The Voltage-fed High Frequency Resonant Inverter Using Induction Heated Dry Steam Generator

Chil-Ryong Kim[1], Jong-Kurl Lee[1], Sang-Hwa Jung[1], Sang-Pil Mun[1], Sang-Don Kim[2], Mutsuo Nakaoka[1][3]

[1]Kyungnam University/Dept.of Electrical Engineering, Masan, Korea

TEL : +82-55-249-2835, FAX : +82-55-249-2839, E-mail : mun2630@kyungnam.ac.kr

[2]Gyeongnam Animation High School, Korea

[3]Yamaguchi University/Dept. of Electrical and Electronics Engineering, Yamaguchi, Japan

Abstract - This paper presents an innovative prototype of a new conceptual electromagnetic induction-based fluid heating appliance using voltage-fed type series capacitor-compensated load resonant high-frequency IGBT inverter with a phase-shifted PWM and a power factor correction schemes. Its operating characteristics in steady-state are illustrated including unique features and evaluated on the basis of its computer simulation and experimental results of 10kw breadboard appliance for hot water producer and superheated steamer. The promising cost effective inverter-fed boiler appliances for electromagnetic induction-heated type fluid-heating in the pipeline systems are proposed for induction-heated boiler, super heat steamer, high temperature water producer, hot gas producer and metal catalyst heating for exhaust gas cleaning in engine, which are more suitable and acceptable for industrial, chemical, and consumer energy utilization for household and business from a practical point of view.

I. INTRODUCTION

In recent years, the electromagnetic induction b ased heating energy processing systems which are controlled by the voltage-fed or current-fed high frequency resonant inverters using the latest IGBTs have attracted special interest from the advantageous viewpoints of high efficiency, high reliability, safety, cleanness, compactness, light weight, rapid responses, as well as stable temperature tracking and precise temperature control ability.

With tremendous advances in the latest power semiconductor devices such as IGBTs, MOSFETs, MCTs, SITs, high performance resonant inverters for induction heating power supplies have been widely applied for the forging, forming, annealing, surface hardening, soldering, brazing, sealing, welding and melting processes of various metals. The new products of induction heated appliances using a single ended high frequency load resonant inverters operating at ZVS mode, by which cooking pan, rice cooker/warmer, fryer, steamer, hot water producer, dryer and exhausted gas cleaner are able to be developed for consumer power electronic appliances. Under these technological backgrounds, the authors have proposed a novel electromagnetic induction based flow-through metal package fluid heating appliance which make use of some voltage-fed PWM high frequency load resonant inverters using IGBTs.

This paper presents an innovative product of the electromagnetic induction based fluid heating appliance with high frequency resonant inverter composed of a phase shifted PWM series loaded resonant inverter using the third generation IGBT modules and their driver interface IC, the advanced auto-tuning PID gain controller, and specially designed thin metallic laminated assembly induction heater incorporated into the non-metal vessel or tank in the pipeline plants. Its inherent steady-state operating characteristics are illustrated as an efficient induction heated Dual Packs Heater (DPH), exchanger and are also evaluated as induction heated steamer, evaporator and dryer from a practical point of view.

II. INDUCTION HEATED FLUID HEARING APPLIANCE

Fig.1 shows a schematic system configuration of the new conceptual electromagnetic induction based fluid(liquids or gases, particles) heating using a voltage-fed high frequency inverter with an active power filtering scheme. This unique high temperature steamer used for the industrial, chemical, and consumer pipeline network systems is basically composed of a single-phase diode rectifier with no smoothing DC capacitor filter link or active three phase PFC converter, a voltage-fed

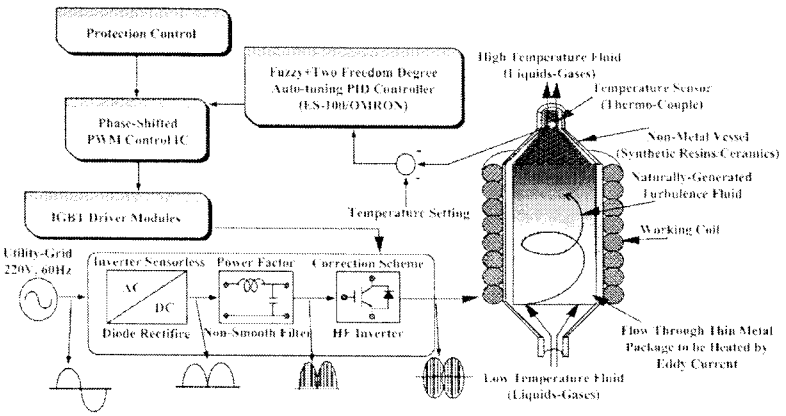


Fig.1 New schematic heated electrical energy conversion & utilization

full-bridge type series load resonant IGBT inverter with a constant frequency phase-shifted PWM power regulation scheme. a specially designed DPH made of electromagnetic induction heated type fluid-thin metallic layer assembly with many spots and mechanically wave through like processed flow channel slits in order to generate natural turbulence in the vessel.

For efficient direct fluid heating. this hot water producer and super heated steamer using induction-heated DPH is designed so as to operate a unity power factor correction and active harmonic current compensation. This induction heated DPH on the basis of the induced eddy current based thin metal heating principle with a large amount of heating surface is tightly and incorporated into the nonmetallic vessel or tank the working coil to generate the high frequency flux due to high frequency inverters. The fluid flowing through induction heated dual packs heater can be directly heated on the basis of heat exchange principle. A precise and stable temperature control feedback loop with an intelligent auto-tuning PID controller and a thermocouple temperature sensor is implemented for inverter type induction heated boiler with DPH .The diagnostic management can be easily achieved on the basis of observing the temperature difference.

This moving fluid heating appliance using high frequency inverter is more suitable for fluid heat transfer processing plants as compact and efficient heat exchanger based upon induction heated boiler, because of cleanness, compactness and high efficiency. quick temperature tracking response, precise temperature control. excellent controllability, high reliability and safety. It is noted that this fluid heating appliance is more cost e ffective as an electromagnetic induction heated boiler, hot water supplier and superheated steamer required for a variety of pipeline heat energy processing systems in addition to hot gas-related dryer. It is experimentally proved that this innovative induction based high temperature steamer using voltage-fed high frequency inverter is cost effective for liquid and gas heating appliances from a practical point of view.

Fig.2 indicates a specially designed eddy current-heated metallic package developed by the authors, which can flow through the moving fluid such as liquids, gasses, powder and particles. In addition, the fluid turbulence when the fluid flows through the dual package assembly can be naturally generated by using induction-heated dual package assembly. When the fluid (liquids, gases, powder) flows through the unique metallic package inserted into the ceramic vessel or tank with a work coil, which is located to the pipeline system.

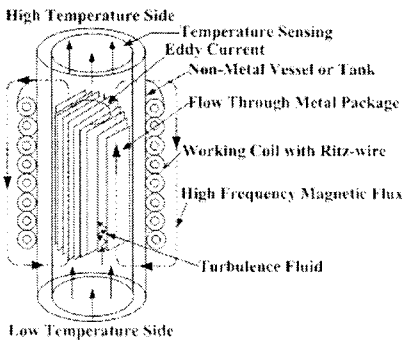


Fig. 2 Heating Package in the vessel and tank

This turbulence moving fluid is to be heated instantaneously and uniformly on basis of the induced eddy current based-heat energy with in the large heating surface which is generated in both surfaces of thin stainless steel package inserted into the vessel. Induction heated dual packed heater energy can efficiently transferred and exchanged as the flowing fluid heat energy.

III. Series Resonant ZVS PWM High Frequency Inverter

Fig.3 shows the voltage-fed full-bridge type series loaded-resonant PWM inverter using the latest IGBT modules with intelligent driver IC. In general, the power matching transformer may be inserted between the inverter output terminals and working coil for induction heated DPH incorporated into the vessel in order to match the load impedance. The operating voltage and current waveforms of the series-loaded resonant inverter operating at a phase-shifted PWM mode are illustrated in Fig.4.

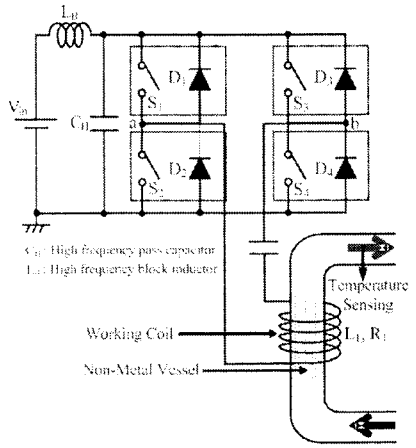


Fig. 3 A voltage-fed full-bridge type series loaded resonant inverter

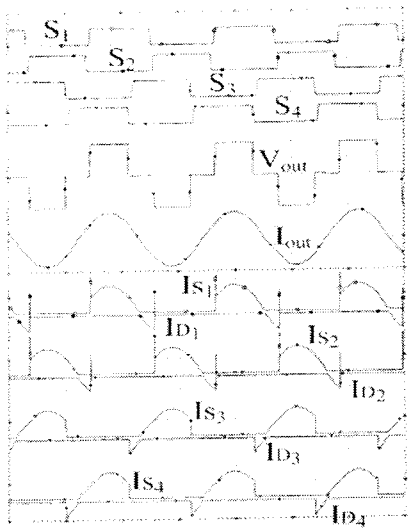


Fig. 4 Voltage and current waveforms

The output voltage and power of this full-bridge resonant inverter using IGBTs can be continuously regulated by the constant frequency phase-shifted PWM scheme. As can be observed in Fig.4, each turn-on switching currents of the active power switches S_1/S_2 in the left bridge leg becomes both positive value in PWM regulation mode.

As a result, the active switches S_1/S_2 are to operate at hard-

switching in the turn-on mode. However, the active switches S_1/S_2 can achieve a soft-switching in the turn-off operation mode under a condition of both zero current and zero voltage transition in spite of the phase-shifted PWM control process and wide load parameter variations. The active switches S_1/S_2 can achieve the zero current soft-switching by means of lossless inductive snubbers

On the other hand, the active switches S_3/S_4 in the right bridge leg can turn-on under a condition of the zero current and zero voltage soft switching in spite of phase-shifted PWM processing and load parameter variations. In case of $f_o > f_r$ (f_o : Inverter frequency, f_r : Series resonant frequency), the active switches S_3/S_4 must always turn off at a certain hard switching condition and turn on at soft-switching condition. Therefore, the active switches S_1/S_4 can achieve the zero voltage soft-switching by means of lossless capacitor snubbers.

IV. Simulation And Experimental Result

TABLE.1 indicates the practical design specifications of the feasible electromagnetic induction b ased fluid-heating appliance using a series loaded-resonant IGBT inverter with a self-tuning PID based feedback control scheme and active filter for current harmonic compensation and power factor correction schemes.

TABLE. 1 DESIGN SPECIFICATION

ITEMS	Design Specification
Input Voltage Vin	Single-Phase 220[Vrms]
Regulated Output Power	0~ 10[kw]
Power Regulation Strategy	Phase-Shifted PWM
Operation Frequency	30[kHz]
Size of DPH	Φ100mm/h190mm
Temperature Control System	Fuzzy + Two Freedom Auto-tuning PID

The AC output power of the high-frequency inverter can be continuously regulated according to the adjustment of the phase-shifted angle Φ(0°≤ Φ≤ 180°)as a control variable. Power conversion efficiency η is estimated by equation (1)

$$\eta = P_{out} / P_{in} * 100[\%] \quad (1)$$

$$P_{out} = (C\,\Delta T\,\Delta Q)/860*1000[W] \quad (2)$$

where, P_{in} : input power

P_{out} : output power estimated by equation (2)

$\Delta T = T_2 - T_1$

T_2=temperature in the inlet of the vessel

T_1=temperature in the outlet of the vessel

$C \fallingdotseq 1.0$ (specific heat)

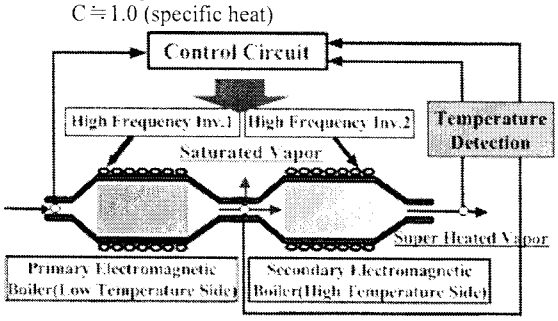
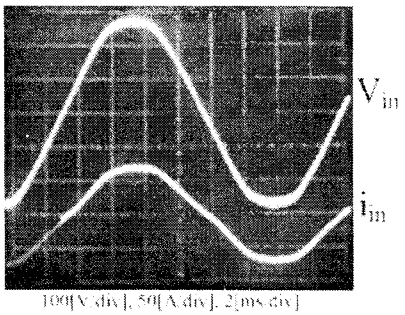


Fig.6 Electromagnetic induction type and evaporator hybrid steamer

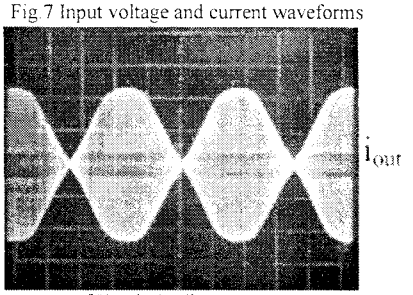
Fig.6 shows the innovative induction heated DPH steam generator system which can generate the low pressure super -heated steam f rom 2 00℃ t o 1 000℃. This s uper-heated steamer is composed of two induction heated DPH boilers to produce saturated steam and super-heated steam.

The input voltage and current waveforms in utility power source which is observed by this feasible induction heated DPH steam generator appliance are displayed in Fig.7.



100[V/div], 50[A/div], 2[ms/div]

Fig.7 Input voltage and current waveforms



50[A/div](auto range)

Fig.8 Output current waveforms

The output high-frequency current waveform with 60Hz, AC voltage envelope corresponding to the input voltage and current waveforms is illustrated in Fig.8. The unity power factor correction and sinewave line Current shaping compensation in utility AC grid bus are sufficiently achieved without an active filtering control implementation with current sensor. Fig.9 indicates the temperature tracking performance of electromagnetic induction heated DPH in case of water as moving fluid.

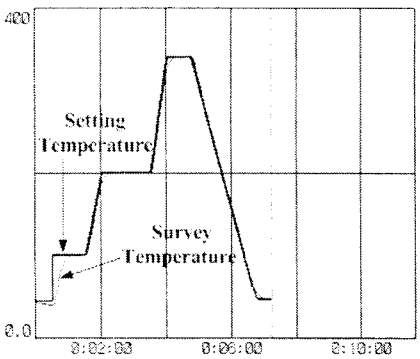


Fig.9 Temperature Tracking

In this figure, the measured temperatures track the preset temperature quickly. This is because this electromagnetic induction heated DPH steam generator system uses fuzzy reasoning type feed forward and feed back PID auto-tuning controller. Fig.10 shows temperature rising response of electromagnetic induction -heated DPH system used water. In this figure, temperature of moving fluid rises up to 200℃ for only about one minute. Owning to these temperature characteristics, it is mentioned that electromagnetic induction-heated DPH steam generator has more excellent higher performance than conventional steam generator.

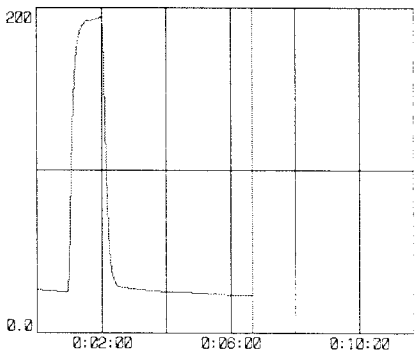


Fig.10 Temperature Rising Response

V. CONCLUSIONS

In this paper, an innovative prototype of the electromagnetic induction b ased fluid-heating appliance using the high-frequency resonant inverter which is named induction heated DPH boiler has been successfully proposed on the basis of a series loaded-resonant PWM high frequency inverter operating at soft s witched PWM scheme, and its self-tuning PID temperature control scheme. It was emphasized that epoch-making and new conceptual fluid-heating principle of this new power electronic appliance using the inverter with a phase shifted PWM scheme is based upon the electromagnetic -induced eddy current which are generated in a flow-through thin metallic package incorporated into the nonmetallic vessel or tank in the pipeline systems.

This innovative efficient appliance driven by the voltage-fed type series-loaded resonant soft-switching PWM inverter topology using lossless snubber inductors and capacitor bridge legs has been newly introduced for a new fluid heating method based on induction heating principle. Furthermore, it has been proved as various chemical industry plants that the new and efficient fluid heating appliances could be more cost-effective for the electromagnetic induction-heated boiler than the conventional sheathed heated type boiler which induction-heated steamer, dryer as well as induction-heated hot water producer, because of compactness in volumetric physical size, cleanness, high-efficiency conversion, quick temperature response, stable and precise temperature control realization.

REFERENCES

[1]Y. Hatanaka, H. Kifune and T. Shimade, "A Novel ZCS High Frequency Inverter with Complex Resonance and Design Procedure for High Amplitude of Output Current," in Proc. of IEEE-PEDS, Vol.1, pp.443-447, September, 2001.

[2]S. Kubota, Y. Hatanaka, "A Novel High Frequency Power Supply for Induction Heating," in Proc. of IEEE-PESC, Vol.1, pp.165-171, June, 1998.

[3] Y.Uchihori, Y.Kawamura, "Novel Electromagnetic Induction Flow-Through Package in Pipeline Type Fluid Heating Appliance using Series Resonant PWM Inverter with Self Tuning PID Controller based Feedback Loop," Proceedings of International Power Electronics Conference(IPEC), pp.660-665, April, 1995.

[4]Monterde, Hernandez, R. Garcia, Martinez; "Comparison of Control Strategies for Series-Resonant Full-Bridge Inverter for Induction Cookers", Proceedings of The 8th European Conference on EPE, vol.1 ~4, pp.1-8(CD-ROM), Sept, 1999

[5]B. K. Lee, J. W. Jung, B. S. Suh, 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-PESC, Vol.2, pp.1232-1237, June, 1999