QUASI RESONANT CIRCUITRY TO IMPROVE HEAT TRANSFER AND EFFICIENCY IN INDUCTION COOKER

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QUASI RESONANT CIRCUITRY TO IMPROVE HEAT TRANSFER AND EFFICIENCY IN INDUCTION COOKER

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ABSTRACT

This research proposes a dual-mode coil structure for induction cookers using a single switching element quasi-resonant circuit and examines its effect on heating performance. In an induction cooker, the material base to be used for the heating process and the coil adaptation significantly affect the heating performance. Since the materials used are user-defined and vary, they may not always be suitable for traditional single-coil structures. The proposed dual coil structure works according to the base diameters of the material to be used and provides adaptation for different diameters. This adaptation optimizes the heat distribution on the coil, allowing the energy to be transferred more effectively. Effective energy transfer by minimizing losses improves the heating performance, making it faster and more efficient. At the same time, with this structure, the magnetic field created by the coil is applied to the material more effectively, reducing the voltage value affecting the switching element. This enables the use of a lower voltage value switching element in the quasi-resonant circuit, which is cheaper and easily controlled since it has a single switching element but is also exposed to high voltage values. The dual-mode coil structure proposed with the quasi-resonant circuit was verified by simulating with MATLAB, and its improvement in heating performance in the induction cooker was experimentally investigated.

ÖZETÇE

Bu araştırmada tek anahtarlama elemanlı quasi-resonant devresi kullanılan indüksiyon ocaklara ikili bobin yapısı önerilip ısıtma performansına etkisi incelenmektedir. Isıtma işlemi için kullanıcak materyalin tabanı ile coil adaptasyonu ısıtma performansını oldukça etkiler. Kullanılan materyaller kullanıcı tanımlı olup değişkenlik gösterdiği için geleneksel tek coil yapısına her zaman uygun olmayabilir. Önerilen ikili bobin yapısı kullanıcak materyalin taban çaplarına göre çalışarak farklı çaplar için adaptasyon sağlamaktadır. Bu adaptayon bobin üzerindeki ısı dağılımını optimize ederek enrjinin daha etkili şekilde aktarılmasını sağlar. Kayıpların minimize edilerek yapılan etkili enerji aktarımı, ısıtma performansını geliştirerek daha hızlı ve verimli olmasını sağlar. Aynı zamanda bu yapı ile bobinin oluşturduğu manyetik alan materyale daha etkili şekilde uygulandığı için anahtarlama elemanını etkileyen voltaj değerini düşürmektedir. Bu durum tek anahtarlama elemanına sahip olduğu için daha ucuz ve kolay kontrol edilebilen ama aynı zamanda yüksek voltaj değerlerine maruz kalan quasi-resonant devresinde daha düşük voltaj değerli anahtarlama elemanı kullanılabilmesini sağlamaktadır. Quasi-resonant devresi ile önerilen ikili coil yapısı MATLAB ile simüle edilerek doğrulanmış ve indüksiyon ocakta ısıtma performasını geliştirmesi deneysel olarak incelenmiştir.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my advisor Asst. Prof. Gokturk Poyrazoglu his help and advice for this project. And I would like to thank VESTEL for supporting the project. I also thank my parents and friends who always support me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Recently, there is a trend towards electrical energy generated from renewable energy sources due to the damages of fossil fuels to the environment and exhaustible. With this trend, the transition to those working with electrical energy in the vehicles and goods we use to meet our needs in our daily life is increasing. For example, the transition from fossil-fuel cars to electric-powered, home-powered electric heaters and electric-powered cookers from fossil-fuel cookers used for cooking. With this process, many research and experimental studies are carried out to ensure more efficient use of electrical energy and reduce losses in power transfer. In this project, the induction cooker technology, which works with electrical energy used for cooking in home life, has been examined and it is aimed to conduct an experimental investigation by conducting research that will facilitate use and improve heat transfer.

Induction cookers are increasing in use due to their efficiency and fast cooking feature. These cookers are not only efficient but also safe in that they transmit heat directly to the material to be heated. The working principle of this technology is based on the heating of the ferromagnetic material placed in the magnetic field created by the electronic circuit by acting as a complementary element to the circuit and passing eddy current through it. The induction cooker performance varies depending on the structure of the coil and ferromagnetic material since the ferromagnetic pot acts as a complementary circuit for the heating process and the energy is transferred by the coil. Since the ferromagnetic material to be used for heating is user-dependent, the induction circuit structure and coil must adapt to these different materials.

Various coil designs increase the heating performance by providing the adaptation between the coil and the ferromagnetic material. These coils usually consist of multi-coil structures that can work in different sizes. Multi-coil structures are controlled by different switching elements and operated according to the material used, ensuring adaptation. These structures usually use topologies such as half-bridge and full-bridge inverters. By detecting the size of the material placed on the coil, the switching elements that control the coils that can adapt to the material are operated and performance is improved. The common goal in these different designs made is to improve the heating performance by ensuring the adaptation of the coil and ferromagnetic material. Since they are controlled by several switching elements, they increase in cost while improving the heating performance. This project, it is aimed to improve the heating performance by minimizing the cost increase by proposing a dual-mode coil structure to the quasi-resonant circuit using a single switching element, unlike the existing multi-coil structures. In the proposed coil structure, both coils are connected to the same switching element and the single switch structure remains the same. Detection is made according to the base diameter of the pot placed on the coil and only the inner coil or two coils work together. The dual-mode coil structure is proposed to match the coil and the ferromagnetic material in an induction cooker using a quasi-resonant inverter, and the improvement in heating performance was examined for experiments of different pot diameters.

1.1 History of Induction Cooker Technology

Induction cookers are modern structures designed depending on technological improvements depending on the development of cooker technology. When the development of cookers is examined, after the construction of the electrically operated vitro ceramics structure, induction cookers with a more modern structure have been designed. As the cooking technology has improved, efficiency has increased. While the efficiency of gas-powered cookers is approximately 40%, vitro ceramic 70%, induction cookers have an efficiency reaching 90% [4]. As the designs develop, it is aimed to transfer the power spent directly to the material to be heated, and ambient losses of heat are prevented.

Figure 1: Gas, Vitro-Ceramic and Induction Hobs

1.2 Motivation

Our future needs to use the energy obtained from various sources in the most effective way. In today's research, the goals are generally to reduce power losses and to provide power transfer most effectively. Induction cooker technology, one of the designs made in line with these goals, provides efficient and fast power transfer. Contributing to this technology and working to produce solutions for human needs motivates me. With the design made in this research, in addition to the heating process with standard-sized ferromagnetic pots in the existing induction cooker structure, efficient heating can be made with small diameter pots, and the dual-mode coil structure will be adapted to user-defined pots of different sizes. I think this method will be used efficiently and practically in our daily life and it will provide comfort.

1.3 Objectives

Heat transfer is aimed to be done in a more advanced way with the dual-mode coil structure. The magnetic field will be directed to adapt to the ferromagnetic material used, and eddy currents will complete the transmission in the shortest path. The dual-mode coil will work according to the material with small and large diameter bases and the heating performance will be improved by balancing the heat dissipation in the coil with this adaptation. A High-frequency alternating current passing through the coil is a single switching element quasi-resonant circuit. Using a single switching element topology, it is aimed to maximize the heating performance in a low-cost circuit. At the same time, thanks to this structure, small diameter ferromagnetic materials can be effectively heated, and this structure provides practicality to the user since ferromagnetic materials are user-defined.

CHAPTER II

LITERATURE REVIEW

2.1 Working Principle

Comparing cooking technologies, induction technology, which is the most efficient in energy transfer, aims to transfer almost all of the energy consumed to the cooked food. The basic working principle of induction technology is based on the use of energy generated by the electromagnetic field. When changing current is applied to the coil used in the induction cooker, a magnetic field occurs around the coil. The eddy currents created by this magnetic field affect the ferromagnetic material placed on the coil for a certain distance. While eddy currents circulate on the ferromagnetic material, the resistance shown against the current causes the material to heat [5]. This heat is transferred directly to the food placed in the ferromagnetic material and the cooking process is performed.

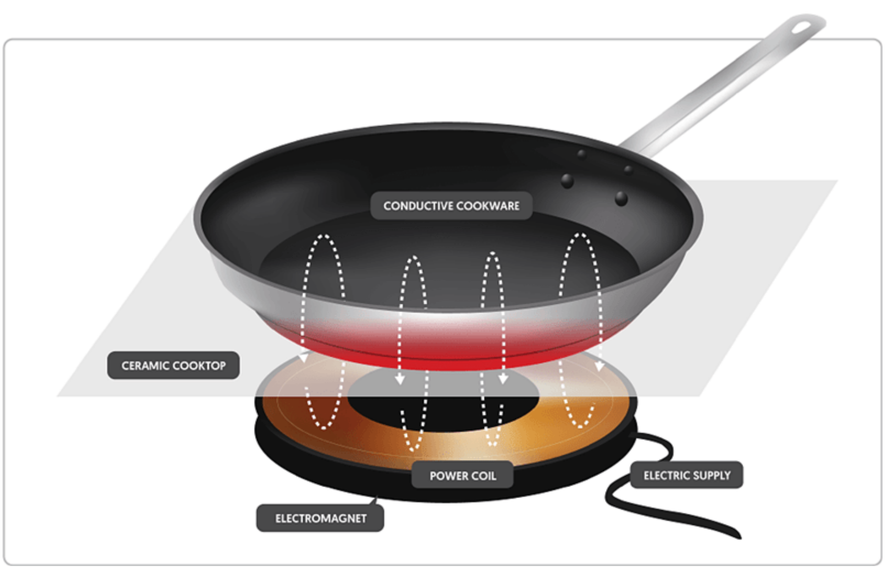

Figure 2: Induction Cooker Working Principle [1]

To perform the heating process with the induction cooker, the material structure to be used must be ferromagnetic. Because the current flows over the ferromagnetic material, the eddy currents that can pass through the material under the effect of the magnetic field are transformed into heat energy. The material provides the cooking process by distributing this heat evenly. If we consider this ferromagnetic material as resistance, as its ferromagnetic increases, its resistance value decreases. When the same power is applied, the material with less resistance value heats up rapidly bypassing more current. The higher the ferromagnetism of the material, the faster and more efficient the cooking process. In non-ferromagnetic materials, the heating process can be done by adding a layer that provides ferromagnetism to their bases. This situation will cause a decrease in productivity due to the losses that will occur.

In the induction cooker, there is a ceramic cooktop between the coil providing the magnetic field and the ferromagnetic material placed on it. This ensures the placement of the material and prevents direct contact with the coil. Since the heat reflected by the heating of the material affects the ceramic cook-top, it must be heat resistant. Since the heat is transferred directly to the material and there is no heat conduction other than the ferromagnetic material, it is safe for the user to touch the cooker's surface.

It is necessary to pass variable induction current through the induction coil to produce eddy currents required to heat the material. To provide this current, the rectifier that converts AC-DC from the grid and the inverter structure that converts this DC to AC by switching it at high frequency and applying it to the coil are used [6].

2.2 Circuit Topologies

The structure that converts AC from the mains to DC in the induction cooker is generally similar to each other. The preferred bridge diode is used according to the current value in the circuit used. Operating modes and performances of induction cooker vary according to the inverter structures used for DC-AC conversion.

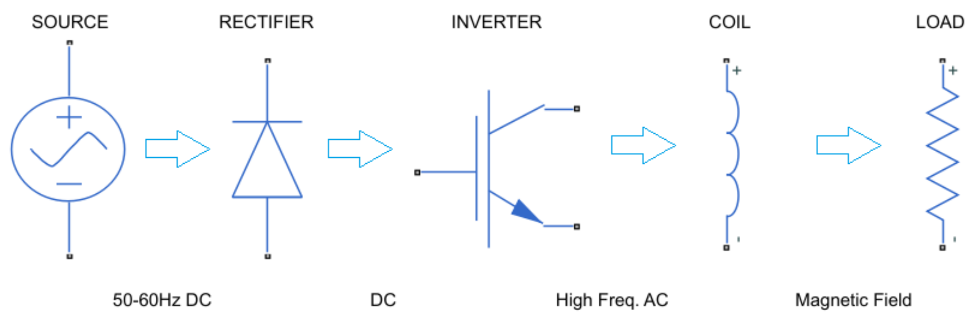

Figure 3: Source to Load Circuit Diagram

There are various circuit topologies used to supply the alternating current to be applied to the induction coil and operate as a DC-AC converter. Topology preferences may vary depending on the number of components used and their efficiency.

2.2.1 Half-bridge series resonant inverter

The half-bridge series resonant inverter, which takes its name from the fact that switching occurs as alternating half loops and contains a series resonant circuit, consists of two switching elements as shown in Figure 4. In this inverter structure, two switches switch at the resonant frequency, preventing audible sounds [7]. High efficiencies can be achieved by switching at high frequencies in this topology structure [7]. In this respect, it is generally used in the induction cooker structure. The two switching elements are triggered sequentially by using dead-time in between, and they are fed with DC voltage to create an alternating voltage at its output.

2.2.2 Full-bridge series resonant inverter

The full-bridge series inverter consists of four switching elements as shown in Figure 5. There is a resonant circuit serially to the inverter circuit that adjusts the resonant frequency. Since four switching elements are used in this inverter structure, the stress

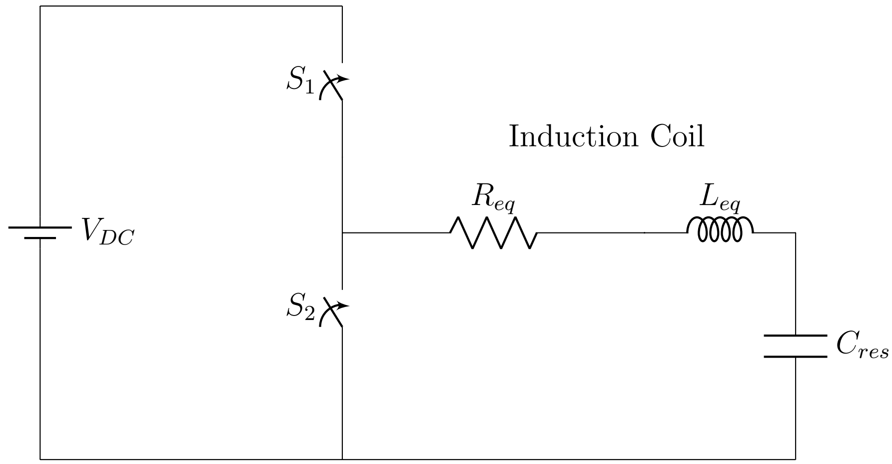

Figure 4: Half-Bridge Series Resonant Inverter Circuit

occurring on the switching elements is less and the resulting switching losses are very low. Compared to a half-bridge inverter, it is more efficient [8].

In a full-bridge inverter structure, the switches are turn-on and turn-off control by twos to form positive and negative cycles. To release leakage inductance between these on and off times, all switches are in the turn-off position for a certain period of time [9]. The output waveform is close to sinusoidal with this topology. This inverter circuit is costly as four switching elements are used and their control structure becomes complex.

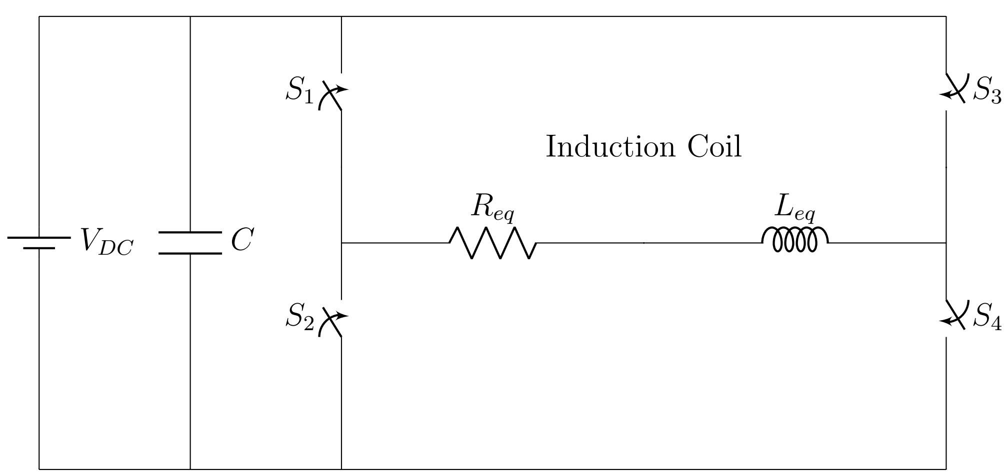

Figure 5: Full-Bridge Series Resonant Inverter

2.2.3 ZVS Single Switch Inverter

Zero current switching inverter aims to minimize losses by switching instantly of zero voltage. Since there is only one switching element in this inverter topology, it is very economical, but when the current flowing through the single switching element increases, it experiences more stress, and switching losses increase [10]. Another advantage is that since there is not more than one switching element, there is no need to control the dead time between the turn-on states of the switches and the control structure is simpler [10]. This inverter structure also has a resonant circuit to adjust the resonant frequency.

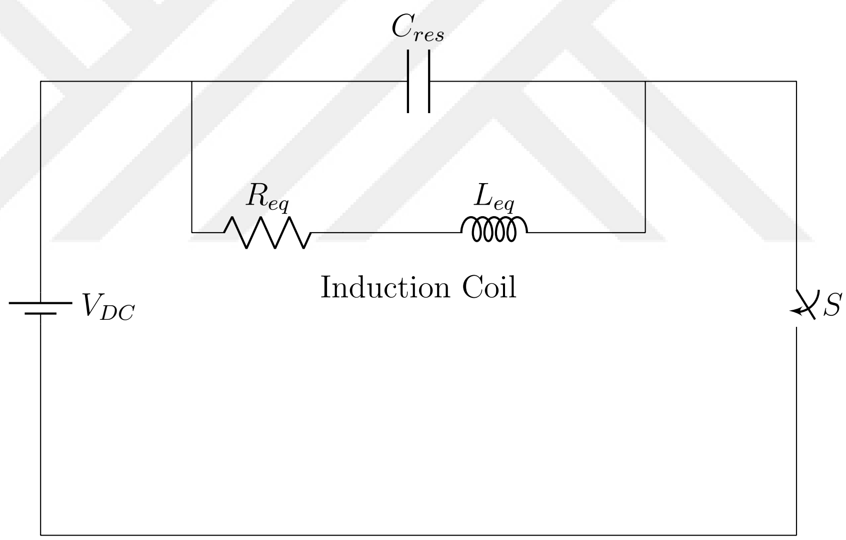

Figure 6: ZVS Single Switch Inverter

2.2.4 ZCS Single Switch Inverter

Zero current switching inverter structure has one switching element like ZVS. In this topology, the switching at zero current and the losses are minimized. While there is voltage resonance in the ZVS single switch topology, the current resonance is different from it in this topology [11].

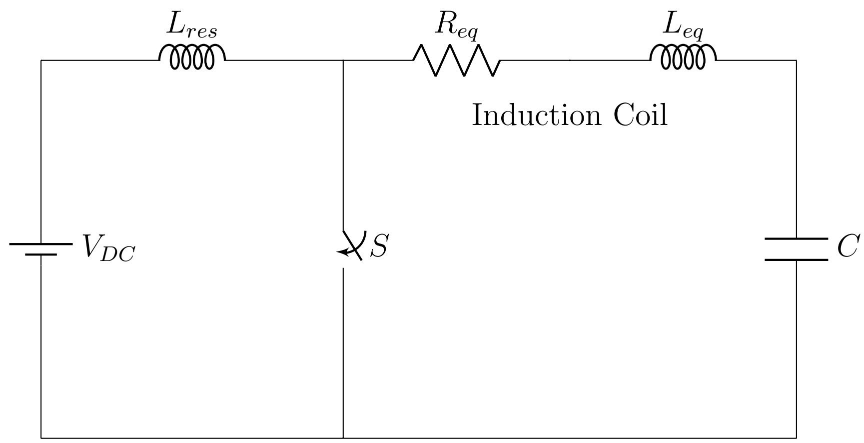

Figure 7: ZCS Single Switch Inverter

2.3 Heating Coil Structure

It is an inductive element that passes high values of alternating current using a switching element over the coil used in an induction cooker. The magnetic field formed by the alternating current passing over it creates eddy currents. The ferromagnetic material placed in this magnetic field is heated with eddy currents. Since high currents pass through the coils and ferromagnetic materials heated by the eddy current it creates, they are highly stressed [12]. The current strength of the conductive wire used in coil design and the temperature resistance of the insulation material surrounding it are very critical. The shape of the coil is generally designed similar to the base surface of the ferromagnetic pot to be placed on. The harmony of the two in shape makes the heat distribution more homogeneous and the cooking process more efficient [13]. The turn number of windings in the coil is preferred according to the inductance value that will create, and the distribution of the winding according to the temperature distribution. Ferrite is used in the coil base, which concentrates the electrical flux by directing the magical field [14]. As the ferrite structure concentrates the flux, it can cause heat density in the areas where it is used. Ferrite placement is done according to its effect on heat distribution.

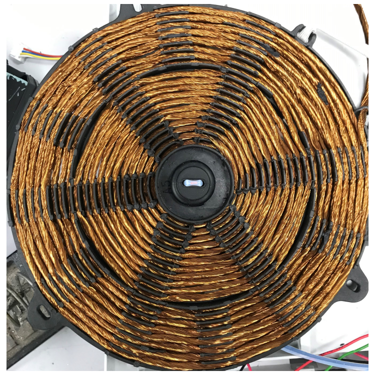

Figure 8: Induction Coil

The shape matching of the coil and the ferromagnetic material to be placed on it for heating is very critical in terms of losses in heat conduction and stress that may occur in the coil windings and the switching element. When coil and ferromagnetic material are in harmony, all these losses are minimized. With this harmony, eddy currents created by the magnetic field reach the ferromagnetic material with a shorter path and heat conduction occurs. However, this adaptation may not always be achieved. There may be types of pots of different sizes and shapes that will be placed on a single-coil structure. When a pot with a diameter smaller than the diameter of the coil is placed on the coil, it becomes difficult for the eddy currents to reach the pot where the coils do not coincide with the outer coils. There are researches and experiments for different coil structures to reduce these losses.

Instead of using a single-coil, heat distribution can be regulated by using a multi-coil structure consisting of small coils as shown in Figure 9. By using the multi-coil structure, it is compatible with the shape of the pot to be placed on the coil, reducing power losses and improving heating performance [2]. By switching with small coils in the multi-coil structure, the heat distribution is balanced and the power management is made more effective, improving the heating performance compared to the single-coil structure [2].

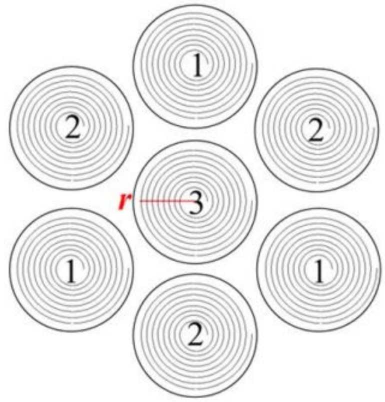

Figure 9: Multi-coil Structure [2]

Depending on the traditional use in different countries, the types of pots vary. A change in the base of this ferromagnetic material may cause a decrease in heating performance. For example, in the wok pan structure used especially in China, the coil is moved away from the base as one goes out of the base. In a different coil structure, it is designed to be adapted with the wok cookware, and the distance between the coil and the bottom of the pan is the same in every part of the base [3]. With the design that the inner part of the planar coil is deeper and the outer part is close to the bottom of the pot, the distance to the base is kept equal, the heat distribution is homogenized and the heating performance is improved [3].

Figure 10: Planar Coil for Wok [3]

The nested coil structure made using the dual half-bridge topology is an example modeling type that improves heating performance by balancing the heat distribution [15]. In the research, which has been obtained from these experimental results, by using different switching elements that manage nested coils, power distribution has been made effective, and performance has been increased [15].

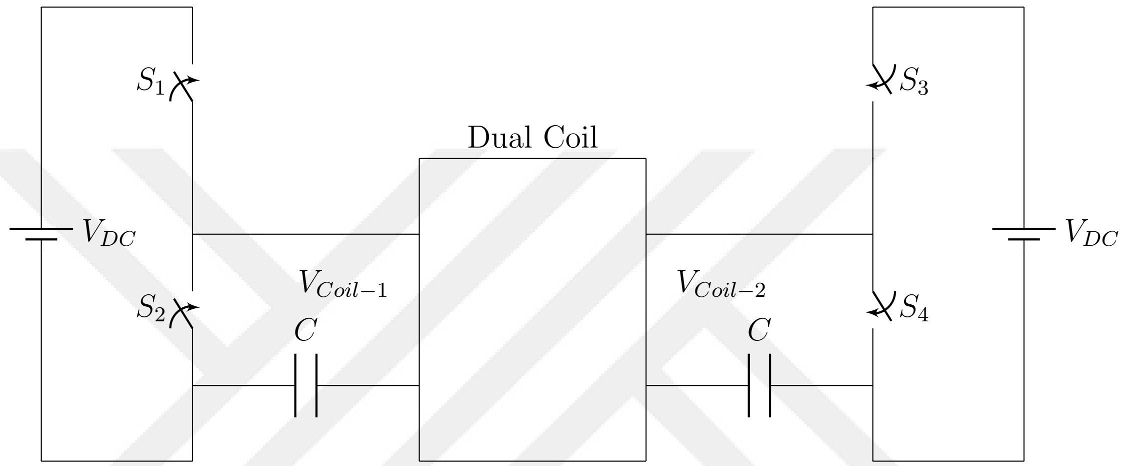

Figure 11: Dual Half-Bridge Topology

2.3.1 Eddy Current

Eddy's current is based on Faraday's law of induction. When a changing magnetic field is created in a conductive wire, the circular currents surrounding the magnetic field are called eddy current [16] as shown in Figure 12. When we examine Lenz's law, the eddy current creates a magnetic field against the magnetic field that creates it. Eddy current, examined according to these laws, is converted into heat energy by spending it on a resistor.

Eddy currents obtained from the magnetic field created by the alternating current passing through a coil are actually undesirable currents. Because these eddy currents affect the conductor and circulate as a loop on the conductor and cause power losses. In order to reduce eddy current losses occurring in various inductive element applications, a structure consisting of multiple layers is preferred in conductors affected

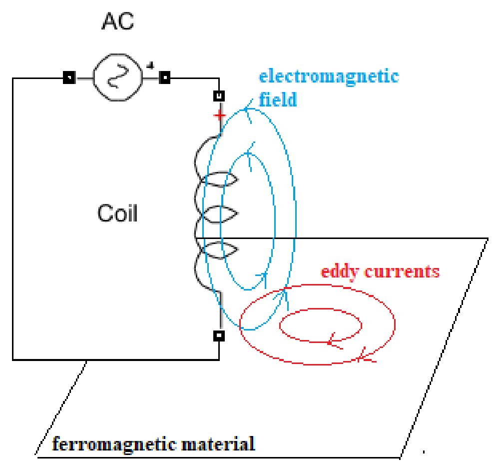

Figure 12: Eddy Current

by currents as shown in Figure 13. When a multi-layer structure is used instead of a single layer, the current circulates loop is limited and the losses are reduced since the eddy currents are exposed to higher resistances [17].

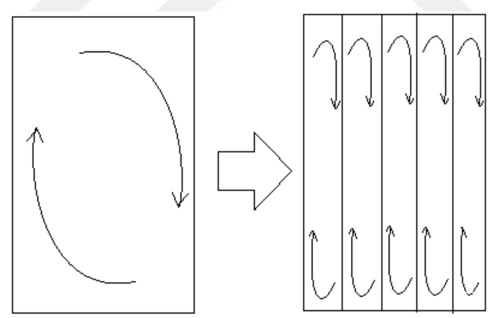

Figure 13: Multi-layer Structure for Eddy Current

Since the losses caused by eddy currents turn into heat, it is widely used in the industry as an induction heating method. The material to be heated, exposed to the magnetic field created by the inductor, can circulate eddy currents and heat this conductive material effectively [18]. Eddy currents, which are undesirable because they create power losses, are used as an efficient heating method in such industrial applications.

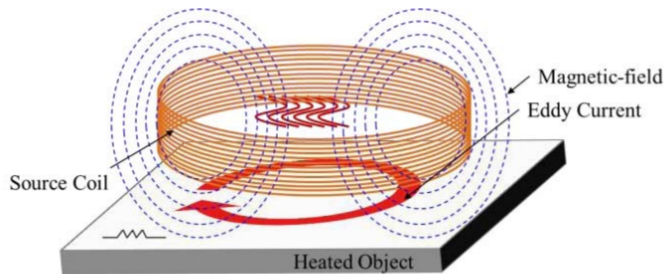

Figure 14: Induction Heating Method [19]

Induction cookers are the application of the industrial induction heating method for home use. These cookers are examples of using eddy current losses for heating. In induction cookers, a coil structure consisting of copper wires with multiple cores is used. In this structure, the high-frequency alternating current applied to the copper wires creates a magnetic field around the wires and the ferromagnetic material heats up with the eddy current created by the magnetic field. In this structure, ferromagnetic material is the resistance that eddy currents complete their circulation. The coils used in an induction cooker are generally designed in the form of a disc suitable for the bottom of the pot to be heated. Ferrite is used at the base of the coil to shape the magnetic field created by the wires wrapped in accordance with this design [19]. Since the ferrites are used to shape the magnetic field, eddy currents formed by the magnetic field are also shaped and reach the ferromagnetic material more effectively.

Figure 15: Ferrite of Coil Base

2.3.2 Ferromagnetic Material Detection

In order to heat the induction cooker, a ferromagnetic pot should be placed on the coil. The circuit topology to be operated to perform the heating process first detects whether a pot is placed on the coil and regulates its operation by sending a signal to the switching element according to this detection. It is necessary to determine the work by detecting the ferromagnetism of the pot to be placed on the coil. Because trying to operate non-ferromagnetic materials may cause malfunctions and power transmission performance may change depending on the ferromagnetic properties of the materials [20].

The material placed on the coil works as a load that completes the circuit. Detection can be made by applying the instant constant voltage to the coil and taking into account the damping on the material [20]. The material's ferromagnetism, its dimensions, and the power it draws varies according to its temperature during operation. Efficient power transfer can be made by detecting according to the type and size of the material and arranging the working frequency accordingly [21].

Figure 16: Ferromagnetic Material Detection

CHAPTER III

METHODOLOGY

3.1 Quasi Resonant Circuit Topology

In this project quasi-resonant circuit was preferred from inverter circuits. The main reason for using the quasi-resonant circuit is because it consists of a single switching element, it is more economical and it is easier to control. But the semiconductor used as the only switching element reaches higher collector-emitter voltage values.

The quasi-resonant circuit is powered by dc voltage. This dc voltage is charged and discharged through inductance using a switching element, and an alternating current is created. IGBT with a high breaking voltage value is used as the switching element in this project.

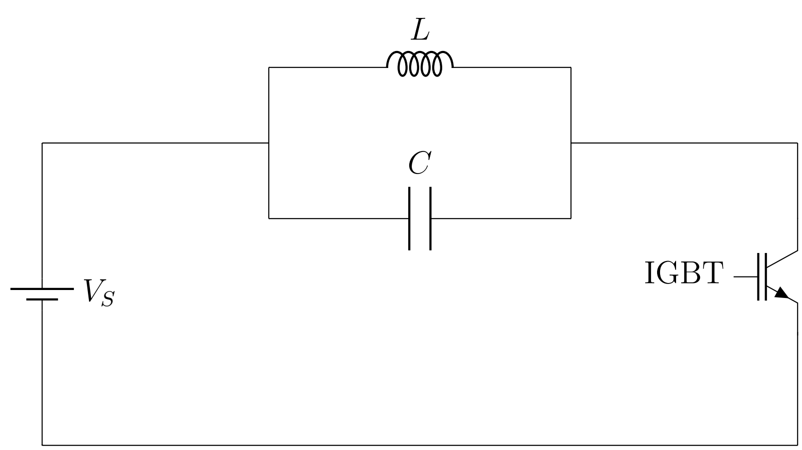

Figure 17: Quasi Resonant Circuit Topology

The circuit is analyzed according to the on and off states of the switching element. While the IGBT is transmission at an on the state as seen in Figure 18, the inductor is charged with the supply voltage, the current flowing through it increases. The voltage of the resonant capacity is equal to the supply voltage.

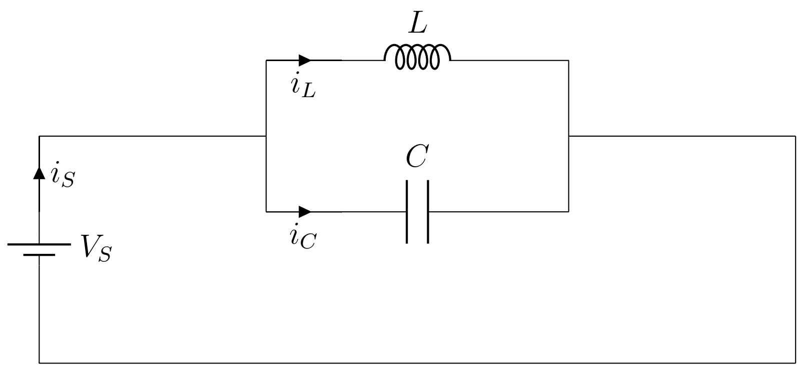

Figure 18: Quasi Resonant Circuit at IGBT On Condition

The calculation of the inductance voltage according to the input voltage is as the following equation.

$$V_s - L\frac{di_L}{dt} = 0 \quad (1)$$

$$V_s - V_c = 0 \quad (2)$$

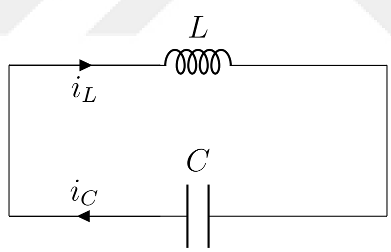

Figure 19: Quasi Resonant Circuit at IGBT Off Condition

When the IGBT is off, a voltage occurs between the current proof and the collector-emitter. In this case, as in Figure 19, the formed LC circuit is the oscillation of the energy stored from the previous state. Oscillation continues until the resonant capacity reaches the input voltage again [22]. The relationship between inductance and capacitance is as follows.

$$\frac{di_L}{dt} = \frac{V_c}{L} \quad (3)$$

$$\frac{dv_c}{dt} = -\frac{i_L}{C} \quad (4)$$

Using the equations obtained from the circuits formed according to the on and off states of the IGBT, we can obtain the waveform of the current passing through the coil and the voltage formed in the resonant capacity. When the graphics are examined, the coil current increases linearly as the source provides energy transmission in the IGBT on the state. When the IGBT is in the off state, the stored current decreases linearly. While the resonant capacity has the input voltage in the on state, since oscillation occurs in the off state, the capacitance voltage decreases until it turns on again.

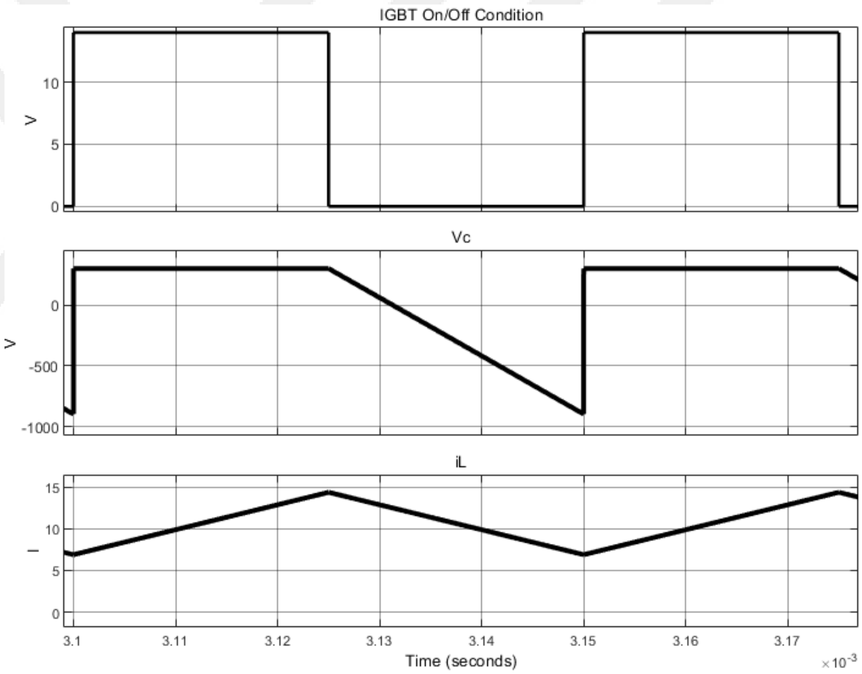

Figure 20: Waveforms of Quasi Resonant Circuitry Elements

When the circuit is analyzed, the IGBT is in the off state and the LC circuit formed is in the resonant tank circuit structure with oscillation. This oscillation is created from the energy transfer between the capacitor and the coil. The oscillation between these two components can ideally last indefinitely. But due to the resistance of the components, the energy is consumed and the oscillation ends by damping. The equivalent LC circuit to which the resistance is added is as in Figure 21.

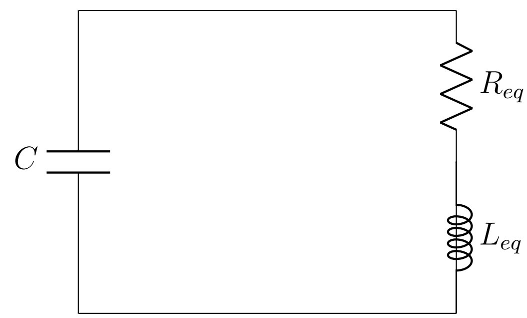

Figure 21: Equivalent Resonant Circuit

The oscillation occurs during the period when the IGBT is in an off state and the damping caused by the energy losses on the equivalent resistance is as in Figure 22. Energy is released from the electric field to the magnetic field and from the magnetic field to the electric field as the transfer.

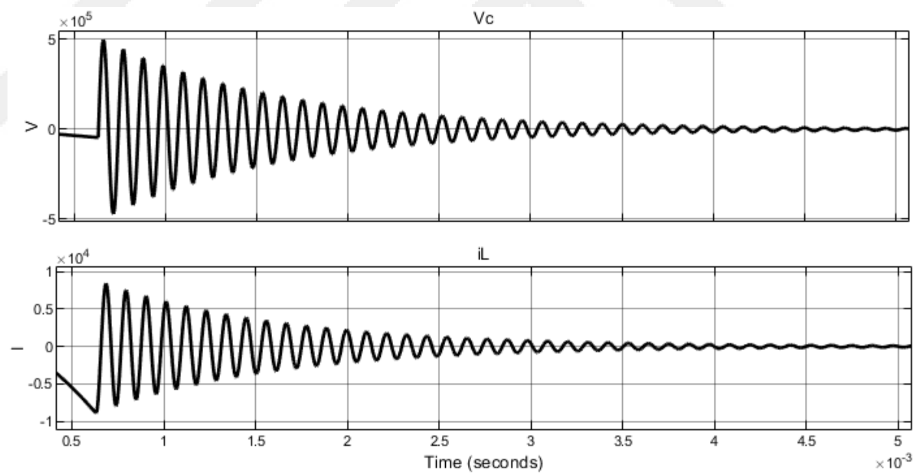

Figure 22: Resonant Circuit Oscillation

The frequency of the oscillation that occurs in this circuit depends on the inductance and capacitance values. Frequency is calculated as in the following equations.

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{5}$$

3.1.1 Pulse Width Modulation For IGBT Control

Since the switched circuit topology is used, the switching element, IGBT, must be controlled by a signal. PWM, a signal modulation technique, is used to perform this control. PWM is the modulation of the widths of the high and low levels of the signal which has a specific frequency. The information sent to the switching element with the PWM signal enables the circuit to be controlled. Two critical parameters provide this information. These are duty cycle and frequency.

Duty Cycle is the ratio of the time that a signal is high to the fixed signal period. It always takes between zero and one. As an example, the calculation of the duty cycle ratio of the signal in Figure 23 is as in the following equation.

$$D = \frac{k}{T} \tag{6}$$

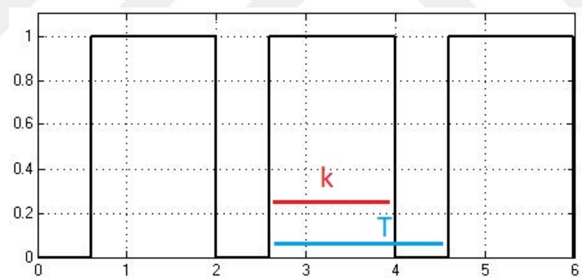

Figure 23: Duty Cycle of PWM Signal

There are different methods for generating the PWM signal. By comparing the two waveforms, the frequency and duty cycle rate of the PWM signal can be determined. For example, the PWM signal is generated by comparing the triangle waveform with a reference value. The sample PWM generation results are shown in Figure 24. When determining the frequency of the triangle wave, the duty cycle ratio is generated by taking the reference value as high when it is smaller than the triangle wave, and low when it is large. The on and off states of the circuit are determined by applying the PWM signal to the IGBT.

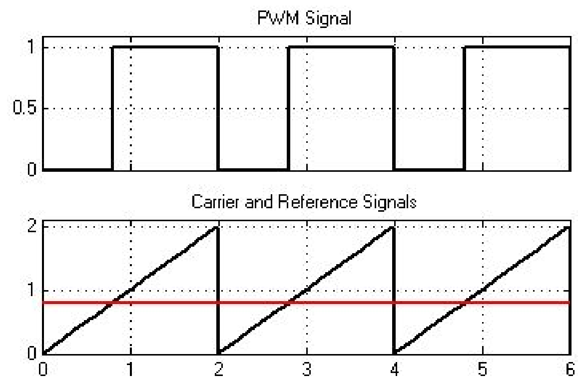

Figure 24: PWM Signal Generation Method

3.2 Proposed Coil Structure

A single-coil structure is used as an inductance in the quasi-resonant circuit. The alternating current created by the switching element creates a magnetic field by passing through this coil and eddy currents are applied to the ferromagnetic material from the magnetic field. In this project, instead of the traditional single coil structure, the dual coil structure is used to create the inductance of the quasi-resonant circuit. The dual-mode coil structure consists of two interconnected inner and outer coils. This structure works in two different modes. The first mode works in series with the inner and outer coils, the same as the existing conventional single coil. In this mode, the inductance value of the traditional single coil and the coil diameter remains the same. The second mode is the structure in which only the inner coil works. In the structure where only the inner coil works, the inductance value, and coil diameter are smaller than the traditional coil because the outer coil is disabled. The maximum coil sizes in the proposed dual-mode structure are the same as the traditional structure and operate in two different modes according to the pot preferences. In the quasi-resonant circuit, two different inductances occur depending on the operating mode of the circuit in the inductor part where the output is.

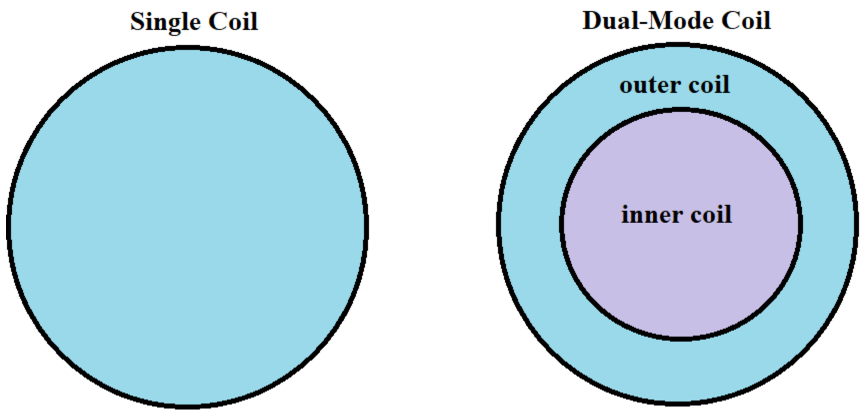

Figure 25: Single and Dual-Mode Coil

3.2.1 Dual Mode Coil Circuit

When the dual-mode coil structure is applied to the quasi-resonant circuit, the topology formed is as in Figure 26. Since there are two different inductance values according to the operating modes, two different resonant capacities are used to keep the resonant frequency the same. Only the inner coil or inner and outer coil work together by choosing according to the operating mode with the switch in the topology.

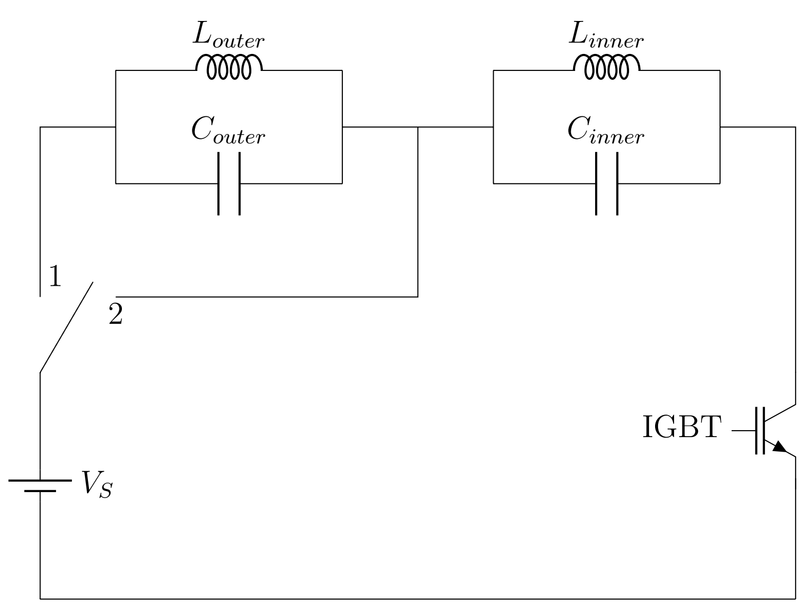

Figure 26: Dual-Mode Coil Quasi-Resonant Topology

First, in the mode where the inner and outer coil works together, the switch in Figure 26 provides transmission in the first position. In this mode, the inner and outer coils are connected in series and there is a series of inner and outer resonance capacitances connected in parallel to the coils as shown in Figure 27. The inductance value in the circuit is equal to the inductance value of the full coil formed by the inner and outer coils.

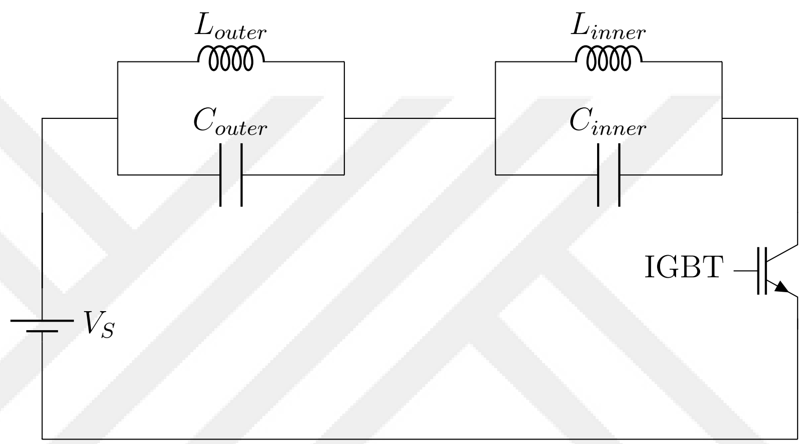

Figure 27: Full Coil Mode of Quasi-Resonant Topology

In the second mode, only the inner coil works. The switch in Figure 26 is in the second position and the outer coil is deactivated and transmission is only through the inner coil. In this mode, the inner resonant capacity connected in parallel to the inner coil is used as shown in Figure 28. The inductance value in the circuit is equal to the value generated by the inner coil.

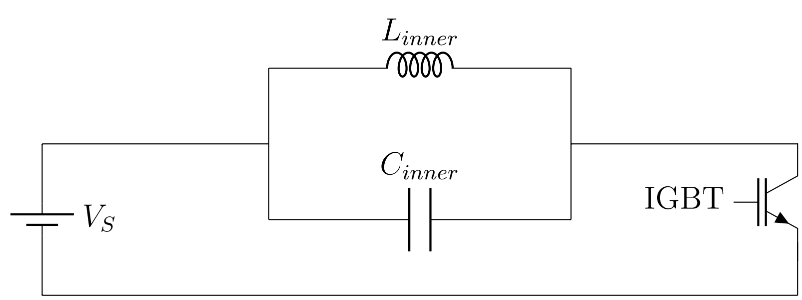

Figure 28: Inner Coil Mode of Quasi-Resonant Topology

3.2.2 Ferromagnetic Material Detection

Oscillation in the resonant circuit is used to detect ferromagnetic materials. In the resonant circuit consisting of coil and resonant capacity, the ferromagnetic material placed on the coil acts as a resistance in this circuit as shown in Figure 29. In this circuit, ferromagnetic material is detected with the damping that occurs after the step pulse.

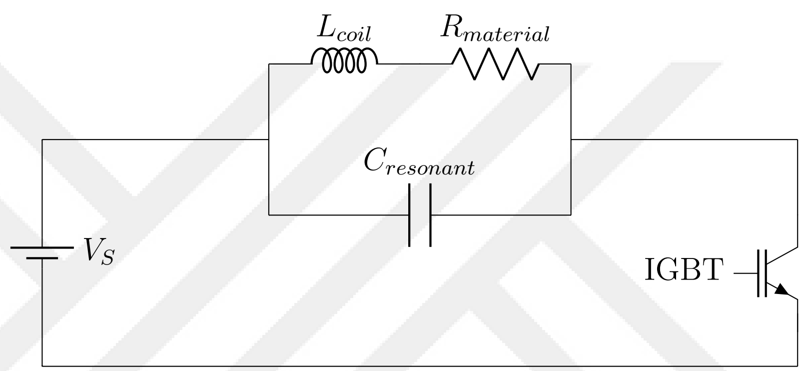

Figure 29: Resonant Circuitry With Ferromagnetic Material

In the resonant circuit, oscillation lasts indefinitely, as there will be a continuous transfer of power between the inductor and the capacitor in the ideal lossless condition. Since there is internal resistance of the circuit, oscillation continues for a certain time and ends. When the ferromagnetic material is placed on the coil, there will be a loss in the circuit as there will be power transfer to the material, and the higher this resistance value, the faster the oscillation damping occurs as shown in Figure 30. Since non-ferromagnetic materials will not be affected by the magnetic field, there is no power transmission to them. In this case, the resonant circuit provides the transmission through the coil as if there is no material resistance, and damping occurs only over the internal resistance of the circuit. The fact that the material placed on the coil is ferromagnetic is perceived by the damping of the oscillation caused by interacting with the magnetic field and acting as an element of the circuit.

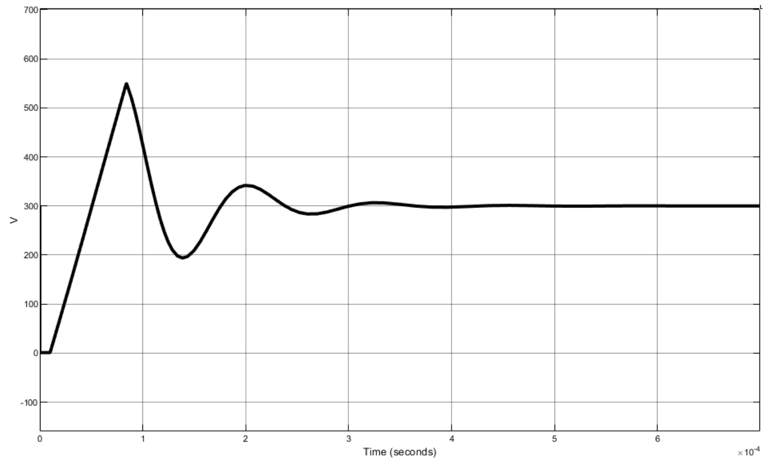

Figure 30: Oscillation With Ferromagnetic Material

3.2.3 Effective Power Transfer

For the power transfer to be effective, the dimensions of the coil used and the ferromagnetic material to be heated must be compatible. When the coil diameter and the base diameter of the ferromagnetic material are equal and the shapes of both are the same, harmony is achieved. This harmony is very important as the circulation of eddy currents produced by the magnetic field created by the alternating current passing through the coil windings in the ferromagnetic material performs heating. In the case that the base of the material covers all the windings, the magnetic field generated in each wire of the coil affects the material equally and homogeneously. The magnetic field, which affects the material in the shortest path, provides a homogeneous and effective heating of the ferromagnetic material base as shown in Figure 31. When small material is placed on the same coil, the material base becomes small to the coil and the outer windings stay away. The magnetic field created by the outer windings will reach the material base in a longer way and more power losses will occur. Since the current passing through the coil windings is equal, the magnetic field created by this current cannot affect the material equally in every region. The magnetic field of the outer windings that are far from the small material cannot be used effectively.

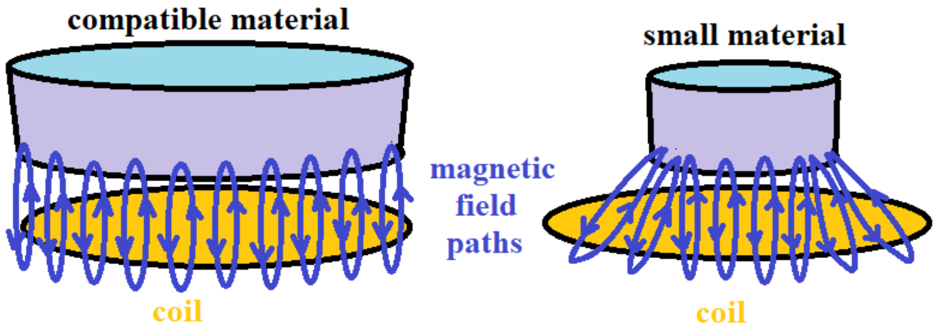

Figure 31: Coil and Material Compatibility

In the proposed dual-mode coil structure, when small material is desired to be heated, only the inner coil is operated to ensure the harmony of the coil and material as shown in Figure 32. The coil structure, which is the operating mode according to the pot base, adapts to large and small pots and transfers power effectively.

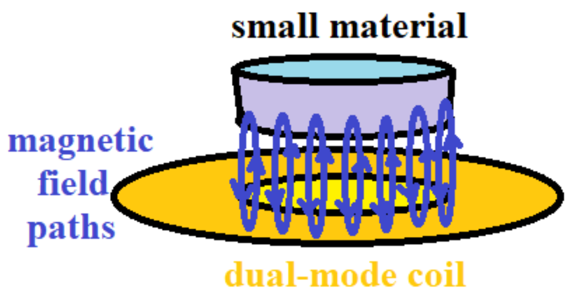

Figure 32: Dual-Mode Coil Compatibility

CHAPTER IV

MODELLING

4.1 Dual-Mode Coil Structure

The proposed dual-mode coil structure consists of two coils traditional to be the same as conventional coil sizes. The serial connection of the inner and outer coils of the dual-mode coil has the same size and electrical characteristics as the traditional coil. Thanks to this structure, the traditional coil structure has been preserved and a different mode has been added in addition. The traditional coil consists of a single-mode and has a diameter of 200 mm. The dual-mode coil structure consists of two different modes with 130 mm and 200 mm diameters as shown in Figure 33. By designing these sizes, it is aimed to maintain the performance of the traditional coil structure and create a different operating mode at the same time. Large-sized pots and small-sized pots are suitable for dual-mode coil structures.

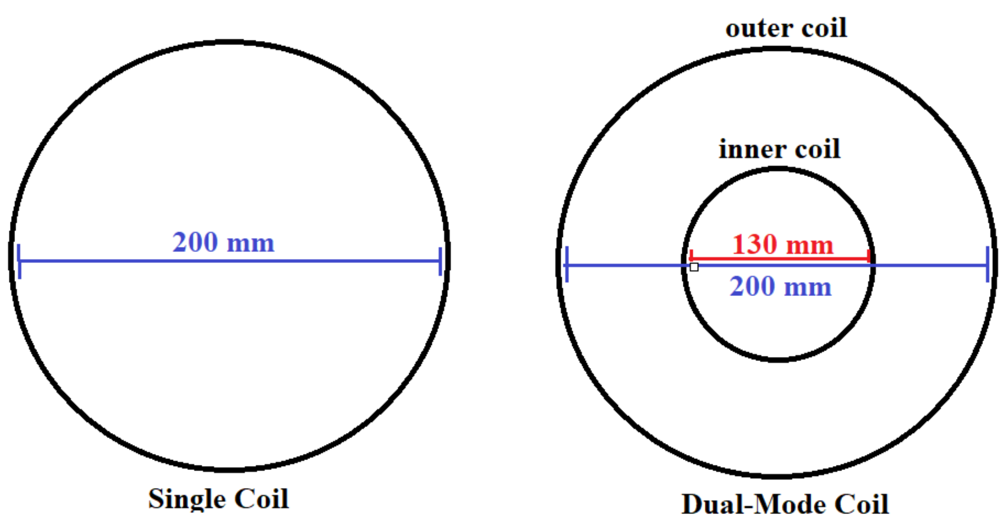

Figure 33: Single and Dual-Mode Coil Sizes

4.2 Dual-Mode Coil Winding Parameters

Multi-core copper wire is used in coil winding and this wire is wound in 19 turns. There are 11 turns in the inner coil with a diameter of 130 mm and 8 turns in the outer coil in its outer windings. Coils are made of copper wire consisting of 30 cores. The inner coil consists of double layers and the outer coil consists of a single layer. The winding and layer distributions of inner and outer coils are shown in Figure 34.

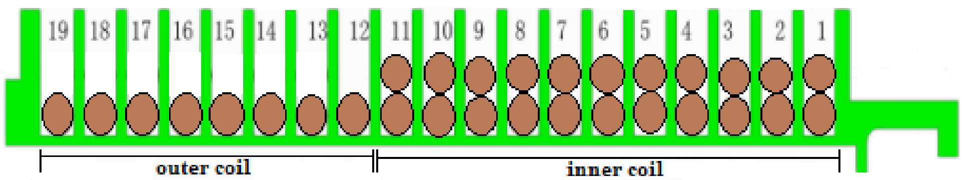

Figure 34: Dual-Mode Coil Windig Layers

The copper wires in the windings are covered with heat-resistant enamel to provide insulation. Since the windings can reach high temperatures under different operating conditions, the temperature resistance of this isolator is 200 degrees. The windings were manually wrapped on the commonly used plastic mold shown in Figure 35.

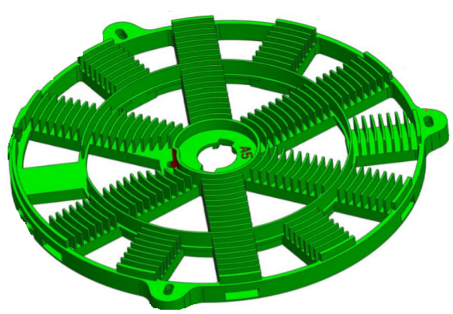

Figure 35: Dual-Mode Coil Plastic Mold

The view from the top surface of the coil, which is coiled according to the determined layer and number of turns, is as shown in Figure 36. The inner coil consisting of two layers and the outer coil consisting of a single layer are as shown.

Figure 36: Dual-Mode Coil Surface

The coil base and the location of the ferrites are shown in Figure 37. Ferrites are used to regularly direct the magnetic field lines created by the current passing through the coils. The magnetic field circulates them.

Figure 37: Dual-Mode Coil Base

4.3 Dual-Mode Coil Electrical Parameters

Since there are two different coils in the dual-mode structure, it is made according to two different inductance values, inner and outer. In addition to these, there is a third inductance value created by connecting these two coils in series. When two coils are connected in series, the inductance value of the resulting coil becomes equal to the sum of the inductance value of the two coils and the mutual inductance value. Mutual inductance is the inductance value that two coils create between each other in the same magnetic field.

The inner coil consists of 1 to 11 winding turns. The inductance value of the inner coil, which is wrapped as two layers to heat small-sized skins effectively, is set to 56 μH. The inductance measurement of the inner coil made with the LCR meter is as shown in Figure 38.

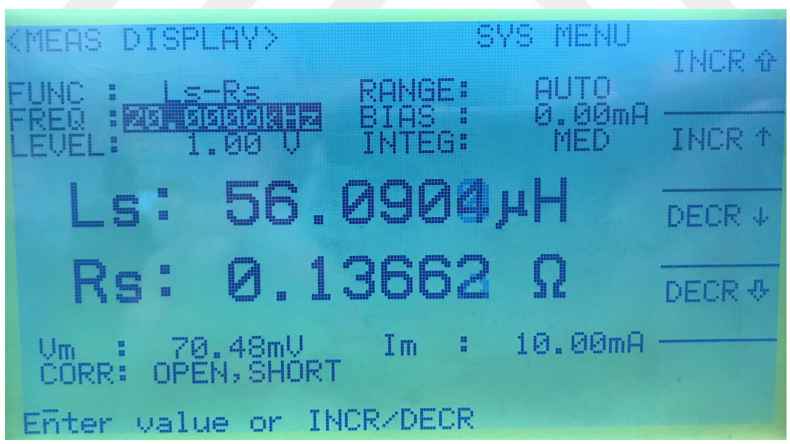

Figure 38: Inner Coil Inductance

The outer coil consists of windings from 12 to 19. For the adjustment of the inductance value, the outer coil is the windings other than the inner coil, which are wrapped as a single layer. The inductance value of the outer coil winding is set to 22 μH. The inductance measurement of the outer made with the LCR meter is as shown in Figure 39.

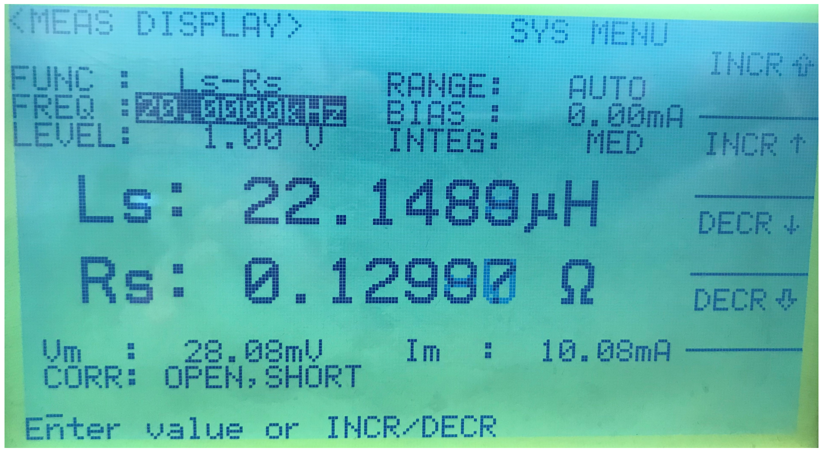

Figure 39: Outer Coil Inductance

When the inner and outer coil coils are connected in series, the inductance value of the coil formed is set to 107 μH. The inductance measurement of the inner series to outer coil made with the LCR meter is as shown in Figure 40.

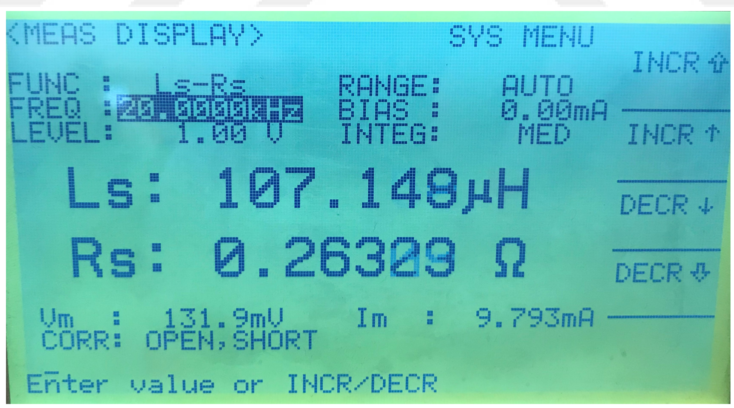

Figure 40: Inner+Outer Coil Inductance

CHAPTER V

RESULTS

5.1 Simulation Results

The dual-mode coil structure proposed in the project was applied to the quasi-resonant circuitry by making simulations before being tested experimentally. The advantages of the proposed structure have been verified with the simulation results. Simulations are made using the power electronic tools in MATLAB.

5.1.1 Quasi Resonant Circuit

First of all, the quasi-resonant topology to be used is established as shown in Figure 41. This circuit is supplied with AC voltage, this AC voltage is regulated as a DC voltage on its bulk capacity using the bridge rectifier. The DC voltage in bulk capacity is converted using the switching element IGBT. After switching, the output of the circuit is obtained from the coil in the resonant circuit. The coil's internal resistance was simulated with Req and its inductance Leq. The resonant capacity, which completes the resonant circuit in parallel with the coil, is used.

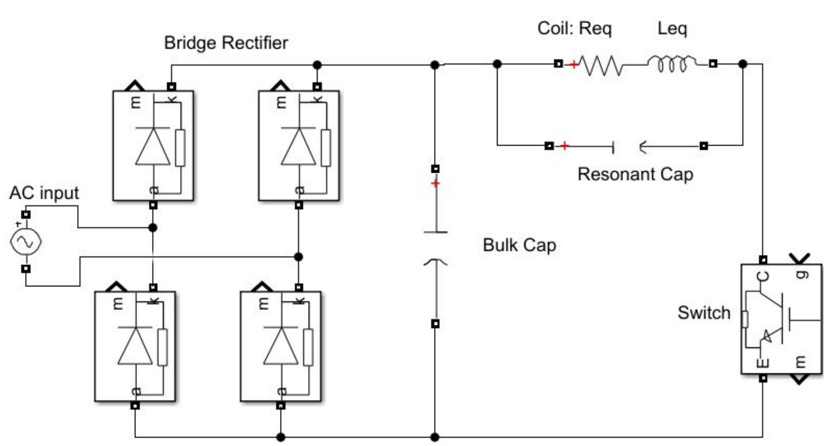

Figure 41: Quasi Resonant Simulation Circuit

The simulation of the AC to DC conversion with bridge rectifier is as shown in Figure 42. The blue waveform in the graph represents the AC voltage at the input and the black waveform represents the DC waveform at the output. AC input represents a single-phase 50 Hz frequency grid and is applied as 310 volts. Bridge diodes rectify the AC voltage consisting of negative and positive cycles and convert it to DC voltage. The bulk capacity used at the output regulates the DC voltage and maintains it in its capacity to provide continuous voltage to the load to be connected to the circuit.

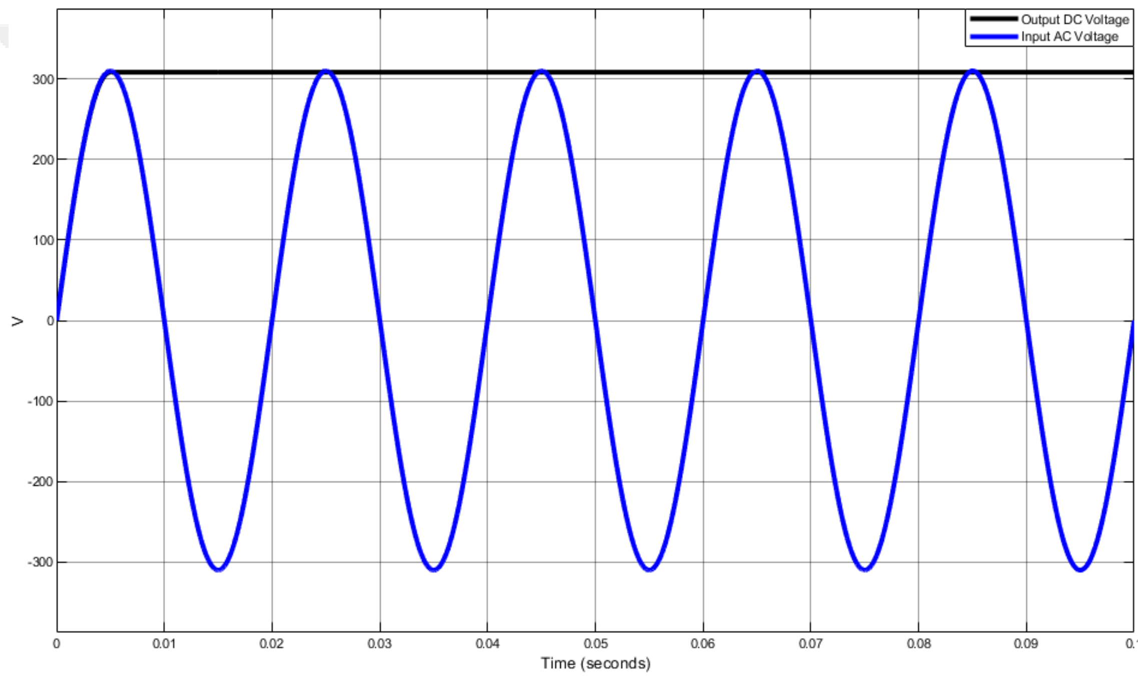

Figure 42: Bridge Rectifier Circuit Simulation

The regulated voltage in bulk capacity constitutes the DC input of the quasi-resonant inverter circuit. This DC voltage creates a changing current on the coil by switching it with the switching element. The simulation of the coil current resulting from a switching frequency of 20 kHz is as in Figure 43. The blue waveform represents the signal applied to the IGBT gate. According to this signal, IGBT is in on or off status. The change of coil current according to these on-off states is shown with the black waveform. The coil is charged in the on state and discharged in the off state.

The waveform of the output voltage on the coil is as in Figures 44 and 45 for different duty cycle values.

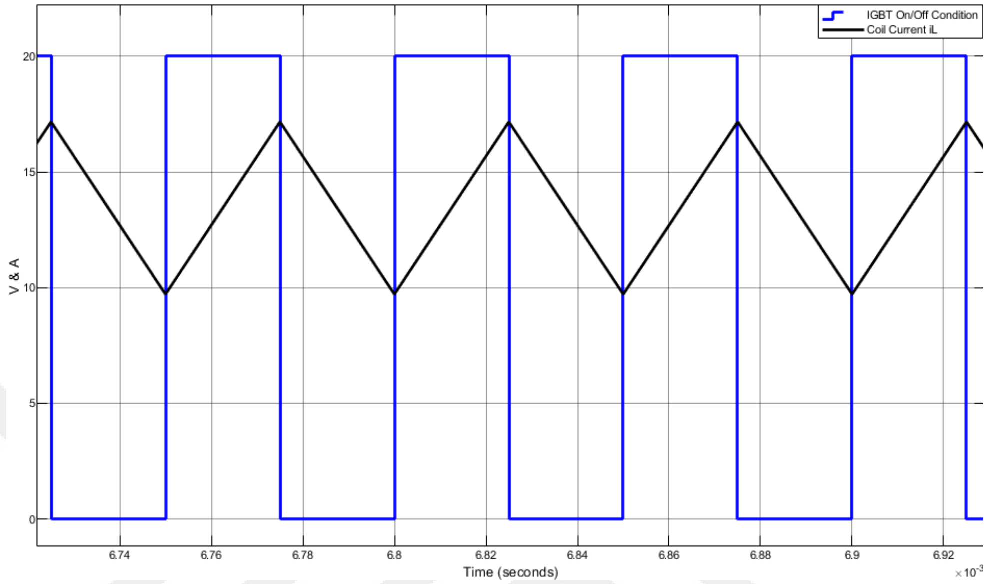

Figure 43: Coil Current Waveform

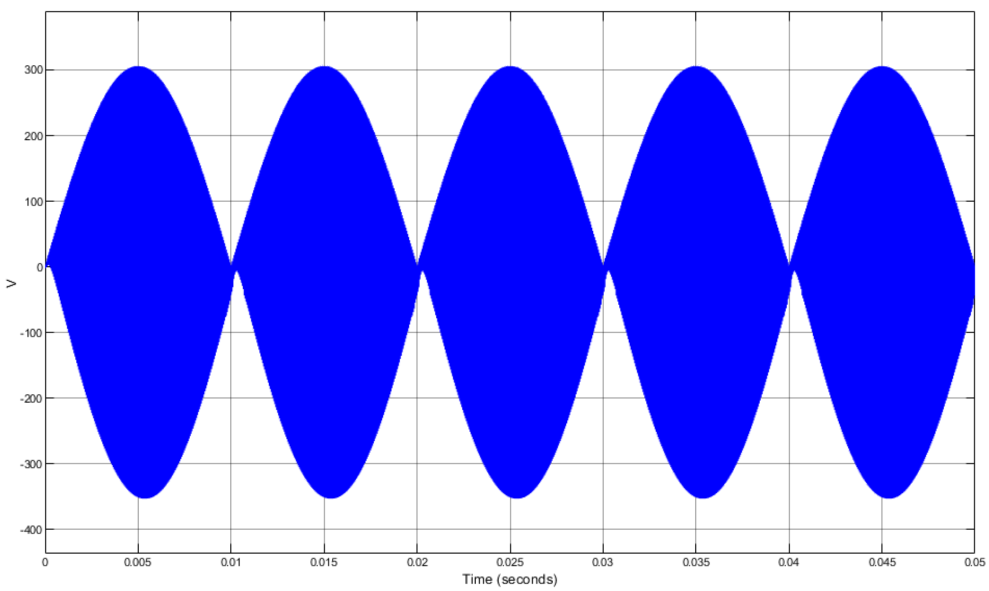

Figure 44: Inverter Output Voltage Waveform for 0.2 duty

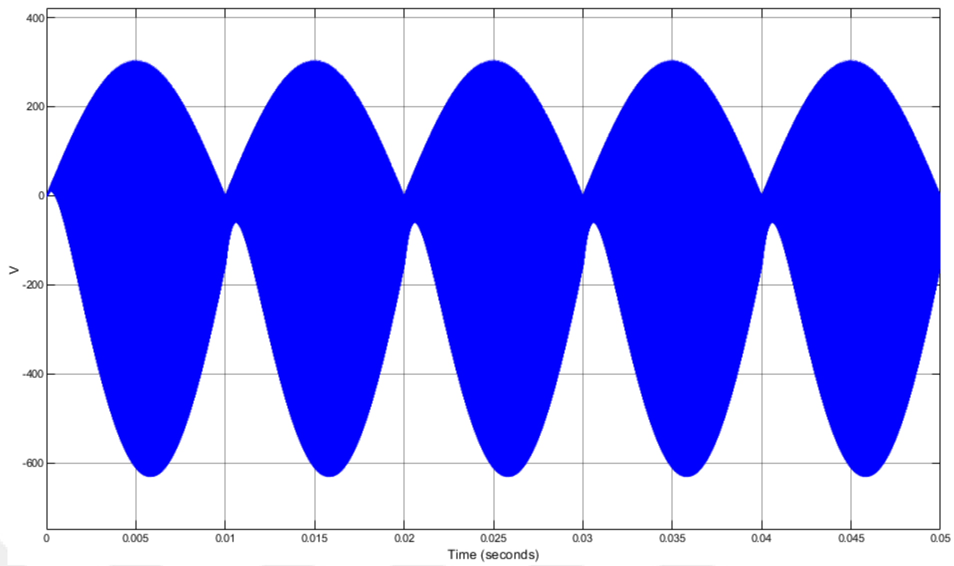

Figure 45: Inverter Output Voltage Waveform for 0.6 Duty

When the IGBT is in the off state, there is the voltage between the collector-emitter. Collector emitter voltage is critical for IGBT as it reaches high values. The waveform of this voltage is as in Figure 46. Collector emitter voltage value changes according to the output power. As the output power increases, the collector-emitter voltage also increases. This waveform zoomed in is in Figure 47.

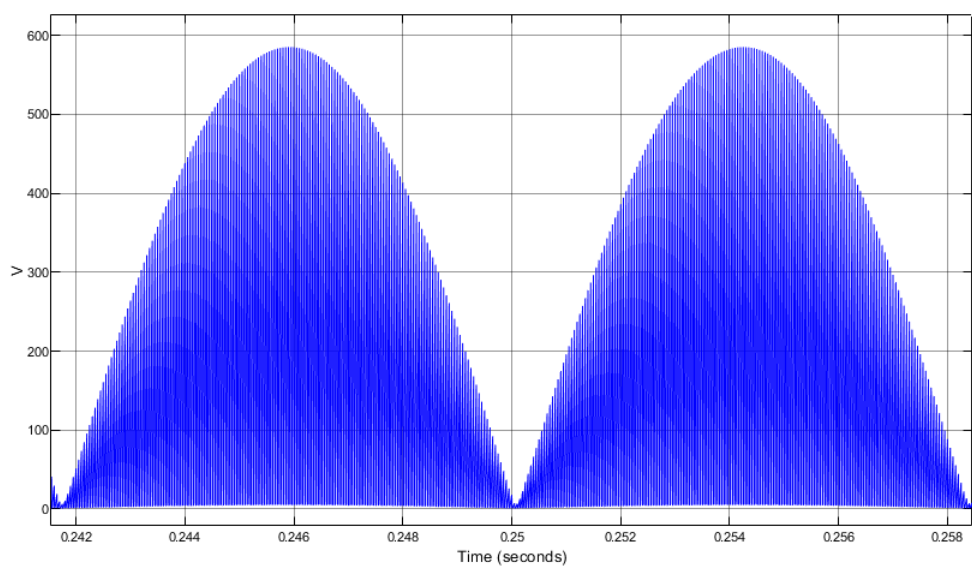

Figure 46: IGBT Collector Emitter Voltage Waveform

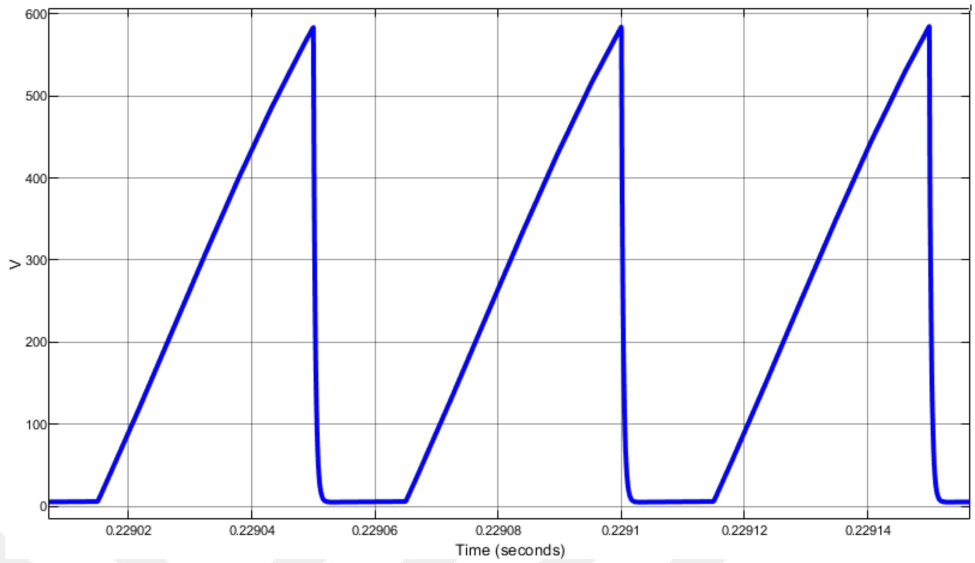

Figure 47: IGBT Switching Waveform

5.1.2 Ferromagnetic Material Detection

The material placed on the coil to be heated is detected and the circuit starts to work. Whether this material is ferromagnetic and the detection of the base size was simulated by setting up the circuit. Since the dual-mode coil structure is used in this project, it is important to detect the size of the base diameter of the material. Different operating modes are used depending on whether the base size of the material is small or large.

Pan detection is performed so that the base diameter of the pot placed on the coil can be detected and operated. The diameter is detected by damping the step pulse applied to the coil with the switching element over the ferromagnetic material. Detection is simulated by using the circuit given in Figure 48, and a step pulse is applied to IGBT. To simulate the ferromagnetic material size, the resistance value depending on the transformer's secondary has been changed. The open-circuit represents a non-material condition, the small resistor value represents a large size material, and the large resistor value represents a small size material.

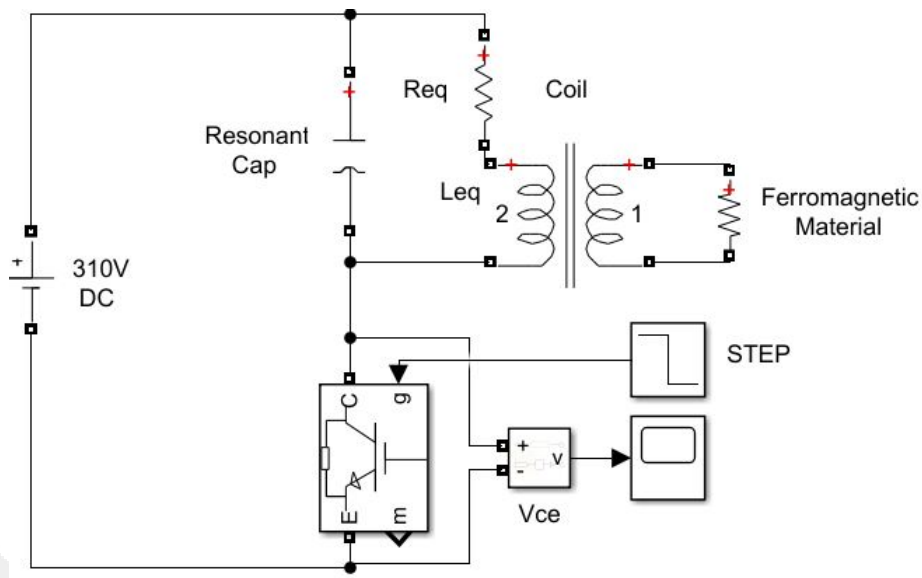

Figure 48: Ferromagnetic Material Detection Circuit

If the material is not placed on the coil or the material is not ferromagnetic, the damping after step pulse is as in Figure 49. Since there is no transmission from the coil to the material, oscillation must continue indefinitely, but damping occurs only through the internal resistance of the coil.

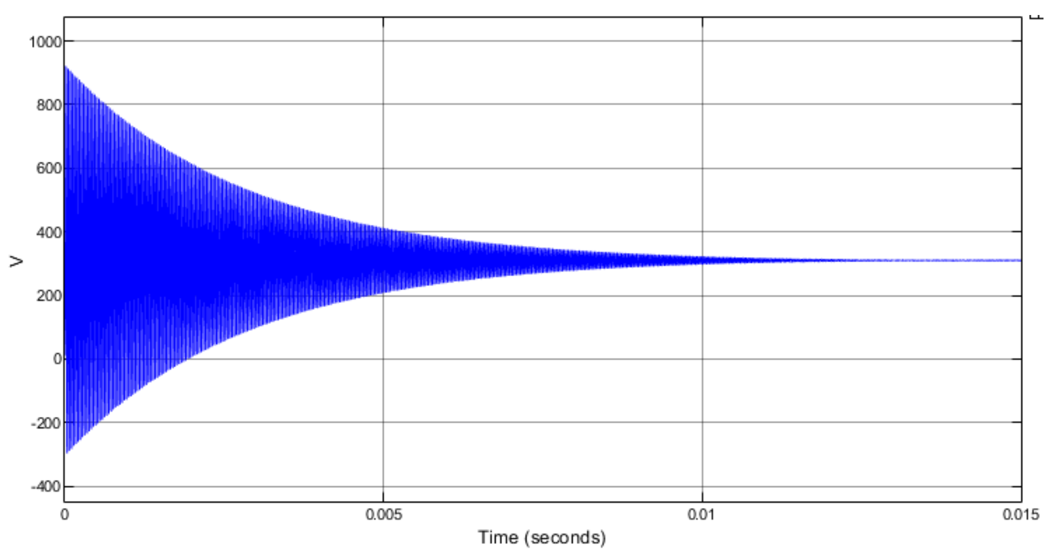

Figure 49: No Ferromagnetic Material Detection

The damping that occurs when large size material is placed on the coil to cover the coil diameter is as in Figure 50. Since the material covers the coil completely, the transmission between the coil material is effective after the step pulse and the damping is fast.

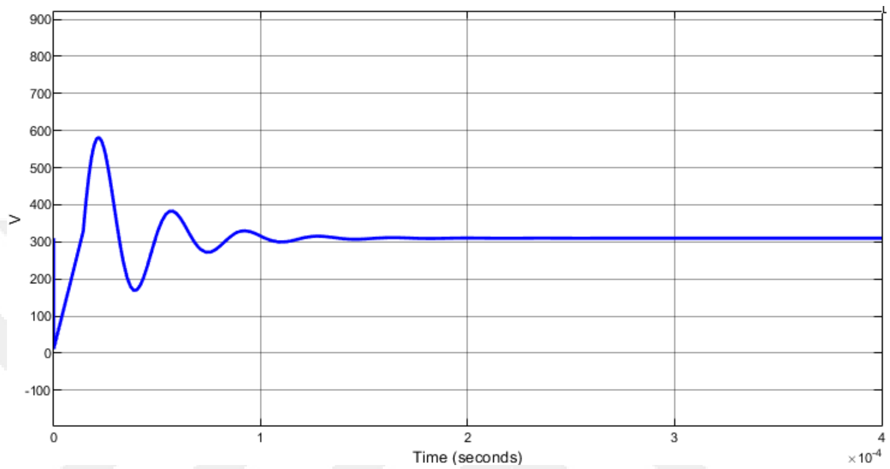

Figure 50: Large Size Ferromagnetic Material Detection

The damping that occurs when small size material is placed on the coil so as not to cover the coil diameter is as in Figure 51. Damping is slower than large size, as the transmission will be more difficult for regions of small material that do not cover the coil.

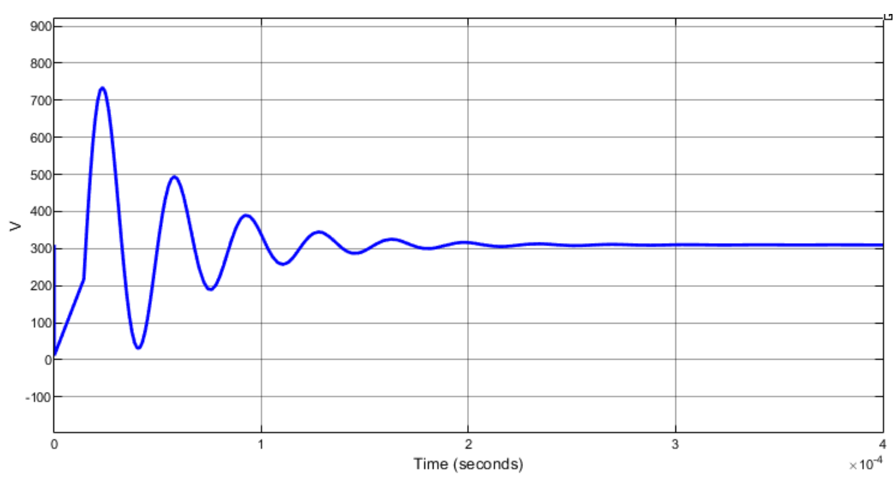

Figure 51: Small Size Ferromagnetic Material Detection

5.1.3 Switched Dual Mode Coil

The simulation circuit in which the dual-mode coil structure is applied to the quasi-resonant circuit is as shown in Figure 52. Instead of the inductor in the quasi-resonant circuit, a two primary single secondary transformer is used to simulate the dual-mode coil. One of the coils on the primary side represents the inner coil and the other represents the outer coil. When the inner coil works alone, a 130 mm diameter coil is formed. When the two coils work in series, the inner and outer coils work together to form a 210 mm diameter full coil. Since the inductance value will change when the operating conditions of the coils change, resonant capacities suitable for these values are used. The resonant frequency changes in proportion to the product of the inductance and capacitance values. For the resonant frequency to remain the same, the capacitance value is changed as the inductance changes so that the product of the inductance and capacitance value remains constant. While the inductance value is 100 μH in full coil mode, the value of the resonant capacity is 180 nF with two series 360 nF capacitors. In the inner coil mode, the inductance value is 50 μH and the resonant capacitance value is 360 nF. In both conditions, the resonant frequency is approximately 37 kHz according to the following equation.

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{7}$$

The coil starts to work in full coil mode by default. When the pan is placed on it, the coil mode is selected after the pan detection is made for the pan size and the work continues. While only the inner coil works for pots with a base diameter of up to 130 mm, inner and outer coils work together in full mode for pots larger than 130 mm.

To simulate the effect of the proposed dual-mode structure on the IGBT collector-emitter voltage, the pan with a base diameter of 130 mm was operated and compared with coils of 200 mm and 130 mm diameter. Since single coils are used in the traditional structure, pot bases of different diameters can only be operated with a 200

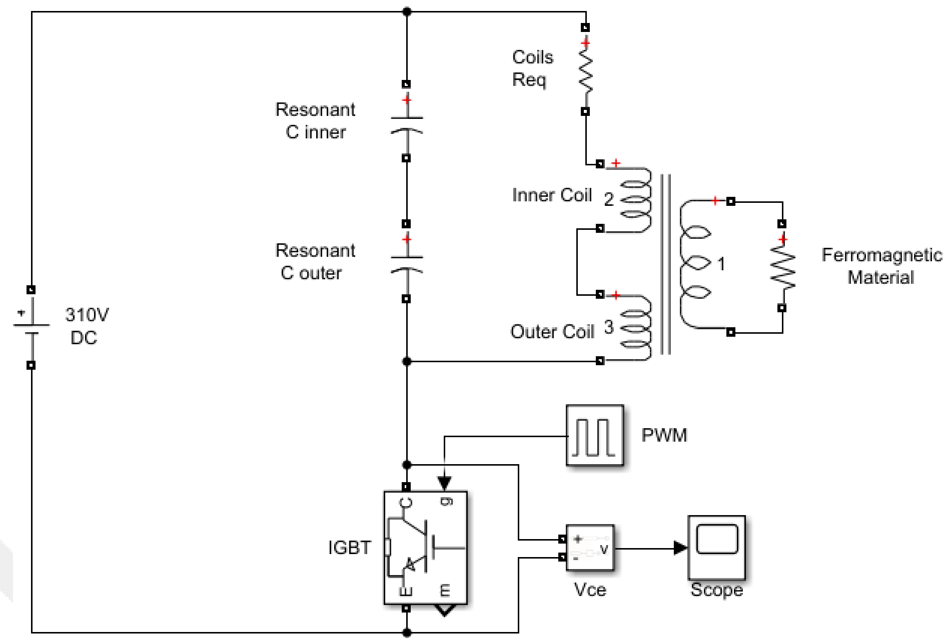

Figure 52: Full Coil Mode

mm coil. When the 130 mm pot is operated with a 200 mm coil, it simulates the traditional structure. When the same pot is operated with a 130 mm coil compatible with it, it simulates the dual-mode coil structure.

Firstly, the circuit operating in full coil mode was established as in Figure 52. In this structure, the inner and outer coils are serially connected and form a full coil. In full coil mode, the coil diameter is 200 mm. Since the two coils will be connected in series, the inductance value increases. Two resonant capacitors were used in series to keep the resonance frequency the same. When simulating the operation of a 130 mm diameter pot with this 200 mm coil, the IGBT collector-emitter voltage waveform is as in Figure 53. The voltage level reaches up to about 900 V.

Secondly, as aimed in the dual-mode coil structure, when a 130 mm diameter pot is detected, the circuit where only the 130 mm diameter inner coil will work was established as shown in Figure 54. In this circuit, the outer coil is disabled and only the inner coil is operated. Since the inductance value will decrease when only the

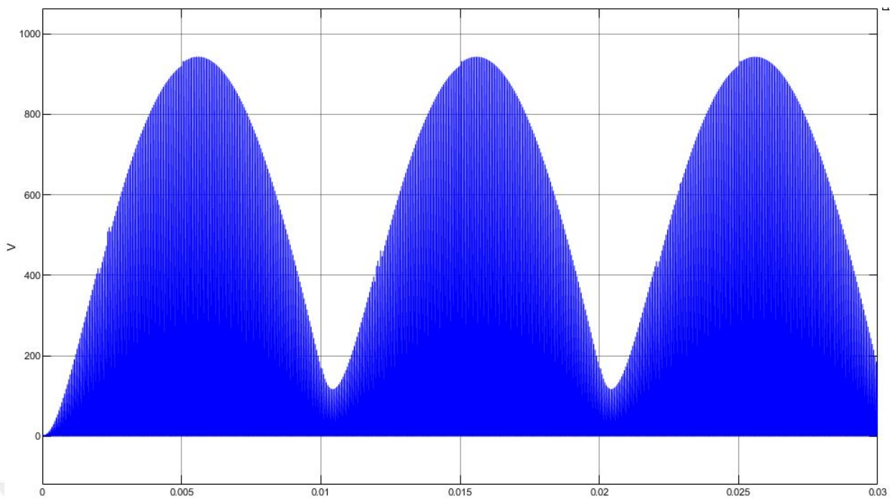

Figure 53: Full Coil Collector Emitter Voltage

inner coil is operating, one resonant capacitor is operated to keep the resonant value the same. When this coil mode is operated at the same power values as the previous mode, the IGBT collector-emitter voltage is as in Figure 54. When the waveform is examined, the voltage value in this coil mode reaches up to 750 V.

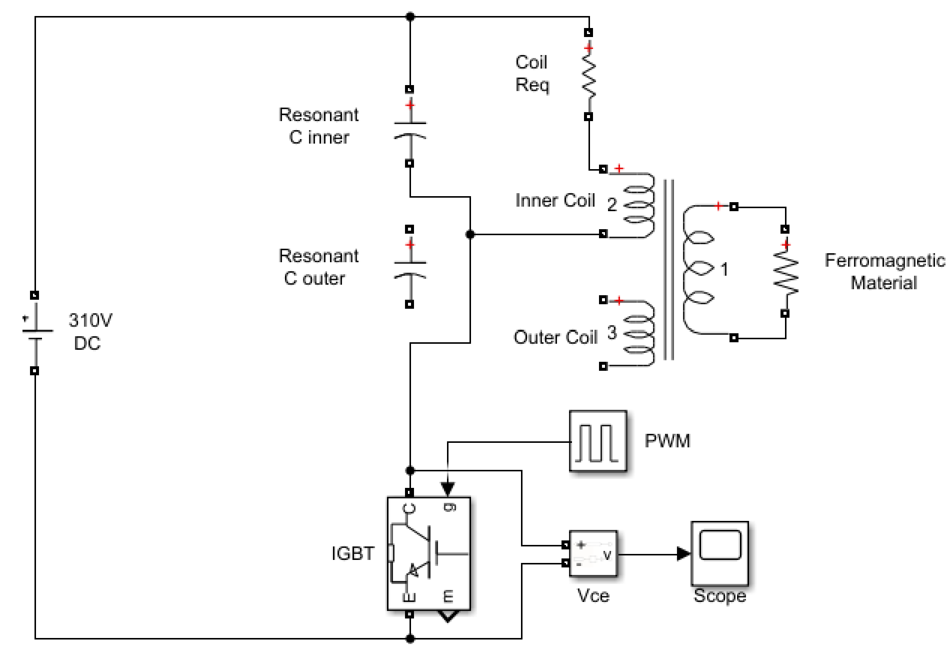

Figure 54: Inner Coil Mode

Comparing the simulation results for the operation in two different modes, operating a 130 mm diameter pot with a 130 mm diameter coil that will be compatible with it instead of a 200 mm diameter coil reduces the IGBT collector-emitter voltage. When the pot coils are fully covered, eddy currents that will heat the pot reach the pot more effectively. But when the coil has a larger diameter than the pot, eddy currents reach the pot more difficultly with the magnetic field formed in the coils outside the pot, and this causes the IGBT collector-emitter voltage to increase at the IGBT off time.

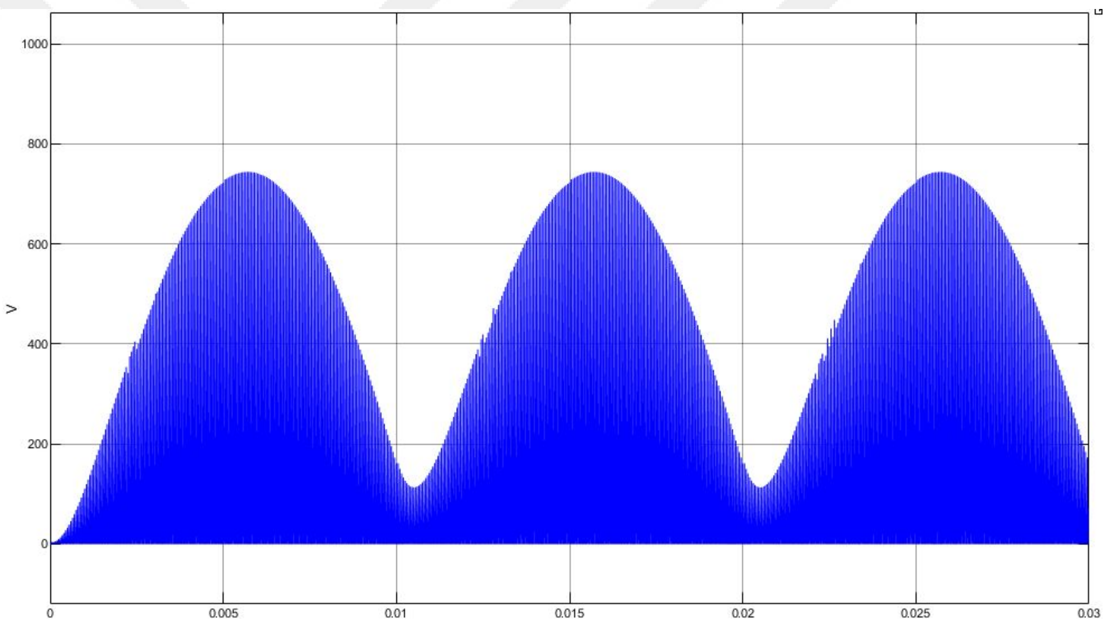

Figure 55: Inner Coil Collector Emitter Voltage

5.2 Experimental Results

Experimental measurements were made by applying the dual-coil circuit suggested in the induction cooker using a quasi-resonant circuit in VESTEL laboratories. The dual-coil structure was created using a plastic coil mold, and the inner and outer coils were created with copper wires. The inner coil diameter is 130 mm, and the outer coil diameter is 200 mm.

5.2.1 Quasi Resonant Circuit

Experimental measurements were made by running a single switch quasi-resonant circuit. This circuit topology is used in the existing single-coil structure. The dual-mode coil structure has been applied to this circuit without changing the topology. The input of the quasi-resonant circuit is powered by DC voltage. The AC voltage in the network is converted into DC voltage with the bridge rectifier and regulated in the bulk capacitor. The AC and DC voltage waveforms with this conversion are as shown in Figure 56. The yellow waveform represents the AC voltage in the grid, while the blue waveform shows the regulated DC voltage on the bulk capacitor. The quasi-resonant circuit is powered by DC voltage and by switching creates the changing current flowing through the coil. With the current flowing through the coil, a magnetic field and eddy currents are created.

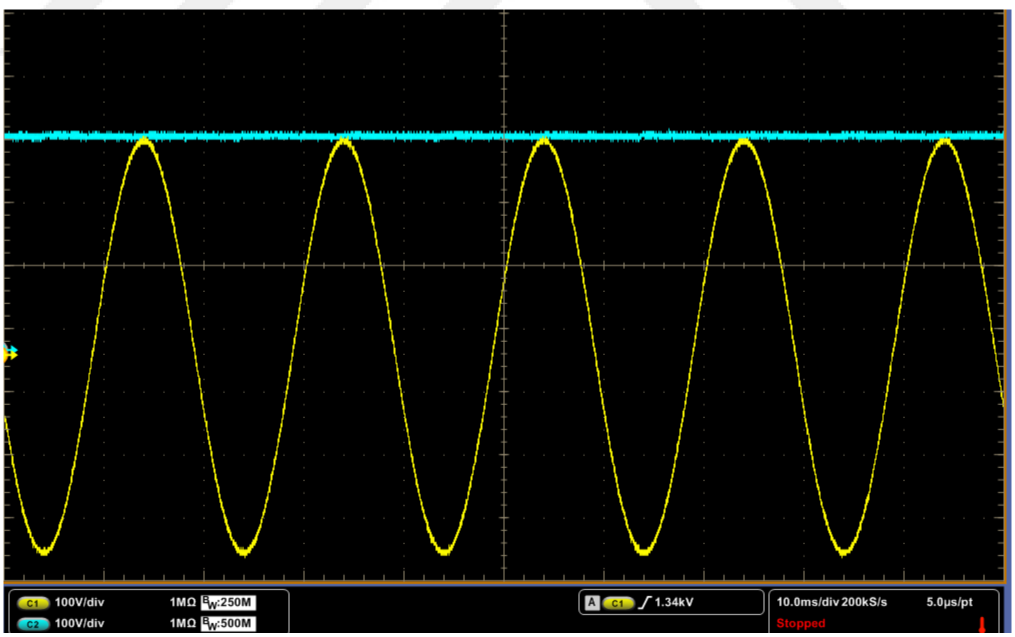

Figure 56: AC to DC Voltage Conversion

The quasi-resonant circuit is generally used with its cheap and simple circuit structure because it consists of a single switching element. But since only one switching element is used in the quasi-resonant circuit, the IGBT reaches high collector-emitter voltage values. In a quasi-resonant circuit that transfers power with continuous operation, the IGBT collector-emitter voltage is as shown in Figure 57. The waveform formed by zooming this voltage graph is as shown in Figure 58. The yellow waveform in Figure 58 shows the IGBT collector-emitter voltage, purple color shows the coil current.

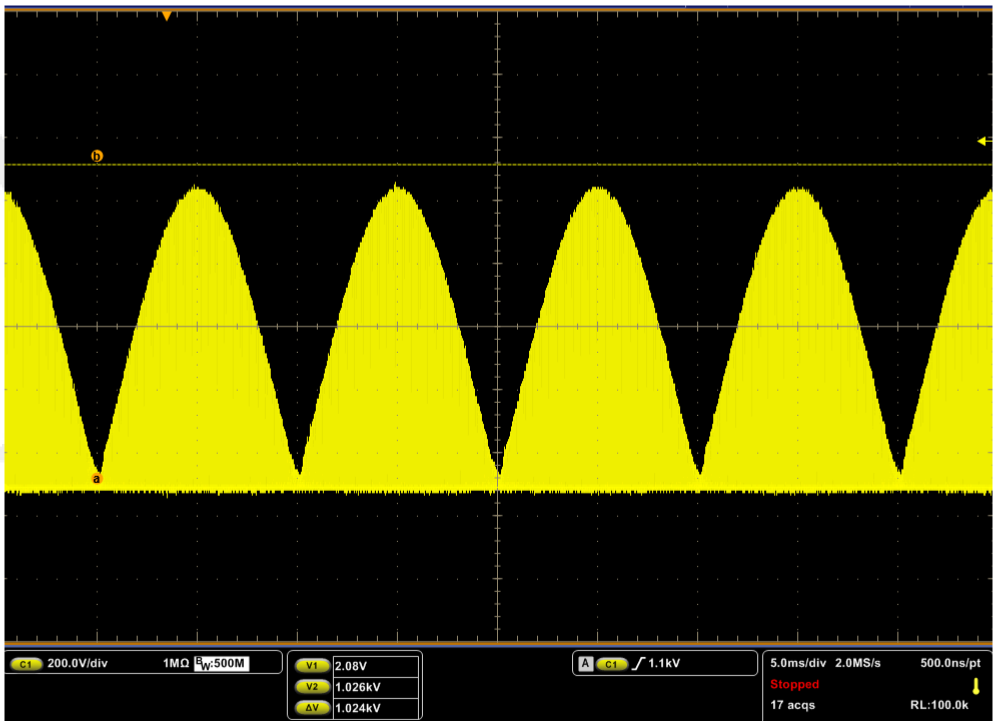

Figure 57: IGBT Collector Emitter Voltage

Reducing the IGBT collector-emitter voltage of the dual-mode coil structure has been observed by operating the small diameter pot with only the inner coil or the outer coil. Eddy current circulation is more effective, as pot coil compatibility is better achieved by using a dual coil structure instead of a traditional single-coil structure. More efficient use of the magnetic field created by the alternating current applied to the coil reduces the collector-emitter voltage of the IGBT while switching. In the experiment, when the pot with a base with a diameter of 130mm is operated only with

Figure 58: IGBT Collector-Emitter Voltage and Coil Current

the inner coil, the voltage value becomes 1024 V, while it is 1164 V when it is operated together with the inner and outer coil like the traditional single-coil structure. Powers transferred in both coil structures are equal and 1500 W. Measurements of the IGBT collector-emitter voltage waveforms are shown in Figures 59 and 60.

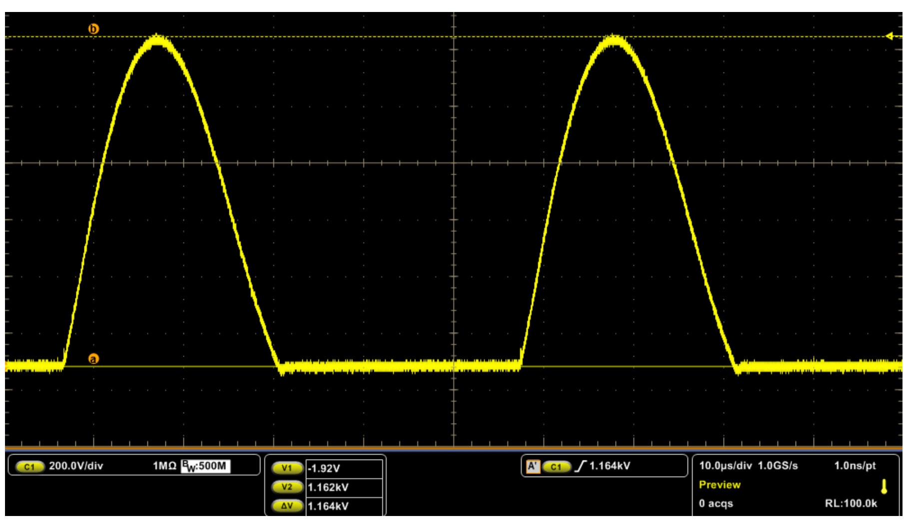

Figure 59: IGBT Collector-Emitter Voltage Single Coil

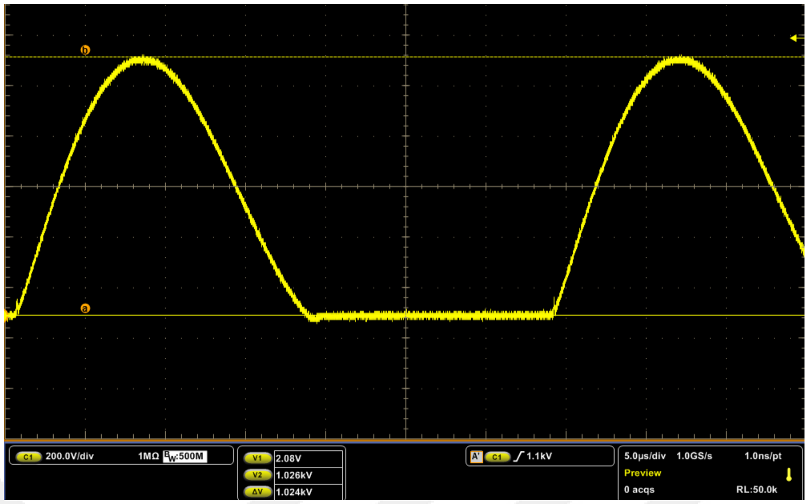

Figure 60: IGBT Collector-Emitter Voltage Dual-Mode Coil

5.2.2 Ferromagnetic Material Detection

The ferromagnetic material placed on the coil is detected by damping the step pulse. When the ferromagnetic material is not placed, the damping takes a long time because it will only occur through the internal resistance of the coil. Ideally, this oscillation continues indefinitely because there will be constant energy exchange between the capacitor and the inductor. With the experimental setup, if no ferromagnetic material is placed on the coil and the circuit is desired to run, this situation is detected and the process does not start. The oscillation that occurs when the ferromagnetic material is not placed is as shown in Figure 61. When the material is placed, it acts as a resistor in the circuit and damping occurs faster through the material.

In the dual-mode coil structure, the size of the pot base is detected and only the inner coil or the inner and outer coil are operated together. When the simulated pan detection method is examined experimentally, the difference between small and large bottom pans is distinguished. The voltage damping graph after pan detection was applied to two different pots in accordance with the coil diameters are shown in Figures 62 and 63.

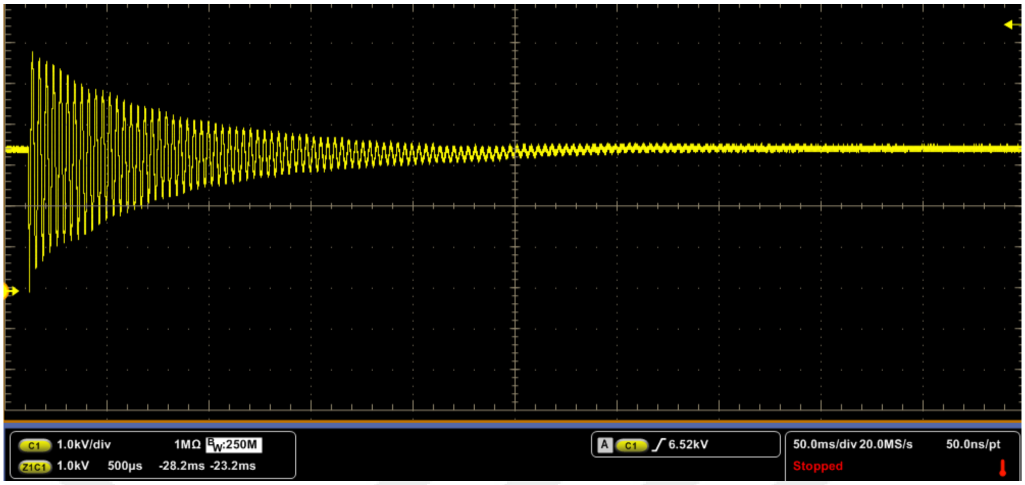

Figure 61: No Ferromagnetic Material Detection

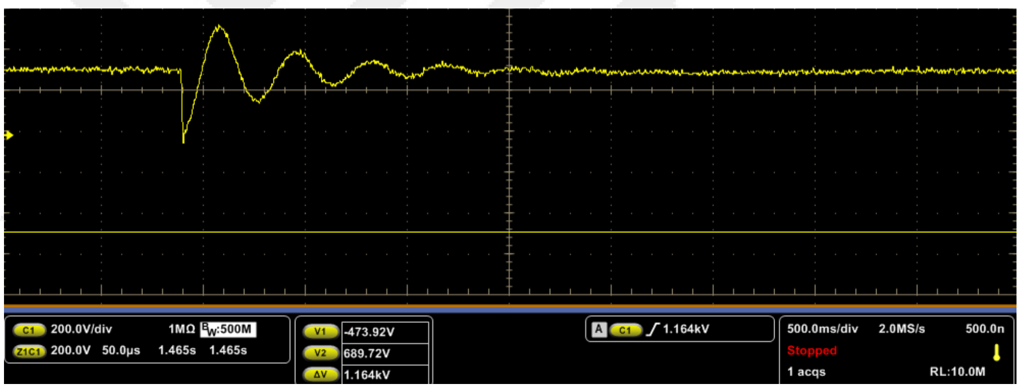

Figure 62: Large Material Detection

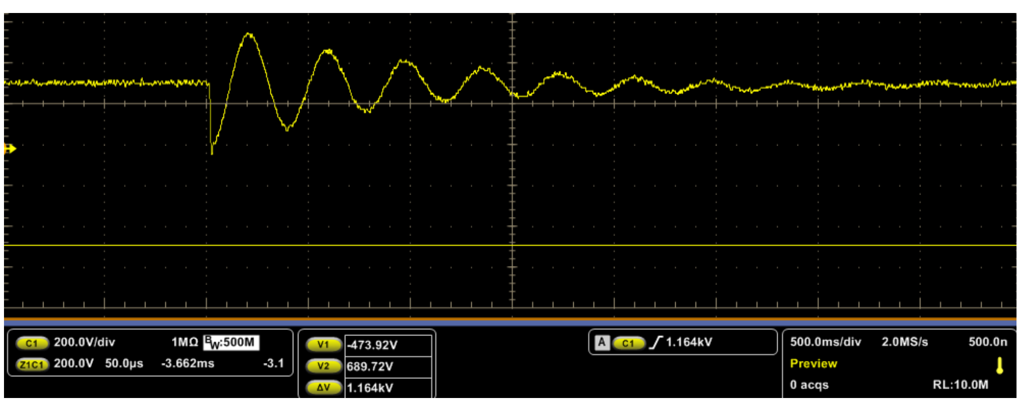

Figure 63: Small Material Detection

5.2.3 Coil Temperature Distribution

While the heating process was carried out with the dual coil structure, the temperature distribution performance in the coil was examined with the thermal camera. It is aimed to regulate the temperature distribution by operating the coil according to the diameter of the pan in the dual coil structure. If the inner coil, which can heat small pots, is used alone, large-diameter pots cause this coil to overheat. The proposed dual coil structure detects large diameter pots and balances the temperature distribution by operating the inner and outer coils together.

To examine the advantage of this structure, the pot with a diameter of 220 mm was filled with water and boiled on the coils for 30 minutes. While the temperature of the coil was measured as 197 degrees after the heating process, in which only the inner coil was operated as shown in Figure 64. When the large pot is operated with only the inner coil, the coils get very hot because they are concentrated only in the inner area.

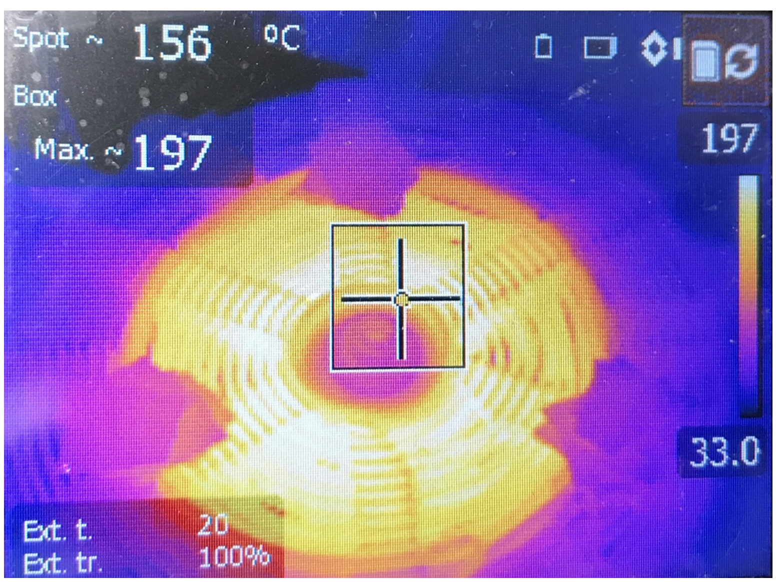

Figure 64: Only Inner Coil Temperature Distribution

The temperature was 164 degrees when the inner and outer coils worked together as aimed in the dual-mode coil structure as shown in Figure 65. When both coils work together, the temperature has been reduced by adapting to the large diameter pot. When the model in which the inner and outer coils work together for large pots, the temperature decreases by spreading to the inner and outer areas. Temperature measurements were taken from the coils after 30 minutes of heat transfer at the same power value.

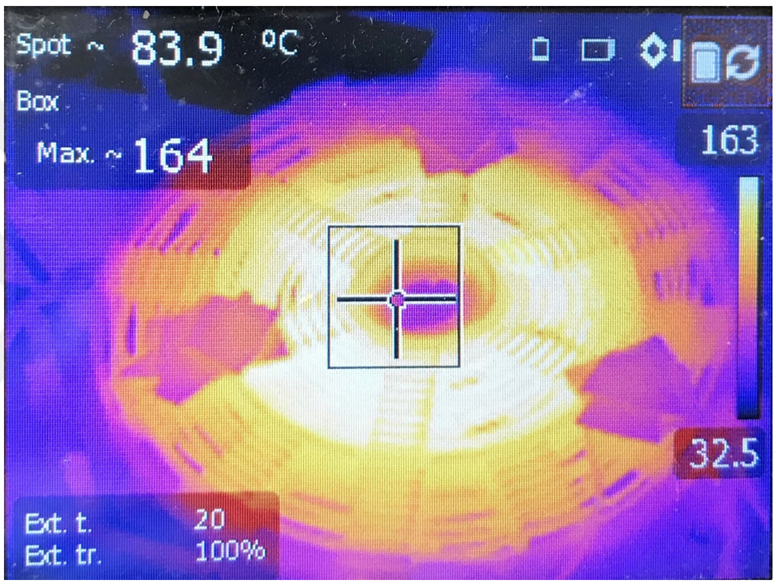

Figure 65: Dual-Mode Coil Temperature Distribution

5.2.4 Heat Transfer Efficiency

It has been experimentally observed that the proposed dual coil structure heats small diameter pots more efficiently. While testing, pots with a diameter of 130 mm are used to compare an inner coil structure with 130 mm diameter and the dual coil structure (inner+outer) which has a 200 mm diameter. In both operating modes, 500 milliliters of water is in the pot and 1,200 W input power is applied. The boiling time of both experiments is measured and the efficiency calculated. When the cooker is operated with the inner coil, the input power is transferred with a minimum loss, since the pot and the coil are in harmony. Under this condition, the water in the pot boiled at 100 degrees after 150 seconds. When the dual-coil structure is used, water boiled after 170 seconds. The temperature change occurring in the experiment conducted in the laboratory environment is 75 degrees. The energy gained by the water is calculated by the following equation.

$$Q = m.c.\Delta T \tag{8}$$

where Q is the energy in $kcal$, m is mass in kg, c is the specific heat capacity in $kcal$ per $kg * K$, T is the temperature in Kelvin.

To convert the $kcal$ to kJ, the conversion rate of $1cal = 4.184J$ is used. Then the output power of the coils can be calculated by dividing kJ by delta time. For the inner coil experiment, the elapsed time is 150 seconds, and it is 170 seconds for the dual-coil experiment.

The efficiency of the inner coil and the dual-mode coil is given in Table 1. In pots with a small base diameter, the dual-mode coil structure works adaptively and heats it faster than the single-coil structure under the same conditions. As the input power is used effectively with its dual-mode coil structure, it has been experimentally obtained that it increases efficiency.

Table 1: Efficiency of Dual-Mode Coil Structure

Coil	**Coil Diameter**	**Pan Diameter**	**Input Power**	**Output Power**	**Efficiency (%)**
Inner	130 mm	130 mm	1,200 W	1,046 W	87.2
Inner+Outer	200 mm	130 mm	1,200 W	922.9 W	76.9

The efficiency test was repeated with different base diameters in pots. It has been observed that the efficiency increases with the inner coil provided by the dual-mode coil structure for small diameter pots. Efficiency has not changed since the dual-mode coil structure with large diameter pots works the same as the single-coil structure by operating the inner and outer coils together. Test results for pots of different sizes are as in Table 2. The tests in Table-1 and Table-2 were made with

IKEA cookware, which is generally used and has low permeability. As a result of the test performed with a 160 mm diameter pot with high permeability to determine the difference between the pot types, the efficiency was %88.3 with the inner coil and %81.7 with the inner+outer coil. These values are %81.7 and %72.6 with standard low permeability cookware as seen in Table 2. As the permeability of the pot increases, heat conduction is better, increasing the efficiency.

Table 2: Efficiency of Dual-Mode Coil Structure For Different Size

Coil	Coil Diameter	Pan Diameter	Input Power	Output Power	Efficiency (%)
Inner	130 mm	100 mm	1,200 W	950.9 W	79.2
Inner+Outer	200 mm	100 mm	1,200 W	747.1 W	62.3
Inner	130 mm	160 mm	1,200 W	980.6 W	81.7
Inner+Outer	200 mm	160 mm	1,200 W	871.7 W	72.6
Inner	130 mm	200 mm	1,200 W	945.2 W	78.8
Inner+Outer	200 mm	200 mm	1,200 W	939.5 W	78.3
Inner	130 mm	250 mm	1,200 W	933.8 W	77.8
Inner+Outer	200 mm	250 mm	1,200 W	939.5 W	78.3

Figure 66: Different Size Pots

CHAPTER VI

COST ANALYSIS

A dual-mode coil structure has been applied to the induction cooker using the existing quasi-resonant circuit. The structure of the induction cooker consists of the mainboard, display, and coils. The mainboard contains the power supply and quasi-resonant circuit. When the dual-mode coil was applied to the existing structure, the switching elements on the coil and main-board were changed. The costs incurred by the changes are as in Table 3 for single coil and dual-mode coil structures. Differences in the switching element and dual-mode coil circuitry are included in the cost of the mainboard. When calculating the main-board costs for dual-mode coil, the cost-down due to the use of lower voltage IGBT and the cost-up of the dual-mode coil circuit is included.

Table 3: Cost Analysis For Single and Dual-Mode Coil

	Single Coil Cost ($)	**Dual-Mode Coil Cost ($)**
Main Board	25,5	25
Display	3,0	3,0
Coil	1,7	2,0
Total	30,2	30

Reducing the IGBT voltage with the dual-mode coil structure allows higher power to be supplied with the same IGBT or the use of switching elements with lower voltage values. A cheaper IGBT with a 150V lower voltage can be used. The lower voltage IGBT is 0.8 dollars less than the current IGBT. The 0.6 dollar price difference that occurs when switching from the existing coil structure to the dual-mode coil structure is covered by the difference between the IGBTs, reducing the total cost by 0.2 dollars. Since there is no standard Mosfet with these rated values, it cannot be used, but as a different option, SiC Mosfet structures can be used. Since SiC Mosfets are new technology, they can be four times as expensive as the currently used switching elements. Since very high frequencies are reached with these structures, power transfer can be made more efficient. SiC Mosfet can be considered as an alternative switching element, as there may be improvements in prices depending on the widespread use in the future. Coil types and switching elements that can be used with them are as in Table 4.

Table 4: Available Switching Elements Price

Switching Element	Rated Voltage (V)	Coil Type	Price ($)
IGBT NGTB30N135H	1350	Single	3,7
IGBT NGTG15N120F	1200	Dual-Mode	2,9
SiC Mosfet NTHL080N120	1200	Dual-Mode	11,6

CHAPTER VII

CONCLUSION

The efficient use of our energy resources is very important for our future. A lot of research is being done to develop renewable energy sources and increase their efficiency instead of using fossil fuels which are harmful to the environment and may be consumed in the future. Researches in the field of power electronics, which allow the energy generated to be used by converting it using different methods, are usually for increasing efficiency. In this project, for induction cookers, which are an example of the transition from fossil fuels to renewable energy sources, the heating process is made effective by using the energy more efficiently in the power converter used. The coil structure that heats the ferromagnetic pot in induction cookers by generating a magnetic field is critical to the efficiency of energy transfer. In this project, the coil structure was investigated and a dual-mode coil structure was proposed for the induction cooker using a quasi-resonant circuit with a single switch. The traditionally used single coil structure cannot adapt to both small-bottom and large-bottom pots. As the difference between the pot bottom diameter and the coil diameter increases, the heating efficiency decreases. Since the diameter of the single-coil structure is always the same, it cannot adapt to pots with different bottom diameters, and when the difference between the diameters becomes too large, the efficiency decreases. With the proposed dual-mode coil structure, the heating process was made more efficient by adapting to pots of different sizes. The dual-mode coil structure works in two different modes, the inner coil mode for small pots and the mode where the inner and outer coils work together, for large pots. While the single-coil structure only has a diameter of 200 mm, the dual-mode coil can work as two different coils with diameters of 130 mm and 200 mm. The experimental and simulation results show that the dual-mode coil structure is used in a quasi-resonant circuit with a switch and transmits power more efficiently and effectively than a single coil. By adapting to small pots, the collector-emitter voltage value of the IGBT used as a switching element was reduced, allowing a lower voltage switching element to be used in a quasi-resonant circuit. The cost of a dual-mode coil structure can be covered by using a lower voltage IGBT. According to the simulation results, using the dual-mode coil structure instead of the single-coil reduced the collector-emitter voltage value of the IGBT by 150 V. When this simulation was experimentally confirmed, a drop of 140 V was observed. The effect of a dual-mode coil on temperature distribution was compared by operating a large 220 mm diameter pot with only a 130 mm diameter inner coil or 200 mm diameter inner and outer coil together. According to the experimental result, the temperature of the coil is 197 degrees when working with small coils and large pots, and 164 degrees when working with large coils. In this structure, the mode in which the inner and outer coils are operated together with large pots creates a large coil structure and reduces the coil temperature. The compatibility of the dual-mode coil with large and small ferromagnetic pots made the heating process more efficient than the single-coil structure by effectively directing the magnetic field to the coil. For small pots, the experiment showed that operating the dual-mode coil with only the inner coil increased the efficiency by directing the magnetic field more effectively to the pot. The experiment was conducted by operating the small diameter pot with only the inner coil or with the inner and outer coils together at the same input power under the same conditions. According to the working principle of the dual-mode coil, the efficiency is %87.2 when the small-diameter pot is adaptively operated with the inner coil only. The efficiency reduces to %76.9 when the inner and outer coils work together. Both small and large materials are heated more efficiently by the adaptation of the dual-mode coil while increasing comfort.

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