



Green Cooking

Ahmed Alebshehy¹, Salama Abo Zeid², Mohamed Kamal Ahmed³
 PG Student¹, Lecturer², Assistant Professor³
 Department of Electrical Engineering
 Al-Azhar University, Nasr City, Cairo, Egypt

Abstract:

The high consumption of energy and environmental pollution resulting from energy use force us to introduce renewable and clean energy in all our daily fields and one of the daily fields that are indispensable is cooking. In this paper, we will discuss the method of clean cooking. By using this method, there is no need for Liquefied petroleum gas or natural gas or even electrical grid. This paper presents the configuration of an induction heater cooker. This configuration depends on solar cells supplying induction heating. Effective control scheme is incorporated in the voltage-fed H-bridge parallel resonant converter, which is based on an auto-frequency tracking strategy. The proposed control strategy ensures stable operation characteristics of overall converter system and operation as well as power regulation. The operation principle and the proposed control scheme are described. Also, the simulation results using MATLAB and the performance characteristics are shown for a prototype induction cooking system rated at 500 w.

Keywords: Green cooking, heat transfer, heat-insulated bowl, Resonant frequency, solar cell

I. INTRODUCTION

In 1820 Oersted observed that if a current passed through a wire, a magnetic effect was created in the deflection of a magnetic needle placed next to the wire as the magnetic field arises from the charges in motion. Oersted's discovery linked a relationship between electro-science and the science of magnetism. Induction heating is a non-contact heating method. All induction heating (IH) applied systems are developed using electromagnetic induction, first discovered by Michael Faraday in 1831. Electromagnetic induction refers to the phenomenon by which electric current is generated in a closed circuit by the fluctuation of current in another circuit next to it. The basic principle of induction heating, which is an applied form of Faraday's discovery, is the fact that AC current flowing through a circuit affects the magnetic movement the secondary circuit located near it. The fluctuation of current inside the primary circuit provided the answer as to how the mysterious current is generated in the neighboring secondary circuit. Faraday's discovery led to the development of electric motors, generators, transformers, and wireless communications devices.[1,2,3,4] Induction heating (IH) technology has become the technology of choice in many domestic and industrial systems, and it is leading technical advances in household appliances due its benefits in terms of efficiency, safety, fast heating, advanced control and cleanness[5]. Heat loss, which occurs during the induction heating process, has been a major headache undermining the overall functionality of a system. [6]. Researchers thought to get benefit from Heat loss, occurring in the process of electromagnetic induction, by turning it into productive heat energy in an electric heating system by applying this law. Many industries have benefited from this by implementing induction heating for furnaces. The principle involved in transferring energy from a heating inductor to a load is equivalent to a transformer which primary and secondary is composed by the induction coil and the load, respectively. [7]

To understand the induction heating we should study [electromagnetic field effect on coil, the skin effect, eddy current and heat transfer].

- **Electromagnetic field effect on coil**

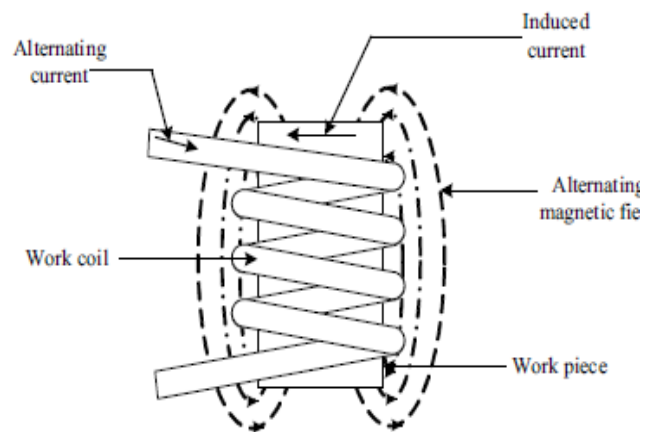


Figure.1. induction coil around work piece

As shown in Figure (1), when the AC current enters a coil, a magnetic field is formed around the coil, calculated according to formula as:

$$B = \mu * \frac{N}{L} * I \quad (1)$$

- **Eddy Currents**

Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor, due to Faraday's law of induction.[8] They normally travel parallel to the coil's winding and the flow is limited to the area of the inducing magnetic field. Eddy Currents concentrate near to the surface adjacent to an excitation coil and their strength decreases with distance from the coil i.e. Eddy Current density decreases exponentially with depth. This phenomenon is known as the skin effect and the explanation is shown in Figure (2).

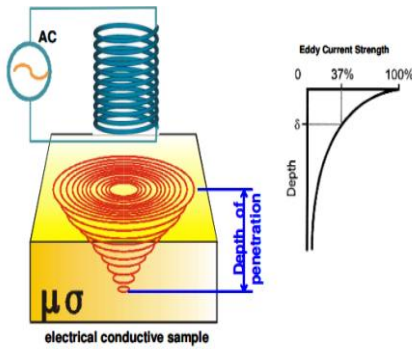


Figure.2.Eddy Current Density And Depth

• Skin effect

Skin effect arises when the Eddy Currents flowing in the test object at any depth produce magnetic fields which oppose the primary field, thus reducing the net magnetic flux and causing a decrease in current flow as the depth increases. Alternatively, Eddy Currents near the surface can be viewed as shielding the coil's magnetic field, thereby weakening the magnetic field at greater depths and reducing induced currents. Eddy Current is used in the inspection of ferromagnetic and non-ferromagnetic materials. The principle of Eddy Current based inspection is explained below.

Skin effect depth calculation from:
$$\sqrt{\frac{\rho}{\pi \cdot f \cdot \mu}} \quad (2)$$

Where:

- ρ is the resistivity of the conductor in $\Omega \cdot m$.
- f is the frequency in Hertz.
- μ is the absolute magnetic permeability of the conductor.
- The absolute magnetic permeability (μ) = $\mu_0 \times \mu_r$.

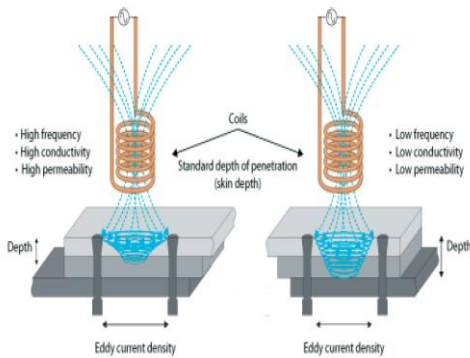


Figure.3.Two Sample for Skin Effect Depth

• Heat transfer

Heat transfer is the transition of thermal energy from a heated item to a cooler item. When an object or fluid is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat transfer, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium. Heat transfer always occurs from a hot body to a cold one, a result of the second law of thermodynamics. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed down.[9], The law of heat Conduction, also known as Fourier's law, states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area through which the heat is flowing.

Thermal conductivity of a material indicates its ability to conduct heat.

$$Q = -KA \frac{\nabla T}{L} \quad (3)$$

Where:

- Q is the heat flow rate by conduction (W)
- k is the thermal conductivity of body material ($W \cdot m^{-1} \cdot K^{-1}$)
- A is the cross-sectional area normal to direction of heat flow (m^2) and
- dT/dx is the temperature gradient ($K \cdot m^{-1}$).

II. SYSTEM DESCRIPTION

Figure. 4 show the diagram of the inverter. The DC voltage which is around 120V, is from solar cell. IGBTs SW1 to SW4 constructed an H-bridge with which the DC voltage is inverted to high frequency AC voltage and controlled by PWM [to get the optimal voltage and frequency], which is applied to the resonant tank constituted by resonant capacitor C and the induction coil L. The high frequency current through the induction coil produces eddy current which heats the magnetic materials pot. We using heat-insulated bowl [using non-magnetic outer coat and magnetic inner coat] to keep the heat in bowl as long as possible.

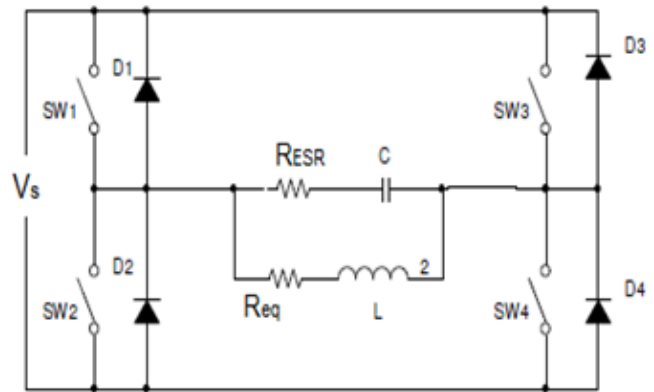


Figure.4.Induction Heater Diagram

II. Induction heater Equivalent Circuit and mathematical equation

We can represent the IH with the transformer, so the heating oil is represented by the primary coil and the load is represented by the secondary coil as shown in the figure (5).

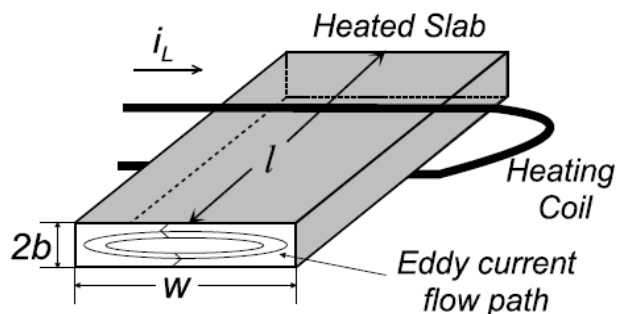


Figure.5.Model of Slab for One Tutm Coil

The current in the induction coil produces magnetic flux which most of it penetrates into the slab (load). In the secondary circuit there is no leakage inductance and the coupling coefficient

equals one. The secondary circuit can be moved to the primary part as shown in Figure (6).

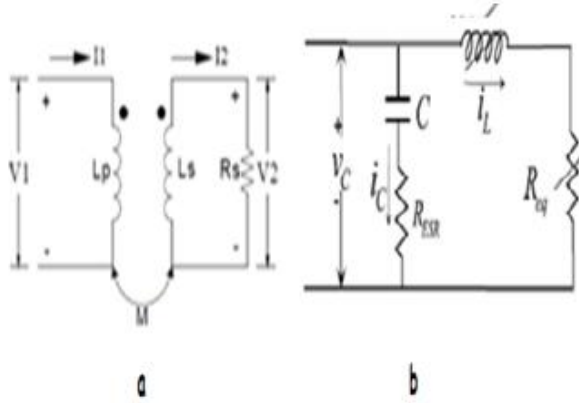


Figure.6.a. Electrical equivalent, b: electrical reduced equivalent.

The slab resistance Rs for one turn coil is given by:

Using Wheeler's formula [5] the inductance of the heating coil can be calculated as follows:

$$L_p = \frac{r^2 + N^2}{9r + 10h} \text{ (}\mu\text{H)} \quad (4)$$

Where: r is the radius, N is the turn number and h is the height of the coil. The coil resistance R_p can be calculated easily. And the slab resistance Rs for N turn coil is given by:

$$R_s = N^2 \rho \frac{2(\omega + 2b)}{l\delta} \quad (5)$$

And l is the effective length of the slab occupied by N turn coil, b and w is defined in Figure 5. δ and ρ are skin depth almost distributed over the surface of slab and electrical resistivity of the material. Simplified equivalent model for a transformer can be represented in Figure6-a : by an equivalent inductance L and resistance R for parallel resonant as shown in figure 7.

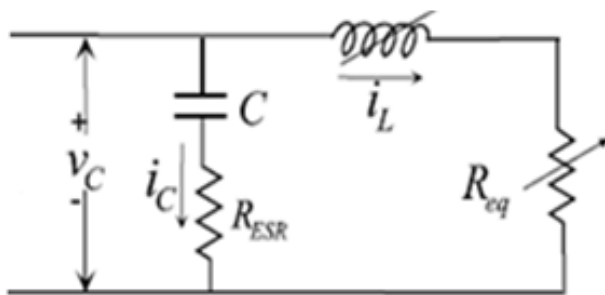


Figure.7.simplified circuit for the total impedance.

The total impedance is given by:

$$Z_t = \frac{(Z_c + Z_{ESR}) \cdot (Z_l + Z_R)}{Z_l + Z_R + Z_c + Z_{ESR}} \quad (6)$$

The rectifier and H-bridge inverter of the induction heater are represented by a square waved current source whose magnitude is equal to the DC-link current I_{dc} . Therefore, the current source expanded in a Fourier series is described as follows:

$$i_s(t) = \sum_{n=1}^{\infty} \frac{I_{dc}}{n\pi} \sin n\omega_s t \quad n = 1, 3, 5, \dots \quad (7)$$

The fundamental component of the square waved current source is given by:

$$i_s(t) = \frac{4}{\pi} I_{dc} \sin \omega_s t = I_s \sin \omega_s t \quad (8)$$

Where $I_s = \frac{4}{\pi} I_{dc}$ is a peak of is The current through R_{eq} and R_{ESR} are represented by I_l and I_c , respectively. The phasor expression of i_l and i_c are described as follows:

$$I_l = \frac{V_c}{Z_l + Z_R} = \frac{Z_c + Z_{ESR}}{Z_l + Z_R + Z_c + Z_{ESR}} I_s \quad (9)$$

$$I_c = \frac{V_c}{Z_c + Z_{ESR}} = \frac{Z_l + Z_R}{Z_l + Z_R + Z_c + Z_{ESR}} I_s \quad (10)$$

$$V_c = Z_t * I_s \quad (11)$$

Where V_c and I_s are phasors of v_c and i_s .

In Figure7, the power generated is consumed in equivalent resistor R_{eq} and R_{ESR} of the capacitor bank. Therefore, the total output power of the induction heater P_t and the capacitor loss P_{loss} are given by:

$$P_t = \left(\frac{I_l}{\sqrt{2}}\right)^2 * Z_{eq} = \frac{1}{2} \left(\frac{Z_c + Z_{ESR}}{Z_l + Z_R + Z_c + Z_{ESR}}\right)^2 * I_s^2 * Z_{eq} \quad (12)$$

$$P_{loss} = \left(\frac{I_c}{\sqrt{2}}\right)^2 * Z_{ESR} \quad (13)$$

$$= \frac{1}{2} \left(\frac{Z_l + Z_R}{Z_l + Z_R + Z_c + Z_{ESR}}\right)^2 * I_s^2 * Z_{ESR} \quad (14)$$

Where I_l and I_c denote the peak of i_l and i_c , respectively.

$$P = P_{out} - P_{loss} \quad (15)$$

$$P = \frac{1}{2} \left(\frac{Z_c + Z_{ESR}}{Z_l + Z_R + Z_c + Z_{ESR}}\right)^2 * I_s^2 * Z_{eq} - \frac{1}{2} \left(\frac{Z_l + Z_R}{Z_l + Z_R + Z_c + Z_{ESR}}\right)^2 * I_s^2 * Z_{ESR} \quad (16)$$

$$P = \left[\frac{1}{2} \left(\frac{Z_c + Z_{ESR}}{Z_l + Z_R + Z_c + Z_{ESR}}\right)^2 * Z_{eq} - \frac{1}{2} \left(\frac{Z_l + Z_R}{Z_l + Z_R + Z_c + Z_{ESR}}\right)^2 * Z_{ESR} \right] * I_s^2 \quad (17)$$

From equations 17:

P depends on I_s , which depends on V_s and so we can control P by PWM .

By using MATLAB we can simulate this circuit with different values of frequency.

For example;

We assume:

$$R_{eq} = .01\Omega, L_{eq} = 1.2\mu\text{H}, F=23.4 \text{ }\mu\text{f}.$$

$$f=[10000 : 100000] \text{ HZ}.$$

$$R_{ESR} = K/C \dots\dots\dots [k \text{ constant} = 1.2 * 10^{-6} \Omega \cdot \text{f}].$$

For maximum power, resonance should occur.

$$x_c = x_l \quad (18)$$

$$x_c = 1/2\pi fc \quad (19)$$

$$x_l = 2\pi fL \quad (20)$$

$$1/2\pi fc = 2\pi fL \quad (21)$$

$$f^2 = \frac{1}{4\pi^2 LC} \quad (22)$$

Resonance frequency equals;

$$f = \sqrt{\frac{1}{4\pi^2 lc}} = \frac{1}{2\pi\sqrt{LC}} \quad (23)$$

$$f = \frac{1}{2\pi\sqrt{1.2 \times 10^{-6} \times 23.4 \times 10^{-6}}} = 30034 \text{ KHZ}$$

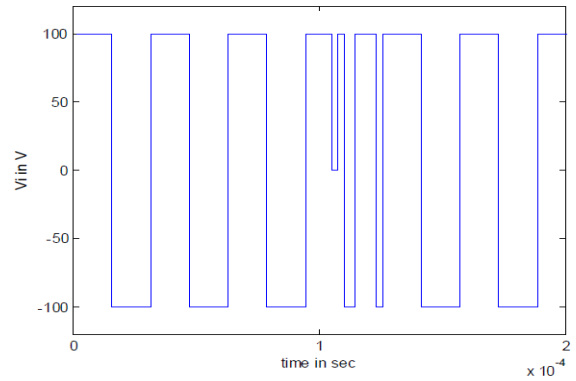


Figure.11.output inverter high frequency voltage

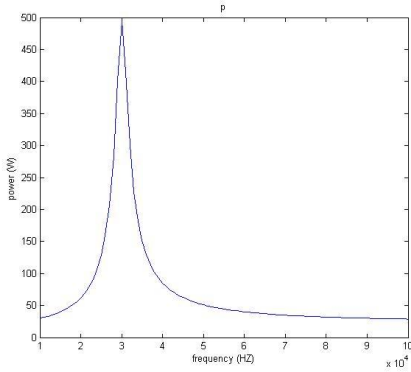


Figure.8.Maximum Power

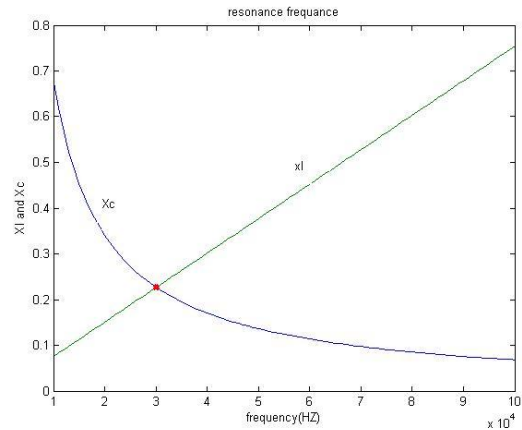


Figure.12.Capacitor and Coil Reactance with Frequency Change

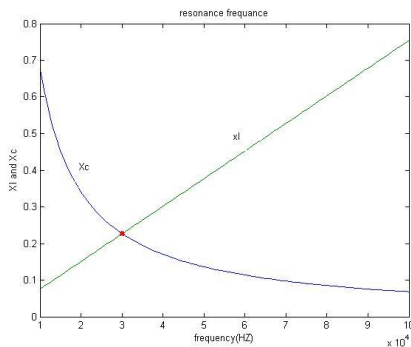


Figure.9.Resonant Frequency

From simulation:

Figure8 the maximum power at 30 KHZ

Figure9 the resonance frequency at 30 KHZ

III. MATLAB SIMULINK FOR GREEN COOKING

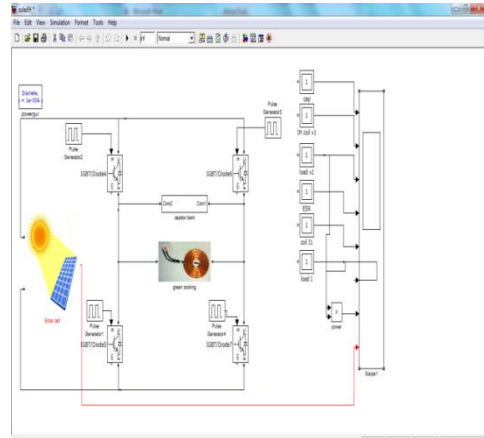


Figure. 10. MATLAB simulink

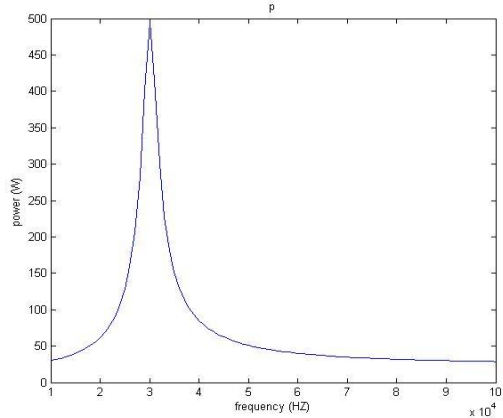


Figure.13. Output power with frequency change

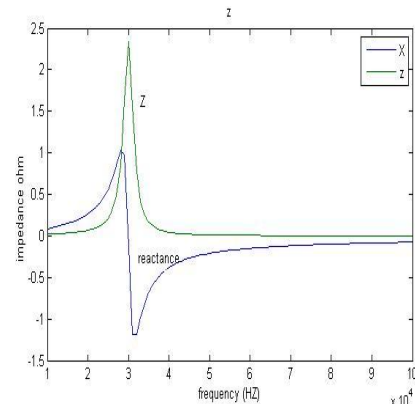


Figure.14. Impedance and Reactance with Frequency Change

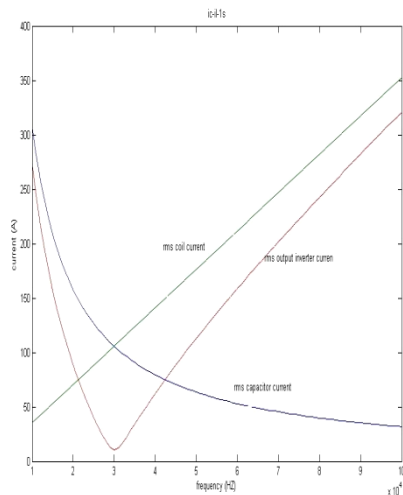


Figure. 15. System currents with frequency change

The parameters of induction heater were utilized in this simulation: $R_{eq} = .02 \Omega$ $L_{eq} = 1.2 \mu\text{H}$ $R_{ESR} = \text{K/C}$ k constant = $1.2 * 10^{-6} \Omega \cdot \text{f}$ $f = 23.4 \mu\text{f}$
 The optimal frequency value is found (by MATLAB) to be 30 KHz.

At this frequency we found that:

- Power is maximum. As shown figure (13).
- The impedance is maximum but the reactance is minimum. As shown figure (14).
- Current is minimum. As shown figure (15).

III. CONCLUSION

In this paper the operation principle of the induction cooker is introduced together with frequency tracking, power regulation. Its performance characteristics are verified by using MATLAB simulation to choose the optimal conditions. The induction cooker is designed to replace ordinary stove plates. The induction cooker model has been developed and the performance is good. It can provide fast heating and the comparison with gas cooking.

IV. REFERENCES

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