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Design and Control of Medium Frequency Induction Furnace for Silicon Melting

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Abstract*— This project is an effort to design an Induction Furnace with better controllability and power efficiency. The hardware implementation considered the fallowing points while designing i.e. Solid state power sources used to drive induction heating loads are very efficient when the load is driven at its natural resonant frequency. This allows zero voltage (ZVS) and or zero current (ZCS) switching of the converter, resulting in reduced power losses in the semiconductor switches. Another advantage of driving a load at resonance is to enable an input power factor close to unity allowing minimal KVA consumption. Environmental cleanliness is another added advantage. The process consists of three phase rectifier to convert three phase AC to filtered DC. Then using an H-Bridge inverter, it is converted back to high frequency single phase AC, with control circuitry. The furnace coil and a capacitor form a resonant tank circuit. The metal to be heated is placed in the coil, resulting in shift in the frequency. The resonant tank circuit is returned via frequency control circuit to achieve resonance and to enable maximum power transfer to the load at all time.

Index Terms— **Power rectifier, H-Bridge, Work Coil, Work Piece, Control Circuitry.**

I. INTRODUCTION

Induction heating is a non-contact heating process. It uses high frequency AC to heat materials that are electrically conductive. Since it is a non-contact type heating process, it does not contaminate the material being heated. Similarly, the molten material does not contaminate the heating element or source. It is also very efficient since the heat is actually generated inside the"work-piece", thereby preventing chances of leakage of heat. This can be contrasted with other heating methods where heat is generated in a heating element, only a part of which is then utilized to heat-up the work-piece. A sizeable fraction of the heat is un-utilized lowering the heating efficiency. Over and above there is minimal environmental pollution. For these reasons, induction heating lends itself to some unique applications in the industry.

In convectional silicon melting like zchoralski, industrial grade silicon is purified to semiconductor grade and poured into ingots. These ingots are later processed and converted into silicon wafers. The process of wafer formation is very tedious and often leads a lot of rejections. Hence adds to the production cost. To overcome these shortfalls we propose to make use of induction melting for silicon.

II. OBJECTIVE OF THE PROJECT

The objective of this project is to design an efficient and controlled induction furnace especially dedicated to melt silicon. We are making an attempt to design a medium frequency induction furnace with enough power output to melt silicon and to maintain temperature. The schematic diagram wave verified with LT spice and later Hardware implementation is carried out.

III. BASIC PRINCIPLE

The electric induction furnace is a melting furnace, uses electric current to melt electrically conductive materials. Induction furnaces are widely used for melting a wide variety of metals with minimum melt losses. The Block Diagram of Induction Furnace is as shown in fig1. The principle of induction furnace is Induction heating. Induction heating is a form of non-contact heating for conductive materials. In induction heating a source of high frequency is used to drive a large alternating current through a coil. This coil is known as the work coil. The passage through this coil generates a very intense and rapidly changing magnetic field in the space within the work coil. The work-piece to be heated is placed within this intense alternating magnetic field. The alternating magnetic field induces a current in the conductive work-piece. The arrangement of the work coil and the work-piece can be thought of as an electrical transformer. The work coil forms the primary where electrical energy fed in, and the work-piece forms a single turn secondary that is short-circuited. This causes high currents to flow through the work piece. These are known as eddy currents. In addition to this, the high frequency used in induction heating

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applications gives rise to a phenomenon called skin effect. This skin effect forces the alternating current to flow in a thin layer towards the surface of the work-piece. The skin effect increases the effective resistance of the metal to the passage of the large current. Therefore it greatly increases the heating effect caused by the current induced in the work-piece.

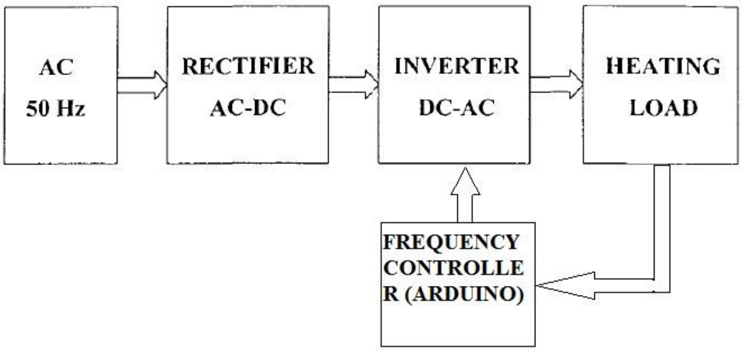

Fig 1: General Block Diagram of a Furnace

The Frequency control circuit is used to generate switching signals with appropriate PWM based on load variation. The controller circuitry which provides the switching signals to the inverter MOSFET switches. To enable maximum power transfer to the load at all times the frequency of induction furnace is controlled with the help of Frequency control circuit.

There are three things essential to implement induction heating:

• A source of high frequency electric power.
• A work coil to generate the alternating magnetic field.
• Frequency Control Circuitry
• An electrically conductive work piece to be heated.

IV. IMPLEMENTATION OF INDUCTION MELTING

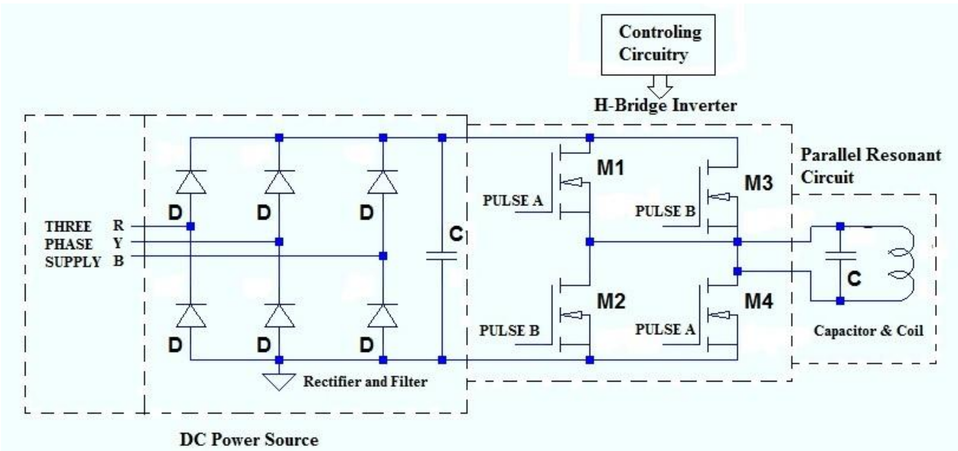

Fig 2: Schematic Diagram of Induction Furnace

The Schematic Diagram of Induction Furnace is as shown in fig2.

- The induction furnace consists of DC power source, Inverter, Frequency control circuitry and load
- A DC power source is derived from rectified mains voltage and filter. This DC power is fed to the H-bridge inverter.
- In the full-bridge load-resonant inverter MOSFET switches are operated in alternate pairs to generate the high frequency alternating current to produce strong eddy currents in the heating coil. The inverter operates at the resonant frequency of the load circuit thereby allowing zero voltage switching; hence no external high speed diodes are needed across the MOSFET switches to carry reactive freewheeling current. The result being that the total switching losses in the inverter are reduced and increasing the inverter efficiency.

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- The Frequency control circuit is used to generate switching signals.
- The gating and gate drive circuitry which is used to convey the switching signals to the inverter MOSFET switches.
- The load consists of induction heating work-coil in which the work-piece is placed.
- A capacitor bank is used to resonate with the reflected inductance of the load at the required frequency.
- The placing of work-piece in the heating work-coil tends to change the frequency characteristic of the load circuit. This results in change in the resonant frequency. This facilitates the need for frequency control to ensure maximum power transfer.
- The resonant frequency of the work coil is tuned and maintained constant by controlling the switching signals of H-Bridge inverter. The amount of correction in frequency is directly proportional to the frequency error.
- To enable maximum power transfer to the load at all times the frequency of induction furnace is controlled with the help of Frequency control circuit.

A. Rectifier

Rectifiers are the circuits used to convert an alternating current (AC) to direct current (DC), a process known as Rectification. This involves a device that only allows one-way flow of current. As we know that a semiconductor diode does this.

- ***Three Phase Bridge Rectifier***

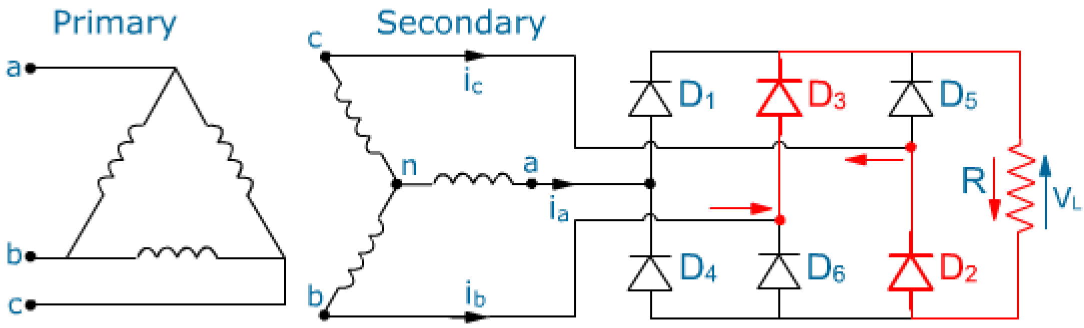

Fig 3: Three Phase Bridge Rectifier Circuit Diagram

The circuit of a three-phase bridge rectifier is as shown in fig3. The conduction sequence for diodes is 1&2, 2&3, 3&4, 4&5, 5&6 and 6&1. In one cycle, each pair of diodes conducts for 60o and each diode conducts for 120o. The pair of diodes connected to the supply lines with the highest instantaneous line-to-line voltage will conduct. The line voltage is 1.73 times the phase voltage of a three-phase star-connected source. It is permissible to use any combination of star- or delta connected primary and secondary windings because the currents associated with the secondary windings are symmetrical.

B. Inverter

Inverters are circuits that convert dc to ac. We can easily say that inverters transfer power from a dc source to an ac load. The objective is to create an ac voltage when only a dc voltage source is available. A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. On the other hand, if the dc voltage is fixed & not controllable, a variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by pulse-width-modulation (PWM) control within the inverter. The inverter gain can be defined as the ratio of the ac output voltage to dc input voltage.

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- ***H-Bridge Inverter***

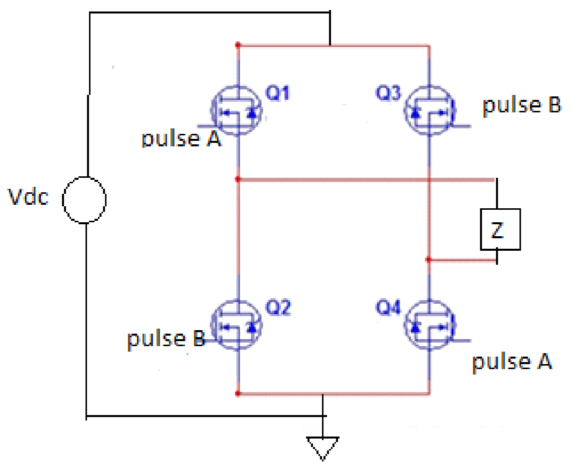

Fig 4: H-Bridge Inverter Circuit Diagram

In this project, the design and simulation of an interconnected H-bridge single phase inverter was explored. The inverter design was divided into three separate sections. Power electronics was used to create an inverter circuit to change a DC input to a high frequency AC output. Additional circuits were used to link the generated control signals to the MOSFET transistors of the inverter circuit. The operation of the three components is validated with computer simulations. Results of computer simulation demonstrate the operation of the proposed single-phase inverter.

With the use of power diodes we get efficient single-phase inverter. The conventional technology used for single phase inverters typically consists of either square-wave or PWM inverters. The square wave type is the simplest method to produce AC from DC.

This project proposes an improved version of H-BRIDGE inverter using MOSFET's connected in such a way that N-MOS MOSFETS fires at positive half cycle and P-MOS MOSFETS fires at negative half cycle, thereby reducing the switching activity and thus current consumption. With the conventional square wave inverter, there are pulses generated by the controller to mimic an AC output.

C. Control Circuitry

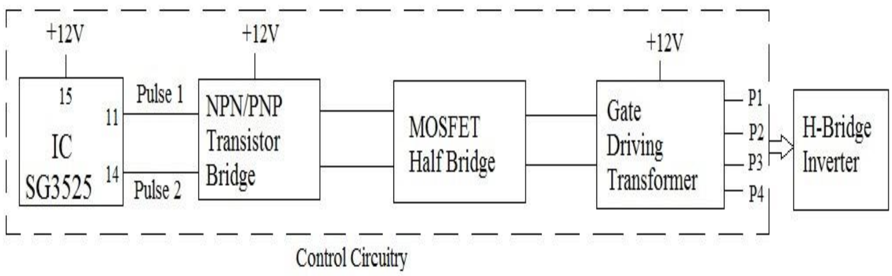

Fig 5: Control Circuitry

The control circuitry mainly consists four parts:

- Pulse Generation IC SG3525
- NPN/PNP Transistor Bridge
- MOSFET Half Bridge
- Gate Driving Transformer

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- ***Pulse Generation IC SG3525***

The IC SG3525 is a single package multi function PWM generator IC. IC generates dual pulses from Pin No. 11 and14, with dead pulse to protect the switches. The pulses generated by the IC are as shown in figure 6.

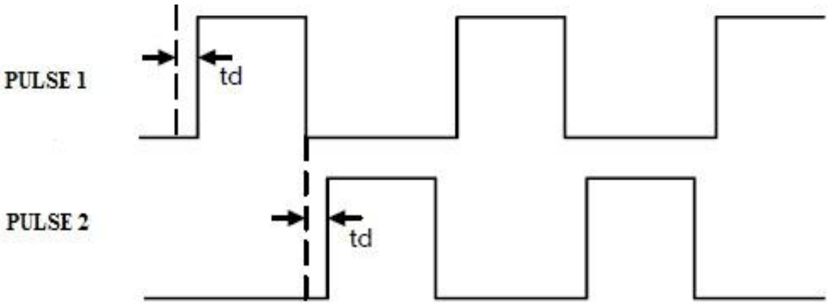

Fig 6: Pulses generated from IC SG3525

- ***Gate Driving Transformer***

The Gate Driving (Ferrite) transformer consists of centre tapped primary winding and four windings at the secondary side. This generates four separate pulses to H-Bridge Inverter.

D. Working of Control Circuitry

- Pulse generation IC SG3525, generates dual pulses from Pin No. 11 and Pin No. 14, with dead pulse. The pulse generations of these two pins are as shown in figure 6. We can see that pulses generated are alternate with each other. These two pulses are applied to the gates of the transistors of NPN/PNP transistor bridge.
- The NPN/PNP transistor bridge is a circuit where Pulse1 is applied to the gates of the transistors at the left hand side i.e. to the NPN1 and PNP1 and pulse2 is applied to the gates of the transistors at the right hand side i.e. to the NPN2 and PNP2. When Pulse1 is high, transistors NPN1 and PNP1 are on and there is flow of current takes place through these two transistors to the ground and voltage generated at the emitter junction is applied to gate of a MOSFET1. When Pulse2 is high, transistors NPN2 and PNP2 are on and there is flow of current takes place through these two transistors to the ground and voltage generated at the emitter junction is applied to gate of a MOSFET2. i.e. Pulse1 turns On MOSFET1 and Pulse2 turns On MOSFET2. This circuit is used to give more power and to protect the IC
- The MOSFET half bridge circuit consists of two MOSFET's with drains of the MOSFET's are connected to either ends of the primary windings of centre tapped gate driving transformer and at the centre 12V DC is applied. When MOSFET1 is turned On current flows in upward direction and at the secondary four windings generates four pulses to the four MOSFET's of H-Bridge Inverter, with polarity start (+) point on top and end (-) point on bottom. When MOSFET2 is turned On current flows in downward direction and at the secondary four windings generates four pulses with polarity start (+) point on bottom and end (-) point on top i.e. in opposite direction. These pulses controls the switches of H-Bridge.

E. Frequency Controller logic

The frequency control circuit involves in sensing the final output voltage, and based on that we are dividing the total of 2^{10} (1024) binary values of arduino to assign them for different duty cycle pulses to keep the output frequency magnitude same. The frequency control operation of induction furnace involves in following steps

- The controller board receives the sensed final AC output across the coil as input.
- It compares input with constant voltage 1V,if it is less than 1V then duty cycle will be set to 20%.
- If the input voltage is between 1V to 2V,duty cycle of the pulse will be set to 40%.
- If the input voltage is between 2V to 3V,duty cycle of the pulse will be set to 60%.
- If the input voltage is between 3V to 4V,duty cycle of the pulse will be set to 80%
- If the input voltage is between 4V to 5V,duty cycle of the pulse will be set to 100%
- The loop will be repeated infinitely

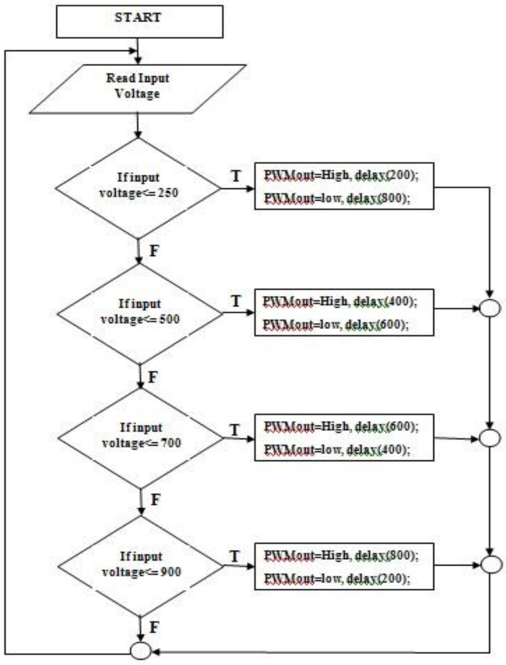

Fig 7: Flow Chart

V. RESULTS

A. Final Simulation Result

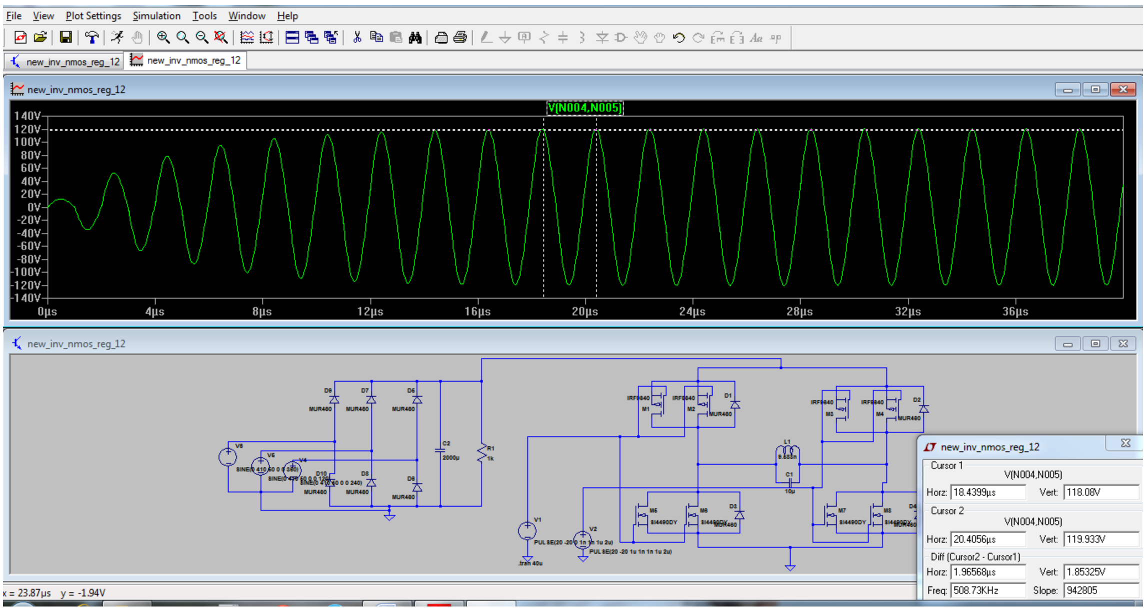

Fig 8: Final Simulation Result

In this project, the design and simulation of an interconnected Full wave rectifier and H-bridge single phase inverter was explored. The inverter design was divided into three separate sections. Power electronics was used to create an inverter circuit to change a DC input to a high frequency AC output. Additional circuits were used to link the generated control signals to the MOSFET transistors of the inverter circuit. The operation of the three components is validated with computer simulations. Results of computer simulation demonstrate the operation of the proposed single-phase inverter.

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This project proposes an improved version of H-BRIDGE inverter using MOSFET's connected in such a way that N-MOS MOSFETS are used as the pull-down devices and P-MOS MOSFETS are used as pull-up devices, firing of these devices must be such that the current must carrying in either direction for pulse width modulation, just as they did for square wave operation. Feedback diodes across the switching devices are necessary to safe guard the MOSFETS. Another consequence of real switches is that they do not turn on and off instantly. Therefore it is necessary to allow for switching times in the control of the switches, just as it was for square wave inverter.

B. Final Hardware Result

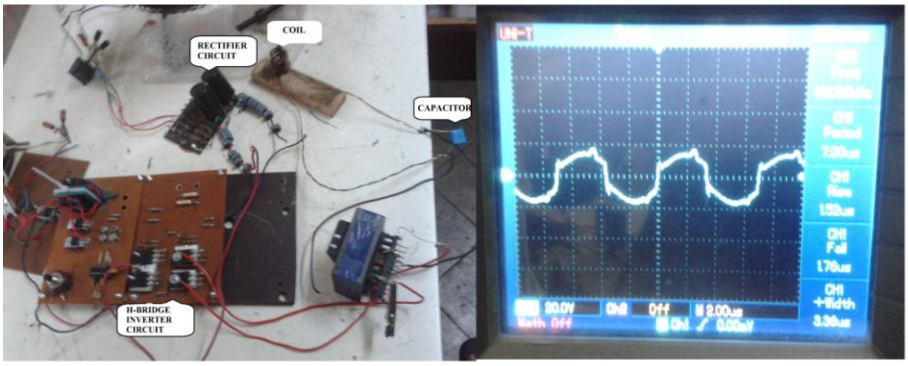

Fig 9: Final Hardware Setup and Output

The above figure shows the Final Hardware Assembly with Work Coil. The LC tank resonated at a frequency of 140 KHz. The work piece to be heated is placed in the heating coil. The high frequency alternating current flowing through the heating coil creates magnetic field around the coil, due to the presence of work piece in magnetic field eddy current is generated in work piece in the opposite direction of induced current and the work piece gets heated. The eddy current is increased by increasing the current frequency in the coil with the help of power electronic components.

VI. CONCLUSION

The project is aimed at design and development of hardware for Three Phase Full Wave Rectifier, H-Bridge Inverter topology and controlling circuitry i.e. generation of pulses for H-Bridge Inverter. The Three Phase Full Wave Rectifier, H-Bridge Inverter and Controlling circuitry has been designed for the required specifications and the necessary hardware has been developed, assembled and tested.

The hardware setup of the project consists of:

- Three Phase Full Wave Rectifier circuit.
- The H-Bridge Inverter circuit.
- The Control Circuitry for the generation of gating signals to the MOSFET's of H-Bridge Inverter.
- The load consists of induction heating work coil in which the work piece is placed.

The generation of high frequency and high voltage is successfully implemented and tested.

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REFERENCES

[1] M. Roy, M. Sengupta, FPGA based control of a self starting CSI fed 2KW, 9.8KHz induction heating unit, Department of Electrical Engineering, Bengal Engineering and Science University, Shibpur, Howrah, W.B., India.

[2] Khan, J. Tapson and I De Vries, "Automatic Frequency Control of an Induction Furnace", Proc. IEEE Coil, Africon '99, vol.2, September 1999.

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[3] Khan, HA Miniature High Frequency Induction Furnace", B.Tech School of Electrical Engineering, Cape Technikon, November 1998.

[4] Ralph Locher, "Introduction to Power MOSFET's and their Applications", Application Note 558, Faiechild Semiconductor, October 1998.

[5] Muhammad H. Rashid, "Power Electronics" (Third Edition, Pearson Prentice-Hall, 2007).

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