SPEED CONTROL OF THREE PHASE INDUCTION MOTOR BY V/F METHOD USING SPWM TECHNIQUE

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Abstract: Induction Motors (IM) are widely used for industrial and domestic applications for motoring operation and also as a generator in variable wind speed power generation schemes. Having wide advantages such as simplicity in control and ease of maintenance, squirrel cage induction machines are prominent and suitable for both motor and generator operation. Different techniques are found in literature which is being practiced for speed control of IM with power electronic systems. V/f (Volts/Hertz) control is the most widely used and predominant method as compared to other variable speed drive applications. Conventionally available V/f converters make use of high end digital signal processors which are inherently expensive, thereby making it impossible to perform cost effective speed control. In this project, a cost effective and simple control scheme for V/f control of 3-phase IM is implemented with Sine wave Pulse Width Modulation (SPWM). Here, V/f speed control causes the variations of power frequency and voltage to provide a superior method of controlling the speed of an IM. The speed of three-phase induction motor is controlled by varying both voltage and frequency while maintaining constant V/f ratio. This project makes use of SPWM, which is the most popular Pulse Width Modulation (PWM) technique. Simulation studies of V/f control have been carried out using MATLAB/Simulink using power system toolbox. The simulation study has been carried out for modulation index varying from 0.8 to 0.9 and waveforms has been obtained. Hardware implementation also done with SPWM technique for 0.5HP (3.7KW), 1.1A, 3 phase IM using PIC microcontroller.

1. Introduction:

Among all electrical machines, IM is widely used because of its economical construction and adaptable response. In earlier times, the only concerned output of the motor was mechanical work. Now a day, when industrial automation has developed a lot and energy conservation is of great concern, precision and accuracy along with the optimized energy consumption is the prime requirement for all the electrical machines. Industrial automation, electric vehicle technology or any other electro-mechanical system necessitates the use of variable frequency drives to obtain the desired torque-speed response in the concerned application because use of motor at fixed power frequency calls for large energy losses. Moreover, accuracy also demands a precise control over the speed of motor, which is also related to the proportional variation of power frequency and voltage. This paper incorporates a detailed discussion of Open-loop V/f Speed control of an IM. The concept behind V/f speed control is variations of power frequency relating to the speed input. Variation of power frequency of an induction motor necessitates the variation of terminal voltage to keep the stator magnetic flux at its rated value. Excessive magnetic excitation can lead to increase in iron losses of the machine and reduction in magnetic flux can affect the generated electromagnetic torque. In order to overcome this, the terminal voltage is also changed so as to maintain a constant V/f ratio, whenever frequency is changed in order to control speed. Each segment of V/f control is discussed in detail in the forthcoming chapters. Variation in voltage and frequency is obtained using PWM techniques. Sine wave Pulse Width Modulation (SPWM) has been implemented in this project, which is a popular PWM technique.

The discussions in this chapter may be summarized as follows.

- Speed Control of an IM in V/f technique.
- SPWM – A popular PWM technique.
- Design and Development of a 3-Phase inverter.

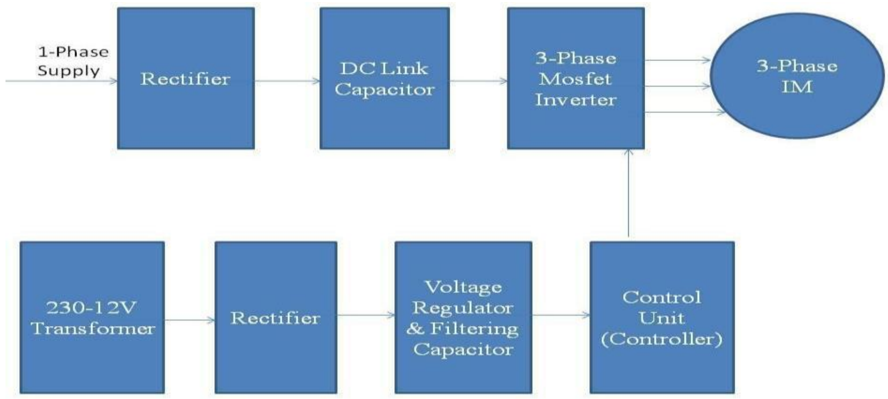


Fig 1.1: Block Diagram

Fig 1.1 shows the block diagram summarizing the introduction given above: In 1885, the IM was independently created by Galileo Ferrari and in 1886 by Nikola Tesla. Ferrari's design displayed the rotor comprising of copper bars. Tesla used a ferromagnetic barrel with windings short-circuited. The fundamental standards and essential outline methods of insight of both models were comparable. George Westinghouse authorized Tesla`s licenses to build a viable IM in 1892. General Electric and Westinghouse consented to a cross-permitting arrangement for the Squirrel-Confine plan of the IM in 1896. Trains in Europe were fitted with IM and could achieve speeds in overabundance of 200 km/hr by the year 1910.
The current induction motors developed from the primitives designed by Tesla with the following advancements.
Good logical models were planned and research was undertaken. Good magnetic, protection materials and cooling frameworks.MOSFET semiconductor PWM Inverters for effective recurrence changing with low misfortunes and more influence thickness. New and good strategies in assembling and also in testing. Better speed and high power applications. With boundary-less performance in a wide range of enterprises, family units and also in transportation, the IM are currently called the "Racehorse of the Business".

1.1. V/f Speed Control of Induction Motor

Speed of the Induction Motor can be controlled with the different methods depending on outcome required. They are as follows:

i. Pole variation
ii. V/f Control
iii. Slip Recovery
iv. Vector Control
v. Supply Frequency Variation
vi. Supply Voltage Variation
vii. Rotor Resistance Variation

V/f control strategy has distinct advantages over the other methods mentioned above, the foremost of which are simplicity and robustness. Metro Trains, escalator incorporates the V/f strategy. However, it has limitations of execution that contrast with vector control. Generally, they are used in the place where accuracy dominates over other parameters.

The advantages of V/f Control are given below:

i. It provides speed change in wide-range.
ii. Low amount of the starting current is required.
iii. Generally, at base speed, Voltage and frequencies reach their rated values.
iv. By controlling the change of supply frequency, the acceleration can be controlled.
v. The cost of it is really less and also easy to implement.

If any other scheme is used to implement the V/f it necessitates the use of digital signal processors (DSP), which is invariably expensive. Mathematically more complicated techniques like space vector modulation can be implemented which includes the advanced programming based primarily on their configured registers like timer, comparator. Above mentioned complexity motivates to achieve V/f control using PIC Microcontroller considering simple controller approach.

Electrical Energy constitutes over 30% of energy utilization on Earth. Moreover, this is set to increase in the future. The massive popularity has been brought by its efficiency of usage, simplicity of transportation and simplicity of era. Some portion of the electrical power generation is used to deliver warm, light and in electrolysis, circular segment heaters, residential warming and so on. Another large part of the of electrical energy generation is used to change into mechanical energy by means of different types of electric motors such as DC, Synchronous and IM.

IM’s are usually named the "Workhorse of the Business". This is based on the grounds that it is a standout among the most generally used motors on the planet. It is used as a part of transportation and industries, and moreover in household apparatuses and research centres. The real usage in the ubiquity of the IM is given as follows:

Cost of the IM is really less as compared to the DC and Synchronous Motors. In this period of clash, this is the prime prerequisite for any of the machine. Because of its cost of acquirement, establishment, utilize, the IM is normally the primary decision for operation.

Squirrel-Cage IM are exceptionally rugged in the development. Their power provides them to be utilized as the part of wide range of conditions and wide span of time.

IM has high efficiency of energy change. In the same manner, they are extremely reliable.

Induction Motors have low support costs because of their simplicity of construction.

IM has high beginning torque. This characteristic is helpful in the usage where the load is connected to the motor.

One more real favourable position of the IM over different motors is the simplicity from which its speed can be changed. Distinctive purpose requires diverse ideal rates of the motor to keep it running at same speed. Control of the speed is a need in IM’s in view of the below given elements:

It provides step less operation.

It provides torque and speeding up control.

Different process needs the motor to keep running for various rates.

It makes up for variable process parameters.

During installation, motor needs to be run at moderate speed.

Each one of the elements shows solid case of the usage of speed control of drives in IM. These are the factors that motivated to concentrate on development of V/f strategy. The second motivation was the great amount of research on optimum level of speed control of IM and proper use of power electronic circuits for smooth control of IM so that this led the project to use the available devices for IM rating.

2. Problem Statement

Induction motor is called asynchronous motor, where it gets it name from the way in which the rotor magnetic field is made from rotating stator magnetic field that induces currents in the short-circuited rotor. The 3-phase IM is the most broadly utilized electric motor worldwide in mechanical offices and expensive structures. It’s one of the most popular drive arrangement regarding cost and performance. The 3-phase IM are characterized into two types which are Squirrel cage IM and Slip ring IM. Talking about 3-phase IM, the major concern is about how the speed control is done and how to keep the motor speed running at rated speed. The speed control of IM is essential to accomplish most extreme torque and efficiency. Traditionally the speed control of 3-phase IM is by utilizing Direct on- line, variable resister and recurrence inverter. When concentrating on the consideration on the speed control part of the 3-PhaseIM, ordinary controller has some issue.

The control and cost estimation of ac drives are in general are more difficult than those of dc drives, this complexity also increases if high performances are considered. The fundamental purposes behind this unpredictability are the necessary for implementing the variable-frequency, converter power supplies, the complexity in controls and variations in parameter of ac machines.

To enhance the capabilities of traditional controller, AC IM are usually used to run in open-loop without feedback. The V/f method for IM speed control has been carried out to maintain at a constant ratio to provide the constant maximum torque over the different range of operating values. This type of control is considered inexpensive and easy to implement. By noting down the voltage, slip can be found, and the motor frequency can be changed accordingly by using PWM Inverter.

2.1 Objective

The primary goal of this project is to design and build up a Simulink model along with the hardware of V/f speed control of IM. The main objective of this project is articulated as follows: Simulation of Open-loop V/f Speed Control of Induction Motor in MATLAB/SIMULINK Platform using power system toolbox. Design of MOSFET based inverter to control IM Generation of PWM pulses for 3 phase inverter MOSFET Bridge. Designing the hardware for 3 phase Inverter. Implementation of the Open-loop V/f Control Scheme for Induction Motor.

2.2 Methodology

The methodology of this project is summarized as follows:-
Simulation study of Open-loop V/f Speed Control of IM in MATLAB/SIMULINK Platform using built in libraries of power system toolbox. The simulation study has been carried out for different modulation index. Hardware implementation for 0.5 HP 3Ph IM of 1.1A current rating Generation of SPWM pulses using PIC Microcontroller

3. Design of V/f Control of IM

The project is of two parts; the software part includes stage such as simulation of V/f Control of the Induction Motor in MATLAB Simulink Platform with the help of built in Power System toolbox. The hardware part involves the implementation and analysing of the results obtained.
Block diagram of the project is shown in Fig 3.1, that mainly consists of 4 part, that are the Rectifier circuit, the 3-phase inverter, 3-phase IM as a load and the PIC microcontroller. First part of the block diagram includes power rectifier and inverter circuit. Power rectifier converts the AC 230V into rectified output which is filtered by 450V,100 uF Capacitor to give DC power for the Power Circuit. The inverter performs function such that it converts the DC voltage to the AC voltage with the help of SPWM gating pulses. In this project, the 3-phase inverter is used because the load is the 3-phase IM. IRF450 is used as the switching device in the inverter circuit along with heat sinks.

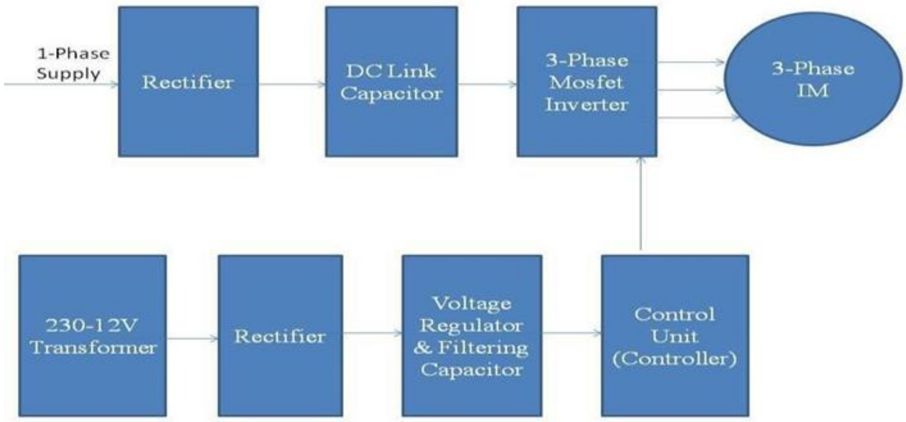


Fig. 2 Basic Block Diagram of the Project

Second part includes control circuit gate driver circuit and the on board low voltage power supply. In the control circuit, PIC microcontroller is used to generate the PWM pulses for Gating of 3 phase MOSFET Bridge. 5V DC Power supply for the PIC microcontroller is given from a 230/12v step-down transformer through rectifier. SPWM Gating Pulses are generated by the PIC controller based on the program written and these generated gating pulses are to be fed into the 3-Phase Inverter which drives the IM.
Before feeding to the MOSFETs directly, the SPWM pulses are amplified with the help of PUSH-PULL amplifier. General flow of the whole project development is shown in the Fig 3.1, it includes hardware and software development. MATLAB Simulink has been used in this project for simulation purpose. The whole Open-loop V/f Speed Control of IM is done and waveforms for different modulation index is obtained and output obtained tends to match with the results referred IEEE papers. Hardware implementation also done with SPWM technique for 0.5HP (3.7KW), 1.1A, 3 phase IM using PIC microcontroller.

4. Simulation of V/f Control

This project makes use of Simulink as the software tool to simulate our system because it is a powerful tool for power system analysis.

4.1 Open -loop Control

In open loop control, we have to manually adjust the speed of the motor according to our requirement. To adjust the speed, we use the V/f control defined above. Ignoring the rotor slip, power frequency required corresponding to a particular speed can be calculated as follow

Ns= 120f/p

Where,

N=Speed in RPM

f = power frequency P = No.of Poles

After determining the frequency, we calculate the voltage magnitude such that, Vpu=fpu

Calculated voltage magnitude and power Frequency is given as input to our Sine wave PWM algorithm to generate the corresponding PWM pattern by the microcontroller. This low voltage PWM signal is amplified by the 3-Phase inverter to apply it to the motor.

4.2 V/f Control of IM using MATLAB/Simulink

This section explains the MATLAB/Simulink software implementation of V/f Control of IM using Simulink model in the under-modulation region. It also describes. This chapter includes detailed discussion of the Simulink models as well as an explanation, where as the result analysis is done in the next chapter.

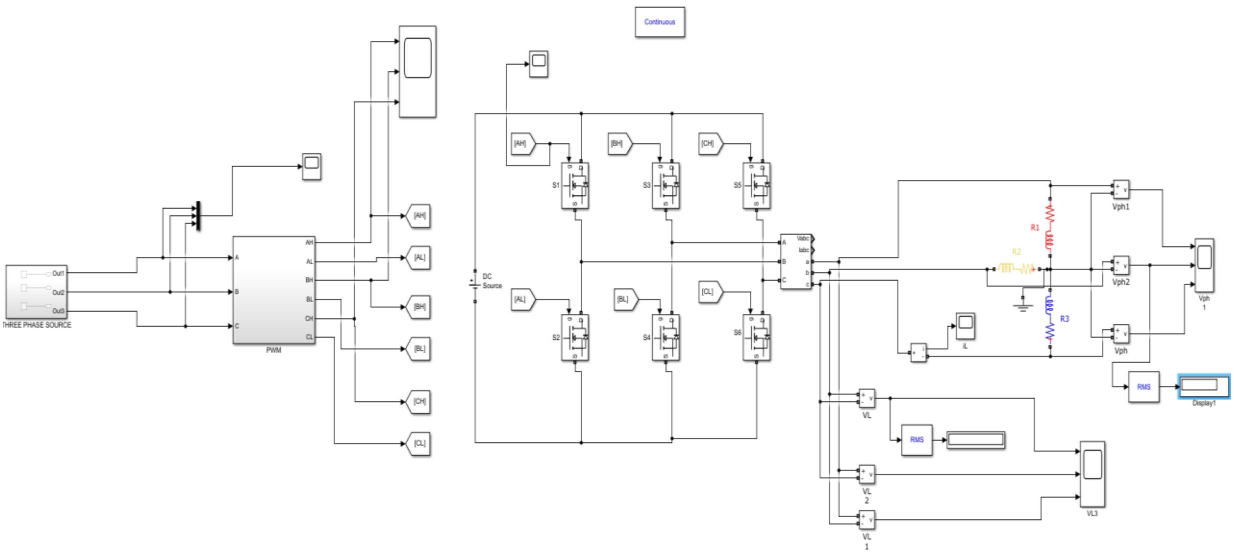


Fig 4.1: Open loop V/f Control of Induction Motor

In the above Fig 4.1 input supply is given from the 3-Phase source to the PWM inverter. PWM output is given to 3 phase Inverter Bridge. Inverter consists of the six MOSFET's, which consists of 3-leg. Each device conducts for 60degree, where as a pair of MOSFET's conducts for 120 degree, where one is from upper leg and one from lower leg. In order to turn on the switches we use the PWM. PWM Generator generates a switching pulse for a phase shift of 120 degree, for upper leg switches and compliment of this signal to lower leg switches. Voltage measurement block is used for to display the waveforms of input supply, inverter output. Results obtained from this simulation have been analysed in next chapter. Here

Modulation index is given as 0.8 and 0.9

PWM Generator: For generating the gate pulse for turning ON the MOSFET this block is used. By comparing a triangular waveform with a reference signal the pulses are generated. The following parameters are entered as follows:-

Generator mode- 3-arm bridge (6 pulses)

Carrier frequency= 1000 Hz

Modulating signal generated internally

Modulation Index= 0.8 to 0.9
Frequency of output voltage= 50Hz
Output voltage phase shift = 120 degrees.

5. Hardware Implementation

This chapter includes the hardware designing and implementation of our project. The major hardware parts are rectifiers, Controller circuit, Gate driver circuits and Inverter Bridge.

5.1 High Power Circuit:

In this project high power circuit refers to 3 phase Inverter Bridge and the rectifier circuit which converts an AC input voltage of 230V into rectified output of 320V which is filtered by 450V, 100µF Capacitor to give DC to give the power for the Power Circuit. The diodes used are IN5408 PN Junction diodes. MOSFETs used for the 3 phase Inverter bridge are IRF450 with heat sinks. 3-Phase Inverter then turns ON based on the gating signals to give AC output, which is input to the Induction Motor, and for the purpose stabilizing the output of AC voltage LC filter can be used.

5.1.1 High Voltage DC Supply

A closed loop bridge configuration is used where four diodes connected to produce desired output. Rectifier circuit which converts AC input voltage of 230V into rectified output of 320V which is filtered by 450V, 100µF Capacitor to give DC to give the power for the Power Circuit. The diodes used are IN5408 PN Junction diodes. Fig.5.1 shows the Full bridge rectifier circuit.

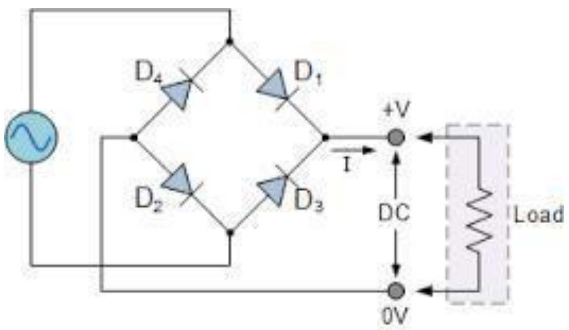


Fig 5.1: Full Bridge Rectifier

Input diodes D1 and D2 conducts during the positive half cycle of and D3 and D4 are reverse biased. Diodes D3 and D4 conducts and D1 and D2 are reverse biased during the negative half cycle. There are large ripple contents in the output of the rectifier. We have to filter out the ripple contents to get the pure DC voltage. 100uF, 450V capacitor will filter out the ripple contents up to large extent. Output voltage of this circuit is provided as HVDC to the drains of high side MOSFETs of inverter

5.1.2 3-Phase Inverter

3-phase inverter consists of six power MOSFET (IRF450). The function of inverter is used to convert DC power into three phase AC power. Power flow from the DC side to the AC side which is nothing but inverter operation, and is capable of carrying 500V.

MOSFET (IRF450):

Fig 5.2: MOSFET IRF450

Fig 5.2 shows MOSFET are switching devices which are controlled through switching sequence applied by the micro-controller. By applying appropriate switching sequence, we produce desired 3 phase voltage to run the induction motor. Following are the rated voltages and currents of the power MOSFET V_{ds}= 500V; V_{gs} = -20 to +20 volt T_c =25°C I_d = 8A at T 25 degree Celsius
Gate to Threshold Voltage (V_{th}) = 2 to 4v

We will apply HVDC of 320V generated from the rectification done by IN5408 bridge rectifier supply at the drains of the MOSFETs. It is within the voltage limits of IRF450. When higher side of MOSFET is turned ON, phase output is connected to positive high voltage DC bus. When lower side of MOSFET is turned ON, phase output is connected to ground. Our induction motor draws maximum of 1.1A current so MOSFET is selected on the basis of 3-4 times this current, so it is also within the current limits i.e. less than the drain current.

5.2 Low Power Circuit:

Low power circuit consists of controller circuit, power supply for control circuit, and Gate driver circuits. 5V DC Power supply for the PIC microcontroller is given from a 230/12v, 1A rating step-down transformer through rectifier bridge of diodes IN4007. In the gate driver circuit MCT2E opto coupler is used to get isolation from power circuit to control circuit. And for amplification purpose npn (BD140) and pnp (BD139) transistors are used. All of the steps of generating the required SPWM will be done in PIC microcontroller. The gate driver provides the voltage range up to 230 to 400V for 3- phase inverter. The 3-phase IM is rated at 0.37kW, 1.1A, 1440 rpm.

5.3 Opto-coupler (MCT2E)

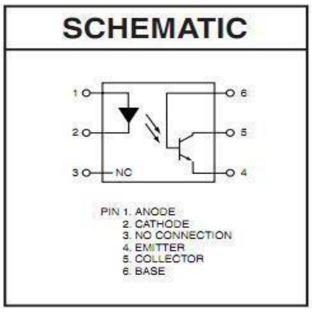


Fig 5.3 Schematic diagram of an Opto-coupler.

An opto-isolator is also called an opto-coupler, photo coupler, or optical isolator in electronics, is a component which by using light that transfers electrical signals between two separated circuits. Opto-isolators help in preventing unexpected high voltages from affecting the system that receives the signal. Opto-isolators available in market can withstand input-to-output voltages up to 10 kV and voltage transients with speeds up to 10 kV/μs. Fig 3.6 shows the schematic diagram of an Opto-coupler, which basically converts electrical input signal into output light signal. It contains the light emitting source (emitter) and a light-emitting diode (LED) in the infrared region. The incoming light is detected by the closed optical channel and a photo sensor and it either modulates electric current flowing from an external power supply or generates electric energy directly. By allowing modulation of light by external objects because of its open optical channel, it goes in the path of light or reflecting light into the sensor. Opto-couplers are biased from the output of voltage regulators. Opto-coupler is used to provide optical isolation between micro-controller and rest of the circuit. In case opto-coupler is not used excessive current greater than 40mA (current rating PIC controller) can damage the micro-controller which is undesirable. So MCT2E provides isolation to save micro-controller from damage.
Current rating of PIC micro-controller = 40mA.
Forward current rating of opto-coupler (MCT2E) = 20mA.
We have to limit the current below 20mA so that micro-controller and opto-coupler do not get damaged.
Voltage peak of PWM from micro-controller is 3V.
We want to limit the current up to l2mA, so $= (3/12)\times10^3 = 250$

Resistance comes out to be 250 ohms. We have inserted 220ohms resistance between microcontroller and opto-coupler. Current according to this resistance comes out: I = 3/220 = 13.6mA
Current = 13.6mA < 20mA
Six MCT2E are used for applying the pulses at the gates of six MOSFETs.
5.2.2 Gate Driver:
The PWM pulses are of nearly 2volts and the MOSFET gate circuit needs more than 4.5V. To increase the voltage level as well as the current level of the PWM pulses gate driver circuit is used. PUSH-PULL amplifier is used as the gate driver here. It consists of two transistors npn(BD140) and pnp(BD139). The amplified 12v output of this driver circuit is given to MOSFET gate circuit.

5.2.3 On Board Low Voltage Supply

We need 12V DC for the biasing of six each gate drive circuit. In six driver circuits, lower leg MOSFETs (in the H Bridge Inverter) can have common ground in Gate-source circuit, but the upper leg MOSFETs will not get common ground as the Drain of lower leg and the source of upper leg are connected together. In this case we provided dedicated grounds for the upper leg MOSFETs. So the number of rectifier units required for the gate driver circuits are only four; one is for the gate drivers of lower leg MOSFETs with common ground and other three for the upper leg MOSFETs with individual ground. These 12 volts are generated in the following three steps as shown in Fig 3.10.

230/12V steps down transformers are used to give 12V.
Full bridge rectifier rectifies the output of transformer to produce 12V DC. Output of rectifier contains considerable amount of ripple contents and capacitor filter out these ripple contents.
Output bridge rectifier is applied to the 12V voltage regulator (7812). 7812 regulates the voltage at the level of 12V. If any ripple contents are present at the output of 7812, capacitor (l000uF, 25V) filter out these contents to produce pure 12V DC.

Fig 5.3: Block Diagram of Low Voltage Supply

5.2.4 PIC Microcontroller

The Microcontroller used in our project to generate SPWM pulses is PIC16F72- I/SP,28-pin package IC. It is a 8-bit CMOS Flash Microcontroller with 5-channel analogue-to-digital converter with 200 nanosecond instruction execution also easy-to- program (only 35 single word instructions). It has 5 channels of 8-bit Analogue-to-Digital (A/D) converter with 2 additional timers, capture/compare/PWM function and the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface or the 2-wire Inter-Integrated Circuit bus. This device is having two memory blocks; program memory and the data memory. Each block has separate buses so that concurrent access can occur.

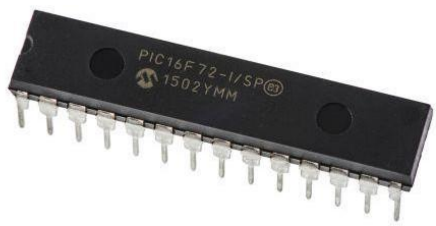


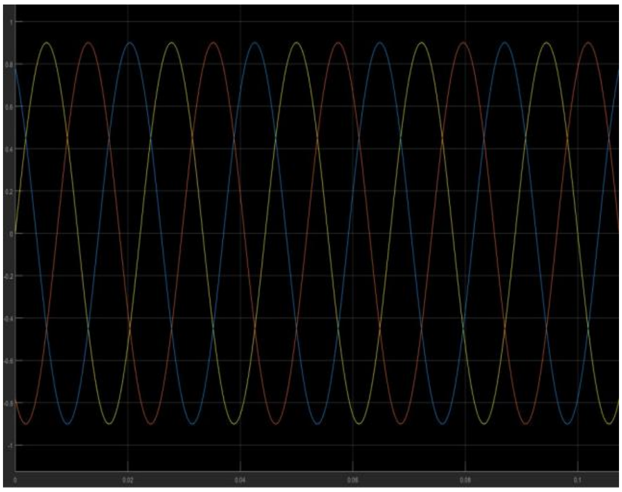
Fig 5.5 PIC16F72-I/SP,28-pin package IC

CPU Speed: 20 MHz
Program memory size: 3.5 KB

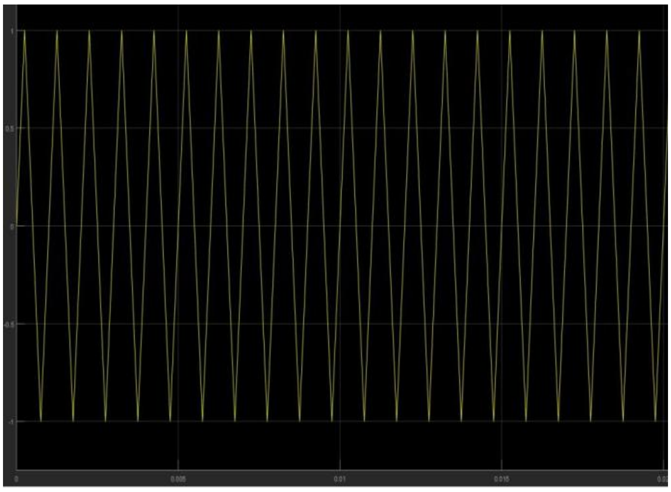
RAM Memory size: 128 Bytes
Number of pins: 28 pins
Supply voltage min: 4V DC
Supply voltage max: 5.5V DC

6. Simulation Results

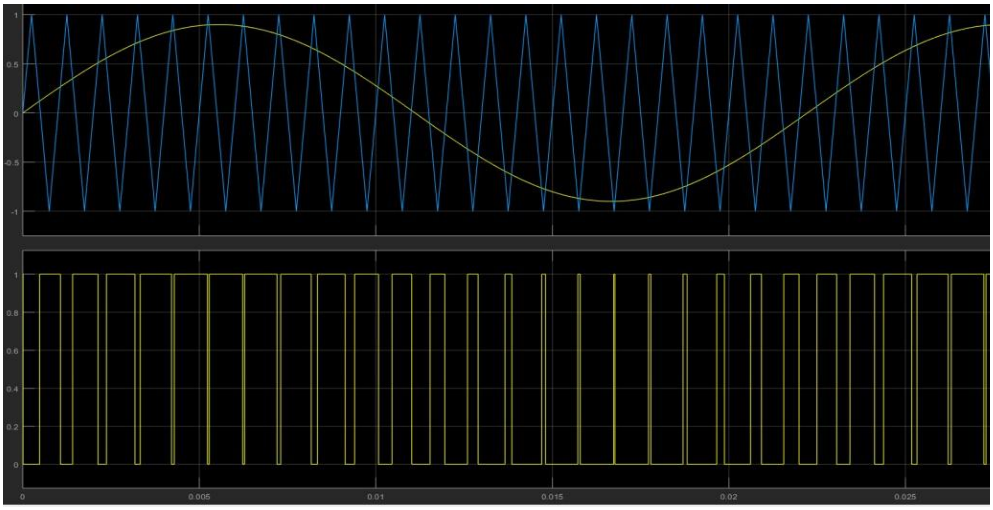
The following figures shown are obtained from the Simulation study of Speed Control of IM by V/f technique in MATLAB/SIMULINK Platform using built in libraries of power system toolbox.



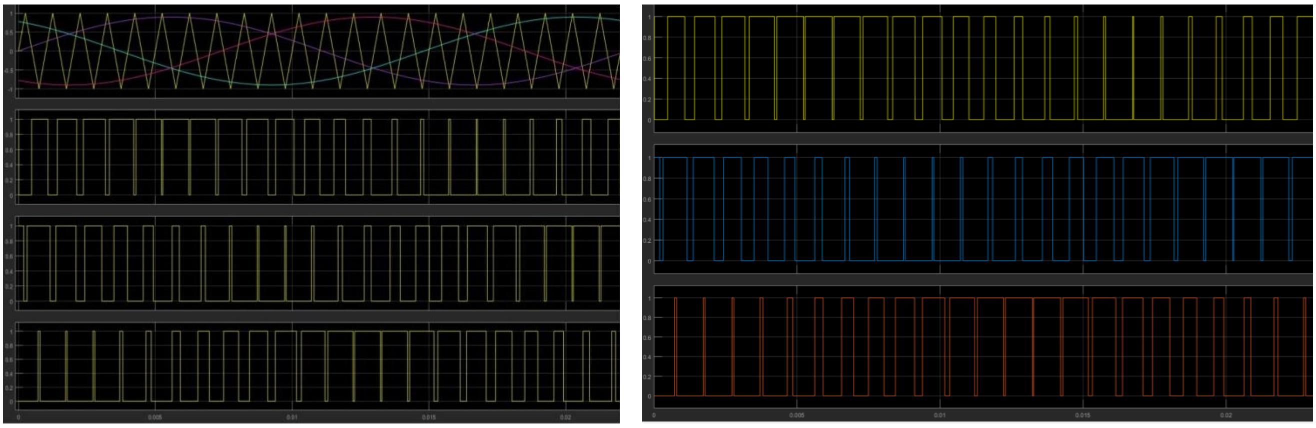
3 Phase sinusoidal reference signal



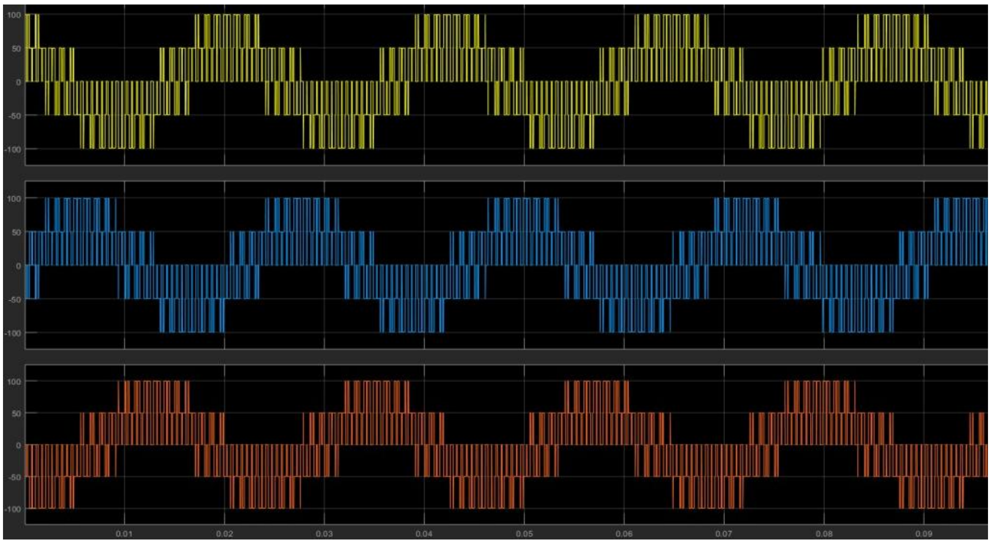
Triangular carrier wave



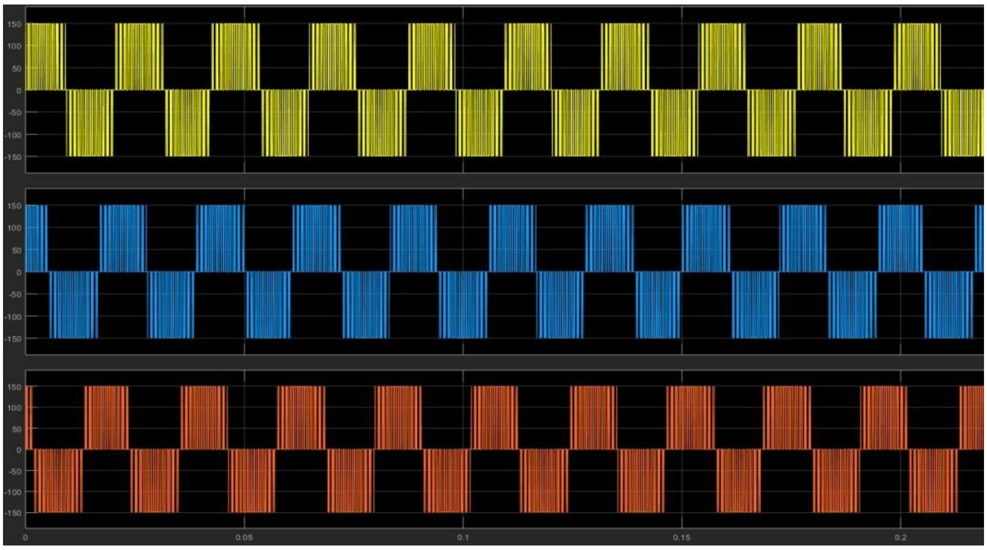
Sinusoidal Pulse Width Modulation



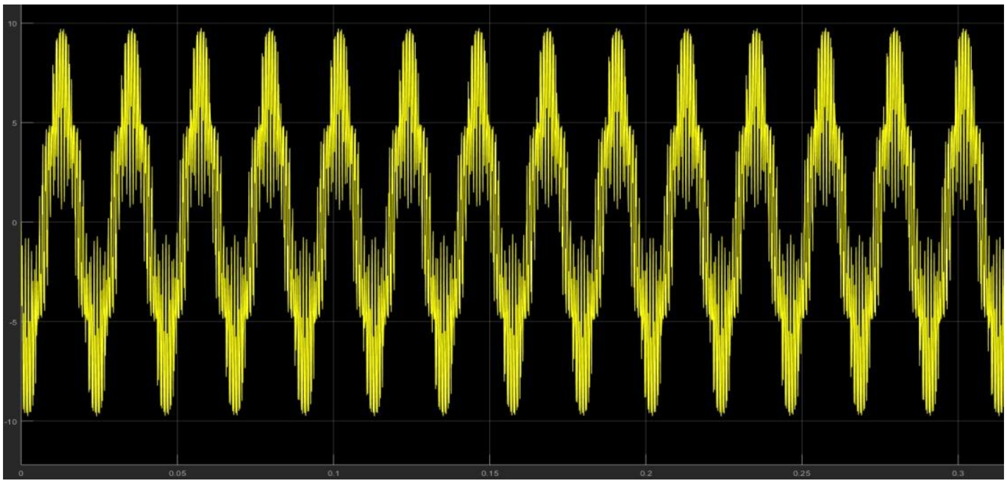
Sinusoidal Pulse Width Modulation for 3 Phase



Output Voltage (Vph)

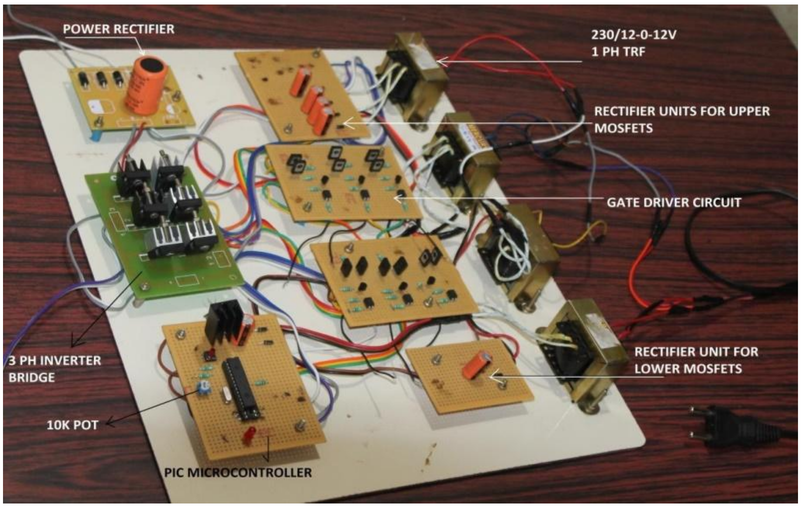


Output Voltage (VL)

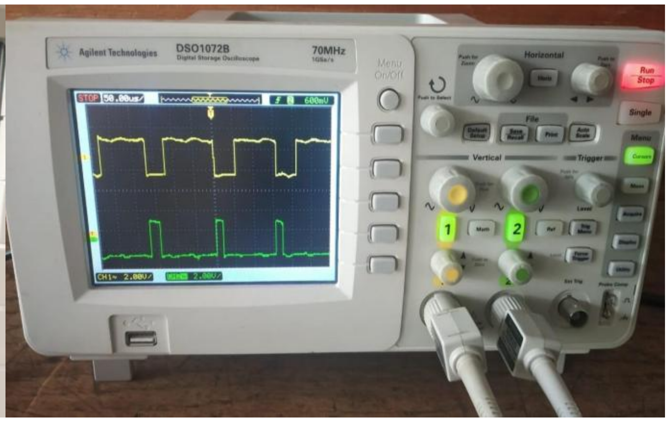


Output Current (IL)

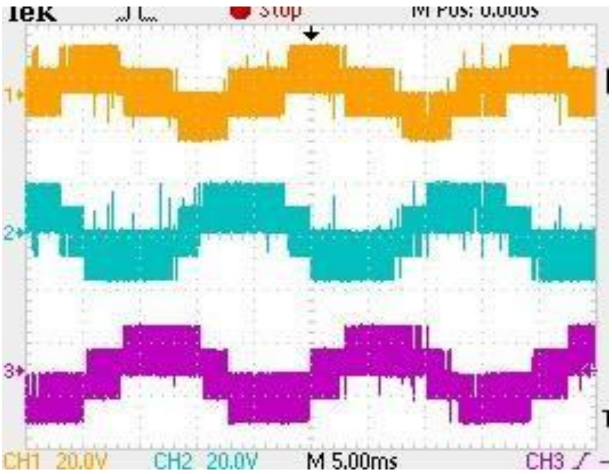
7. Hardware Results



HARDWARE SETUP



Output of first two mosfets Output of second two mosfets



Output of third two mosfets Output of three phase inverter

8. Conclusion

In this paper, both Simulation studies and Implementation of the V/f Control Scheme with a hardware module have been carried out. Testing of performance for the control of speed has been performed. Simulation of V/f speed Control was done using MATLAB/Simulink. The sine wave PWM algorithm will be implemented on PIC Microcontroller which causes a radical simplification of design and coding as opposed to the conventional DSP based control systems. Hardware design to control the speed of 0.5HP 3Ph IM has been carried out using PIC Microcontroller and tabulated the required V/f results and in both hardware and software implementation we are getting V/f as constant. The designed control module is significantly cheaper than any other comparable system.

9. References

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