DUAL DUTY CYCLE CONTROLLED SOFT-SWITCHING HIGH FREQUENCY INVERTER USING AUXILIARY REVERSE BLOCKING SWITCHED RESONANT CAPACITOR

Bishwajit Saha [(1)], Ki-Young Suh [(1)], Hyun Woo Lee [(1)], Mutsuo Nakaoka [(1)(2)]

[(1)] Electric Energy Saving Research Center, Kyungnam University, Masan, Republic of Korea.
[(2)] Industrial College of Technology-University, Hyogo, Japan.
E-mail: bsaha@ieee.org

Abstract-This paper presents a new ZVS-PWM high frequency inverter. The ZVS operation is achieved in the whole load range by using a simple auxiliary reverse blocking switch in parallel with series resonant capacitor. The operating principle and the operating characteristics of the new high frequency circuit treated here are illustrated and evaluated on the basis of simulation results. It was examined that the complete soft switching operation can be achieved even for low power setting ranges by introducing the high frequency dual duty cycle control scheme. In the proposed high frequency inverter treated here, the dual mode pulse modulation control strategy of the asymmetrical PWM in the higher power setting ranges and the lower power setting ones, the output power of this high frequency inverter could introduce in order to extend soft switching operation ranges. Dual duty cycle is used to provide a wide range of output power regulation that is important in many high frequency inverter applications. It is more suitable for induction heating applications the operation and control principle of the proposed high frequency inverter are described and verified through simulated results.

Keywords- Zero voltage soft-switching, Reverse blocking switched resonant capacitor, Dual duty cycle control

I. INTRODUCTION

With great advances of high frequency power electronics, an efficient electromagnetic eddy current based induction heating (IH) technology is more acceptable for consumer food cooking and processing appliances such as cooking heater, rice cooker and warmer, hot water producer, along with super heated steamer. A variety of IH equipments not only fill the key demands of safety and cleanliness, but also has excellent advantages of very high thermal conversion efficiency, rapid heating, local spot heating, direct heating, high power density, high reliability, low running cost and non-acoustic noise. Aforementioned IH appliances using high frequency inverters make use of eddy current based Joule's heat and hysteretic loss heat due to Faraday's electromagnetic induction law and can supply high frequency power to IH load, which consists of working coil and eddy current based heating materials. Some high-frequency inverters operating over power frequency ranges from 20 KHz to several MHz need to be cost effective high efficiency and high power density. There is various high frequency inverter topologies, such as full-bridge, half-bridge, single-ended push-pull, center tap push-pull and boosted half-bridge. Of these, the voltage source type ZCS (Zero Current Soft switching) SEPP (Single-Ended Push Pull) resonant and quasi-resonant hybrid high-frequency inverter has unique features as simple configuration, high efficiency and wide soft commutation range. As we know the concept of induction heating is employed of an IH cooker, this concept can be simplified as follows. First convert the utility AC voltage to DC using rectifier then connected to high frequency switching circuit to supply high frequency current to the working coil. The proposed high frequency inverter consists of half bridge series resonant converter and bypass switch. The operation and control principle of the proposed high frequency inverter are described and verified through simulated results. The advantages of half bridge series resonant converter are stable switching, low cost and streamlined design.

II. NEW HIGH FREQUENCY INVERTER TOPOLOGY

A .Circuit construction

Figure 1 shows the newly developed duty cycle ZVS PWM high frequency inverter circuit topologies using the latest trench gate IGBTs and operating with constant frequency PWM control strategy. This voltage-fed PWM high frequency inverter circuit consists of two main switches of reverse conducting IGBTs Q_1 (SW_1/D_1) and Q_2 (SW_2/D_2), a single reverse blocking auxiliary switch Q_3 (SW_3/D_3). The modified versions of the proposed ZVS inverter are illustrated in Fig. 2 (a)-(c).The resonant circuit comprises of resonant inductance (L_0) and resonant capacitance (Cr). The capacitors, C_1 and C_2, are the lossless turn-off snubbers for these switches, Q_1 and Q_2.

B. Power regulation scheme

The output high frequency AC effective power of the proposed inverter circuit in Fig. 1 can be continuously regulated by a constant frequency dual duty cycle PWM control scheme under a condition of zero voltage transition soft switching principle. The PWM gate pulse timing sequences are illustrated in Fig. 3. By the constant frequency asymmetrical PWM control scheme which is based on varying the time ratio of total conduction times T_{on} of Q_1, Q_2 and Q_3 to the operating switching period T of high frequency, the proposed high frequency inverter circuit can control the high frequency output power continuously. The conduction time T_{on1} of Q_1 (SW_1/D_1) and the conduction time T_{on3} of Q_3

can be varied. As a control variable in the proposed dual duty cycle PWM schemes, duty factor is defined as

$$D_1 = \frac{T_{on1}}{T} \qquad (1)$$

$$D_2 = \frac{T_{on3}}{T} \qquad (2)$$

By varying the two duty factor D_1 and D_2 can be regulated the high frequency inverter output power continuously.

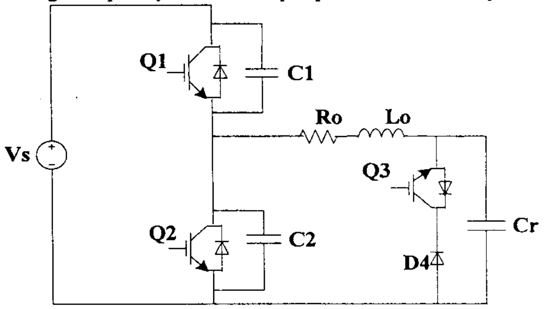

Fig. 1 Single ended ZVS inverter with low side switched capacitor.

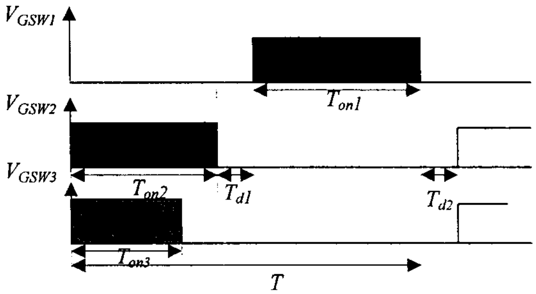

Fig. 2 A schematic gate pulse timing sequences.

C. Remarkable features

The outstanding features of the newly developed soft switching high frequency inverter are summarized below:

(i) The DC component of the high frequency current through the working coil is zero because the series capacitor compensated resonant tank.

(ii) The ZVS soft switching commutation range becomes much wider.

(iii) The effective efficiency of this high frequency inverter is much higher over wider power regulation range from high power settings to low power settings because of selective dual duty cycle mode PWM control scheme.

(iv) Constant frequency operation can be implemented.

III. PRINCIPLES OF OPERATION

The current operating waveforms and relevant modes of this inverter in steady state are illustrated in Fig. 3. The switching modes, voltage and current waveforms and the proposed zero voltage soft switching high frequency inverter in steady state during one switching cycle are shown in Fig. 3. The switches of ZVS resonant converter turn on and off at zero voltage switching. The capacitor *C* is connected in parallel with switch S_1, S_2, S_3 to achieve ZVS, the internal switch capacitance is added with the capacitor *C* and its effect the resonant frequency only, thereby contributing no power dissipation in the switch, the switch is implemented by Q_1, Q_2 with anti parallel diode D_1, D_2. So the voltage across C is clamped by D_1, D_2 and these switches operate in half wave configuration and the voltage across *Cr* is clamped by D_3. If the diode D_4 is connected in series with Q_3 the voltage across *Cr* is oscillates freely and the switch is operated in a full wave configuration as shown in Fig. 2 (a), (b) and (c).

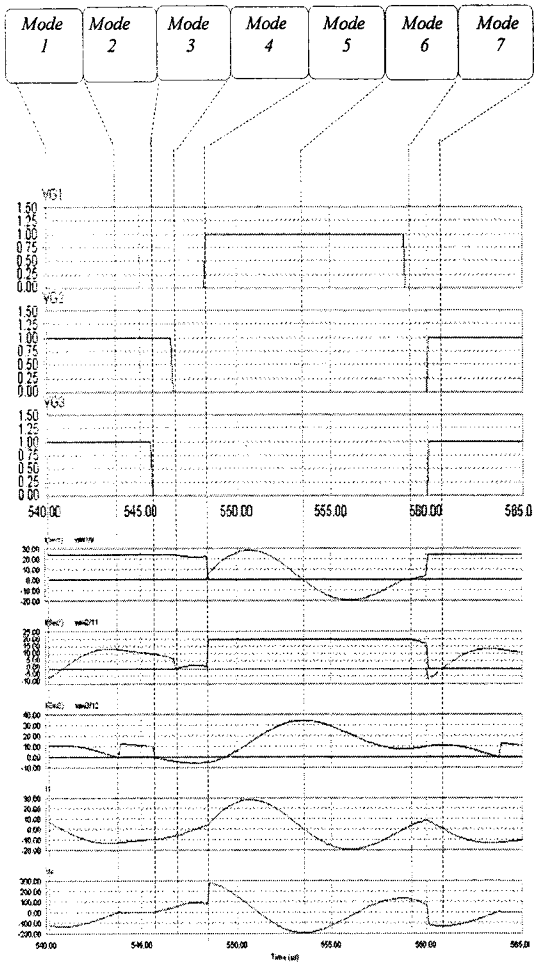

Fig. 3 Relevant voltage and current waveforms.

Mode 1: this mode starts when SW_2 of Q_2 begin conducting, the current will flow through *Ro*, *Lo*, *Cr* until D_4 is forward biased.

Mode 2: starts when D_4 begin to conduct, the current passing through *Ro*, *Lo*, D_4, Q_3, Q_2 until Q_3 is turned off at this moment Mode 3 starts.

Mode 3: Current circulates in *Cr*, *Lo*, *Ro* and Q_2 until Q_2 is turned off.

Mode 4: after Q_2 turned off C_1 will be in series with the parallel combination of C_2 and $(Cr+Lo+Ro)$. After dead time T_{d1} switch Q_1 is turned on (mode 5).

Mode 5: switch Q_1 is turned on, the supply current passing through SW_1 and divided between $(Cr+Ro+Lo)$ and C_2.

Mode 6: after the voltage across C_2 is exceeded its maximum value D_1 now is conducting.

Mode 7: D_2 conducts due to energy stored in Lo until Q_2 start conducting (mode 1).

IV. CIRCUIT EFFICIENCY ANALYSIS

The output power versus duty factor characteristics for the proposed voltage source type dual duty cycle high frequency inverter with PWM control scheme is depicted Fig. 4. In this diagram high frequency inverter circuit proposed here, the input power of this inverter can be regulated approximately from 0.2 KW to 3.4 KW at switching frequency 50 KHz under a principle of ZVS soft-switching commutation. The soft-switching operating range is relatively large in the proposed ZVS-PWM dual duty cycle high frequency inverter. The diagram of output power versus auxiliary control duty cycle has shown in Fig. 5. From this diagram, we will get the output power regulation due to an auxiliary control at certain the value of main control scheme. Figure 6 has shown the output illustrated power regulation characteristics of the proposed inverter.

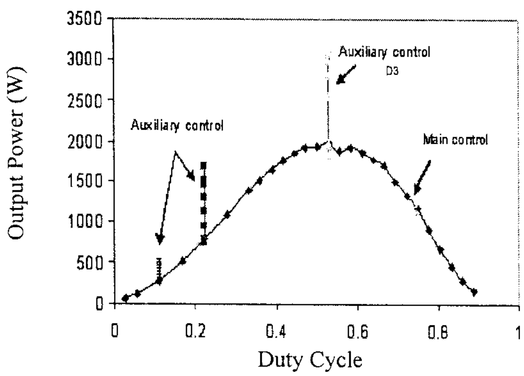

Fig.4 Output power regulation characteristics.

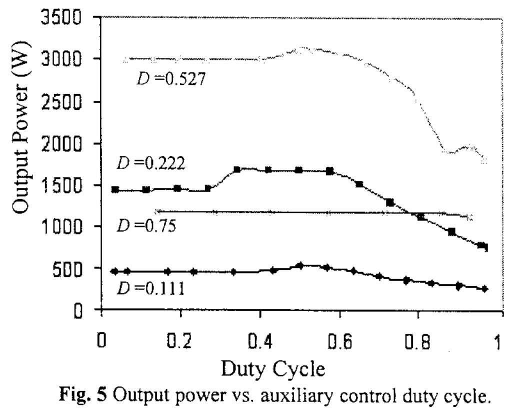

Fig. 5 Output power vs. auxiliary control duty cycle.

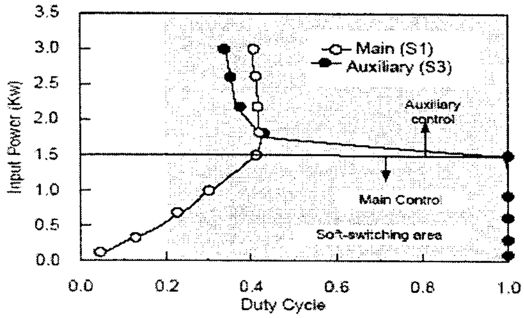

Fig. 6 Power regulation characteristics.

V. CONCLUSIONS

In this paper, a new topology of a dual duty cycle controlled ZVS high frequency inverter with single auxiliary reverse blocking switch in parallel with series resonant capacitor, the operating principle and the operating characteristics of the new high frequency circuit treated here were illustrated and evaluated on the basis of simulation results. It was examined that the complete soft switching operation can be achieved even for low power setting by introducing the high frequency dual duty cycle control scheme. In the proposed high frequency inverter treated here, the dual mode pulse modulation control strategy of the asymmetrical PWM in the higher power setting and the lower power setting, the output power of this high frequency inverter could introduce in order to extend soft switching operation ranges. Therefore, it was proved from that the proposed ZVS soft switching PWM high frequency inverter can actually achieve high efficiency, high performance and obtain wider soft switching range in selective dual duty cycle PWM control scheme. For a consumer IH cooking heater and IH steamer, the practical effectiveness of the proposed voltage source ZVS-PWM dual duty cycle high frequency inverter was proved on the basis of the simulation results.

ACKNOWLEDGMENT

Ministry of Commerce, Industry and Energy (MOCIE) financially supported this work through Industry and Energy Research Center (IERC) program.

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