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Design of Three Phase Voltage Source Inverter (VSI) and Comparative Study with Three Phase Current Source Inverter (CSI)

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Abstract:- Now a day's air pollution and global warming are on alarming stage in the world; therefore, Hybrid Electric Vehicles (HEV) are very much useful and desirable. For electric vehicles, three-phase voltage-fed inverters almost exclusively used for induction motor drives. At present, the PMOSFETs based inverter is most attractive, accepted by many modern EVs. Microcontroller based voltage source inverter for HEV's are the essential component. The purpose of this article is to give idea of designing Voltage source inverter(VSI) using Power MOSFETs and Microcontroller ATMega16 and comparison with current source inverters(CSI) The output waveforms of the designing VSI under 120 degree conduction mode match the theoretical modal. The developed voltage source inverter is acceptable for all type of electric motor drives in various road loads used in HEVs.

Keywords:- *HEV, ICE, PMOSFET, MICROCONTROLLER, ATMega16*

I. INTRODUCTION

Hybrid Electric Vehicle (HEV) is a sort of vehicle that is propelled by electrical energy as well as natural fuel to increase fuel efficiency and to reduce oil dependence. The main components of HEV are IC engine, electrical motor, inverter, etc. The strict regulations on smock emissions due to global warming and fuel economy due to constraints on energy resources [1-3]. Murali et al; [4] has designed the voltage source inverter for HEV. It utilizes wind and solar energy. They have utilized MOSFET based inverters which is designed using PIC controllers. Raju et al; [5] t hey have focused on the generation of Sinusoidal pulse width modulation SPWM using operational amplifier OPAM circuits for three phase PWM VSI. B Singh & S Singh have studies presents various configurations, control schemes and design of single-phase power factor controller (PFC) topologies for development of PMBLDCM drives. Several AC–DC converter (buck, boost, buck–boost, Ćuk, SEPIC, Zeta, push–pull, half bridge, full bridge based PFC topologies are designed, modelled and applied to a 1.5 kW Permanent magnet brushless DC motor PMBLDCM drive for comparison of performance. Some of bidirectional bridge converter and unipolar inverter topologies are also evaluated to provide a comprehensive comparison of the PFC topologies for PMBLDCM drives. The proposed PFC converter topologies show conformity to international power quality standards with improved performance of PMBLDCM drive, such as reduction of AC mains current harmonics, near unity power factor and reduction of speed and torque ripples. To study of three-phase voltage source inverter in HEVs the simulation in MATLAB. The PCB design for power circuit and firing circuit of VSI in eagle software and design hardware of power circuit and firing circuit of Microcontroller based VSI and tests it under various load condition. In this paper the hardware details of Microcontroller based three phase VSI loaded with 1kW of induction motor has been explained. The switching frequencies of the controlled switches are controlled by pulse width modulated signal to obtain the sinusoidal waveform of required frequency at the output. With 500Hz frequency of carrier waveform and 50% duty cycle we obtain the three-phase voltage and current waveform.LC low pass filter has been designed for filtering higher order harmonics. This system configuration is shown below in Fig2.1,

II. THREE PHASE CURRENT SOURCE INVERTER (CSI)

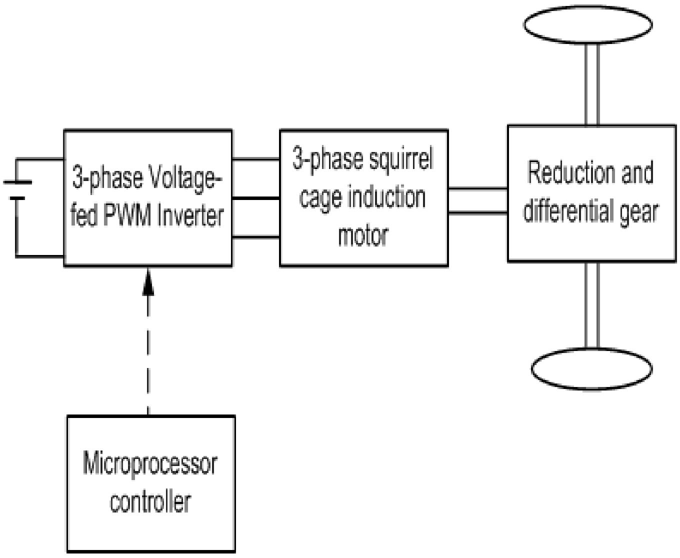

Fig 2.1 Basic HEV Induction Motor Drive Configuration

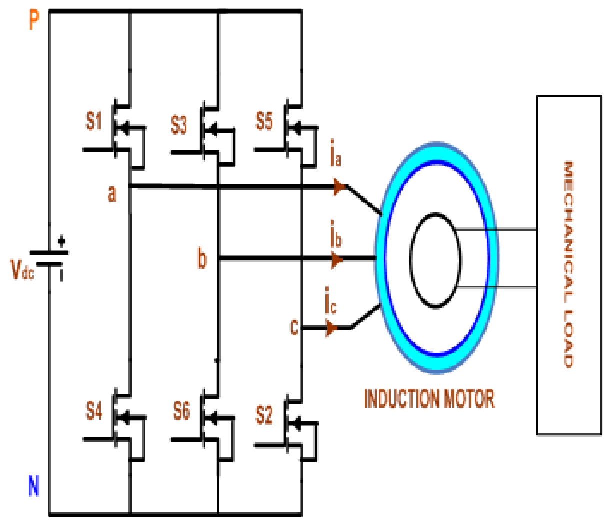

Fig2.2 Power circuit of Three-Phase Voltage Fed Inverter using PMOSFETs.

2.1 THREE PHASE VSI (120^0 MODE)

In this category of conduction mode, each switch conducts for 120˚. At any moment of time, only two switches conduct. Gate pulse show the conduction period of each switch. In this case also six commutation per cycle are needed. The gating signals and various voltage waveforms of three phase bridge inverters with 120^0conduction for each switch is shown in Fig2.7, Fig2.8. In this figure, one period of inverter operation has been divided in to six intervals. The firing sequences of six switches are prepared in table 4.2. Like $180^0 120^0$ mode inverter also requires six steps, each of 60^0duration for completing one cycle of the output a.c. voltage.

S. No.	Interval	Conducting devices	Incoming device	Outgoing device
1	I	S6,S1	S1	S5
2	II	S1,S2	S2	S6
3	III	S2,S3	S3	S1
4	IV	S3,S4	S4	S2
5	V	S4,S5	S5	S3
6	VI	S5,S6	S6	S4

Table 2:- Operation table (120 deg. conduction mode)

Following points we can observe from the waveforms of fig2.7, 2.8 and the operating table 2

- Conduction period of each switch is 120^0.
- The phase shift between the triggering of every two adjacent switches is 60^0
- Three line voltages V_{ab} , V_{bc} and V_{ca} are six steps waves, with step heights $V_s/2$ andV_s. The three-line voltages are mutually phase shifted by 120 ˚.
- The three-phase voltages are V_{an}, V_{bn} and V_{cn} are quasi square wave with peak values of $V_s/2$. They are also mutually phase shifted by 120 ˚.
- The line-voltage V_{ab} is leading the phase voltage $V_{an}$by 30 ˚.

From fig2.6 and table 2 it is observed that two switches conduct at a time one from upper half and other from lower half. There are three modes of operation in one half cycle and the equivalent circuits for a star connected load are shown in Fig 2.6.

I) During interval I, for $0 < \omega t < \frac{\pi}{3}$, switches S1 and S6 conduct.

$$V_{an} = \frac{V_s}{2} , V_{bn} = \frac{-V_S}{2} , V_{cn} = 0 \quad (2.1)$$

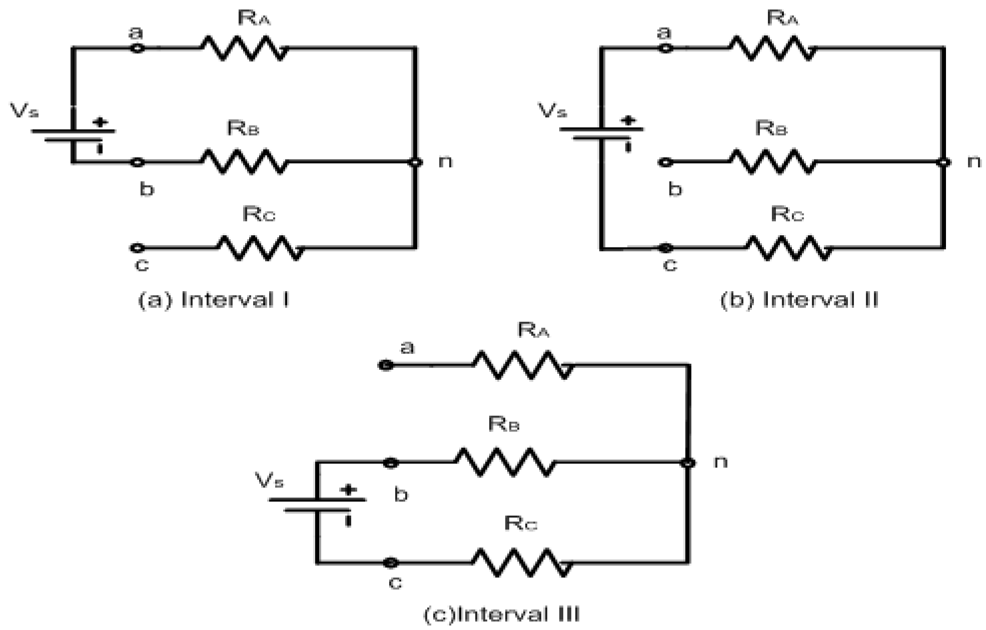

Fig2.3 Equivalent Circuits

II) During interval II, for $\frac{\pi}{3} < \omega t < \frac{2\pi}{3}$, switches S1 and S2 conduct.

$$V_{an} = \frac{V_s}{2}\ ,\ V_{bn} = 0\ ,\ V_{cn} = -\frac{V_s}{2} \tag{2.2}$$

II)

III) During interval III, for $\frac{2\pi}{3} < \omega t < \frac{3\pi}{3}$, switches S2 and S3 conduct

$$V_{an} = 0\ ,\ V_{bn} = \frac{V_s}{2} \tag{2.3}$$

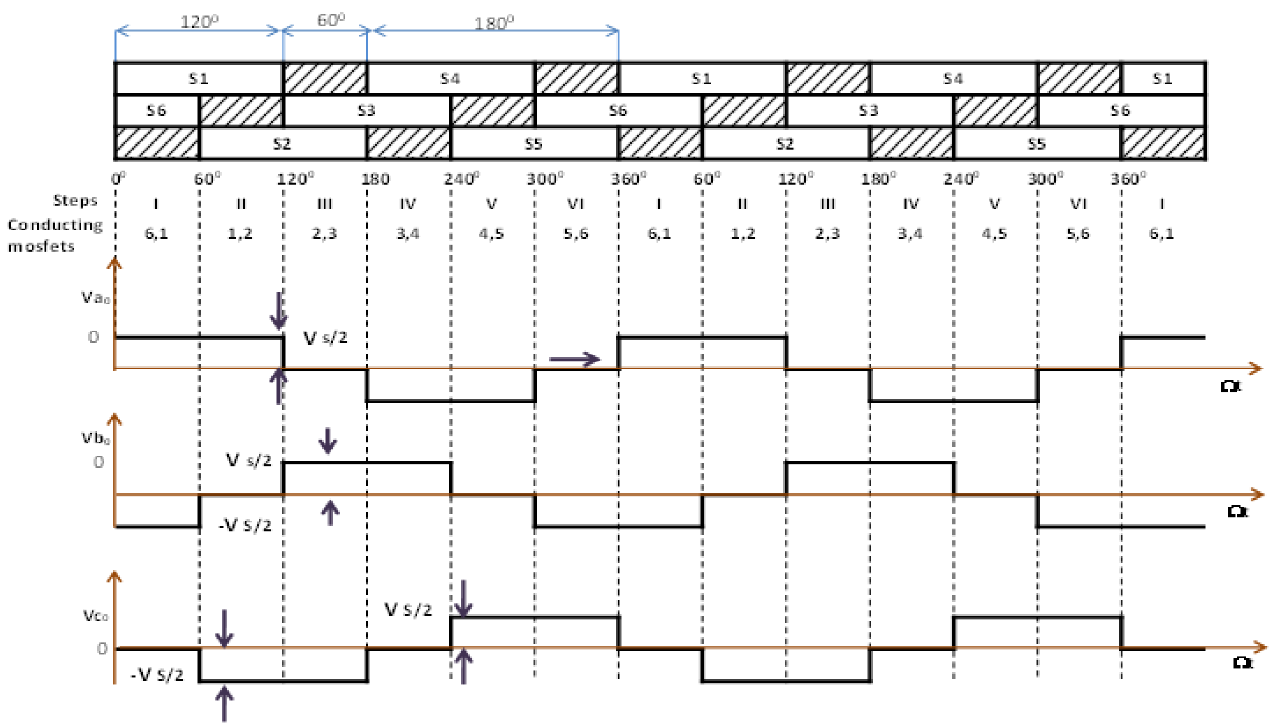

Fig2.7 Phase voltage waveforms of VSI (120 °mode of conduction)

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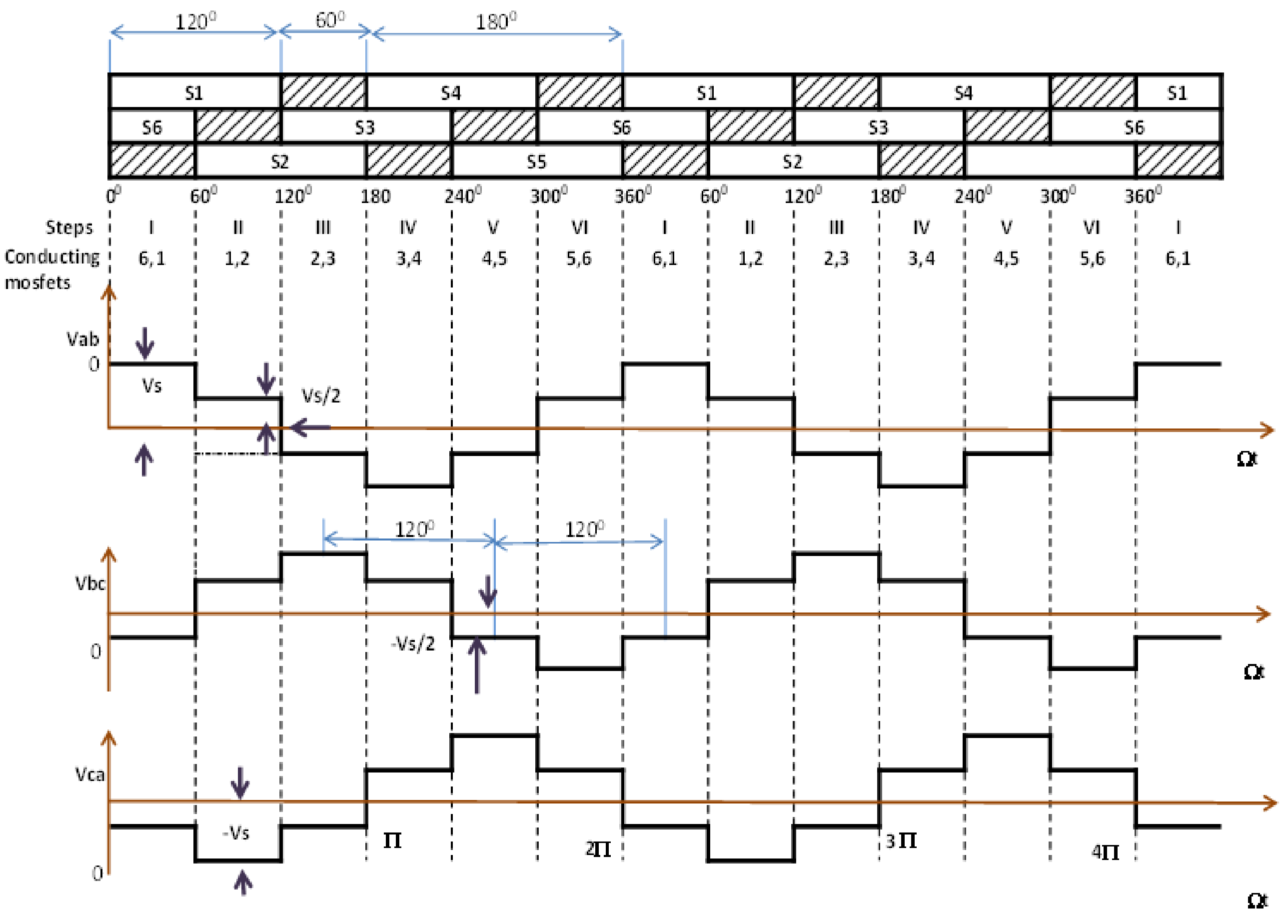

Fig2.8 Line voltage waveforms of VSI (120 ˚mode conduction)

Line to neutral voltages of square wave can be expressed in Fourier-series as

$$V_{ao} = \sum_{n=1,3,5}^{\infty} \left(\frac{2V_s}{n\pi} \cos\frac{n\pi}{6} + \sin n\left(\omega t + \frac{\pi}{6}\right) \right) \qquad 2.4$$

$$V_{bo} = \sum_{n=1,3,5}^{\infty} \left(\frac{2V_s}{n\pi} \cos\frac{n\pi}{6} + \sin n\left(\omega t - \frac{\pi}{2}\right) \right) \qquad (2.5)$$

$$V_{co} = \sum_{n=1,3,5}^{\infty} \left(\frac{2V_s}{n\pi} \cos\frac{n\pi}{6} + \sin n\left(\omega t + \frac{5\pi}{6}\right) \right) \qquad (2.6)$$

The Fourier analysis of line voltage waveform is

$$V_{ab} = \sum_{n=6k+1}^{\infty} \left(\frac{3V_s}{n\pi} \sin n\left(\omega t + \frac{\pi}{3}\right) \right) \quad \text{Where k = 0, 1, 2, 3} \qquad (2.7)$$

Rms value of fundamental phase voltage, from equation 2.5 is,

$$V_p = \left[\frac{1}{\pi} \int_0^{2\pi/3} \left(\frac{V_s}{2}\right)^2 d(\omega t) \right]^{1/2} = \sqrt{\frac{2}{3}}\,\frac{V_s}{2} = \frac{V_s}{\sqrt{6}} = 0.4082 \text{ Vs} \qquad (2.9)$$

Rms value of phase voltage,

$$V_P = \frac{V_L}{\sqrt{3}} = \frac{\sqrt{2}V_S}{3} = .4714\, V_S \qquad (2.10)$$

$$V_{L1} = \frac{3V_S}{\sqrt{2}\pi} = 0.6752\, V_S = \sqrt{3}\, V_{p1} \qquad (2.11)$$

Rms value of line voltage,

$$V_L = \sqrt{3}\, V_p = \frac{V_s}{\sqrt{2}} = .7071\, V_s \qquad (2.12)$$

III. SIMULATION AND HARDWARE IMPLEMENTATION

Simulation is a flexible methodology we can use to analyze the behavior of a real time or hypothetical situation on a computer so that it can be studied to see how the system works. By performing simulations and analyzing the results, we can gain an understanding of how a present system operates, and what would happen if we changed its variables or we can estimate how a proposed new system would behave. In order to analyze the circuit performance, we first simulate the simulink model of the circuit. Then by voltage measurement and current measurement block we observe the simulated results in the scope and compare it with theoretical results a hardware implementation on other hand means that job is done using physical device or electronic circuit as opposed to being done by a computer program. A hardware implementation often takes longer to create and that can make it more expensive. It is usually faster in operation and has the advantage that once built it cannot easily be tampered with or reprogrammed. In this chapter simulated and hardware results of PWM based Voltage Source Inverter are shown. Simulation is done in MATLAB and for hardware implementation the circuit layout was made with the help of eagle software. With the help of this layout PCB was designed and then the component was soldered and tested under different load. A special feature of this hardware development is that firing of six PMOSFET is done using microcontroller as well as OPAL-RT.

3.1 SIMULATION IN MATLAB

SIMULINK MODEL

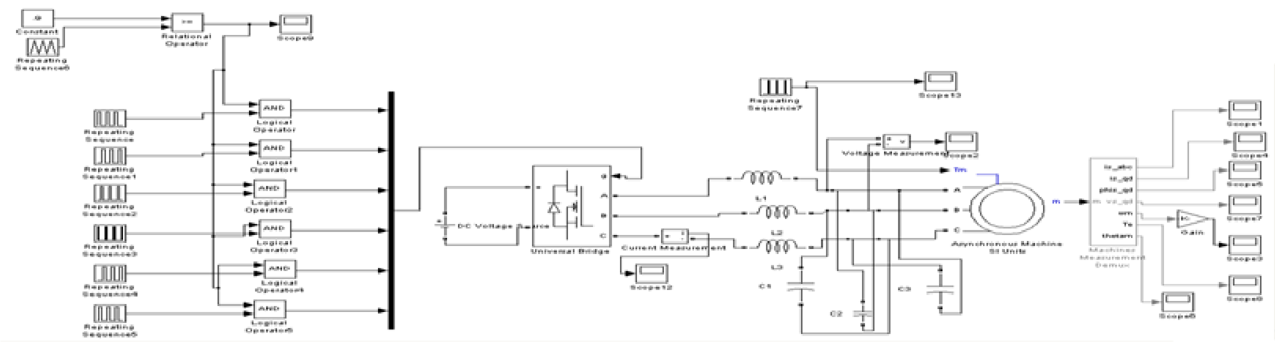

Fig 3.1 Simulink model of Three Phase VSI with low pass LC filter

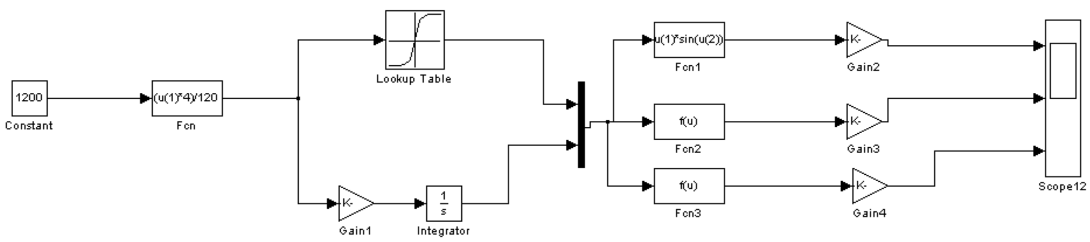

Fig 3.2 V/f open loop control in simulation

SIMULATION RESULT WITH RESISTIVE LOAD

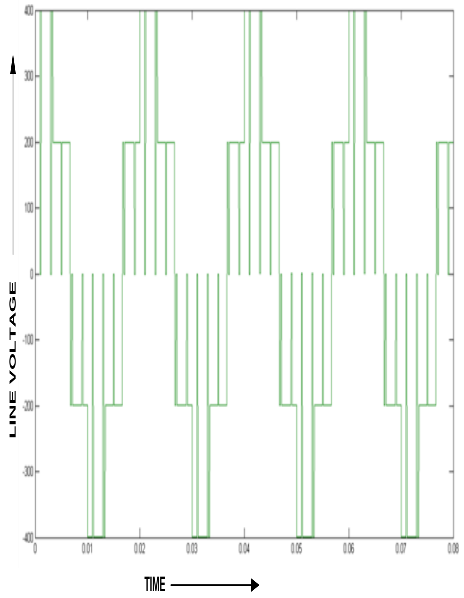	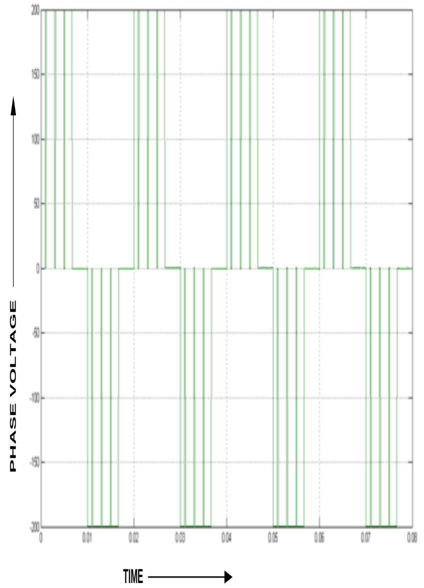	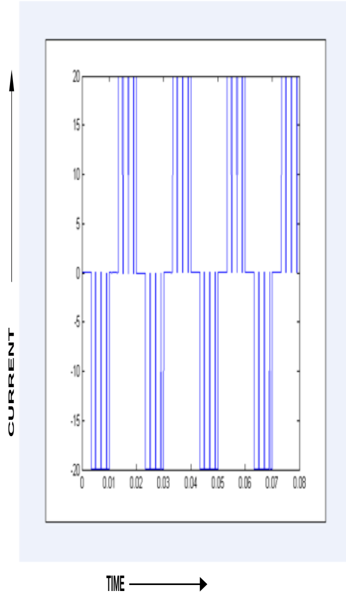
Fig.3.3 Line voltage waveform at R-Load	Fig. 3.4 Phase voltage waveform at R-Load	Fig 3.5 Current waveform at R-Load

SIMULATION RESULT AT MOTOR LOAD (without filter)

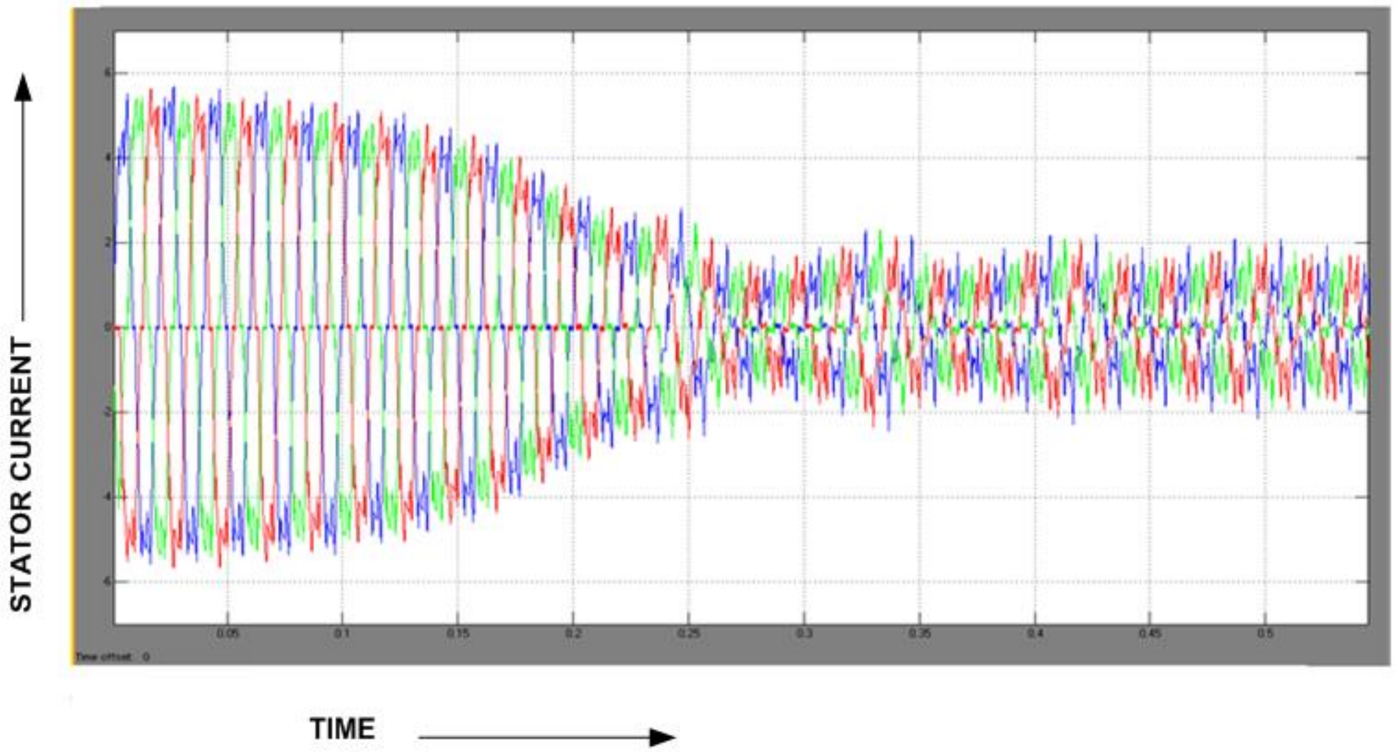

Fig 3.6 Three phase stator current at 1kW motor load

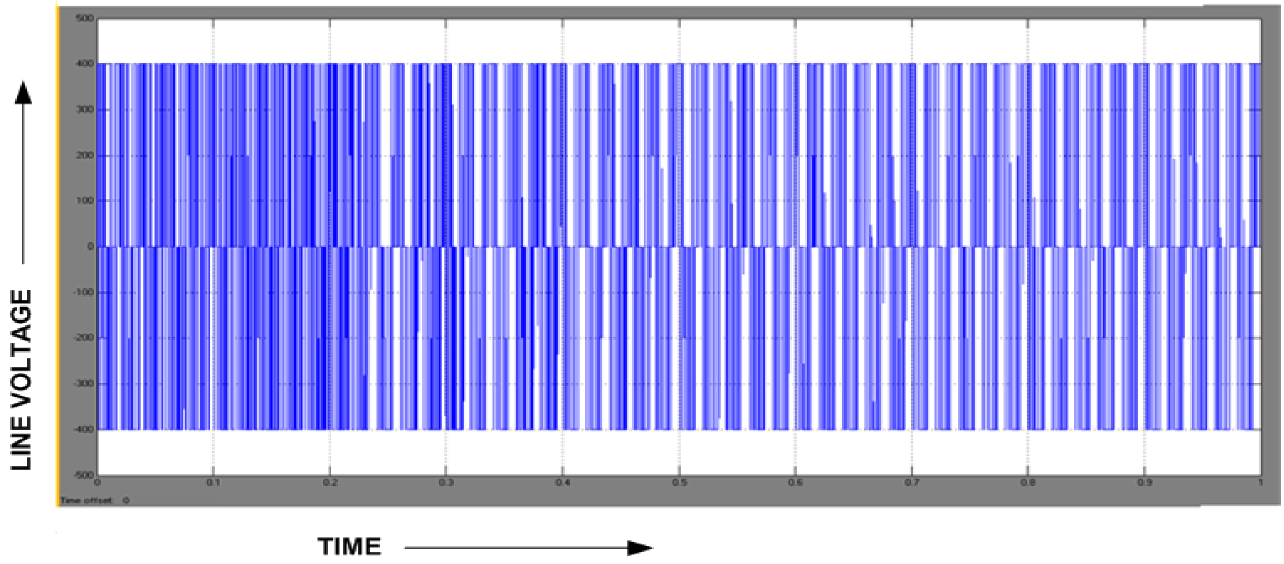

Fig 3.7 Voltage waveform at motor load

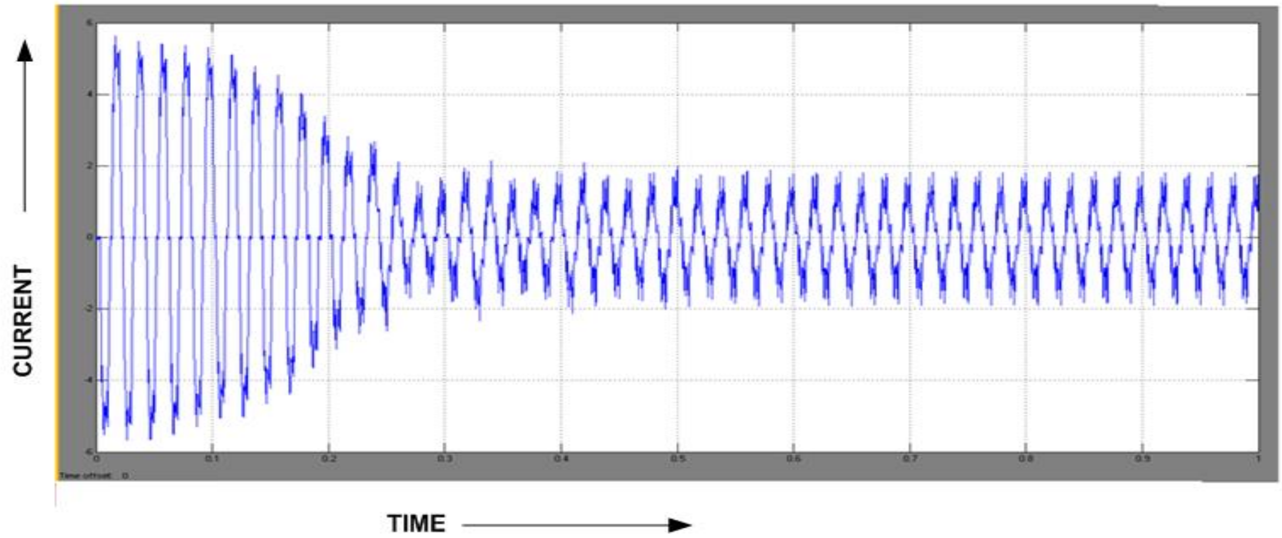

Fig. 3.8 Current waveform at motor load

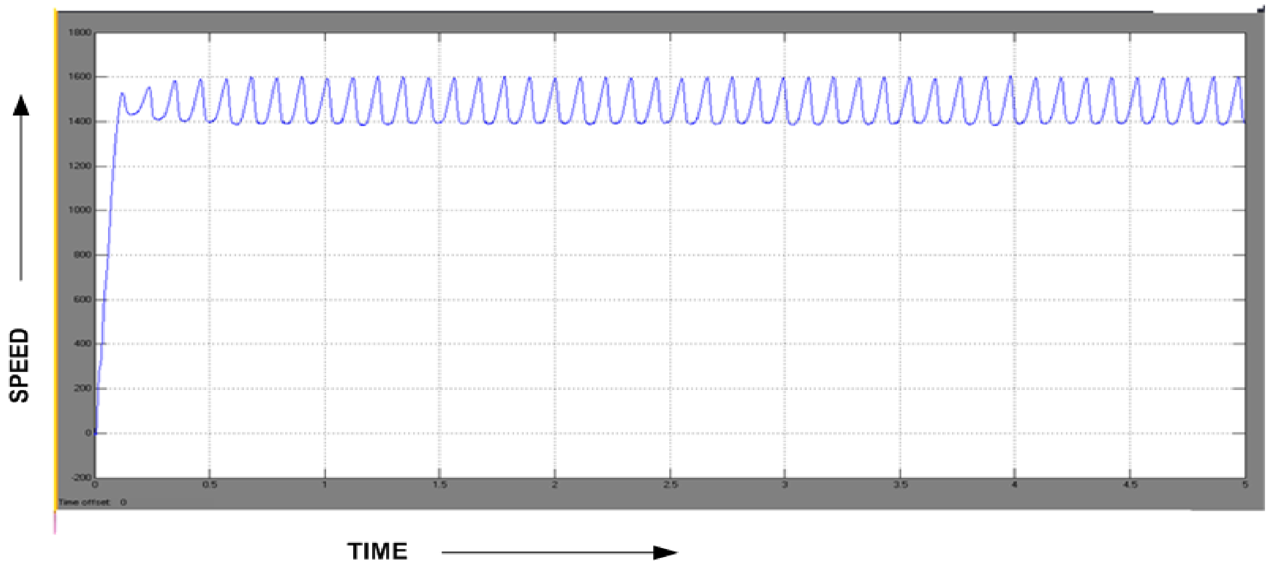

Fig. 3.9 Speed waveform

SIMULATION RESULT AT MOTOR LOAD (with filter)

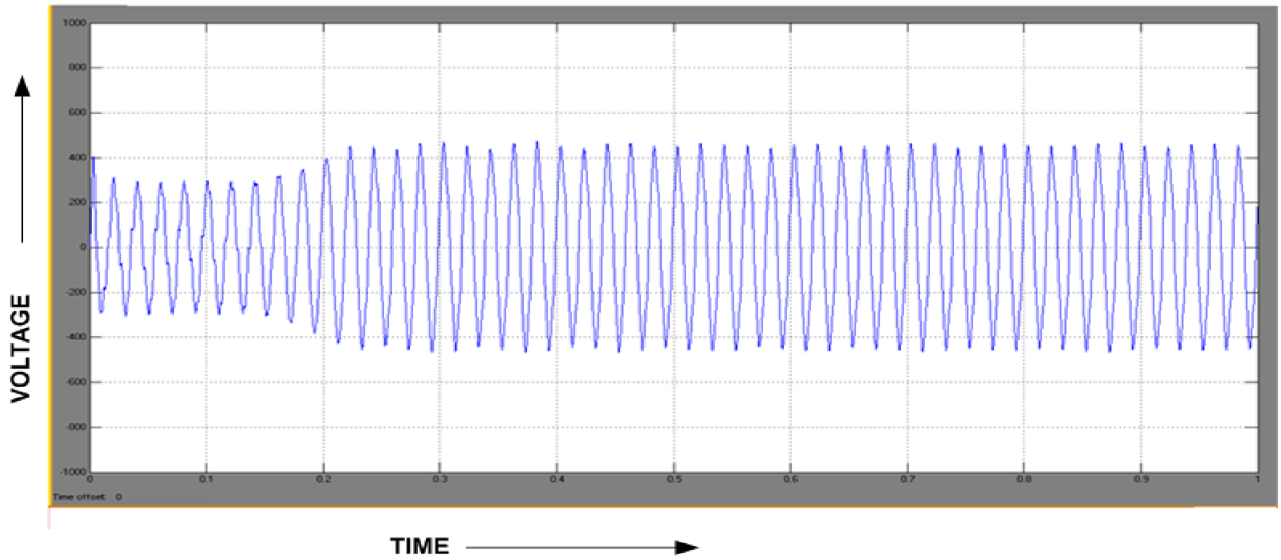

Fig.3.10 Voltage waveform with filter (at 1hp motor load)

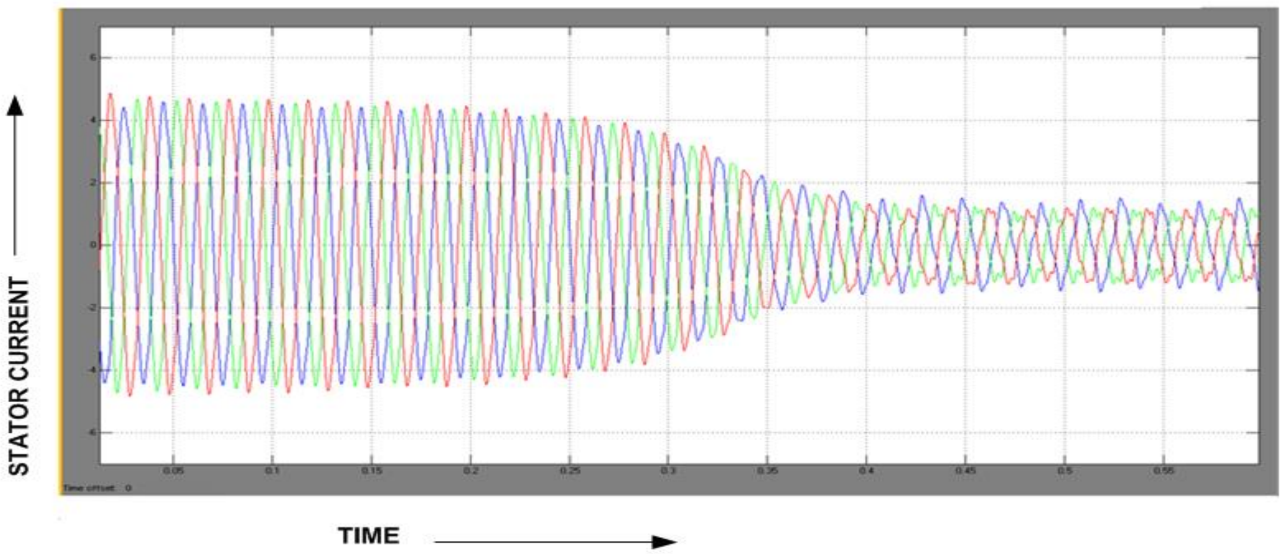

Fig 3.11 stator three phase current

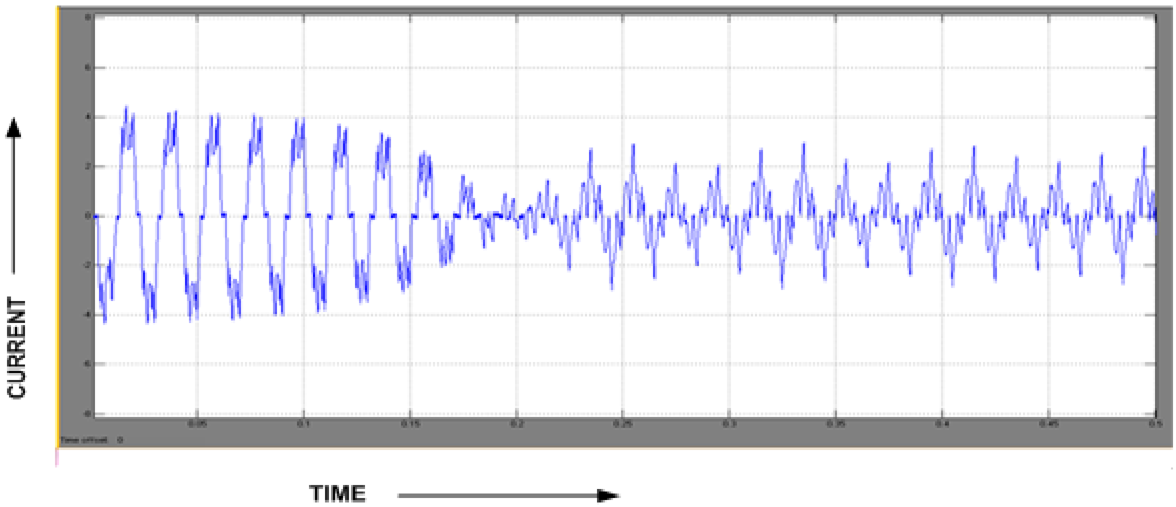

Fig3.12 current wave form

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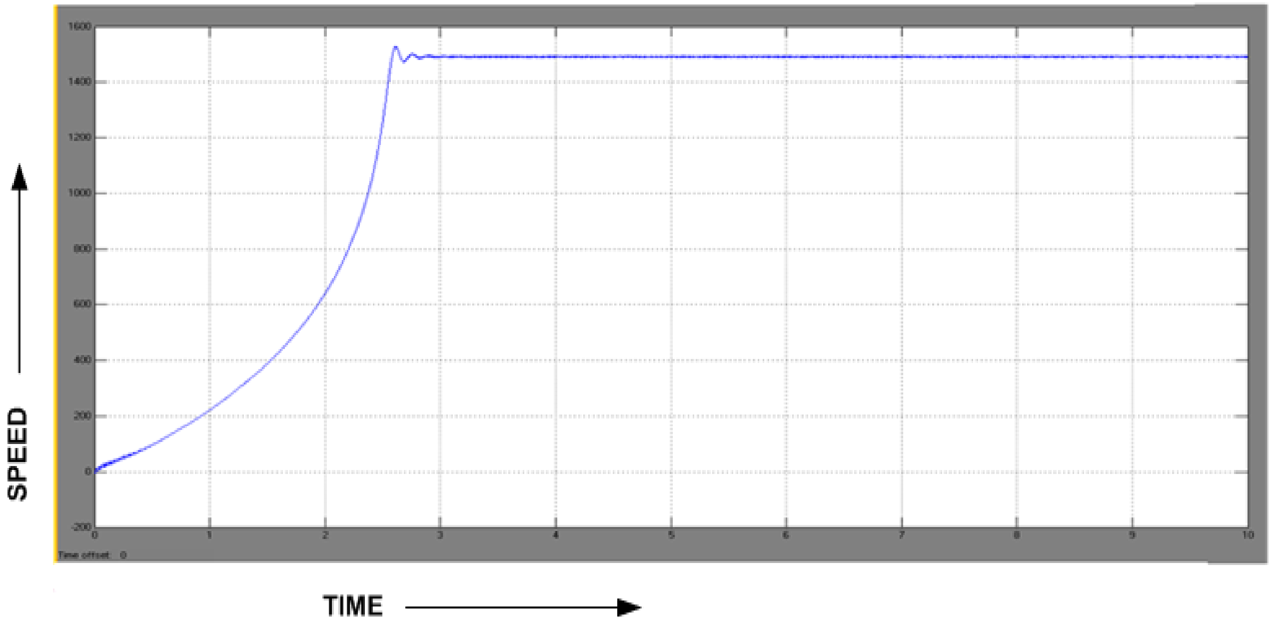

Fig. 3.13 Speed waveform

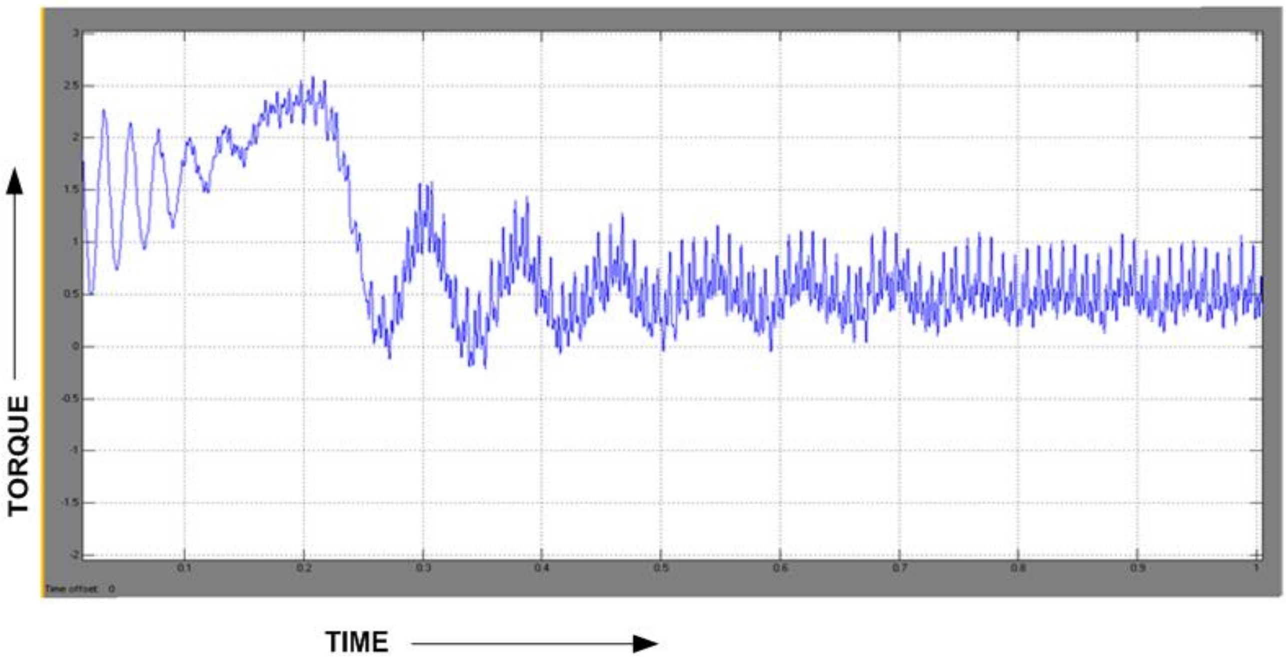

Fig3.14 Torque waveform

3.2 PCB DESIGN

A printed circuit board, (PCB) is used to mechanically support and electrically connect electronic components using conductive pathways and tracks or signal traces etched from copper sheets laminated on to a non conductive substrate. It is also referred to as printed wiring board (PWB) or etched wiring board. A PCB populated with electronic components is a printed circuit assembly (PCA), also known as a printed circuit board assembly (PCBA).and soldering wire.

PCB LAYOUT OF VSI

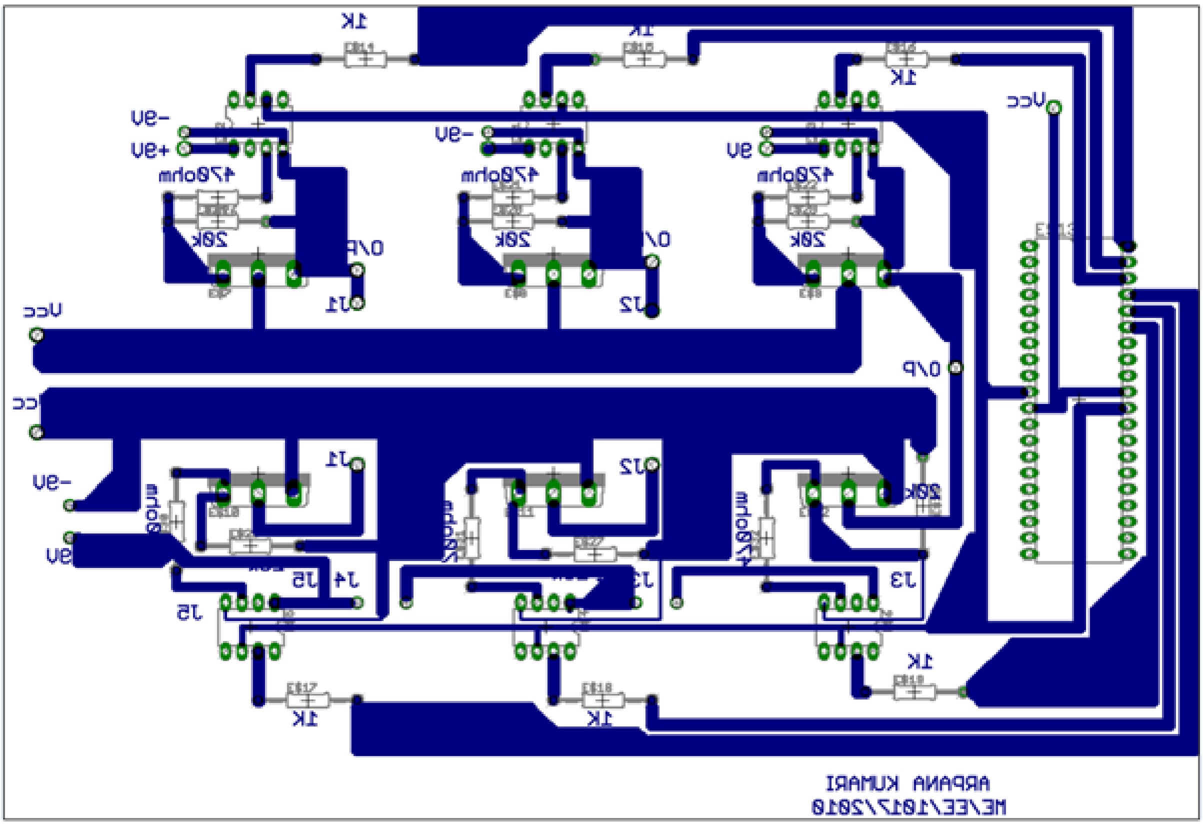

Fig3.15 PCB Layout of three-phase VSI

HARDWARE CIRCUIT AND RESULTS

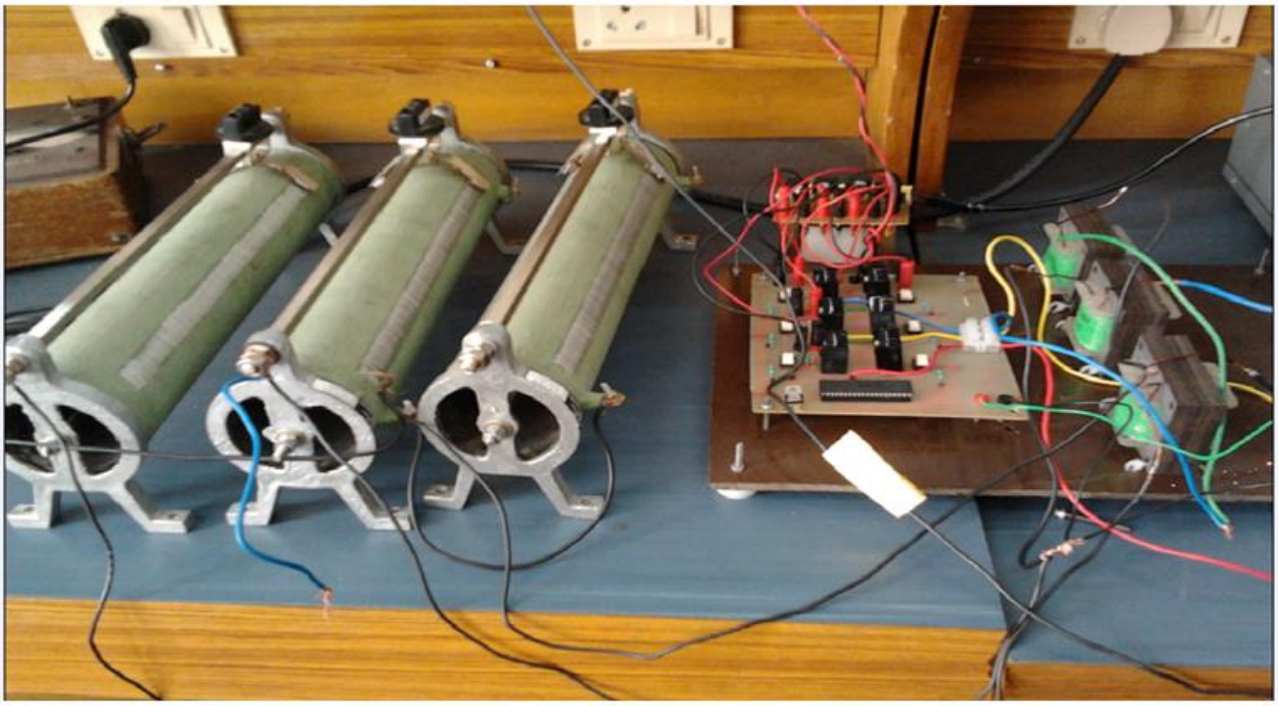

Fig.3.16 Hardware of Microcontroller based Voltage Source Inverter

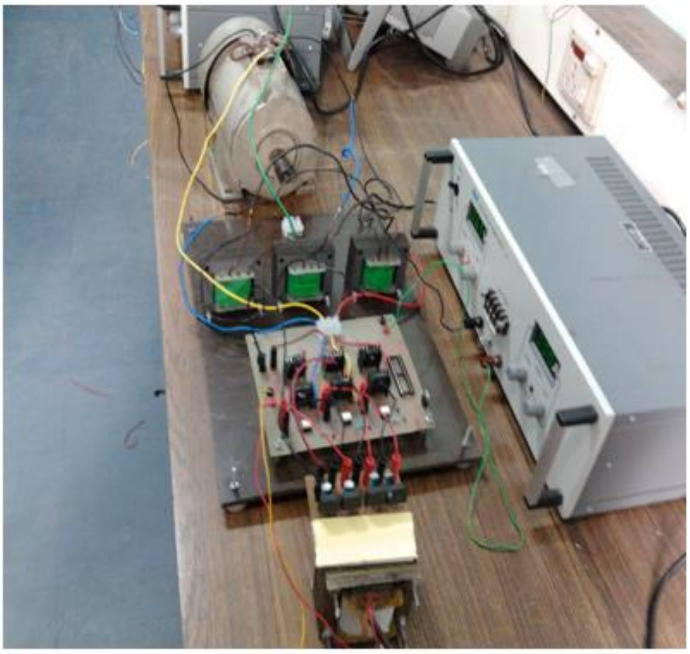

Fig.3.17 VSI with Motor Load

Fig.3.18 VSI with Resistive Load

FIRING PULSES GENERATED FROM MICROCONTROLLER

Fig 3.19 Gate pulses for switch 1, 3, 5 & Gate pulses for switch 4, 6, 2

Fig 3.21 gate pulse of switch 1 and 4

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PULSES GENERATED FROM MICROCONTROLLER

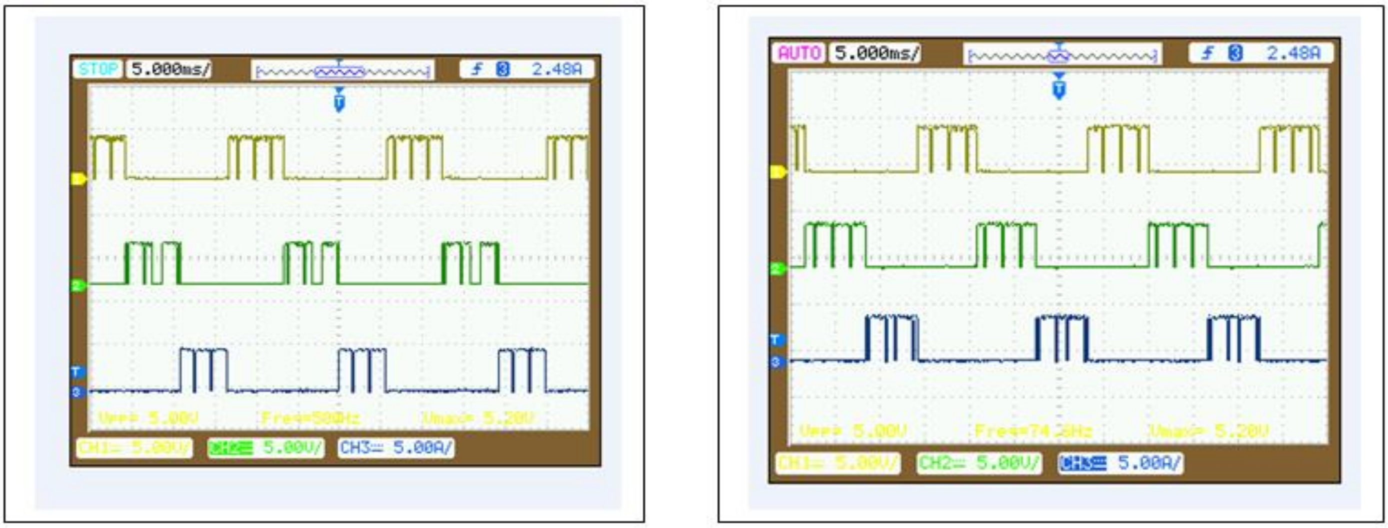

Fig.3.22 Firing pulses for switch 1, 3, and 5 & Firing pulses for switch 4, 6,and 2

HARDWARE RESULTS WITH R-LOAD

Fig3.24 phase voltage

Fig. 3.25 Line Voltage

Comparison of voltage source and current source inverters

VOLTAGE SOURCE INVERTER	CURRENT SOURCE INVERTER
1) DC voltage remains constant in VSI. 2) Output voltage independent of load. (3)Inverter grade thyristors are used. (4)High operating frequencies are possible. (5)The voltage source inverter is used with sources of lower impedance. (6)Power BJT, Power MOSFET, IGBT, GTO with self commutation can be used in the circuit.	(1)Input current of CSI is constant. (2) The amplitude of Output current independent of load. (3)Converter grade thyristors are used. (4) Operating frequencies are limited due to commutation delay. (5) To maintain source current constant the source must have a large inductance so CSI is used with source of higher impedance. (6)CSI cannot be used as these devices have to withstand reverse voltage.

Advantages of VSI:
(1) VSI has small size hence required less space in HEV.
(2) VSI output voltage waveform does not depend on the type of load so it is best suitable of HEV.
(3) Starting current is limited by using VSI is easy.
(4) Speed control is obtained by varying firing angle of the thyristor.

IV. CONCLUSION

The suggested system was verified by means of simulation in the MATLAB. Hardware design of 3- phase Voltage Source Inverter for Hybrid Electric Vehicle was done. In hardware PCB board was designed in the power electronics laboratory using eagle software. For providing the gating pulses for the six Power MOSFETs Multiple Pulse Width Modulation (MPWM) technique has been adopted, in which carrier signal frequency was taken 500Hz and reference frequency was 50Hz .Generation of switching patterns for six P-MOSFETs of VSI was done using Microcontroller. Gating pulses are also obtained using OPAL-RT (FPGA). Also low pass LC filter had been designed to reduce the current harmonics in the output voltage. The voltage source inverter was loaded with three phase 1Kw induction motor in the power electronics laboratory and various tests were performed. Simulation and experimental results of output voltage, currents waveforms were presented and discussed under various load conditions. It has been found that the experimental result matches with theory. It is observed in the simulation that starting current of Induction motor is 4-5 times higher than steady state current. This is due to transient or switching actions. It depends upon electrical time constant and mechanical time constant. Induction motor has very high electrical as well as mechanical time constant. The purpose of this article is to give idea of designing Voltage source inverter using Power MOSFETs and Microcontroller ATMega16. The output waveforms of the designing VSI under 120 degree conduction mode match the theoretical modal. The developed voltage source inverter is acceptable for all type of electric motor drives in various road loads used in HEVs.VSI has small size hence required less space, Starting current is limited by using VSI is easy, Speed control is obtained by varying firing angle of the thyristor it output voltage waveform does not depend on the type of load so it is best suitable of HEV.

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