CHAPTER 1

INTRODUCTION

Heating systems can be classified into conventional heating systems (such as gas-fired furnaces, electric and fuel fired furnaces, fluidized bed furnaces and Infrared heaters) and induction heating system. Induction heating is a flame free, non-contact heating method, which is mainly depending on wireless electrical power transfer concept. The main advantages of induction heating over the conventional heating systems are (i) no smoke emanated from the process, i.e. environment friendly, (ii) small heat losses, (iii) very fast heating with low running and maintenance cost, and (iv) more efficient. Induction heating also provides better surface quality for the work-piece and it has the ability to heat a specific part of a material with high heating intensity. This system requires smaller start up and shut down time, smaller size and having a lower floor space [1].

The principle of the induction heating systems is shown in Figure 1.1, it is similar to the transformer theory, but with single secondary turn causing very high secondary current, which is needed to heat or melt the metal [2]. The single secondary turn represents the metal to be heated (will be mentioned as a work-piece) which is heated rapidly by the induced eddy current caused by electromagnetic induction; these currents produce heat by the joule effect (I^2R).

Hysteresis loss is defined as the friction between molecules when the material is magnetized first in one direction and then in the other. The molecules may act as small magnets, which turn around with each reversal of direction of the magnetic field. Therefore, in ferro-magnetic materials hysteresis losses improve the induction heating efficiency. For nonmagnetic materials, the heat generated in the work-piece is due to eddy current only [3].

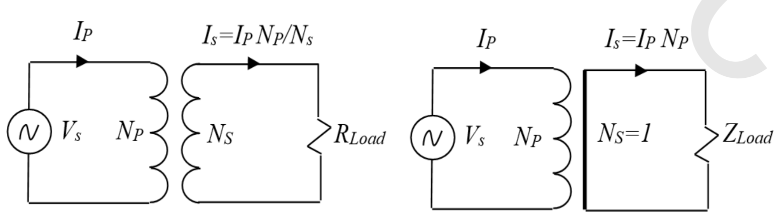

Figure1.1 Basic concepts of induction heating
(a) Transformer circuit. (b) Short circuit secondary circuit.

This eddy current tends to concentrate close to the work-piece surface into a peripheral layer with thickness (δ) called skin depth or penetration depth. This is referred to the skin effect.

The skin effect is a phenomenon, which electric current flows only in the limited area near surface of conductive material [4].The penetration depth has reverse proportional to the eddy current frequency. The frequency of the induced eddy currents in the work-piece is determined by the frequency of the power source.

Induction heating has many industrial applications such as food industry, cement industry, cars industry and motors industry, etc. The main industrial applications of induction heating are showing in Figure 1.2.

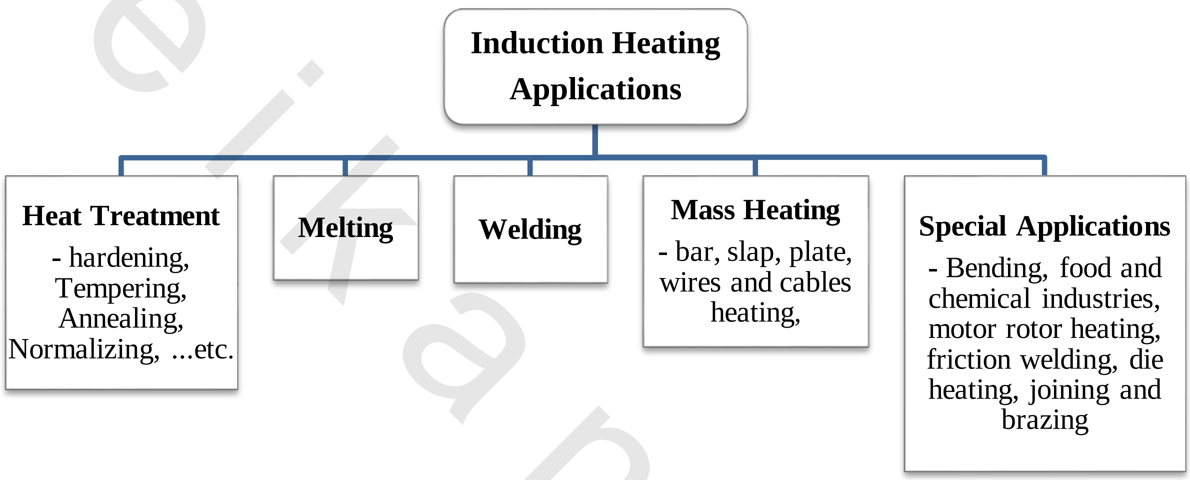

Figure 1.2 Induction heating applications [1]

The main elements of an induction heating system are:

(i) The high frequency power supply,

(ii) The induction heating load circuit,

(iii) The control circuit.

This thesis focuses on the development of a new control circuit for the induction heating furnaces.

With respect to the first mentioned element, the important parameters of the power supply are its frequency, output voltage, current, and power ratings. The main types of power supplies used in induction heating are as follows [2]:

1. Supply systems: this system operates at supply frequency and its multipliers “50 to 450 Hz” with resonant circuit, and no need for converter circuit.
2. Motor alternator: a fixed frequency alternator driven by an induction motor and the power is controlled by the field current control.
3. Radio frequency converters: it is used for small depth applications.

4. Solid-state converters: They are the most common power supply in the induction heating system. The output power of these systems varies, depending on the application, from several kilowatts to tens of megawatts [2]. Three types of solid state converters used in induction heating systems [5], (i) frequency converters with thyristors which has a limited frequency range from 100 Hz to 10 KHz, because of the limited frequency characteristics of the thyristors, (ii) frequency converters with transistors with larger frequency range up to 500 KHz [4], and (iii) frequency converters with vacuum tubes with a frequency range up to 3 MHz

On the other hand, the load circuit of an induction heater consists of work-coil and work-piece. The work-coil is usually designed for specific applications and is therefore found in a wide variety of shapes and sizes it is made of copper pipes to allow water-cooling as a large value of current paths through the coil due to effect of resonant state [5]. The work-piece is the material to be heated; it is referred to equivalent resistance and inductance in the circuit analysis.

The general block diagram of solid-state induction heating system is shown in Figure 1.3, which consists of:

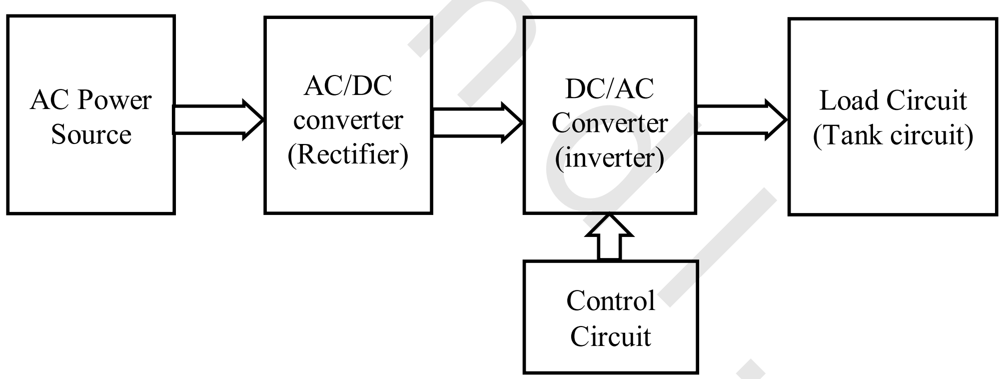

Figure 1.3 Layout of basic induction heating system

- AC power source: It may be single-phase or three-phase AC voltage supply, depending on the power rating of the unit, the induction heater power rating is calculated from the required heat content of the heated or melted material, in addition to the heat losses.
- Rectifier: It converts AC voltage into DC. The rectifier may provide a fixed or variable DC voltage based on the type of control approach. There are two main types of power control in induction heating systems, the first approach used variable DC voltage level ,by using controlled rectifier, while maintaining the inverter frequency constant in the range of resonant frequency "i.e. the frequency will change but with limited range",

this system has a great range of power control and called load resonant generator [2]. The second approach called swept frequency generator, this type maintains constant DC voltage level, by using uncontrolled rectifier, while controlling the power by changing the system frequency through inverter triggering circuit. The main drawback of load-resonant generator is that it is not a self-starting system, complex control system and needs a variable DC source that reflects negatively on the system cost. In addition, the swept-frequency generator has lower power efficiency, limited range of power control, and higher switching losses [2].This thesis deals with another approach called pulse density modulation (PDM) technique, which combines the features of the two basics inverter systems. Detailed illustration of PDM technique will be introduced later.

- Inverter: It converts the rectified DC voltage into single-phase AC output voltage with desired frequency. A triggered circuit (controller) controls this part.
- Control circuit: It is responsible of generating the inverter gate pulses.
- Load or tank circuit: It consists of inductive and capacitive elements. The work coil and work piece represents the inductive element connected to a capacitive banks forms a resonance circuit.

Resonant inverters are widely used in applications that require higher output power control capability such as induction heating. The resonant inverters also may provide lower switching losses due to the possible soft commutation of the switching devices, which allows high frequency operation [6]. Many control schemes have been proposed for controlling output power of the resonant converters such as Pulse Frequency Modulation (PFM), Phase Shift Control (PS), and Duty Cycle Control (DCC). These control schemes may result in increasing of switching losses and electromagnetic noises because the switching devices are not turned on and off at zero current [7]. To overcome all of these drawbacks, PDM technique is proposed by [7]. When PDM control technique is used to control the resonant inverter, the switching devices operate at zero current, which allows the resonant inverter to operate with very low switching losses at high power factors [7], in addition there is no need to use a controlled rectifier, which reflects positively on the system cost.

The PDM operates the inverter in run and stop modes alternatively. At full power, the inverter has no stop cycles and delivers continuous output voltage to the load. By including a stop periods to the inverter cycles load power can be controlled. At the stop cycles, PDM provides a free-wheel circuit for the resonant current to flow through the load [8]. The stored energy in series capacitive and inductive elements is dissipated in the resistive component, which results in decaying of AC current magnitude.

Despite its advantages, PDM converters output power response is discrete and often nonlinear. In this thesis, a new closed loop controller for the output power using a three stages feedback control system is presented to regulate PDM converters output power.

1.1. THESIS OBJECTIVE

The main objective of this thesis is to model and simulate an effective new control scheme for a series-resonant voltage-source inverter based on pulse density modulation (PDM) control strategy for a complete induction heating system. The common power control techniques for resonant converters results in increasing of switching losses and electromagnetic noises. This disadvantage treated in the proposed technique using a three stages feedback control system.

1.2. THESIS LAYOUT

This thesis is divided into five chapters that describe the modeling and simulation of induction heating systems based on PDM technique. A brief description of the material in each chapter is presented below:

Chapter 1, Introduction

This chapter presents a brief introduction to the induction heating, its advantages over conventional heating systems, and its applications in industry. This chapter also explains the main elements of an induction heater, and the purpose of the new proposed controller for the existing PDM technique.

Chapter 2, Literature Review

This chapter presents a survey of previous work done by the other researchers in the induction-heating field and its power control.

Chapter 3, Theory of Induction Heating

Chapter 3 provides different types of power supplies used for induction heating; a variable tuned solid-state power supply, which is the most common power source of induction heating, is described in details. Resonant pulse converters and commutation circuits are also presented.

A comparison is given between power semiconductors in resonant converters to show the advantage of the Isolated Gate Bipolar Transistors (IGBT) based inverters.

A different control schemes for controlling output power of the resonant converters are also presented. Investigated pulse density modulation control technique for induction heating is discussed with coverage of main objective, features, operating modes, analysis of output power and control circuit.

Chapter 4, Modelling of pulse density modulation control

The modeling of a new controller for the PDM technique is presented in details in this chapter. The operation of the three main feedback circuits that combines power feedback, pulse density modulation control and phase angle feedback for the proposed new PDM controller is illustrated. The design procedure is emulated in this chapter. Simulation models have been built using Matlab/Simulink software package. The simulation results of the resonant converter based on PDM are described in details.

Chapter 5, Conclusion and future work.

Conclusion of the work is presented in this chapter with recommendations for the future work.