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Implementation of Three Phase Induction Heating By Using Half Bridge Series-Resonant Inverter Topology

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***Abstract* - Today most of domestic induction heating technology functions on a single-phase power due to the limited quantities of cooking material being heated. While on other hand in most of the industrial environments, where the larger cooking material volumes are processed, heat generation intensifies. Hence three phase power comes into picture, by which we can achieve the resonant frequency for achieving the desired heat generation. Resonant-mode power supplies can minimise switching losses, enabling the operation of resonant converters at exceptionally high frequencies. The inverter operates at in a frequency range of 20-30 kHz. Industrial induction heating technology also requires a high output power levels with the minimum number of components in a compact size. In this paper, an induction furnace that is employing with half bridge inverter built around the pair of (Insulated Gate Bipolar Transistor's) IGBT's as its switching device. High frequency converter to convert the constant DC to the high frequency AC by switching the devices (IGBT's) alternately. The simulation implementation of this topology with the help of MATLAB/ SIMULINK environment.**

Keywords: Induction Heating (IH), Insulated Gate Bipolar Transistor (IGBT).

I. Introduction

In recent years Induction heating technology has become more popular amongst various sectors. Induction heating is the method of heating an object by using electromagnetic induction. Induction heating is comprised of three basic factors that are electromagnetic induction, the skin effect, and heat transfer. Electromagnetic induction is a fundamental phenomenon with profound implications in science, technology, and everyday life. There's been a lot of focus on creating inverters that can deliver high power across a wide frequency range, from 10 to 200 kHz. It involves using an electromagnet through which a high-frequency alternating current is passed. Magnetic hysteresis losses in materials with sufficient permeability that leads to heat generation. A half-bridge IGBT inverter is very well suitable for heating both magnetic and nonmagnetic materials quickly and efficiently at high frequencies. Using a half-bridge topology effectively doubles the output voltage, resulting in reduced current flowing through the load while maintaining the same output power. As a result, the induction target undergoes heating through two physical mechanisms: eddy currents and magnetic hysteresis. Applied magnetic fields are then opposed by eddy currents, resulting the heat generation by Joule effect. The effective parameters of the induction heating load vary throughout the heating cycle.

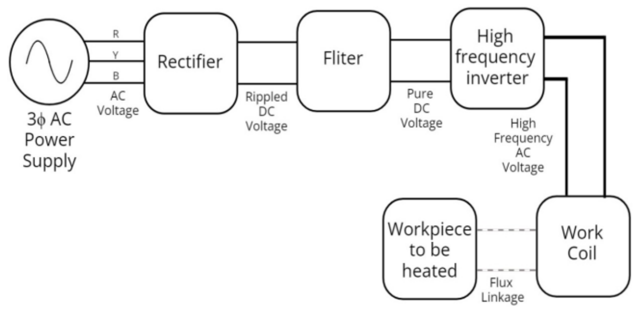

Figure 1: Power Control Block Diagram of Three Phase Induction Heating Appliance

II. Fundamental Principles

The principle of electromagnetic induction, as formulated by Faraday's law of electromagnetic induction and Lenz's law, establishes the relationship between changing magnetic flux and induced electromotive force (emf) in a conductor. The strength of the magnetic field surrounding the coil relies on the coil's number of turns. This magnetic field induces a current in the metal workpiece it penetrates. Generally, this induced current predominantly flows within the workpiece. Mathematically, Faraday's law can be expressed as:

$$\mathcal{E} = -\frac{d\Phi}{dt} \qquad (1)$$

Where ε is the induced emf and Φ is the magnetic flux.

The altered magnetic field induces heat on the surface of the workpiece as shown in Fig. 2 below. This heat generation is influenced by the magnitude of the induced current. The heat produced is then transferred away from the surface through various processes such as convection, conduction, and

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radiation. The fundamental concept behind induction heating resembles how a transformer operates. When electricity flows through the coil, it creates a magnetic field around the coil, as described by Ampere's law. When an object is placed within a magnetic field, it alters the rotation of the magnetic field lines. This change in rotation affects the density of magnetic field lines on the surface of the object, in accordance with Faraday's law of induction and the concept of eddy currents.

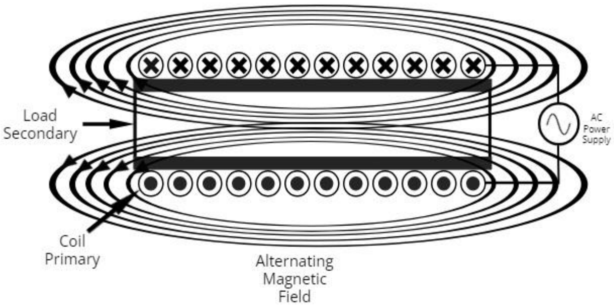

Figure 2: Concept of Induction Heating

III. Skin Effect

The skin effect is an electrical phenomenon where the current tends to flow more densely near the surface of a conductor compared to the interior, particularly in AC (alternating current) circuits. This leads to changes in the resistance of the conductor with varying frequencies is shown in Fig. 3 below.

The skin effect is observed in alternating current (AC) circuits, where the current tends to flow more densely near the outer surface of a conductor compared to the interior. This occurs because changing currents in the conductor create magnetic fields, which in turn induce currents that oppose the original current. At higher frequencies, these induced currents become stronger, forcing the main current to flow closer to the surface where it experiences less opposition. As a result, the effective resistance of the conductor increases with frequency. The skin effect can lead to inefficiencies and heating in high-frequency AC circuits, which is important to consider in the design and operation of such systems.

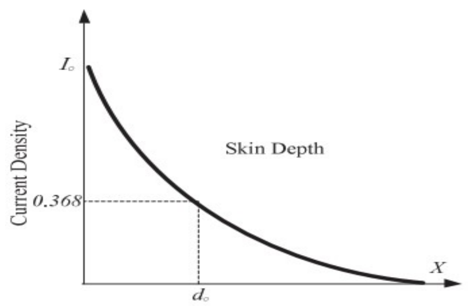

Figure 3: Distribution of current density and skin thickness

IV. Half Bridge Inverter

High frequency alternating current is generated in the heating coil of the cooker by resonant power inverter employing two semiconductor switches. The input AC supply voltage is rectified by the full wave rectifier at the AC input side. The capacitor is used to bypass high frequency current components generated by the power inverter and reduces their magnitude on the main side. The capacitor is not too large as to smooth DC input signal; therefore, a DC signal which is composed of rectified AC half cycles is fed to the power stages. The main task of the power stage is to transfer a mount of power to the inductance (and hence the container) at the resonant frequency of LC circuit. This frequency is about 24k Hz.

There is no DC output level to be regulated in induction cooking system. Therefore, the voltage feedback input is related to the output power of the cooker or inductor current level. The protection circuit in the gate operating circuit controls the output voltage by varying the oscillator output frequencies. The required frequency pulse signal is carried from the comparator to pulse transformer throughout the driver section. The output of the comparator is 180. Out of phase pulse signals which is fed to the IGBT gate in the half-bridge series resonant converter. The power has not been drawn any current when the IGBT is turned off. The initial spikes when the transistor is turned on are due to the short circuit that charges the resonant capacitor and flows through the IGBT. Once the capacitor is charged, and the current begins to flow through the heating coil. The container of the cooker is put inside the magnetic field, and then induced the voltage and eddy current are created on the skin depth of the container as a result of the skin effect. This generates heat energy on the surface of the container and material is cooked by this heat energy.

A half-bridge series resonant inverter is a versatile power electronic circuit used in applications such as induction heating, welding, and high-frequency power conversion. This topology consists of two power switching devices, typically IGBTs, connected in series across the DC input voltage. Each device is linked to one end of the primary winding of a resonant tank circuit, typically an LC circuit with an inductor and capacitor. Operating at a frequency determined by the resonant frequency of the tank circuit, the inverter achieves efficient power transfer and minimizes switching losses. Controlled by pulse-width modulation and phase-shift modulation techniques, the inverter provides precise control over output voltage and frequency. Commonly used in high-frequency power conversion applications, it offers advantages like high efficiency, low EMI emissions, and precise control, while requiring careful parameter tuning and device selection

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due to its complexity and operational challenges. However, designing and implementing half-bridge series resonant inverters can be complex due to the need for precise tuning of the resonant circuit parameters and careful control of the switching devices. Additionally, high-voltage and high-current operation present challenges in terms of device selection, thermal management, and protection against overvoltage and over current conditions. The inverter is controlled using a pulse-width modulation (PWM) technique, where the duty cycle of the switching signals is adjusted to regulate the output voltage or power. The control strategy may also incorporate phase-shift modulation to control the frequency of operation.

The power converter generally implemented in domestic IH appliances is a resonant inverter due to its improved efficiency and lower size. The main power circuit employs a half-bridge series converter switching at a high frequency. The half-bridge series resonant inverter is the most employed topology due to its simplicity, its cost-effectiveness, and the electrical requirements of its components [2]. The switching circuit consists of an IGBT. Zero voltage/current turn-on switching is enabled by turning on the IGBT while the diode is in turn on period. The resonant circuit comprises of resonant inductance (Lr) and resonant capacitance (Cr) [4]. The capacitors, C1 and C2, are the lossless turn-off snubbers for the switches, S1 and S2. The resonant frequency fr of the converter is mainly determined by the inductance Lr band the capacitance Cr of the series capacitor.

$$f_r = \frac{1}{2 * \pi\sqrt{Lr * Cr}} \qquad (2)$$

V. Simulation Results

The simulation of an induction heater is conducted using MATLAB/Simulink, and the obtained results are outlined here. The SIMULINK model of System is shown in Fig. 4 below. As shown in figure consists of three phase power supply, is connected to Three phase rectifier which gives output as rippled DC voltage, then it is further connected to filter which eliminates ripple in supply. Filter provides pure DC supply to the input of Half-bridge series resonant converter. This Half-bridge series resonant generates high frequency AC.

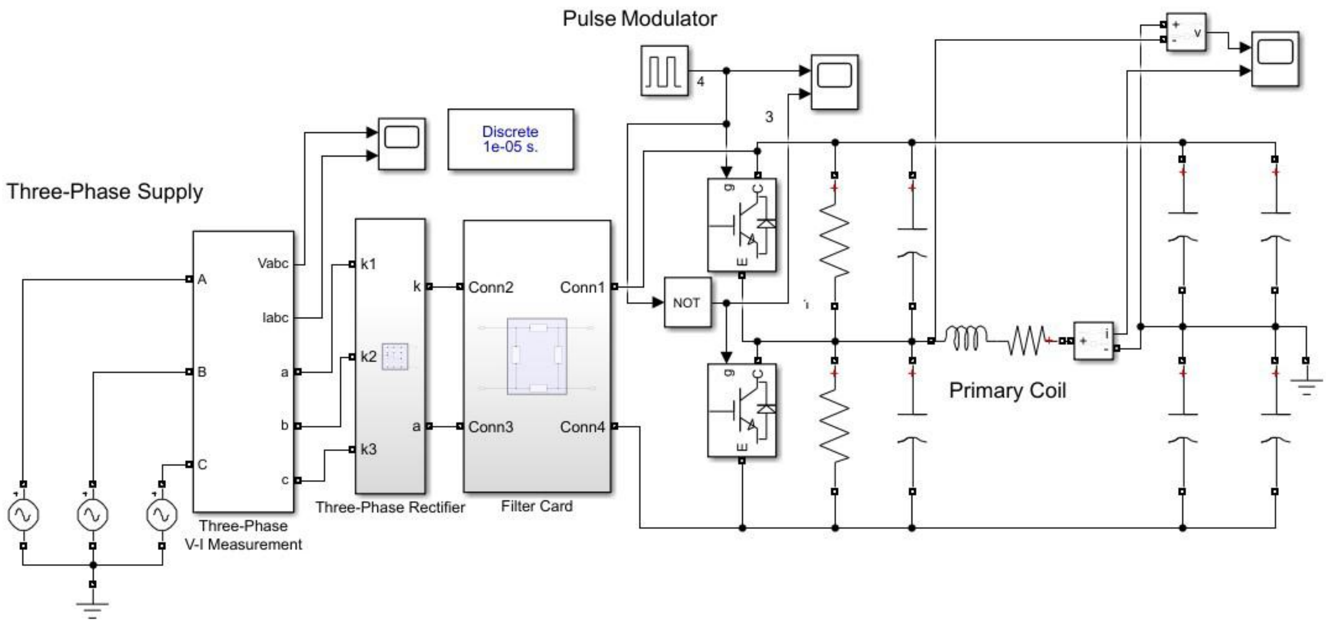

Figure 4: Simulation model of System

The table shows the important parameters and there value which were implemented in MATLAB/SIMULINK. The simulation was conducted with a duty cycle of 25% and a presumed switching frequency of 20 kHz.

Table 1: Parameter Values

Parameters	Value
Supplied Power	3-phase 50Hz AC Supply
Switching Frequency	20kHz
Equivalent resistance, Req	18 Ω
Equivalent inductance, Leq	120 μ H

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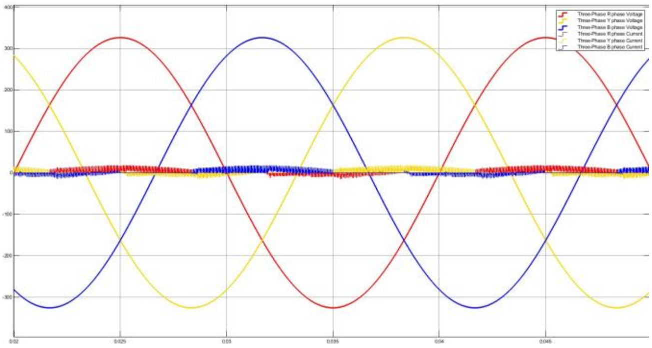

Figure 4: Input 3-Phase AC supply waveform

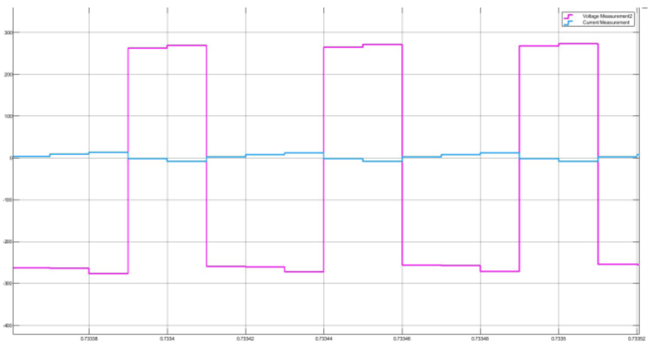

Figure 5: Output voltage and current across primary coil side

The coil is heated at all the three switching conditions representing three different frequencies. It has been observed that the coil heats up faster when the delay between both the switches (upper and lower) is low. A model representing the above discussed converter is implemented. Simulation Output has been shown in Fig.5. The MATLAB/Simulink simulation has been successfully implemented.

VI. Conclusion

In this paper, the design and construction of the power system for the induction heating cooker based on resonant converter is presented. This project choice of a half-bridge series resonant converter configuration has high efficiency and practicality. This converter offers numerous advantages, including efficient power conversion and enhanced control over output parameters. Moreover, this approach enhances the project's scalability and replicability, making it adaptable to future iterations or similar endeavors.

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