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Design and Development of LCL Resonant Inverter for High –Frequency Induction Heating Applications

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***Abstract*- A power electronic inverter is developed for high-frequency induction heating application. The applications requires up to 1.5kW of power at a frequency of 7OkHz. Voltage source and current source inverters both using ZCS or ZVS are analyzed and compared. To attain the level of performance required, an LCL load resonant topology is selected to enable ZVS close to the zero current crossing of the load. This mode of soft switching is suitable to greatly reduce the MOSFET losses. Inverter control is achieved via DSPIC 2010 microcontroller IC.**

***Index Terms*- Efficient, High Frequency, Half Bridge, Induction heating.**

I INTRODUCTION

The load in induction heating applications generally turns out to have a very low power factor. To compensate reactive power, the inductive load is extended to a resonant tank by adding further capacitive and sometimes inductive devices. An MOSFET-inverter supplying a third order resonant tank is presented. This paper will put the main stress on a detailed, application-specific analysis of the circuit to obtain design rules for active and passive components. A control scheme to match the demands and characteristics of the present load is derived.

The induction heating application discussed in this paper requires high active power (more than 1.5kW) and at the same time operates at frequencies around 70 kHz. There are other induction heating applications mentioned in the literature that make similar demands on the power supply. Due to the high frequency, the suggested inverters are mainly set up with MOSFETs . This is an economically feasible solution only for lower power requirements. The developments in MOSFET-technology make it possible to build more compact and cheaper inverters for higher frequencies using MOSFETs. A voltage source inverter that is
coupled to a series resonant load via a transformer is used. In section II, it will be shown that for the present application,
the voltage source inverter with the ***LCL*** resonant tank has an advantage over the current source inverter.

II. CONVERTER TOPOLOGIES

A Feasible Converter Topologies with the switching times of today's high-voltage MOSFETs being still quite high, 800V MOSFETs are chosen for the 7OkHz application. These IGBTs can operate at a 5OOV dclink voltage. To avoid a transformer, these demands result in the design of a third order resonant circuit with suitable passive devices. The two feasible solutions for the inverter and resonant circuit are the current source inverter with capacitive coupling and voltage source inverter with inductive coupling of the load. Table 1 summarizes the features of both topologies.

Table I DUALITOY OF TOPOLOGIAES A ND B

Topology A (LCL resonant tank)	Topology B (CCL resonant tank)
Voltage source inverter	Current source inverter
Bidirectional current flow through semiconductors	Bidirectional voltage blocking through semiconductors
Rectangular output voltage, sinusoidal output current	Rectangular output current, sinusoidal output voltage
Dead time required for the commutation process	Overlap time required for commutation process
Switching instant slightly before zero crossing of the load current	Switching instant slightly before zero crossing of the load voltage
Inverter has to be switched off in case of a short circuit	All semiconductors must conduct in case of short circuit

B Comparison of Converter Topologies Table II

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VSI with inductive coupling of the load (LCL resonant tank)	CSI with capacitive coupling of the load (CCL resonant tank)
Zero-current soft-switching at resonant frequency.	Zero-voltage soft-switching at resonant frequency
Good usage of voltage-blocking capability of the MOSFET resulting in low conduction losses.	Due to the sinusoidal voltage waveforms the blocking capability of the MOSFET s is poorly used resulting in higher currents and consequently leading to higher losses
MOSFETs are standardized for usage in voltage source inverters No additional series diodes necessary.	Additional series diodes necessary **as** high-speed symmetric devices are not yet available.
The resonant capacitor can be placed close to the inductor thus reducing losses by minimizing the length of the high-voltage, high-current connection.	To minimize the stray inductance in the cable between inverter and load, the capacitor bank is split with the parallel capacitor close to the inverter. This leads to high losses and voltage drops across the connection.
Design of the output resonant coil is difficult, taking care of leakage fields and losses.	Design of the DC link is not critical.
DC link design must be of extremely low inductance.	Better short-circuit and no-load handling capability because of the Current-limiting DC link.

Table II gives an overview of the most important advantage and disadvantage of the voltage source and current source inverter topologies.

In the voltage source inverter, the output capacitance of the MOSFET influences the switching instant. Switching at the zero crossing of the current leads to additional turn on losses because of discharging capacitance .Switching below the resonant frequency that is after the zero crossing of the current means current commutation from opposite diodes .This mode of operation should be avoided in each case because of possible voltage and current peaks due to the reverse recovery effect of the diodes..The high frequency inverters are equipped with very fast drivers to reduce switching times. Hence a lagging load current that is a slightly inductive load characteristic is the desired mode of operation because ZVS can be realized.

III SYSTEM ANALYSIS

The entire induction heating system is shown in figure 1. On the input side the high frequency MOSFET inverter is connected to bridge rectifier via voltage link. The inverter supplies a resonant LCLR load with a LC circuit coupling the output inductor to the inverter. This LC circuit serves two purposes

1) It provides reactive current drawn to the output inductor.
2) It provides current amplification.

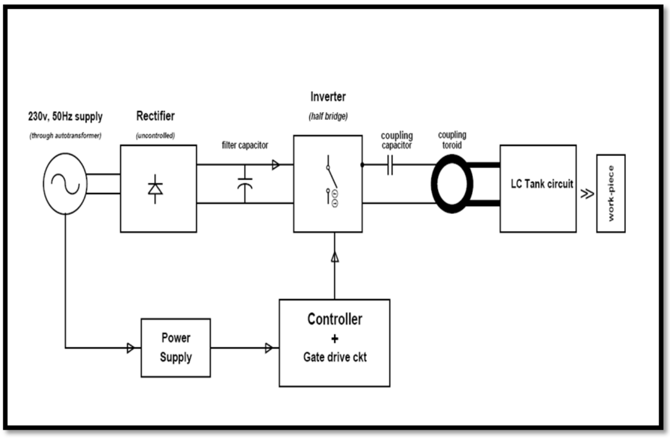

Figure 1 Complete Block Diagram of Induction Heating System

It mainly consists of a diode rectifier, DC link capacitor, MOSFET, transformer, resonant capacitor and induction heating coil. The rectified DC voltage will be chopped with a high switching frequency that is 70 KHz by the half bridge inverter. This chopped high frequency AC voltage will be transferred to the second side of the transformer connected with a series resonant capacitor and induction coil. The applied high frequency AC voltage enables to operate resonant circuit mode and achieves ZVS (Zero Voltage Switching) Operation in the MOSFET switches.

IV INVERTER CONTROL

The control of switching instants with a frequency of 70 KHz is to be implemented with microcontroller DSPIC2010 IC. As shown in figure 2.

The control circuit of the proposed scheme consists of a microcontroller DISPIC 2010 and a gate drive IC for the generation of pulses of required frequency. The microcontroller is operated at 24MHz crystal frequency. The internal timer is used as a clock to determine the timing and a counter is used for counting the pulses from the proximity sensor.

According to the requirement, a software program is written and is fed to the microcontroller, which decides the voltage of pulse to be applied to the gate of the power MOSFET. The control software essentially compares the zero signal voltage coming from +5V supply and the gate signal of MOSFET.

Based on the difference between these two voltages, it decides the control scheme and a zero crossing voltage signal which acts as firing pulse to the gate of MOSFETs in order to bring to obtain soft switching for MOSFET.

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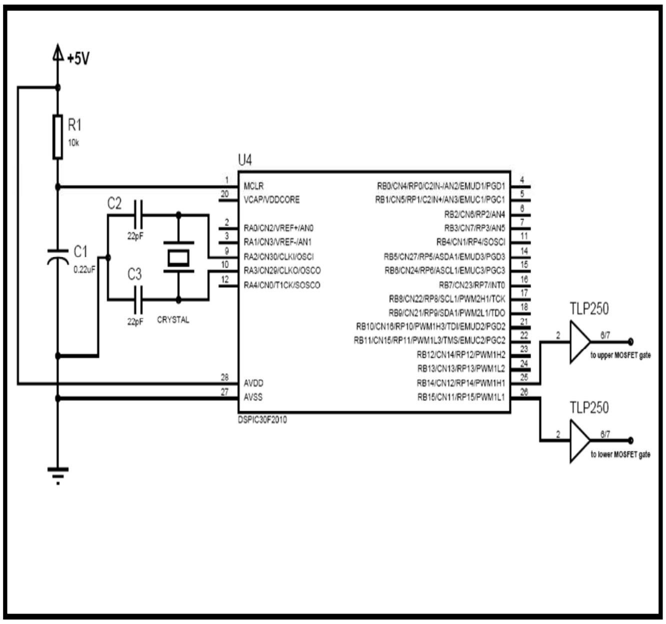

Figure 2 MOSFET Control Circuit

The controller also decides the instant timing of the gate signal to be given to the MOSFETs. In this project Fairchild's IRF 840, N-channel enhancement type MOSFETs are used. Therefore the gate voltage is essentially positive Pin 25 ,26 are connected to give the gate signal for two MOSFETS.

V EXPERIMENTAL SETUP AND IT'S VERIFICATION

The control design has been verified with the help of MOSFET inverter operating at 70 KHz as the total time period of one cycle applied at the gate of MOSFET is 14 µs.So the frequency at which the MOSFET are operating is 70 KHz, as tested in laboratory.

The proposed new induction heating invertors generates 1.5KVA maximum power under 220volts ± 20(%) input voltage condition. As explained above the whole power control is performed by micro controller. Table III shows the major design, specifications and parameters for new induction heating inverter.

Fig.5 shows gating pulses of MOSFETs which is having time period 14µs , generating 70 KHz frequency at the output of inverter. The LC tank generates the resonant frequency as 70 KHz, based on the selected values of capacitor and inductor, according to the table1.The inverter Frequency matches with the resonant frequency so maximum power transfer takes place without losses in the inverter. So the efficiency of induction heating system is very high.

Table II Design Specifications and parameters

Item	Specifications
Input Voltage	220[v]±20[%]
Max.Power	1.5KVA
Switching Frequency	70KHz
Resonant Capacitor	5.2µF
IH Coil Inductance	1µH
Control Method	Microcontroller Based (DSPIC 2010)

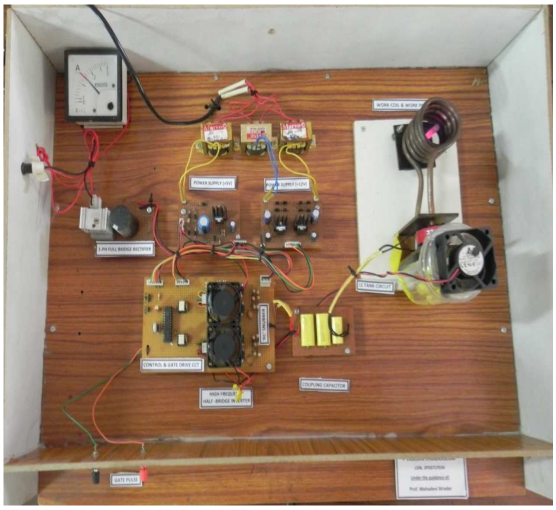

Figure 3 Experimental Setup

Figure 4 Work Coil and Work Piece At temperature 650^{0}c the Iron Rod becomes Red Hot.

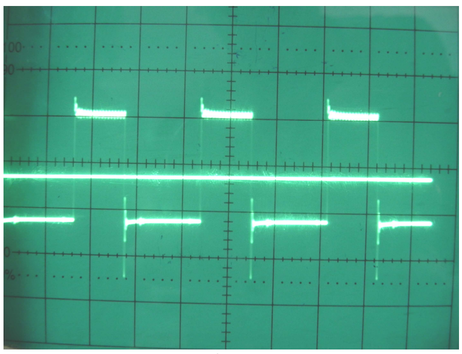

Fig.5 Gating pulses for MOSFETS (5µs/div)

VI CONCLUSION

In this paper, the design of MOSFET based powered supply for induction heating system has been presented. The variable load is inductive and takes 1.5 KVA of active power at a frequency of 70KHz.Based on detail topology investigation a LCL resonant circuit supplied by a voltage source half bridge inverter is chosen. The high frequency inverter operates at the resonant frequency of the parallel resonant circuit and soft switching operation is realized. The simple, low cost, high efficient, high frequency, soft switching inverter has been developed and tested. This high frequency inverter is applied for consumer high power induction heating products in home and industrial uses.

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