Constant Frequency Adjustable Power Active Voltage Clamped Soft Switching High Frequency Inverter using The 4th-Generation Trench-Gate IGBTs

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Abstract-**This paper presents a novel prototype of active voltage-clamping capacitor-assisted edge resonant soft switching PWM inverter operating at a constant frequency variable power (VPCF) regulation scheme, which is suitable for consumer high-power induction-heating cooking appliances. New generation IGBT with a trench gate is particularly improved in order to reduce conduction loss due to its lowered saturation voltage characteristics. The soft switching load resonant and quasi-resonant inverter designed distinctively using the latest IGBTs is evaluated from an experimental point of view.**

Index Terms: **Active voltage-clamped capacitor, edge-resonant VPCF inverter, constant frequency variable power regulation, 4th generation IGBT, zero voltage switching operation, active power filter function.**

I. INTRODUCTION

The consumer use inverter type induction heating cooking heater equipped with multiple 2 kW class burners which is connected to 200V utility AC busline and are immensely expected to grow up in demand as principal kitchen equipment.

Although an operating frequency higher than the audio frequency ranges is used to eliminate acoustic noise generated from pans or vessels for electromagnetic induction eddy current-based inverter type cooking equipment. However, the induction-heating cooking heaters using the inverter operating at variable frequency mode inherently includes a problem with interference acoustic noise caused by the difference in operating frequencies of adjacently located burners which are within the audio frequency range. The operating frequency is varied in accordance with the load types and heating power control requirements. In order to work out this problem, VPCF (Variable-Power Constant-Frequency) control-based resonant inverters that allow the power to adjust at constant frequency have been put into practice in consumer use since 1990. The previously used non-resonant SEPP inverter allowed easy control as well as simple topology but had the inherent problem of generating a large amount of switching losses in a high frequency operation mode more than 20 kHz, in addition , a large amount of EMI/RFI noise is generated due to hard switching operation. To solve these problems, in 1994, the voltage-source half-bridge quasi-resonant inverters were put into a practical use, allowing both VPCF control and zero voltage soft

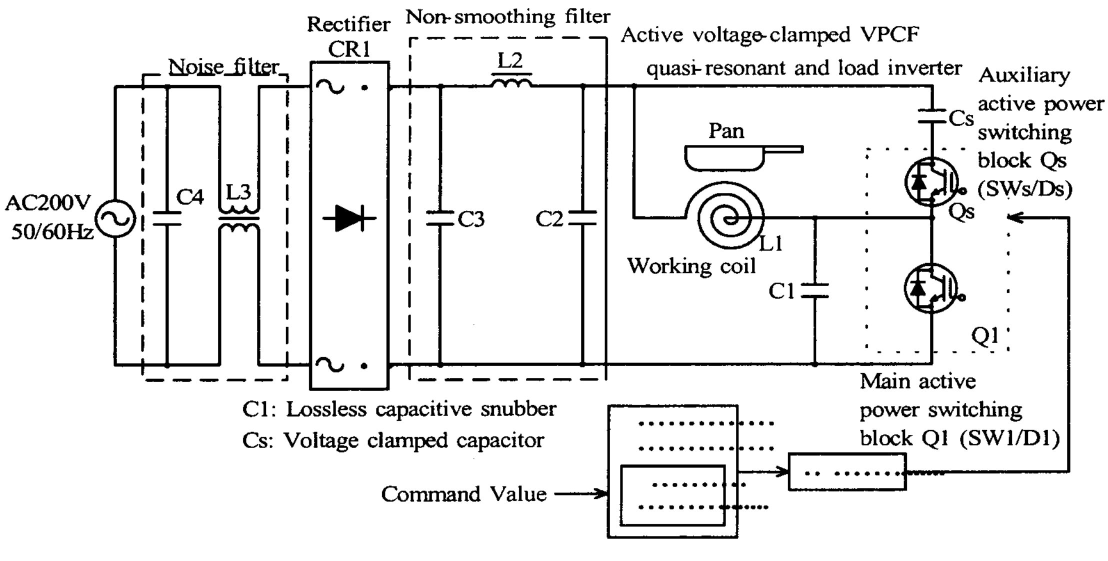


Fig1. A schematic diagram of active voltage-clamped VPCF inverter using IGBTs.

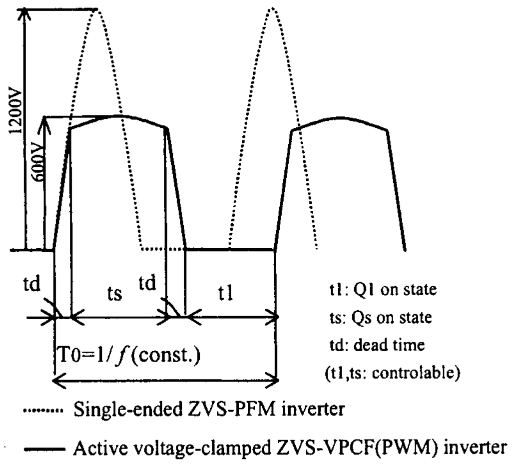


Fig.2. Voltage waveforms of active-voltage clamped ZVS-VPCF inverter using IGBTs.

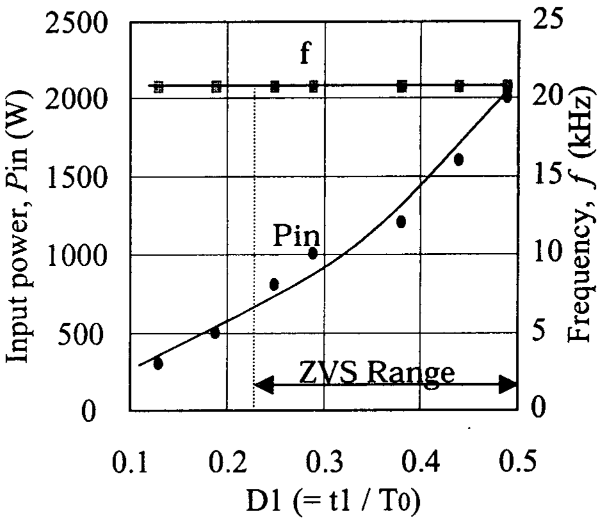


Fig.3. Power regulation characteristics of active voltage-clamped ZVS-VPCF inverter

TABLE I

RATINGS OF Q1 & Q2

Characteristic	Symbol	Q1	Q2	Unit
Collector-Emitter Voltage	Vces	900	900	V
Gate-Emitter Voltage	Vges	25	25	V
Collector Current(DC)	Ic	65	40	A
Collector Power Dissipation(T_c=25°C)	Pc	200	55	W
Junction Temperature	Tj	150	150	°C

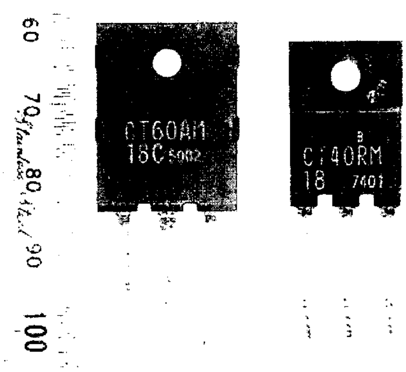


Fig.4. Physical appearances of active power switches Q1 and Qs

switching operations saimultaneously. Recently, the authors have developed a new inverter, which is based on the active voltage-clamped quasi-resonant inverter shown in Fig. 1. On the other hand, using the 4th-generation IGBTs, it is possible to reduce both physical size and cost of inverter effectively in terms of simplifying power conditioning and processing stage and minimizing electrical dynamic stresses *di/dt* and *dv/dt* of the power semiconductor devices.

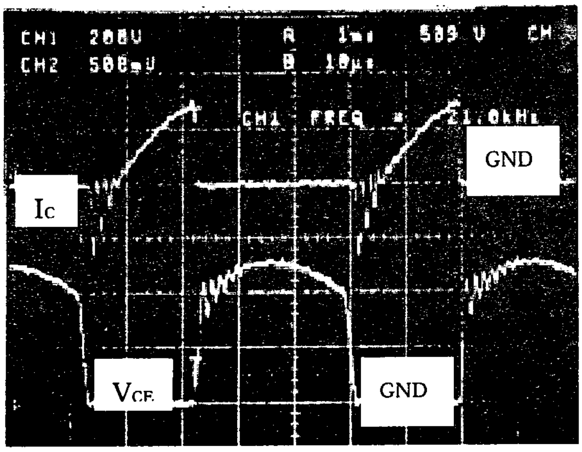
II. ACTIVE VOLTAGE-CLAMPED EDGE-RESONANT INVERTER

Fig. 1 shows a schematic configuration of newly developed active voltage-clamping type edge-resonant inverter for the consumer induction-heating cooking appliances, which is able to operate under a condition of ZVS-PWM (VPCF) control strategy in order to solve harmful acoustic noise generating problem in multi-burner integration. The inverter depicted in Fig.1 is composed of a voltage-source single-ended ZVS-PWM inverter with active voltage clamped capacitor.

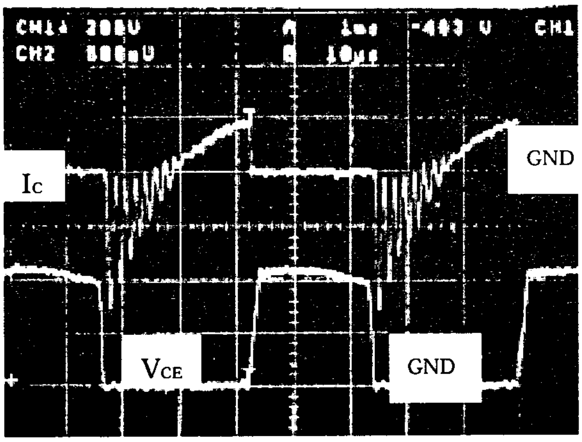
This high-frequency quasi-resonant inverter with VPCF (Variable Power Constant Frequency) function is connected to a utility-grid single-phase full-bridge diode rectifier with a power factor correction with sine wave current shaping function. A newly developed ZVS-PWM quasi-resonant inverter with a VPCF function is directly combined to multiple-integrated induction-heating burners as the load vessels which are coupled to each pancake-like working heating coil in two or more arranged burners. Its microcomputer-based control circuit for a constant frequency power regulation and system protection control schemes and integrated module circuit for compact IGBT drivers are incorporated into the quasi-resonant inverter treated here, which operates under a principle of ZVS.

In this inverter circuit, the reverse conducting active power switches, Q1 and Qs, incorporate the new-generation high frequency and lowered saturation voltage-type IGBTs designed for soft switching. Table1 indicates their design specifications and Fig.4 represents their appearances.

The steady-state operation of this ZVS-PWM inverter

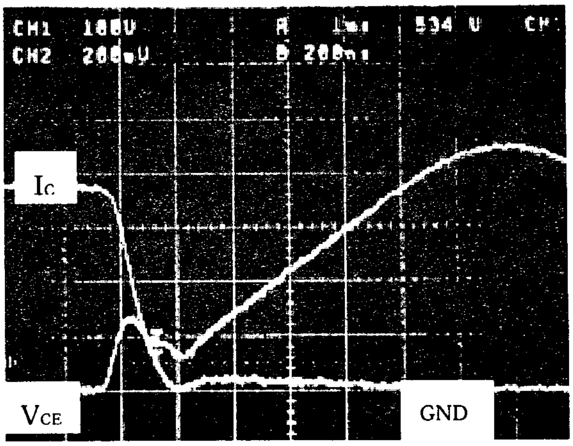


(a)

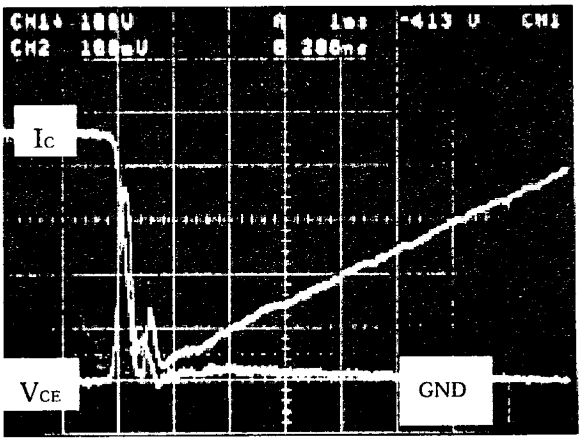


(b)

Fig.5. Voltage and current waveform of active power switches (a)Q1,(b)Qs, I_c =50A/div,V_{CE}=200V/div and time scale; 10μs/div .



(a)



(b)

Fig. 6. Voltage and current waveform of active power Switches at turning off (a)Q1 , (b)Qs, I_c = 20A/div,V_{CE}=100V/div and time scale: 200ns/div

circuit is• basically described in Fig.2 as compared with ZVS-PFM inverter circuit. A heating coil L1 and resonant capacitor C1 form the main resonance circuit, and the circuit includes a conventional single-ended ZVS inverter with active power device Q1.Capacitor Cs and sub active power switch Qs serve to clamp the resonant voltage of Q1 to approximately 600 V as illustrated in Fig. 2. The off period of Q1 consists of a quasi-resonant transition interval td during ZVS operation and a non-resonant transition interval ts when clamping with Qs and Cs. Heating power is able to be controlled by varying the operating period t1, and variable power control can be achieved at a constant frequency by interpolating during the non-resonance mode ts . Since the current in the resonant capacitor C1 is generated only during•switch transition and current flowing through the voltage-clamping capacitor Cs is generated only during• •clamping(Qs: on) mode, the capacitors with a low current capacity can be used.Fig.3 shows the inverter input power power regulation•••characteristics for the duty factor control of Q1 under an operation condition of a constant frequency 20.8 kHz.

III. PERFORMANCE CHARACTERISTICS OF NEWLY DEVOPLOPED SWITCHES POWER DEVICES

A. Loss Analysis of Switching of Power Devices

Fig.5 (a) and Fig.5 (b) show the measured voltage and current operating waveforms of Q1 and Qs, respectively. As illustrated in the figures, the clamping effect of resonance voltage is realized. The losses of the switching devices in this inverter consist of conduction loss and turn-off switching loss. Since turn-on loss can be essentially ignored because of soft switching due to ZVS and ZCS operations, switching loss is equal to turn-off losses.

Conduction power losses of the power devices and

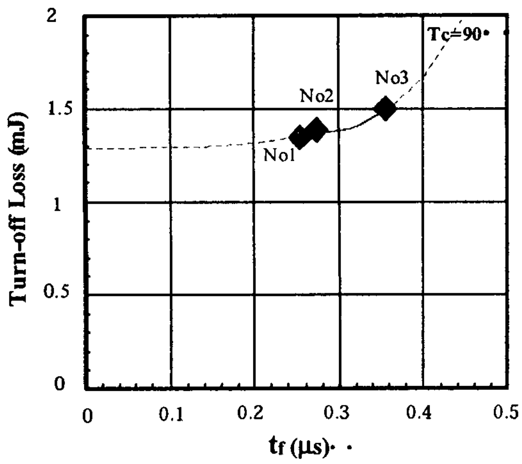


Fig. 7. Turn-off loss vs. falling time characteristics of IGBT(Q1).

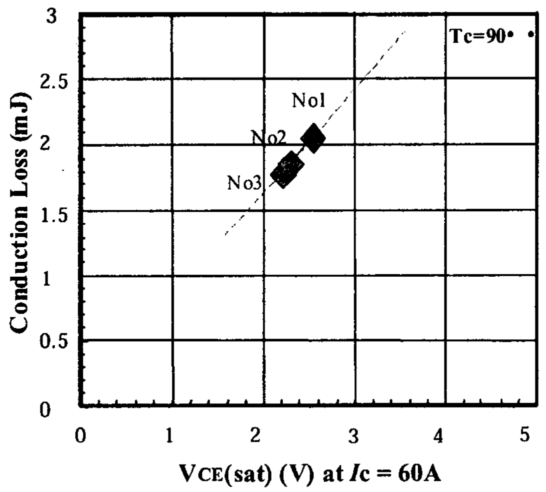


Fig. 8. Conduction loss vs. VCE(sat) characteristics of IGBT(Q1).

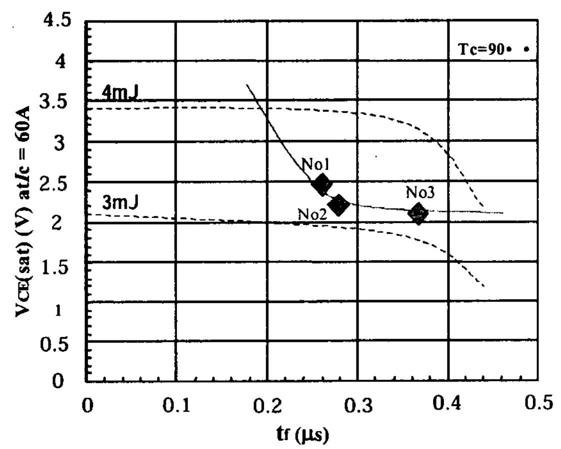


Fig. 9. Loss contour lines and falling time vs. VCE(sat) characteristics of IGBT(Q1).

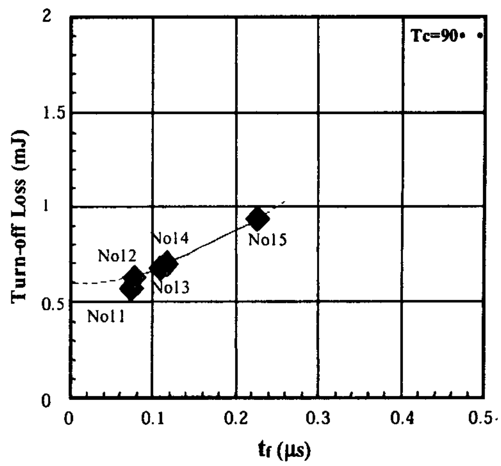


Fig. 10. Turn-off loss vs. falling time characteristics of IGBT(Qs).

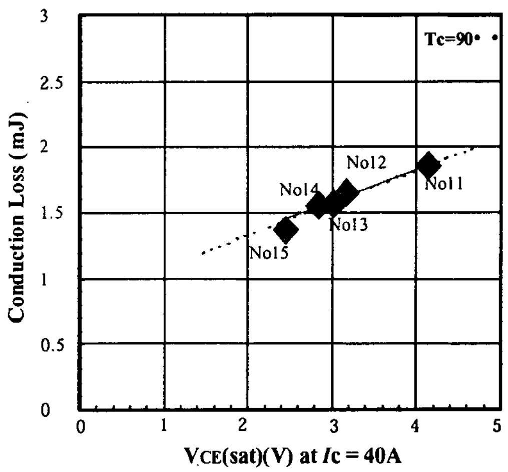


Fig. 11. Conduction loss vs. VCE(sat) characteristics of IGBT(Qs).

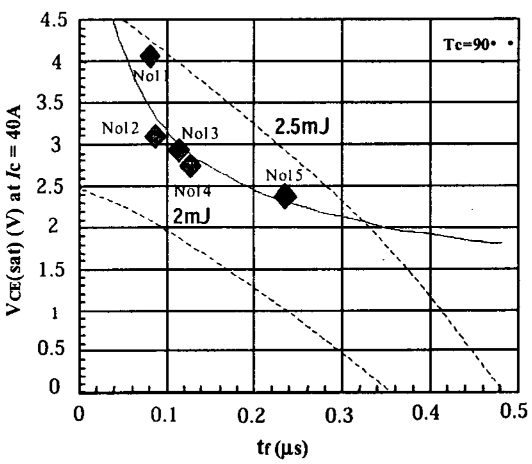
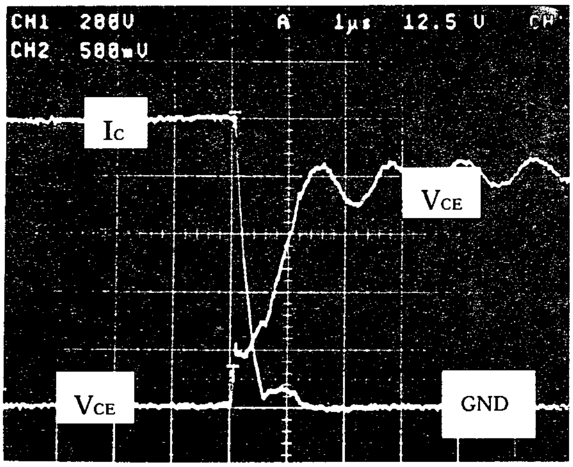
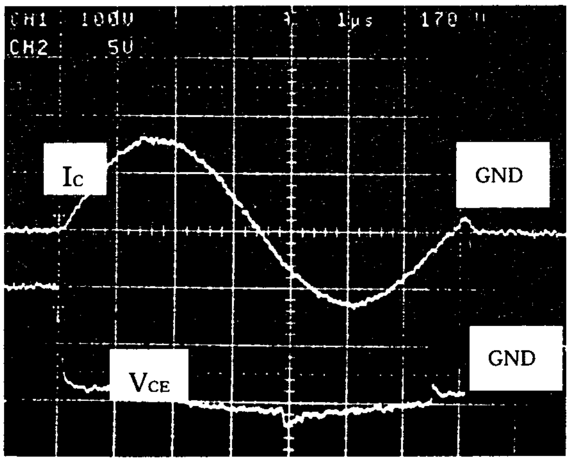


Fig. 12. Loss contour lines and falling time vs. VCE(sat) characteristics of IGBT(Qs).

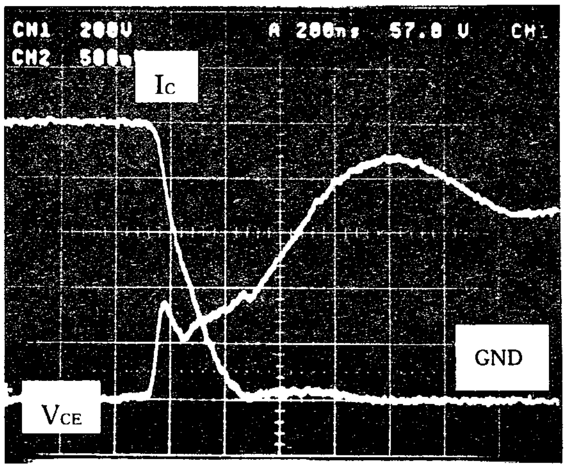


(a)

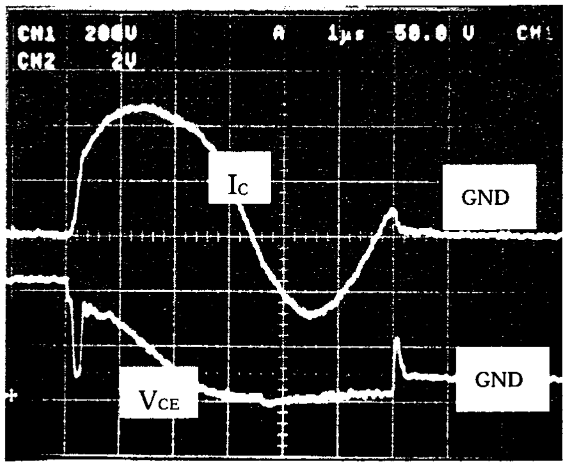


(b)

Fig. 13. High current operations of newly developed IGBT for Q1.
(a) Ic=50A /div, VCE=200V /div and time scale: 1μs /div,
(b) Ic=500A/div,VCE=200V/div and time scale: 1μs /div.



(a)



(b)

Fig. 14. High current operations of newly developed IGBT for Qs.
(a) Ic=50A /div, VCE=200V /div and time scale: 200ns /div,
(b) Ic=200A/div, VCE=200V/div and time scale: 1μs/div

switching power losses can be estimated from measured operating waveforms. The measured results of power losses analysis for Q1 and Qs are shown in Figure 7 to Fig 12.Fig.7 and Fig.10 show the correlative characteristics with the turn-off switching power losses measured with some sample power devices to various types of Q1 and Qs falling times *tf.* The figures indicate that the turn-off switching power loss is closely correlative to *tf.* The conduction power loss becomes an increasing function of VCE(sat) as shown in Fig.8 and Fig.11.

Since the loss at any point can be estimated on the tf vs. VCE (sat) plane for Q1 from Fig. 7 and Fig. 8 and for Qs from Fig. 10 and Fig. 11.constant power loss can similarly be obtained from Fig.9 and Fig.12By comparing these constant power loss lines with the IGBT trade-off curves shown in solid lines, minimum IGBT power loss design can be performed.

For example, in the case of Q1, reduction of *V*CE (sat) lowers losses more effectively than decreasing tf. The power device sample ; IGBT No.2 can accomplish the optimum design specifications and for Qs IGBT No. 14 can do that.

B. High Current Operation of Switching Devices

Allowable current waveforms of the produced IGBT on trial, which is incorporated into a testing inverter circuit as the single-ended ZVS inverter, are experimentally shown in Figs.13 and Fig.14. The turn-off switching operation is represented in Fig.13 (a) for Q1 and Fig.14 (a) for Qs, and the short-circuited operation under the capacitive-load is displayed in Fig. 13(b) for Q1 and Fig. 14(b) for Qs. Taking into account these testing data, the new IGBT

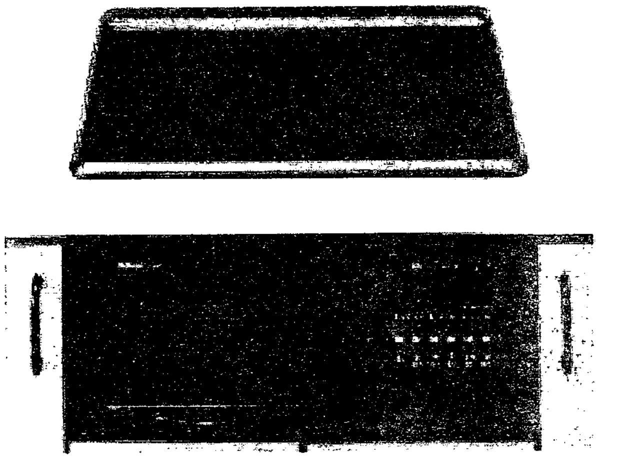


Fig. 15. Appearance of induction-heating cooking heaters equipped with developed active voltage-clamping type quasi-resonant inverter.

produced here can switch off 4 times the rating current. Moreover, it can short 13 times and 12 times as large as the rating current at Tj=150°C for Q1 and Qs respectively.Fig.15 demonstrates the appearance of the two burner heaters composed of two VPCF soft switching high frequency inverters using the latest IGBTs.

IV. CONCLUSIONS

A novel prototype of active voltage-clamped quasi-load resonant soft-switching PWM inverter using the 4th generation IGBTs developed newly has been presented for consumer induction-heating cooking appliances. A new type of IGBT with power loss reduction has been achieved introducing a trench gate IGBT with low saturation voltage characteristics and evaluated for inverter type induction heating cooker. Further optimizations leading to better performance should be carried out under a variety of MOS gate switching power semiconductor devices and their related power modules with new unique structures.

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