HIGH-FREQUENCY RESONANT MATRIX CONVERTER USING IGBT-BASED BIDIRECTIONAL SWITCHES FOR INDUCTION HEATING

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ABSTRACT: This paper deals with a novel type soft switching utility frequency AC- high frequency AC converter using asymmetrical PWM bidirectional active switches which can be defined as high frequency resonant matrix converter. This power frequency changer can directly convert utility frequency AC power to high frequency AC power ranging more than 20kHz up to 100kHz. Only one active edge resonant capacitor-assisted soft switching high frequency load resonant cyclo-converter is based on asymmetrical duty cycle PWM strategy. This high frequency Cyclo-converter uses bidirectional IGBTs composed of anti-parallel one-chip reverse blocking IGBTs. This high frequency cyclo converter has some remarkable features as electrolytic capacitor less DC bus line link, unity power factor correction and sine wave line current shaping, simple configuration with minimum circuit components and low cost, high efficiency and downsizing. This series load resonant cyclo converter incorporating bidirectional active power switches is developed and implemented for high efficiency consumer induction heated food cooking appliances. Its operating principle is described by using equivalent circuits. Its operating performances as soft switching operating ranges and high frequency effective power regulation characteristics are discussed on the basis of simulation and experimental results.

Index terms - Bidirectional switches, Direct power frequency conversion, High frequency PWM cyclo converter, Soft switching commutation, Induction heating, One-chip reverse blocking IGBTs.

I INTRODUCTION

An efficient high-speed bi-directional data transmission scheme for isolated AC-DC and DC-DC switched mode power converters is presented. The bi-directional scheme supports fast, efficient and reliable transmission of digitally encoded data across the isolation barrier and enables primary side control, allowing effective start-up and a simple interface to system controllers. Another key feature is that the bi-directional communication is independent of coupler gain and degradation and only the minimum number of couplers is required. The digital interface can also be used to transmit auxiliary signals between both sides. For test purposes, the scheme has been implemented on FPGAs and verified using a custom-built SMPC board. Many electronic-fed home appliances are based on dc-link inverters which provide frequency adjustable Excitation required for motors, air conditioning systems, or induction heating device. This architecture provides a straight forward implementation, but also implies a two-stage power conversion which decreases power density and efficiency. Direct ac-ac conversion has been thoroughly studied in the past in order to provide an efficient and compact solution with no energy storage elements. These converters have been compared to other alternatives and successfully applied to drives aerospace applications, or power supplies. Matrix converters have also been applied to series resonant loads for 3-phase systems in . Considering the induction heating application, several resonant matrix converters featuring MOSFETs (Nguyen-Quang et al. 2006; Nguyen- Quang et al. 2007) or RB-IGBTs (Gang et al. 2008; Sugimura et al. 2008) have been proposed. All the proposals previously described show some common positive points including improved power factor and harmonic distortion, increased power density, and reduction of electrolytic bus capacitors. However, the main drawback is the use of additional switching devices to implement the matrix converter, which lead to increased control complexity and cost. This issue becomes critical for certain cost-oriented applications. This may be the main reason A New Multiple-Output Resonant Matrix Converter Topology Applied To Domestic Induction Heating for the low percentage of use of matrix converters compared to classical dc-link inverters some areas as the home appliances segment. the aim of this paper therefore is to propose a new multiple-output resonant matrix converter topology based on the series resonant multi-inverter (O. Lucía et al. 2010) to modify traditional power conversion based on a dc-link inverter (Fig. 1 (a)). The proposed multiple output resonant matrix converter (Fig. 1 (b)) combines the advantages of matrix converters with the improved cost and power control of the series resonant multi-inverter. Since the matrix converter block is shared with a high number of induction loads, the overall cost is significant reduced, and the proposed topology can target the home appliances market.

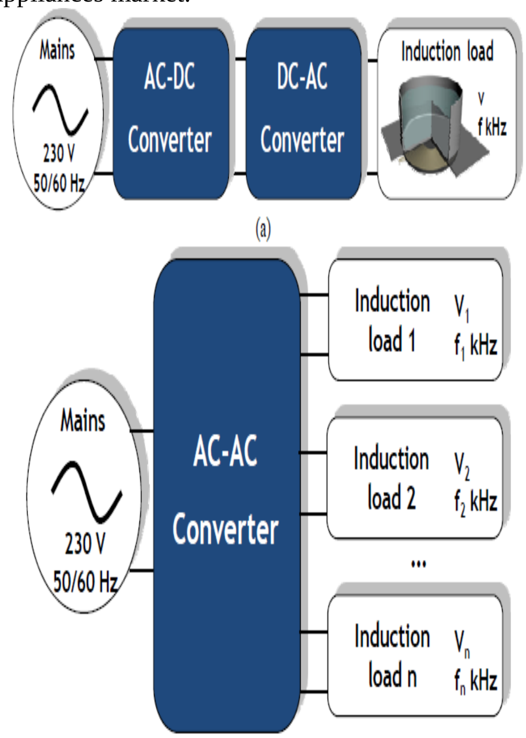


Fig 1.0 Introduction of heating system

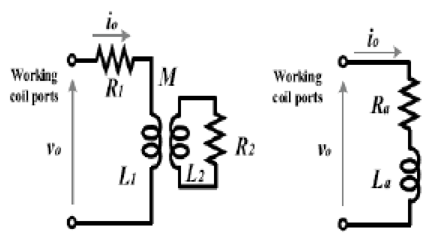
This paper proposes high frequency PWM cyclo converter defined as the UFAC to HFAC direct power frequency changer using bidirectional power semiconductor switching devices based on one chip reverse blocking IGBT anti-parallel connection. The operation principle of the soft switching high frequency cyclo-converter treated here is described by using switching equivalent circuits. Furthermore its circuit performance characteristics on the basis of simulation are illustrated herein

II. EQUIVALENT MODELING OF INDUCTION HEATING LOAD

The equivalent circuit modeling of the electromagnetic induction heating load discussed below is shown in Fig.1 (a) and (b). Figure 1 is an approximate linear equivalent model of the induction heated load circuit represented by equivalent effective inductance *La* in series with equivalent effective resistance *Ra* in referred the input side of working coil terminals of the generic induction heater. *Ra* and *La* of the IH load are respectively determined by the self-inductance *L*1 and internal resistance *R*1 of the working coil, self-inductance *L*2 of eddy current heated device in electromagnetic induction transformer secondary side and mutual inductance *M* between *L*1 and *L*2. It is actually considered that these circuit parameters in spite of output power regulation delivered to the high frequency IH load is approximately kept constant, when high frequency AC power is regulated for a constant frequency PWM. The high frequency dependent resistance *R*2 recognized and estimated by the skin effect resistance is kept constant under a principle of a fixed frequency asymmetrical PWM scheme. . The measurement methods of circuit parameters *Ra* and *La* in the regulated IH load are as follows. High frequency AC voltage is provided to the IH load via ceramic spacerand working coil excited by high frequency inverter, high frequency cyclo-converter as well as high frequency linear power amplifier. The effective AC value *Vrms* of HFAC voltage and effective value *Irms* of HFAC current with electrical angular frequency (ω=2πf),power factor cos*θ*(cos *θ*: difference angle between output voltage and output current) are directly measured for high frequency IH load with working coil driven by HFAC power supply. Equation (1) is simply obtained on the basis of the sine wave AC circuit theory.

$$\begin{cases} \dfrac{Vrms}{Irms} = Z = \sqrt{Ra^2 + \omega La^{\,2}} \\ \cos\theta = \dfrac{Ra}{\sqrt{Ra^2 + \omega La^{\,2}}} \quad \ldots\ldots\ldots\ldots\ldots (1) \\ \sin\theta = \dfrac{\omega La}{\sqrt{Ra^2 + \omega La^{\,2}}} \end{cases}$$

The impedance *Zrms* of the high frequency induction heating load for the angular frequency ω of output voltage and output current from high frequency linear power amplifier or high frequency inverter is calculated using the equation (1). By using measured fundamental power factor, the equivalent circuit parameters *Ra* and *La* of the high frequency IH load with pan, kettle and utensil or vessel placed exactly on pancake type working coil are estimated. In the case of considering internal resistance *R*a of the planar working coil itself, the equivalent effective resistance value becomes *Ra* + *R*1. The circuit parameters coupling coefficient *k* between *L1* and *L*2and time constant τ expressed in Fig.1(a) are represented as follows by using *Ra* and *La*.



$K=\frac{M}{\sqrt{L1L2}}$; *Ra : equivalent effective resistance*

$\tau = \frac{L2}{R2}$ *La*.: equivalent effective inductance

(a) Transformer type *equivalent circuit model* (b) R_a- L_a *Series* equivalent circuit model

Fig.1 Equivalent circuit modeling of electromagnetic induction eddy current based joule's heating load

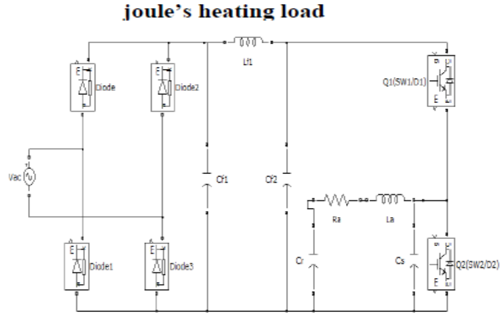
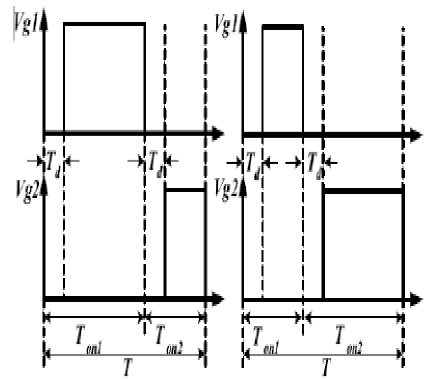


Fig.2 Asymmetrical PWM soft switching high frequency inverter

III. ASYMMETRICAL PWM SOFT SWITCHING HIGH FREQUENCY INVERTER

A. Circuit Description

Figure 2 illustrates the circuit topology of the voltage source type SEPP (single-ended push-pull) soft switching PWM high frequency inverter composed of two stage power conversion (UFAC-DC-HFAC) processing circuits.



(a) High power input (b) Low power input

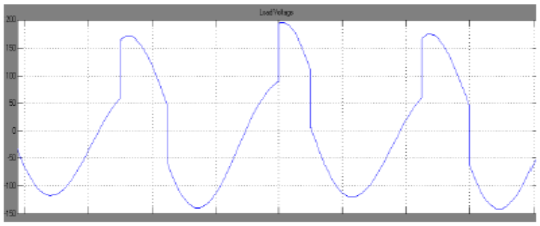
Fig.3 Gate voltage pulse signal sequences of asymmetrical PWM

B. Constant Frequency Asymmetrical PWM Control

The gate pulse signal timing sequences for constant frequency asymmetrical PWM control are depicted in Fig.3. The asymmetrical PWM as a control variable in output power regulation of this high frequency inverter is defined as eq.(2).

$$D = \frac{Ton\,1}{T} \quad \text{.........................} (2)$$

The duration proportion of on time *Ton1* of the power switches for a high frequency inverter period *T* is named as a duty factor or a duty cycle *D* in the asymmetrical PWM control scheme. In this case, the duration time of *Ton1* contains a dead time *Td*. By introducing this time ratio control strategy, due to the soft switching PWM controlled high frequency inverter enables to supply the desired high frequency output AC regulation power for the IH load



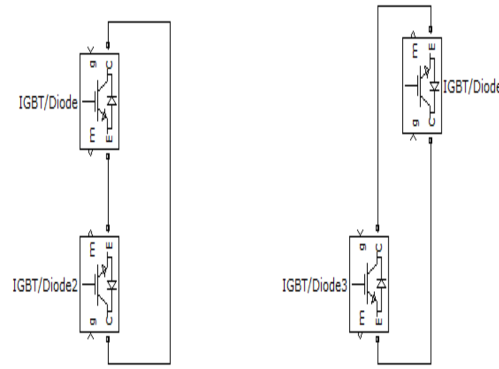
Load voltage

C. Simulation Results

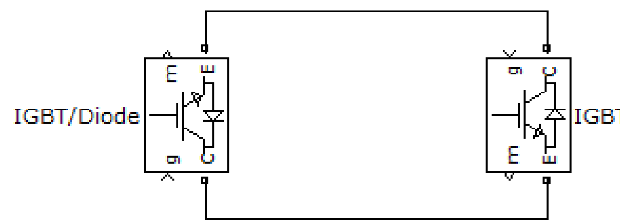
Figure 4 shows simulation waveforms of asymmetrical PWM controlled voltage source SEPP soft switching high frequency inverter for IH applications. As can be seen, the measured voltage and current waveforms have good agreements with the simulation waveforms.

IV. ANTI PARALLEL ONE CHIP REVERSE BLOCKING IGBT BASED BIDIRECTIONAL SWITCH

A new structure type IGBT has been recently developed by IXYS Corporation (IXRH40N120), providing reverse blocking capability for one chip IGBTs. This unique feature is needed a variety of applications, such as current source resonant inverters, a voltage source edge-resonant inverters, and high frequency resonant matrix converters. The rated data of the reverse blocking IGBT developed newly is listed in Table I. The bidirectional switches which make use of anti parallel reverse blocking IGBTs are applied to voltage source high frequency inverter such as half bridge, single ended topologies. By substituting the switch parts of the high frequency inverter in Fig.2 with the bidirectional switches, and then, diode bridge rectifier of commercial AC input side can be eliminated for high frequency AC output. In short, one stage power conversion can be achieved for the high frequency cyclo-converter or high frequency resonant matrix converter. Figure 5 shows bidirectional switches using conventional IGBTs with reverse conducting diode and anti-parallel reverse blocking IGBTs for high frequency cyclo-converter. The following features can be expected by using the reverse blocking IGBT: cost reduction, downsizing, reduction in ON-state voltage, high reliability, electrolytic capacitor DC filterless.



(a) 2 IGBTs & 2 Diodes(4 device



(b) 2 Reverse blocking IGBTs(2 devices)

TABLE 1
REVERSE BLOCKING IGBT IXRH40N120

Item	Symbol	Value
Collector-Emitter voltage	V_{CES}	$\pm 1200V$
Collector current	I_{C25}	55A
Collector-Emitter saturation voltage	$V_{CE(Sat)}$	2.3V

V. SOFT SWITCHING PWM HIGH FREQUENCY CYCLO CONVERTER WITH BIDIRECTIONAL SWITCHES

A. Circuit Description

Figure 6 illustrates the circuit structure of the soft switching PWM high frequency cyclo-converter using the bidirectional switches shown in Fig.5. A novel circuit topology of high frequency cyclo-converter with

PWM scheme, so called, high frequency matrix converter introduces the anti-parallel one chip reverse blocking IGBT type bidirectional switches into two switch high frequency inverter. The conventional two stage power converter including rectification converter and high frequency inverter are converted utility frequency AC power into regulated high frequency AC power. However, this high frequency cyclo-converter circuit topology can realize the commercial frequency AC to high frequency AC conversion directly without the rectification DC link stage due to the electrolytic capacitor filler. Accordingly , this high frequency resonant cyclo-converter (Matrix converter) can achieve cost reduction, because the high frequency cyclo-converter does not substantially require the diode bridge rectifier with electrolytic DC capacitor filter link.

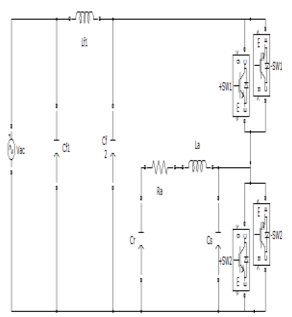
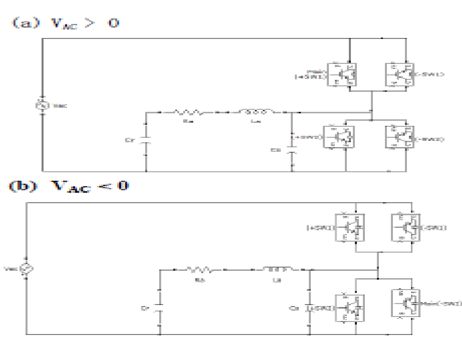


Fig.6 Soft switching high frequency cyclo-converter



This voltage-fed ZVS-PWM high frequency cyclo converter with bidirectional switches, which can operate soft commutation scheme is composed of low pass filter *Lf1*, *Cf1*, *Cf2*, high frequency IH load, bidirectional switches Q1(+SW1/–SW1) and Q2(+SW2/–SW2), lossless snubber capacitor *Cs*, series load resonant tuned capacitor *Cr* and single phase 100Vrms input commercial AC power grid.

TABLE 2
DESIGN SPECIFICATIONS AND CIRCUIT PARAMETERS

Item	Symbol	Value
Utility ac voltage (rms)	V_{AC}	100V AC
Switching frequency	f	21kHz
Series resonant capacitor	C_r	2.5μF
Lossless snubbing capacitor	C_s	0.20μF
Effective resistance component of IH load	R_o	0.910
Effective inductance component of IH load	L_o	30.8μH
Dead time	T_d	3.0μsec

B. Control Scheme

The voltage-source type soft switching PWM high frequency cyclo-converter has to input the control signal pulses synchronized with 50Hz/60Hz frequency of the utility AC power supply into the switches Q1 and Q2, because high frequency AC power converter from commercial AC power directly. Figure 7 shows the gate drive signals delivered to the switches.When instantaneous voltage of 60Hz frequency is during the positive half wave period, the asymmetrical PWM signal trains are provided in order to regulate the high frequency output AC power by the switches +SW1 and +SW2. During this case, the switches – SW1 and –SW2 are on-state continuously. On the other hand, during negative half wave of utility AC input voltage, the switches +SW1 and +SW2 are on-state continuously. By using this control scheme, the HFAC output power of the high frequency cyclo-converter can be smoothly regulated by asymmetrical PWM control scheme described in chapter III.

CONCLUSIONS

This paper proposed the novel prototype of one stage voltage-type multi-resonant SEPP-ZVS PWM high frequency AC power conversion circuit operated as the resonant high frequency PWM cyclo-converter (resonant high frequency matrix converter) using the anti parallel one chip reverse blocking IGBT type bidirectional switches for consumer induction heating appliances. The soft switching PWM resonant high frequency cyclo converter discussed in operation principle and power regulation characteristics on the basis of simulation. In the future, the actual efficiency and conventional efficiency characteristics should be evaluated for resonant high frequency cyclo-converter using bidirectional switches. The optimum circuit design method of the utility AC input filter part of the resonant high frequency soft switching cyclo-converter treated here should be investigated from a practical point of view

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