Selection of Power Semiconductor Switches - a Tool to Reduce Switching & Conduction Losses of High Frequency Hybrid Resonant Inverter fed Induction Cooker

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Abstract—An exhaustive method for the selection of different power semiconductor switches for high frequency hybrid resonant inverter fed induction heater is presented here. Heating coil of the induction heater is made of litz wire which minimizes the skin effect and proximity effect at high operating frequency. With the calculated optimum values of inductance and resistance of heating coil at a particular operating frequency, high frequency hybrid resonant inverter topology has been simulated using PSPICE software as well as constructing the experimental model of same rating. Obtained the voltage waveforms across heating coil and current waveforms through it, have been taken for further analysis. From this analysis, selection of suitable power semiconductor switches like IGBT, GTO and MOSFET are made. Waveforms have been shown to justify the feasibility for real implementation of high frequency hybrid resonant inverter fed induction heater in domestic applications.

Index Terms—Hybrid resonant inverter, Induction heater, PSPICE simulation, Semiconductor switches.

I. INTRODUCTION

In the process of induction heating, a disc of metal is surrounded by a copper coil through which an alternating current is made to flow. The disc has a finite diameter and thickness. It is placed at a given distance from the coil and concentric to it. Secondary current is induced in the disc and this induced current circulates around the outer surface of the disc resulting heating effect. Modern devices like IGBT's [1] make easier to apply induction-heating technique in kitchen heating-ranges for domestic use [2, 3]. Induction heating technique in heating-ranges is becoming a strong alternative to gas, normal electrical hotplates and microwave oven. Compared to dielectric heating as in microwave oven, the proposed technique of induction heating is more convenient

and cost effective [1, 4]. For example, in microwave oven, food is cooked in a special non-metallic bowl inside a closed chamber, while the proposed method would permit heating using normal house-hold metal utensils like steel pan, GI pressure-cooker, iron bowl etc., leading to a lot of savings in cost of utensils. The proposed topology also possesses a unique advantage for Indian sub-continental style of cooking [3, 7]. Besides, the proposed induction heating system is absolutely safe from shock hazard during cooking [4, 5]. The induction-heating system is also extremely rugged because of absence of red-hot temperature in the induction coil resulting in no deterioration or aging of coil [5]-[9].

For self-commutation, a resonant circuit is essential. It is assumed that the circuit is under damped; a mandatory condition for the circuit. The capacitor required for under damping can be connected in series or in parallel with the load. In the modern times, IGBTs, GTOs, MOSFETs are preferred to SCRs mainly because they offer convenient turn OFF characteristics. Some auxiliary circuits and equipment are required to minimize switching losses occurring at high frequencies. According to Koertzen et al. [10] the requirements for the induction heaters are as follows:

- *Switching in high-frequency range*
- *High efficiency*
- *Power factor close to unity*
- *Wide power range and*
- *Reliability.*

Induction heaters are usually designed to operate with a vessel made from a specific material, mainly cast iron or ferro-magnetic stainless steel. The following is therefore desired characteristic for the inverter;

- No reactive components other than the heating coil and the non-smooth filter inductor,
- No input or matching transformers,
- 50% duty ratio, simplifying the control and gate circuits,
- Zero current switching (ZCS) and / or zero voltage switching (ZVS),
- Clamped switch voltage and / or current,
- The use of uncontrolled voltage source.

Different inverter topologies suitable for induction heating and melting applications are presented in [11]. The

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comparison is based on the criteria such as input power factor, component ratings, maximum and minimum operating frequencies, operation under varying load conditions, inverter starting capability and system and control simplicity. Llorente et al. [12] have made a comparison between four inverter topologies commonly used in induction cookers. The considered topologies are the full-bridge inverter, the half-bridge inverter, and two single-switch inverters. All of them are designed for the same specifications and they are compared in aspects such as power device stresses, efficiency, frequency control, and electromagnetic emissions. In these papers, separate inverter configurations have been discussed & compared, but no light is thrown to the type & necessity of power semiconductor switches for different inverter topologies. Same circuit can respond differently with the variation in power switches. In this present paper, response of high frequency hybrid resonant inverter is tested & verified with different power switches and finally appropriateness of the switches is confirmed. With the same designed parameters of the said inverter circuit, various switches such as IGBT, GTO and MOSFET have been used. Complete inverter configuration then has been simulated using PSPICE.

Hybrid resonant inverter is powered from single phase AC supply to energize the heating coil which is made of litz wire. This type of wire is configured by many strands of single insulated wire in order to reduce the losses caused by skin effect & proximity effect.

II. PRESENT SCHEME

One hybrid resonant inverter consists of four semiconductor switches (IGBT's) for each heating-range. The switching frequency of present scheme lies between 25 to 35 kHz. The inverter is a combination of both series and parallel resonant circuits where the switching is made at zero current cross-over (ZCS). An H-bridge with its load impedance is shown in Figure 1. The load can be of series type, that is Z_s , or it can be a parallel type like Z_p . An advantage of the series circuit is that both zero current and zero voltage switching are possible.

The inverter for two cooking zones is shown in Figure 2 [1]. It consists of two parallel resonant circuits which represents two cooking zones. The two zones have diameters and output power levels of 14 cm for 1100 W and 18 cm for 1800 W respectively. Figure 3 represents the hybrid resonant inverter system for four cooking zones. The four zones have diameters and output power levels of 10 cm for 800 W, 14 cm for 1100W, 18 cm for 1800 W and 22 cm for 2200 W respectively. Different diameters of induction coils have been chosen for different diameters of flat bed utensils. For getting maximum efficiency of the system, the coil diameter and the diameter of the utensils must be equal. Different control strategies have been discussed [13]-[19] to show that an optimum concerning efficiency occurs when switching around the zero crossing of the parallel resonance circuit. With the inverter implemented in an induction heating system, the total system efficiency (i.e. from the mains to the load) of around 88.2 % has been achieved.

However, the full resonant current must pass through the switches resulting in ON losses. Another disadvantage is that the supply voltage must be reduced which means that a dc / dc converter must be used. Depending on the converter there will be reactive power consumption or more complexity. In a parallel load, Z_p there would be lower ON losses in the switches but turn-on / turn-off losses would be more as the switching takes place at high voltage and current. Therefore, by using both series and parallel combined circuit, a hybrid inverter can be used to reduce the losses in the switches. Figure 4 shows a resonant inverter system for one cooking zone. The mode of operation basically consists of interaction between two resonant circuits where the energy is transferred from the series resonant circuit (consisting of C_R and L_1) to the parallel resonant circuit (consisting of C_R , R_L and L_R). By turning on one of the transistor pairs S1, S4 or S2, S3 a resonant current starts flowing through L_1 to C_R and when this circuit current is zero the transistors are switched off.

Thereafter the series resonant circuit is disconnected and the energy transferred to C_R is now dissipated as heat in R_L by the current flowing in the parallel resonant circuit. R_L is mainly an equivalent resistance for the magnetic loss mechanism in the induction heating system and secondly it represents the ohmic resistance of the parallel resonant circuit components.

Figure 1: Inverter with resonant load

Figure 2: Hybrid resonant inverter system for two cooking zones [1]

Figure 3: Hybrid resonant inverter system for four cooking zones

Figure 4: Hybrid resonant inverter system for one cooking zone

III. TESTING CONDITIONS

The circuit diagram used for the simulation work has been constructed using PSPICE software as shown in the Figure 5.

The parameters of the inverter configuration have been shown in Table 1.

TABLE1: INPUT PARAMETERS OF SIMULATION

Filter circuit components	$L1=50\mu\text{H}$, $L2=100\mu\text{H}$, $C1=5\mu\text{F}$
Heating coil parameters (reflected values):	$L3=140\mu\text{H}$, $R1=0.002\Omega$
Parallel capacitors (C2):	$0.2\mu\text{F}$
Switching frequency	30 kHz

Firstly, the inverter circuit is simulated with IGBT as power switch. There after IGBT has been replaced by GTO & MOSFET. In each case, coil current waveform & voltage across it have been recorded & investigated. A real time experiment has been carried out to validate the simulation result.

IV. RESULT AND DISCUSSION

With the selected circuit parameters & configuration, following waveforms have been obtained using PSPICE software and real time experimental model for different power semiconductor switches:

Figure 5: Circuit diagram for PSPICE Simulation of hybrid resonant inverter using IGBT

Figure 6: Coil current & coil voltage using IGBT by (a) PSPICE software and (b) real time experimental model

Figure 7: Coil current & coil voltage using GTO by (a) PSPICE software and (b) real time experimental model

Figure 8: Coil current & coil voltage using MOSFET by (a) PSPICE software and (b) real time experimental model

Using IGBT in the hybrid resonant inverter circuit, it is observed in Figure 6 (a) & (b) that magnitude of current through the coil has almost equal in both positive and negative halves. Such a peak to peak symmetrical current produces more heat. Hence heating effect becomes very prominent for the same operating frequency range. Further,

it is observed that the real voltage across heating coil and current through it, are almost identical to the PSPICE simulated result.

In Figure 7, the real voltage across heating coil and current through it, are almost indistinguishable to the PSPICE simulated result. But, current through the coil using GTO in the hybrid

resonant inverter circuit, doesn't have equal positive and negative peaks. Hence, rms value of the current will be less. So heating effect will also be less compared to IGBT. Furthermore, GTO-based topology requires the arrangement of sending a negative gate pulse through the gate terminal of GTO in order to turn it off which enhances the circuit complexity.

Figure 8 depicts that using MOSFET in the hybrid resonant inverter circuit, the real voltage across heating coil and current through it, are almost same to the PSPICE simulated result. Here also, coil current doesn't have equal positive and negative peaks. Hence, rms value of the current will be less. So heating effect will also be less compared to IGBT.

V. PHOTOGRAPHS OF PRESENT DEVELOPED SYSTEM

Photograph-1: Assembly of single induction coil

Photograph-2: Assembly of different diameters induction coils for multi-zones induction cooker

Photograph-3: Experimental setup of 4 zones induction cooker

Photograph-4: Timer control PCB of 4 zones induction cooker

VI. CONCLUSION

After having compared the wave-forms of PSPICE simulation and real time experiment, it is quite obvious that the selection of IGBT as a power semiconductor switch in high frequency hybrid resonant inverter is advantageous for induction heating purposes for frequency below 50 kHz and highly acceptable. IGBT offers highest rms value of coil current among all the probable configurations using different power semiconductor switches. For a frequency range of above 50 kHz, MOSFET will be a better option due its low switching & conduction losses.

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