# A NOVEL ZVS-PWM QUASI-RESONANT INVERTER WITH ACTIVE VOLTAGE-CLAMPED CAPACITOR FOR HIGH-FREQUENCY INDUCTION-HEATED APPLIANCE

K. Izaki, I.hirota, H. Yamashita and H. Omori
Home Appliance & Housing Electronics Research Laboratory,
Matsushita Electric Industrial Co. Ltd., Osaka, 561-0821, Japan

K. Matsumoto, K. Nishida, J. M. Sun and M. Nakaoka
The Graduate School of Engineering and Science,
Yamaguchi University, Yamaguchi, 755-8611, Japan

**ABSTRACT** - This paper describes an advanced prototype of voltage-fed zero voltage soft-switching PWM resonant inverter with an active voltage clamped capacitor, which is put into practice for high-frequency high-power induction-heated appliances. This application-specific quasi-resonant inverter using the latest generation IGBTs for soft-switching can regulate its output power under a principle of a fixed frequency ZVS-PWM strategy. Its operating principle and unique features are presented as compared with a conventional quasi-resonant ZVS inverter for induction-heated cooker, together with its power regulation characteristics on the basis of its simulation and experimental results. The steady-state performances of this inverter developed for multi-burner type induction-heated food cooking appliance are evaluated and discussed from a practical point of view.

## 1. INTRODUCTION

With innovative advances of discrete MOS gate power semiconductor devices designed for high-frequency switching control and their related hybrid IC modules, there have been advanced practical developments of cost-effective induction heating appliance using inverter. At present, the voltage-fed type, current-fed resonant type inverter topologies have been developed for high power induction heating applications. In addition, a variety of voltage-fed resonant inverters of single-ended, single-ended push-pull, half bridge, full bridge circuit topologies including the other quasi-resonant soft-switching circuit topologies have been introduced for high-frequency induction heating applications.

In consumer power electronics applications such as induction heating cooking and fluorescent lamp drive and ozone generating tube drive appliances, the new topologies of soft switching resonant inverter circuits operating in the frequency range more

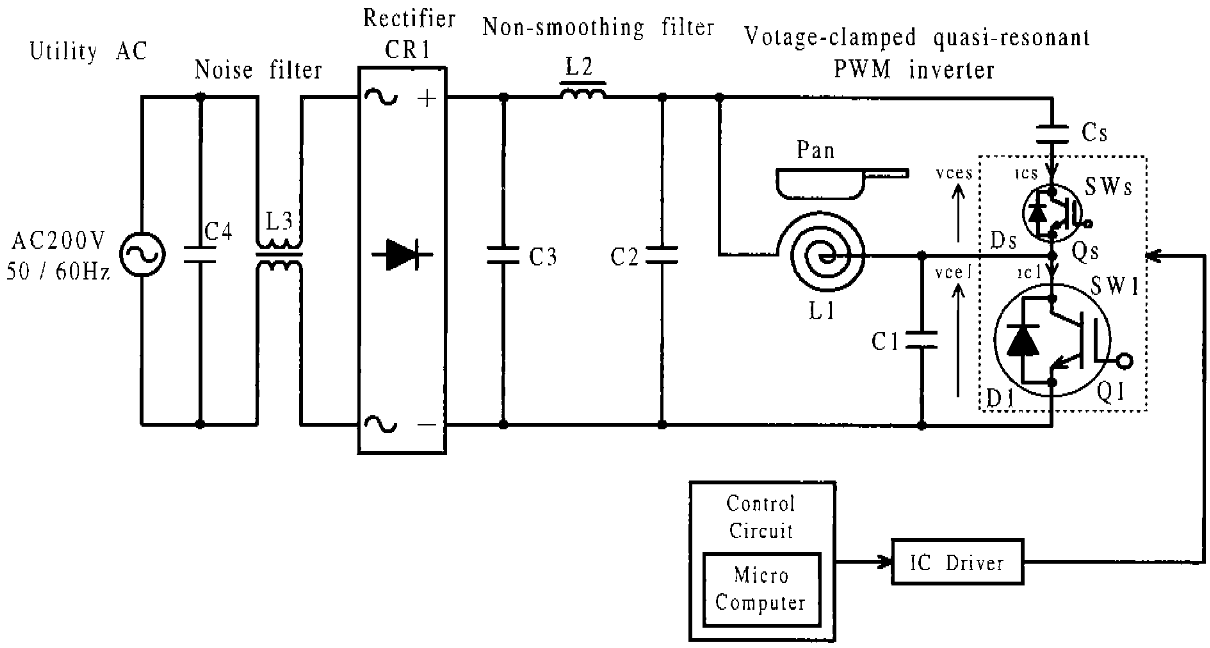


Fig.1 Schematic system configuration for the electromagnetic IH cooking appliances

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than 20kHz under a principle of zero voltage soft-switching range have been proposed and discussed by the authors. Thus, this paper presents a new conceptual inverter topology of voltage-fed zero voltage soft-switching PWM inverter with an active voltage-clamped capacitor snubber, which incorporates the latest trenched type IGBTs designed for soft-switching and high-frequency switching. This is to be more acceptable for the high power induction heated food-cooking appliance with two or multiple burners. The operating principle of this new circuit of quasi-resonant soft-switched PWM inverter with active capacitor clamp is described including its unique features. The steady-state power regulation characteristics of this resonant inverter using the latest IGBTs are illustrated on the basis of simulation and experimental results.

## 2. INVERTER CIRCUIT DESCRIPTION

Fig.1 shows a schematic total system configuration including new soft-switched PWM inverter circuit topology for the electromagnetic IH food cooking appliances. This inverter is based upon a principle with active filtering function in utility-power AC side that is recently developed of ZVS-PWM control strategy in order to solve harmful acoustic noise problem in the case of multi-burner integration.

This power supply system shown in Fig.1 is mainly composed of a diode rectifier with a non-smoothing LC filter, a voltage-fed type single-ended ZVS PWM inverter with an active voltage clamped capacitor, a pancake working coil and induction-heating load, in this case, pan or vessel.

This high-frequency quasi-resonant PWM inverter with VPCF (Variable Power Constant Frequency) function directly connected to a utility-grid single-phase full-bridge diode rectifier with a power factor correction with sinewave current shaping functions.

This newly developed ZVS-PWM quasi-resonant inverter with a VPCF function is directly combined to multiple-integrated IH load vessels placed between pancake-like working heating coils incorporated into two or more arranged burners.

Its computer-based micro control circuit for constant frequency power regulation and system protection schemes, and integrated circuit module IGBT driver are implemented into this inverter system. In this inverter circuit, two reverse conducting power switches; main switch Q1 (SW1 and D1) and Qs (SWs and Ds) incorporate the 4th-generation high-frequency and lowered

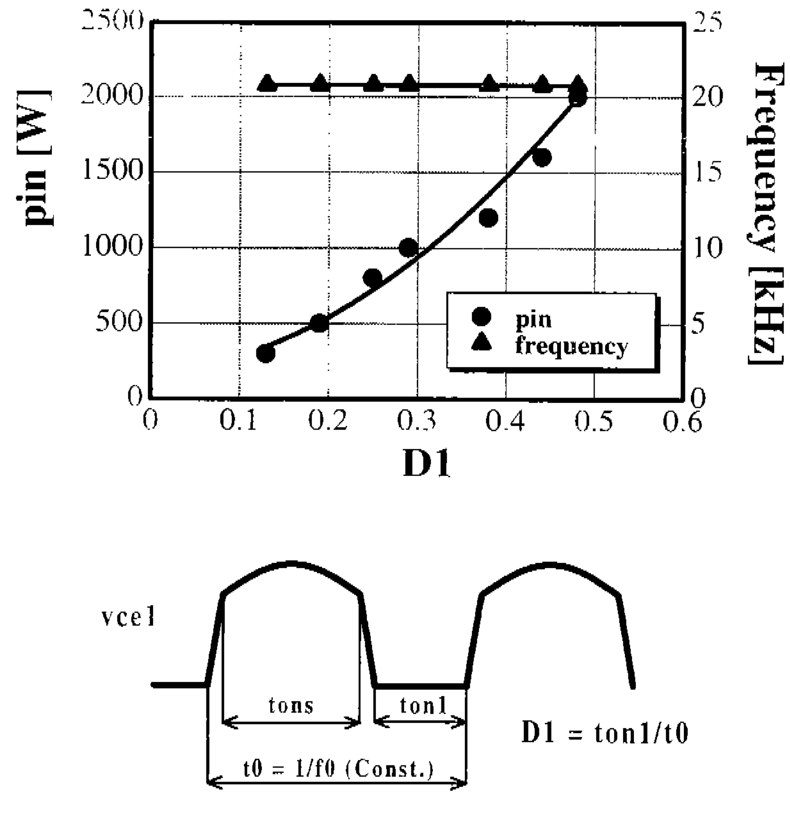
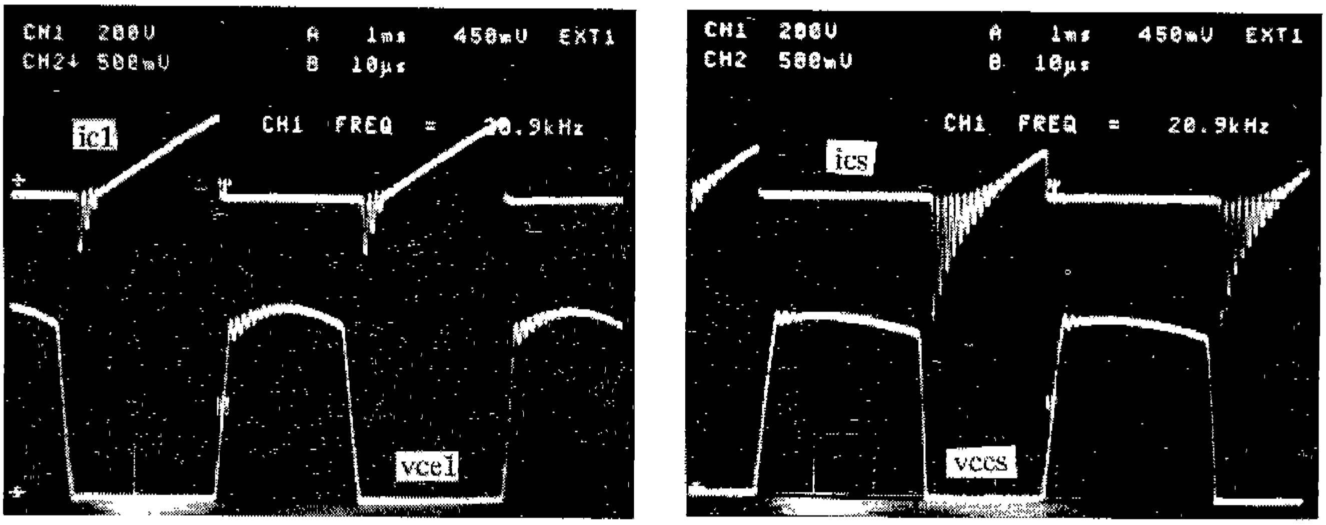



Fig.2 PWM control characteristics




(ic1;50A/Div, vce1;200V/Div, 10$\mu$S/Div) (ics;50A/Div, vces:200V/Div, 10$\mu$S/Div)

Fig.3 Experimental waveforms of power devices Q1, Qs (ic1, vce1, ics, vces)

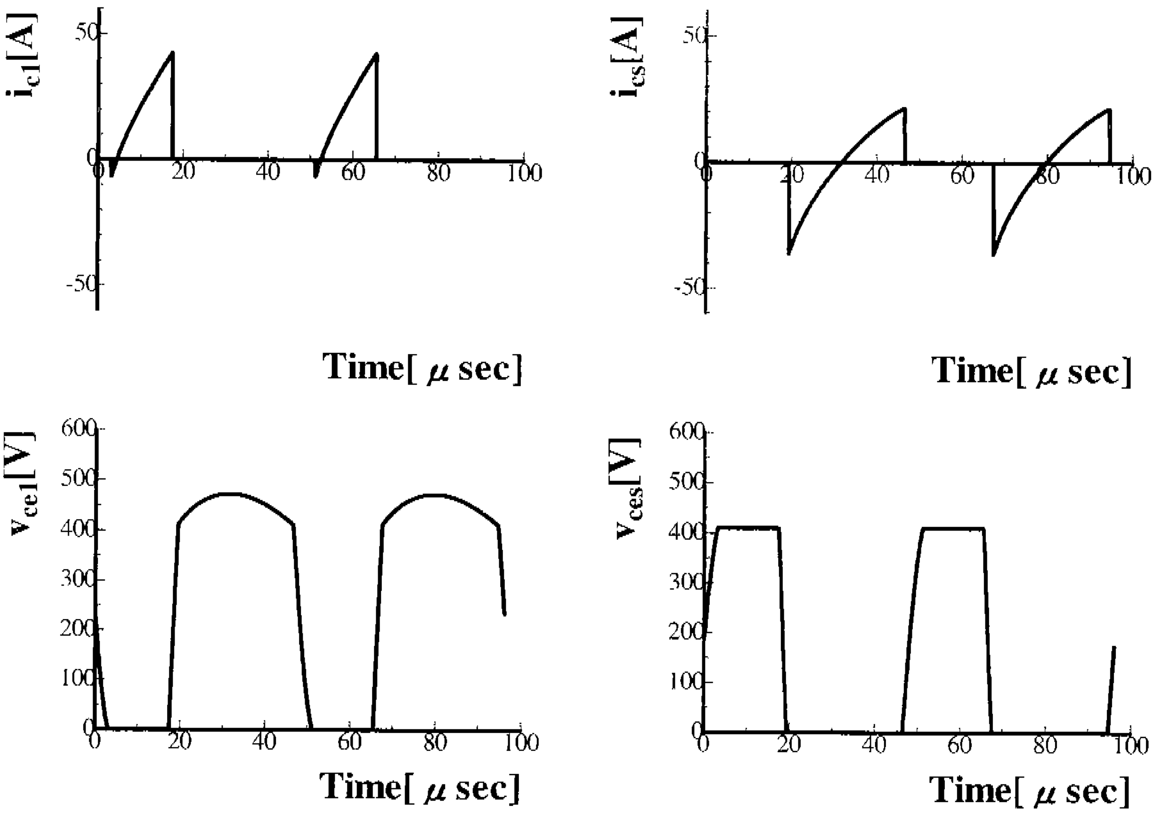



Fig.4 Computer simulated waveforms of power devices Q1, Qs. (ic1, vce1, ics, vces)

saturation voltage type trench IGBTs designed for soft-switching.

The capacitor Cs uses high-frequency plastic film capacitor to clamp an excessive peak voltage applied to Q1 (SW1 and D1), The capacitor C1 is a high-frequency capacitor for quasi-resonance including a parasitic capacitor of IGBT. The IH load constitutes a pan or a vessel placed on the ceramic space through the distributed flat working coil. The power semiconductor switches; IGBTs (Q1 and Qs) in the reverse conducting switching arms of the new modified half-bridge resonant inverter topology can be driven in accordance with the gate pulse signals due to the asymmetric PWM strategy controlled by the micro computer.

With such a modified half-bridge inverter topology operating at quasi-resonant ZVS-PWM scheme, the zero voltage soft-switching operation under a condition of VPCF control strategy is to be achieved for various types of IH loads; stainless steal, iron steal, for food cooking. With respect to the switching losses of IGBTs used here and the practical feasible problems related to their dynamic electrical stresses, EMI/RFI noises and acoustic noise are able to be effectively reduced by introducing this new high-frequency inverter topology.

## 3. SIMULATION AND EXPERIMENTAL RESULTS

The experimental results of the input power and inverter operating frequency are shown in Fig.2 as a function of the duty factor D1(=$t_{on1}/t_0$), $f_0=1/t_0$: inverter operating frequency, $t_{on1}$: conduction time of Q1. As illustrated in this figure, the operating frequency of the voltage-clamped VPCF inverter is maintained constant at 20.8kHz, the input power can be continuously regulated by varying the duty factor D1 due to asymmetrical PWM scheme.

Fig.3 illustrates the observed voltage and current and waveforms the Q1 and the Qs. As can be seen, Q1 and Qs are turned on at zero voltage.

Fig.4 shows the operating voltage and current waveforms of this inverter which operates under a constant frequency variable power regulation scheme.

With this new type of inverter, the acoustic noise due to the burner proximity is effectively suppressed.

## 4. CONCLUSIONS

In this paper, an active voltage-clamped quasi-resonant PWM high-frequency inverter system, employing the latest IGBTs for soft-switching has been developed for induction-heated cooking appliance in consumer power electronic applications. It was mentioned that this appliance includes the salient features such as the constant frequency variable power scheme in addition to unity power factor correction and active power filtering functions. From a practical point of view, the unique inherent advantages of this new soft-switching PWM inverter system are summarized as follows:

(a) total suppression of acoustic noise due to burners proximity
(b) reduced peak voltage stress across IGBTs(Q1 and Qs)
(c) lowered losses of power devices
(d) cost effective

## 5. REFERENCES


[1] K.Izaki, I.Hirota, H.Yamashita, M.Kamli, H.Omori, M.Nakaoka, "New Constant Frequency Variable Powered Quasi-Resonant Inverter Topology Using Soft-Switching Type IGBTs for Induction-Heated Cooking Appliance with Active Power Filter", Proceedings of EPE-Spain, September 1995.

[2] K.Izaki, I.Hirota, H.Yamashita, M.Kamli, H.Omori, M.Nakaoka, "New Constant-Frequency Variable- Powered Quasi-Resonant High-Frequency IGBT Inverter with Power Factor Correction for Induction-Heated Cooking Appliance", proceedings of IPEC-Yokohama Conference, pp. 656-659, April 1995.

[3] K.Izaki, H.Omori and M.Nakaoka, "Variable Power Constant Frequency Quasi-Resonant Inverter for Induction Heating Cooker", proceedings of IEE-Japan IAS, National Convention, pp. 290-291, August 1994.

[4] M.Takechi, K.Izaki, I.Hirota, H.Omori, M.Nakaoka, "A Novel Induction-Heating Rice Cooker", Proceedings of the 45th Annual International Appliance Technical Conference, pp. 541-551, May 1994.

[5] I.Hirota, H.Omori, M.Nakaoka, "Performance Evaluations of Single-Ended Quasi-Load Resonant Inverter Incorporating Advanced 2nd Generation IGBT for Soft-Switching", proceedings of November International Conference on Industrial Electronics, Instrumentation and Automation (IECON), pp. 223-228, 1992.

[6] Y.Uchihori, M.Nakaoka, "The State-of-the Art Electromagnetic Induction Flow-Through Pipeline Package Type Fluid Heating Appliance Using Series Resonant PWM Inverter with Self-Tuning PID Controller-Based Feedback Implementation", Proceedings of International IEEE/IAS Conference on Industrial Automation and Control-Emerging Technologies, pp. 14-21, May 1995.

[7] I.Hirota, H.Omori, M.Nakaoka, "Practical Developments of High-Efficient Induction-Heating Appliance using New IGBT", Proceedings of The 45th IEEE/IAS International Appliance Technical Conference, IATC'95-USA, pp. 83-92, May 1994.

[8] K. Izaki, I. Hirota, H. Yamashita, H. Omori, Y. Arai, K. Ogasawara, M. Nakaoka, "Active Voltage-Clamped Quasi-Resonant PWM High-Frequency Inverter for Induction-Heated Food Cooking Appliance", Proceedings of PCIM INTER'98 JAPAN, pp. 93-98, April 1998.