Study of Three-Phase Induction Motor Speed Control using Pulse Width Modulation (PWM) Technique

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Abstract—**Three phase induction motor (squirrel cage) have many applications in the industries such as for cranes, lifts, elevators, etc. The speed control of induction motor is important to achieve the maximum torque and efficiency. In this paper, the speed control of three phase induction motor in Pulse Width Modulation (PWM) technique using MATLAB Simulink was studied. PWM technique is an effective way to control the speed of induction motor. The purpose of this project is to develop algorithm to perform the PWM operation using MATLAB Simulink version R2010a. The control algorithm was also developed to enable the rotational direction switching. This method provides means to control speed of induction motor.**

Keywords-component; Induction Motor; Speed Control; Pulse Width Modulation (PWM); Insulation Gate Bipolar Transistor (IGBT); MATLAB Simulink.

I. INTRODUCTION

AC Induction motors are being applied today to a wider range of applications requiring variable speed. Generally, variable speed drives for Induction Motor require both wide operating range of speed and fast torque response, regardless of load variations. The three phase induction motor is rotating electric machine designed to operate from a three phase source of alternating voltage [1]. Induction motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction.

Three phase of the induction motor (squirrel cage) widely used in industrial application which is used in elevators, lifts, cranes, etc. This is because the induction motor is of high efficiency and the loss is low. Figure 1 is the equivalent circuit for the induction motor.

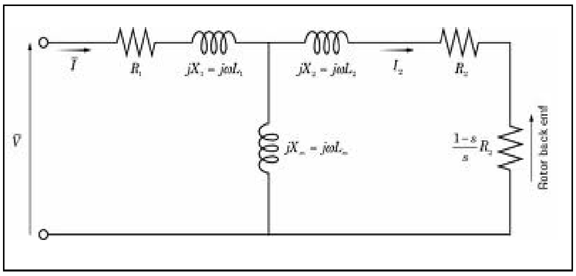

Figure 1: Equivalent circuit for the induction motor.

There are many techniques to control speed of induction motor such as varying the slip and synchronous speed, and Pulse Width Modulation (PWM). Changing the rotor resistance or terminal voltage can vary the slip. When changing the rotor resistance, it requires wound rotor induction motor and any resistances inserted to the rotor circuit will reduce the efficiency of the motor. By changing terminal voltage will limit the range of speed control. Changing the number of poles or supply frequency can vary the synchronous speed. Changing the number of poles requires a motor with special stator winding [10]. Changing the frequency is the best method because it is applicable to any types of induction motor. The speed of the induction motor is depending on the rate of its magnetic field or synchronous speed. The speed of the induction motor is directly proportional to the frequency [2].

PWM is a powerful technique for controlling analog circuits with a processor's digital output and employed in a wide variety of applications, ranging from measurement and communication to power control and conversion [3].

The PWM technique is used to control the frequency of three phase voltage supplied to the motor from the Insulated Gate Bipolar Transistors (IGBTs) inverter circuit. The IGBTs is a three terminal power semiconductor device, noted for high efficiency and fast switching. It function is to invert voltage from DC voltage to AC voltage [4]. It is a combination of Bipolar Junction Transistor (BJT) and Metal Oxide Semiconductor Field Effect Transistor (MOSFET). BJT has low conduction loss and having longer switching period while MOSFET has high conduction loss and low switching period. Therefore the IGBT has low conduction loss and high switching period. Figure 2 is the equivalent circuit for the IGBT.

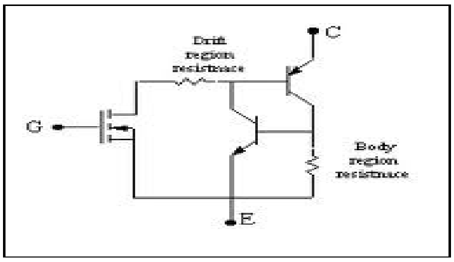

Figure 2: Equivalent circuit for the IGBT.

The rotating magnetic field of the stator imposes a torque on the magnetic field of the rotor because to rotate steadily.

$$Ns = \frac{120 \times f}{P} \qquad (1)$$

Ns = synchronous speed in rpm

f = frequency

P = number of magnetic pole

$$S = \frac{Ns - Nr}{Ns} \qquad (2)$$

Nr = rotor speed in rpm

S = slip (ratio)

$$Nr = Ns(1 - S) \qquad (3)$$

II. SCOPE OF STUDY

In this project, the scopes of works include:

1. Study the model of the PWM signal generator and model of the induction motor.
2. Enhance knowledge of MATLAB Simulink.
3. Analyze the speed of the induction motor for different frequencies from MATLAB Simulink.
4. Analyze the output result.
5. Achieve the maximum torque for the induction motor with minimum loss.

III. METHODOLOGY

A. Block diagram of the project.

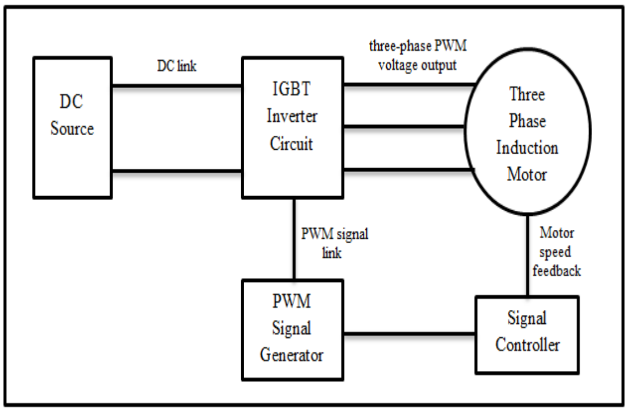

Figure 3: Block diagram of the project.

The block diagram in figure 3 shows the three phase voltage that supply to the induction motor. The PWM signal generator is designed to connect with the IGBT inverter circuit to make it work. DC source supply voltage to the IGBT inverter circuit which is inverts the DC voltage to AC voltage [4]. The three phase induction motor will be operated when the three phase PWM voltage output is connected. The three phase PWM voltage output is produced by the combination of AC voltage and PWM signal.

The signal controller is used to determine the error in motor speed and give the feedback. If the error occurred, the block in the PWM signal generator will have to improved or changed to clear the error. The speed motor is depending on the frequency from PWM signal generator. The figure 4 shows the flowchart for the block diagram of the project.

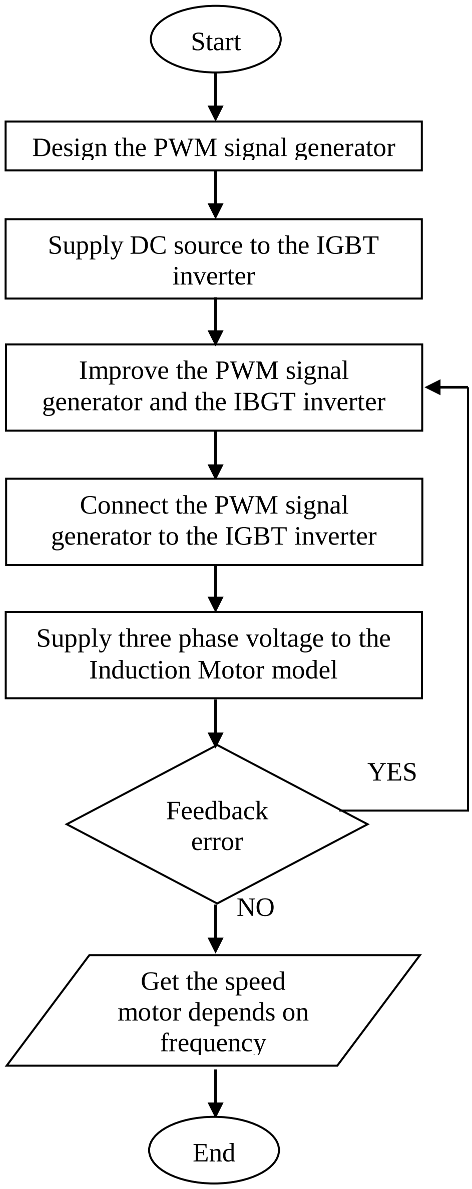

Figure 4: Flowchart for block diagram of the project.

B. Flowchart for the progress of the project.

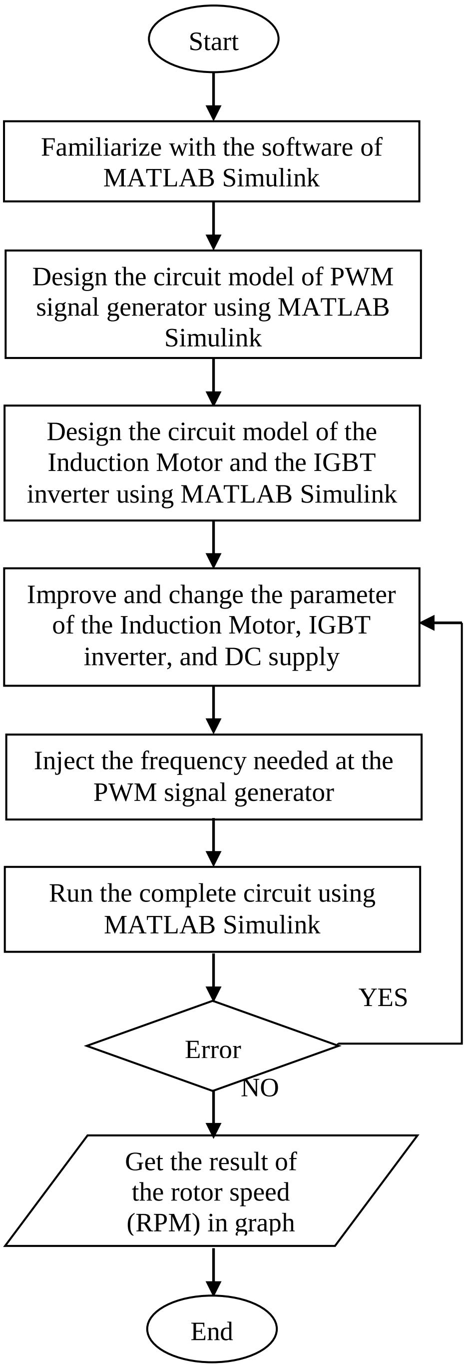

Figure 5: Flowchart for the progress of the project.

Figure 5 shows the progress of the project until gets the expected result. To get the result for the project, the process must be started with familiarizing and understanding the software of the MATLAB Simulink. Then design and develop the circuit model of the PWM signal generator using MATLAB Simulink. The circuit model of the induction motor and the IGBT inverter also must be designed using MATLAB Simulink. After that, the parameters of each block in the induction motor, IGBT, and DC supply are included. But DC supply, the voltage was fixed 400V to provide a constant direct current. When all the parameters are filled and the circuit was complete, the frequencies need to inject at the PWM signal generator. The frequency was set and run the complete circuit using the MATLAB Simulink and gets the result. When the error was occur, the MATLAB Simulink was detect the error and must to solve the error to get the result. To solve the problem, the parameters of the error block must change until get the expected result. The result shows the rotor speed radian per minutes (RPM) in graph.

C. PWM signal in single phase and three phase.

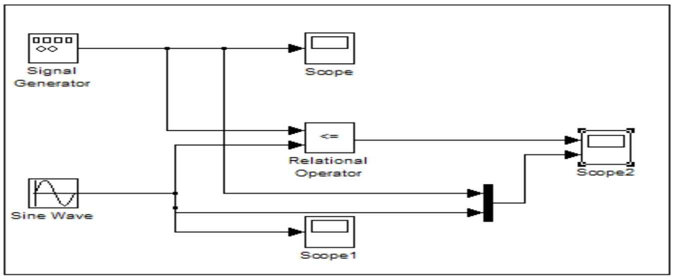

Figure 6: Single phase PWM signal.

Figure 6 shows the design of the single phase PWM signal. This circuit used the *signal generator (sawtooth signal)* block, the *sine wave (control signal)* block and the relational operator. All the scope in this figure is to show the signal waveform.

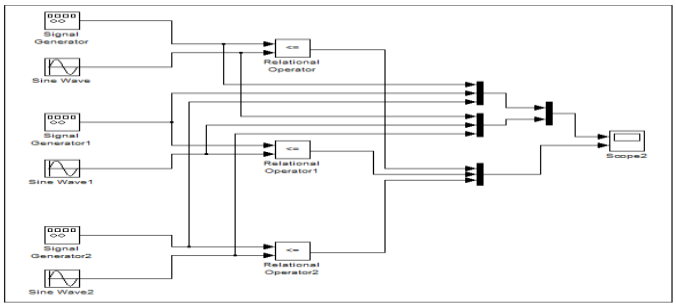

Figure 7: Three phase PWM signal.

Figure 7 shows the circuit of the three phase PWM signal. Similar to the single phase PWM signal, but add two PWM signal was added to get the three phase PWM signal. But the different in the three *sine wave (control signal)* block is the phase which is 0 radian, $2\pi/3$ radian, and $4\pi/3$ radian. This is to show the starting wave for all phase in different time.

D. Circuit model of the project.

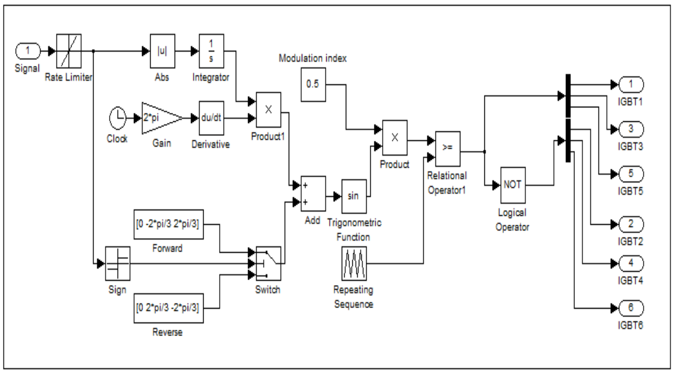

Figure 8: The PWM signal generator circuit model.

Figure 8 shows the circuit model of the PWM signal generator. This model is the first stage and important to complete the simulation in MATLAB Simulink. Many blocks were used in this circuit model which is *signal, rate limiter, integrator, derivative, forward and reverse, clock, repeating sequence, etc*. The set point value was represented by *signal* block which is the port to inject the frequencies needed. The *rate limiter* block was used to provide increment from zero to any value of the input signal. The *integrator* block outputs the integral of its input at the current time step. The *derivative* block was connected to the clock to prevent the output from time block to increase rapidly. *Derivative* block enabled the *integrator* block to integrate the frequency input value from the *rate limiter* so that the generated sine wave could increase or decrease smoothly with respect to the reference frequency needed. The principle of AC machine operation is when in balanced three-phase voltage, each with equal magnitude and shifted in phase by 0^0, -120^0, and 120^0 respectively, the magnetic field produced inside the stator winding will rotate in the same direction of the phase rotation. If any two of three-phase voltage are swapped, the magnetic field will reverse its rotational direction [5]. In the PWM signal generator, they have two blocks which is *forward* block has the value of [0 -π/3 2π/3] and *reverse* block has the value of [0 2π/3 -2π/3] where the difference sequence at phase B and C. both blocks were connected to the *phase switch* block.

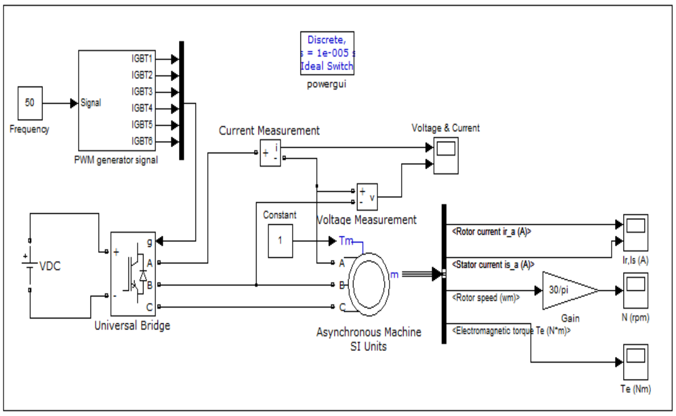

Figure 9: The complete circuit model of the project.

In the second stage before simulated the circuit model, the PWM signal generator need to connect to the IGBTs model and IGBTs model was connected to the induction motor model shown in figure 9. Before that, the frequency must to set and connect to the PWM signal generator first. The controllable DC voltage was supplied to the IGBTs model where in the IGBTs model has capacitor, which is used to maintain a smooth DC voltage in spite of the current pulsation produce by the IGBTs [6]. The block of current and voltage measurement is to measure the current and the voltage from the IGBT model. To get the induction motor functioning, the current need to supply to the induction motor. Set the induction motor parameter which is 10HP, 400V, 50Hz, and 1440RPM. The speed of the induction motor controlled by frequency of PWM to get the speed maintain and efficiency. It is because the speed of the induction motor is directly proportional to the frequency [7]. After all the parameter was filled, simulations were run in MATLAB and the results were observed on the corresponding scopes. Graphs of the rotor speed, the electromagnetic torque, the stator and the rotor current, the voltage and the current were shown in graph which is the graph is versus time. The developed control strategy is not only simple, reliable, and may be easy to implement in real time applications, but also cost-effective as when this control scheme is implemented in real time, the size of the controller will become very small. Figure 9 is the complete circuit model in the project and need to simulate to show the expected result from the entire scope block.

IV. RESULTS AND DISCUSSION

A. Simulation Result.

From the simulation of the complete circuit model of the project, the result was shown in the graph which is all the graphs versus time. Figure 10 is the result for simulation of the single-phase PWM signal and the output waveform is same as the theoretical waveform.

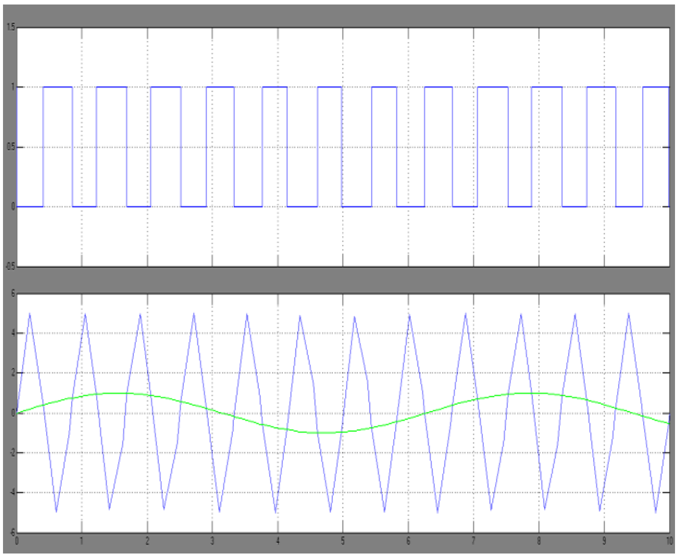

Figure 10: Single-phase PWM signal output waveform.

The figure 11 below is the result for simulation of the three-phase PWM signal output waveform.

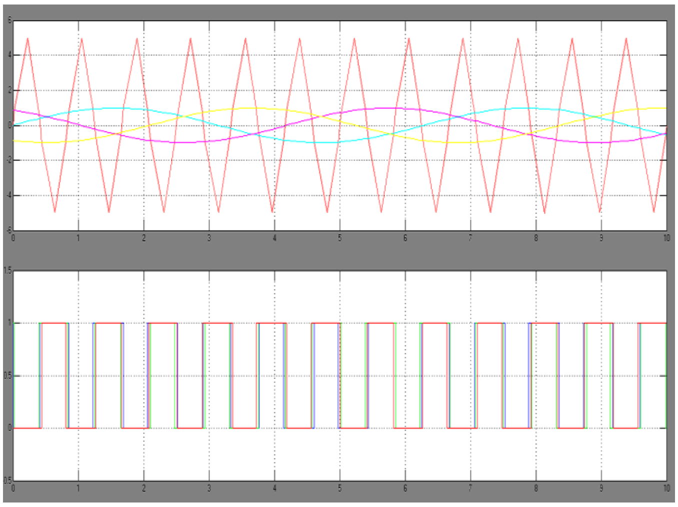

Figure 11: Three-phase PWM signal output waveform.

The current and the voltage output waveform is shown in figure 12 below. This current and voltage come from IGBT model.

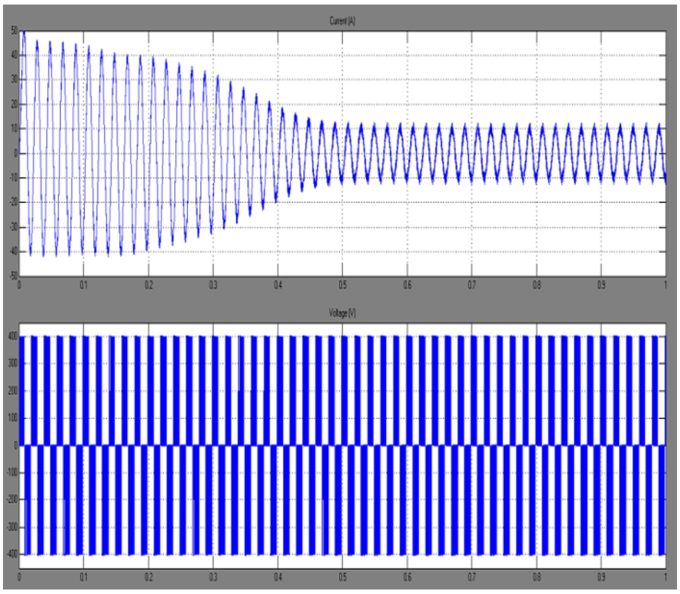

Figure 12: The current and the voltage output waveform.

The output waveform for the rotor and stator current will show in figure 13 and figure 14. The figure 15 is the output waveform for the electromagnetic torque. And the figure 16 is show the rotor speed of the induction motor output waveform. The important things in the project, the rotor speed of the induction motor because this project wants to maintain the rotor speed using frequency. The frequency used is 50Hz.

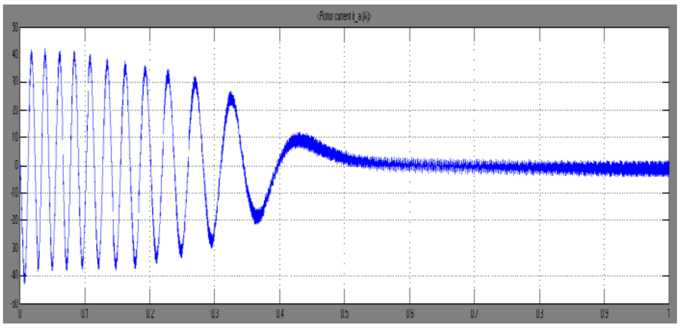

Figure 13: The rotor current waveform.

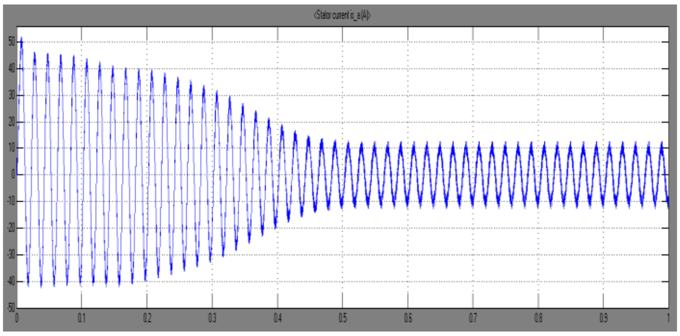

Figure 14: The stator current waveform.

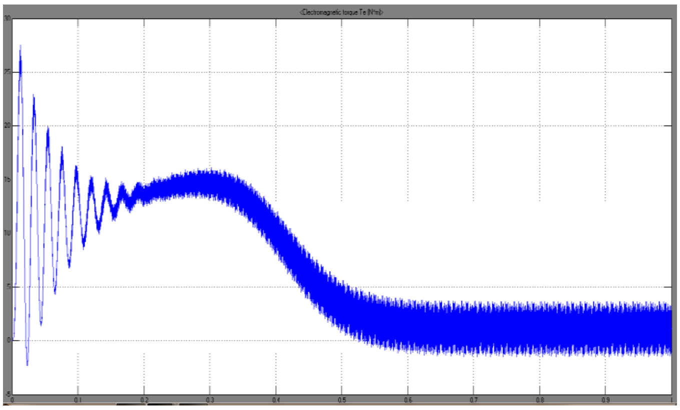

Figure 15: The electromagnetic torque output waveform.

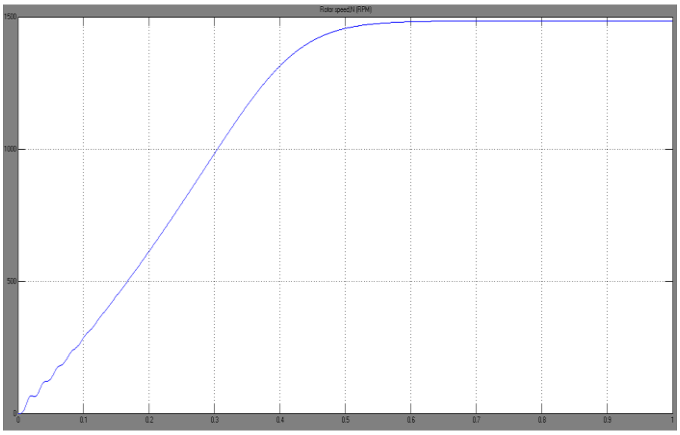

Figure 16: 1484rpm speed of the induction motor output waveform.

B. *Simulation Discussion.*

In this project, all graph figures, the time unit is second (s), the current unit is ampere (A), the voltage unit is volt (V), the rotor speed unit is radian per minute (rpm), and the electromagnetic torque unit is newton meter (Nm). For all simulation frequencies, the amplitude voltage of the positive value is 400V and negative value is -400V. All the graph is from the inject frequency 50 Hz.

In figure 10 and figure 11, the simulation waveforms in single-phase and three-phase PWM signal are shown. It is similar from the theoretical waveform of PWM. In figure 12, the time used is one second. The starting current from waveform was high and reduces until 0.5 second and the current maintain after that. The voltage show the positive value is 400V and the negative value is -400V. This happen because the IGBT inverter is invert voltage 400V from DC voltage to AC voltage.

From the figure 13 and figure 14, shows the rotor and stator current waveform. The current is high when starting and reduce until 0.5 second and the current maintain because the speed of the induction motor is constant. In figure 15 shows the electromagnetic torque waveform. The electromagnetic torque achieves the maximum torque when the time is 0.3 second when the frequency is 50Hz. Figure 15 shows the rotor speed waveform when the frequency is 50Hz. At the time is 0.6 second, the speed rotor was constant and it's constant at 1484rpm. From 0 to 0.6 second, the speed increase rapidly until the speed constant at 1484rpm from 0rpm. When increase the frequency to 100Hz, the rotor speed increase rapidly from 0 to 2930rpm at the time is 6.5 second. After that, the speed of rotor is constant and maintain at 2930rpm. When change the speed again from 100Hz to 10Hz, at 0.05 second the speed is increase immediately to the 320rpm and decrease to 297rpm at the time is 0.1 second. After that time, the speed is constant at 297rpm. In table 1, there is a table has the signal frequency in Hz and the rotor speed in rpm. The frequency takes from 10Hz to 100Hz and the constant rotor speed shows in the table. Therefore the rotor speed is directly proportional to the frequency.

TABLE I. TABLE OF THE SIGNAL FREQUENCY AND ITS CORRESPONDING THE ROTOR SPEED

Signal Frequency (Hz)	Rotor Speed (rpm)
10	297
20	598
30	896
40	1190
50	1484
60	1777
70	2068
80	2357
90	2644
100	2930

CONCLUSION

As a conclusion, the expected results from this project are development of the algorithm to perform the Pulse Width Modulation (PWM) operation using MATLAB Simulink. This method will provide a means to control speed of induction motor and get the speed efficiency. The proposed speed controller gives maximum torque over the entire speed range. In the steady state, the efficiency of the induction motor is increased. The validity of the proposed controller is confirmed through the simulation results. To implement it in the laboratory various parameters like rotor flux, rotor current and operating points, rotor parameter tuning are to be estimated. The proposed speed control system can be useful for the variable speed drive system.

FUTURE DEVELOPMENT

In future, this project can be improved when implement the ramp function which is acceleration and deceleration ramp to make the motor safe when the speed of the motor change rapidly. This project also can improve when implement the forward and reverse direction function. This function can make the motor run both forward and reverse direction. To continue this project and make a better result, this project can combined with the hardware.

ACKNOWLEDGMENT

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REFERENCES

[1] http://en.wikipedia.org/wiki/induction motor

[2] Stephen J. Chapman, "Electric Machinery and Power System Fundamentals", McGraw Hill International Edition, 4th Edition, 2005.

[3] Prasad N Enjeti, et.al, "A new PWM Speed Control System for High Performance AC Motor Drives", IEEE Transactions on Industrial Electronics. Vol 37, No 2, April 1990, pp. 143-151.

[4] "http://www.eetchina.com/ARTICLES/2003JUN/PDF/2003.

[5] Khaleed E Addoweesh, et.al, "Induction Motor Speed Control Using a Microprocessor-Based PWM Inverter", IEEE Transactions on Industrial Electronics. Vol 36, No 4, Nov 1989, pp. 516-522.

[6] Staff of Lab-Volt (Quebec) Ltd, "Familiarization with the Lab-Volt Power Electronics Equipment", Lab-Volt Ltd, 2nd Edition, 2001.

[7] I. Maswood, M.A. Rahman, "Performance of 3-phase Induction Motor FED from Improved Delta PWM Voltage Source Inverter", Power Engineering Society Winter Meeting, 2000. IEEE, pp. 381-386.

[8] B.R. Gupta, Vandana Singhal, "Fundamentals of Electric Machines", New Age International Publishers, Revised 3rd Edition, 2005.

[9] S. H. Kim and S. K. Sul, "Voltage control strategy for maximum torque operation of an induction machine in the field weakening region," in Proc. IECON'94, 1994, pp. 599–604.

[10] B. K. Bose, Power Electronics and AC Drives. Englewood Cliffs, NJ:Prentice Hall, 1986.