SYNOPSIS

For the Ph.D. thesis

"Design, Simulation & Implementation of Embedded Controller For Induction Melting machine employing optimal Resonant converter"

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Research Scholar:
Mr. Hiren M. Shah

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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 is the frequency the more are 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, you can reduce the size of a transformer and filter, 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. This is called "Soft Switching", 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 [1] is to avoid the turn-off switching loss by allowing no current to flow through the circuit right before turning it off. The voltage or current administered to the switching circuit can be made zero by using the resonance created by an L-C resonant circuit. This topology is named a "resonant converter."[5]

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.

The resonant converter can be further classified into two major types: a half-bridge series resonant converter and a quasi-resonant converter. Due to single switch requirements the quasi-resonant converter is chosen for the work.

Refractory material is required between the charge and the induction heating work coil[2]. This can be either a rammed monolithic refractory or of a preformed-crucible construction. Conducting crucibles are essentially reformed high temperature refractory pots made in different shapes and sizes, which have relatively-low electrical resistivity ranging typically from 10 " 5 Qm to 6 x 10 ~4 Qm at room temperature. Conducting crucibles made of carbon-bonded silicon carbide have resistivity from 10"5 Qm to 10~4 Qm, whereas the resistivity of clay-bonded graphite crucibles is up to 6 x 10 " 4 Qm at room temperature. The flexibility of production associated with the melting of nonferrous metals in portable crucibles or tilting furnaces with preformed crucible linings is well suited to foundries where relatively small amounts (typically less than 200 kg) of different metals or alloys are required.

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 in to 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. For the proposed work LPC2478 ARM controller was chosen for its following features.

NXP Semiconductors designed the LPC2478 microcontroller, powered by the 16-bit/32-bit ARM7TDMI-S core with real-time emulation, to be a highly integrated microcontroller for a wide range of applications that require advanced communications and high quality graphic displays. The LPC2478 microcontroller has 512 kB of on-chip high-speed flash memory. This flash memory includes a special 128-bit wide memory interface and accelerator architecture that enables the CPU to execute sequential instructions from flash memory at the maximum 72 MHz system clock rate. The LPC2478, with real-time debug interfaces that include both JTAG and embedded trace, can execute both 32-bit ARM and 16-bit Thumb instructions.[39,42]

The LPC2478 microcontroller incorporates a TFT controller, a 10/100 Ethernet Media Access Controller (MAC), a USB full-speed Device/Host/OTG Controller with 4 kB of endpoint RAM, four UARTs, two Controller Area Network (CAN) channels, an SPI interface, two Synchronous Serial Ports (SSP), three I2C interfaces, and an I2S interface. The very high speed execution & all modern peripheral support the need of next generation facilities and powerful controlling can be accomplished using LPC2478 ARM controller.

The use of software development support tools [24] such as MATLAB, SIMULINK and Tool Boxes [25,26] makes simulation study as well design of graphical user interface simpler.

The work described in the thesis includes:

1. Design and implementation of 3-ph power circuit based on a new-generation of power semiconductor devices (IGBT's) & driver cards.
2. Development of MMI & 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. [27,28]
9. To explore new concept to melt gold/silver.

The thesis is organized in the form of ten chapters as follows:

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

Chapter: 2 Introduces 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.

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.

Chapter: 4 A modified quasi-resonant converter is proposed to eliminate large amount of filter capacitors. 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 It discusses the software implementation for micro-controller board & ARM-7 board. As well as development and design of MMI with TFT, touch screen and all modern facilities are presented.

Chapter: 8 It deals with the experimental verification of proposed induction Melter. The auto-tuning algorithm, the temperature accuracy and efficiency is verified.

Chapter: 9 Final conclusions and future extension of the work and future scope in this field are elaborated in this chapter.

Chapter:10 Thesis ends with Bibliography which includes the list of references used in each chapter and list of publications and presentations done based on this work.