MATLAB Simulation of Inverters for Induction Heating System
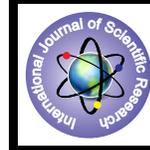
Engineering

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ABSTRACT   This paper presents simulation of Inverters using IGBT, MOSFETS & PWM Technology for harmonic reduction using uniform & non uniform pulses for a typical Induction Heating system. The Simulation is done in MATLAB & Results for all Inverters are presented.

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.
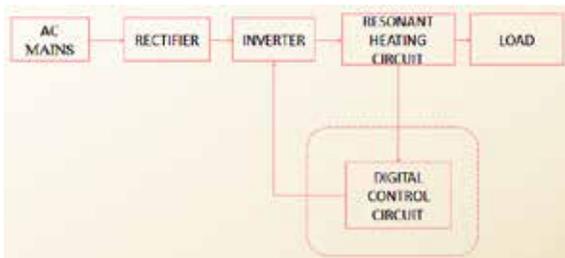

Figure 1 Basic Block Diagram of Induction Heating system.

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. To realize this high power frequency product, several inverters or several power semiconductor devices have to be connected in parallel, because the maximum rating of a single inverter unit is often far below the required rated power. 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 MATLAB codes & simulation results for Full wave voltage series Inverters using MOSFETS, IGBTs & PWM technology for different component values in order to check which adapts to the Induction heating systems working at High frequency around100KHz and high power around 100 watts.

II. INVERTER OPERATING PRINCIPLE

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

Classification of Inverters:
- VSI-voltage source inverter
- CSI –current source inverter
- Square wave inverter
- PWM inverter

Voltage-fed inverter and current-fed inverter are two most popular technologies for high power applications .In the first case, the heating inductor is compensated with a capacitor in parallel, and in order to block the inverse voltage a fast recovery diode in series with power device is needed, which increases the power losses. Additionally, the stray inductance between the inverter output and the resonant tank may cause switching losses and parasitic oscillation, and influence the output power, so cable connections are quite sensitive for it. While in the second case, the compensation capacitor is placed in series with the heating inductor, and for this type inverter, if the cable is a bit long, only operating frequency will be changed and it has little influence on the output power and efficiency.

In **Square wave inverter** closing and opening of the switches should be in appropriate sequence. Disadvantage is the output changes only when input DC is changed.

In **Pulse width modulated Inverters** (PWM) depending on the required output response one or More Pulses can be in each half cycle. PWM technology is used in Inverters to give a steady output voltage of 230 or 110 V AC irrespective of the load. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage. Advantage of the system is The output voltage control with this method can be obtained without any additional components. With the method, lower order harmonics can be eliminated or minimized along with its output voltage control. As higher order harmonics can be filtered easily, the filtering requirements are minimized, output harmonics can be controlled by increasing the no of pulses. The main disadvantage of this method is that SCRs are expensive as they must possess low turn-on and turn-off times.

The inverter output current i_{tank} and the inverter output voltage u_{tank} are measured with high-frequency voltage transducers with negligible delay and the zero crossings of these voltages are detected and compared. The output of the comparator is filtered to yield a DC voltage proportional to the phase difference between the inverter voltage and current. This voltage is isolated and applied to the analogue input of the DSP.

The switching frequency has to be adjusted so that this difference is made zero. When this condition is achieved, the capacitor and the inverter voltages are in quadrature, which ensures that the inverter voltage and current are in phase.

The pulse width modulated (PWM) outputs of the DSP are used to generate switching pulses for the inverter IGBTs.

III. SIMULATION RESULTS

MATLAB code is written for Full Bridge inverter to obtain square wave AC output voltage and analyze the harmonics.

Formulae in code:
phi = atan(2*pi*f*L/R);   phase angle
Z = R + (i*2*pi*f*L); reactance at 50 Hz
t1 = [0:td:pi]; Angles in first half cycle
t2 = [pi:td:2*pi];   ngles in second half cycle

[f,voh,ph] = harmonic(vo/Vs); harmonic component with 10 harmonics
voh1 = 2 * (abs(voh))/n;
VO2 = voh(2); Fundamental component
vo2 = VO2*sin(t); Sinusoidal of fundamental component.

IO2 = 4*Vs/(pi*abs(Z));
io2 = IO2*sin(t-phi); output current lags behind Plot of Inverter output voltage & current is plotted V/s Time.
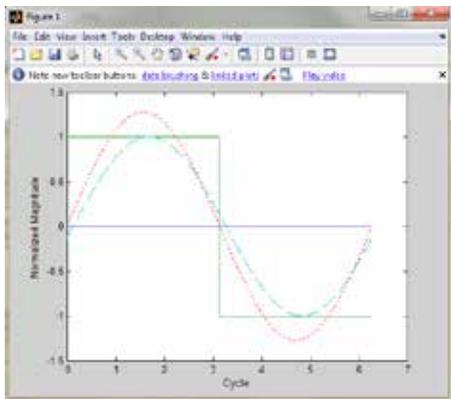

Figure 2 : Output of Full Bridge Inverter
Fundamental component represented in Red colour , Green : AC output voltage, Blue : output current lags behind by phi.

Sr. no.	R (ohms)	L (mHenry)	F (Hz)	Phi (radians)	Phi (degrees)
1	100	1	200	0.1250	7.16
2	100	1	2k	.8986	51.48
3	100	1	1000k	1.5706	89.9909
4	500	1	1K	0.1250	7.1625
5	500	1	5K	0.5610	32.1419
6	500	1	10K	0.8986	51.4881
7	1K	1	1K	0.0627	3.5953
8	1K	1	5K	0.3044	17.4406
9	2.5K	1	10K	0.2462	14.1078
10	2.5K	1	25K	0.5610	32.1419
11	2.5K	1	50K	0.8986	51.4881
12	5K	0.5	10K	0.0627	3.5953
13	5K	0.5	50K	0.3044	17.4406
14	5K	0.5	75K	0.4404	25.2316
15	5K	0.5	100K	0.5610	32.1419
16	5K	0.5	125K	0.6658	38.1460
17	5K	0.5	150K	0.7558	43.3038
18	10K	0.2	50K	0.0627	3.5953
19	10K	0.2	75K	0.0940	5.3841
20	10K	0.2	100K	0.1250	7.1625

Table 1- shows the variation of phase difference between output current and output voltage with changes in resistance, inductance and frequency.

CONCLUSION:

For frequency of the order of 100 kHZ , resistor of 10k and inductor of 0.2mH is not sufficient, as the phase difference will not be zero.

Pulse Width Modulation:

PWM inverters are quite popular in industrial applications. PWM techniques are characterized by constant amplitude pulses. The width of these pulses is however modulated to obtain inverter output voltage control and to reduce its harmonic content. The different PWM techniques are as under:

(a) Single-pulse modulation
(b) Multiple pulse modulations

Formulae in code :

phi=atan(2*pi*f*L/R); phase angle
Z=R+(i*2*pi*f*L); reactance at 50 Hz

vo=[zeros(size(t0))   Vs*ones(size(t1))   zeros(size(t2)) -Vs*ones(size(t3)) zeros(size(t4))];
vrms =Vs*sqrt(delay/pi);   rms value of o/p voltage
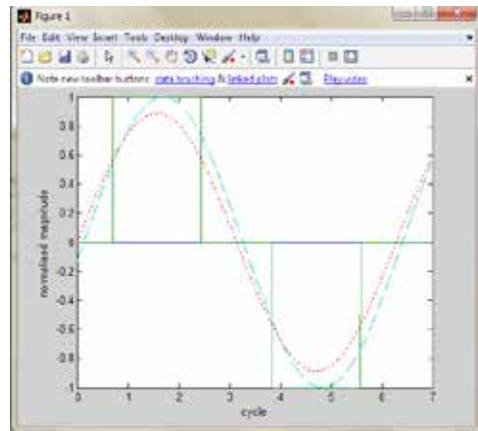

Figure 3 shows AC output voltage of a PWM inverter, and also that current lags behind voltage by phase difference phi.

R(OHM)	L(MH)	F(HZ)	PHI(RAD)	PHID(DEG.)
10	1	50	0.3044	17.4406
10	1	100	0.5610	32.1419
10	1	200k	1.5700	89.9544
100	1	1K	0.5610	32.1419
500	1	1K	0.1250	7.1625
500	1	5K	0.5610	32.1419
500	1	10K	0.8986	51.4881
500	1	25K	1.2626	72.3432
500	1	50K	1.4130	80.9569
1K	1	1K	0.0627	3.5953
1K	1	5K	0.3044	17.4406
2.5K	1	10K	0.2462	14.1078
2.5K	1	25K	0.5610	32.1419
2.5K	1	50K	0.8986	51.4881
2.5K	1	75K	1.0830	62.0533
2.5K	1	100K	1.1921	68.3030

CONCLUSION:

For frequency of the order of 100 KHz, resistor of 10k, and inductor of 0.2mH is not sufficient, as the phase difference will not be zero.

Non Uniform Multiple Pulse Width Modulated Inverter to Obtain Controlled ac o/p Voltage.

MATLAB code is written and analysed for 3,4,5,7.8,9,10 up to 20 pulses to check the harmonic response. Observations are as under:
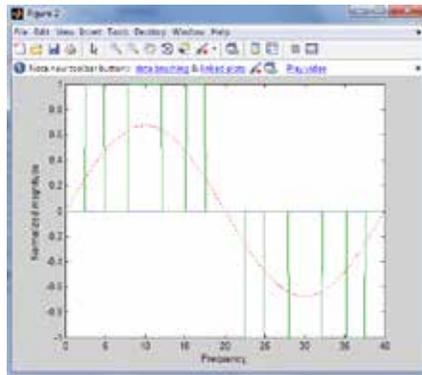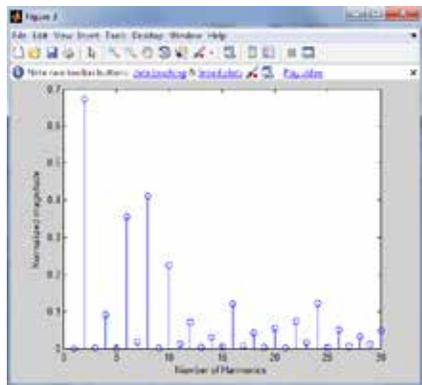

Figure 4: 3pulses/Half cycle
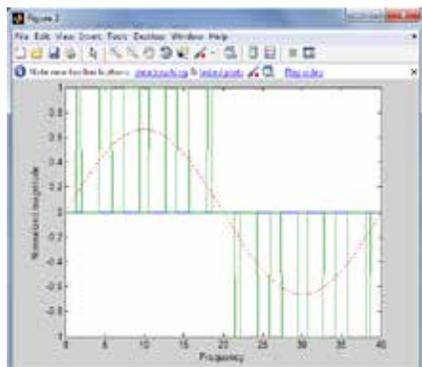

Figure 5 : Harmonics for 3 pulses
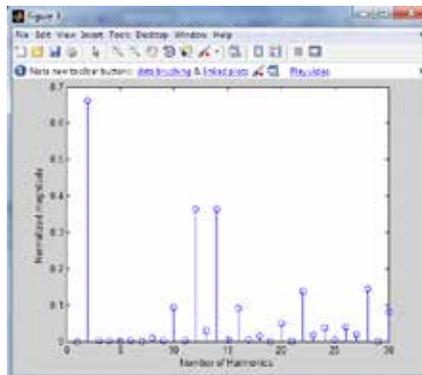

Figure 6: 6 pulses/half cycle

Figure 7 : Harmonics for 6 cycles
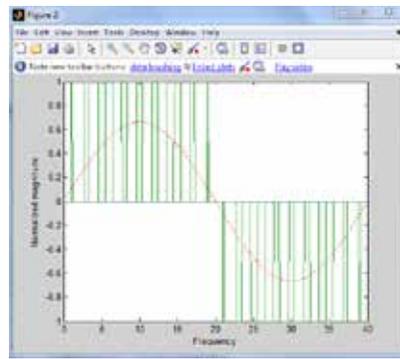
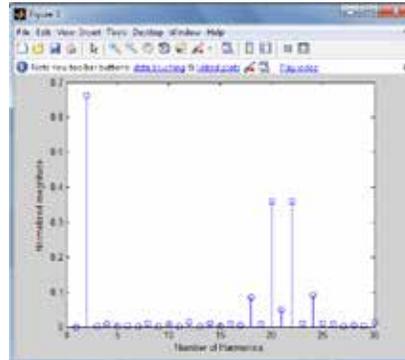
Figure 8 : 10 pulses/Half cycle
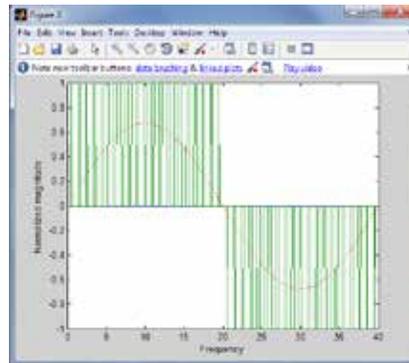

Figure 9: Harmonics for 10 cycles

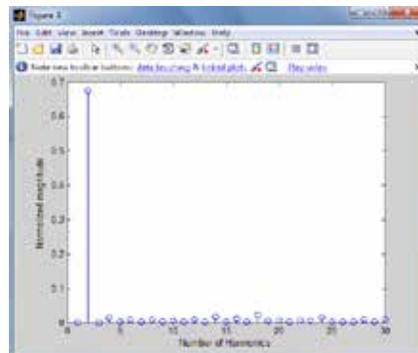**Figure 10: 20 pulses/Half cycle**

Figure 11: Harmonics for 20 cycles

CONCLUSION:

It is seen that the number of Harmonics in the AC o/p of PWM inverter decreases as number of pulses in each half cycle is increased and harmonics become negligible when number of pulses in each half cycle is 20.

REFERENCE
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