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Design and Analysis of Zero Current Switching Resonant Inverter based High Frequency Induction Heating

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***Abstract*—This paper deals with design and analysis of Zero Current Switching (ZCS) resonant inverter based high frequency induction heating. The basic circuits consist of a half bridge inverter and an induction heating coil. This equipment works on the principle of eddy current induction. The high frequency current is given to the coil which acts as a primary winding of the transformer. The work piece acts like a short circuited secondary of the transformer. The heating effect is obtained by the eddy current induced in the work piece. Since eddy current is proportional to square of the frequency, heating effect will be high at high frequency. The heat can be varied by varying the frequency. When high frequency in the range of several hundred kHz is used, the switching losses will be more. To reduce the switching losses ZCS soft switching is employed in this work. Simulations are performed in MATLAB to understand the working of ZCS based high frequency induction heating. Also, hardware results are obtained using ZCS IC UC3865N.**

Keywords— Induction Heating; Zero Current Swithching;

I. INTRODUCTION

In recent years there has been a great increase in the use of high-frequency currents for heat treatment of metals in such processes as surface hardening, brazing, and soldering. Much attention has therefore been focused upon the development of inverters capable of supplying high-power to induction heating loads at frequencies ranging from few Hz to several hundred kHz. However increasing switching frequency to high value in the above range will result in more switching losses and EMI problem .Recently for solving this problem, a number of soft switching Pulse Width Modulation (PWM) techniques were proposed, aimed at combining desirable features of both conventional PWM and resonant techniques.[1]-[4]. There are many configurations for inverter circuits each one having their own particular merits. Resonant inverter is one of them having more advantages compared to any other configurations such as reduced switching losses, high frequency of operation, less weight and higher efficiency. Increases in operating frequency have been the result of improved semiconductor device technology and elimination of switching losses by means of soft-switching techniques. Various devices, such as power MOSFET's, SI thyristors, and static induction transistors (SIT'S), applicable to high frequency and/or high-power induction heating systems have been reported in the literature [5]-[8].

Induction heating is a method of providing fast, consistent heat for various applications. All induction heating applied systems are developed using electromagnetic induction. Electromagnetic induction refers to the phenomenon by which electric current is generated in a closed circuit by the fluctuation of current in another circuit placed next to it. The principle of induction heating is based on Faraday's law. When AC current flows through a circuit, it affects the magnetic movement of a secondary circuit located near it. The current in the neighboring secondary circuit is generated due to the fluctuation of current inside the primary circuit. The efficiency of the induction heating system is reduced greatly by the heat loss which occurs during the induction heating process. This heat loss can be minimized by laminating the magnetic frames placed inside the motor or transformer. Electric heating system requires heat energy which can be obtained from the heat loss occurring in the process of electromagnetic induction. Many industries have benefited from this new breakthrough by implementing induction heating for furnacing, quenching and welding[9]. In these applications, induction heating has made it easier to set the parameters without the need of external power source. Induction heating provides better quality, safe and less energy consuming such as electronic rice cookers and pans.

II. SYSTEM CONFIGURATION

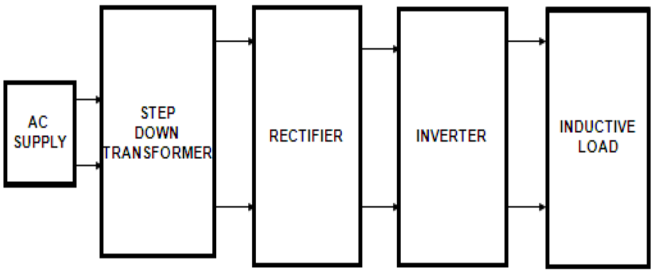

Figure 1.Block diagram of the overall system

Figure 1 shows the block diagram of the overall system. It consists of an AC supply, step down transformer, rectifier, inverter and an inductive load. The AC supply is given to step down transformer .The step-down transformer steps down the voltage and its output is given to rectifier. The function of rectifier is to change DC voltage into AC voltage. The output of rectifier is given to inverter which converts DC into AC. The inverter we used here is half bridge inverter with inductive load.

A. *Inverter circuit design*

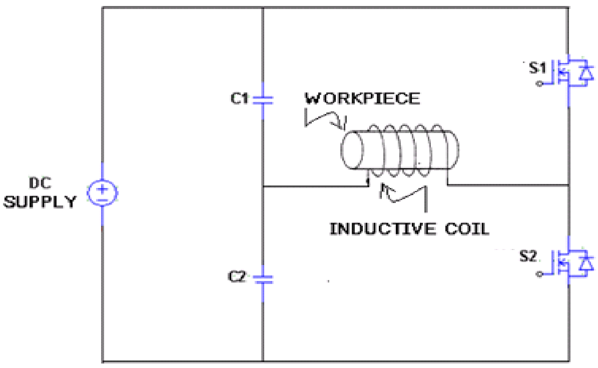

Figure 2 Half bridge resonant inverter circuit diagram

Figure 2 shows the circuit diagram of half bridge resonant inverter. The half bridge resonant inverter consists of two switches S_1 S_2, capacitors C_1 C_2, DC supply, an inductive coil and work piece placed within the coil which is to be heated. The load inductor itself acts as one of the components of the series resonant circuit. The capacitors serve two purposes: (i) it is used in resonant circuit and (ii) it is used to divide the supply into two halves, thus eliminating the need of two inverters for half bridge configuration. When there is no signal at S_1 and S_2, capacitors C_1 and C_2 are charged to a voltage of $V_{dc}/2$ each. When switch S_1 is turned on by applying gate pulse to it, capacitor C_1 discharges through the switch S_1 and the inductor and the capacitor C_2 charges and current flows through the coil in one direction. Now when switch S_2 is turned on by applying gate pulse to it, capacitor C_2 discharges through inductor and C_1 charges through it and now current flows through the coil in opposite direction. Hence an alternating current flows through the coil. Load inductor and capacitor forms a series resonant circuit. Hence the output frequency is high. When this high frequency alternating current is applied to the inductive coil, a magnetic field will be produced around the coil. If a work piece (conductor) which is to be heated is placed in this magnetic field, eddy current will be induced in it producing high localized heat without direct contact between coil and work piece.

B. *System Design Specifications*

- Power rating : 1kw
- Voltage : 200V DC
- Maximum load current : 5A
- Switching Frequency : 120 kHz
- Value of inductance of the coil: 92μH
- Resistance of the coil : 0.1
- Value of capacitance used : 2nF

C. *Design consideration of coil*

The inductive coil shown in figure 2 acts as a primary side of transformer and the work piece acts as a secondary side of the transformer. Hence we use many characteristics of transformers for coil design.

In transformers, the efficiency of coupling between the primary and secondary windings is inversely proportional to the square of the distance between them. In addition, the current in the primary of the transformer multiplied by the number of primary turns is equal to the current in the secondary of the transformer multiplied by the number of secondary turns. When we design coil for induction heating several factors have to be considered as given below.

1. Maximum energy transfer in coil takes place when it is coupled to the part as closely as possible. It is desirable that the largest possible number of magnetic flux lines intersect the work piece at the area to be heated. The current generated in the part is more if we have more concentrated flux.

2. The solenoid coil has greatest number of flux lines towards the center of the coil. The flux lines are concentrated inside the coil providing the maximum heating rate there.

3. Since more flux is concentrated close to the coil turns and decreases farther from them, the geometric center of the coil is a weak flux path. Hence the area closer to the coil turns could intersect a greater number of flux lines and therefore be heated at a higher rate, whereas the area of the part with less coupling would be heated at a lower rate. This effect is more pronounced in high frequency induction heating.

4. The magnetic center of the inductor is not necessarily the geometric center, The point where the leads and coil join, the magnetic field is weaker. This effect is more apparent in single-turn coils. Due to the impracticability of always centering the part in the work coil, the part should be offset slightly towards this area. In order to provide uniform exposure, the path should be rotated, if possible.

5. The coil will not have any inductance if the opposite sides of the inductor are too close to each other. Hence care must be taken to prevent cancellation of the magnetic field.

By considering the above mentioned points we can make coils to readily transfer more power to a load.

III. SIMULATION RESULTS

Figure 3 shows the simulated circuit diagram with current sensing resistor for practical implementation purpose. In this circuit, voltage across the current sensing resistor is measured with voltage measurement block. The output of pulse generator is given to the R input of the upper RS flip-flop and the output of the same pulse generator with 50% time delay is given to the R input of the lower RS flip-flop.

The voltage across current sensing resistor and the R input of the two flip-flops are given as two inputs for the two NAND gates and the output of which is given as S input of two flip-flops. The outputs Q of upper and lower RS flip-flops are given as gate pulses to the upper and lower switches respectively.

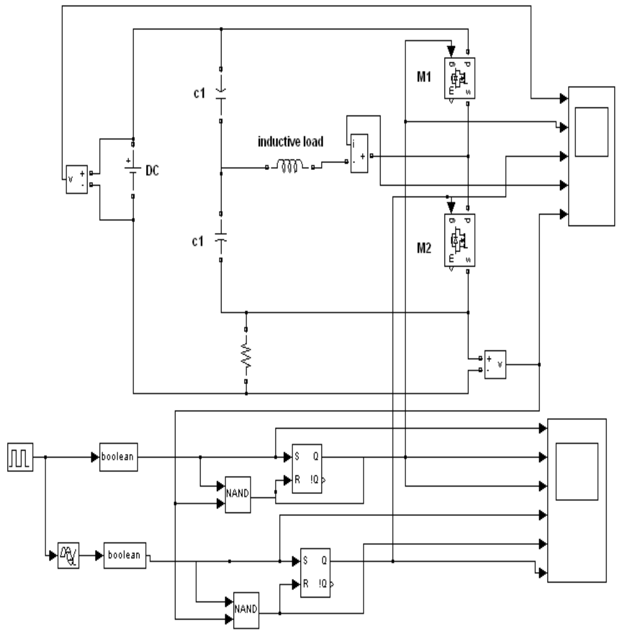

Figure 3.Simulation diagram of the system

Figure 4 shows the input and output pulses of the RS flip-flop. The output Q of two RS flip-flops is given as gate pulses to two MOSFET switches.

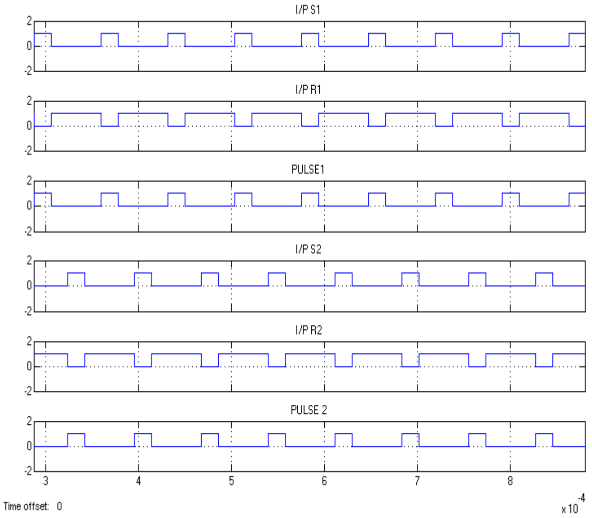

Figure 4.Input and output pulses of R-S flip-flop

Figure 5 shows the input voltage, gate pulses, output current and voltage across current sensing resistor and load voltage of the simulated circuit diagram.

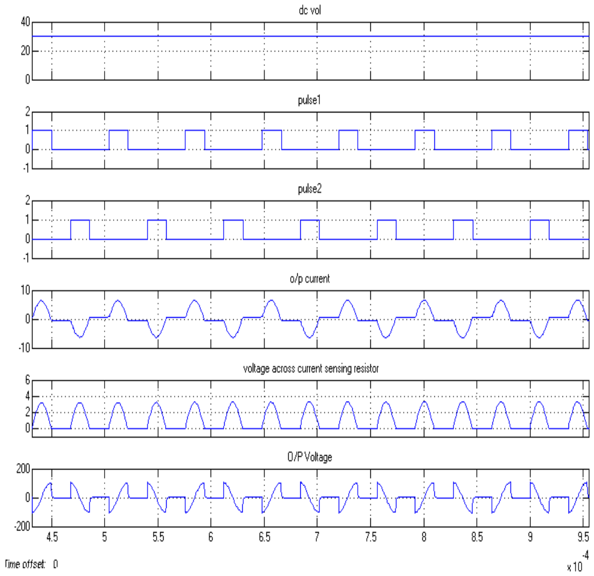

Figure 5 Input and output waveforms

IV. HARDWARE IMPLEMENTATION

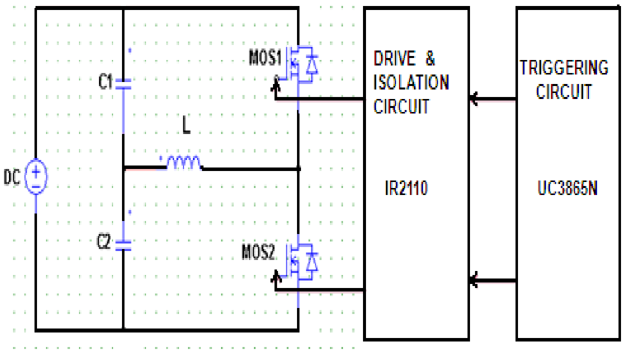

Figure 6.Hardware diagram

Figure 6 shows the hardware setup of induction heating unit which consists of half bridge resonant inverter, an inductive load, triggering circuit and isolation circuit. Whenever current is passed through a conductor, eddy current will be produced on the metal and is proportional to the frequency of current through it. This principle is used in induction heating. Here a high frequency current is applied to the coil which acts as a primary of the transformer. If a conductor is placed near it, current will be induced in the conductor by electromagnetic induction which forms a single turn short circuited secondary. This induces eddy current in the conductor and produces heat which heats the things placed in the conductor. At high frequency, heat produced will be high & switching losses will be more. If hard switching is employed the switching losses will be high at high frequencies. This will reduce the efficiency. To avoid this soft switching is employed. There are two types of switching namely zero voltage switching (ZVS) and zero current switching (ZCS). In ZVS, the switching is done at zero voltage. When switch is turned on, the voltage across it should be zero and current through the switch should rise to maximum value. But this will not occur in normal hard switching. During switching there occurs some peak voltage and current in the switch. The product of this gives the power loss during switching. The zero voltage switching condition is achieved in resonant circuit. In this circuit, load inductor and capacitor forms the series resonant circuit. This circuit will have a resonant frequency. The triggering circuit is designed to produce pulses at resonant frequency. If the switching is done at zero current, then the switching is called zero current switching. In this paper zero current switching is employed to reduce switching losses.

Triggering circuit is used to produce gate pulses which are used for driving the MOSFETs. Since two MOSFETs are used for the above half bridge inverter configuration we need to generate two pulses here. Here ZCS IC – UC3865N is used to produce gate pulses for the two MOSFETs.The triggering circuit and power circuit should be isolated properly. If there is no isolation then problems occurring in power circuit will affect the triggering circuit. Here IC-IR2110 is employed for isolating triggering circuit and power circuit.

A. High frequency ZCS triggering circuit

The circuit diagram of triggering circuit is shown in the figure 7. Two triggering pulses are required for triggering two MOSFETs used in half bridge inverter. To obtain this IC UC3865N is used. It is a pulse generator with 16 pin DIP configuration. It produces two output pulses with 180^0 phase shift. Since the two MOSFETS in the in the inverter should not be triggered at the same instant this phase shift is necessary. The out pulses from pins 11 and 14 are given to the pins 10 and 12 of IC IR2110 respectively. The value of resistance R_{min}, Range and capacitor value C_{vco}, determine the maximum and minimum oscillator frequency.The maximum & minimum oscillator frequency is 500 KHz & 50 KHz respectively.

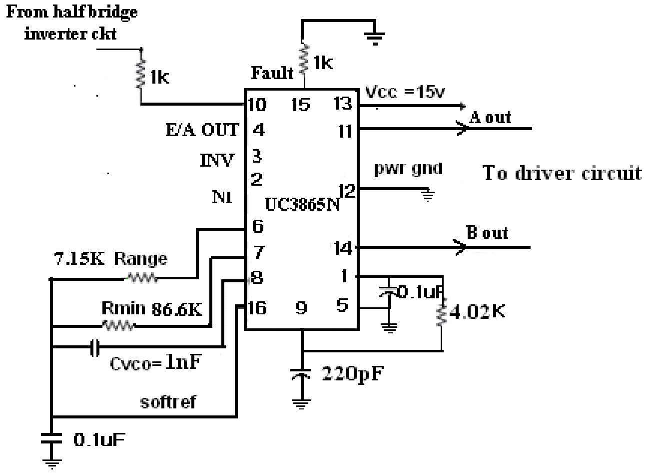

Figure 7 Triggering Circuit

The value of resistors Range , R_{min} & capacitor C_{vco} determines the maximum and minimum oscillator frequency . Minimum oscillator frequency is set by R_{min} and C_{vco}. The minimum frequency is approximately given in (1).

$$f_{min}=4.3/\ (R_{min}\times C_{vco}) \qquad (1)$$

Maximum oscillator frequency is set by R_{min}, Range & C_{vco}.The maximum frequency is approximately given in (2).

$$f_{max}=3.3/\ (R_{min} \| \mathrm{Range})\times Cvco \qquad (2)$$

Let us assume fmax=500 kHz and fmin=50 kHz,
To have the above oscillator frequency, Range=7.15kΩ, R_{min}=86.6kΩ, C_{vco}=1nF.

B. Gate drive circuit using IR2110

Figure 8 shows the drive and isolation circuit using IC IR2110. The IR2110 is a high voltage, high speed MOS-gated power device driver with independent high side and low side referenced channels. The output drivers of this IC use low impedance totem-pole arrangement designed for low cross conduction current spike. Propagation delays for the two channels are matched which simplify the use in high frequency applications. The output pulses from pins 11 and 14 of UC3865N are applied to the pins 10 and 12 of IR2110 respectively. The pins 1 and 2 constitute the channel for lower MOSFET and the pins 5 and 7 constitute the floating channel for upper MOSFET.

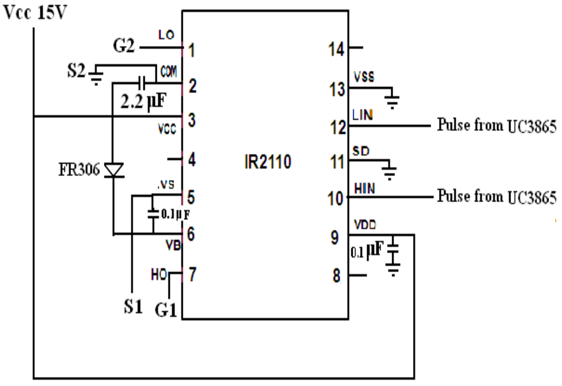

Figure 8.Drive and isolation circuit

C Hardware outputs

Figure 9 shows the output pulses from triggering circuit using IC UC3865.The two pulses produced are 180^0 out of phase with each other.

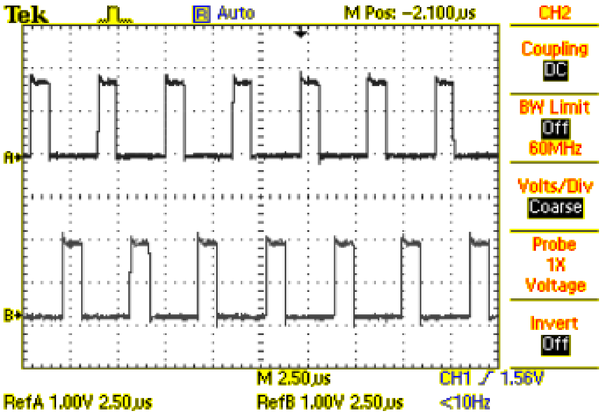

Figure 9 Output pulses from UC 3865

Figure 10 shows the output pulses from drive and isolation circuit using IC IR2110.

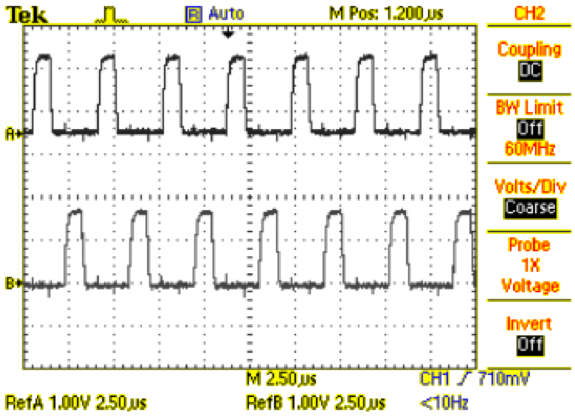

Figure 10. Output pulse from IR2110

Figure 11 shows the voltage across the current sensing resistor used in half bridge inverter configuration. This voltage is given to 10th pin of UC3865 to achieve zero current switching.

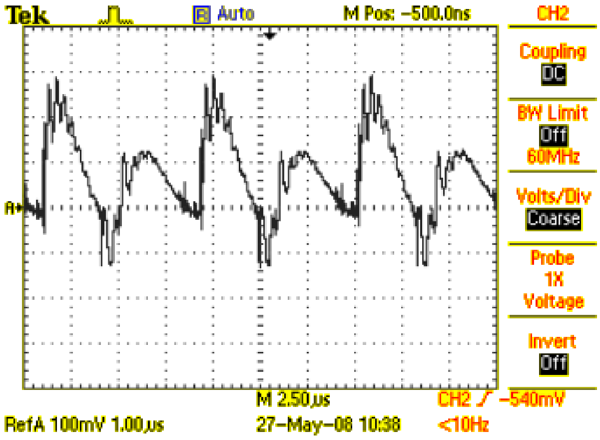

Figure 11.Voltage across current sensing resistor

The output of resonant inverter is shown in the figure 12.The resonant output frequency is 280kHz.

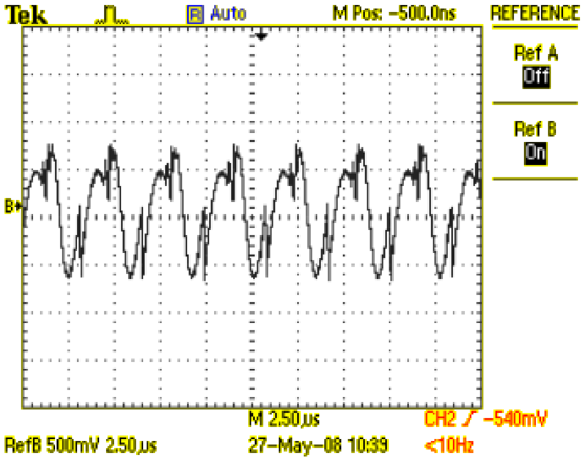

Figure 12. Inverter output

V .CONCLUSION

In this work high frequency induction heating unit has been designed using half bridge inverter configuration. Induction heating is applicable for kitchen and various industrial applications. It is advantageous over commonly used resistance heaters because of its better efficiency, safety and durability. With high frequency induction heating the cost of heating is reduced to a greater extent. By using induction heating, production quality can be improved in industries. Here zero current switching resonant controller is designed using UC3865. By using zero current switching, switching losses are reduced to a greater extent compared to hard switching.

REFERENCES

[1] G. Hua, C.S. Leu, Y. Jiang, and F.C. Lee, "Novel zero-current transition PWM converter," IEEE Transactions on Power Electronics., vol. 9, no. 6, pp. 601–606, 1994.

[2] Lin, R.L., and Lee, F.C.: 'Novel zero-current-switching-zero-voltage switching converters'. IEEE PESC Conf. Rec., Baveno, Italy, 1996,pp. 438–442

[3] A. Elasser and D.A. Torrey, "Soft switching active snubbers for dc/dc converters," IEEE Transactions on Power Electronics., vol. 11, no. 5, pp. 710–722, 1996.

[4] R. Rangain, D.Y.Chen, J.Tang and J.Lee, "Application of insulated gate bipolar transistor to zero-current switching converte," IEEE Transactions on Power Electronics , vol. 4, pp. 2–7, 1989.

[5] P. K. Jain and S. B. Dewan, "Analysis of a clamped series inverter with a transformer coupled load," IEEE Tranactions on Industrial Applications, vol. 25, no. I,pp. 153-161, Jan.-Feb. 1989.

[6] K. B. Zhao, P. C. Sen, and G. Premchandran, "A thyristor inverter for medium-frequency induction heating," IEEE Transaction on. Industrial Electronics," vol. 31, no. 1, pp. 34-36, Feb. 1984.

[7] F. Z. Peng, H. Akagi , and **A.** Nabae, "High-frequency current source inverters using SI thyristors for induction heating applications," IEEE Transactions on Industrial Applications , vol. 25, no. 1, pp. 172-180, Jan.-Feb. 1989.

[8] Oscar Lucía, , Pascal Maussion , Enrique J. Dede and José M. Burdío, "Induction Heating Technology and Its Applications:Past Developments, Current Technology, and Future Challenges," IEEE Transaction on. Industrial Electronics," vol. 61, no. 5, pp. 2509-2519, May. 2014.

[9] Jesús Acero, Rafael Alonso, José M. Burdío, Luis A. Barragán, and Diego Puyal ,"Frequency-Dependent Resistance in Litz-Wire Planar Windings for Domestic Induction Heating Appliances," IEEE Transactions on Power Electronics , vol. 21, no. 4 , pp. 856–866, July 2006.