Three Phase Permanent Magnet Synchronous Motor Speed Control Using IGBTs and Pulse Width Modulation Technique Based On Matlab Simulation

Muhammad Hilmi Bin Dzulkefli
Bachelor of Electrical Engineering (Hons)
Faculty of Electrical Engineering
Universiti Teknologi MARA
40450 Shah Alam, Selangor
Email: kruzito_07@yahoo.com

Abstract —**Three-phase permanent magnet synchronous motors are widely used in low and mid power applications because have some performance advantages over wound stator types, and have become predominant in fractional horsepower applications. However, users need to control the speed of the motor depending on the desired speed and application. So, this project presents the three phase permanent magnet synchronous motor speed control by varying the electrical frequency. In this project, the frequency is adjusted by using insulated gate bipolar transistor (IGBT) and pulse width modulation (PWM) technique based on Matlab simulation as a variable frequency drive. The speed of permanent magnet motor will depends on the rate of rotation of its magnetic field. So, the objective is to study the general characteristic of the three-phase permanent magnet motor and the speed control technique by using IGBTs and PWM. Simulation results are presented, with design PWM control algorithm for switching of IGBTs to control the speed of permanent magnet motor. The simulation results were carried out using Matlab/Simulink R2008a (version 7.4.0.324).**

Keywords – Permanent magnet synchronous motor, Insulation Gate Bipolar Transistor (IGBT), Pulse Width Modulation (PWM).

1. INTRODUCTION

The three-phase permanent magnet motor is a rotating electric machine with permanent magnet rotor designed to operate from a three-phase source of alternating voltage. [1]

The permanent-magnet synchronous motor (PMSM) has advantages over other machines that are conventionally used for ac servo drive. Compared with the inverter-fed induction motor drive, the (PMSM) has no rotor loss and hence it is more efficient than other machines. In a voltage source inverter, both the sinusoidal output voltage and current is obtained by pulse width modulation (PWM) strategies using insulated-gate bipolar thyristors (IGBTs). [3]

This project was launched specifically to control the speed of three phase permanent magnet motor. Basically this project will focuses on controlling the electrical frequency control using Pulse Width Modulation (PWM) technique.

A PWM IGBTs voltage source inverter circuit which consists of six IGBT's was designed. The proposed inverter can supply the sinusoidal current containing no harmonics, not only to a motor but also to static loads, by utilizing the optimal PWM pattern. Moreover, a permanent magnet synchronous motor can be smoothly driven with no torque pulsation in the range of the low speed.

In order to generate the standard control algorithm for the speed control of permanent magnet motor, this project required the usage of MATLAB/SIMULINK that has the function Sim Power System. This project also presents the development of the algorithm to perform the PWM operation using Matlab Simulink.

2. INSULATED PWM and IGBTs

PWM is a influential technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. [8]

In PWM, there are three main important elements, which are saw-tooth wave signal generator, input signal control voltage and comparator. It is important because it is involve in the process of modifying the width of the pulse. Insulated Gate Bipolar Transistor will be used in the inverter circuit. PWM signal is used to control the IGBTs switches gate.

The main purpose of using the PWM technique is to extract the low frequency signal from a train of high frequency signal square waves. However, in PWM, there are two classes available. The first class is the non-sinusoidal PWM and the second class is the sinusoidal PWM.

In the first class, all the pulses in the signal are having the same width and are normally modulated equally to control the output of the voltage. In the second class, the pulse width is modulated sinusoidal (*Figure 2.1*). The width of each pulse is proportional to the instantaneous value of a reference sinusoid whose frequency equals to that of the fundamental components.

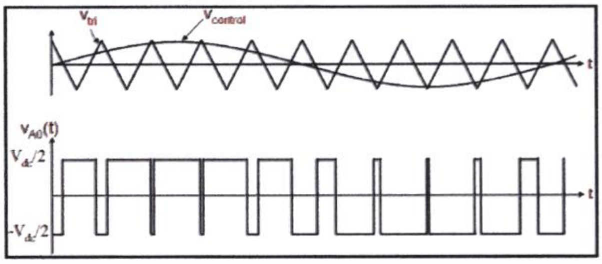

Figure 2.1: The sinusoidal pulse width modulation signal

The Insulated Gate Bipolar Transistor (IGBTs) is a three-terminal power semiconductor device, noted for high efficiency and fast switching. It function is to invert voltage from dc to ac. [2]

It is a combination of BJT and MOSFET. BJT has low conduction loss and having longer switching period. MOSFET has high conduction loss and having lower switching period. Therefore, IGBT has low conduction loss and lower switching period. The gate of the IGBT can be control by applying reverse voltage.

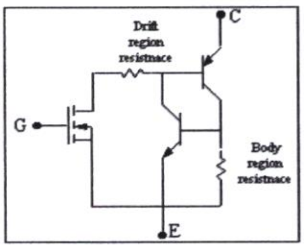

Figure 2.2: Equivalent circuit of the IGBTs

The power inverter that is available in the Insulated Gate Bipolar Transistor is used to implement the PWM technique. To simplify the order, here is the simplified block diagram of the project outcome.

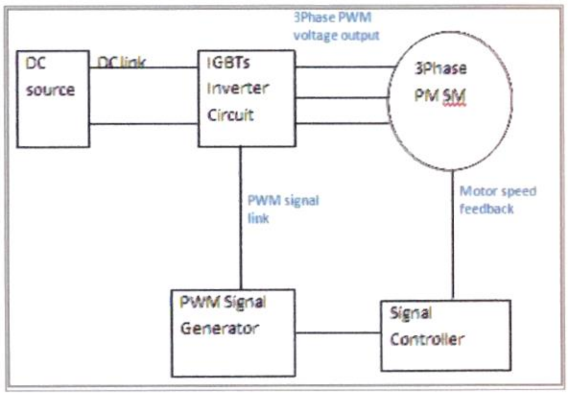

Figure 2.3: General block diagram of the project

3. METHODOLOGY

Figure 3.1 shows the methodology for the study on the three phase permanent magnet motor speed control using IGBTs and PWM.

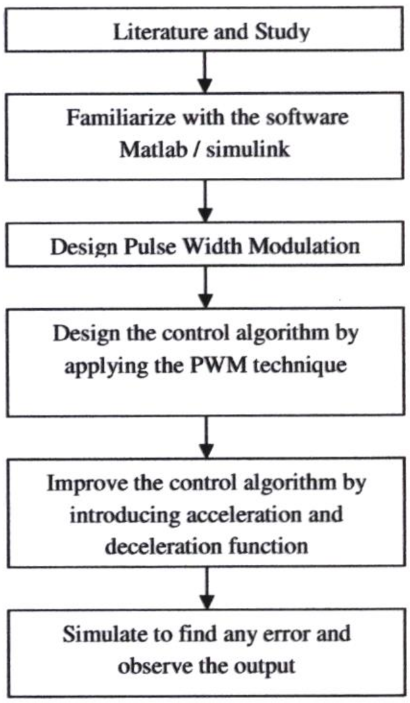

Figure 3.1: Project Flow

3.1 Designing the single phase Pulse Width Modulation

Figure 3.2 shows designing the single PWM. The comparator process has been designed using the signal processing blocksets such as *sawtooth signal* block and *control signal* block.

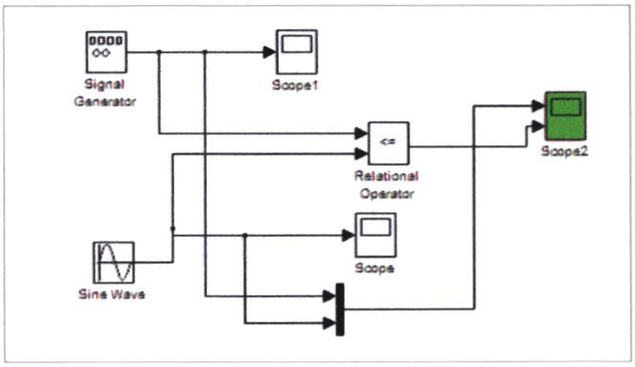

Figure 3.2: The single PWM

3.2 Designing the three phase Pulse Width Modulation

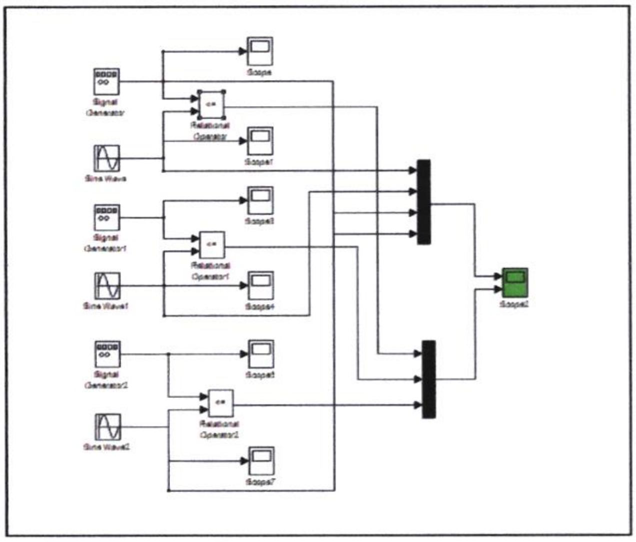

Figure 3.3: The three phase PWM

By adding another two PWM signal generators, a three-phase signal is implemented to the model. The phase angel between all three signal generators must be 120° and 240° which is equal to *2*pi/3* radian and *4*pi/3* radian.

3.3 *Simulating the inverter using IGBTs block set*

Figure 3.4 show the step to design the three-phase inverter using the IGBTs. All six IGBTs are arranged into bridge connection. For phase A, the phase is 0°. Phase B was set for -120°. Then for the phase C, set it for -240°. This is for to get right sequence. The 400 DC source is used in this simulation to provide a constant direct current. The three-phase output is connected to the output symbols which is representing the output ports at the subsystem when it will be implemented into the motor model.

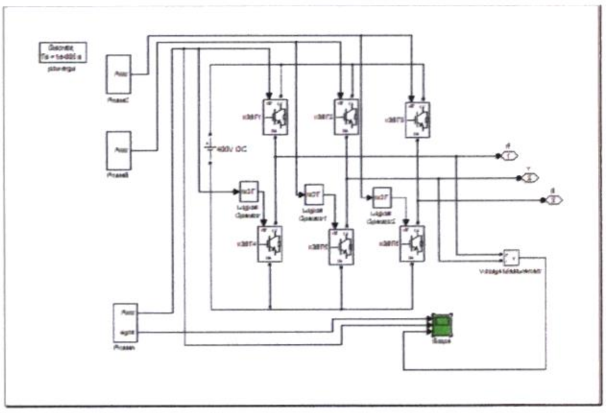

Figure 3.4: The blockset with IGBTs in bridge connection for simulation

3.4 *Simulating with resistive and inductive load*

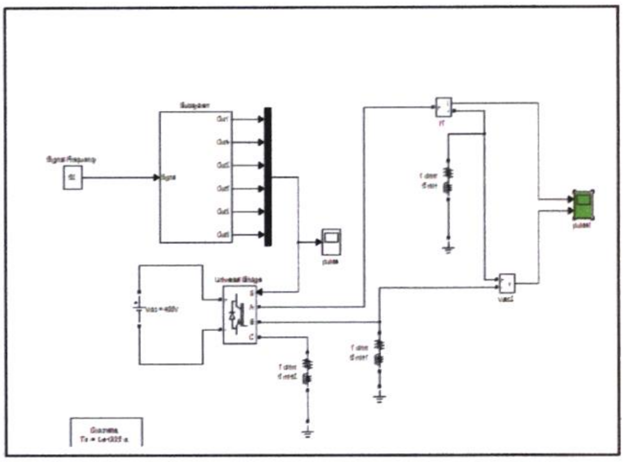

Figure 3.5: Simulating with resistive and inductive load

When the PWM Inverter subsystem block is connected to the motor and DC source, the simulation could not run because of this discretized error. In the PWM Inverter block, there are six units of individual IGBT connected in bridge. Circuits containing individual IGBT blocks cannot be discretized. However, discretization is permitted for IGBT bridges simulated with the *Universal Bridge* block.

3.5 *Simulating with permanent magnet motor model*

The PWM signal generator is connected to the IGBTs model, and permanent magnet motor model in Matlab Simulink. The complete simulation model is shown in Figure 3.6. The simulation was done to make sure the PWM signal generator created, is able to control the speed of permanent magnet motor.

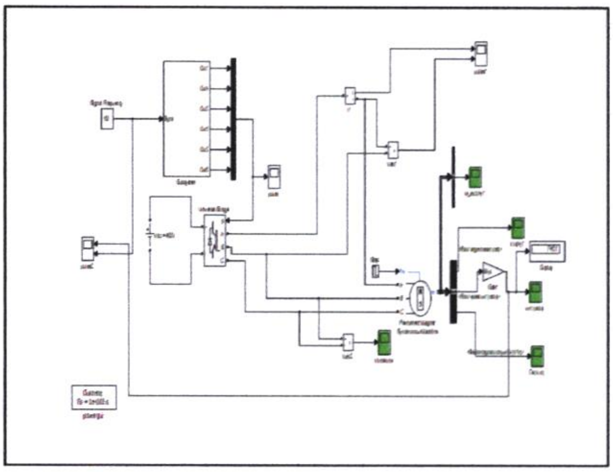

Figure 3.6: Complete simulation model in Matlab Simulink

4. RESULTS AND DISCUSSION

4.1 *Designing the single phase Pulse Width Modulation*

The result from the simulation was obtained in term of the output waveform from the *Relational Operator* block *(Figure 4.1)*. In the simulation, the PWM signal waveform from the output is similar to the theoretical waveform as shown in *Figure 2.1*.

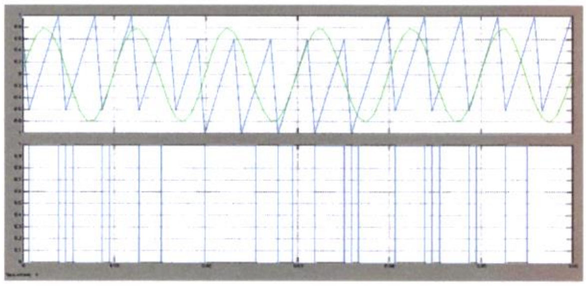

Figure 4.1: The generated PWM signal in the simulation

4.2 *Designing three phase Pulse Width Modulation*

The amplitude is set to be *0.8*. This value represents the value of modulating index since the amplitude of carrier frequency is *1.0*. The output waveform for the three-phase PWM signal is shown in *Figure 4.2*.

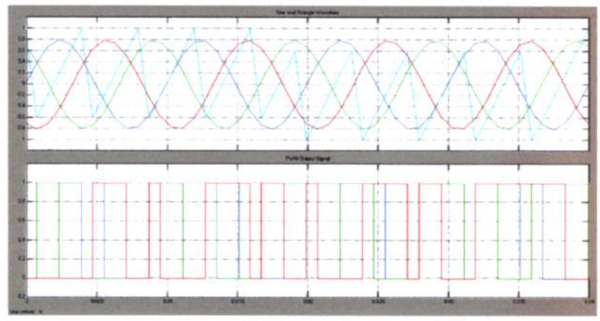

Figure 4.2: The 3-phase signal and its generated 3-phase PWM output signal

4.3 *Simulating the inverter using IGBTs block set*

Figure 4.3 show the result the voltage output in the simulation is the line-to-line voltage

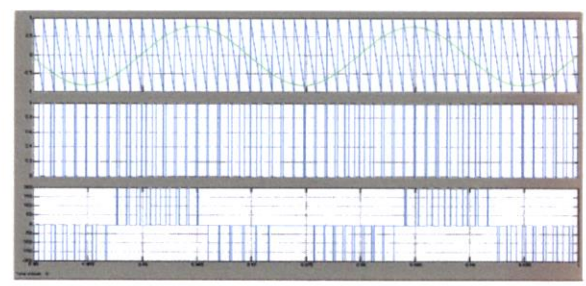

Figure 4.3: The line to line output voltage

4.4 *Simulating with resistive and inductive load*

From Figure 4.4, since the output voltage for one of the phase is in the PWM waveform, the current in the three-phase load is generated with a small ripple which is the effect of the sampling process during the pulse width modulation output generation.

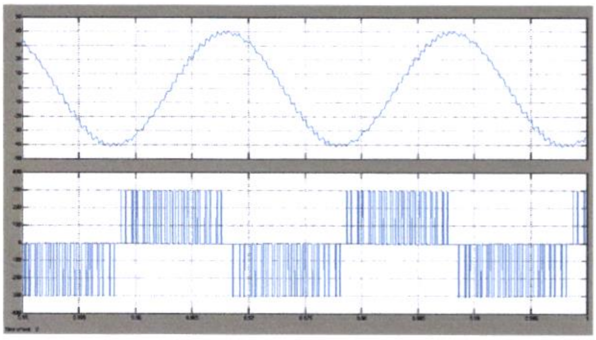

Figure 4.4: Current at the load and output voltage from the inverter.

4.5 *Simulating with permanent magnet motor model*

The simulation is done for about 10 seconds. From the output waveform, the line to line voltage show figure 4.5 was the same as the PWM output voltage in Figure 4.3. By observing the current output waveform show Figure 4.6, the motor will draws high starting current for both rotor and stator windings. The currents oscillate in large magnitude from 0 to approximately 0.6 seconds. After that, currents oscillate in low magnitude because the motor already reach a constant speed. The same observation can also be seen from the electromagnetic torque to show figure 4.7.

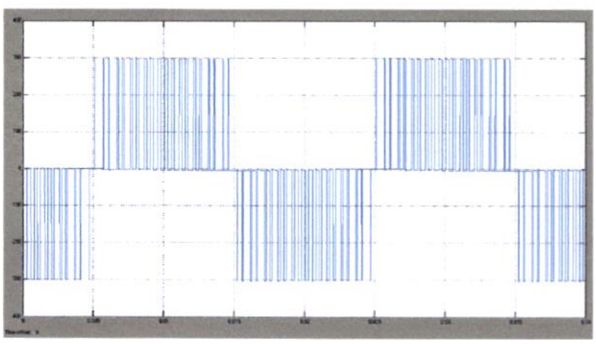

Figure 4.5: Line to line voltage at inverter output

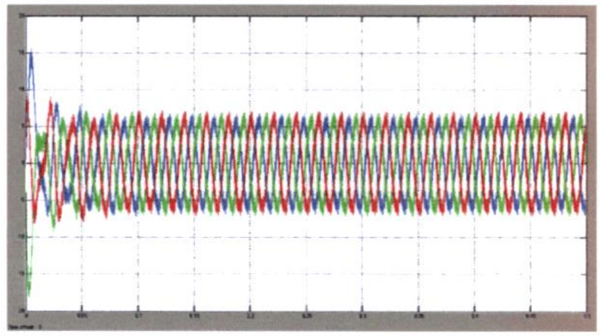

Figure 4.6: Three phase line current

In figure 4.6, it is clear that the current is non sinusoidal at the starting and becomes sinusoidal when the motor reaches the controller command speed at steady state.

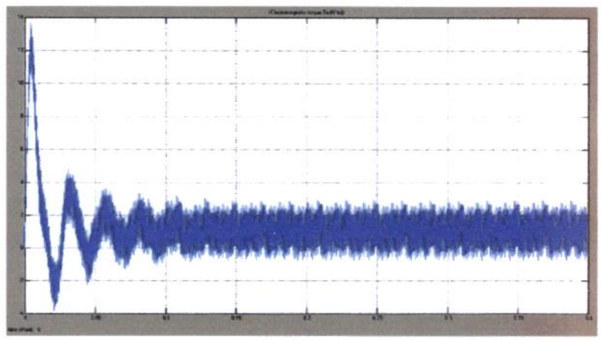

Figure 4.7: Electromagnetic torque of the motor

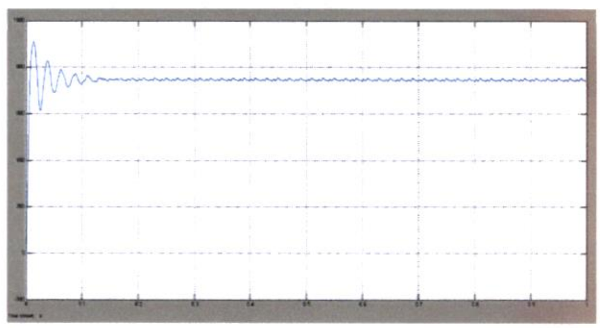

Figure 4.8: The rotor speed

Figure 4.8 shows a variation of the speed with time. The steady state speed is the same as that of the commanded reference speed. For other frequency signal value, the motor speed is corresponding to its value as shown in TABLE I.

TABLE I. The table of signal frequency and its corresponding motor speed

Signal frequency (Hz)	Motor speed (rpm)	Actual Motor speed (rpm)	Speed error (%)
10	209.5	200	4.53
20	409.8	400	2.39
30	609.5	600	1.56
40	795.8	800	0.528
50	994.8	1000	0.523
60	1211	1200	0.908
70	721.3	1400	94.09
80	551.9	1600	189.91
90	391.9	1800	359.3
100	-177.6	2000	-

5. CONCLUSION

The simulation results for of the development of the algorithm to perform the PWM operation using Matlab Simulink, to control the speed of permanent magnet motor are presented. The design meets the requirement by varying the frequency to control the speed, acceleration and deceleration function.

6. FUTURE DEVELOPMENT

In future, this project can be improved by implementing ramp function to make the motor safe from damaged with sudden change. This project can also be improved by implementing reverse direction function so that the motor can run both forward and reverse direction. The control algorithm can further be continued on hardware implementation.

7. ACKNOWLEDGEMENT

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