A Constant Frequency Variable Power Regulated ZVS-PWM Load-Resonant Inverter for Induction-Heating Appliance

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Abstract— **This paper presents a novel type of voltage-fed quasi-load resonant half-bridge IGBT inverter operating at constant frequency variable power (CFVP) regulation scheme which is more suitable and acceptable for new high-frequency high-power induction-heated (IH) cooking appliances. This application-specific high-frequency inverter using a new generation specially-designed IGBTs can efficiently operate under a principle of ZVS-PWM control strategy. The operating principle of a new inverter circuit is presented together with its power regulation characteristics on the basis of its computer-aided simulation analysis and its experimental results. The steady-state characteristics of cost effective quasi-resonant inverter developed for high-frequency IH cooking appliances such as multi-burner type IH cooker are discussed herein from a practical point of view.**

I. INTRODUCTION

In recent years, the feasible technology developments of switched-mode resonant high-frequency inverters and converters using new MOS-gate controlled power semiconductor devices have attracted special interest in the fields of industrial, consumer, medical, aerospace and automotive applications as well as telecommunication energy applications.

This paper deals with a CFVP quasi-resonant ZVS-PWM high-frequency half-bridge inverter using new-generation IGBTs for soft-switching, which is to be more acceptable for the IH cooking appliance with two burners. The steady-state operating principle of a novel prototype of quasi-resonant soft-switched PWM inverter using the main and auxiliary IGBT is described and its unique features are pointed out. The steady-state power regulation characteristics of the quasi-resonant mode ZVS-PWM inverter are illustrated on the basis of the experimental and computer-aided simulation results.

II. NEW HALF-BRIDGE ZVS-PWM INVERTER DESCRIPTION

A. Induction Heated Appliance

The high-frequency resonant inverters are more suitable for IH cooking heater, IH rice cooker, IH warmer, IH steamer, IH super steamer, IH dryer, IH fryer and IH hot water producer. These consumer power electronic appliances using high-frequency inverters have to achieve the following items; high performances; compact volumetric size and light weight in the fields of household and business uses because of largely-lowered cost of power semiconductor devices as new generation IGBTs for soft-switching, and circuit power components as inductor and transformers, their intelligent driver circuit module, integrated custom control circuit devices and new types of inverter circuit topologies with the diode rectifier circuit with non-smoothing filter to provide active power filter function.

These IH consumer appliances mentioned above basically make use of the heat energy based on induced eddy currents in the pan or the vessel, which is directly placed through thin ceramic spacer in a high-frequency magnetic field produced by working coil connected to the new high-frequency resonant inverter.

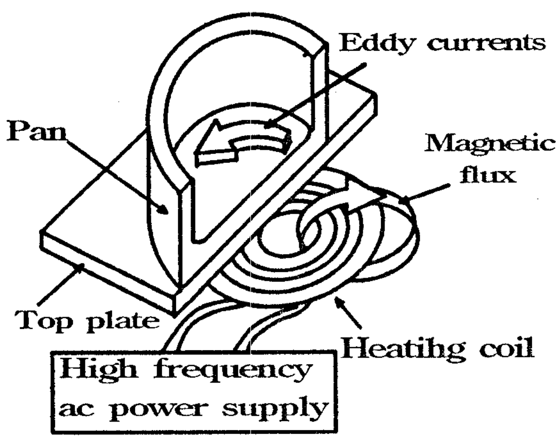


Fig.1 . Principle of Induction-heating for consumer appliances

The induced eddy currents due to the electromagnetic induction make it to generate Joule's heat directly in the pan or the vessel on the basis of the heating principle shown in Fig.1. This principle essentially characterizes cleanness, safety, high reliability, maintainability, controllability and high efficiency.

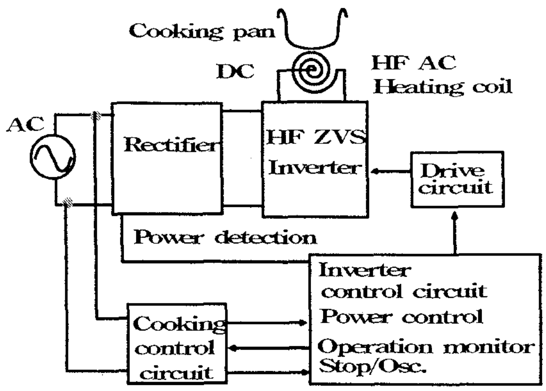


Fig. 2 Circuit structure of IH rice cooker

Fig.2 shows a schematic block diagram of the inverter-fed IH consumer. In general, IH consumer appliances include some interesting ones such as IH cooking heater, IH rice cooker, IH warmer, IH steamer, IH super steamer, IH dryer, IH fryer and IH hot water producer. Main power processors of the IH cooker include an active power filter using a diode rectifier with a non-smoothing DC filter, quasi-resonant ZVS-PWM high-frequency inverter circuit using IGBTs with intelligent drive hybrid circuit modules. This inverter control implementation for the IH cooking appliance.

B. Soft-switched PWM inverter

Fig.3 shows a new constant frequency variable power (CFVP) quasi-load resonant inverter configuration for the electromagnetic induction-heated appliances for IH cooker, which is used as shown in Fig.2. The ZVS-PWM quasi-resonant inverter using new generation IGBTs and their related driver modules, which is operated under the condition of a CFVP control strategy in order to exclude harmful acoustic noise in case of two burner cooking appliance.

This new power electronic appliance in consumer fields is specially introduced for two burners or multi-burners system structure for business uses. This high-frequency quasi-resonant inverter with CFVP function which can operate under a principle zero voltage soft switching mode is connected to a single-phase full-bridge diode rectifier with a power factor correction scheme with sinewave line current shaping function.

A newly-developed zero voltage soft-switching PWM quasi-resonant half-bridge IGBT inverter with CFVP function is successfully combined to multiple IH load vessels or pans coupled to each pancake-like working heating coil in two burners. Its control circuit for power regulation and system protection schemes, and IGBT driver IC hybrid modules are incorporated into new soft-switched half-bridge inverter. In this inverter circuit, the reverse blocking power switch Q1a and D1a, and the reverse conducting power switch Q1b and D1b incorporate the third-generation lowered saturation voltage type IGBTs designed for soft-switching which are developed as the new generation IGBTs.

Table 1 Power ratings of Q1a and Q1b

Device	Q1	Q2
Type	GT80J101	GT60M105
V_{CES} (V)	600	900
Ic(A)	80	65
V_{CE}(V)	2.2	1.9
tf(μs)	0.25	0.22

Additional power ratings of IGBTs developed are indicated in Table 1.

C1a is a high-frequency plastic film capacitor for quasi-resonance and C1b is a high-frequency capacitor for alleviating an excessive peak voltage applied to Q1b. The diode D1c is indispensable for expanding the zero-voltage soft-switching operation range required for different metal types of IH loads.

C. Comparative Evaluations

Fig.4 illustrates the switching voltage and current waveforms of the conventional single-ended ZVS-PFM inverter (Type1) and Hard-switched PWM Inverter (Type2) and developed quasi-resonant ZVS-PWM inverter (Type3) system.

The conventional quasi-resonant ZVS-PFM inverter developed previously can be operated under zero-voltage soft-switching condition by means of variable frequency in order to regulate the output power for heating energy control. The half-bridge hard switched PWM inverter operating at a fixed frequency has the advantage of excluding the acoustic noises generated from its cooking system appliance with two or more burners.

However, the inverter system of Type 2 includes inherent problems of generating the large switching losses in a high-frequency operation mode in addition to the generation of EMI/RFI noises due to hard-switching scheme. The IH load constitutes a pan or a vessel placed

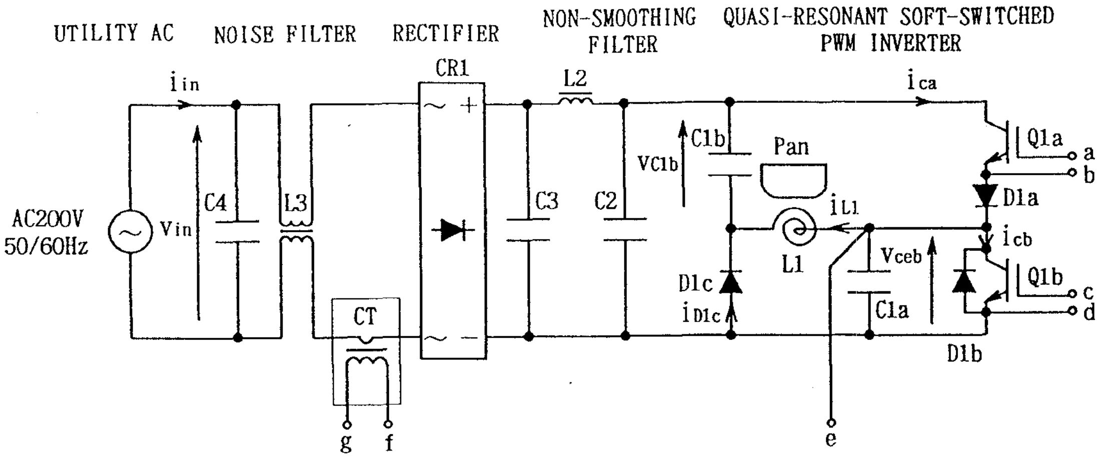


Fig.3 New CFVP quasi-resonant inverter system circuit configuration

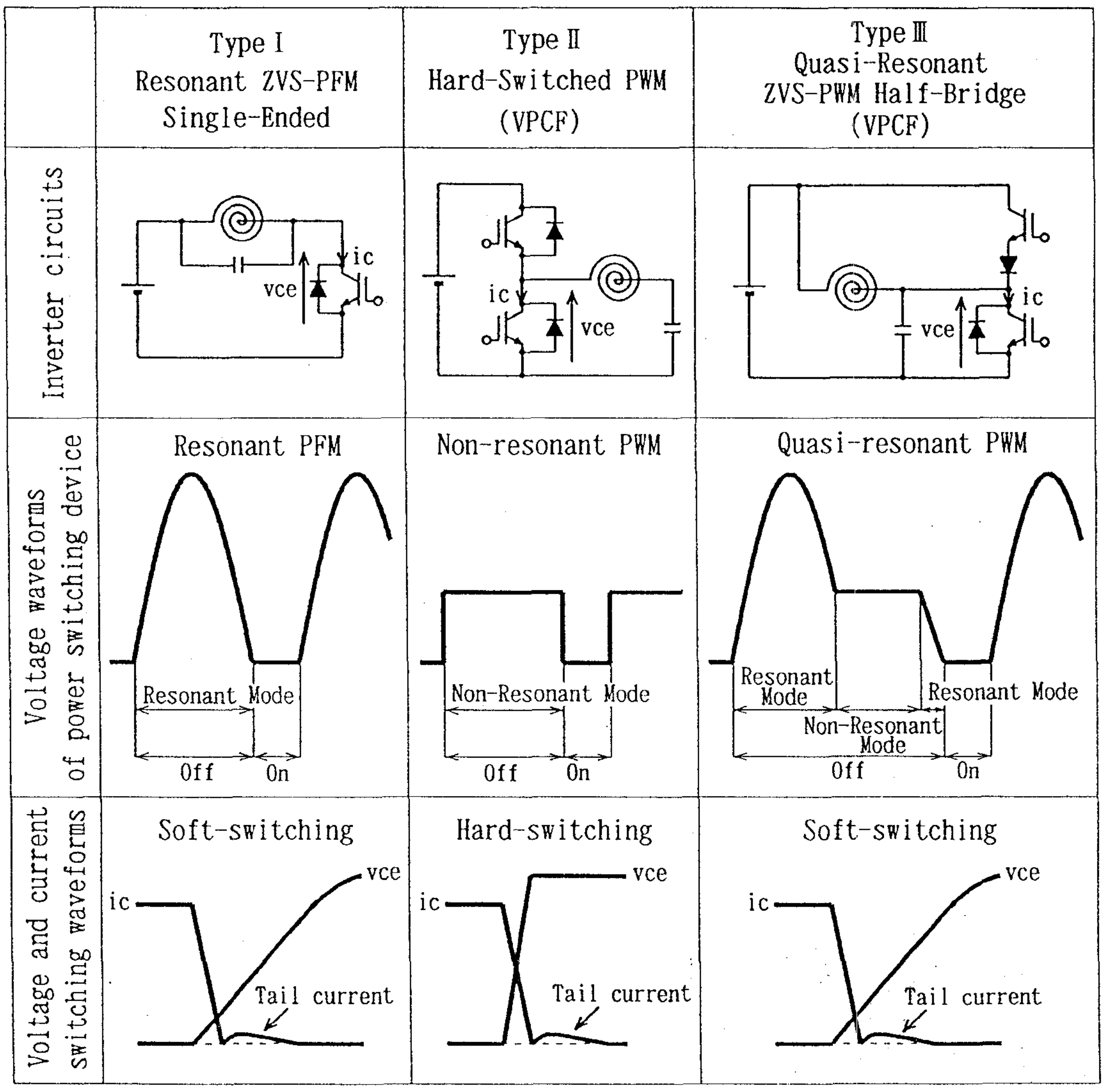


Fig. 4 The switching voltage and current waveforms of the Type1, Type2 and Type3

on the flat working coil with a specific ceramic spacer in addition to distributed side-face working coil wrapped around the pan or vessel.

As can be seen from Fig.5, the peak collector to emitter voltage of Q1b could be reduced from 1200V to 500V by adding a capacitor C1b to the circuit of Fig.5(a). By further connection of the diode D1c as shown in the circuit of Fig.5(c), the soft-switching range can be widened and the voltage at turn-on of Q1a (Vona) can be reduced from 180V to 80V at Da=0.1.

The power semiconductor switches IGBTs (Q1a and Q1b) in the switching arms of the new half-bridge resonant inverter topology can be driven in accordance with the gate pulse signals due to the unsymmetric PWM strategy. With this quasi-resonant ZVS-PWM half-bridge inverter topology, the soft-switching operation under the condition of CFVP control strategy can be achieved for various types of feasible IH loads.

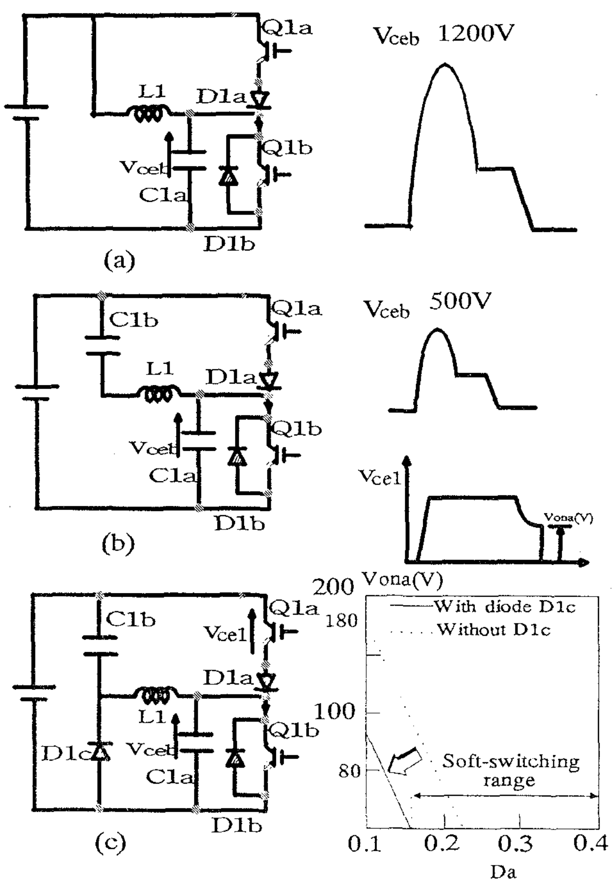


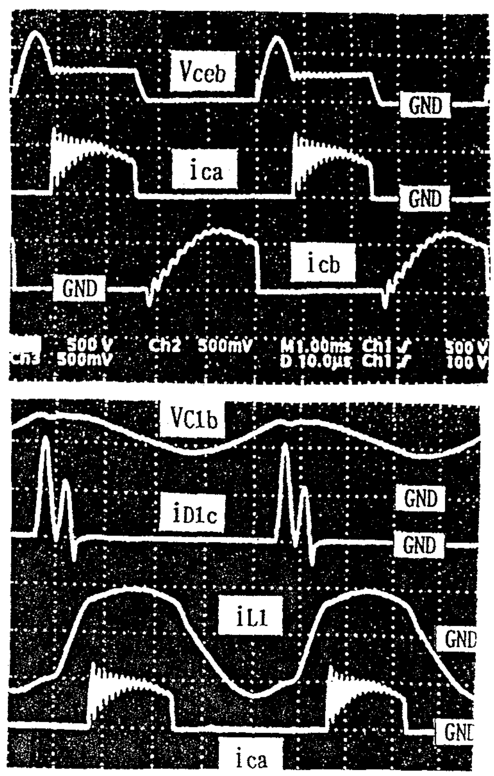
Fig.5 Effects of capacitor C1b and diode D1c

III. EXPERIMENTAL RESULTS AND THEIR DISCUSSIONS

The typical measured voltage and current waveforms of this quasi-resonant ZVS-PWM half-bridge inverter treated here are shown in Fig.6.

As can be seen in this figure, it is clearly proved that Q1b can operate under a condition of zero-voltage soft-switching. In addition to this, the soft-switching operation of Q1b can be also achieved completely in spite of PWM regulation process. It is noted that the soft-switching operations of Q1a and Q1b can be completely realized on the basis of a constant-frequency PWM strategy to regulate the output power of this inverter.

With respect to the switching losses of IGBTs and the practical problems related to their dynamic electrical stresses, EMI/RFI noises as well as beating interference acoustic noise can be effectively reduced by introducing this new high-frequency inverter circuit topology operating at a constant frequency.



(*Vceb*: 500V/div, *ica*: 50A/div, *icb*: 50A/div, *Vc1b*: 500V/div, *iD1c*: 50A/div, *iL1*: 50A/div, 10 μ s/div)

Fig.6 Observed voltage and current waveforms in the soft-switched operation

Fig.7 illustrates the inverter input power regulation characteristics vs. the duty factor Da=Ta/T0 and Q1a under an operating condition of a constant frequency; 20.5kHz. The duty factors Da can be controlled to provide the output power regulation under a constant frequency scheme. In this case, the maximum input power of this inverter can be obtained for Da=0.5.

In the case of using two ZVS-PWM quasi-resonant inverters suitable for IH cooking appliance with two or multiple burners, harmful acoustic beating interference-based noise causes from a little difference of the operating frequencies between two or more quasi-resonant inverter with ZVS-PFM control strategy can be effectively minimized in spite of variable power regulation process because of a constant frequency operation principle. The quasi-resonant ZVS-PWM half-bridge inverter with CFVP scheme treated here can operate under an optimum condition of considerably reduced switching losses of IGBTs (Q1a and Q1b) and their electrical dynamic and peak stresses in addition to the reduction of harmful acoustic interference noise level.

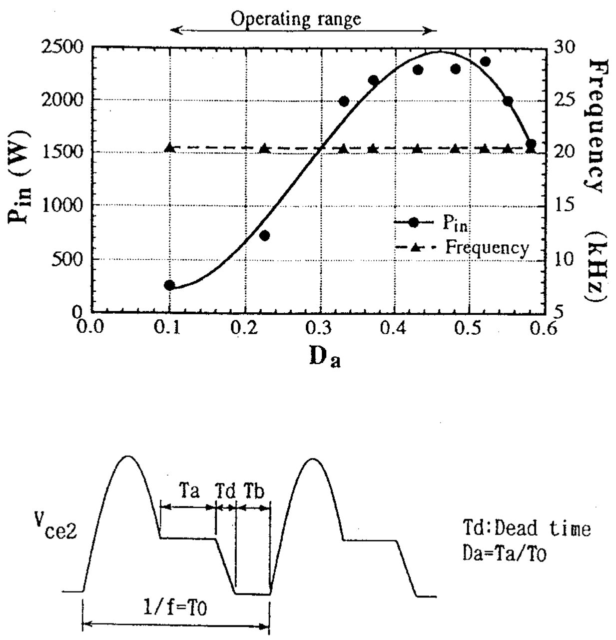


Fig.7 Power regulation characteristic of the new type VPCF inverter

IV. CONCLUSIONS

In this paper, an advanced prototype of voltage-fed half-bridge quasi-load resonant inverter circuit using IGBTs and its circuit system topology with active power filtering function have been presented for high-power IH cooker, hot water producer, hot air producer, cooking fryer and cooking steamer appliances. In consumer power electronic systems, the power semiconductor device technology of the new generation IGBTs modules, designed for soft-switching and their related drive and intelligent control circuit modules are incorporated into the ZVS-PWM high-frequency quasi-resonant inverter with active power filter in utility side.

The voltage-fed soft-switching high-frequency quasi-resonant inverter combining both reverse conducting IGBTs and reverse blocking IGBTs, which operates under CFVP regulation scheme which operate at wide ZVS-PWM mode has been also evaluated and discussed for high-power IH rice cookers/warmers, hot water and hot air producers, and cooking steamer for the new development of two or multi-burner cooking appliances and complex-appliances including inverter-fed microwave oven.

The operating principle of quasi-resonant PWM inverter working at ZVS mode has been described for IH cooking appliances. The inherent salient features of the power processor have been pointed out from a practical point of view.

For the future prospects, the epoch-making promising and unique applications of this soft-switched quasi-resonant inverter treated here should be investigated for possible electromagnetic induction type fluid heating in the pipeline systems such as IH boiler, IH evaporator, IH high-temperature super heat steamer, IH hot gas dryer and IH hot water producer in industrial, chemical, mechanical, medical, ocean, space and consumer energy utilization plants.

V. REFERENCES

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