Design and Construction of Power System for Induction Heating (IH) Cooker Using Resonant Converter

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Abstract

Induction Heating (IH) systems using electromagnetic induction are developed in many industrial applications in Myanmar. Many industries have benefited from this new breakthrough by implementing induction heating for melting, hardening, and heating. Induction heating cooker is based on high frequency induction heating, electrical and electronic technologies. From the electronic point of view, induction heating cooker is composed of four parts. They are rectifier, filter, high frequency inverter, and resonant load. The purpose of this research is mainly objected to develop an induction heating cooker. The rectifier module is considered as full-bridge rectifier. The second portion of the system is a capacitive filter. The ripple components are minimized by this filter. The third is a high frequency converter to convert the constant DC to high frequency AC by switching the devices alternately. In this research, the Insulated Gate Bipolar Transistor (IGBT) will be used as a power source, and can be driven by the pulse signals from the pulse transformer circuit. In the resonant load, the power consumption is about 500W. Construction and testing has been carried out. The merits of this research work is that IH cookers can be developed because of having less energy consumption, safe, efficient, quick heating, and having efficiency of 90% or more.

1. INTRODUCTION

In this paper, the interest is induction heating, which is a combination of electromagnetic induction, the skin effect, and the principle of heat transfer. In short, induction heating refers to the generation of heat energy by the current and eddy current created on the surface of a conductive object (according to Faraday’s Law and the skin effect) when it is placed in the magnetic field, formed around a coil, where the AC current flows through (Ampere’s Law). Faraday’s Law was followed by a series of more advanced discoveries such as Lentz’s Law. This law explains the fact that inductive current flows inverse to the direction of changes in induction magnetic movement. The fundamental theory of IH, however, is similar to that of a transformer.

2. TYPES OF POWER SYSTEM

The converter portion of the power supply converts the AC line frequency input to the direct current and the inverters and oscillators change the direct current to single phase alternating current. These
are basically oscillator circuits. To consider the The converter portion of the power supply converts
the AC line frequency input to the direct current working in induction heaters, a brief description of
oscillators is firstly explained. There are four basic types of induction heating equipment used for
inductively heating metal parts. These are

1. From vacuum tube oscillator and electronic generator
2. From spark-gap generator
3. From motor-generator set
4. From solid-state inverters

In principle they are alike in that an inductor or heating coil surrounds the work to be heated,
or perhaps is formed to suit the area requiring heat, so that with a flow of current induced to the
work’s surface from the coil, an immediate heating action takes place. However, since the frequency
of the current has direct effect on the depth of current penetration, one type of unit will perform some
types of heating operations better than others.

Today, we have a wide range of induction heating equipment that utilizes various forms of
solid state power supplies, ranging from SCR, IGBT and MOSFET power circuits. IGBT based
induction heating equipment is typically used for medium frequency applications that will range
generally from 10 kHz to 90 kHz. This range is ideal for the most of heat treating processes that
require 1.5mm to 3 mm case depth. In this research, for the construction of the power system the
IGBT is the most suitable to be used as a power source.

2.1. Comparison

Here is one example of induction heating for thin slab of continuous casting. The main power
circuit of a parallel resonant converter, such as typically used for induction heating application is
shown in Figure 1. The three phase converter is controlled to make a constant DC current in the choke.
The H-bridge inverter feeding the parallel resonant circuit is fed from the current dc link. The inverter
is made by four thyristors which can be commutated by the resonant of the capacitor bank and the
heating coil. Therefore this type of inverter is called as a load commutated inverter. The inverter
provides a square waveform input current to the resonant circuit (capacitor bank and heating coil).

![Figure 1: Induction Heating System: Three Phase Thyristor Controlled Rectifier and Parallel
Resonant Half-Bridge Inverter](image)

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Another one is an induction heating system using Colpitt’s oscillator as a power source.

The AC supply voltage is stepped by means of a step up transformer and further rectified by a bridge rectifier. The ripple components are minimized by the use of LC filter. The ripple-free high voltage DC is fed to a colpitt’s oscillator. The oscillator circuit produces high frequency power and feeds it to the input of an inductive coil which is the primary of the work coil. The work piece acts like a short-circuited secondary. The frequency used in the case of non-magnetic is about 50k Hz.

The last example is the SCR type inverter in induction cooking. In following figure, the short-excited oscillation is produced in the series “tank”, \( L_1/C_4 \), when the SCR is caused to switch on and off periodically. The oscillation is not sustained, but is produced in single-cycle “bursts”. The resonant frequency is in the neighborhood of 35 kHz.

Figure 2: High frequency power supply for induction heating using colpitt’s oscillator

Figure 3: Induction cooking unit with SCR-series type inverter
3. METHODOLOGY

The block diagram is shown in Figure 4. High frequency alternating current is generated in the heating coil of the cooker by resonant power inverter employing two semiconductor switches. The input AC supply voltage is rectified by the full wave rectifier at the AC input side. The capacitor is used to bypass high frequency current components generated by the power inverter and reduces their magnitude on the main side. The capacitor is not too large as to smooth DC input signal; therefore, a DC signal which is composed of rectified AC half cycles is fed to the power stages. The main task of the power stage is to transfer a mount of power to the inducance (and hence the container) at the resonant frequency of LC circuit. This frequency is about 24k Hz.

There is no DC output level to be regulated in induction cooking system. Therefore, the voltage feedback input is related to the output power of the cooker or inductor current level. The protection circuit in the gate operating circuit controls the output voltage by varying the oscillator output frequencies. The required frequency pulse signal is carried from the comparator to pulse transformer throughout the driver section. The output of the comparator is 180. Out of phase pulse signals which is fed to the IGBT gate in the half-bridge series resonant converter. The power has not been drawn any current when the IGBT is turned off. The initial spikes when the transistor is turned on are due to the short circuit that charges the resonant capacitor and flows through the IGBT. Once the capacitor is charged, and the current begins to flow through the heating coil. The container of the cooker is put inside the magnetic field, and then induced the voltage and eddy current are created on the skin depth of the container as a result of the skin effect. This generates heat energy on the surface of the container and rice is cooked by this heat energy.

3.1. Design

As heat is generated in the process of energy exchange between the inductor and the capacitor in the resonant circuit, the level of inductance and capacitance is very important factor. The following descriptions are the main factors which determine this inductance value.
Design Specifications

Power Consumption - 500 W
Rice Cooker Size - 25 cm diameter
10 cm height
Material - Ferrous/Stainless Steel

AC Current
Power Source: half-bridge series resonant converter for 100V-50Hz power source with ±15% of voltage fluctuation

Resonant Frequency

To avoid the noise generated within audio frequency band, the resonant frequency is set at over 20kHz.
During this process, taking resonant frequency is 24 kHz to operate in the circuit.
Firstly, assume the input AC current is the average of the resonant current in the main power circuit.

\[
I = \frac{2\pi \times P_{\text{avg}}}{V_{\text{peak}}} = \frac{2\pi \times 500}{85\sqrt{2}} = 26.1 \text{ A}
\]  

Therefore, the current which is needed to design the IGBT is 26.1 A. IGBT peak voltage is \(85\sqrt{2} = 120\) V. The switching frequency is around 24 kHz. Thus for design purposes, IRG4PH50KD with ultrafast soft recovery diode IGBT is chosen because of its parameters. The inductance of the load coil is computed from capacitance at resonance. From load current values, the capacitance can be found using this equation:

\[
C = \frac{I}{2\pi f V} = \frac{26.1}{2\pi \times 24 \times 10^{-3} \times 85\sqrt{2}} = 1.43\mu\text{F}
\]
Therefore, use 1.5\,\mu F as commercially available component. And then, use a 1.5 \,\mu F Mylar or mica capacitor at 25k Hz rating and 400 V_{max}.

The inductance of the load coil is calculated from

$$L = \frac{1}{(2\pi f)^2 C} = \frac{1}{\left(2\pi \times 24 \times 10^3\right)^2 \times 1.5 \times 10^{-6}} = 29.3 \,\mu H \quad \therefore \text{Use } 30 \,\mu H$$

(3)

To calculate number of turns of coil

Use

$$L = \frac{a^2 N^2}{9a + 10b} \quad \text{(micro hennery)}$$

Where,

Let

$$L = \text{inductance (29.3} \,\mu H)$$

$$a = \text{diameter of coil (10 inches)}$$

$$b = \text{height of coil (4 inches)}$$

$$N = \text{number of coil}$$

$$30 = \frac{10^2 \times N^2}{(9 \times 10) + (10 \times 4)}$$

$$N^2 = \frac{30 \times 130}{10^2}$$

$$N = 6.24 \,\text{turns}$$

Use coil of 10 inches diameter and 4 inches height having 10 turns, and coil current 26.1 A preloading at 24 kHz. Thus, use the load coil with 8 SWG copper wire with design as shown in figure.

Then, the driver section will be needed to be designed. The pulse transformer is chosen to be constructed. Wire gauge can be from #32 to #36 AWG of ferrite core or E-E core.

Figure 7: Constructed Work Coil
Using the input voltage (15V) input pulses from driver IC at 0 levels, the 2SA970 transistor conduct.

\[
V_{BE} = \frac{100}{2200 + 100} \times 15 = \frac{1500}{2300} = 0.652\text{V (>0.6V)}
\]

With \( h_{fe} \) typical for 2SA970 of 250,

\[
I_c = \frac{V_{supply}}{4.7k + 100} = \frac{30}{4800} = 6.25\text{mA}
\]

Current to sink into driver is

\[
I_B = \frac{6.25\text{mA}}{250} = 25\mu\text{A}
\]

\( I_c \) sink current = 25 \( \mu \)A (The current follows the path is shown in Figure.)

Sawtooth wave generators using op-amps are very common. But the disadvantage is that it requires a bipolar power supply. Sawtooth wave generator can be built using a simple 555 timer IC and a transistor as shown in the circuit diagram.

Initially the capacitor is fully discharged. The internal comparator inside the 555 connected to pin2 causes the 555’s output to go high, and the internal transistor short the capacitor C to ground opens. The capacitor starts charging to the supply voltage.
2.2k: 

Figure 9: A Sawtooth generator

When its voltage increases above 2/3\textsuperscript{rd} the supply, the 555’s output goes low and short C to ground, thus discharging it. Again, the 555’s output goes high when the voltage across C decreases below 1/3\textsuperscript{rd} supply. Hence, the capacitor charges and discharges between 2/3\textsuperscript{rd} and 1/3\textsuperscript{rd} supply. The frequency of the circuit is given by:

\[ f = \frac{V_{cc} - 2.7}{(R \times C \times V_{pp})} \]

Where, \( V_{cc} \) is 15 V, zener voltage is 2.7V, let \( V_{pp} = 12V \). Therefore, take \( R = 10 \text{ k}\Omega \) and \( C = 2.2\text{nF} \) with commercial value.

4. EXPERIMENTAL RESULTS

Waveforms

HA17555 timer is used as a sawtooth wave generator and output frequency must be 24kHz and in sawtooth shape. The output result from oscilloscope is shown as below.

Figure 10: Practical output waveform across the capacitor  
Figure 11: Result Waveform of the gate driver circuit  
Figure 12: Waveform in the resonant load
Figure 13: Test result graph for AC supply (V) with filter capacitor Vs Load Coil Voltage (V) and Vdc.

Figure 14: Varying Load voltage, Power and Vdc due to supply without filter capacitor

The load voltage is also varied by varying the resonant frequency of the resonant tank circuit as shown in figure 15.

Figure 15: Varying Load voltage by varying the resonant frequency of the resonant tank circuit

And then, the load voltage is tested by varying AC supply voltage at the resonant tank circuit. The result can be described as follows:
5. DISCUSSION AND CONCLUSION

In this paper, the design and construction of the power system for the induction heating cooker based on resonant converter is presented. The maximum output power will be around 500 W and the resonant frequency is 24 kHz. The control circuit is composed of error amplifier, time delay section, oscillator section, gate pulse section, oscillator section, gate pulse transformer and resonant tank circuit. The half-bridge series resonant converter and configuration is chosen. This project has been designed with the locally available components to get the optimum performance.

It proves advantages in cost compared with the induction heating (IH) cooker imported from abroad. Therefore, this research will be a good foundation for high quality product manufacture. In the not too distant future, the author look forward to apply this induction heating technology for the furnaces in modern foundries of Myanmar.

REFERENCES


