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Contributions to Optimization of Functioning of Induction Heating System Using Simulink

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Abstract : This paper presents complete modeling of induction heating system comprising (Rectifier Filter, Inverter, Digital PLL control block and work coil) for high frequency around 100 KHz and high Power around 100Kwatt applications. The Modeling is done using Simulink & results at all the stages are presented.
Keywords: PLL.

I. INTRODUCTION

Induction heating is the process of heating an electrically conducting object (usually a metal) by electromagnetic induction, where eddy currents are generated within the metal and resistance leads to Joule heating of the metal. An induction heater consists of an electromagnet, through which a high-frequency alternating current is passed. Heat may also be generated by magnetic hysteresis losses in materials that have significant relative permeability. The frequency of AC used depends on the object size, material type, coupling (between the work coil and the object to be heated) and the penetration depth.
A very crude system block diagram is shown below which roughly outlines the proposed system.

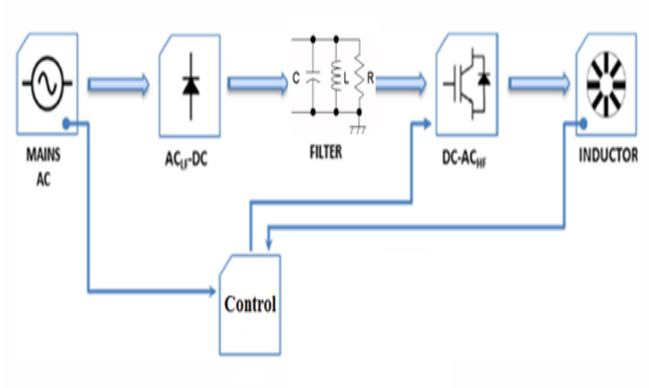

Figure 1 Basic Block Diagram of Induction Heating system.

The AC supply which may be single phase or three phase depending upon the scale of the application, is converted to DC by using rectifier and filter. The DC voltage thus obtained is given to inverter which converts DC to AC. The inverter output is given to a coil which is to be heated, also called as work-piece or work-coil in which the object to be heated is placed without any contact.
The induction heating application requires high active power (more than 100kW) and at the same time operates at frequencies around 100 kHz.

Due to the high frequency, the suggested converters are mainly set up with MOSFETs. This is an economically feasible solution only for lower power requirements. The developments in IGBT-technology make it possible to build more compact and cheaper converters for higher frequencies using IGBTs. At high power high frequency, the IGBT losses are very important and the IGBT losses are totally dominated by the turn-off losses. The maximum output power rating of the inverter is mainly limited by the IGBT losses.
This paper investigates the Simulink model of complete Induction heating system comprising rectifier, filter, Inverter, Digital PLL control system & work coil, working at High frequency around100KHz and high power around 100Kwatts.
Simulink results for all stages are presented and discussed.

II. SIMULINK MODEL: RECTIFIER AND FILTER

The very first step of converter system is rectifier. It converts given AC into DC. It consists of four diodes for Full wave Rectification . The Capacitor Filter is used to remove ripples in output of Rectifier(To convert Rippled DC into constant DC). Simple diode rectifier was modelled in simulink with proper filter capaciter value to get constant dc at the output.

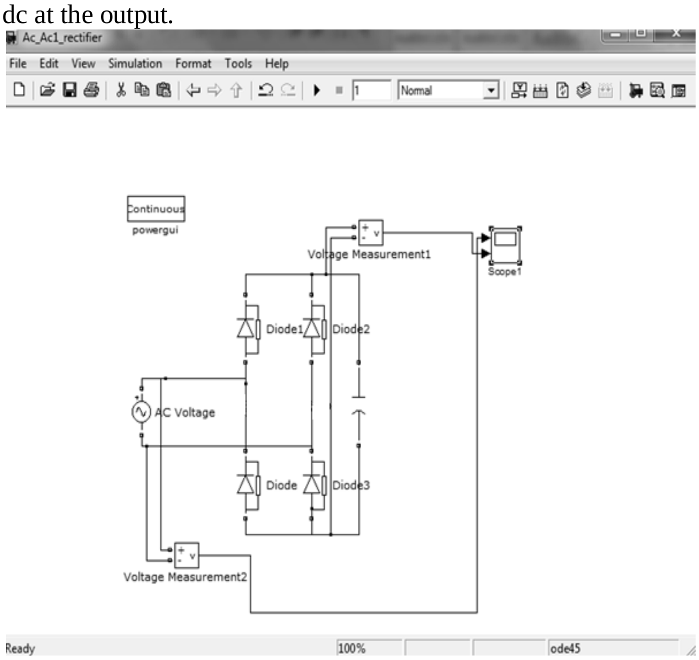

Figure2 Simulink model of Rectifier & C filter

Specifications : AC voltage : 230 Vrms , 50 Hz
Snubber Resistance =500ohms
Checked output for different values of C from C=100uF, 1000uF, 10^4 uF, 10^5 uF, 1F &10F.

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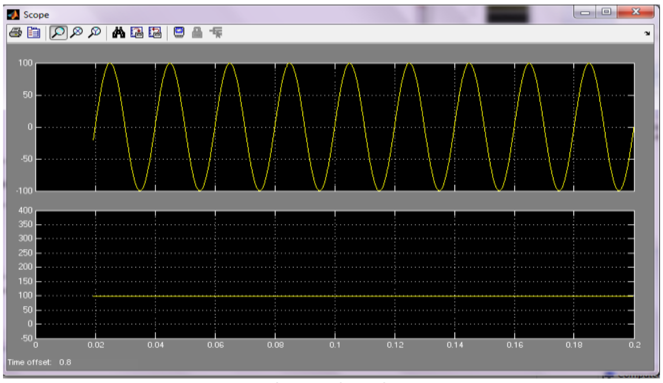

Figure 3 Output of rectifier for C= 1Farad

Conclusion : For C= 1F output ripple is nearly zero, we get constant DC at the output of rectifier.

III. SIMULINK MODEL : INVERTER

Inverters are circuits that convert dc input voltage to a ac output voltage by which both magnitude and frequency can be controlled.

Voltage-fed series resonant inverters: In series resonant tanks, the inductor is connected in series with the capacitor. In this case, the tank behaves as a current source and the inverter used is a voltage-fed inverter, which means that the inverter is fed with a constant voltage source. This implies that the inverter is fed by a capacitor with a high capacitance value that maintains the voltage constant.

In most applications above 5 kW, the inverter used is the H-bridge. This topology is used because it allows transmitting the same power with less current for a given voltage. This is the reason why the H-bridge is the inverter used during the whole study. In voltage-fed inverters, two switches of the same inverter leg cannot be turned-on at the same time, otherwise short-circuit occurs. The time between the turning-on of one of these switches and the turning-on of the other is called dead-time. In this topology, antiparallel diodes are necessary to allow inductor's current conduction when the opposite switches are turned-on.

However, it is assumed that switches SW1 & SW4 and SW2 & SW3 commutate alternatively with a duty-cycle of 50 % and the power is controlled by varying the voltage of the source.

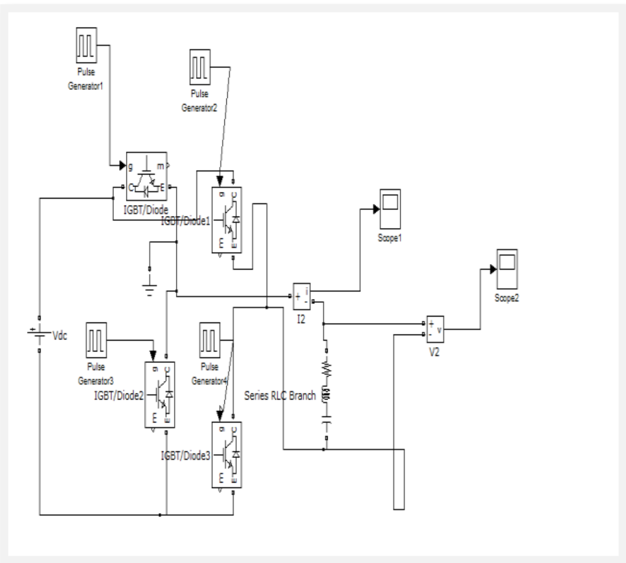

Figure 4 Simulink model of IGBT Inverter

Concluded value of Load for proper output waveforms : R=5.75Ω, L=154uH ,C=5.62nF , Snubber resistance-26.6Ω, Snubber capacitance = 30nF
Inverter output voltage 560V
Inverter output current 120A

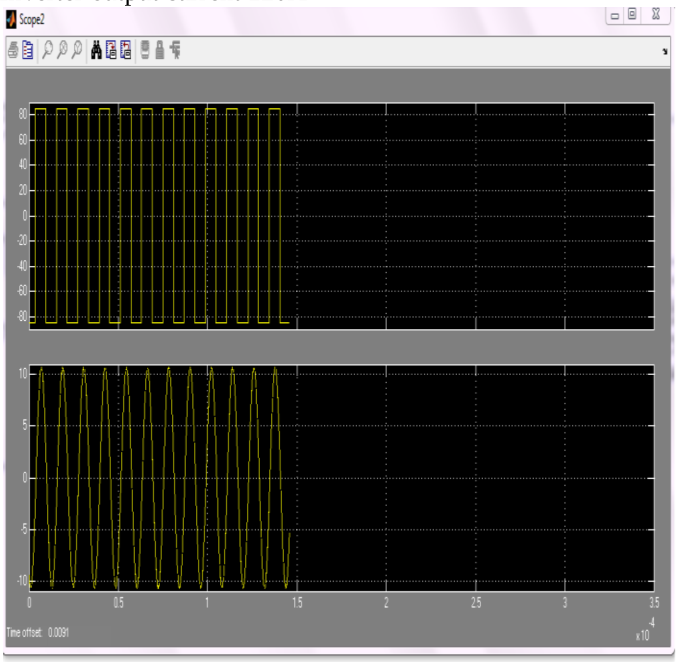

Figure 5: Inverter output Current & Voltage

Triggering Pulses are generated for the 4 IGBTS using Digital PLL block.:Parameters for Pulse generator to drive IGBTs : Resonating Frequency-170.84kHZ

Conclusion:Simulink Models of IGBT & MOSFET Inverters were designed and compared for typical Induction Heating application & it was found that the IGBT offers low on resistance and requires very little gate drive power, it is widely used in generators with frequencies up to 100 kHz, but the frequency about 400 kHz is hard to achieve for the state-of -the art IGBT. MOSFET has the advantages like high switching speed (the turnoff time of 36A/1000V MOSFET is less than 75 ns), easy to be paralleled, so MOSFET is used in the range of high frequencies (in the range of 100-800 kHz) and high-power applications.

IV. SIMULINK MODEL OF ENTIRE SYSTEM

Dead Time - Due to parasitic capacitances associated with IGBT the switching of IGBTs takes more than zero time as assumed in theory, the time needed for complete turn-off or turn-on of IGBT is dead time. Formula of dead time td,

$$t_d \geq \frac{1}{\omega} arccos\left(1-\frac{2\omega U_e C_p}{\hat{i}_{tank}}\right)$$

Where Ue – peak output voltage measured
Itank- peak output current measured
Cp- parasitic capacitance associated with IGBT
w- 2*pi*frequency of the system

Method to accommodate dead time - Gate pulses are separated by time greater than dead time.

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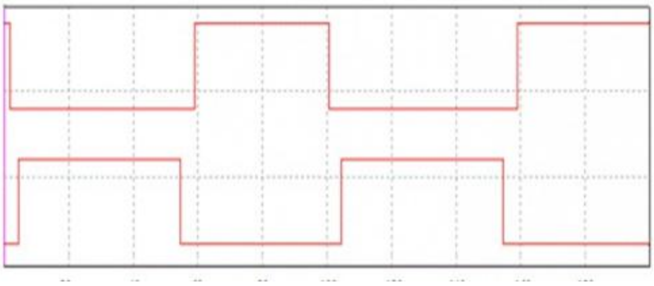

**Figure 6 a) Gate pulses for SW1 & 4 ,
b) Gate pulses for SW2 & 3**

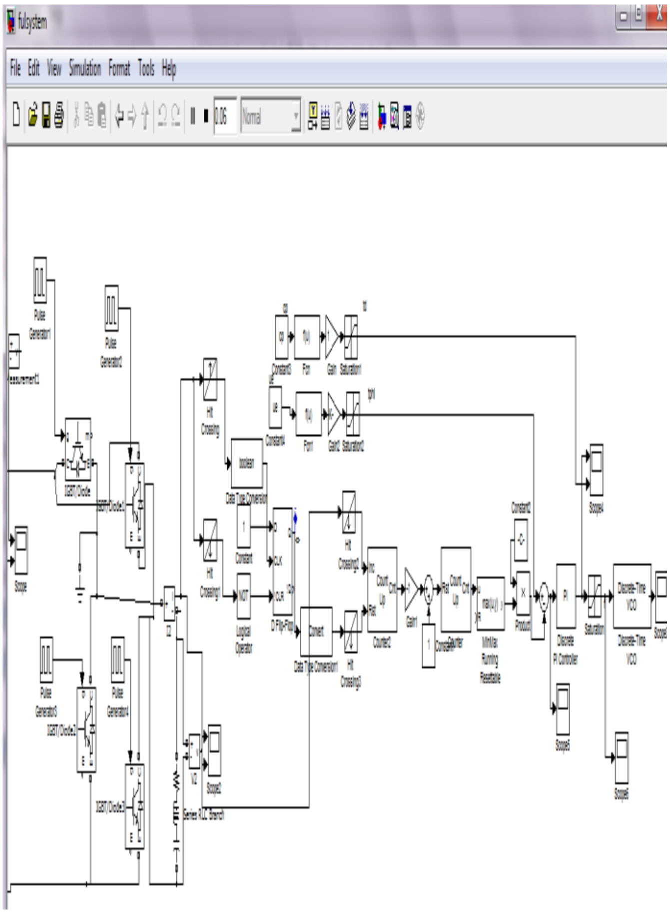

Figure 7 Simulink Model of entire system with digital PLL

Conclusion : The comparison of different Rectifier filter & inverter topologies was done by modeling them in Simulink and the merits and demerits of each were studied. From this exercise we concluded that the best topology depends upon the application. For low power applications, single unit of inverter is enough. However, for high power applications, multiple inverters are needed to be connected in Cascade. The switching device selection also depends upon the frequency required for the applications. IGBTs Inverters are used upto 100KHZ and are not generally used for very high frequency operations due to high switching losses.

The implantation of the idea of testing the control block on Simulink models of actual system was initiated. The efforts to connect the independently working blocks were done.

The tried & tested component values of simulink models can be used for actual Hardware Implementation work.

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