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INDUCTION HEATING OF TWO MAGNETICALLY INDEPENDENT LOADS WITH A SINGLE TRANSMITTER

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Abstract: ***The design of a system capable of heating two magnetically independent ferromagnetic loads placed on different horizontal planes, which uses a combination of induction h heating and inductive coupling, called inductively coupled heating. The system uses a single primary inductor acting as a transmitter to transfer power to a secondary inductor attached to the bottom load, which is connected electrically with a third inductor that heads the top load. Since power of the whole systm is supplied by a simple half bridge inverter, the ratio of the delivered power to each of the loads, which is critical for cooking results, is entirely dependent on the system"s geometry, coil"s number of turns, and compensation capacitors. The proposed system utilizes a unique coil design and control algorithm to efficiently transfer energy to both loads, while maintaining precise control over the heating process. The advantages of this approach includes reduced material costs, increased reliability, simplified design.***

Index Terms - **Induction heating (IH), Inductive coupling, Wireless Power Transmission.**

I. INTRODUCTION

Induction heating is a technique that produces heat in electrically conductive materials by means of electromagnetic induction. When an alternating current (AC) flows through a coil (transmitter), it creates a time varying magnetic field, which induces eddy currents within a nearby conductive load. These induced currents produce resistive heating, causing the material to heat up. Conventional induction heating systems typically involve a single transmitter coil coupled with a single load, allowing for precise energy transfer. However, in many industrial applications, there is a need to heat multiple workpieces simultaneously. Using separate transmitters for each load can be inefficient, leading to increased complexity, energy consumption, and costs. Therefore, a more advanced approach is required to heat multiple loads effectively using a single transmitter.

The induction heating of two magnetically independent loads with a single transmitter is the main objective of this work. It takes careful coil design, ideal frequency selection, and load matching strategies to heat numerous loads effectively and independently. Interference between magnetically connected loads may result in unequal heating and decreased efficiency. Each load can receive energy without influencing the others if the loads are kept magnetically independent. The system can be designed to isolate or barely interact with the magnetic flux paths in order to accomplish this. Furthermore, impedance matching networks and frequency-tuned circuits aid in the efficient distribution of power among the loads, guaranteeing that each gets the energy needed for consistent heating. Performance can be further improved by using sophisticated control techniques like phase control and adaptive power distribution.

In industrial applications like metal forging, electronic component processing, and automobile manufacture where several components must be heated simultaneously, the suggested approach provides substantial advantages. The system eliminates energy losses, lowers hardware costs, and streamlines the design by using a single transmitter to heat many loads. Additionally, precise temperature control made possible by independent load heating enhances both process effectiveness and product quality. The foundation for future advancements in high-efficiency industrial heating applications is laid by this research, which establishes the framework for creating sophisticated multi-load induction heating systems.

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II. METHODOLOGY

Using a single transmitter, the system is intended to accomplish wireless power transfer (WPT) for heating two magnetically independent loads. Creating high-frequency alternating current (AC) to cause eddy currents in the secondary coils and produce heat is the main goal.

Power Source (24V DC): The circuit receives the required DC voltage from the power supply. In order to create the alternating magnetic field needed for induction heating, this DC power is subsequently transformed into high-frequency AC utilizing the inverter circuit.

Inverter (IRFP250N MOSFETs): The task of turning DC into high-frequency AC falls to the full-bridge inverter. It creates an alternating current at 25 kHz by using four IRFP250N MOSFETs, which turn on and off at a regulated pace. For wireless power transfer to be effective, this high-frequency current is essential.

Gate Driver Circuit (TLP250F Optocoupler): The MOSFETs' switching is managed by the TLP250F gate driver. By supplying suitable voltage levels and isolation between the control circuit and power circuit, it guarantees that the MOSFETs function well. This enhances circuit reliability and lowers switching losses.

Microprocessor (PIC16F877A): The PWM (Pulse Width Modulation) signals required to regulate the MOSFETs' operation are produced by the PIC16F877A microcontroller. It guarantees the proper switching order, which is necessary to generate the intended high-frequency AC output.

Resonant Tank Circuit (Capacitor and Induction Coil): An induction coil and a capacitor make up the resonant tank circuit, which is intended to reach resonance at 25 kHz. This guarantees minimal losses and effective power transfer. In order to heat the secondary coil, the coil creates an alternating magnetic field that causes eddy currents.

Primary Coil: When the high-frequency AC from the inverter excites the primary coil, it functions as a transmitter and produces an alternating magnetic field. Wireless energy transfer is made possible by this field's induction of current in the secondary coils, or loads.

Secondary coil: The secondary coils function as separate loads and are positioned close to the primary coil. Eddy currents are produced when subjected to the magnetic field produced by the primary coil, which heats the load material. This is the main way that induction heating works.

Oscilloscopes and Instruments for Measurement: To view the voltage and current waveforms in various circuit sections, an oscilloscope is utilized. This aids in confirming whether power transfer is effective and whether the inverter is producing the proper 25 kHz frequency.

System Components:

- Power Supply: A 24V DC power source is used to power the circuit.
- Full-Bridge Inverter: Converts DC into high-frequency AC using MOSFET switches (IRFP250N).
- Control Circuit: The PIC16F877A microcontroller and TLP250F driver circuit control the MOSFET switching to generate the required frequency.
- Resonant Tank Circuit: Comprises induction coils and capacitors to achieve resonance at 25 kHz for efficient power transfer.
- Primary and Secondary Coils: The primary coil (transmitter) generates an alternating magnetic field, which induces current in the secondary and tertiary coils (loads).

The given block diagram represents an induction heating system with wireless power transfer using a multi-coil setup.

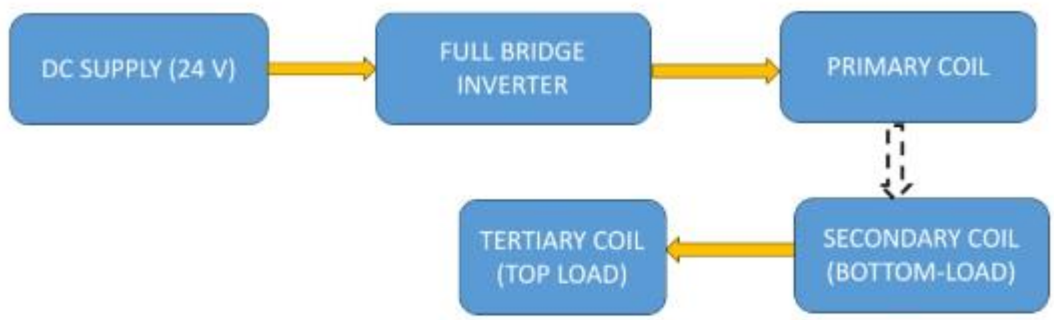

Fig No.1 : Induction Heating System

III. Modes of Operation

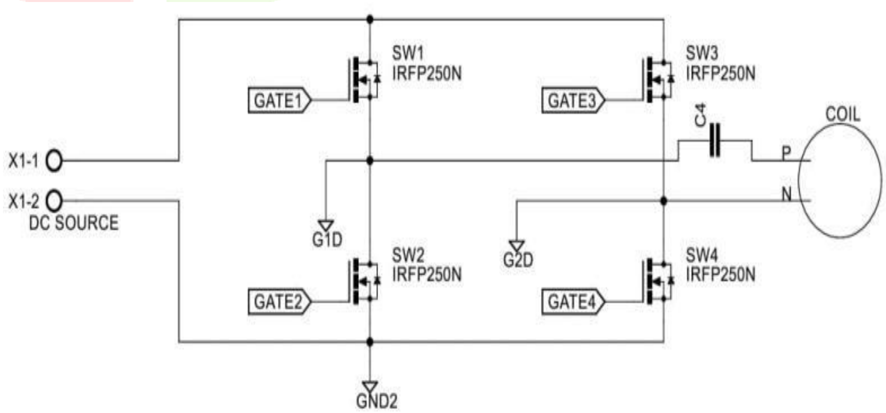

Fig No.2 : Full Bridge Inverter Circuit

Using four IRFP250N MOSFETs (SW1, SW2, SW3, and SW4), the provided inverter circuit is a full-bridge (H bridge) inverter made for an induction heating system. It transforms DC power into the high-frequency AC needed for induction heating. In order to generate an alternating current flow through the induction coil, the circuit switches these MOSFETs in pairs (SW1-SW4 and SW2-SW3). This creates a time-varying magnetic field that induces eddy currents in a conductive load, causing heating. The

MOSFETs, which are managed by gate drive signals (GATE1 to GATE4), switch the input power from the DC source (X1-1 and X1-2). A capacitor (C4) is placed in parallel with the coil to form a resonant LC tank circuit, ensuring efficient energy transfer by matching the operating frequency with the coil's resonance. The full-bridge topology enables bidirectional current flow through the coil, maximizing power delivery and improving efficiency. The use of high-power MOSFETs (IRFP250N) ensures the system can handle high currents with minimal losses. This inverter design is crucial in induction heating applications where high-frequency AC is needed to generate the necessary electromagnetic fields for efficient and controlled heating.

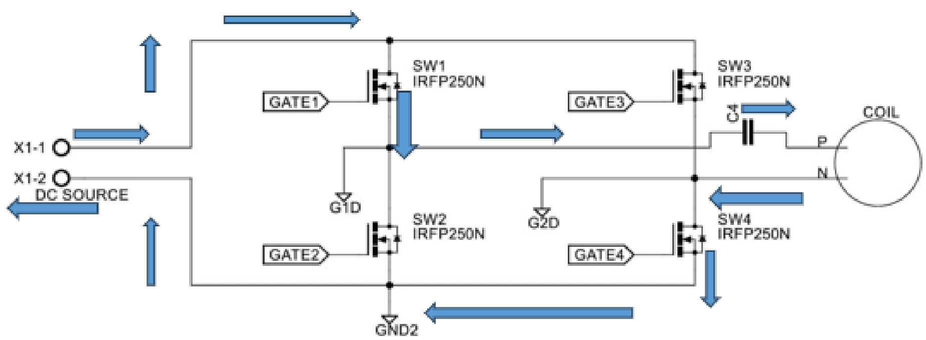

Fig No.3 : The flow of current When SW1 and SW4 is ON

Mode 1: Flow of Current Using SW1 and SW4

This mode permits current to flow through the primary coil in a single direction by turning on switches SW1 and SW4 in the full-bridge inverter. This creates a magnetic field that causes currents to flow through the secondary and tertiary coils, heating the loads in the process. To provide uniform heating, the generated current oscillates in a regulated manner.

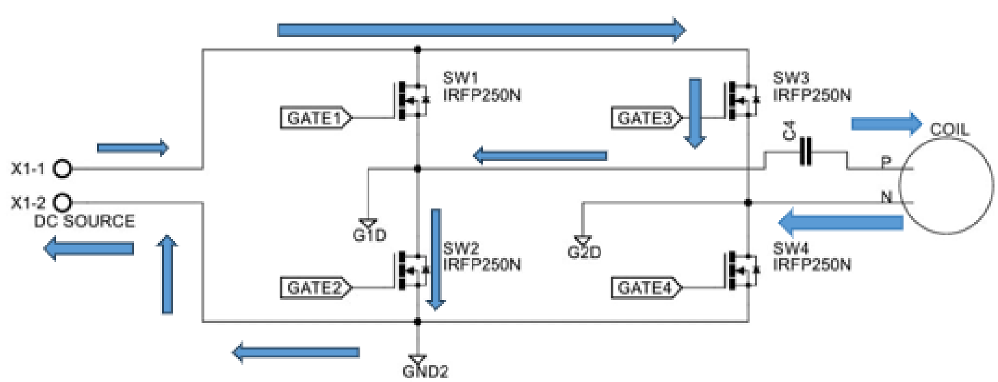

Fig No.4 : The flow of current When SW2 and SW3 is ON

Mode 2: Flow of Current Using SW2 and SW3

In this mode, the primary coil's current flow direction is reversed by activating switches SW2 and SW3. A steady electromagnetic field is ensured by the high frequency (25 kHz) of this alternating current cycle. Consequently, there is little interference between the two independent loads and they both get steady heating.

IV. Design of Components

Every part of the system is precisely engineered to coincide with the 25 kHz resonance frequency. This frequency is attained by selecting the values of the inductor and capacitor, guaranteeing effective power transfer. Because of their high current and voltage carrying capacity, which guarantees dependable operation, MOSFETs were chosen. To maintain peak performance, the microcontroller is configured to control the switching sequence. Before being implemented on hardware, the entire circuit is simulated to confirm its effectiveness.

- The following formula is used to find the resonant frequency (F):

$$F = 1/\ 2\pi\sqrt{LC}$$

where L (18.42 μH) and C (2.2 μF) are selected for resonance at 25 kHz.

- To switch effectively at high frequencies, a gate driver circuit powers the MOSFETs.
- Although initial testing yields 50 W, the system is intended to deliver 750 W of output power, highlighting potential for optimization.

Fig No. 5 : Induction Heating Coils

A primary coil and a secondary coil make up the dual-coil induction heating system depicted in the illustration. When an AC current passes through the primary coil, it produces a high-frequency alternating magnetic field. Resistive heating results from the eddy currents this field creates in adjacent conductive materials. As an extra receiver of the electromagnetic energy, the secondary coil which is magnetically connected to the primary coil allows for either independent heating or energy transfer to a different load. Wireless power transfer to numerous heating zones is made possible by this setup, which also guarantees effective power distribution. The coil structure is appropriate for uses like induction cooktops, industrial heating, and wireless power transfer systems since it is made to maximize energy coupling while minimizing losses. By distributing the magnetic flux uniformly, the radial winding arrangement enhances heating efficiency and homogeneity. The tertiary coil in the induction heating system looks to be the one depicted in the second picture. It serves as an extra receiving coil in this project, enabling wireless power transfer and heating independent of the primary secondary coil arrangement. This coil is probably made to absorb electromagnetic energy from the alternating magnetic field of the primary coil and use it to either heat a load directly or supply electricity to another circuit. It may function as a power relay or secondary heating element in a multi-load induction system due to its helical form, which indicates that it is ideal for effective energy absorption and conversion. By using this tertiary coil, the system can preserve magnetic independence from the primary and secondary coils while heating various items separately or delivering improved power distribution. Applications needing more heating zones, increase defficiency, or personalized heating profiles can benefit from this capability.

V. Simulation

An alternating current (AC) passing through an induction coil creates a magnetic field, which is the basis for how induction heating systems work. Nearby conductive materials, usually metals, experience electric currents called eddy currents as a result of this magnetic field. Heat is produced when these currents run in to resistance in the material. The coil design, the AC supply frequency, and the electrical characteristics of the substance being heated are some of the variables that affect how efficient this heating process is. For a variety of industrial processes, including soldering, frying, and metal hardening, induction heating is used due to its quick and precise heating capabilities. Simulation models of induction heating systems help in optimizing their design and function by allowing engineers to visualize the magnetic field distribution, temperature gradients, and overall heating performance. By altering design parameters such as coil geometry and frequency, simulations can predict how changes will affect heating efficiency and uniformity. This predictive capability is essential for enhancing the performance of induction heating systems and can lead to improvements in energy consumption and processing times, ultimately making them more effective for specific applications in manufacturing and engineering.

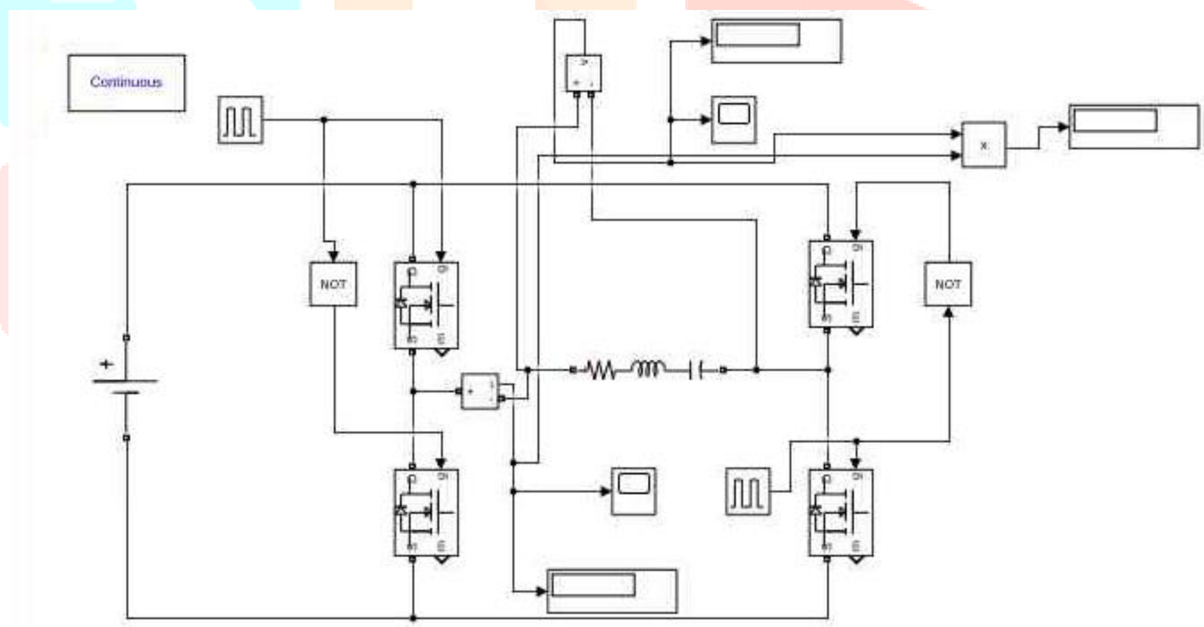

Fig No. 6 : Simulation diagram

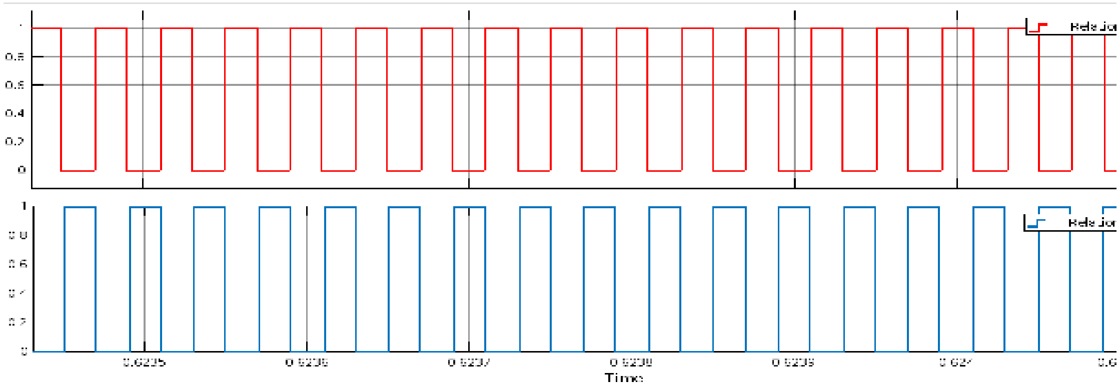

Fig No.7 : Gate Drive Signals waveform

The switching signals for the induction heating system's power electronics components are represented by this waveform, which was most likely produced by a Pulse Width Modulation (PWM) control circuit. The two plots show square waveforms that represent the gating signals of the inverter circuit's semiconductor switches, such as MOSFETs or IGBTs. In order to ensure that the inverter runs in a controlled manner and produces the necessary high-frequency AC power for the induction coil, the red waveform (Relational Operator2) and the blue waveform (Relational Operator1) show complementary switching patterns.The induction heating system's stability and efficiency are determined on the exact timing and duty cycle of these signals. A high switching frequency ensures appropriate energy transfer and sustains resonance conditions for effective heating, which is consistent with the behavior expected of an inverter driving an induction heating load.

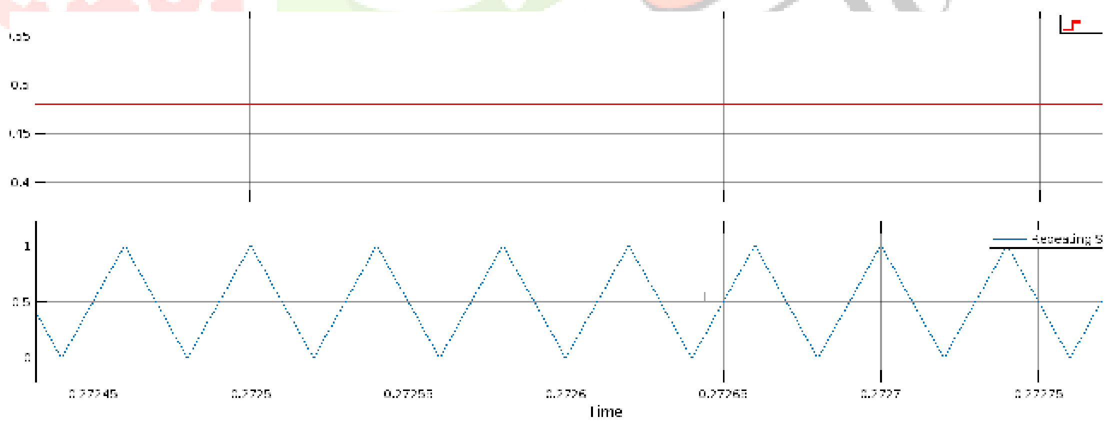

Fig No.8 : PWM Carrier Signal

The reference signals utilized in the induction heating system's Pulse Width Modulation (PWM) control are represented by this waveform. A threshold for comparison may be established by the fixed reference value of the upper waveform (Constant4). Triangular waves like the lower waveform (Repeating Sequence2) are commonly employed as carrier signals in PWM creation. To provide switching pulses for the inverter, which control the output voltage and frequency, this triangle waveform is compared to a control signal. These waveforms' function is to guarantee appropriate switching device modulation, which permits effective and reliable power supply to the induction coil.

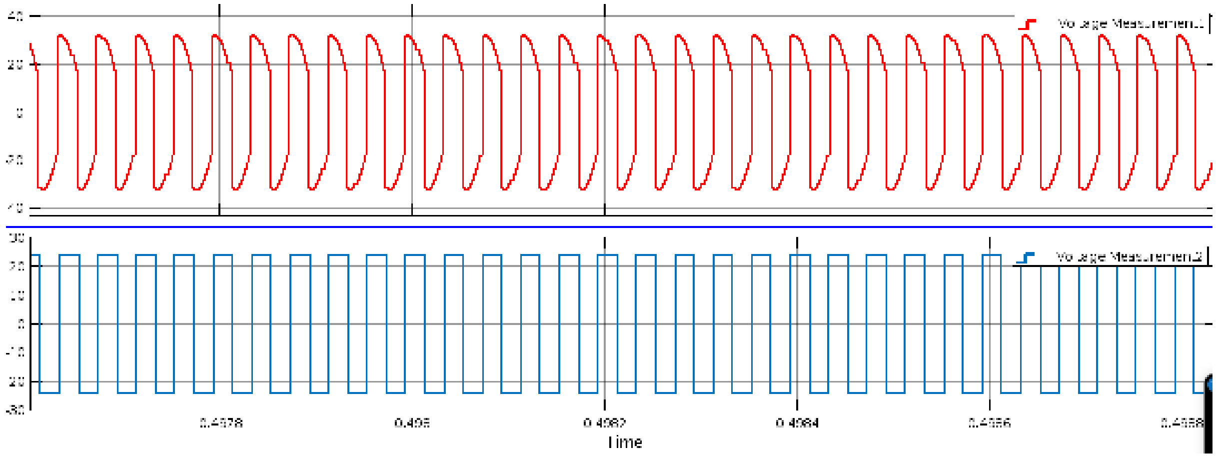

Fig No.9 : Inverter Output Voltage waveform

The voltage characteristics of the induction heating system are shown by this waveform. The induction coil's high-frequency AC voltage is probably represented by the higher waveform (Voltage Measurement1), which exhibits a sinusoidal character as a result of resonance. The inverter output voltage prior to filtering is probably represented by the lower waveform (Voltage Measurement 2), which looks to be a square wave. The induction coil is powered by this square wave, which transforms electrical energy into a magnetic field for heating. These waveforms serve to demonstrate the power conversion process, guaranteeing effective energy transfer and steady induction heating system functioning.

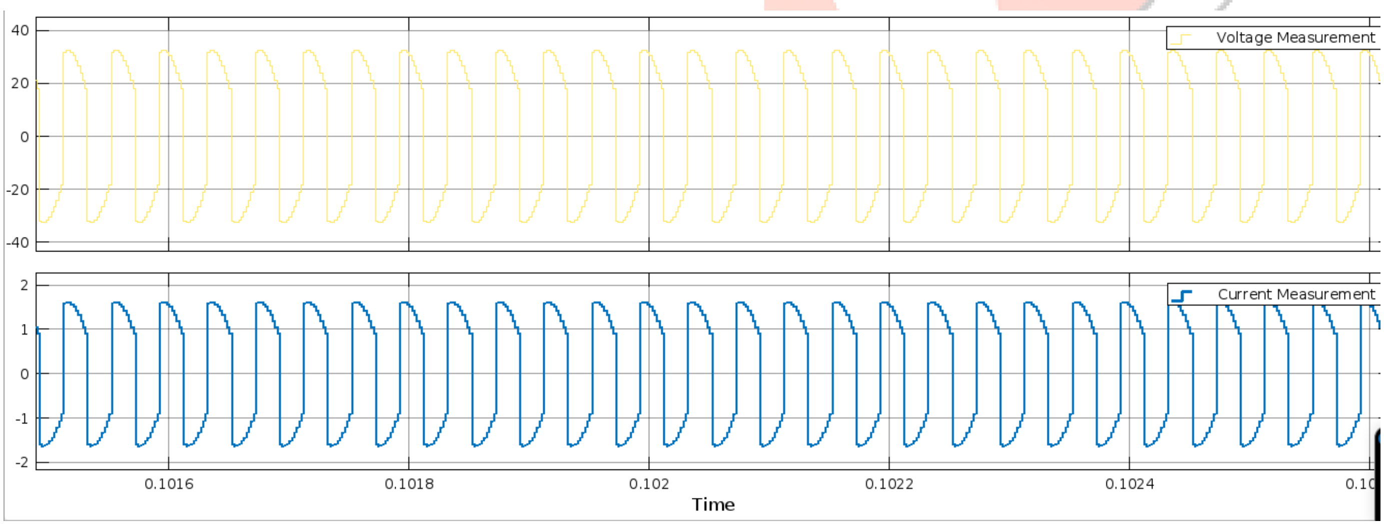

Fig No.10 : Resonant Tank Waveform

The induction heating system's voltage and current response is shown by this waveform. The high frequency AC voltage applied to the induction coil is displayed in the upper plot (Voltage Measurement), and the corresponding current waveform is shown in the lower plot (Current Measurement). These signals indicate the resonance condition of the system, which is essential for efficient energy transfer and effective heating. The current waveform's sinusoidality indicates that the inverter and the coil's electromagnetic induction process are operating correctly. Keeping an eye on these waveforms aids in system performance analysis and guarantees that the voltage and current are in phase for optimal effectiveness. The simulation effectively verifies the operation of a high-frequency induction heating system based on an H-bridge, showcasing effective resonant switching and load power supply. The resulting waveforms validate the anticipated high-frequency, high-voltage oscillations (~25 kHz), which are necessary for efficient induction heating. The resonant voltage waveform and square wave switching that are seen show that the inverter circuit is operating correctly, guaranteeing the best possible energy transfer to the work coil. This demonstrates that the system is ideal for both industrial and research applications since it can efficiently provide the electromagnetic field needed for heating applications.

VI. Hardware

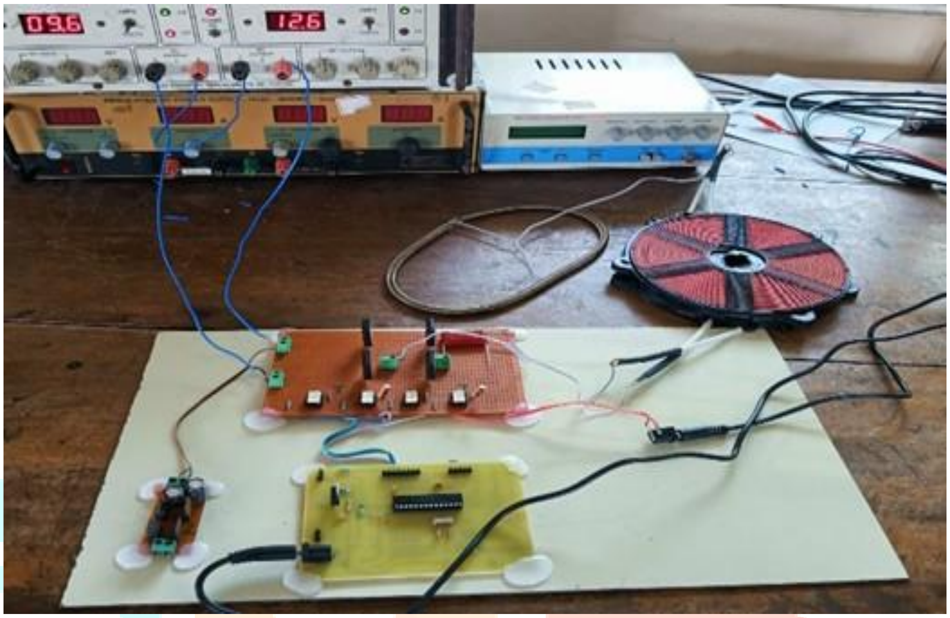

Fig No.11 : Hardware Setup

Figure 11 shows the hardware setup of induction heating system This hardware configuration is an example of an induction heating system that uses a single transmitter to heat two magnetically independent loads. The system consists of a high-frequency induction coil, a control circuit, a switching driver, and a regulated DC power supply. The MOSFET/IGBT driver stage receives high-frequency switching signals from the control circuit, which is probably controlled by a microcontroller. By quickly changing the current flowing through the induction coil, this driver produces an alternating magnetic field. This technology is intended to effectively transmit energy to two distinct loads without causing direct magnetic interference between them, in contrast to conventional single-load induction heating. This is accomplished by carefully placing the load and designing the coil so that each load gets the required heating effect on its own. The system guarantees efficient energy transfer to both loads with minimal loss by optimizing factors including coil geometry, operating frequency, and power distribution. Filtering and regulating circuits reduce noise and guarantee smooth operation, while the power supply supplies steady voltage and current. Applications like industrial heating operations, metal treatment, or biomedical applications that need for consistent heating across several items benefit from this kind of technology. For multi-load induction heating systems, using a single transmitter is an effective way to cut costs and complexity in the hardware.

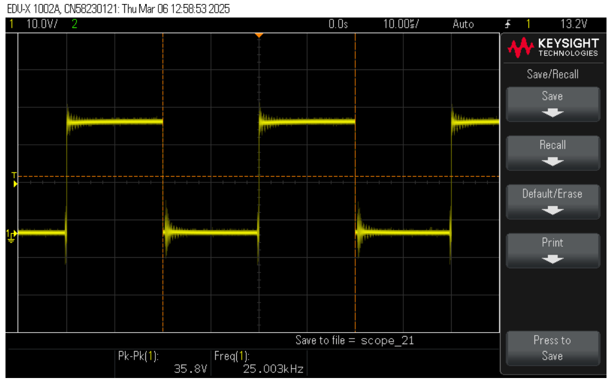

Fig No.12 : Output of PIC16F877A Microcontroller

The oscilloscope capture shows the PWM (Pulse Width Modulation) output of the PIC microcontroller, which is used to drive the full-bridge inverter in the induction heating system. With a frequency of 25.003 kHz and a peak-to-peak value of 35.8V, the waveform displays a square wave signal, suggesting that the microcontroller is producing high-frequency switching pulses to regulate the MOSFETs (IRFP250N) in the inverter circuit. The high-frequency AC signal needed for effective induction heating is produced by this signal, which transforms the DC supply. The sharp transitions in the waveform suggest that the MOSFETs are being switched with minimal delay, ensuring effective power transfer to the induction coil. Additionally, the small noise spikes present in the waveform may be due to switching transients, which are common in high-power applications. Overall, this PWM signal ensures that the inverter operates at the designed frequency, allowing for resonant induction heating of the magnetically independent loads in the system.

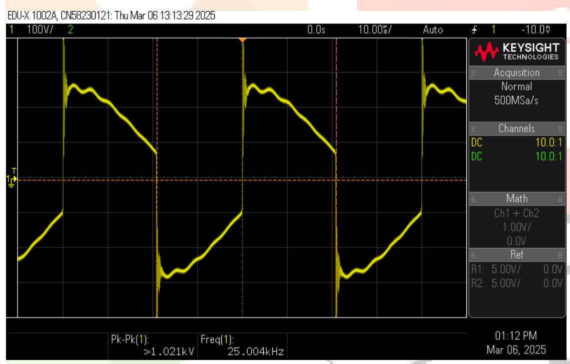

Fig No.13 : Output Voltage waveform

This oscilloscope-captured waveform depicts the induction heating system's output voltage as it appears in the hardware configuration. At a frequency of 25.004 kHz, the waveform displays a high-voltage oscillating signal (~1.021 kV peak-to-peak), which corresponds to the normal operating frequency of an LC resonant circuit in an induction heater. The sloped parts show resonant charging and discharging of the LC tank circuit, while the abrupt peaks imply high- frequency switching behavior, most likely caused by a MOSFET-based inverter. In order to create the alternating magnetic field that causes eddy currents to flow through a conductive workpiece and cause induction heating, this voltage waveform is essential.

VII. Conclusion

High-frequency electromagnetic induction for practical and contactless heating applications is demonstrated by the induction heating system in this study. A primary induction coil that creates eddy currents in a conductive workpiece is driven by alternating current (AC) generated at 25 kHz by a full-bridge inverter topology that is managed by a PIC microcontroller. The oscilloscope measurements confirm that the inverter circuit, which produces the required high-frequency AC output for the induction coil by alternating MOSFETs 1 and 4 and MOSFETs 2 and 3, is operating correctly. The tertiary coil, observed in the setup, likely serves as a feedback mechanism for tuning the resonance frequency or monitoring voltage spikes to ensure stable operation.

The waveforms parasitic oscillations demonstrate the impacts of circuit inductance and high-frequency switching, both of which can be lessened with the right snubber circuits or gate drive optimization. The technology is perfect for industrial processes like melting, soldering, and metal hardening because it effectively transforms DC power into high-frequency AC, allowing for localized heating without direct contact. The achieved high voltage across the inverter's output ensures sufficient power delivery to the induction coil, demonstrating the practical viability of this system for real-world applications. With further refinements in circuit design, thermal management, and feedback control, this induction heating system can be optimized for greater efficiency, stability, and adaptability to various heating applications.

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