Speed Control Of Three Phase Induction Motor Using PWM Inverter

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***ABSTRACT* – Pulse Width Modulation (PWM) technique to control the speed of three phase induction motor was analyzed. The induction motor is a type of AC motor whereby power is provided to rotor by technique of electromagnetic induction by way of. Controlling the speed of induction motor is mostly which in the motion industry appliances. PWM inverter control technique was used to vary the three phase induction motor speed by varying frequency applied to inverter for three phase induction motor. PWM is the efficient method of providing the quantity of electrical source between fully off state and fully on state. MOSFET and IGBT are used as the inverter switching element that provides a smooth way to control the frequency, voltage magnitude and current supply to the motor. Simulation on this method was carried out by using the software for simulation of power electronic and motor drive module called PSIM. Results obtained from the simulation indicated that PWM inverter is capable for controlling the speed of three phase induction motor.**

***KEYWORDS* – MOSFET (Metal Oxide Semiconductor Field Effect Transistor), IGBT (Insulated Gate Bipolar Transistor), PWM (Pulse Width Modulated), AC (Alternating Current).**

I. INTRODUCTION

Induction motors are the most widely used motors for appliances like industrial control, and automation; hence, they are often called the workhorse of the motion industry [1]. The induction motor may be operated as a motor and as a generator but it is rarely used as a generator delivering electrical power to the load since the performance are not purposely for certain of applications. There are two commonly used types of induction motor which are wound rotor type and squirrel rotor type.

Many industrial applications required several speeds or a continuously adjustable speed drive system. Traditionally a DC motor have been used the adjustable drive systems but DC motor are expensive, required periodic maintenance for commutators and brushes and also not prohibited in hazardous environment. Squirrel cage induction motors are cheap, rugged, no commutators and suitable for high speed applications. The availability of solid state controllers although more complex than used for DC motors, has made it possible to use induction motors in variable speed drive systems.

There are several techniques to control the speed of induction motor which are changing line frequency, changing number of poles, changing line voltage and changing the rotor resistance, slip frequency operation, closed loop control, constant flux operation, constant current operation and rotor slip energy recovery.

For changing number of poles is not very practical now since the development of modern solid state control circuit. Motor speed can be varied by changing the rotor resistance but seriously reduce the efficiency of motor.

Controlling the motor speed by changing the line voltage is limited by range such as in small motor driving fan. Maintaining the voltage and torque at the certain limits as long as the frequency can be varied is required to avoid the motor saturation. For efficient operation of an induction motor, it is desirable to operate it at a fixed or controlled slip frequency. For closed loop feedback systems is required complex system. To obtain high torque throughout the speed range, the motor air gap flux should be maintained constant. The motor flux should not be allowed to decrease at lower frequencies as a result of the increasing effects of the stator resistance. The motor can be operated at constant current by providing a current loop around AC- DC converter. For rotor resistance required the solid state control for smoother operation. If the slip power lost in the resistance could be returned to the AC source, the overall efficiency of the drive system would be increase rapidly.

Synchronous speed is proportional to the line frequency, so it is possible to adjust the speed of induction motor by varied the line frequency. In order to control the rotating speed of a three phase induction motor, a three phase inverter is required [2]. The switching power converters such as Isolated Gate Bipolar Transistor (IGBT) and Metal Oxide

Semiconductor Field Effect Transistor (MOSFET) has offered an easy way for controlling the magnitude and frequency of the voltage and current fed to 3 phase induction motor. The ability that switching power converters distribute to a motor is controlled by Pulse Width Modulated (PWM) signals employ to the gates of the power switch at the inverter. The inverter is provided to converts direct current to alternating current and fed the converted current to the motor.

The objective of this research is to control the speed of 3 phase induction motor by using PWM technique. A few steps are taken for the analysis. Firstly, the induction motor is studied to determine what kind of features can be manipulated to control the speed. Secondly, studies are made about the techniques to control three phase induction motor speed. Then the PWM inverter circuit is designed to feed the motor and recorded the simulated results. The speed of the motor from the simulation will be a major result for this thesis.

These projects have three objectives:

(A) To implement the technique speed control of 3-phase induction motor.

(B) To verify the viability of PWM inverter can affect the speed control of 3-phase induction motor.

(C) To mitigate the harmonic effect using harmonic filter.

II. INDUCTION MOTOR

The induction motor usually can be used in a volatile or aggressive environment because there are no problem with spark and corrosion. These advantages however are superseded by control problems when using an induction motor in industrial drives with high performance demands **[3].** Induction motor with squirrel-case rotors are wide range of power ratings such as fractional horsepower to 10 MW. Both 3Φ and 1Φ motors are widely used. The induction generators are seldom used. Their typical application is the wind power plant. A typical motor that separated by a small air gap contains two parts which is stator and rotor. Stator is static part while rotor is rotation part. There are two category of inside rotor which is squirrel-cage rotor and wound rotor. The stator is made up by layered iron core alongside the slots. Three or single phase winding are constructed by arrange the coils in the slots. Squirrel-cage rotor is layered iron core with the slots. Alternatively winding along two rings circuit, the Metal such as Aluminum bar type is form alongside the slots forming a squirrel-cage shaped circuit. For cooling the circuit, fans are connecting to shaft besides of the rotor. Winding of Wound rotor are similar to Squirrel-cage winding but Squirrel-cage winding are cheaper than wound rotor winding since the brushes and slip ring of wound rotor winding are required maintenance. Therefore the wound rotors are not popular for industry application purpose. Usually it for large 3Φ induction motors. When the current flows into the stator, it produces the magnetic field which is rotating. The speed of rotation of magnetic field is given by **[4]:**

$$\mathbf{Ns = 120x}\ \frac{f(Hz)}{P(number\ of\ poles\ per\ phase\ )} \qquad \mathbf{(1)}$$

Ns: rotating speed in RPM

F = frequency (Hertz)

P = Number of poles per phase

The rotor speed depends on the magnetic field rotation and the speed of rotation of stator and rotor magnetic field is called synchronous speed. The shaft speed (rotor speed) of induction motor when driving load will always be less than the synchronous speed. The percent difference in synchronous speed and shaft speed is called slip **[5].**

$$N_{slip} = N_{sync} - N_m \qquad \mathbf{(2)}$$

N_{slip}**:** slip speed of the motor

N_{sync}**:** speed of magnetic fields

N_m**:** mechanical shaft speed of rotor

$$s = \frac{N_s - N}{N_s}\ \mathbf{x\ 100\ (\%)} \qquad \mathbf{(3)}$$

N: rotor speed in RPM

s: speed slip

A. SPEED CONTROL METHOD.

In the stable region of operation in the motoring mode, the curve is rather steep and goes from zero torque at synchronous speed to the stall torque at a value of slip s = ˆs

[6]. Before introduction of solid state device, induction motor was not popular machine for speed variable application. After the introduction of solid state device such as Isolated Gate Bipolar Transistor (IGBT) and Metal Oxide Semiconductor Field Effect Transistor (MOSFET), the cheaper AC Drive system was introduced. Several techniques are available for the speed control purpose as listed below **[7]:**

i) Pole Changing,

ii) Line Voltage Control,

iii) Supply Frequency Control,

iv) Rotor Resistance,

v) Slip Frequency Operation,

vi) Closed Loop Control,

vii) Constant Flux Operation,

viii) Constant Current Operation,

ix) Rotor Slip Energy Recovery.

Pole changing method is applicable for a cage rotor motor. Rotor resistance is applicable for wound rotor only. Line voltage control and supply frequency control are applicable for both types of rotor motor.

For Supply frequency control, voltage induced in stator is equivalent to the product of supply frequency (f_s) and air-gap flux (ϕ_m).

$$V = 4.44\ N\ \phi_m f_s \qquad (4)$$

N = the number of the turns per phase

ϕ_m = Air-gap flux

f_s = the supply frequency

The motor terminal voltage is directly proportional to the product of frequency and flux. At the constant terminal voltage, any reduction in the supply frequency f_s can cause the increase of air gap flux (ϕ_m). The increased of in flux will cause the motor saturated. Therefore, the variable frequency control below rated frequency is generally carried out at rated air gap flux by varying supply voltage with frequency so as to maintain V/F ratio constant at the rated value. Applications of line frequency speed control ways need the frequency alter. To maintained the air gap **(ϕ_m),** V/F ratio must be increase for low frequency. The voltage input for the induction motor will be changed by PWM inverter.

B. PULSE-WIDTH MODULATION (PWM)

The inverter job is to take this DC input and convert to AC output, where the magnitude and frequency can be controlled **[8].** The inverter is called PWM inverter because it using PWM inverter switches to regulate the magnitude and frequency of the AC voltage with the supply voltages of DC voltage that are originally uniform in magnitude. The pulse-width modulation (PWM) for three-phase inverter is generated by comparing three phase sinusoidal control signals with a high frequency triangular carrier waveform. The triangular voltage waveform (V_T) is compared with three sinusoidal voltages (V_{AG}, V_{BG}, and V_{CC}), which are 120° out of phase with each other. Definition of terms in PWM can be expressed as:

$$\textbf{Modulation Index} = M = \frac{V modulating\_signal}{V carrier\_signal} \qquad (5)$$

$$\textbf{Frequency Index} = M_f = \frac{fs}{fsine} \qquad (6)$$

A graphical representation of the generated PWM waveform for three phase system is shown in Figure 1.

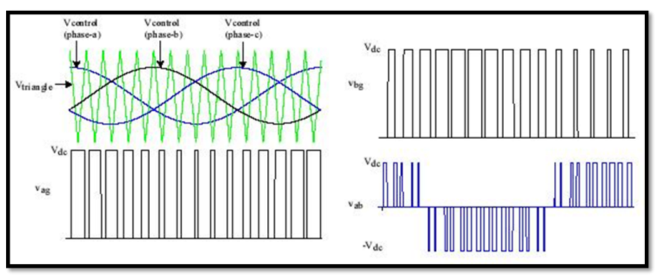
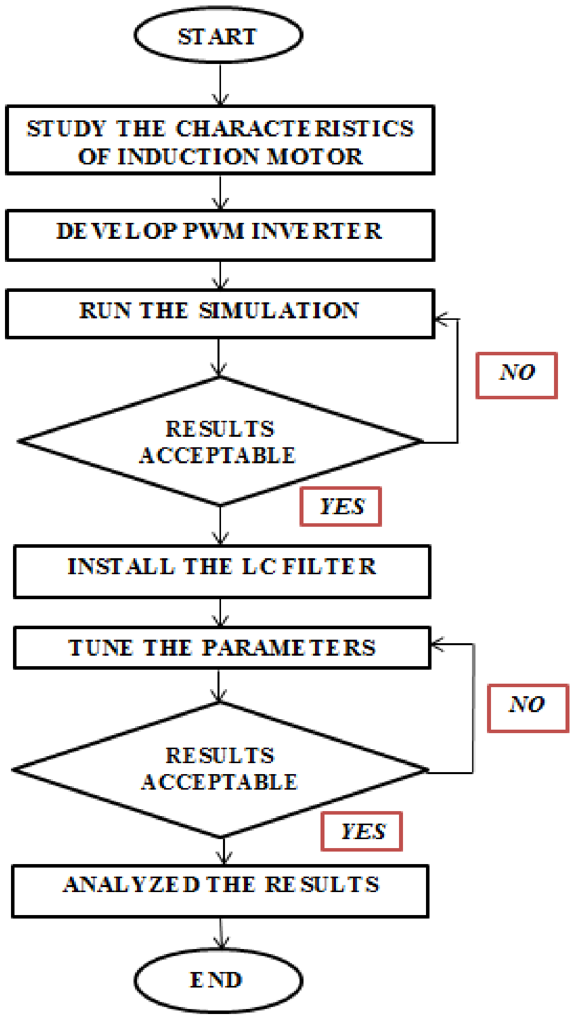


Figure 1: Sine-triangle, Pulse Width Modulated control waveforms (upper left), phase voltages V_{AG} and V_{BG}, and line voltage V_{AB}

C. HARMONIC MITIGATION

There are several types of harmonic filter that already install in the electrical network. Many studies on harmonic mitigation technique using different types of filter and effect of ASD load in contributing harmonics at the point of common coupling has been carried out **[9].** Since the V_O of 3 phase of PWM is not pure direct voltage, a filter used to eliminate spikes, harmonics and ripple component.

III. METHODOLOGY



The scope of work in this project is described as below:

1. Study the operation on three phase asynchronous motor.
2. Study the method or technique to control the three phase asynchronous motor speed.
3. Study the PWM technique and its application to control the three phase asynchronous motor speed.
4. Run the simulation of PWM inverter fed the three phase asynchronous motor by using PSIM software.
5. Install the LC filter to reduce harmonic produce by PWM before fed the voltage supply to induction motor.
6. Analyze the results and conclude the finding for this project

A. DEVELOP THE PWM CIRCUIT

Inverter is a power electronic converter that converts direct current to alternating current. In this project, one three phase based inverter were used to fed the three phase induction motor. Inverter consists of 6 IGBT or MOSFET power switch to produce three phase current fed into the induction motor. The switching of the IGBT/MOSFET for the inverter was controlled by pulses that were produced from control circuit which consists of references sinusoidal and triangular voltages sources, comparators and Not-gates.

There are several considerations relevant when using PWM technique:

I) Frequency index (M_f): The fundamental frequency at the PWM voltage output of the Fourier series is same as the reference signal. At and around multiple of switching frequency, the harmonic frequency is produced. The simple low-pass filter installation might be efficient ways to remove the harmonic. Increment of the carrier frequency (f_s) with the increment of Modulation frequency index (f_s) will raise the harmonics produced.

II) Modulation Index (M): Modulation Index are control the amplitude of fundamental frequency of the PWM output. Modulation index value might be tuned to satisfy the constant amplitude output of DC voltage variations. Therefore, M must be less or equal than 1 to satisfy that. If M is bigger than 1, the amplitude of the output will not linearly proportional to M.

III) Switches: The switch must be able to conduct current in both direction for PWM. The real switch will not function immediately, so it is required to allow for switching times in the control of the switches. For IGBT/MOSFET switch, only two switches are conduct at a time. One from upper group (S1, S3, S5) and the other one from the lower group (S2, S4, S6).

IV) Reference voltage: The sinusoidal reference voltage generated must be within the control circuit of the inverter. DC supply is provided to the motor as the power source. Therefore the reference signal is not necessary to be a sinusoidal signal.

Table 1 show the parameters used in this project including induction motor parameters, DC source parameters, and Sinusoidal with Triangular sources.

Table 1: Parameters

V_{DC}	DC supply voltage	220V
Triangular waveform	V_{PP}	2
	Frequency	1500Hz
	Duty cycle	0.5
	DC offset	-1
	T_{Start}	0
	Phase Delay	-90^0
Sinusoidal Waveform	Peak Amplitude	0.5
	Frequency	30Hz
		40Hz,
		50Hz
		60Hz
		70Hz
	Phase Angle, V_A	0^0
	Phase Angle, V_B	120^0
	Phase Angle, V_C	240^0
	Dc offset	0
	T_{Start}	0
Induction Motor	Rs (stator)	0.294
	Ls (stator)	1.39m
	Rr (rotor)	0.156
	Lr (rotor)	0.74m
	Lm (magnetizing)	41m
	No. of Poles P	6

B. RUN THE SIMULATION AND ANALYZE THE RESULT

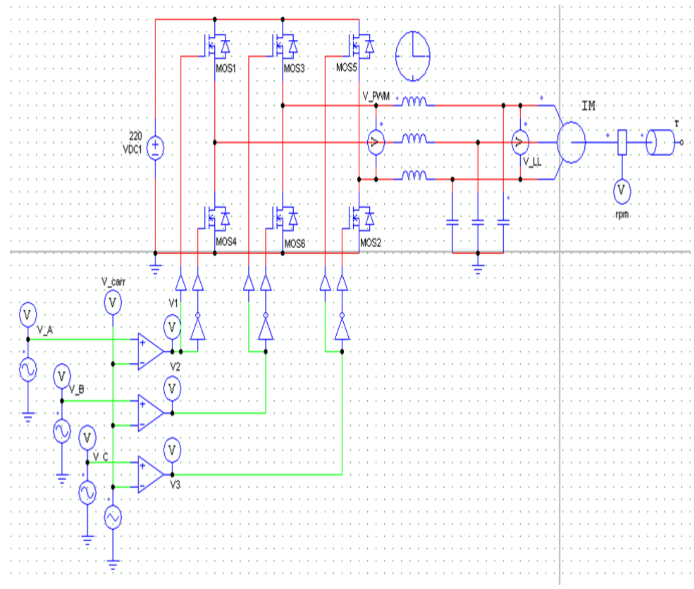


Figure 2: Simulation Circuit

C. RESULTS

Simulation waveform

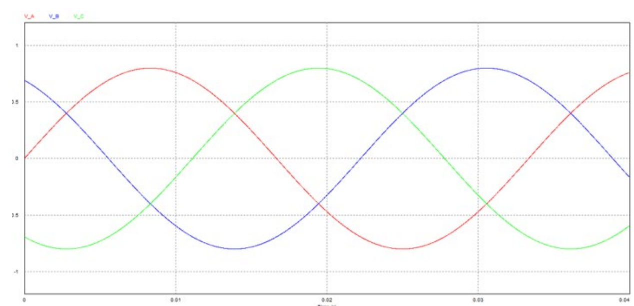


Figure 3: Sinusoidal Modulating Voltage

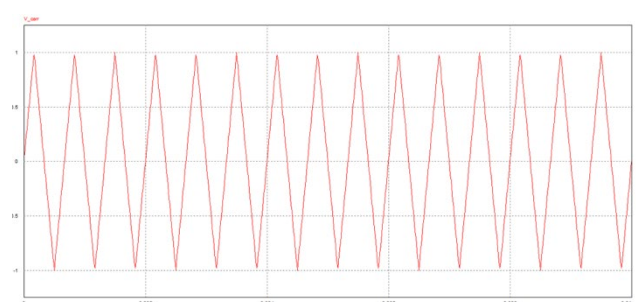


Figure 4: Triangular Carrier Signal

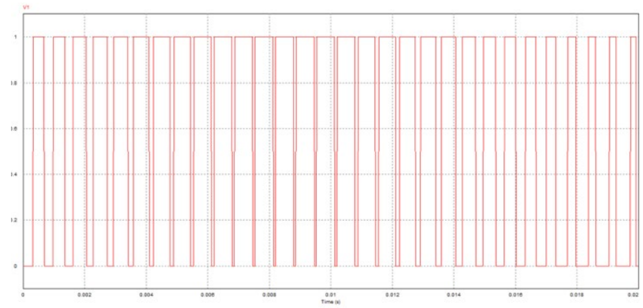


Figure 5: Pulse from the comparator

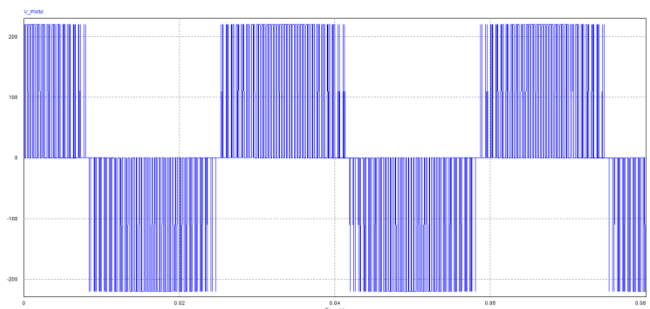


Figure 6: PWM waveform at the output of the inverter

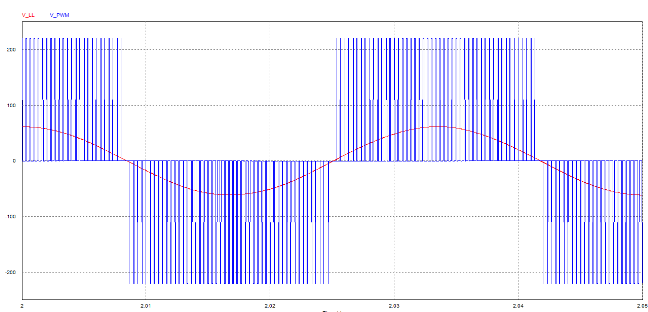


Figure 7: Line voltage waveform for induction motor input (Red) vs. PWM waveform (Blue)

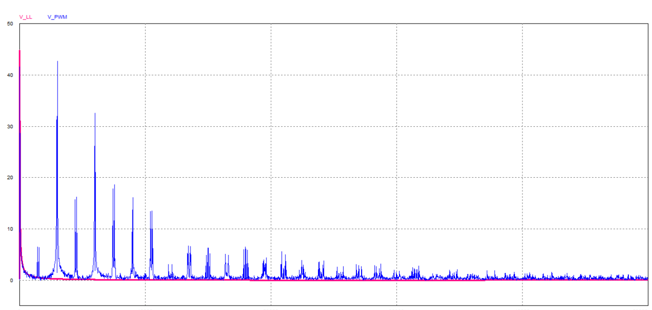


Figure 8: Harmonic Spectrum Line voltage waveform for induction motor input (Red) vs. PWM waveform (Blue)

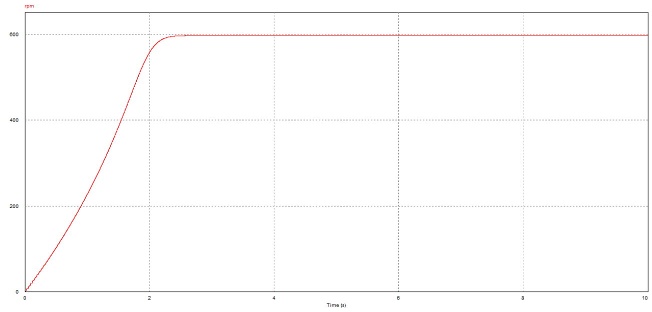


Figure 9: Speed vs. Time (600 rpm) of induction motor for 30Hz

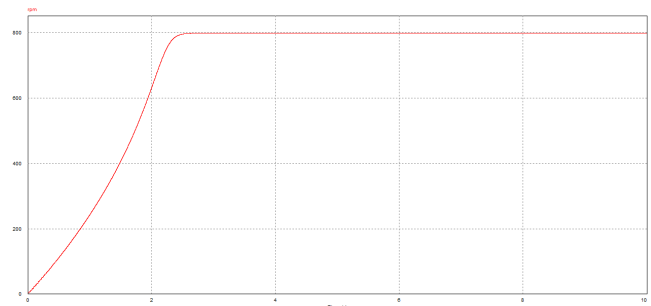


Figure 10: Speed vs. Time (800 rpm) of induction motor for 40Hz

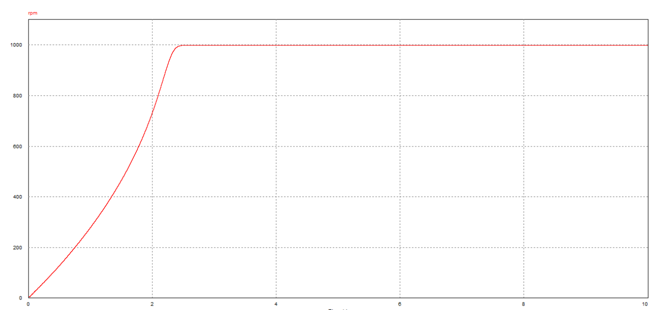


Figure 11: Speed vs. Time (1000rpm) of induction motor for 50Hz

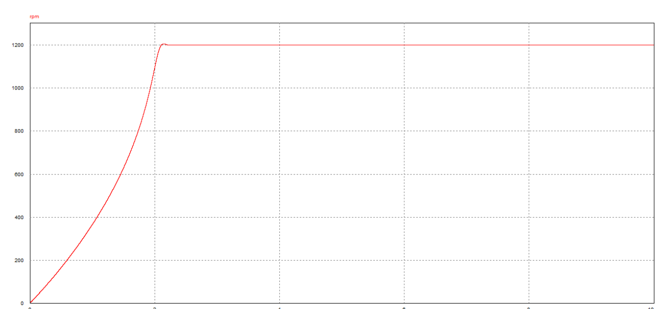


Figure 12: Speed vs. Time (1200rpm) of induction motor for 60Hz

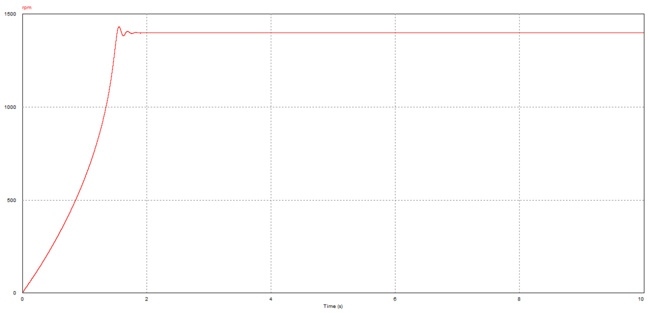


Figure 13: Speed vs. Time (1400rpm) of induction motor for 70Hz

Table 2: Simulation results

Frequency (Hz)	**Modulation Index**	**Ns**	**Nr**
30	0.3	600	596
40	0.4	800	797
50	0.5	1000	998
60	0.6	1200	1199
70	0.8	1400	1399

IV. DISCUSSIONS

In the simulation, there are three sinusoidal signals such as in Fig. 3 which are 120^0 out of phase between each other. Each of the signal is fed to different comparator. The sinusoidal signal are compared with a high frequency triangular signal such as in Fig. 4. From the comparison of sinusoidal modulating and triangular carrier signal, pulses as shown in Fig. 5 are produced. These are fed to Isolated Gate Bipolar Transistor (IGBT)/MOSFET (Metal Oxide Semiconductor Field Effect Transistor) to control the switching. The waveform produced from the inverter is shown in Fig. 6. After through the filter, the PWM waveform is changed to sinusoidal waveform such as Fig. 7 (Red). That waveform is fed to 3 phase induction motor for controlling the speed. Since the PWM produced a spikes in the waveform, therefore the filter is used to smoothing the waveform fed to the induction motor. The presence of spikes can harm the induction motor. The filter is a passive filter since it only consists of an inductor and a capacitor and it does not has any active component that can dissipate the energy like resistance component. Fig. 8 show the Harmonic Spectrum before (Blue) and after (Red) the waveform being alter by the passive filter. Fig 9 until Fig. 13 shown the speed of 3 phase induction motor varied along the supply frequency. Based on the results shown in Table. 2, the speed of three phase induction motor is decreasing with the decreasing of line frequency value. This prove that the PWM inverter using supply frequency control technique can control the speed of three phase induction motor. The three phase induction motor speeds obtained are near to speeds as given by Eq. 1. The difference between motor speed and synchronous speed is called slip speed. The slip speed is always exists because the three phase induction motor speed cannot be equal to synchronous speed value. If the induction motor speed is equal to synchronous, voltage will not be induced then there will be no rotor current and rotor magnetic field. Thus the induction motor can speed up only near the synchronous speed. When the value of supply frequency is changed, the line voltage also has to be change in order to maintain V/F ratio. It is really necessary to maintain the V/F ratio value to prevent motor saturation condition. The performance of an IGBT is closer to the MOSFET but only differ in switching frequency range which is MOSFET is higher than IGBT. Since the rating used in this simulation is all below IGBT and MOSFET maximum range, both is shown the similar performance.

V. CONCLUSION

The PWM technique to control the three phase induction motor has successfully studied. The PWM circuit was design, simulated and the results showed that PWM inverter using line frequency control method can vary the speed of three phase induction motor. Speed of three phase induction motor depends on the line voltage and frequency of the motor input. The higher line voltage and line frequency of the three phase induction motor input will produced the higher speed of three phase induction motor. The PWM is the efficient way to control voltage of three phase induction motor. Since PWM generate harmonics that are huge than fundamental frequency, therefore PWM spikes are able to reduce by installing the passive filter. The motor reached steady state speed after 2s. This issue can be improved by altering the value of inductance and capacitance.

VI. RECOMMENDATION

This project has done successfully proves that three phase induction motor can be controlled by using PWM technique. For future recommendation, some modification can be used in this simulation circuit to improve the speed control performance. Adding speed controller feedback might be improved the performance of 3 phase induction motor. Furthermore, the voltage booster is required at lower speed.

VII. ACKNOWLEDGMENT

In the name of Allah, the Almighty God, I wish a thousand thank because of strength and mercy given to finish this paper. I would like to express my deepest appreciation to all those who provide me the possibility to complete this paper. A special gratitude Prof Madya Muhammad Bin Yahya, who's always supervise me to complete my paper especially to finish this paper without feeling exhausted and weary.

VIII. REFERENCES

[1] Rodolfo Echavada, Sergio Horta, Marc0 Oliver, ”A Three phase motor drive using IGBT‟s and Constant V/F speed control with slip regulation”, 0-7803-3071-4/95 1995 IEEE.

[2] Pedro Nuno da Costa and Joao L. Afonso, Development of a Variable Frequency Power Electronic Inverter to Control the Speed of a Three- Phase Induction Motor, HSCI' 2006.

[3]. S.B Geuseppe and P.K. Marian, "Direct Torque Control of PWM Inverter- Fed AC Motor", in IEEE Transactions on Industrial Electronics, Vol. 51, No. 4, August 2004.

[4]. J.C. Stephen, Electric Machinery and Power System Fundamentals, New York: Mc Graw Hill, 2002,pp. 288-295, 332-337

[5] Atul M. Gajare and Nitin R. Bhasme, A Review on Speed Control Techniques of Single Phase Induction Motor, International Journal of Computer Technology and Electronics Engineering (IJCTEE) Volume 2, Issue 5, October 2012

[6]. Prof. Krishna Vasudevan, Prof. G. Sridhara Rao, Prof. P. Sasidhara Rao, "Speed control of Induction Machines, Electrical Machines II", Indian Institute of Technology Madras, November 2011

[7]. R. Abhra, N. Amit, D. Arijit., M. Arkendu, C. Ayavana., P. Kunal., D. Maniak., S.N. Soumya., P.Saurav., S.R. Subrata., " PWM Based Inverter Fed Induction Motor", Sept 2010.

[8]. Nazmul Islam Raju, Md. Shahinur Islam and Ahmed Ahsan Uddin, "Sinusoidal PWM Signal Generation Technique for Three Phase Voltage Source Inverter with Analog Circuit & Simulation of PWM Inverter for Standalone Load & Micro-grid System", International Journal of Renewable Energy Research, Vol.3, No.3.

[9] J. C. Das, "Passive Filter Potentialities and Limitation", Pulp and Paper Industry Technical Conference, Conference Record of the 2003 Annual, pp. 187-197.