Innovative Electromagnetic Induction Eddy Current-based Far Infrared Rays Radiant Heater using Soft Switching PWM Inverter with Duty Cycle Control Scheme

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Abstract- This paper presents an innovative prototype of a new conceptual electromagnetic induction heated type far infrared rays radiant heating appliance using the voltage-fed edge-resonant ZVS-PWM high frequency inverter using IGBTs for food cooking and processing which operates under a constant frequency variable power regulation scheme. This power electronic appliance with soft switching high frequency inverter using IGBTs has attracted special interest from some advantageous viewpoints of safety, cleanliness, compactness and rapid temperature response, which is more suitable for consumer power electronics applications.

Keywords- Voltage source high frequency inverter, Edge-resonant soft switching, ZVS-PWM power regulation scheme, Induction heating, Far infrared rays radiant heater, Consumer power electronics

I. INTRODUCTION

Gas combustion heating system and sheath wired heating system for consumer home and business applications are usually used as the heating means for the food cooking and processing. Besides, low frequency and high frequency electromagnetic induction heating (IH) methods have been considered for food cooking and processing in business-use production plants and household kitchen applications. This actual heating efficiency is relatively high for consumer IH appliances as compared with traditional food cooking appliances. The induction heating appliances using power electronics circuits are more excellent in respect of energy saving, temperature control, clean environment, quick heating processing, safety and reliability. They are utilized in various power application fields for food cooking processing such as boiling, baking and steaming. The high frequency edge-resonant inverters and high frequency resonant cycloconverters are essentially indispensable for implementing the heating controllability, high efficient heating in addition to improvements of cleanliness, safety and reliability of the heating processing work in the high efficient power conversion stages.

For a moment, the voltage source type single-ended edge-resonant zero voltage soft switching PFM high frequency inverter using a single IGBT for the commercial utility AC 100V grid has been developed so far for cost effective practical power applications. This type of high frequency zero voltage soft switching inverter has attracted special interest because of low cost, compact, high-efficiency, low noise. But, audible acoustic noise below 20kHz due to frequency difference cause in multi burner system composed of PFM control-based zero voltage soft switching inverter scheme, voltage peak stress across the power switching semiconductor device: IGBT becomes extremely high. The operating range of this inverter is relatively small. In recent years, the modified topologies of zero voltage soft switching PWM high frequency inverter added an auxiliary active power switch connected in series with the capacitor for voltage clamping on the basis of conventional single ended high frequency inverter are practically developed for utility AC 100V or 200V grid consumer power applications. This paper presents an innovative prototype of the voltage source type high frequency edge-resonant soft switching inverter using IGBTs, which is based upon asymmetrical PWM control scheme due to Duty Cycle Time Ratio Control, which is newly developed for electromagnetic induction eddy current based far infrared rays radiant heating as a new generation griddle for food cooking processing. Its operation principle is described and unique salient features of this consumer power electronic appliance using a high frequency inverter are discussed and evaluated on the basis of computer-aided simulation and feasible experimental results, along with the development on the latest induction heated device as a griddle.

II. EDGE-RESONANT ZVS-PWM SOFT SWITCHING HIGH FREQUENCY INVERTER FOR INDUCTION HEATER

Fig.1 shows a schematic total system configuration including a high frequency edge-resonant (quasi-resonant)

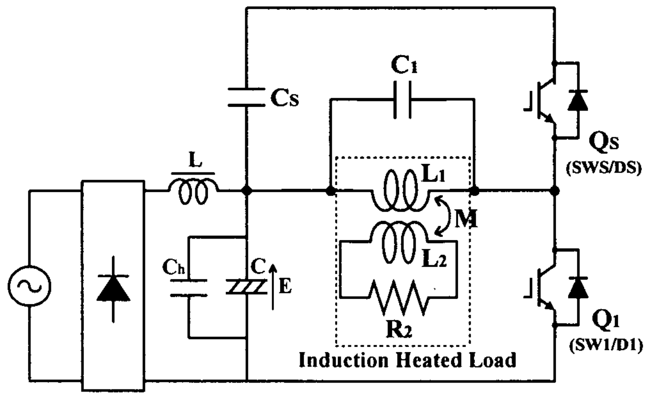


Fig.1 Total high frequency inverter system configuration

inverter circuit topology using two IGBTs that can operate under a principle of ZVS and constant frequency asymmetrical PWM control strategy. This high frequency inverter topology is newly applied for an electromagnetic induction eddy current based far infrared rays radiant heating appliance as a new generation griddle for food cooking and processing.

The voltage source type high frequency zero voltage soft switching inverter with the duty cycle control-based variable power constant frequency (VPCF) function is connected to a single-phase utility AC 100V grid or 200V grid, the full bridge diode rectifier with the smoothing filter as shown in Fig.1.

III. HIGH FREQUENCY EDDY CURRENT-BASED FAR INFRARED RAYS RADIANT HEATING APPLIANCE

The produced induction heating griddle appliance using the high frequency inverter for consumer power electronic applications is shown in Fig.2. This consumer power appliance is composed of the eddy current-based planar spiral stainless steel heating plate: SUS304 ($70-80\mu\Omega cm$), wool board called ceramic fiber for heat insulating material, pancake type working coil, voltage source high frequency soft switching inverter without a matching transformer, forced air cooling fan driven by DC motor. The output current obtained from the voltage source high frequency soft switching PWM inverter flows through the working coil made of litz wire. The eddy current is directly induced into the spiral planar stainless steel plate by electromagnetic induction principle and its plate is directly heated on the basis of joule low. It is noted that this appliance is to make use of the radiant heat from spiral planar stainless steel plate.

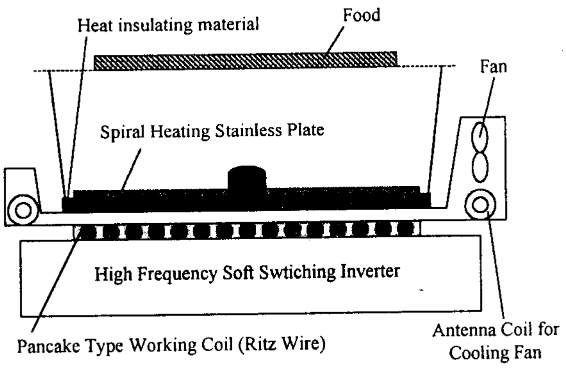


Fig.2 Griddle power appliance using electromagnetic induction heating ranges

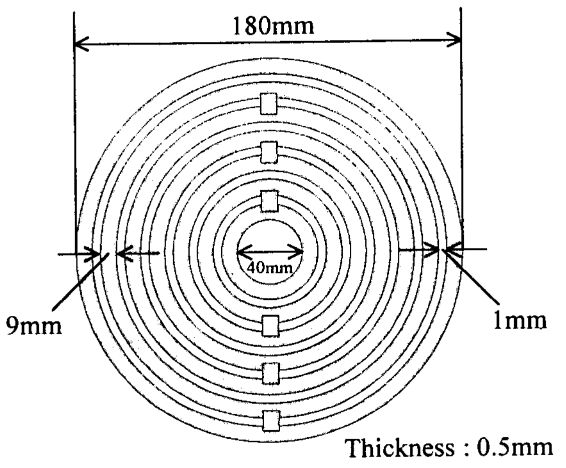
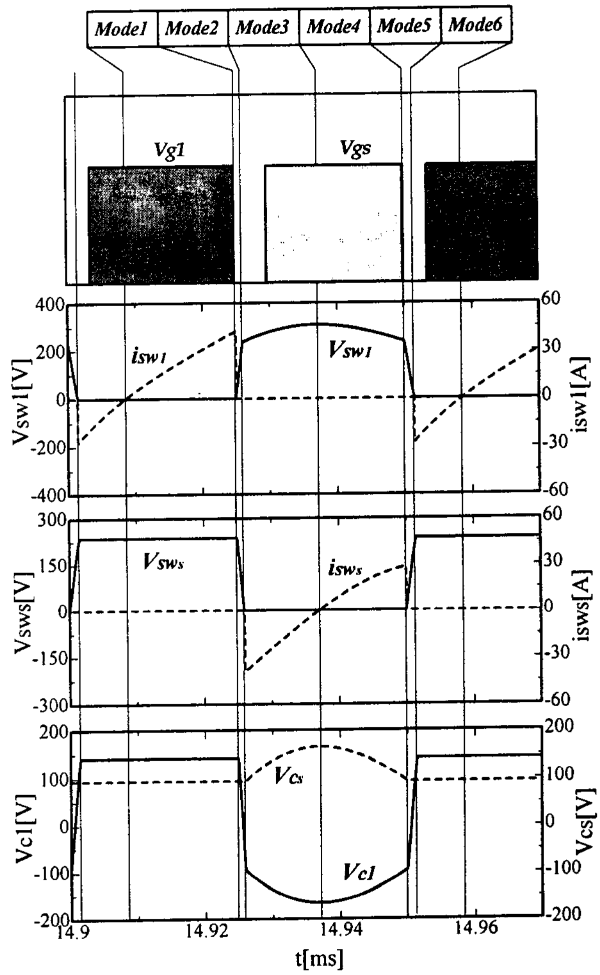
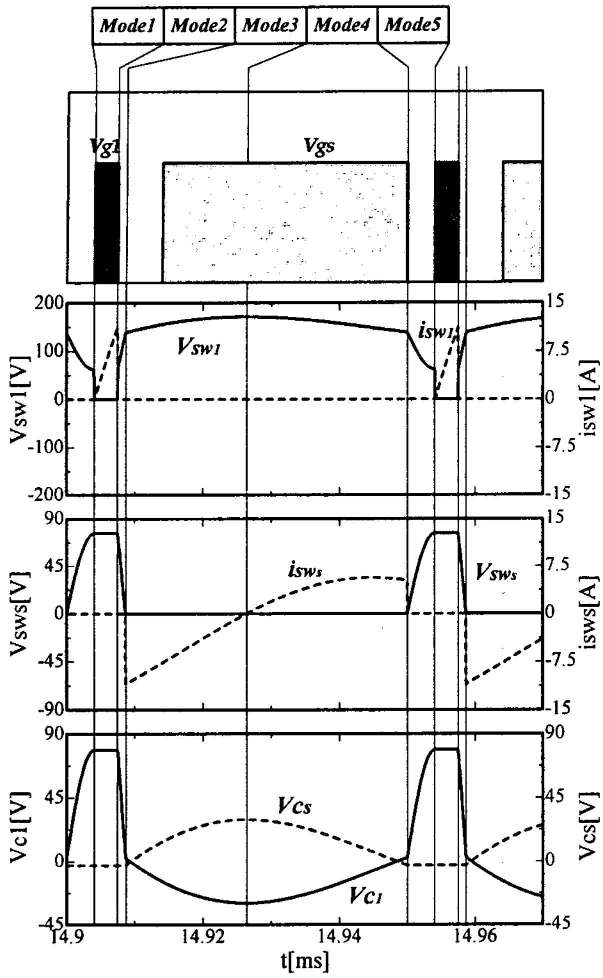


Fig.3 Eddy current-based heating plate shape

Fig.3 demonstrates a geometric structure of a new electromagnetic induction heating plate designed newly for consumer food cooking applications in household and business use. The condition required for the heating plate is specified that it heats rapidly when the output power is delivered to the load, on the other hand it rapidly stop to heat when the output power is shut off. In other words, the heat capacity of spiral planar heating plate is as small as possible. The heating material uses SUS304 of the non-magnetic material. The geometric structure of the diameter of the heating plate has the outer diameter: 180mm, the inside diameter: 40mm, the remainder width: 9mm, the chute width: 1mm. Its shape of groove connection is the special structure of the zigzag combination in order to prevent the thermal deformation when it is heated.



(a) In case of D=0.5



(b) In case of D=0.15

Fig.4 Steady state voltage and current switching waveforms for two duty cycle control conditions

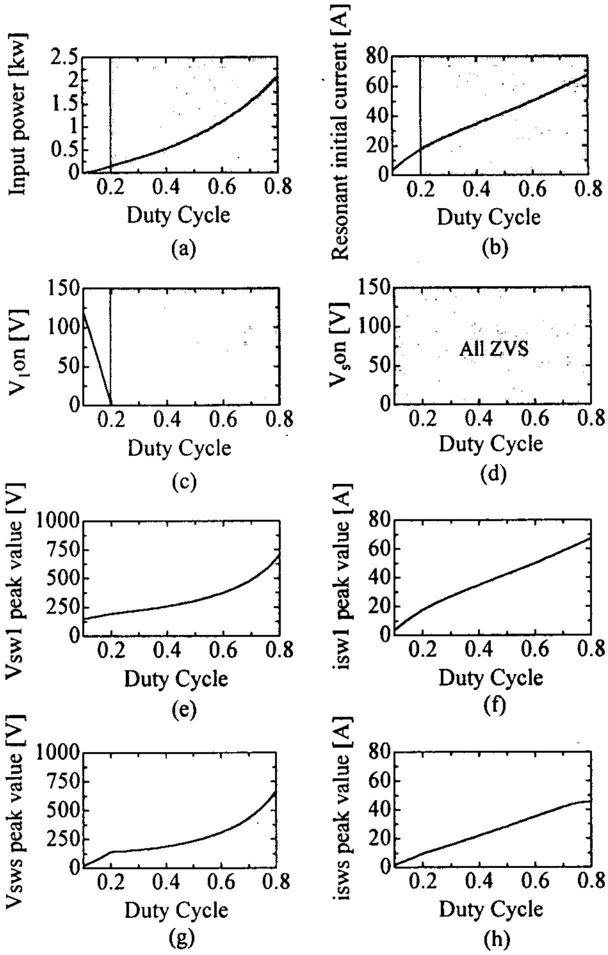


Fig.5 Various inverter characteristics for Duty Cycle Control

IV. INVERTER PERFORMANCE EVALUATIONS

Fig.4 illustrates the steady-state switching voltage and current waveforms of the main and auxiliary active power switching blocks; $Q_1(SW_1/D_1)$, $Q_S(SW_S/D_S)$, capacitor voltage V_{C1} and V_{CS} under two conditions of (a)D=0.5 and (b)D=0.15. Observing V_{SW1} in Fig.4(a), it is noted that zero voltage soft switching mode transition can be achieved for this inverter. On the other hand, from V_{SW1} in Fig.4(b), the hard switching mode transition can be observed in the case of D=0.15. This maximum duty cycle is determined by the maximum voltage value of the active power switch SW_1 and SW_S.

The simulation and experimental results of this IH griddle appliance for consumer cooking applications are illustrated and its steady-state operating performances are evaluated form a practical point of view on the basis of Duty Cycle Time Ratio Control defined in Fig.5 under 20kHz. Main active power switch SW_1 operates with ZVS when Duty Cycle is set to a value more than 0.2, and it becomes a hard switching operation mode, when Duty Cycle is set to a value smaller than 0.2. It is noted that the auxiliary active power switch SW_S can operate in ZVS in spite of the Duty Cycle: D control scheme and load circuit parameters. This high frequency edge-resonant soft switching PWM inverter can continuously control electric power at the constant frequency. In addition, the soft switching operation of this inverter in this case; 20kHz (see Fig.1) is able to be done in 90% of the all Duty Cycle: D. The zero voltage soft switching of this inverter is not possible in the standby low electric power state when D is less than 0.2 under circuit parameters designed for induction heater as a griddle appliance.

V. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Comparative Operating Waveforms

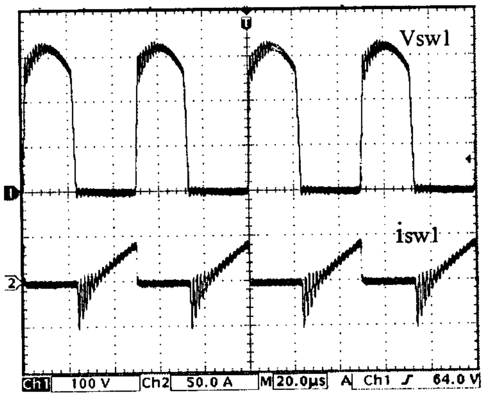
Fig.6(a), Fig.6(b), Fig.6(c) and Fig.6(d) depict the measured voltage and current switching waveforms of the main active power switching block; $Q_1(SW_1/D_1)$, in addition to voltage and current waveforms of the auxiliary active power switching block; $Qs(SWs/Ds)$, the electromagnetic induction heater (see Fig.3) and the capacitor voltage and current waveforms under a condition of D=0.5. These measured voltage and current waveforms have a good agreement with simulated results, which are obtained from the simulation analysis developed by the authors. It is proved that this quasi-resonant ZVS-PWM high frequency inverter with VPCF (Variable Power Constant Frequency) scheme can completely work under a soft switching operation for a wide Duty Cycle control implementation.

TABLE.I indicates the practical design specifications and circuit parameters of the feasible electromagnetic induction eddy current-based far infrared rays radiant heating appliance, which is built by edge-resonant ZVS-PWM high frequency inverter using the latest IGBT modules.

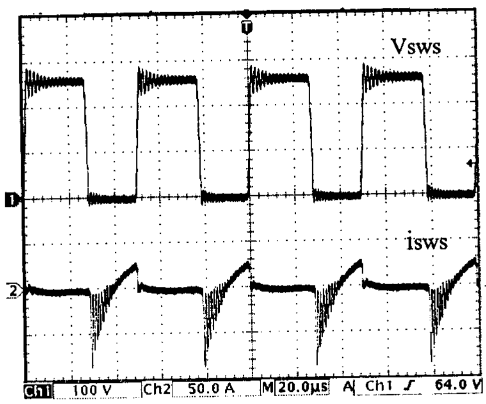
TABLE. I
Design specifications and circuit parameters

Item	Symbol	Parameter Value
DC Source Voltage	V	141.4[V]
Switching Frequency	f	20[kHz]
Edge Resonant Lossless Snubber Capacitor	C_1	0.18[μF]
Active Voltage Clamped Capacitor	C_S	3.0[μF]
Working Coil	L_1	65.1[μH]
Electromagnetic Coupling Coefficient	k	0.652
Load Time Constant	τ	12.5[μsec]
Dead Time	t_d	3.0[μsec]

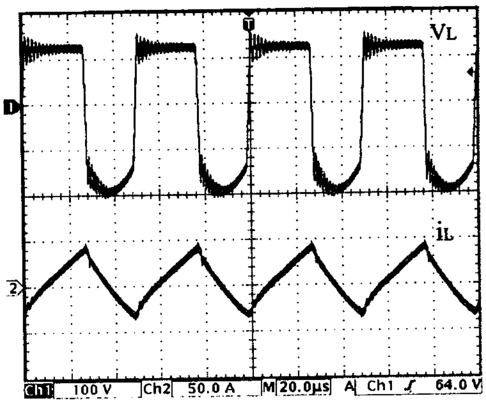
In addition, it is understood that this edge-resonant high frequency inverter using IGBT power module can clamp an excessive peak voltage applied to the main active power switch. Accordingly, the conduction power losses of the IGBTs and the current stresses of switching power semiconductor devices (IGBTs) can be effectively reduced by adopting this voltage-fed soft switching high frequency inverter.



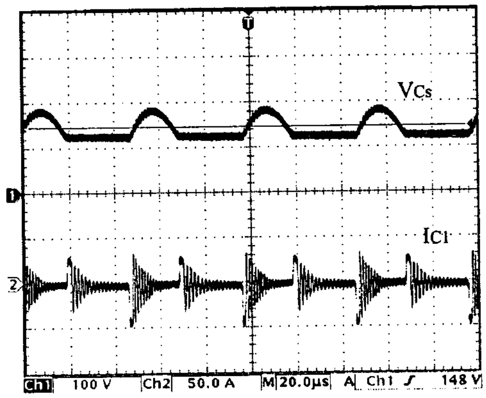
(a) For switching block Q_1



(b) For switching block Qs



(c) For load circuit



(d) For voltage of Cs and current of C_1

(100[V/div], 50[A/div], 20[μsec], D=0.5)
Fig.6 Observed voltage and current waveforms

B. Power Regulation Characteristics

Fig.7 represents Duty Cycle D vs. input power regulation characteristics under a fixed operation frequency (20kHz) asymmetrical PWM (Duty Cycle Time Ratio Control) strategy. Observing Fig.7, it is clearly proved that Duty Cycle as an independent control variable can be continuously adjusted in the accordance with the inverter output power.

C. Temperature Characteristics of Induction Heater

Fig.8 illustrates temperature characteristics of the spiral planar stainless heating plate using high frequency inverter shown in Fig.1 for the feasible setup in experiment. It is noted that this electromagnetic induction eddy current heated far infrared rays radiant heating processing scheme can more rapidly heat than the general purpose of gas combustion type or sheathed wired heating type heater for consumer food cooking and processing applications.

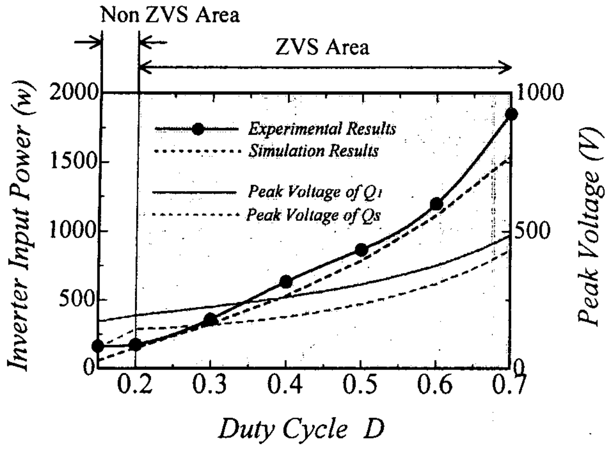


Fig.7 Duty cycle vs. input power characteristics

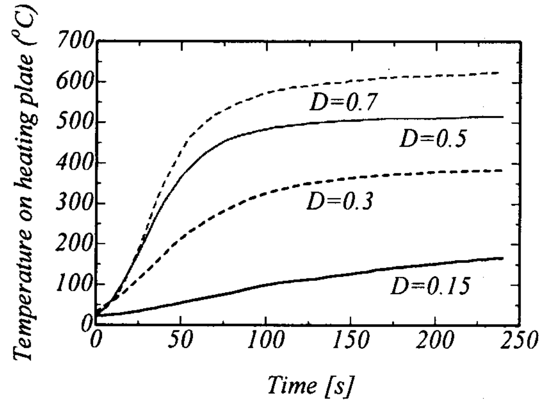


Fig.8 Temperature characteristics of induction heated stainless steel plate

VI. CONCLUSIONS

In this paper, an innovative implementation of the electromagnetic induction eddy current-based far infrared rays radiant heating appliance using the specially designed spiral planar stainless steel heater has been successfully proposed as consumer household and business use products by using a voltage fed type active voltage clamped edge-resonant ZVS-PWM high frequency inverter using the latest IGBTs power modules, which can efficiently operate under the soft switching commutation on the basis of the asymmetrical PWM-Duty Cycle Time Ratio Control strategy and load parameter variations. Its steady state operation and power regulation characteristics have been evaluated in spite of simulation and experimental results.

Furthermore, this paper has been proved as a variety of industrial, automobile heat energy processing plants as well as consumer heat energy processing plants. The new and efficient induction heated far infrared rays radiant heating appliance using high frequency soft switching inverter could be cost effective than the gas combustion heating.

In the future, the power loss analysis of this soft switching high frequency soft switching inverter using the trench gate IGBTs and high conductivity IGBT (HiGT) should be done and the new generation consumer power electronics appliances for electromagnetic induction eddy current-heated far infrared rays radiant heating should be evaluated and discussed from a practical point of view. The computer aided design procedure of this power electronics appliances using a new inverter topology in the pipeline system should be studied from a theoretical point of view. The comparative studies between the zero voltage soft switching inverter treated here and zero current soft switching inverter has to be discussed in practical for induction heated griddle.

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