Design of Three Phase Sinusoidal Pulse Width Modulation Inverter

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Abstract - *As the use of renewable energy sources are increased and will going to be increased to a large extend in future. Specially, solar energy will going to play a huge role as a major energy source. The output of the inverter is direct current, so an inverter becomes a critical component for the flow of electricity from solar modules to storage battery, loads and grids. A three phase voltage source inverter Sinusoidal Pulse Width Modulation based inverter is going to be utilized. High frequency triangular carrier wave is compared with sinusoidal reference wave of desired frequency. The width of each pulse is varied in proportion to the amplitude of a sine wave called SPWM. The advantage of SPWM technique is that it reduces the harmonic contents of the output voltage compared to single pulse width modulation and multi-pulse modulation. The advantage of inverter with two stage three phase bipolar SPWM is good performance and efficiency as it doubles the switching frequency of inverter voltage and so the output filter becomes smaller, cheaper and easier to implement. A three phase two level SPWM inverter based voltage source inverter is going to be simulated for with and without filter across resistive load using MATLAB and the Total Harmonic Distortion of both is compared. The application of SPWM inverter in speed control of three phase induction motor by volts/hertz method is implemented. MATLAB simulation for speed control of induction motor is simulated and its THD analysis along with current and voltage is carried out. A hardware implementation of speed control of induction motor is made.*

Keywords: SPWM (Sinusoidal Pulse Width Modulation), PWM (Pulse Width Modulation), MATLAB, Inverter, Induction Motor, Frequency Modulation, Speed Regulation of AC Motor, MOSFET, Diode, DC Link, triggering signal, open loop control.

I. INTRODUCTION

As the amount of non-renewable energy sources such as coal, gas, petrol, diesel, etc are vastly consumed and getting reduced very quickly. Another option of energy i.e. renewable form of energy such as wind power, solar power, hydrodynamic generator are now getting rapid extension in use. So to use renewable power efficiently, an inverter of good quality is required. In past inverter having higher THD levels and complicated circuit were used. Now a days PWM (Pulse Width Modulation) inverters are gradually taking over other types of inverters in industrial applications. The PWM techniques are characterised by amplitude pulses. The width of these pulses are modulated to obtain inverter output voltage control and to reduce its harmonic contents. So output of different PWM techniques, Sinusoidal PWM techniques is the better one which provides less harmonics. Electrical motor consumes a very large part of generated energy Worldwide; as its application is very diverse in industrial as well as domestic. Constant speed application consumes more energy as the machine works with the full rated input supply even if the required speed or working load is not full. Regulated speed drives

became one of the most prime factors especially during Industrial Revolution around the world. Traditional method is to provide controlled input supply to the motor using a variac, this technique has many drawbacks; power electronics came with most efficient and versatile method of speed control of motor. This application leads to the power conversion i.e. AC/DC and DC/AC. AC/DC converting device, also know a rectifier is designed using diode or thyristor to provide uncontrolled and controlled dc power, also said as unidirectional and bidirectional devices. Other than Adjustable Speed Drive (ASD); Switch Mode Power Supply (SMPS), DC power supply (for measurement and testing), Uninterrupted Power Supply (UPS), Battery charging set, Grid interface of Solar PV module, and etc. employs AC/DC conversion. Controlled device is advantageous as the input harmonics is less and power factor is higher as compared to uncontrolled, because of which used of heavy and costly line filters can be eliminated. These controlled device uses power switches like MOSFET, IGBT, GTO, etc.

One of the best methods for speed control application is V/F control of induction motor, Pulse Width Modulation (PWM) or Sinusoidal Pulse Width Modulation (SPWM) can be use to provide

the triggering pulse for both the converters with feedback control (in some applications)[3]. For more reliable operation and results filters can be used at the line side [8]. PWM gate pulse is designed with suitable modulation index; it will also give the required Total Harmonic Distortion (THD). By varying the modulation index (m) current and voltage harmonics can be varied [8]. rectifier. required pulse of triggering signal generator [1][4].

Regulated speed induction motor is widely used for more than 45 years, in industrial as well as domestic applications. Moreover it's used is increasing ever since because of the efficient operation, flexible speed control, ruggedness and low maintenance qualities. Induction motors are addressed as workhorse of the increasing automation demand in industries. Some other prior application areas are fans & elevators (in domestic area), conveyer belts, robotics, overhead cranes, paper mills, textile mills, etc. In general regulated speed AC induction motor is referred as AC Drives; it offers advantages like low cost, low maintenance, smaller size and reliable operation. The speed controlling have became more flexible after combining with power electronics; different kind of AC/ DC, DC/AC and AC/DC/AC configurations are used to provide desired speed operation of induction motor. The basic of variable speed operation is to apply variable voltage and variable frequency supply to the stator terminals of the induction motor.
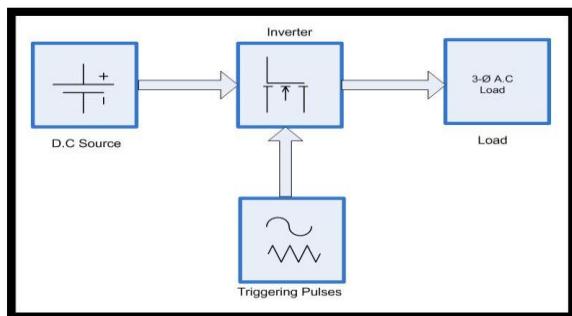

Figure 1: Basic Block diagram of SPWM Inverter.

Because of the growing energy crisis, the ways of saving the energy is always an prior issue as it is concern with the economic operation of the system. It is calculated that about a half of the generated electricity of the world is used in motors in various industrial and domestic applications. Mostly those motors are driven without a frequency converter. Without a frequency converter a motor can only be driven full speed or not driven at all. A frequency converter gives the ability of control to motor input energy. A frequency converter has a user interface that allows the modification of the driving input frequency of the motor terminals. It means that the motor can be driven with almost unlimited variety of frequencies providing a wide range of speed control. A frequency converter use can save up to thirty percents of energy. The total energy savings could thus be gigawatt hours per year around the world.

II.   INDUCTION MOTOR

Both stator and rotor are laminated and consists of an insulated winding to carry current and magnetic flux. The stator provides path for the magnetic field and the housing for the stator windings. The stator and rotor are laminated to reduce eddy current losses. When single phase alternating supply is fed to the stator of induction motor, the ac current circulates in the stator winding. This flowing current produces a flux having alternating nature known as stator flux. The generated flux links with the rotor windings and hence rotor conductor cuts the stator flux as a result emf induces in the rotor winding. Current will flow in the rotor as the rotor windings are short circuited, this current is said as rotor current. Flow of rotor current in the rotor winding will produce rotor flux. These two fluxes will produce the desired torque which is required by the rotor to rotate.

A. *Working Principle*

The working principle of three phase induction motor is a bit different than single phase. As its stator houses three phase winding which are displaced in space by 120 degree, when three phase supply is fed to the stator windings, a rotating magnetic flux (rotating at synchronous speed) is established in the stator.

Synchronous Speed, $N_s = 120f / P$

Where,   f = supply frequency

P = number of pole

This flux passes through the air gap and cuts the stationary rotor conductors as a result of relative speed (motion) emf are induced in the rotor winding. Since the rotor conductors are short circuited, rotor current will produce whose direction will be same as of the rotating magnetic field according to Lenz's Law.

B. *Speed control technique for induction Motor*

V / f control speed control technique (frequency control).

This is one of the most widely used methods especially for the Adjustable Speed Drive (ASD) or Variable Frequency Drive (VFD) which is basically used for controlling the speed of the motor. When three phase supply is fed, the stator rotating magnetic field rotates with the synchronous speed given by:

Ns = 120*f / P

The induced emf of induction motor is given by:

E or V = 4.44*Φ*k*T*f

Where,   K = winding constant

T = number of turns / phase

f = supply frequency

From above equation we can observe that change in frequency will directly affect the induced emf (E). But with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor and stator cores which will further cause increase in no load current of the motor. That means it is important to maintain flux (Φ) constant and it is only possible by changing voltage too as it is the only other variable term. If the frequency is reduced than voltage must be increased to make the flux constant. Hence we are keeping the ratio of V / f constant.

C. *Total Harmonic Distortion (THD) effect in Induction Motor*

The advancement in the controlled operation and other applications of controlled output voltages leads to the increasing use of power electronics. This power switches are one of the major reasons for the production of harmonics with different orders in the system. It is nothing but the sine component of the periodic waveform having a frequency in the integral multiples of the fundamental frequency. First order harmonic is addressed as Fundamental frequency (f), second order harmonic can be described as 2f followed by third harmonic as 3f and likewise. Even harmonics are eliminated naturally as the overall distortion gets cancelled, positive cycle = negative cycle.
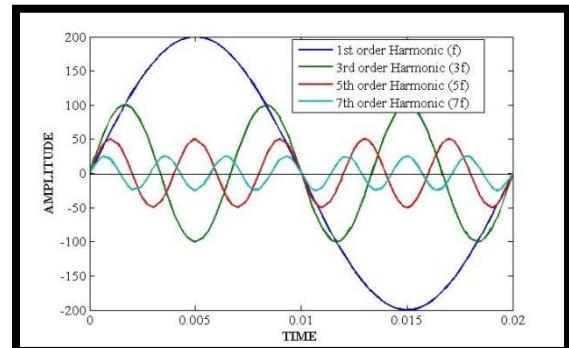

Figure 2.3: Waveform of different harmonic order

As name suggest THD is the combined effect of the orders of the harmonics present in a single system. Total Harmonic Distortion (THD), is the ratio of the summation of all the harmonic components (3rd, 5th,… orders) of the current or voltage waveform compared to the fundamental component (f).

$$THD = \frac{\sqrt{I2^2 + I3^2 + I3^2 + I4^2 + \cdots + In^2}}{I1} * 100 \%$$

Where I1 is the fundamental current (mention all variables)

The equation above shows the calculation for the THD components of the currents. The calculated value is a percentage comparing the harmonic component to the fundamental component of the current. For THD analysis, MATLAB have a ready to use tool in powergui block i.e. FFT Analysis.

III.   *PULSE WIDTH MODULATION TECHNIQUE*

In conventional method fixed gate signal are given to switch from a pulse generator, the switch will operate likewise. While PWM technique enables the user to change the duty cycle by changing frequency and amplitude of the modulation.
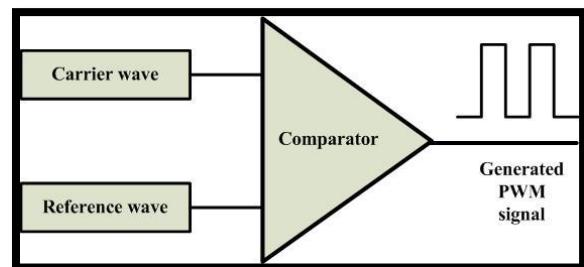

Figure 3.2: Basic block diagram of PWM

The above figure shows basic working of PWM (Pulse Width Modulation).Two different signals i.e. Reference signal & Carrier signal are compared

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together through a Relational Operator (Matlab). It will compare both the waveforms and gives result with the condition provided. It will consider one reference signal & other as carrier signal. Here in example 1 (below) reference signal in Fixed DC while Triangle wave is carrier signal. Now the condition <= (less than or equal to) works when the reference signal is less than the carrier signal means when Fixed DC is less than Triangle wave than we will get output otherwise the output will be zero (0). By changing modulation index we can vary the output directly. Modulation index is given as m = Am / Ac where Am is Amplitude of sine and AC is Amplitude of carrier triangular.

Three phase induction motors are most widely used for any industrial control and concern automation. It is often required to control the output voltage of inverter for the constant voltage/frequency (V/f) control of an induction motor. PWM (Pulse Width Modulation) based firing of inverter switches provides the best constant V/F control of an induction motor. Amongst the various PWM techniques, the Sinusoidal PWM (SPWM) is good enough and most popular that provides smooth changeover of V/f, four quadrant operation, harmonic elimination, etc in both closed and open loop applications. When three phase inverter is feeding a three phase induction motor it requires six pulse control (at least).
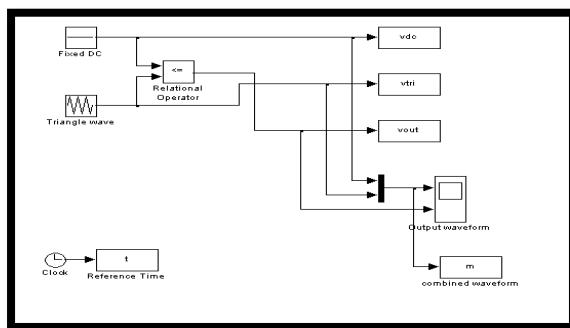
Figure 3.3: Simulation of simple PWM Generator
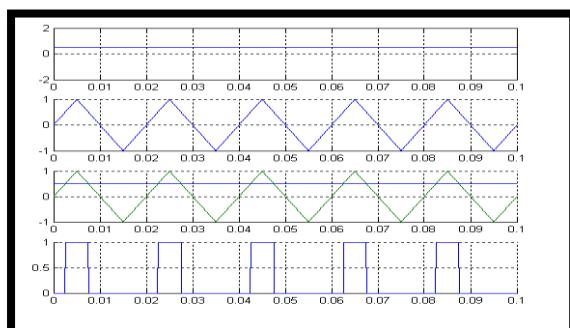
Figure 3.4: Waveforms – Simulation of simple PWM Generator
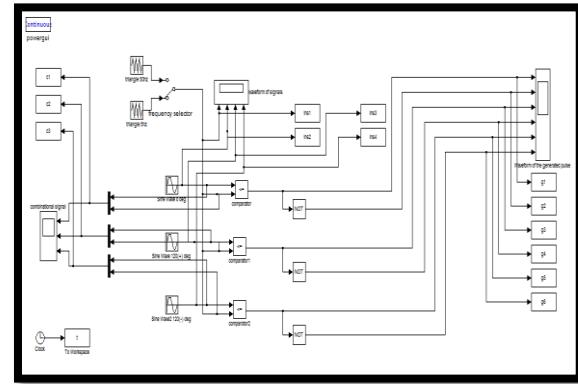
Figure 3.5: Simulation of 6 pulse PWM Generator.

As shown in fig 3.5, for generating 6 pulses for triggering sinusoidal reference wave is compared with high frequency carrier triangular wave. The three sine waves are delayed for 120 degree from each other. The comparator action and is results are shown in below figures.
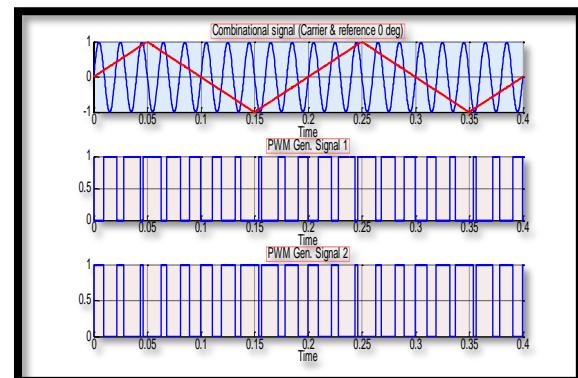

Figure 3.5 (a): waveform – Simulation of 6 pulse PWM Generator
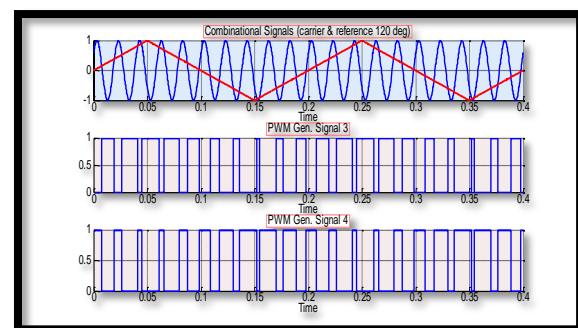
Figure 3.5 (b): waveform – Simulation of 6 pulse PWM Generator

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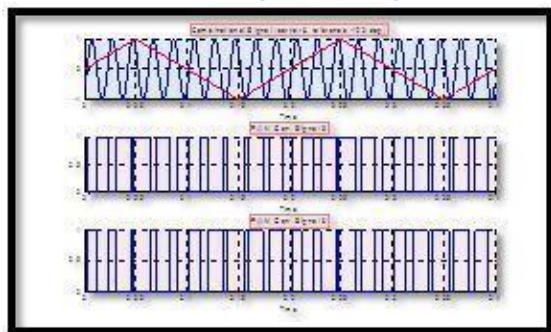
Figure 3.5 (c): waveform – Simulation of 6 pulse PWM Generator.

IV.   SIMULATION AND RESULTS

A.Open Loop SPWM inverter with and without filter.
Here a simulation done for SPWM inverter for resistive load connected in star with filter and without filter. Comparative analysis of THD of current and voltage is carried out. A constant 400 volt dc supply is given to the inverter circuit. For triggering of the switches, SPWM is taken with modulation index less one. Line voltage, phase voltage and current THD are measured and compared for both with filter and without filter.

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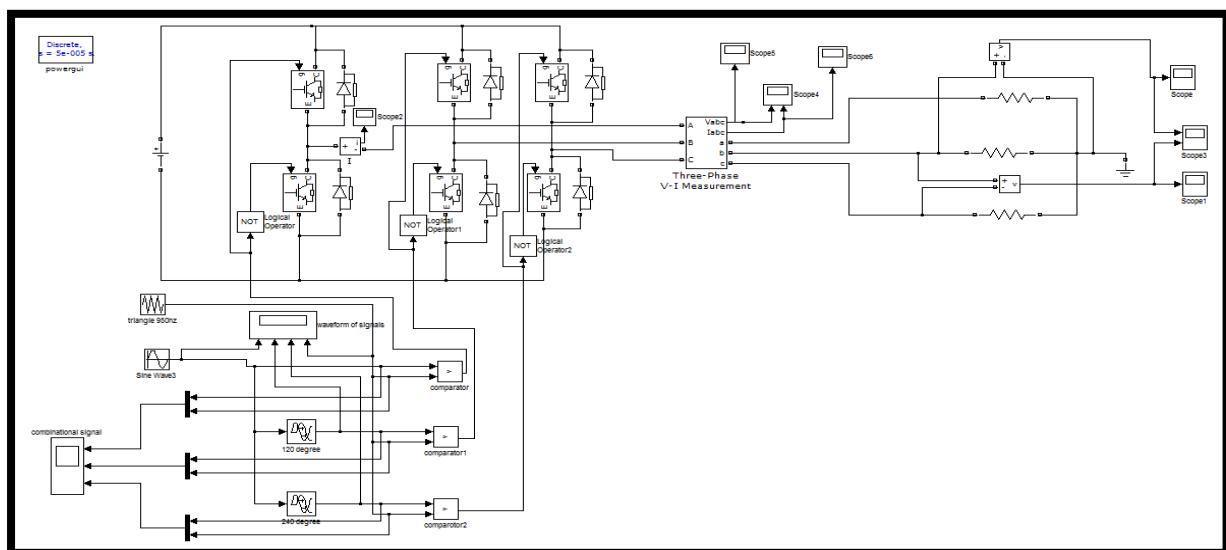
Figure 4.1: Simulation of Open Loop SPWM inverter
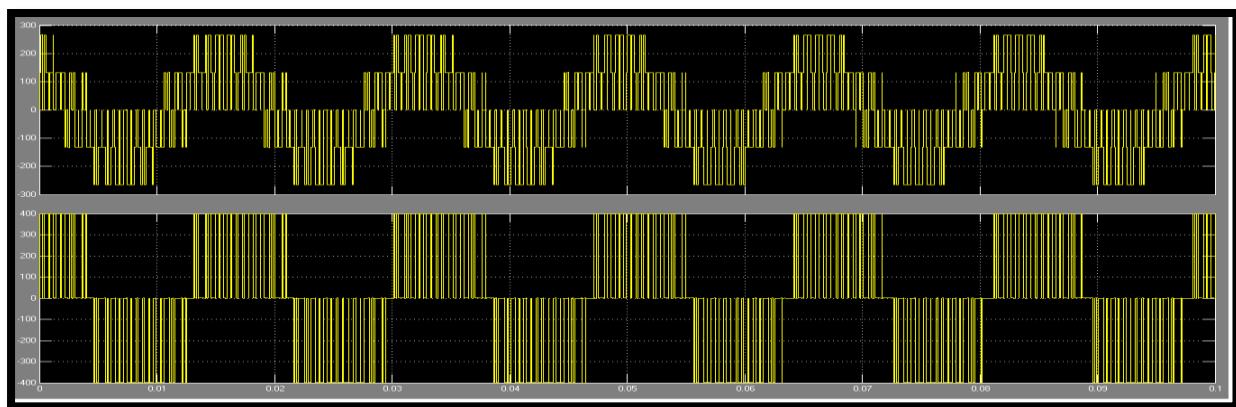
Figure 4.2: Waveform of Output voltages V_P and V_L of 3-Ø SPWM inverter without filter.

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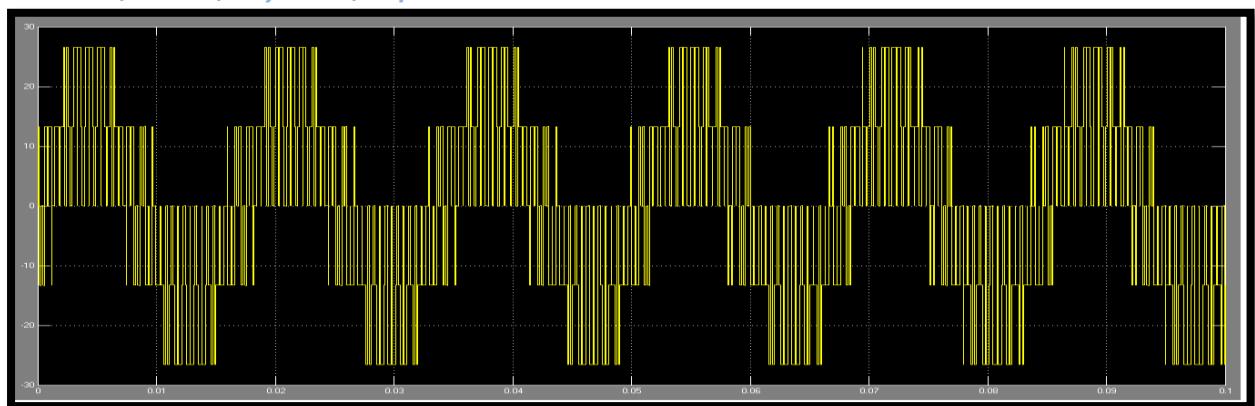
Figure 4.3: Wave form of output current of 3-Ø SPWM inverter without filter.
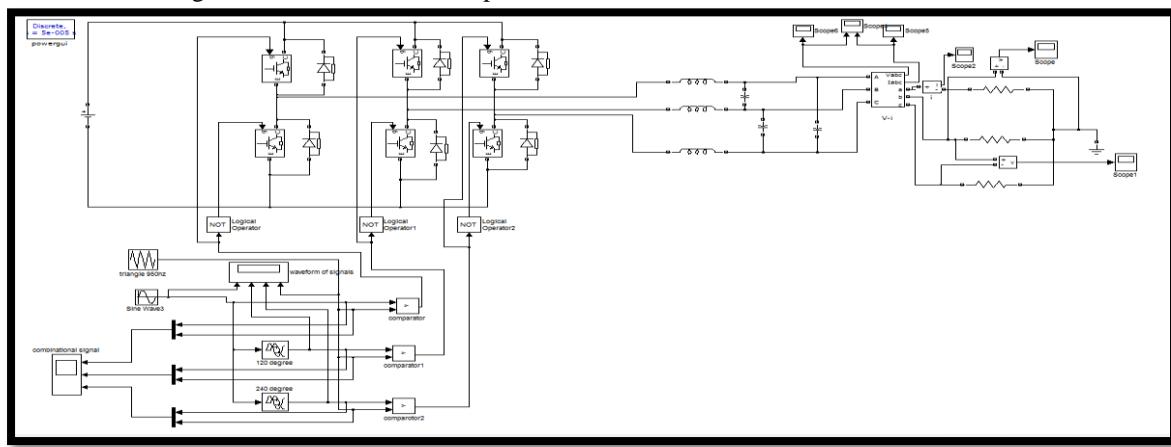
Figure 4.4: Simulation of 3-Ø SPWM inverter with filter.
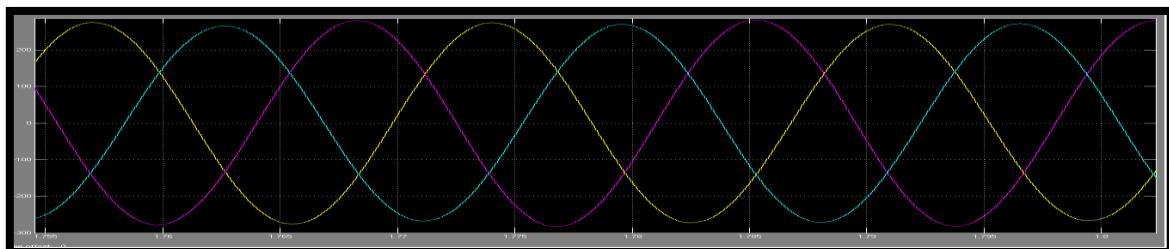
Figure 4.5: Waveform of 3- Ø Output voltage

Figure 4.6: Waveform of 3- Ø Output current

Table 4.1: Comparative result analysis:

| Inverter Mode		SPWM without Filter	SPWM with Filter
Input DC		400V	400V
Output V$_L$		400V	450V
V$_p$		260V	250V
I		26A	26A
THD	**V$_L$**	84.98%	2.33 %
	V$_P$	91.18%	3.18 %
	I	91.18%	2.68 %
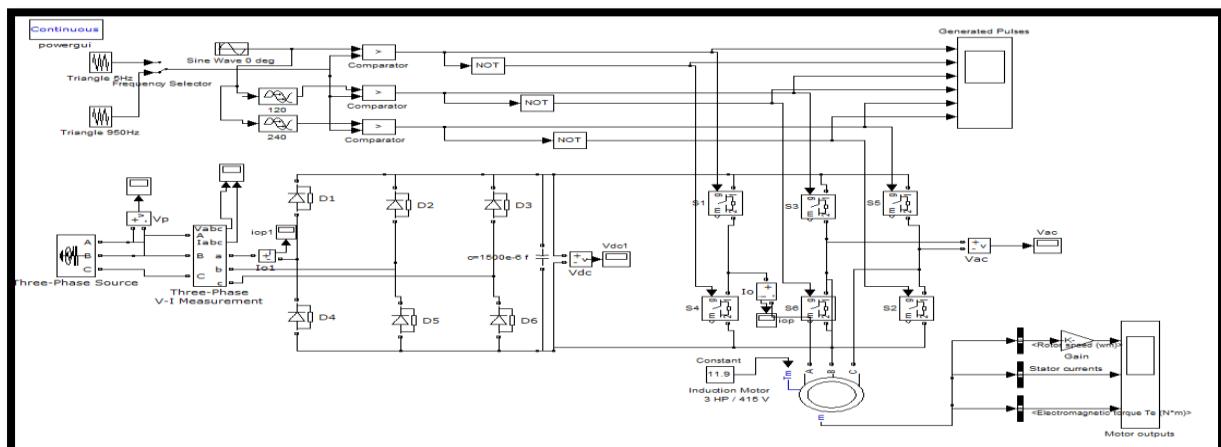
Figure 4.7 Speed control of induction motor by V/F method using SPWM inverter.
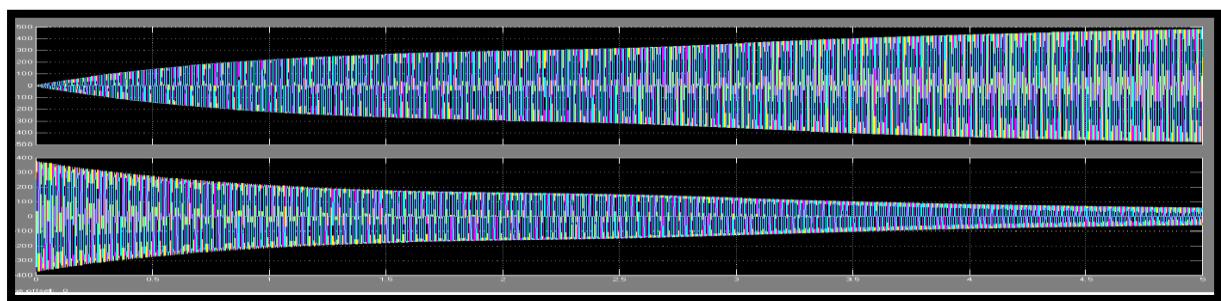

Figure 4.8: Input Voltage and Current.
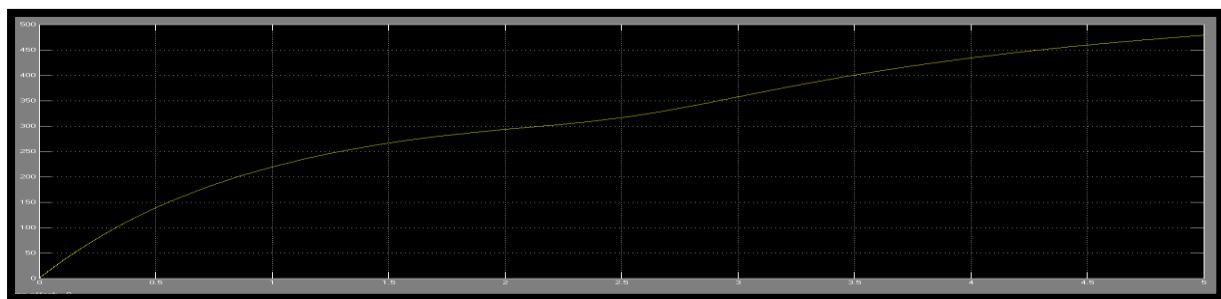
Figure 4.9: Output of rectifier.
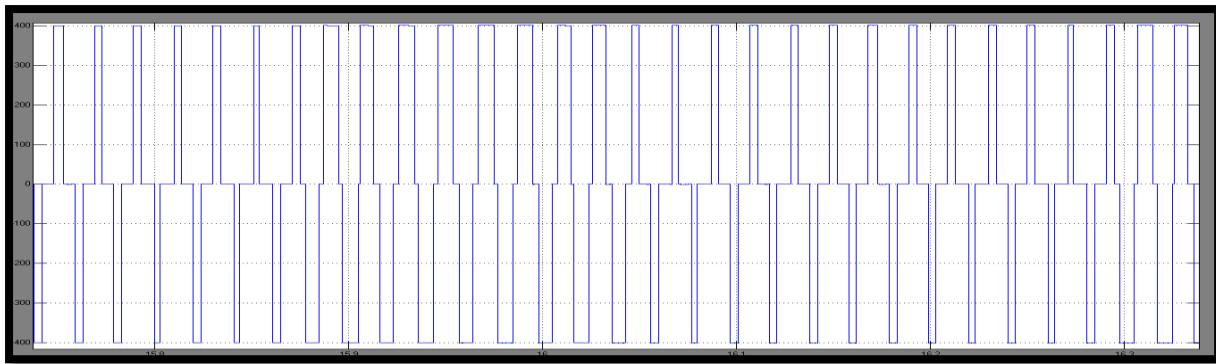
Figure 4.10: Output Voltage.
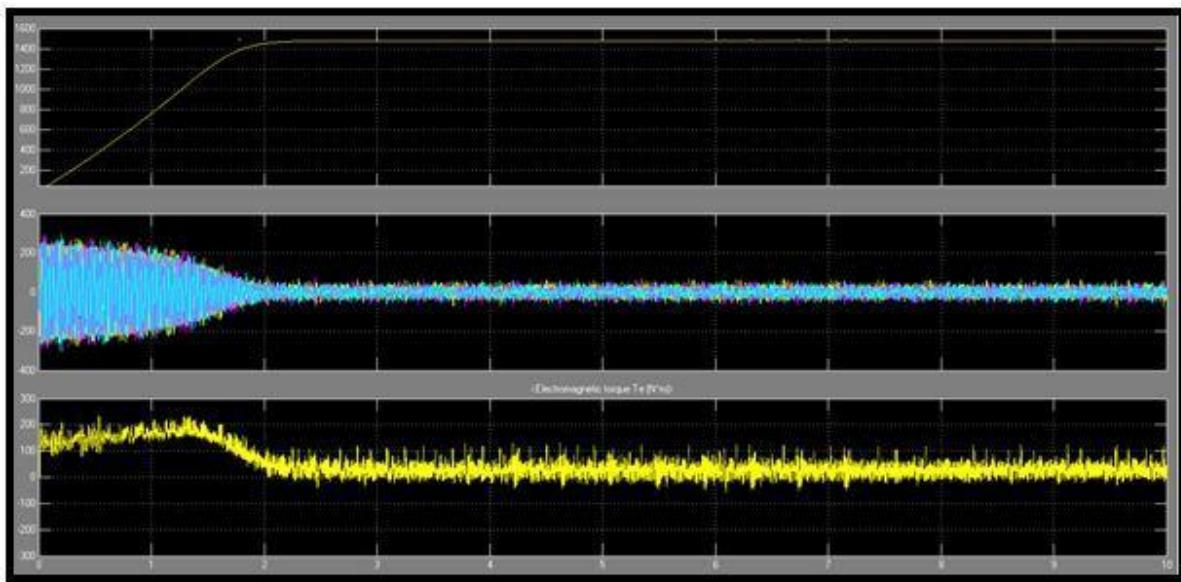

Figure 4.11 Motor Speed, Stator current and Electromagnetic torque.

Current THD %		Voltage THD %	
Input	Output	Input	Output
3.48	2.81	26.73	29.30

Table 4.2: THD analysis for Open Loop Speed Control.

V . HARDWARE IMPLIMENTATION OF SPEED
*CONTROL OF INDUCTION MOTOR USING V/F*
CONTROL METHOD.

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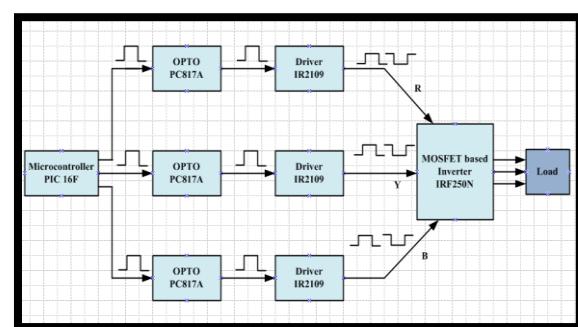
Figure 5.1:Hardware block diagram.

Here fig 5.1 and fig 5.2 shows the block diagram of hardware and hardware inplementaion respectively. Three pulses are generated by the microcontroller which are given to the opto coupler PC817A which provide safety between the power circuit and control circuit. The output of optocoupler is then given to driver circuit where IR2109 driver is used to get six pulses to trigger the mosfet switches IRF250N inverter. The inverter output is given to three phases of three phase induction motor.
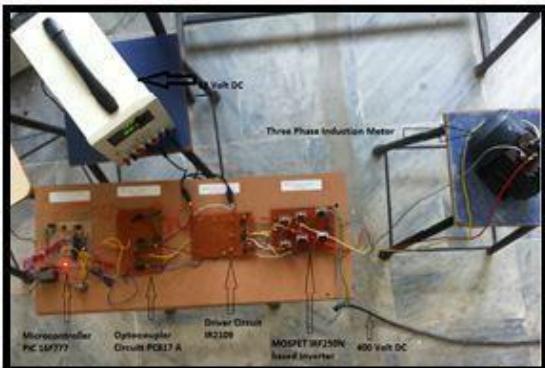

Figure 5.2: Hardware arrangement.
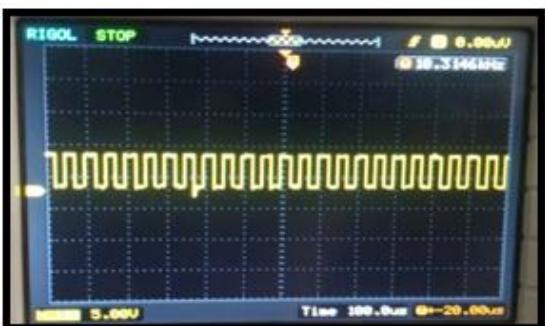

Figure 5.3:Pulse of Microcontroller
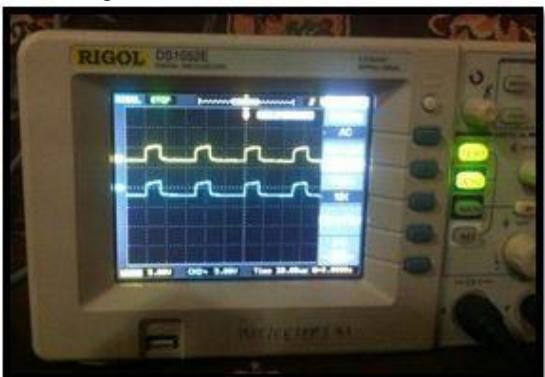
Figure 5.4: Optocoupler output for R and Y phases.
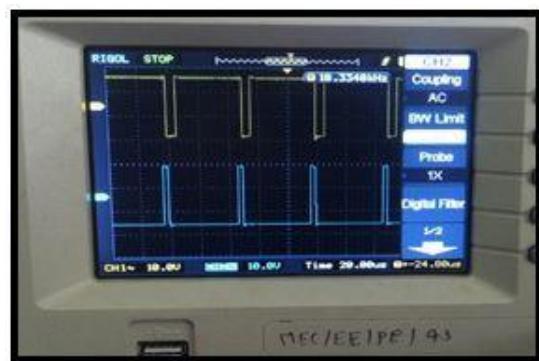

Figure 5.5: Output of driver circuit.
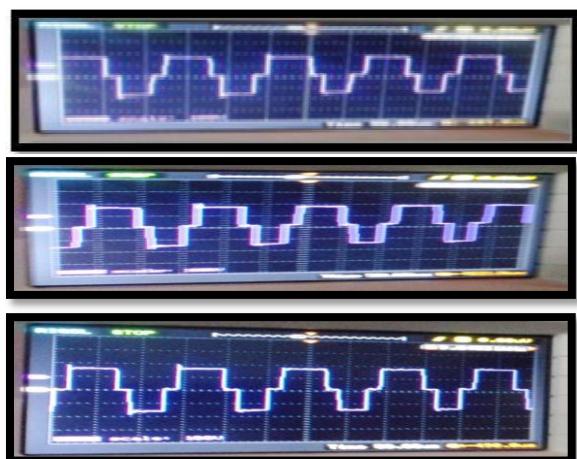
Figure 5.6 Output of three phase Inverter.

VI. CONCLUSION

On the basis of the above mention simulations it is clear that the THD of SPWM inverter without filter is higher compared to the THD of SPWM inverter with filter. For the speed control of induction motor efficient results were obtained and there THD measurements were shown in table 4.2. The simulation work of speed control of induction motor is done in matlab and its prototype is made and results of individual circuits and output of three phase inverter is shown and smooth control of speed is achieved.

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