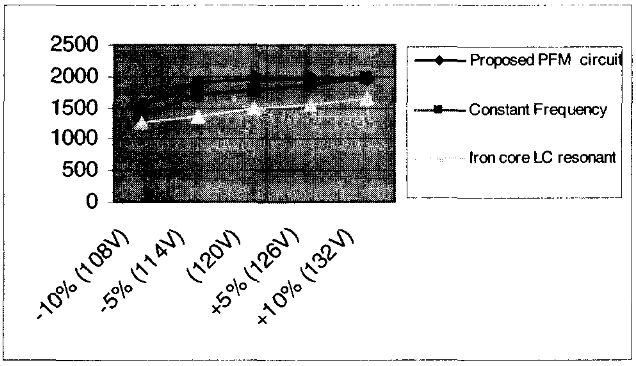

Fig. 16 The input power according to the input voltage variation

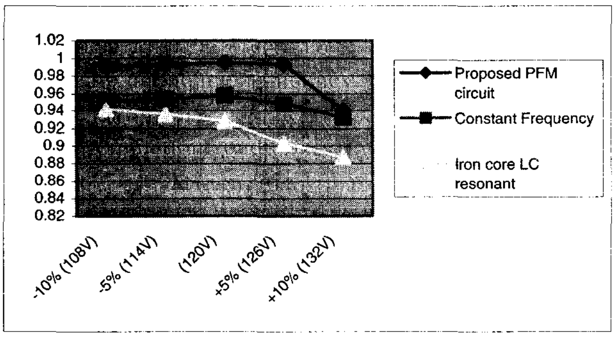

Fig. 17 The power factor according to the input voltage variation

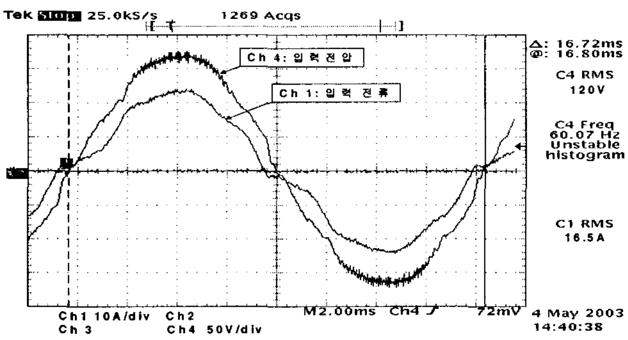

Fig. 18 Voltage & current waveform of proposed inverter

Fig. 16 shows variations of used power according to variations of input voltage. At the inverter which took proposed PFM circuit, we find used power marks constantly at the 5[%] of input voltage.

Fig. 17 shows variations of power factor according to variations of input voltage. In case of the inverter which took proposed PFM circuit, it is marked very high about 99[%] by -10~+5[%] of input voltage, but decreased more or less as low 94[%] by 132[V].

Fig. 18 shows an input voltage of proposed inverter, and current phase waveform, Their phases are almost alike. The inverter is measured that input current is 16.53[A], and used power is 1,971[W] at the high frequency output 1,206[W]. The power factor is measured high as 99.5[%], and its result from oscillating time of MGT becomes longer cause by proposed PFM circuit. It is occurred that MGT temperature increases then power factor decreases.

5. Conclusion

In this paper SRHB inverter for 1.2[kW]/120[V] output power MWO power supply and a generalized method for analyzing SRHB inverter has been presented.

Input current is not exceed 17[Arms] at the 1.2[kW] output power. Unfortunately we did not analysis of active load of MGT. Therefore the parameters of high voltage parts are designed way of a experimental, so it is necessary to do more studying of be related high voltage capacitor with output power.

Acknowledgements

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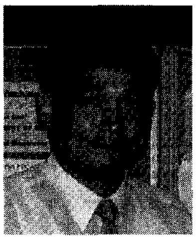

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