Development of Induction Heater Hot Water System using New Active Clamping Quasi Resonant ZVS PWM Inverter

Soon-Kurl Kwon* · Sang-Pil Mun

Abstract

This paper presents a new conceptual electromagnetic induction eddy current based stainless steel plate spiral type heater for heat exchanger or dual packs heater in hot water system boiler steamer and super heated steamer, which is more suitable and acceptable for new generation consumer power applications. In addition, an active clamping quasi-resonant PWM high frequency inverter using trench gate IGBTs power module can operate under a principle of zero voltage soft commutation with PWM is developed and demonstrated for a high efficient induction heated hot water system and boiler in the consumer power applications. This consumer induction heater power appliance using active clamping soft switching PWM high frequency inverter is evaluated and discussed on the basis of experimental results.

Key Words : Hot Water System, Active Clamping Quasi Resonant PWM High Frequency Inverter

1. Introduction

With great advances in the latest power semiconductor switching devices such as MOSFETs, IGBTs, SITs, MCTs and SI-Thyristor, high performance voltage and current- fed type high frequency load resonant inverters for induction heating power supplies have been widely applied for the forging, brazing, sealing, welding, melting heat treatment processing in industrial power processing plants and induction fusion of the pipeline[1-2].

In recent years, electromagnetic induction eddy current based heat energy processing and utilization systems using a variety of the high frequency high power inverters have attracted special interest from the view points of high efficiency, high reliability, safety, cleanliness, compactness in volumetric size, light in weight, rapid temperature response for particular high power applications in industry automotive and consumer fields[3-5].

This paper presents a new conceptual energy saving type electromagnetic eddy current based induction heater, which is more suitable and acceptable for induction heated hot water system,

* Main author : Department of Electrical Engineering, Professor Kyungnam University, KOREA
Tel : +82-55-249-2633, Fax : +82-55-249-2839
E-mail : soonkurl@kyungnam.ac.kr
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boiler and steamer. On the other hands, active voltage clamped type ZVS PWM high frequency inverter connected to utility AC 220[V_{RMS}] for consumer power applications is developed and demonstrated from a practical point of view. In this paper, a new style compact induction heated hot water system and steamer using soft switching PWM high frequency inverter is also discussed and evaluated from the experimental points of view.

2. Active Clamping Quasi Resonant ZVS PWM High Frequency Inverter

2.1 Total system & Involute type heat exchanger

A novel prototype system of an electromagnetic induction eddy current based hot water system appliance in pipeline is schematically depicted in Fig. 1. This energy conversion appliance consists of No. 1 and No. 2 induction heating (IH) boilers in the pipeline systems which are driven by the independently controlled voltage-fed high frequency soft switching inverters and diode rectifier.

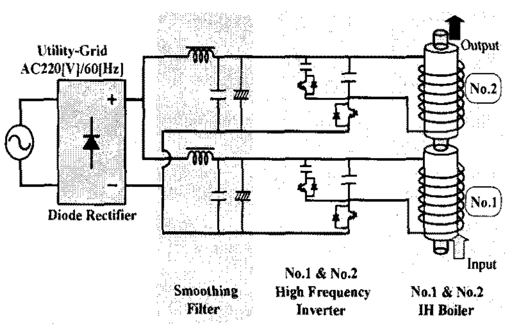


Fig. 1. Induction eddy current based hot water system appliance

Fig. 2 shows schematic combination types of two IH boilers. In the hot water system appliance, by using two boilers in series, the heating response is much faster than using a single one. On the other hand, by using two boilers in parallel, it is possible to produce more quantity hot water than a single one. In this experiment, series connection type is adopted.

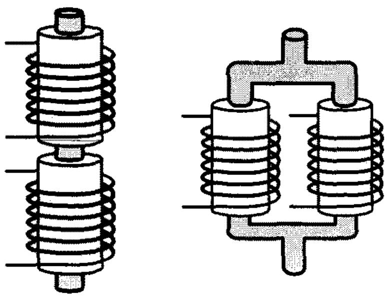


Fig. 2. Two IH boilers for fluid-heating appliance

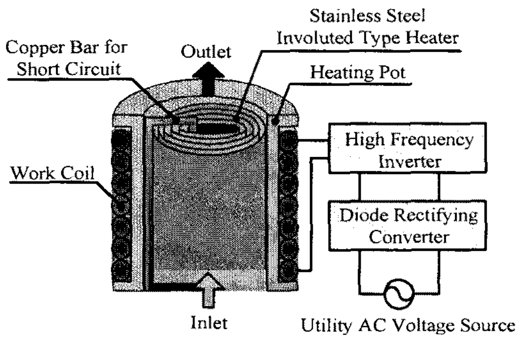


Fig. 3. Schematic diagram of induction heating boiler

The schematic diagram of IH boiler is shown in Fig. 3. This boiler consists of a new type induction heat exchanger, working coil and non-metal heating vessel in the pipeline. A new conceptual induction heating body made of non-magnetic stainless steel SUS316 plate is demonstrated that has an involute structure with a short circuit for rapid heating response. It is composed of the spiral assembly and its outside edge point is connected to the inside edge point by the copper bar. In this technique, it is possible to achieve rapid heating response of this induction hot water system appliance because of electromagnetic induction eddy current flows through this heat exchanger entirely.

In general, it is difficult to form the spiral structure toward the center of involute type heat exchanger.

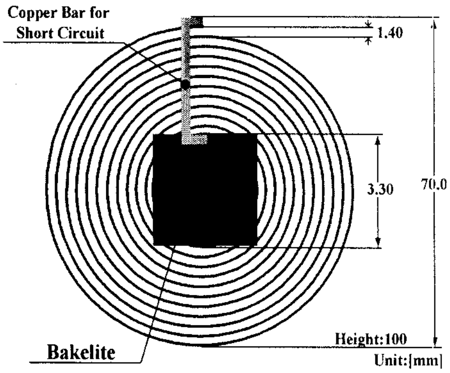


Fig. 4. Size of involute type heat exchanger

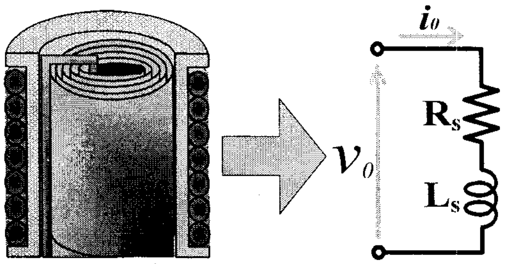


Fig. 5. Equivalent circuit model

In case of rolling up to its center, effective heating surface increment could not expect actually. But if no obstacle is inserted in the center of spiral structure, heat exchange efficiency of this induction heater decreases because a large majority of heated liquid easily flows through the center. To improve reduced heat exchange efficiency, the cylindrical polycarbonate bakelite is inserted into the center.

2.2 Gate pulse control implementation

Fig. 6 illustrates the timing pulse sequences of an asymmetrical PWM gate voltage pulses. The gate voltage pulses are supplied to the main power switch (S_1) and the auxiliary switch (S_s). In this case, the duty factor (D) is defined as the following to duty factor serves as a control variable for the continuous power regulation for this high frequency inverter. When the high power is delivered to the IH load, the conduction interval (T_{on1}) including dead time(T_d) of the main switch (S_1) is to be lengthened as indicated in Fig. 6 (a). On the other hand, when the high power is not necessary to IH load, the conduction interval is to be shortened as indicated in Fig. 6 (b).

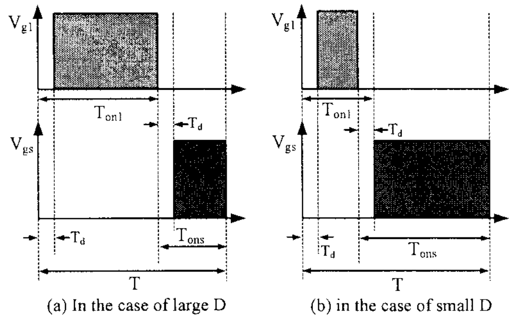


Fig. 6. Asymmetrical PWM gate voltage pulse signal sequences

2.3 Circuits Features and Operation

Fig. 7 demonstrates high frequency inverter circuit topology. This inverter can operate under practically excellent conditions of low peak voltage stress across power switching devices, constant frequency duty factor control strategy for power regulation, and ZVS. This power electronic appliance is developed and implemented for induction hot water system processing in the pipeline system. In Fig. 7 this inverter is shown, which has an equivalent load circuit is represented as the R_s-L_s series circuit model.

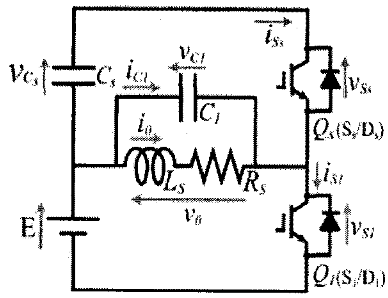


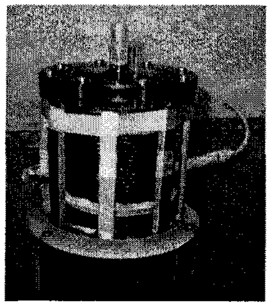
Fig. 7. Active voltage clamped quasi resonant high frequency inverter

3. Experimental Results and Their Evaluations

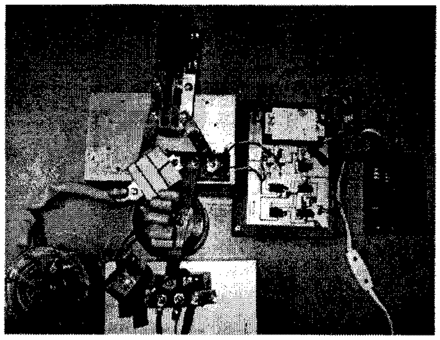
Table 1 indicates the practical design specifications of the proposed electromagnetic induction eddy current based hot water system appliance using the quasi resonant ZVS PWM high frequency inverter. It is constant and above audible frequency. Load parameters of the proposed IH boiler using involute type heat exchanger are measurement values. In order to achieve soft switching, quasi resonant capacitor (C_1) and voltage clamped capacitor (C_s) are designed in accordance with load parameters R_s and L_s.

Table 1. Design specifications and circuit parameters

Item	Value
DC power source voltage(E)	282.8[V]
Quasi resonance lossless capacitor(C_1)	0.18[μF]
Active voltage clamped capacitor(C_S)	3.40[μF]
switching frequency(f)	20[kHz]
Load Inductance(L_S)	34.82[μH]
Load resistance(R_S)	1.465[Ω]



(a) Prototype of induction heating boiler

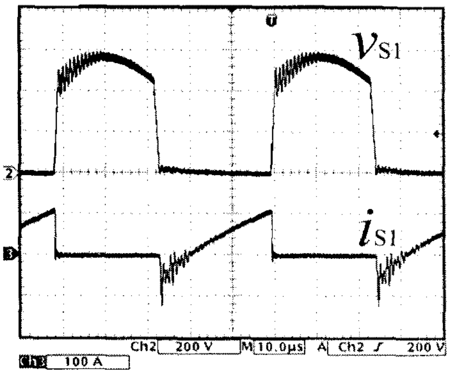


(b) Prototype of high frequency inverter with gate drive circuit

Fig. 8. Photograph of the trial manufacture

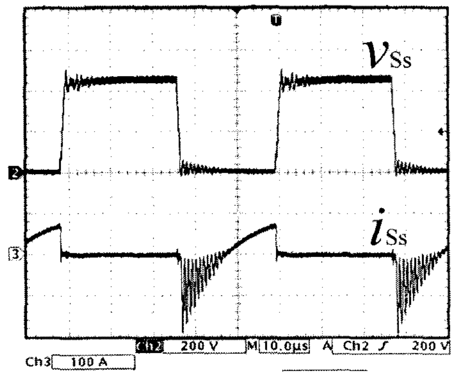
In addition, voltage clamped capacitor (C_s) is also designed to reduce peak voltage across the main power switch (S_1) less than rated voltage of IGBT used here. Developed prototype of IH boiler and active voltage clamped type high frequency inverter with gate drive circuit are shown in Fig. 8.

Fig. 9 depicts the steady state observed switching voltage and current waveforms of the main switching block (Q_1), the auxiliary switching block (Q_s), the induction heating load (L_s & R_s) and the quasi resonant capacitor (C1) under the condition of D=0.5. Besides it is proved that this quasi resonant ZVS PWM high frequency inverter can completely work under ZVS operation. This high frequency inverter can clamp an excessive peak voltage applied to the main power switch less than rated voltage of using IGBT.



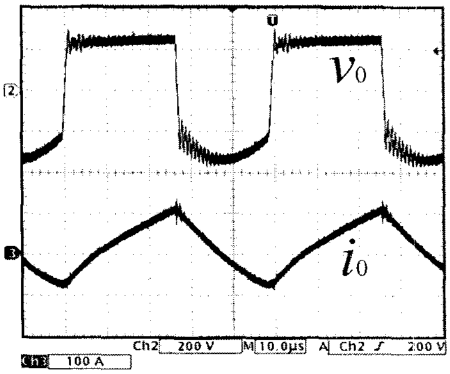
200[V/div], 100[A/div], 10[m/div]

(a) switch Q_1



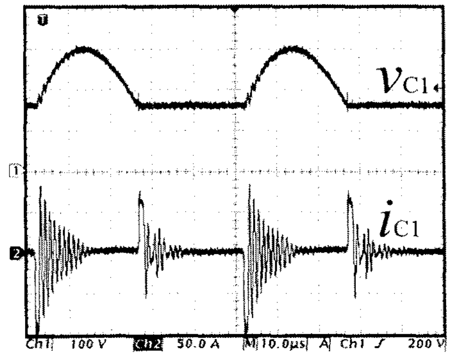
200[V/div], 100[A/div], 10[m/div]

(b) switch Q_s



200[V/div], 100[A/div], 10[m/div]

(c) IH load



200[V/div], 100[A/div], 10[m/div]

(d) resonant capacitor C1

Fig. 9. Experimental voltage and current waveforms(Duty Factor D=0.5)

Fig. 10 represents duty factor vs. input power regulation characteristics for induction heating load, including peak voltage across the main power switch (S_1) characteristics. Observing this figure, it is clearly proved that the inverter output power can be continuously regulated in accordance with duty factor (D) as a control variable under a constant frequency.

Fig. 11 illustrate temperature characteristics of a single IH boiler using high frequency inverter in experimental setup. In this experiment, flow rate is fixed to 1.0 liter per minute.

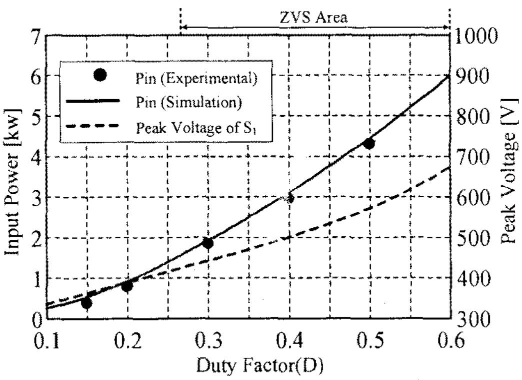


Fig. 10. Input power characteristics and peak voltage characteristics of the main power switch

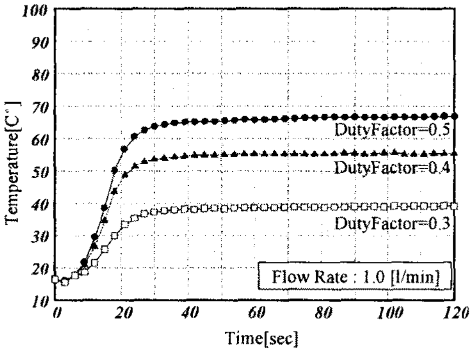


Fig. 11. Heating response characteristics using a single IH boiler

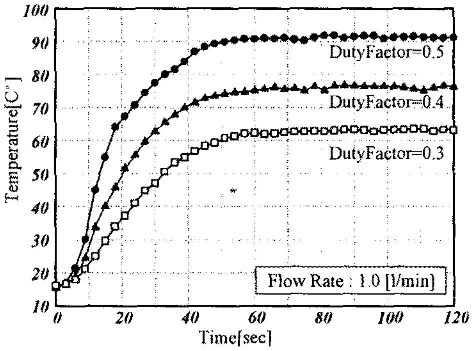


Fig. 12. Heating response characteristics using double IH boilers

It is noted that proposed electromagnetic induction eddy current based involute type heat exchanger has rapid temperature characteristics. Observing Fig. 11, the output temperature of this IH boiler reaches stable temperature with less than 30 seconds.

Fig. 12 illustrates temperature characteristics of double IH boilers system as shown in Fig. 1. In this experiment, the flow rate is also fixed to 1.0 liter per minute and the power delivered to No.1 IH boiler is fixed to 2.6 kilowatts. Output temperature of No. 1 IH boiler reaches about 40 degrees centigrade. In No. 2 IH boiler, the output temperature of proposed IH hot water system appliance can be regulated by means of a constant frequency duty factor control strategy of No. 2 high frequency inverter. It is noted that this inverter type consumer appliance using the involute type electromagnetic induction heat exchanger in pipeline system can heat rapidly. In the future, introducing closed loop control scheme, heating response of this hot water system will be much faster.

Fig. 13 illustrates the dependence of output power efficiency and output power relating to the pulse density modulation ratio. As can be seen the output power of the inverter can be regulated linearly by changing the pulse density modulation ratio. At the same time, power conversion efficiency more than 94[%] can be achieved for output power regulation ranges from 5[%] to 100[%] of the maximum output power.

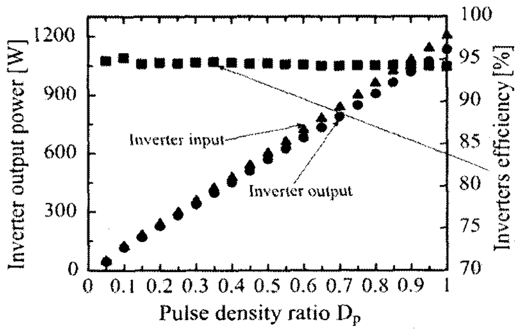


Fig.13. Power Regulation Characteristics in Experience

In the developed inverter the turn-off signal is applied to the switch when antiparallel diode is conducting, therefore, power losses related to the current fall and current tail of switch are very low. Main components of power losses in this inverter are conducting power losses in Q_1 and Q_2 and the switching losses at turn-on, however, by using the inductive snubbers the later component are significantly reduced. Then using the measured in experiment inverters total power, switching losses can be calculated.

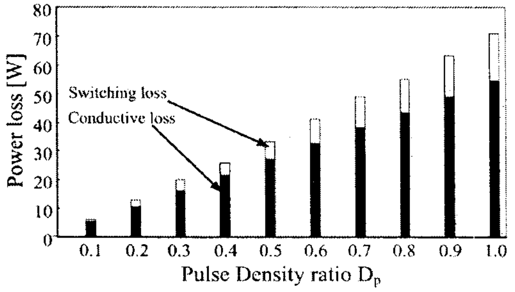


Fig. 14. Power Loss Analysis

4. Conclusion

In this paper, the high efficiency and high performance electromagnetic induction eddy current based hot water system using high frequency quasi resonant inverter has been successfully proposed and demonstrated from a practical point of view. In addition, an active voltage clamping quasi resonant ZVS PWM high frequency inverter using the IGBTs, which can efficiently operate under a ZVS on the basis of asymmetrical PWM strategy. This fluid heating appliance could be more cost effective than conventional gas combustion or sheathed wired heating type.

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Biography

Soon-Kurl Kwon

Received Ph. D (Dr-Eng) degree in Electrical Engineering from Young-Nam University, Daegu, Republic of Korea. He joined the Electrical Engineering Department of Kyungnam University, Masan, Republic of Korea, in 1983 as a professor. He was a visiting professor of Virginia Polytechnic Institute and State University, USA in 1997. His research interests include application developments of power electronics circuits and system. He is a member of the KIEE and KIPE.

Sang-Pil Mun

Received B.S. degree in Electrical Engineering from Pukyong University, Pusan, Korea in1997 and M.S. and Ph.D. degrees in Electrical Engineering from Kyungnam University, Masan, Korea in 1999 and 2003 respectively. He was joined with the Electrical Energy Saving Research Center, Kyungnam University from 2003~2005 as a researcher. His research interests are in the areas of photovoltaic power generation systems, power electronics, soft-switching technology. He is a member of the KIEE, KIPE, KIIEE.