



# Chapter 1

## INTRODUCTION

### 1.1 General

All Induction Melting applied systems are developed using electromagnetic induction which was first discovered by Michael Faraday. 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 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 of a secondary circuit located near it. Heat loss, occurring in the process of electromagnetic induction, could be turned into productive heat energy in an electric heating system by applying this law. Many industries have benefited from this new breakthrough by implementing induction heating for furnacing, quenching and welding.

In these applications, induction heating has made it easier to set the heating parameters without the need of an additional external power source. This substantially reduces heat loss while maintaining a more convenient working environment. Absence of any physical contact to heating devices precludes unpleasant electrical accidents. High energy density is achieved by generating sufficient heat energy within a relatively short period of time.

The demand for better quality, safe and less energy consuming products is rising. Such systems are described in the literature but no commercial design is available. Theoretical aspects are well understood but the practical utility and cost analysis are to be investigated.

The different types of electric heating/melting are Resistance heating, Conduction heating, Infrared Radiation heating, Induction heating, Dielectric Hysteresis heating, Electric Arc heating, Plasma heating, Electron Beam heating & Laser heating.

Resistance heating is the most common type of electric process heating. It uses the relationship between the voltage and current of resistance in Joule's Law.

Conduction heating exploits the heat energy generated when an object is placed between two electric poles, which is another application of Joule's Law. In this case, however, a different relationship exists between voltage and current, especially when the circuit current is high, because the object itself contains both resistance and inductance features.

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).

Generally, semiconductor switching devices operate in Hard Switch Mode in various types of PWM DCDC converters and DC-AC inverter topology employed in a power system. In this mode, a specific current is turned on or off at a specific level of voltage whenever switching occurs. This process results in switching loss. The higher the frequency the more the switching loss, which obstructs efforts to raise the frequency. Switching also causes an EMI problem, because a large amount of  $di/dt$  and  $dv/dt$  is generated in the process.

By raising the switching frequency, the size of a transformer and filter can be reduced, which helps build a smaller and lighter converter with high power density. But as presented earlier, switching loss undermines the efficiency of the entire power system in converting energy, as more losses are generated at a higher frequency. Higher energy conversion efficiency at high frequency switching can be obtained by manipulating the voltage or current at the moment of switching to become zero, which can be subcategorized into two methods: Zero-voltage switching and Zero-current switching. Zero-voltage switching refers to eliminating the turn-on switching loss by having the voltage of the switching circuit set to zero right before the circuit is turned on. Zero-current switching is to avoid the turn-off switching loss by allowing no current to flow through the circuit right before turning it off which was presented by K.H.Liu and F.C.Lee at IEEE INTELEC Conference & IEEE Power Electronics Specialists Conference [1],[2].

## 1.2 State of The Art

This section provides a comprehensive review of the literature pertaining to the different resonant topologies for induction heating, melting applications. Emphasis is given to both historical papers of classical importance, as well as to the current state of the art.

The voltage or current administered to the switching circuit can be made zero by using the resonance created by an L-C resonant circuit. As a resonant converter provides most of the energy conversion efficiency in a power system by minimizing switching loss, it is widely used in a variety of industries. And this is also the reason why the converter is adopted in the Induction Melting Power System Topology.

The resonant converter can be further classified into two major types: a half-bridge series resonant converter and a quasi-resonant converter. K.H.Liu, R.Oruganti and F.C.Lee proposed Resonant topologies & characteristic in IEEE Power Electronics Specialists Conference [3].

H.Ogiwara , A.Okuno and M.Nakaoka presented the paper which was mainly concerned with a resonant capacitor voltage-clamped type half-bridge topology of new instantaneous resonant current vector-regulated high-frequency inverter with phase-shifting control, which efficiently operates at zero-current soft-switched quasi-resonant and load resonant tank circuit sub-resonant hybrid soft-switching schemes. Its analytical results and performance evaluations were described through computer-aided simulating methods [4].

The efficient single ended type high-frequency induction-heating quasi resonant inverter circuit using a single advanced 2<sup>nd</sup> generation IGBT for soft-switching and its specially designed driver IC, which operates at a zero-voltage soft switching(ZVS)mode under PFM-based power regulation strategy was presented by Izuo Hirota, Hideki Omori, Kundu Arun Chandra and Mutsuo Nakaoka. The generic voltage-fed and current-fed circuit versions of single-ended resonant inverters for home power electronics appliances were systematically proposed and classified on the basis of the soft-switched PFM mode inverter family. These new technologies are especially developed for quasi-resonant ZVS high frequency inverter with working coil-linked induction - heating loads. This high-efficient high - frequency quasi-resonant inverter system with high-power factor correction and sine wave line current shaping functions is practically demonstrated including a high-frequency IGBT with reduced saturation voltage characteristics, and discussed on the basis of high-power density home-power electronic appliances in the next generation[5].

A New IGBT half-bridge inverter topology with active auxiliary resonant circuit (A'RC) was proposed by Ryoung-Kuk Lee, Jin-Woo Jung, Bum-Seok Suh and Dong-Seck Syun. The A'RC permits the large lossless turn-off snubber capacitor to be successfully used. Therefore, it makes IGBT be used efficiently in high power and high frequency induction heating system. The operation principle and the design procedures of the proposed A'RC are described in detail [6].

Wang, S.; Izaki, K.; Hirota, I.; Yamashita, H.; Omori, H.; Nakaoka, M. presented a new prototype of a voltage-fed quasi-load resonant inverter with a constant-frequency variable-power (CFVP) regulation scheme, which is developed for the next-generation high frequency high power induction heated appliances. This application specific high frequency single ended push pull inverter using new generation specially designed insulated gate bipolar transistors (IGBTs) can efficiently operate under a principle of zero-voltage switching pulse width modulation (ZVS-PWM) strategy [7].

### 1.2.1 Half-bridge Series Resonant Converter

The merits of a half-bridge series resonant converter are: stable switching, low cost, and a streamlined design. As the voltage of the circuit is limited to the level of the input voltage, the switching circuit can have low internal pressure, which helps reduce the cost. The design of the switching control component, inside a circuit, can be streamlined. There are also some demerits. As the half-bridge method requires two switching circuits, the overall working process becomes more complicated and the size of the heat sink and PCB should also be larger. In addition, the gate operating circuits must be insulated.

### 1.2.2 Quasi-resonant Converter

One of the merits of a quasi-resonant converter is that it needs only one switching circuit inside. This enables a relatively smaller design for the heat sink and PCB, making the working process far simpler. Another strong point is the fact that the system ground can be shared. A quasi-resonant converter is not free from defects. Most of all, switching is relatively unstable. And high internal pressure of the switching circuit, caused by the resonant voltage administered to both sides of the circuit, pushes the cost of the circuit higher. Besides, the design for the controlling component is more complicated. But as mentioned earlier, technological improvements in high frequency semiconductor switching devices has lead to innovation in terms of low price, high performance, and reliability.

## 1.3 Motivation

As a resonant converter provides most of the energy conversion efficiency in a power system by minimizing switching loss, it is widely used in a variety of industries. And this is also the reason why the converter is adopted in the Induction Melting Power System Topology, which is the major area of work for this thesis.

Project envisages the development of Embedded Controller to improve the performance of Induction Melter. Ideas of the practical application of such a Melter for Gold & other metals with all next generation facilities and cost benefit analysis have to be looked into detail. The project provides sufficient insight into these aspects. The technical report discusses technical and economical competitiveness of the prototype. Commercialization of the technology is positive.

Hence the motivation behind the research work reported in this thesis was

1. To design and implement 3-ph power circuit based on a new-generation of power semiconductor devices (IGBT's) & driver cards.
2. Development of MMI & Embedded controller board around LPC2478 ARM processor.
3. Designing of Coil, Capacitor, power circuit & developing controller hardware.

4. Proposal and implementation of modification in quasi-resonant power circuit to eliminate large amount of filter capacitors.
5. Simulation study of the design setup including power circuit & control circuit.
6. Development of Controller software.
7. Developing algorithm for auto-tuning PID using Ziegler-Nichols Frequency Domain method.
8. Software development using Keil Real-View for LPC2478 ARM processor.
9. To explore new concept to melt gold/silver.

## 1.4 Thesis Organization

The chapter 1 provides a preview and the context for the remainder of the thesis.

In chapter 2 the introduction is given on the induction melting application and problem, which presents a brief state-of-art survey of research work carried out in the area of induction melting. Various power topologies are presented and the need for resonant converter is explained. The various resonant topologies have been presented for switching devices. The latest development on melting application and problem has been reviewed and lays down the motivation behind the research work carried out.

In chapter 3 a quasi-resonant converter has been proposed, to reduce total switching loss. The design and implementations of a quasi-resonant converter for melting at a high temperature has been carried out.

In chapter 4 a modified quasi-resonant converter is proposed to eliminate large amount of filter capacitors. It also includes the simulation study of control strategy using MATLAB/SIMULINK.

Chapter 5 discusses Design, Analysis and Simulation of power circuit for the proposed topology. The chapter includes the implementation of Power circuit.

Chapter 6 describes the development of the control circuit for quasi-resonant converter. It also contains the development and design of main generator card with new generation SCALE-2 IGBT-driver circuits.

Chapter 7 discusses the software implementation for micro-controller board & Embedded controller (ARM-7) board. As well as development and design of MMI with TFT, touch screen and all modern facilities are presented. Chapter 8 deals with the experimental verification of proposed induction Melter. The auto-tuning algorithm, the temperature accuracy and efficiency is verified.

In chapter 9 final conclusions and future extension of the work and future scope in this field are elaborated.