Induction Cooking Application Based on Class E Resonant Inverter: Simulation using MATLAB

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Abstract: ***This paper presents simulation of induction cooker circuit using class E resonant inverter in MATLAB. Induction heating is well known technique for producing very high temperature in fraction of time. Induction cooking is an application of induction heating which is used for residential and commercial usage. With the help of class E resonant inverter, high power factor and low line current can be obtained, which are very attractive in terms of commercial production. The induction cooker's parameters using class E resonant inverter are designed properly and details of design are described. Switching technique using pulse density modulation (PDM) is presented for the inverter to control the temperature. Along with the description of system model simulation results are obtained and verified with the system model.***

Keywords: Class E resonant inverter, Induction cooker, MATLAB Simulink, Pulse density modulation (PDM)

1. Introduction

There are three main methods of cooking chemical, electrical and induction heating. In chemical heating it burns some combustible substance such as wood, coal, gas. Electric heating uses an electrical current through a resistance element. It has disadvantages like poor efficiency, high power loss considering it is a contact heating method. Induction heating is a very efficient technique to produce very high temperature in very less time. In induction heating AC current is flowing through the heating coil generates flux causing eddy currents to flow in the load to be heated thus electric energy gets converted to heat. It is mainly used for applications like surface hardening, melting, brazing. In these applications appropriate frequency and skin depth are the main factors to be taken into consideration. Due to all advancements in the power electronics, induction heating technique can be applied for domestic use. Induction cooking system consists of an inverter for generating AC, inductor coil, insulator between coil and pan, cooking vessel. High frequency resonant inverters are used which consists of half bridge or full bridge configuration depending on the requirement of the performance and control capabilities. Half bridge topology is used due to its simplicity and compactness where as full bridge is used due to its control capabilities.

The induction cooker is an application of induction heating which is used for commercial and residential usage. Higher speed, energy efficiency, low wastage of heat, cleanliness, uniform heating and safety are the main characteristics of an induction cooker. Due to low switching losses of semiconductor devices and low cost due to simple circuit, induction cook tops have attracted special interest for consumer induction heating appliances. Fig.1 shows the induction cooking block diagram. AC supply is passed through rectifier for getting required DC voltage as inverter's input. When current reaches to induction coil, it's been increased to a frequency 1000 times higher than that of a wall socket. Power losses during switching transitions and harmonics in the circuit can be reduced by using resonant network. In order to compensate the inductive nature of the coil, a resonance capacitor is placed in parallel to the coil. Semiconductor switches operate in hard switch mode with a very high frequency that's why pulse density modulation (PDM) technology is used in system.

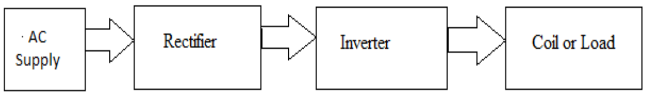

Figure 1: Induction cooking block diagram

The sufficient heat needed to produce useful cooking within the cookware requires a very high rate of change in the magnetic field and a high frequency of alternating current flowing through the induction coil. Induction cooktops contains electronic devices that increase the frequency and protects wiring. Frequency at the coil is very large than input frequency. Induction cookware is basically ferrous metals because these are relatively poor conductor of electricity so they have high resistance. When a current is run through a material with a high resistance, much of the current is converted to heat. The heat used to cook food on an induction cooktop comes from this electrical resistance and changes in the magnetic field of the cookware.

Initially it employs a centre tapped transformer of high frequency at output to provide the impedance matching function. The transformer must be cooled to remove excess heat generated in the system. Series resonant inverter requires transformer for matching output power to the load but it carries very high current so power loss occurs and efficiency gets reduced. Series resonant inverter impedance is very small at the resonant frequency so maximum gain can be obtained at resonant frequency. So that use of class E resonant inverter is very effective for low conduction loss, high efficiency, low total harmonic distortion.

The objective of this paper is to introduce MATLAB Simulink for induction cooker based on class E resonant inverter. The output power can be controlled by varying switching frequency and inverter operates under zero voltage switching (ZVS) for triggering of devices. In ZVS power is switched ON or OFF when output is zero volts. ZVS ensures minimum heating of the devices making the operation very efficient and effective. The pulse density modulation method regulates the output power by varying the period in which the inverter supplies high frequency current to the induction coil. Proposed induction cooker is designed for an operating frequency of 32 kHz, a 220 V line rms voltage, a 50 Hz line frequency and a 1 kW output power [1].

The paper is organized as follows, Section I gives brief introduction and classical approach of the project. Section II contains description about system model with mathematical modelling. Section III has overview of pulse density modulation. Experimental results with simulation model and results are explained in section IV. Section V has conclusion included with references.

2. System Model

Fig.2 illustrates the circuit of the proposed zero voltage switching class E resonant inverter for induction cooking application. It is made up of a bridge rectifier D1-D2-D3-D4, an electromagnetic filter L1–C1 and a class E resonant inverter Q-L2-C2. The pulse density modulation of the gate signal is controlled to regulate the temperature, in order to guarantee the zero-voltage switching (ZVS) condition[1][2]. As IGBT is switched at zero voltage, power losses are reduced to minimum.

As shown in Fig.2, the diodes D1, D4 operate during the positive half cycle. Mode 1 is active when switch *Q* is ON. During mode 1, the active switch *Q* is turned ON with ZVS, the current flow the through L2. The collector current through *Q* increases till Q gets off. The diodes D2 and D3 of the bridge rectifier operate during the negative half cycle. Mode 2 is active when Q is turned OFF.

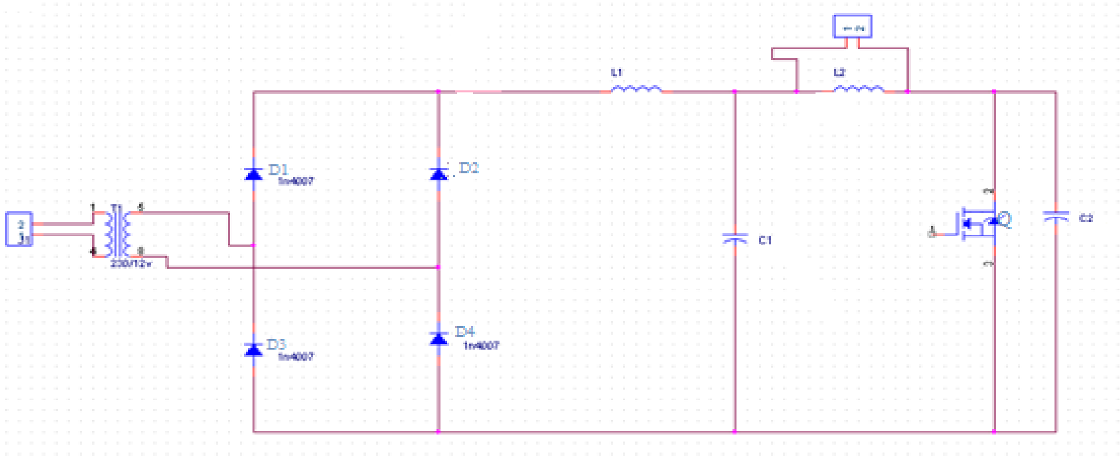

Figure 2: Proposed Induction cooker with Class E Resonant Inverter

The active switch can be operated under the ZVS condition due to which conduction losses and harmonic currents can be reduced. Power is switched ON or OFF when output is zero volt which increases life of cooking appliance. High efficiency, high power factor and low line current harmonic distortion ensures higher efficiency for induction cooker [3].

Referring to the equivalent circuit of induction cooker with class E resonant inverter [4] is shown in Fig.2. For the operating frequency of 32 kHz, a 220 V line rms voltage, 50 Hz line frequency and 1 kW output power[1]. Now, Equivalent resistance – R, Resonant inductor – L, Resonant capacitor – C2 Line voltage – V, Output power – Po, Switching frequency – f1 Resonant frequency – f2 , Switching angular frequency – w

$$R = \frac{1.552\ V \times V}{Po} \quad (1)$$

$$L2 = \frac{0.065\ R}{f2} \quad (2)$$

$$C2 = \frac{0.162}{f2 \times R} \quad (3)$$

3. Pulse Density Modulation

Control strategies like frequency control and phase shift control have disadvantages like switching losses, noise as not all the semiconductor devices work on ZVS. These drawbacks are overcome by another strategy which is pulse density modulation. PDM has fix firing pattern at zero voltage. Power regulation is done by adjusting the number of pulses during ON time. In PDM switching frequency is equal to the resonant frequency. ON and OFF pattern is obtained by keeping switching frequency constant. It is relative density of the pulses that corresponds to the amplitude of the signal. Generally pulse width modulation (PWM) is used to generate an analog output signal using digital microcontroller. It is implemented in hardware itself but if not then PDM technique is used. It produces comparable results to PWM but with lower interrupt layer. It conveys signal by modulating density of the pulses.

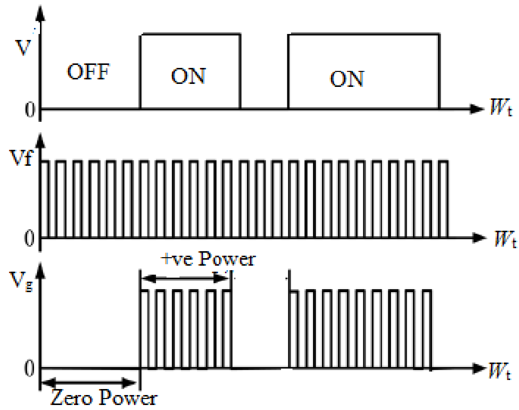

Figure 3: PDM technique

PDM technique can be explained as in Fig.3. For the induction cooking purpose, PDM technique is used for temperature control purpose. As appropriate temperature for heating food items is very essential, PDM technique adjusts temperature by controlling duty cycle. Duty cycle for PDM is given as,

$$D = \frac{ton}{T} \tag{4}$$

Where $T = t_{on} + t_{off}$

Let V is the square shaped signal, V_f is the switching frequency signal and V_g is the pulse density modulated signal of the V and V_f which is obtained by adjusting the duty cycle. In case of induction cooker, vessel temperature is compared with command value of vessel temperature. If it is less than command value then duty cycle will increase otherwise it will decrease.

4. Experimental Results

The proposed induction cooker with high frequency class E resonant inverter, controller in Fig.2 is simulated in the MATLAB Simulink using design parameters as shown in Table I[1].

Table I: Circuit parameters of the prototype

Symbol	Parameter Expanded	Value of the parameter
V	Input Voltage	220 V
C1	Filter Capacitance	4.7 µF
C2	Resonant Capacitance	67 nF
L1	Filter Inductor	500 µH
L2	Resonant Inductor	152 µH

With the help of parameters in Table I, putting together the characteristics of different circuit elements a complete and powerful tool for the evaluation of the induction cooker's parameters has been built and implemented in the MATLAB environment. As MATLAB is user friendly, it can be used for numerical computing environment, creation of user interface and also for comparison of different types of circuit parameters. Simulink adds graphical multi domain simulation and model based design for dynamic and embedded systems.

Fig.4. shows the MATLAB Simulink simulation circuit diagram of Fig.2. As shown in Fig.4, AC voltage supply of 220V is applied as input to the circuit which consists of a full bridge rectifier D1-D2-D3-D4, filter Lf-Cf and resonant inverter Lr-Q-Cr. PWM generator is used for pulse generation. Values for inductors and capacitors are mathematically calculated from (1) (2) (3). The high frequency inverter feeds the load by the required power at 32 KHz from the 50 Hz supply through a diode rectifier. Voltage, current and power measurements are taken at input and output.

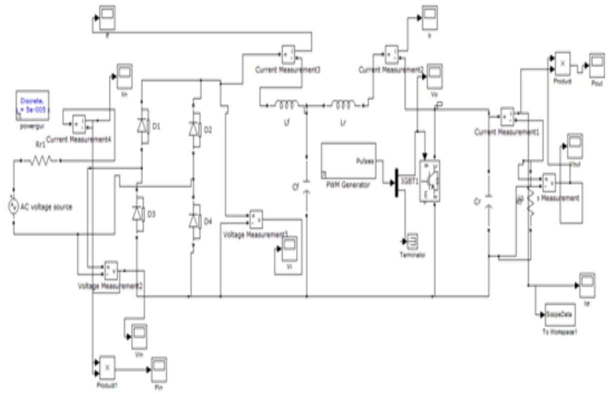

Figure 4: Modelling of proposed induction cooker in MATLAB Simulink

Following are the waveforms at every instant which are taken for 1 second time span,

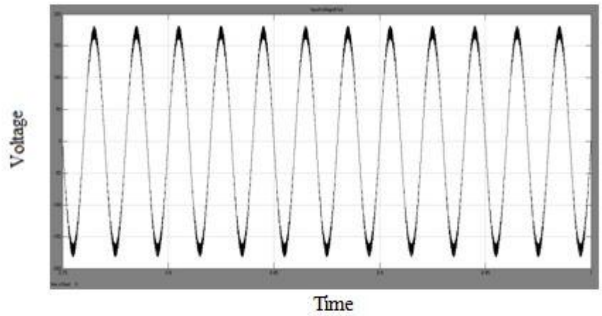

Figure 5: Input voltage (Vin)

Input voltage is calculated from the scope connected to the input port which is about 200 V.

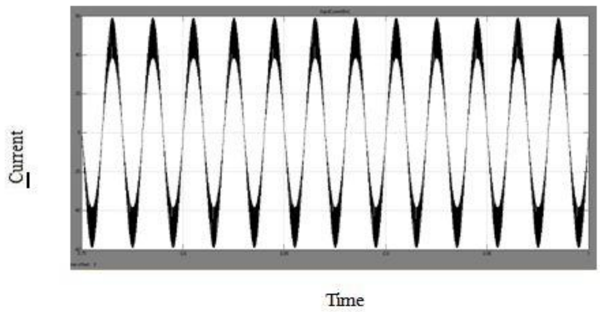

Figure 6: Input current (Iin)

Simillarly input current is measured at the input scope which is as shown in Fig.5

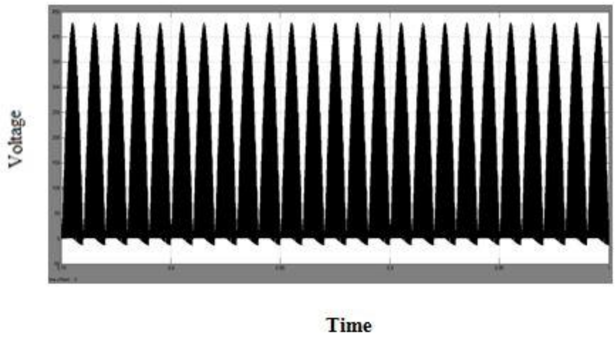

Figure 7: Output voltage (Vout)

Output voltage which is higher than input due to increase in frequency is measured at output scope.

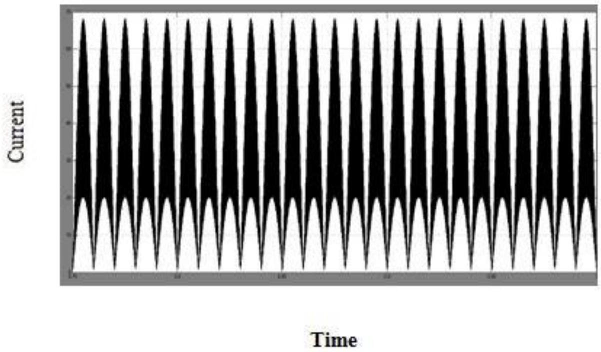

Figure 8: Resonant inductor current

Resonant inductor current and resonant capacitor current are measu red across resonant inductor and capacitor.

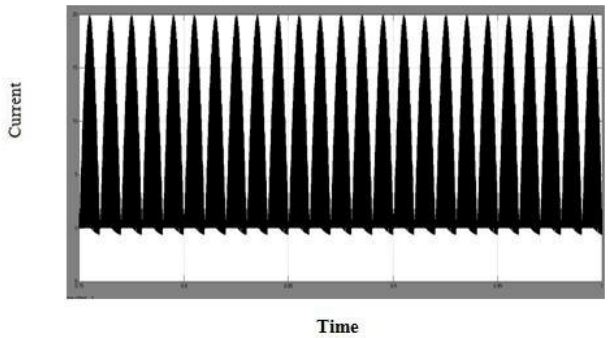

Figure 9: Resonant capacitor current (Icr)

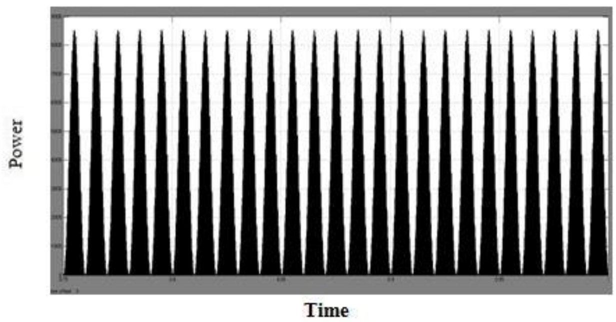

Figure 10: Output Power waveform (Pout)

Output power which is approximately 0.86 kW[1] is measured at output scope. The experimental results from MATLAB Simulink are summarized in Table II. By observing and comparing all the reference values and simulink waveforms, the proposed circuit design for class E resonant inverter for induction cooking purpose is verified.

Table 2: Experimental results obtained with MATLAB

Parameter	Parameter expanded	Value
V_{in}	Input voltage	200 V
I_{in}	Input current	50 A
V_{out}	Output voltage	420 V
I_r	Resonant Inductor current	68 A
I_{cr}	Resonant capacitor current	20 A
P_{out}	Output power	0.86 kW

5. Conclusion

Now a days, Induction hobs have become a sophisticated device pogressively appreciated by a growing number of users. **Induction heating** is the process of heating an electrically conducting object by electromagnetic induction, where eddy currents are generated within the metal which leads to heating of the metal. In this paper the history of induction heating along with applications, advantages. The classical approach for working of an induction cookware and with class E resonant inverter is studied and it's simulation in MATLAB Simulink is done where all the waveforms of -input and output are verified.

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