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OPTIMIZATION FOR PMSM BY USING PARTICLE SWARM OPTIMIZATION

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I hereby declare that I have read this thesis entitled *"Optimization for PMSM Drive Using Particle Swarm Optimization"* and in my opinion this thesis is sufficient in terms of scope and quality for awarding the degree of Bachelor in Electrical Engineering (Control, Instrumentation and Automation)

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OPTIMIZATION FOR PSMS DRIVES USING PARTICLE SWARM OPTIMIZATION

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A report submitted in partial fulfilment of the requirements for the Bachelor of Electrical Engineering

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

I declare that this thesis entitled *"Optimization for PMSM Drive using Particle Swarm Optimization"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ……………………………………………………...

Name : ……………………………………………………

Date : ……………………………………………………

To my beloved mother and father

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ABSTRACT

This report shows a modern method for speed control of a PMSM utilizing the Particle Swarm Optimization (PSO) algorithm to improve PI- Controller parameter such as Kp and Ki. This project promotes the software which can perform the result and performance of PMSM drive. There are three objectives to be achieves in this project which are to design a model of PMSM base on vector control approached, to apply PSO technique to improve PMSM drive, to verify the effectiveness of the proposed PSO technique through experiment analysis. The usage of PSO as an optimization algorithm creates the drive tough, with advance dynamic response, progressive accurateness and sensitive to load deviation. Contrast amid different controllers is accomplished, utilizing a PI controller which is tuned by two techniques, firstly conventional and secondly utilizing the PSO method. The performance of PMSM will be evaluated based on the speed response produced by different tuning methods. The rise time, overshoot and settling time will be recorded for making comparison. The result show by applying PSO method for tuning the PI parameters, the overshoot and settling time is decrease compare with trial and error method. But, the rise time for PSO method is more than trial and error method.

ABSTRAK

Laporan ini menunjukkan kaedah moden untuk mengawal kelajuan PMSM menggunakan algoritma Pengoptimuman Swarm Partikel (PSO) untuk memperbaiki parameter PI-Pengawal seperti Kp dan Ki. Projek ini mempromosikan perisian yang dapat melaksanakan hasil dan prestasi pemacu PMSM. Terdapat tiga matlamat yang dapat dicapai dalam projek ini iaitu untuk merekabentuk model PMSM berdasarkan kawalan vektor mendekati, untuk menggunakan teknik PSO untuk meningkatkan pemanduan PMSM, untuk mengetahui keberkesanan teknik PSO yang dicadangkan melalui analisis eksperimen. Penggunaan PSO sebagai algoritma pengoptimuman menghasilkan pemacu yang sukar, dengan tindak balas dinamik yang maju, ketepatan progresif dan sensitif terhadap sisihan beban. P pengawal yang berbeza telah dicapai, menggunakan pengawal PI yang ditala oleh dua teknik, pertama konvensional dan kedua menggunakan kaedah PSO. Prestasi PMSM akan dinilai berdasarkan respon laju yang dihasilkan oleh kaedah penalaan yang berbeza. Masa kenaikan, masa pelarasan dan masa penyelesaian akan direkodkan untuk membuat perbandingan. Hasilnya menunjukkan dengan menggunakan kaedah PSO untuk menala parameter PI, masa overshoot dan penyelesaian adalah berkurang berbanding dengan kaedah percubaan dan ralat. Tetapi, masa kenaikan untuk kaedah PSO adalah lebih daripada kaedah percubaan dan kesilapan.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Permanent Magnet Synchronous Motor (PMSM) is widely used in industries involving motor usage. PMSM is popular due to high power density and large torque according to inertia ratio, high efficiency and speed of the motor can be controlled. The criteria required in the high performance drive system used in robotics, rolling mill, and machine tools are fast and accurate system response, and not sensitive parameters to variation. Not only eliminating the torque and flux that make the system respond quickly, PMSM drives that using the vector control scheme also make control tasks be easy. To fulfil the criteria required to improve drive performance, the speed controller plays a very important role. The usage of controllers such as proportional integral (PI) and proportional integral differential (PID) has been widely used to control DC and AC motors. For controllers like PI and PID, this controllers are difficult to design if the model system is not available. Another weakness for this controller is unknown load dynamics and other factors such as noise, temperature, saturation, etc. affect the performance of these controllers for wide range of speed operations [1]. Some ways have been used to improve PMSM performance such as, Adaptive fuzzy PI, Intelligent technique and genetic algorithm PI controllers. This project using Particle Swarm Optimization (PSO) to tuning PI controllers. The intelligent PI speed controller utilizes the PSO to enhance algorithm the PI-parameters (*Kp* and *Ki*). The entire objective, scope and other will be discussed in the next subchapter

1.2 Problem Statement

By using a PI controller, there are some problems that have come out. First and foremost, when used the step reaction of Ziegler Nichols method, Root-locus method, and Particle Swarm Optimization technique, the problem has come from the tuning part. This problem will make the tuning section become difficult and take long time to finish it.

PI controller is used to control the speed and current available in axis d and q. However the PI controller has some limitations such as its design depending on the exact machine model and the exact parameters.

In addition, PI controller have some weaknesses such as very sensitive to interference such as parameter variation and load disturbances [2]. This difficulty leads to complicated control design. However, for intelligent controller, the design does not require the exact mathematical model of the system. Intelligent controller is able to solve nonlinear problems through learning, Artificial Neural Network are applied for this area.

In conclusion, in this project, all of the problem that was stated will be trying to overcome. Lastly, the validation results that we get from the simulation are recorded to overcome the problem.

1.3 Objectives

The objectives to be achieved in this project are:

- To design a model of PMSM drives using vector control approached.
- To apply PSO technique to improve PMSM drive
- To verify the effectiveness of the proposed PSO technique through simulation analysis.

1.4 Scope of Project

There are several scopes that should be achieved in this project:

- To design the PMSM drive system by using MATLAB/ Simulink.
- To find the value parameter PI controllerKp, Ki and from trial and error method, and Particle Swarm Optimization method.
- To compare, the better system response by using different method of tuning the PI controller.

1.5 Motivation

The motivation to run this project are to make easy work for tuning PI parameters (Kp and Ki) by using optimization technique. As world know, nowadays technology grows up very fast. All of the work should be done in very faster to reduce of working time. In conclusion of this project, it can help of industries to minimize of their problem in tuning of controller for PMSM drive.

1.6 Summary

From this chapter, the general task is presented in details. From the objective and the scope of the project, some ideas of this project is explained. In the next chapter, the literature review will be discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses some conclusion about several projects that has been carried out by others researcher in this world. To complete this "Optimization for PMSM Drives using Particle Swarm Optimization (PSO)", a lot of research papers were used as a reference.

2.2 Types of Synchronous AC Motors

There are several types of AC Synchronous Motor, each types of AC motor have a difference characteristic such as construction and working principle. The following are the types of synchronous motors.

- Salient pole
- Non salient pole (round or cylindrical rotor)
- Permanent magnet (surface, inset, buried/interior, imprecated
- rotor)
- Reluctance motor (synchronous reluctance, switched reluctance)
- Stepping motor (variable reluctance, permanent magnet, hybrid)

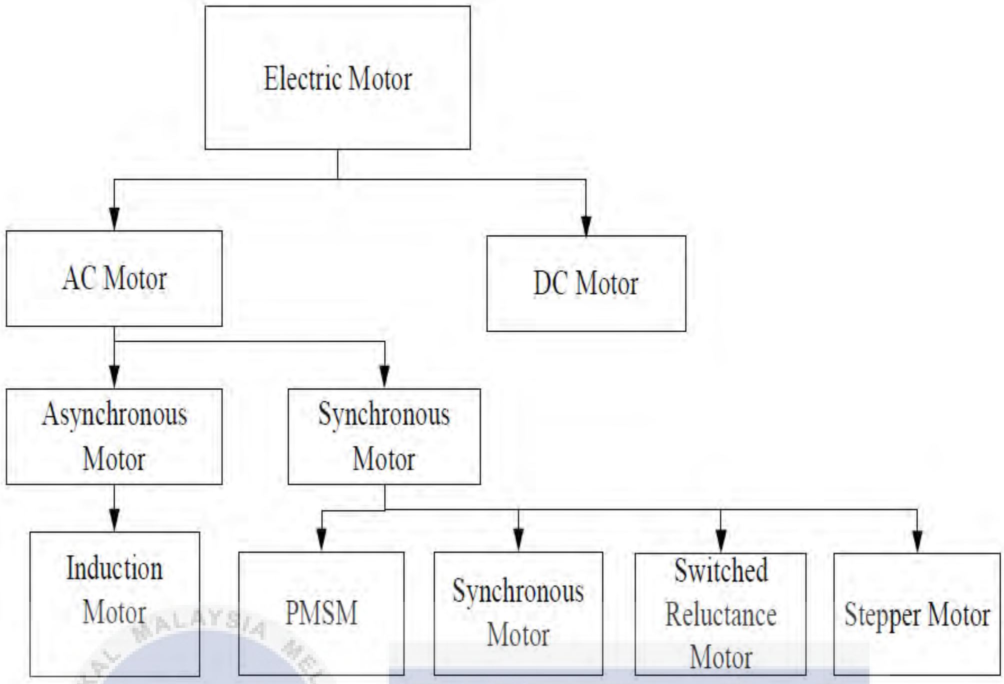


Figure 2.0: Types of Electric Motor

Figure 2.0 shows the type of electric motors. It can be divided into two groups, which are AC motor and DC motor. AC motor can be classified into two types which are asynchronous motor and synchronous motor. Induction motors in the Asynchronous motor category, while Synchronous motors comprise of PMSM, Switched Reluctance Motor, and Stepper Motor.

2.3 Advantage of PMSM over than other Motors

1) Permanent Magnet Synchronous Motor (PMSM) has a lower inertia compared to Induction Motor because of no rotor cage in the construction of PMSM. This cause the reaction to the electric torque faster. This means the torque to inertia ratio of this PMSM is higher.

2) Efficiency for PMSM is higher than Induction Motor. This is because the rotor losses for Permanent magnet machines is ignored. This theory applies to continuous flux operations.

3) To achieve excitation, IM require a source of magnetization. However, the excitation for PM machines is in the form of rotary magnet.

4) For the same capacity, the PM machine has a smaller size than IM machine. This is very useful if the area is limited.

2.4 Field oriented control of PMSM

Field oriented control (FOC) is one of the important variations in controlling PMSM in term of vector control methods [3]. FOC play a role in controlling the magnetic field and torque through control the component of d and q of stator current or relative flux.

By using FOC technique, motor torque and flux can be controlled very effectively through the information obtained from the stator current and the rotor angle. One of the advantages of FOC is the fast response and small torque ripple [4].

The FOC technique is implemented using two current regulators such as direct-axis component, quadrature-axis component, and one speed regulator.

2.5 Direct Torque Constant of PMSM

In 1980, I. Takahashi and T. Noguchi introduced the direct torque control technique for induction motors as an alternative to controlling flux and torque [5]. The DTC control the state of inverter directly, by comparing the error between the reference and the approximate value of torque and flux. One of the six voltage vectors produced from the voltage source inverter is selected for storing and supplying at the limits of two hysterical bands. The advantages of DTC are dynamic torque feedback, low complexity, and robustness [6]. Figure 2.1 shows the basic block diagram of the conventional DTC PMSM. The components that found in the diagram are current transform, flux estimators for torque and stator, hysteresis comparators for flux and torque, a switching table, and a voltage source inverter.

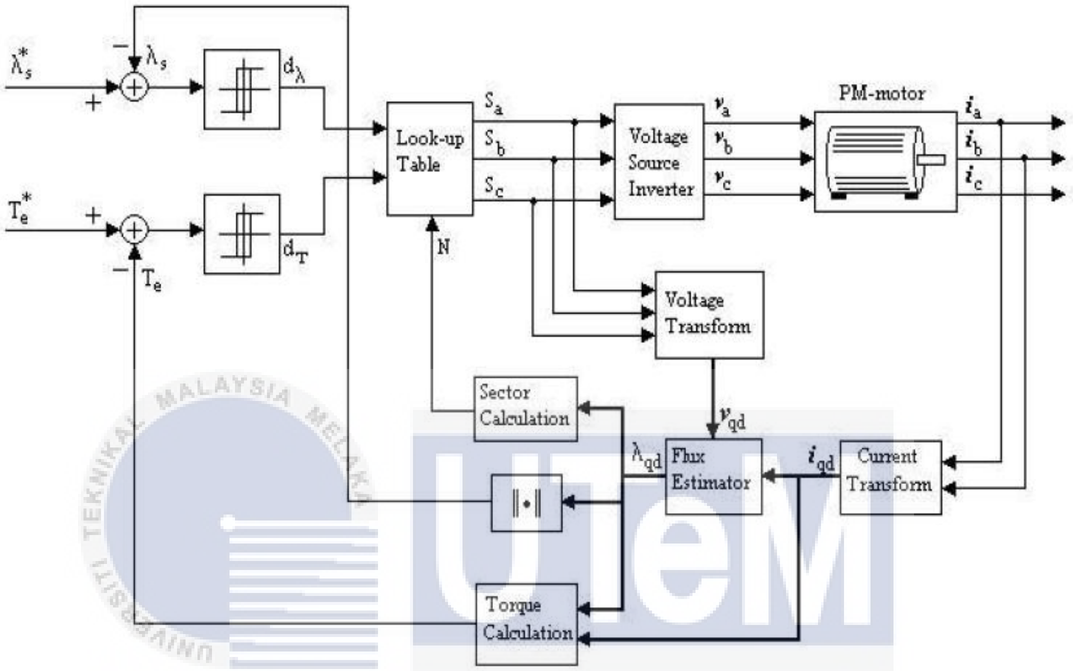


Figure 2.1: Block Diagram of the conventional DTC

2.6 Comparison of Static and Dynamic Performance

This journal explain the differences between DTC and FOC. The authors made studies related to static and dynamic performances of FOC and DTC [7]. Every information obtained from simulation by using the MATLAB / Simulink Power System Block.

The objective of this project is to compare the control strategies, by using the same power section.

This journal presents the advantages and disadvantages of each type of command. This command is very important to meet the need to know:

- Static and dynamic performance of a system (FOC and DTC).
- Control with best prosecution guidelines
- Best releases disturbance.
- Not sensitive to changes in parameters.

2.6.1 Comparison at the level of regulation speed

Diagram 2.2 shows the results of the simulation for FOC hysteresis and DTC technique by applying torque load equal to 5N.m at t = 0.1s and a reference speed equal to 100 rad /s. The result of the simulation shows the peak torque at start up for FOC is greater than the DTC, since the application of the load at t = 0.1s, so the torque reacts quickly, which causes rapid rejection of the disturbance.

The advantages of DTC compared with FOC hysteresis is the speed of DTC has high dynamic without start-up, overshoot, and the response time is also reduced.

For stator flux, DTC can achieve its reference value without overrun, contrast with FOC hysteresis there is an overrun during start-up.

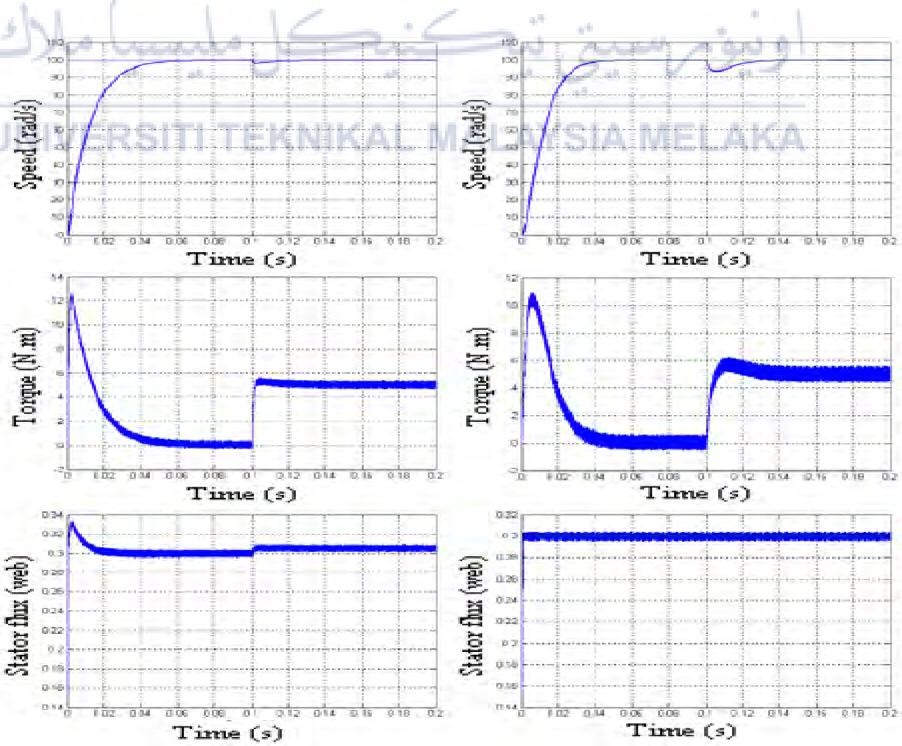
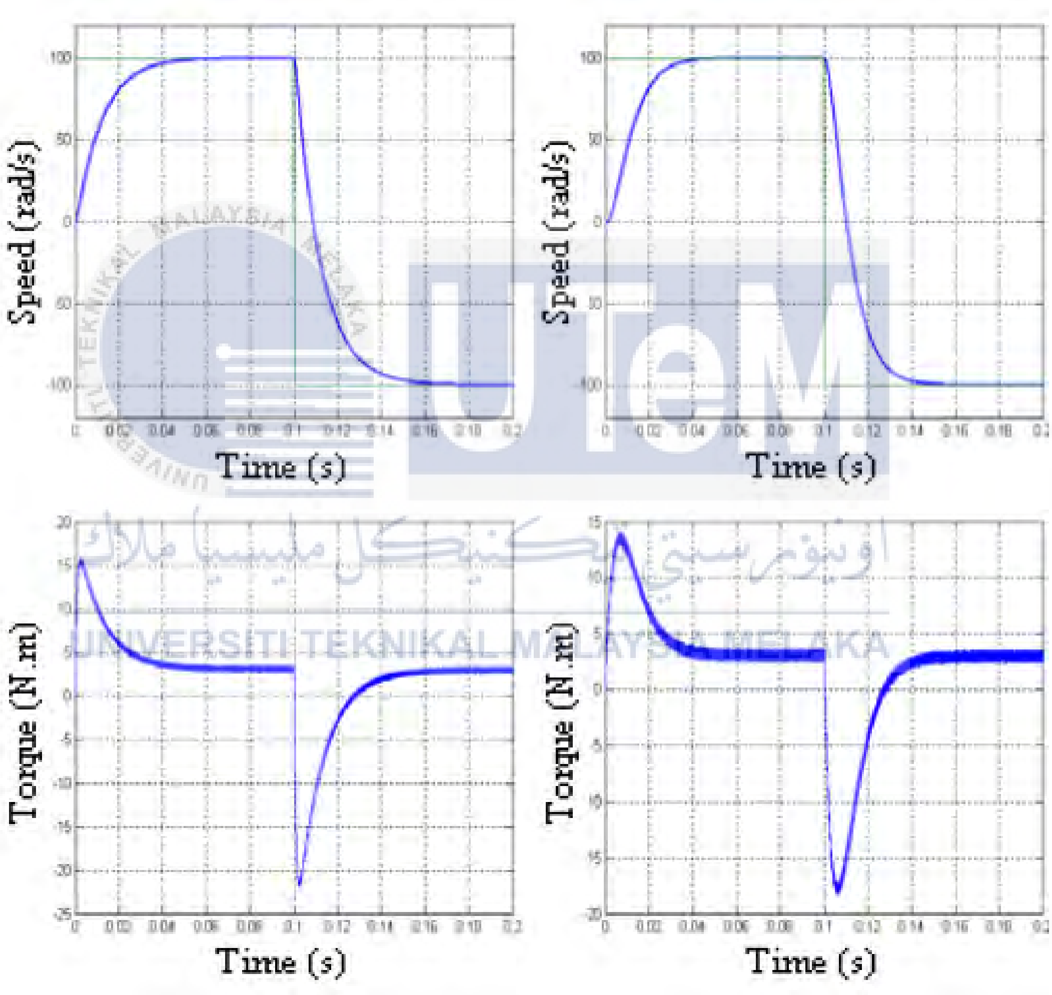


Figure 2.2: Regulation of speed followed by an application of torque load at the t = 0.1 s [7]

2.6.2 Test of Strength for Reversing Rotation of the Machine

The speed reference is changed from +100 rad/s to -100 rad/s aimed for testing the strength of the both technical command for the reverse direction at time, t = 0.1s when the torque load is 3Nm. Figure 2.3 shows that continuity in speed is normal and there is no overrun for DTC and FOC. In addition, the difference between both technical command is FOC hysteresis present the peak torque than DTC.

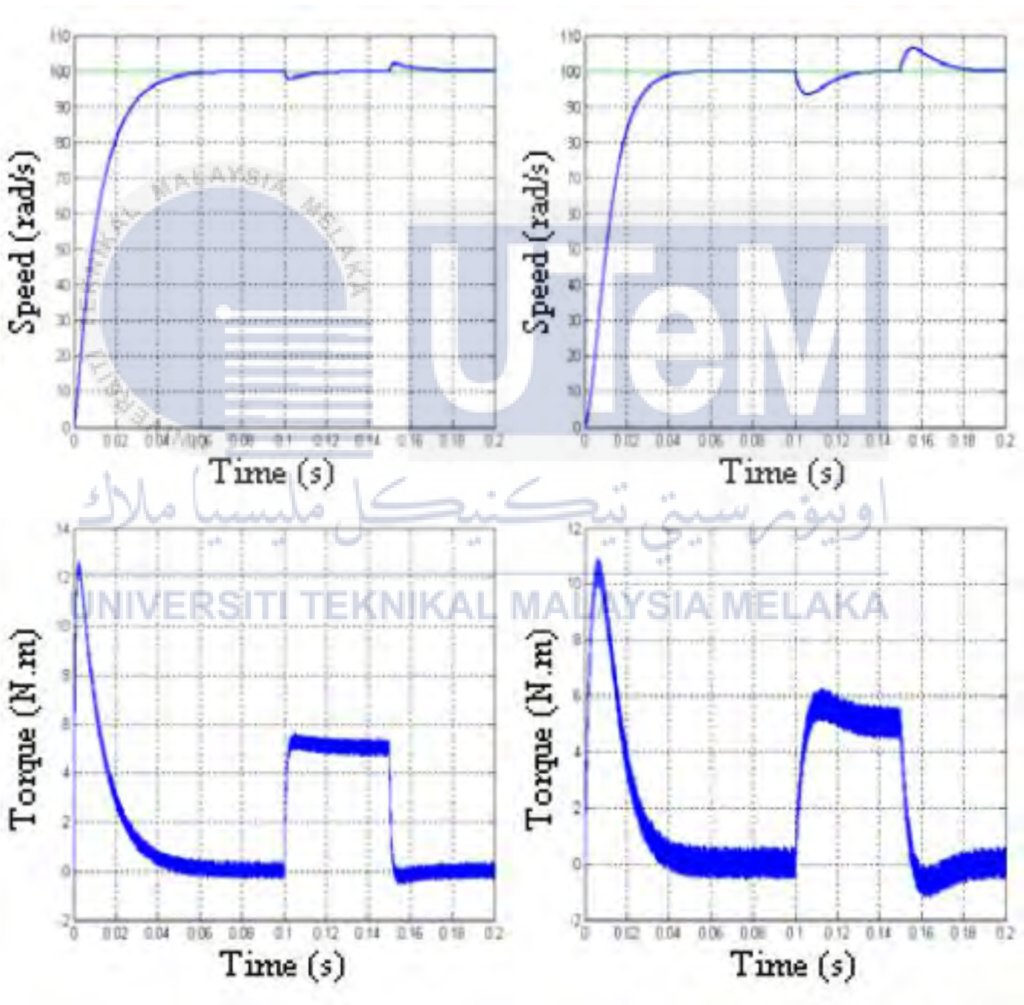


(a) FOC (b) DTC

Figure 2.3: Comparison of inversion speed between 100rad/s to –100 rad/s [7]

2.6.3 Test of Robustness for Load Change

The speed, flux stator, and torque as shown in figure 2.4 are from the machine in case of starter vacuum at speed level is 100rad / s. The load torque that be used is 5N.m at time t = 0.1s, then the load torque is changed to 0N.m at time t = 0.15s. The result shows the torque reacts immediately, and the speed reaches the reference when a minor flaw in the FOC case. In contrast, the speed of DTC reaches its reference after a considerable strain.



(a) FOC (b) DTC

Figure 2.4: Comparison at the variation torque load [7]

2.7 PI controller

In process industries, designing steadying PI controllers had been excessive standing for research ever since the controller's common use. The values among Zeigler-Nichols method and several methods was definitely available and commonly used. The design of steadying P, PI and PID controller get more widespread. To create of robust controller is working out of the solidity section using stability boundary locus [8]. To control this processes multi-input multi-output (MIMO) manner are used. MIMO processes are more challenging compared to SISO processes. Decouple is created to remove the interface among loops and stabilizing parameters PI controller is gained in the parameter plane (Kp,) [8].

PI controller is created by comparing the real and imaginary portion the characteristic equation for mutually loop once decoupling put on to zero. By plotting the stability boundary locus in a $Kp{-}Ki$ plane, the value of the controller can obtain.

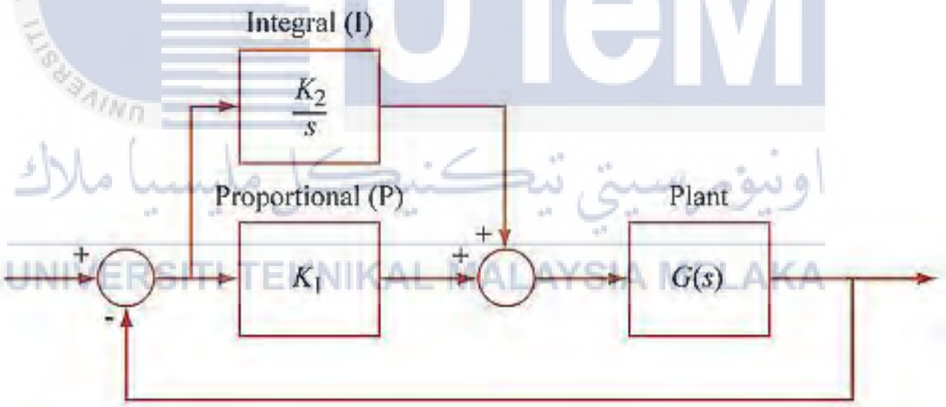


Figure 2.5: Schematic Diagram of PI Controller

2.8 PI Speed Control of PMSM Drive

There have been several components in PMSM drive. The components in PMSM drive are motor, PWM current controller, reference current generator, position sensor, and voltage source inverter (CC-VSI) IGBT based current controlled. To get a speed error of the motor, reference speed of the motor minus with actual speed of motor. Figure 2.6 shows the basic building blocks of PMSM drive [9].

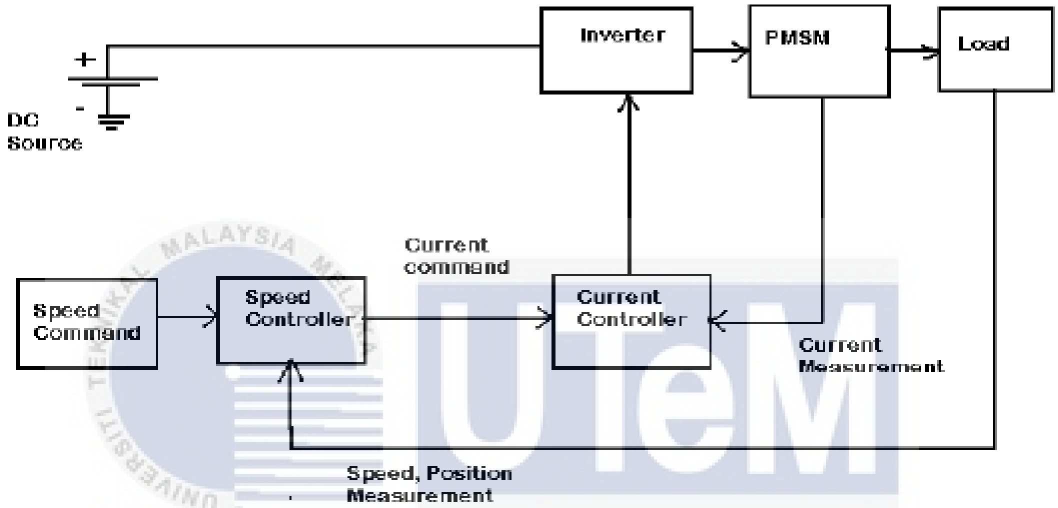


Figure 2.6: Basic Block of PMSM drive

Figure 2.7 shows PI speed controller of PMSM drive. PI speed controller have gains which is, *Kp* and *Ki*. The reference torque is considered as output of this system. A limit is placed on output of speed controller depending on permissible max winding currents. From current regulator block, the reference of current regulator block produces three phase reference currents such as *ia*, *ib*, and *ic*. By utilizing the limited peak current magnitude chosen by the position sensor and controller.

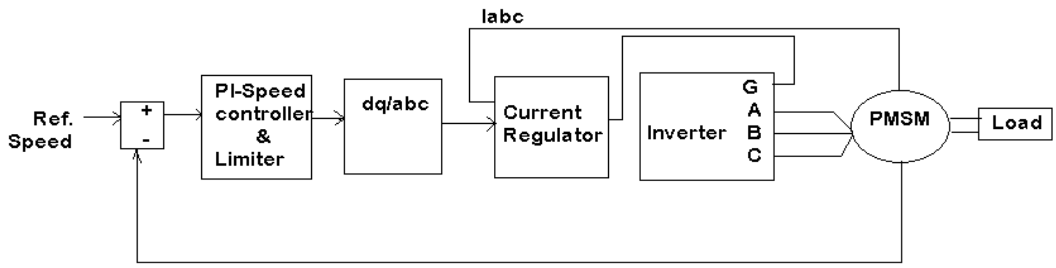


Figure 2.7: PI speed controller of PMSM

2.9 Conventional PI tuning techniques

2.9.1 Ziegler-Nichols Method

Ziegler-Nichols proposed procedures best well-known that has been implemented in systems control to define the values of PI controller [10]. This principal methods that be used in PI controller tuning is Ziegler Nichols tuning methods. Step response method and ultimate frequency method is the two methods in this tuning ways.

The degeneration proportion is related of largeness for two consecutive fluctuations. It would be self-directed response to the system and must be determined by simply on the roots of the characteristic equation [10].

2.9.2 Root-locus technique

All values of limitations are fixed toward nothing once the system is online. Standards are puffed out till productivity of round fluctuates and several counter balance is accustomed excessively and doubt essential, till the circle is suitably rapid to variety its point once disturbance was added. On the other hand, exceptionally will cause an excessively plentiful reaction and overreach. A reckless PI circle tweaking commonly overextends a tiny toward the set point extra fast.

2.9.3 C-C (Cohen-Coon) Method

Cohen-Coon technique is the system's behaviour is arranged toward stage deviation as a first order response compulsory dead time, using the Cohen-Coon method. From this response, three values: K, τ, and Kc are originated. K is the output steady state divided by the input step change, τ is the effective time constant of the first order response, and Kc is the dead time [11]. PI values have gotten since K, τ, was obtained and from formulas.

2.9.4 Particle Swarm Optimization (PSO) Techniques

"PSO" means Particle Swarm Optimization. PSO is an optimization method based on effect by the community. This technique is shown successfully solve many optimization problems.

PSO is an optimization method initially established by Kennedy and Eberhart [12]. The improvements original algorithm undertook had been recognized once the potential for optimization was identified to increase its convergent and optimization potential. Due to Shi and Eberhart, possibly the utmost substantial, refining the convergence behaviour of PSO the inactivity weight variation, Clerc and Kennedy [12], the essential interactions among the PSO values to interrupt conjunction and van den Bergh is fixed the contraction feature.

In this project, it has well thought-out that use PSO provided that extra supply by combining the technique of bearing in mind numerous information, although isolated character of every single information was kept. From the results of this project, particle swarm produces an extension that will tolerate it to be the better as an optimization technique.

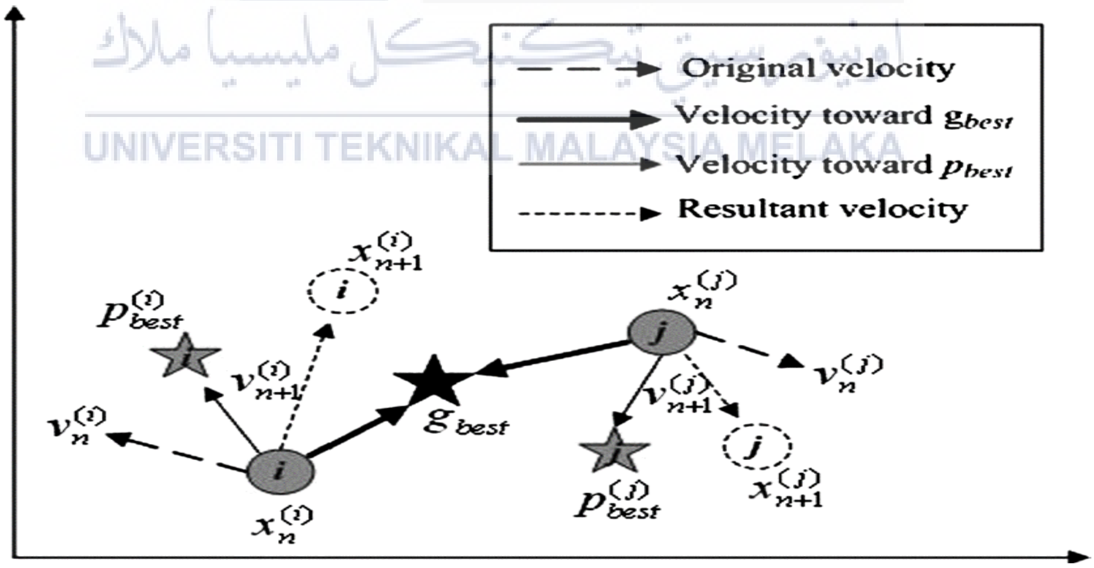


Figure 2.8: Illustrating the dynamics of a particle in PSO [13]

CHAPTER 3

METHODOLOGY

3.1 Overview

In methodology part, the step to achieve the objectives of the project is explained in detailed. Step by step of the project flow such as literature review, modelling PMSM drive and tuning PI controller using conventional method and PSO technique will be explained in this section. Proper project planning is important to settle down this project on time. Based on Figure 3.0, the project begins with some research and literature review of PMSM and PSO. Some of the sources for this project are journal papers, conferences, and books. Many data about PMSM and PSO such as modelling of PMSM, equivalent circuit of PMSM motor, current control for PMSM drives, basic PSO algorithm, and method for tuning PI controllers obtained from the literature review. Then, the useful data extracted for use in this project. Software that be uses for simulate PMSM drive is Matlab Simulink.

3.2 Flowchart

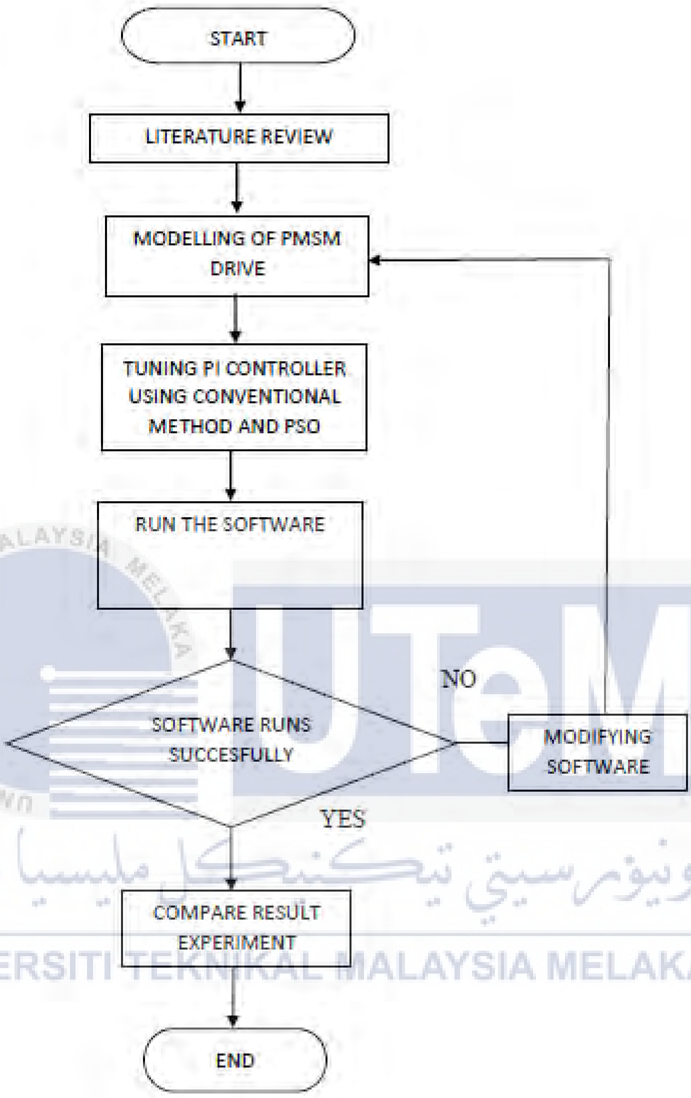


Figure 3.0: Project Flow Chart

3.3 Literature Review

Literature review is the process where the researcher get information about the project their going to do. It comes from many types of sources as stated in the previous subtopic. Some of it can take as the literature review and some of it can take as an extra knowledge.

The literature review provided the basic of PMSM drives which is, modelling of PMSM, Park Transformation D-Q modelling, equivalent circuit of PMSM, and current control for PMSM drives. Some of the other study that has been includes in this part are study on the tuning method for PI controller using PSO.

All the information of this literature review part is from internet, journal, books, and library research is used in order to accomplish for this project.

3.4 Modelling of PMSM Drives

Modelling of PMSM drives will be describe in this subtopic. Figure 3.1 shown the d-q rotor reference frame. From the Figure 3.1, we can see that, the rotor reference axis create an angle θ_r at every certain time t, with constant stator axis. There is an angle α between stator mmf and rotor d-axis. Moreover, the stator mmf revolves at the similar speed with rotor axis.

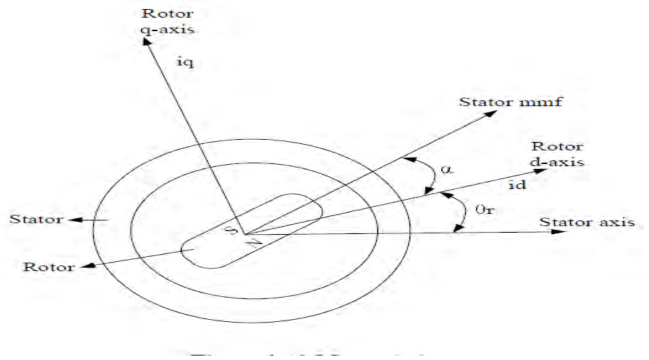


Figure 3.1 The d-q rotor reference frame

The PMSM model for exclude damper winding already developed based on rotor reference frame by using a few assumptions:

- Saturation is ignored.
- The signal of EMF is sinusoidal.
- Hysteresis losses and eddy current are ignored.
- Does have not field current dynamics.

3.4.1 Mathematical Model of PMSM Drives

The equation for voltage of stator in *dq* axis:

$$Vq = Rs\, iq + \omega r\, \lambda d + \rho\, \lambda q \tag{3.1}$$

$$Vd = Rs\, id - \omega r\, \lambda q + \rho\, \lambda d \tag{3.2}$$

Where *Iq* and *Id* are current of stator in *dq* axis

Flux Linkage equation:

$$\lambda q = Lq\, iq \tag{3.3}$$

$$\lambda d = Ld\, id + \lambda f \tag{3.4}$$

Where λq and λd are flux linkage of stator in *dq* axis while λf is flux linkage of PMSM

Sub equation (3.4) and (3.3) into (3.1) and (3.2)

$$Vq = Rs\, iq + \omega r\,(Ld\, id + \lambda f) + \rho\, Lq\, iq \tag{3.5}$$

$$Vd = Rs\, id + \omega r\, Lq\, iq + \rho(Ld\, id + \lambda f) \tag{3.6}$$

Form a matrix equation from equation (3.5) and (3.6)

$$\begin{pmatrix} Vq \\ Vd \end{pmatrix} = \begin{pmatrix} Rs + \rho Lq & \omega r\, Ld \\ -\omega r\, Lq & Rs + \rho Ld \end{pmatrix} \begin{pmatrix} iq \\ id \end{pmatrix} + \begin{pmatrix} \omega r \lambda f \\ \rho \lambda f \end{pmatrix} \tag{3.7}$$

Developed torque equation:

$$Te = \frac{3}{2}\left(\frac{P}{2}\right)(\lambda d\, Iq - \lambda q\, Id) \tag{3.8}$$

With applied *Id* and reluctance torque with zero, the higher efficiency and torque per amp with linear characteristics can be achieved. Below show equation for mechanical torque.

$$Te = TL + B\,\omega m + J\frac{d\omega m}{dt} \tag{3.9}$$

From the equation above,

$$\omega m = \omega r\left(\frac{2}{P}\right) \tag{3.10}$$

Where ωr is electrical speed of rotor while ωm is mechanical speed of rotor.

3.4.2 Equivalent Circuit of PMSM

By using equation of stator voltage, the equivalent circuit can be obtained from *d q* modelling of the motor. Since PMSM has rotor d axis is equivalent with a constant current source as shown in the equation below. The equivalent circuit for PMSM is shown in figure 3.2

$$\lambda f = Ldm\, If \tag{3.11}$$

Where, λf is field flux linkage

Ldm is Magnetizing Inductance in d axis

If is Field current for equivalent PMSM

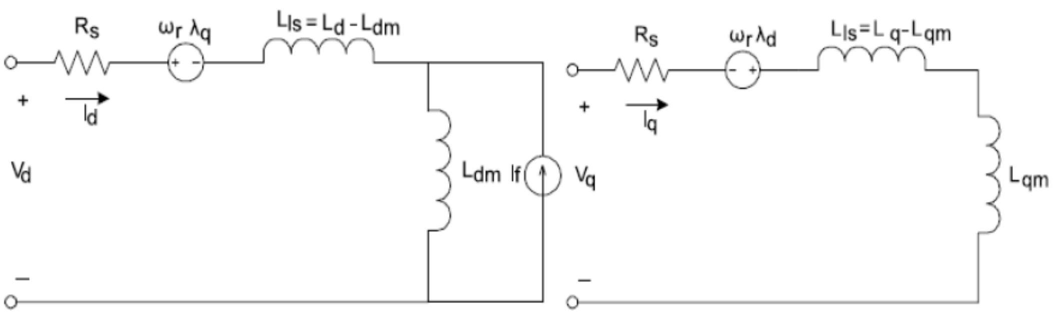


Figure 3.2: Equivalent Circuit of PMSM

3.4.3 Park Transformation

The use of dynamic dq modelling is to analysis the steady state and transient of motor. Park Transformation works with transforming the 3 phase current or voltage to dq0 variables. From the Park Transformation process, several equations can be obtained.

$$\begin{pmatrix} Vq \\ Vd \\ V0 \end{pmatrix} = \frac{2}{3} \begin{bmatrix} cos\theta r & cos(\theta r - 120) & \cos(\theta r + 120) \\ sin\theta r & sin(\theta r - 120) & \sin(\theta r + 120) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \tag{3.12}$$

By inverse the matrix above, the value of Va, Vb, and Vc can be obtained.

$$\begin{pmatrix} Va \\ Vb \\ Vc \end{pmatrix} = \frac{2}{3} \begin{bmatrix} cos\theta r & sin\theta r & 1 \\ cos(\theta r - 120) & sin(\theta r - 120) & 1 \\ cos(\theta r + 120) & sin(\theta r + 120) & 1 \end{bmatrix} \begin{bmatrix} Vq \\ Vd \\ V0 \end{bmatrix} \tag{3.13}$$

3.5 PMSM Drives

Figure 3.3 shows the block diagram for PMSM drive. The block diagram consist of PI speed controller, current controller, PWM generator, speed/position estimator, inverter and PMSM.

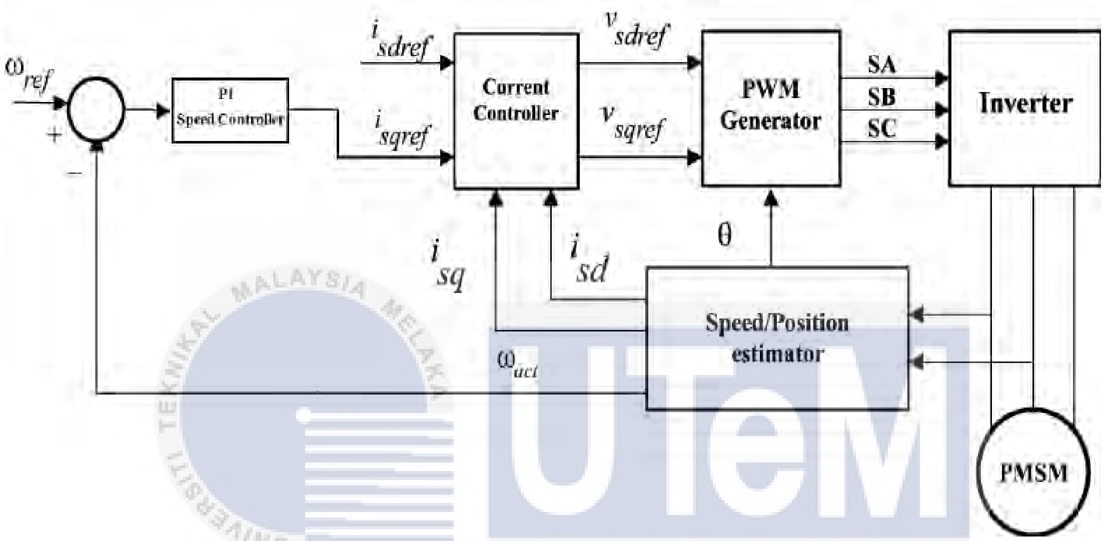


Figure 3.3: The block diagram for PMSM drive

3.6 The PI control tuning method

In this few decades, many manufacturing in this world is implemented Proportional Integral (PI) controller. The creation of PI control is in 1910 and the Ziegler-Nichols straightforward modification law in 1942. This controller has obvious to use by the many industries because of this controller are have modest structure that can simply to understand by the employee plant. Besides that, this PI controller have low cost preservation that can help the industries from spending the money to the process plant. This controller reliefs to become the output wherever can get it, in a little period, least overextend, and tiny error. This controller is given profits to the industry due to the lower cost. Several nonlinear practices can be measured consuming the well-known and technologically recognized PI controller. A substantial straight enactment rise is required after changing a straight control method with any progressive. Table 1 shows the effects of increasing a parameter independently.

The transfer function of PI Controller is: $G_c\ (s)\ +Kis$ (3.14)

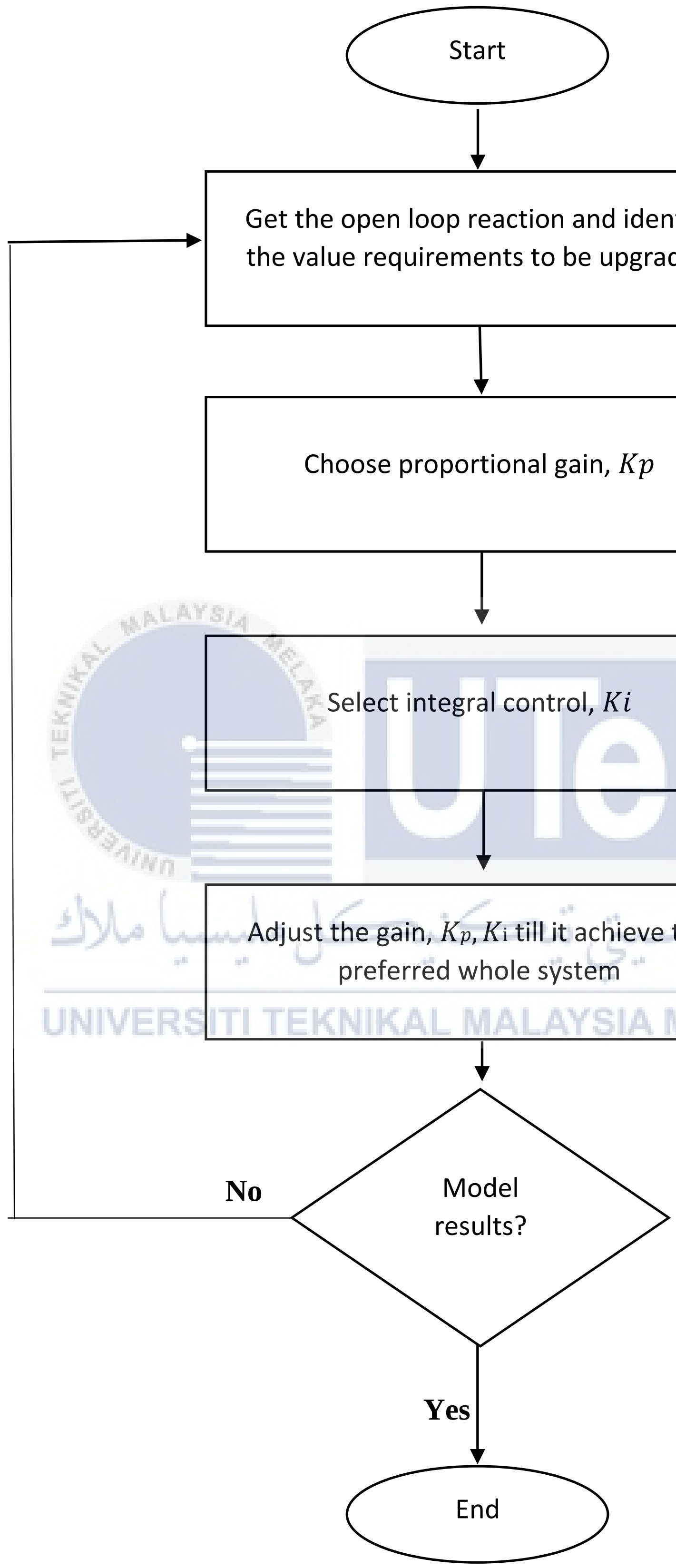


Figure 3.4 Steps to design a PI controller in order to obtain the desired response

Figure 3.4 shows the steps to design a PI controller in order to obtain the desired response. It start with open loop reaction and identify the value requirement to be upgraded. Then, the second step is to choose the proportional gain and integral control, *Kp* and *Ki*. The last step is Adjust the gain, *Kp* and *Ki* till it achieve the preferred whole system.

Table 1: Effects of increasing a parameter independently

Parameter	Rise time	Overshoot	Settling time	Steady-state error	Stability
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor change	Decrease	Decrease	No effect	Improve when K_d small

Table 1 shows the effects of increasing a parameter independently. By increasing the *Kp* value, rise time and steady- state error will be decrease. But overshoot will be increase and stability is degrade. By increasing the *Ki* value, rise time is decrease and it will eliminate the steady state error. But, the overshoot and settling time will be increase and stability is degrade. Finally, by increasing the *Kd* value, minor change for rise time and the steady state error is no effect. However, the overshoot and settling time is decrease.

3.7 Speed Controller of PMSM drives

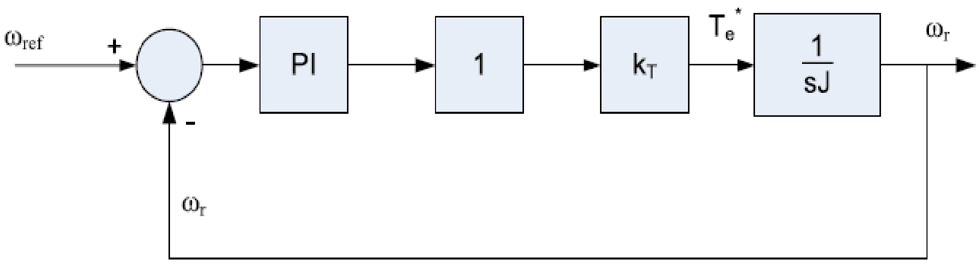


Figure 3.5: The block diagram of speed loop

Figure 3.5 shows the block diagram of speed loop. The equation of open loop transfer function for the motor is shown in below.

$$GH(s) = \left(\frac{ki\ kt\ \alpha}{J}\right)\left(\frac{1+s\frac{kp}{ki}}{s^2}\right) \quad (3.15)$$

Where *Kt* is equal with Permanent motor flux

The parameter of PI controller can be obtained by using equation 3.16 and 3.17.

Phase Margin = $\phi_{OL} + 180°$

$$\left|\frac{kikt\alpha}{J.s^2}\left(1+s\frac{kp}{ki}\right)\right|_{s=j\omega} = 1 \quad (3.16)$$

$$\text{Angle}\llcorner\left|\frac{kikt\alpha}{J.s^2}\left(1+s\frac{kp}{ki}\right)\right|_{s=j\omega} = 180+\phi PM \quad (3.17)$$

By using motor parameters and choosing a frequency, the the *Kp* and *Ki* of PI controller can be obtained.

3.8 Optimization Technique

Optimization technique is a finding alternative with the highest characteristics less than the certain condition. By increasing the possibilities preferred features and reducing undesired ones. Run through of optimization is constrained by deficiency of info available.

3.8.1 Particle Swarm Optimization (PSO)

PSO is an optimization algorithm was demonstrated from the imitation of societal performance of birds in the group. When the pears were updated, PSO will make ready a clutch of haphazard units and will examinations for the bests. For every unit, the performance will be taken from how close by the unit is since the worldwide optimal. This performance will be restrained by via a suitability, purpose which be influenced by on the optimization cases.

- There are the methodology of PSO algorithms:
- The particles will be initialized
- For each particle, the fitness values will be calculated
- When personal best is better than current fitness, the current fitness will be assigned as new personal best
- If the personal best is not better than current fitness, the personal best will be used same like previous
- Best particle’s the personal best will be assigned a value to food’s coordinate
- The velocity for each particle will be calculated
- To update its data values, each particle’s velocity will be used
- Determine the target of maxi maximum epochs either reached or not

PSO has two main operators, which are position and velocity. Throughout each iteration, every possible solutions is elevated toward their last best position and their global best position. At every iteration, a new velocity value for each possible solution determined primarily based on its current velocity, the gap from its last best position, and the gap from the global best position. Current best velocity value is then uses to calculate the following position of the possible solution within the search area. This procedure is then iterate a set quantity of time or until an optimum solution is accomplished. A particle in the search space is playing role as an individual in swarm system in PSO [9]. Every particle serve as a possible solution to the problems. The new position after an iteration is based on its personal best location and the global best position within the search space. Particle position x_i are adjusted using;

$$(t+1)=(t)+v_i(t+1) \tag{3.18}$$

Wherein the velocity component, vi, represents the step size. For the next operator of PSO, velocity, v_i

$$v_{i,j}(t+1)=wv_{i,j}(t)+c_1r_{1,j}(t)(y_{1,j}(t)-x_{i,j}(t))+c_2r_{2,j}(t)(\check{y}_j(t)-x_{i,j}(t)) \tag{3.19}$$

Wherein w is the inertia weight to control the velocity of the possible solutions, c_1 and c_2 are the cognition and social behaviour coefficients, r_1,, $r_{2,j}$ random position of possible solution, $\check{i}$ and $\check{y}_i$ is the global best position of particle $\check{y}$. The global best position of particle $\check{y}_i$ depends on search space used [10]. $\check{y}_i$ is the new global best if the personal best is farther than the global optimum value.

$$\check{y}_i(t)\in\{y_0(t),y_1(t)\ldots y_s(t)\}=min\{f(y_0(t)),f(y_1(t))\ldots f(y_s(t))\} \tag{3.20}$$

Wherein s is the size of population.

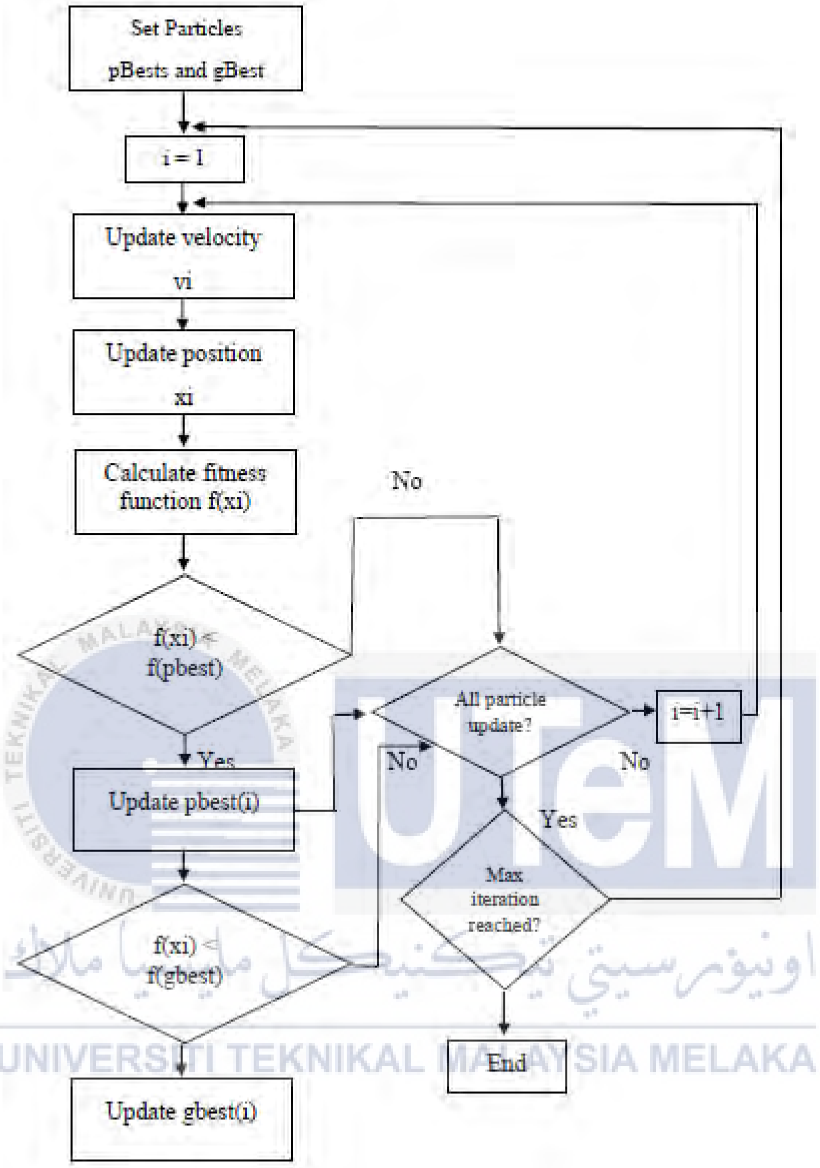


Figure 3.6: Flowchart Particle Swarm Optimization (PSO) Technique

3.9 Simulation

Most of the operation in this world are interacting with the simulation process. The simulation process required a model that should be developed. PMSM by using FOC Hysteresis were decided as a plant in this project while Proportional Integral (PI) is decided to be a controller for the motor drive. This simulation is to produce a characteristic of the system. In designing, tuning PI controllers for PMSM drive, MATLAB/Simulink is decided to use to get the response of the system.

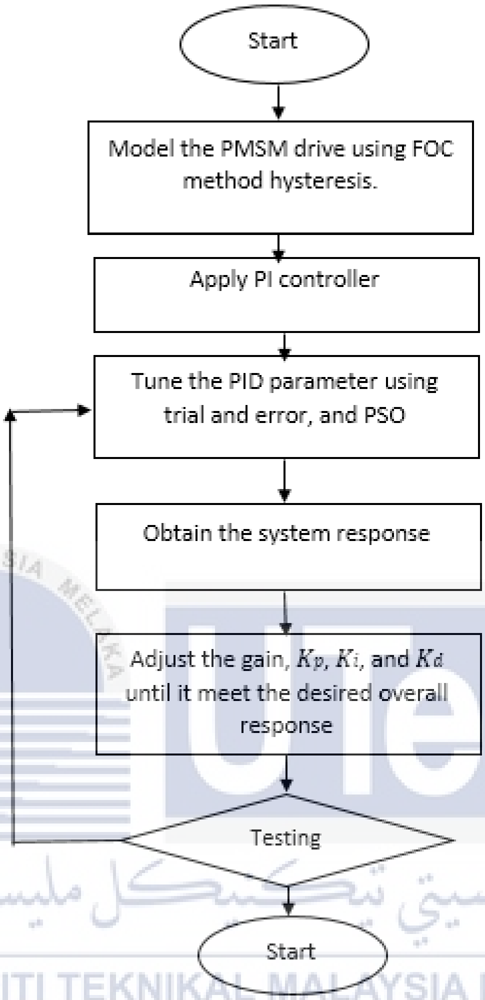


Figure 3.7: Steps to design in simulation

3.10 Simulation Model in Matlab Simulink

The software that will be used to build the PMSM drives model is Matlab Simulink. The purpose of using Matlab Simulink is to analyse performance of PMSM drives and to make comparison the best PI tuning method. Figure 3.8 shows the model of PMSM Drives in Simulink.

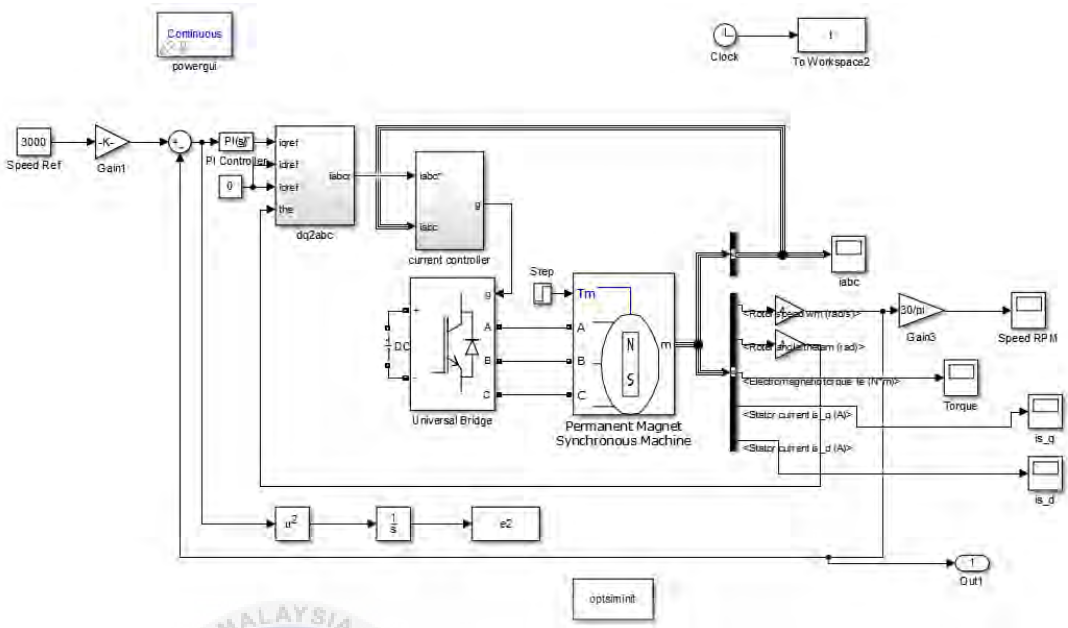


Figure 3.8: Model of PMSM Drives in Simulink

From the figure above, reference speed is set to 3000 rpm and to convert rpm to rad/sec reference speed need to multiply with pi/30. The function of PI controller is to reduce error between actual speed and reference speed. The parameters for PI controller are *Kp* = 40 and *Ki* = 5. The method that be used to tuning PI controller is Trial and Error and PSO.

From the model Simulink id is set to zero. *Id* is represent for magnetic flux. For PMSM motor the magnetic flux is constant, that why *id* is set to zero. Park transformation are used for convert *Iq* and *Id* to *Iabc*. The model using hysteresis as current control to supply switching frequency for inverter. The DC voltage for three phase inverter is 220 *Vdc*.

Figure 3.9 shows the coding for *tracklsq*. The function of *trackslq* coding is to connect the PSO coding with the Simulink model. Additionally, coding *trackslq* works to calculate the error resulting from the Simulink model output.

Intelligent optimization algorithms can be assessed analytically in domain frequency by applying performance criteria such as IAE, ISE, and ITSE. By using these performance criteria, it can indicate optimization, and make the drive system robust. Performance criteria can demonstrate the performance of the system in terms of overshoot, rise time, settling time and steady state error. The formulas for performance criterion are shown below:

Integral Square Error (ISE) = $\int_0^\infty e^2(t).dt$

Integral Absolute Error (IAE) = $\int_0^\infty |e(t)|.dt$

Integral Time Square Error (ITSE) = $\int_0^\infty t.e^2(t).dt$

For the PSO technique, ITSE is used as a fitness function in this project. The parameter for PMSM motor and PSO are shown in table 2 and table 3.

```
function F = tracklsq(pid)
         % Track the output of optsim to a signal of 1
        % tracklsq yang dh jadi
         % Variables a1 and a2 are shared with RUNTRACKLSQ
         Kp = pid(1);
         Ki = pid(2);
         %Kd = pid(2);

         sprintf('The value of interation Kp= %3.0f,Ki=%3.0f',
pid(1),pid(2));
         % Compute function value
         simopt =
simset('solver','ode14x','SrcWorkspace','Current','DstWorkspace','Cu
rrent');  % Initialize sim options
         [tout,xout,yout] = sim('pmsmxpso',[0 0.1],simopt);
         e=yout-1 ;  % compute the error
         sys_overshoot=max(yout)-1; % compute the overshoot

      alpha=1;beta=1;
      F=e2*beta-sys_overshoot*alpha;

    end
```

Figure 3.9 Coding for *tracklsq*

Table 2: Parameter for PMSM motor

Number Phase	3
Rotor Type	Round
Stator phase resistance Rs (Ω)	2.875
Armature Inductance (H)	0.00153
Inertia (J(Kg.m^2))	0.8e-3
Viscous Damping F(N.m.s)	0
Pole Pair	4
Vdc (V)	220
Rated current (A)	30

Table 3: PSO parameter

Max iteration	10
Population Size	30
Inertia Weight	0.9
C1	1.12
C2	0.12

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

This chapter discusses the results obtained from simulation by using Matlab Simulink. The performance of PMSM will be evaluated based on the speed response produced by different tuning methods. The rise time, overshoot and settling time will be recorded for making comparison. The comparison between the simulation outcomes will be talked over in this section.

4.2 Performance PMSM drive for rated speed 3000 RPM

This sub-chapter present, the performance of PMSM drive in rated speed 3000 rpm will be discussed in detail. Analysis will be done by applying load and no load to the motor. Performance of PMSM drive is evaluated by obtains the value of overshoot, rise time, and settling time from the simulation.

4.2.1 Speed result for no load and load

Figure 4.0 and Figure 4.1 show the speed performance for PMSM by applying no load and full load test. The load used in this test is 3N.m when t = 0.03. Figure 4.2 shows the load effect on speed. Performance PMSM is evaluated by values of overshoot, rise time and settling time obtained from the simulation. Table 4.0 shows the values of overshoot, rise time, and settling time.

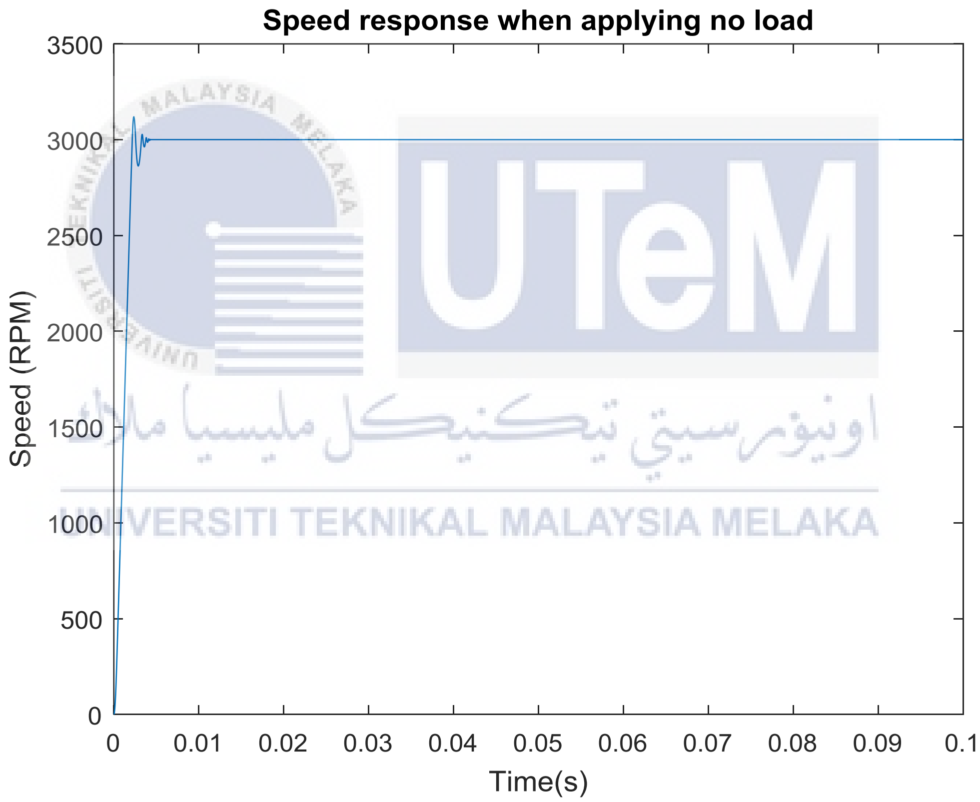


Figure 4.0

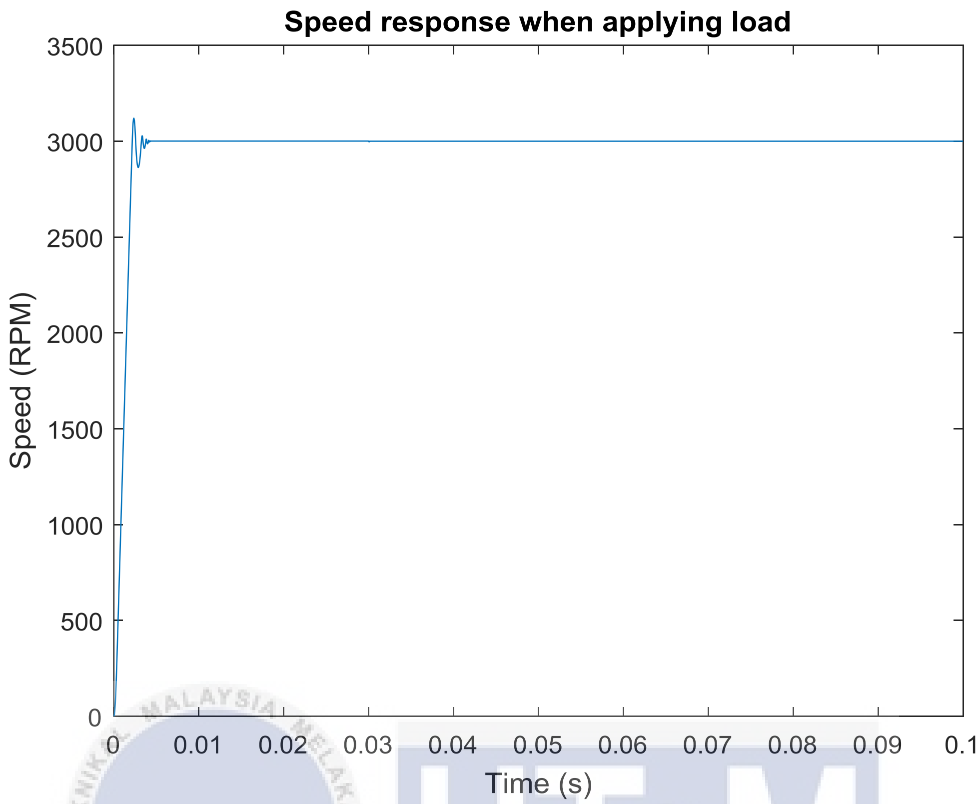


Figure 4.1

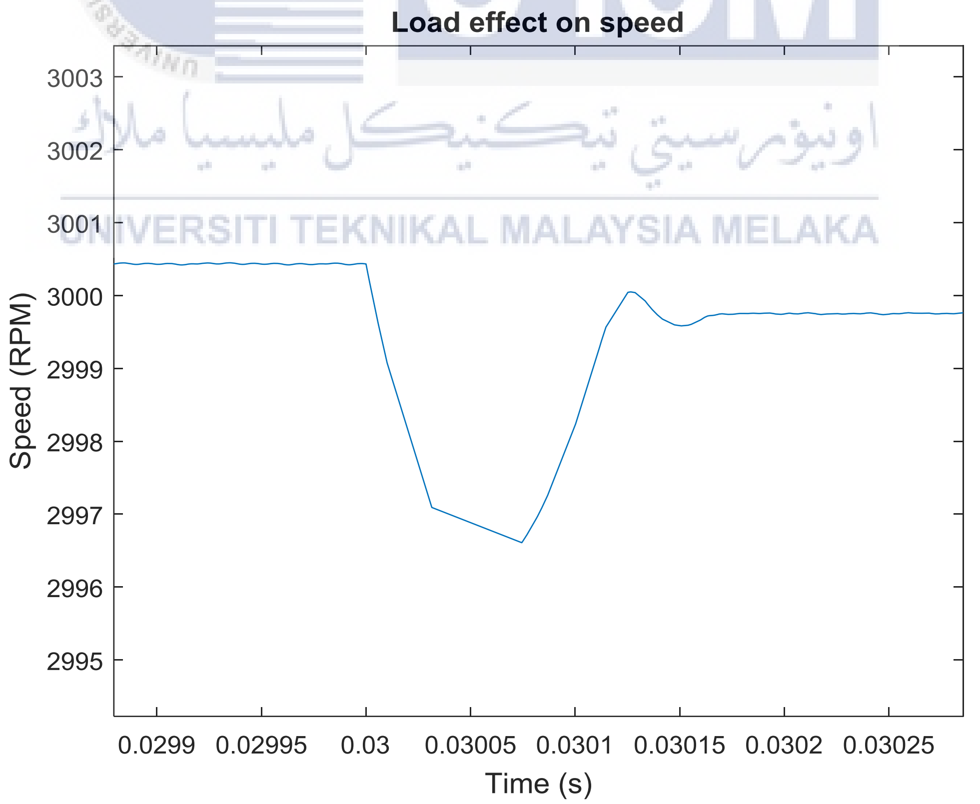


Figure 4.2

Table 4: Speed response at 3000rpm

Types	***Tr*** **(ms)**	***Ts*****(ms)**	**OS (%)**
Value	1.148	2.200	5.072

4.2.2 Result for *iabc* during no load and full load

Figure 4.3 shows the signal of *iabc* for no load and full load. From t = 0s until t = 0.03s the signal of *iabc* current is close to zero. This is because no load was applied at that time. While at t = 0.03 until t = 0.1, the waveform of *iabc* current has maximum and minimum values 3 and -3. This is because the *iabc* current influenced by the existence of load 3 N.m.

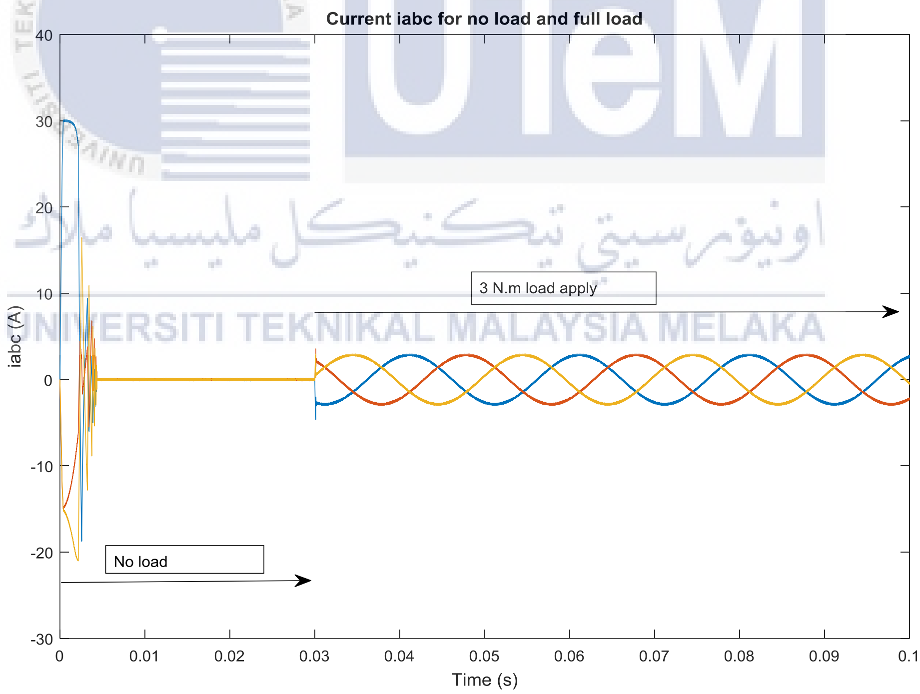


Figure 4.3

4.2.3 Result for stator current *id* during no load and full load

Figure 4.4 shows the stator current *id* for no load and full load. At the beginning, the stator current id experienced a sharp rise and a sharp decrease with the amplitude around 4A and -4A. But the increase is in a small time range. From the diagram below, the stator current id is not affected by the existence of the load. This is because when the load is applied, stator current id value is still approaching to zero. But when the load is applied at t = 0.03s, the value of stator current id decreases about to -2 A. But the decrease is in a small time range.

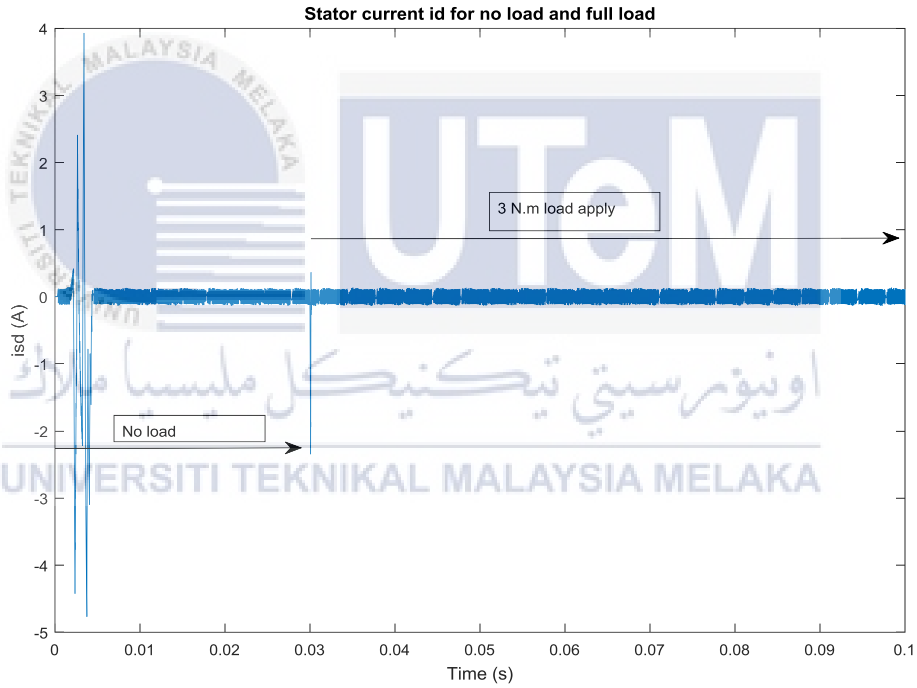


Figure 4.4

4.2.4 Result for stator current *iq* during no load and full load

Figure 4.5 shows the stator current *iq* for no load and full load. At the beginning, the stator current *iq* experienced a sharp rise and a sharp decrease with the amplitude around 30A and -20A. The property of stator current *iq* is same with *iabc*, which is the stator current *iq* influenced by the existence of load 3 N.m.

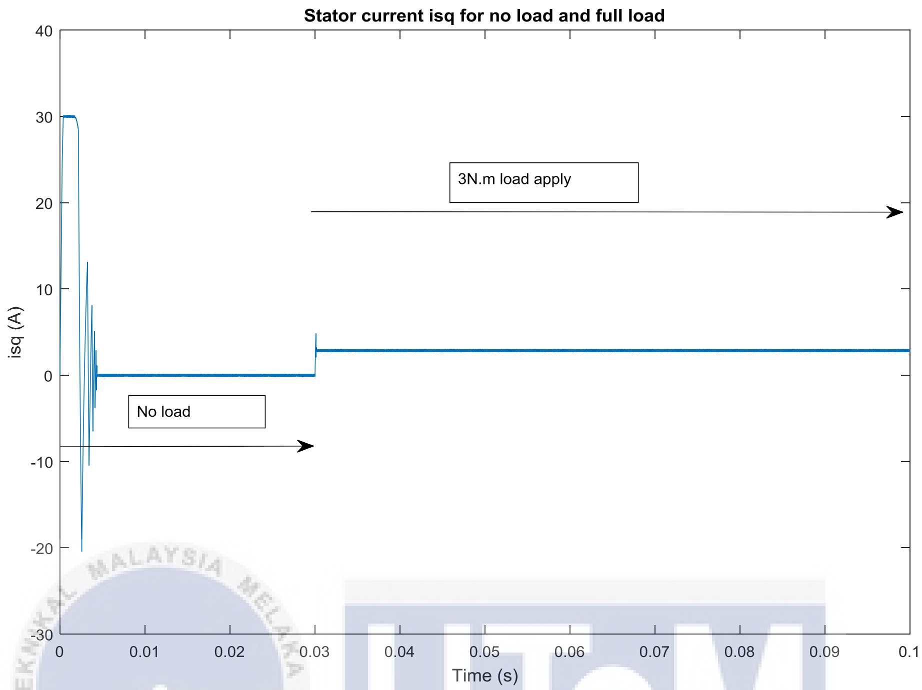


Figure 4.5

4.3 Performance PMSM drive for speed 1500 RPM

In this subtopic, the performance of PMSM drive in speed 1500 rpm will be discussed in detail. Analysis will be done by applying load and no load to the motor. Performance of PMSM drive will be evaluated by obtained the value of overshoot, rise time, and settling time from the simulation.

4.3.1 Speed result for no load and load

Figure 4.6 shows the speed performance for PMSM by applying no load and full load test. The load used in this test is 3N.m when t = 0.03. Figure 4.7 shows the load effect on speed. Performance PMSM is evaluated by values of overshoot, rise time and settling time obtained from the simulation. Table 4.1 shows the values of overshoot, rise time, and settling time.

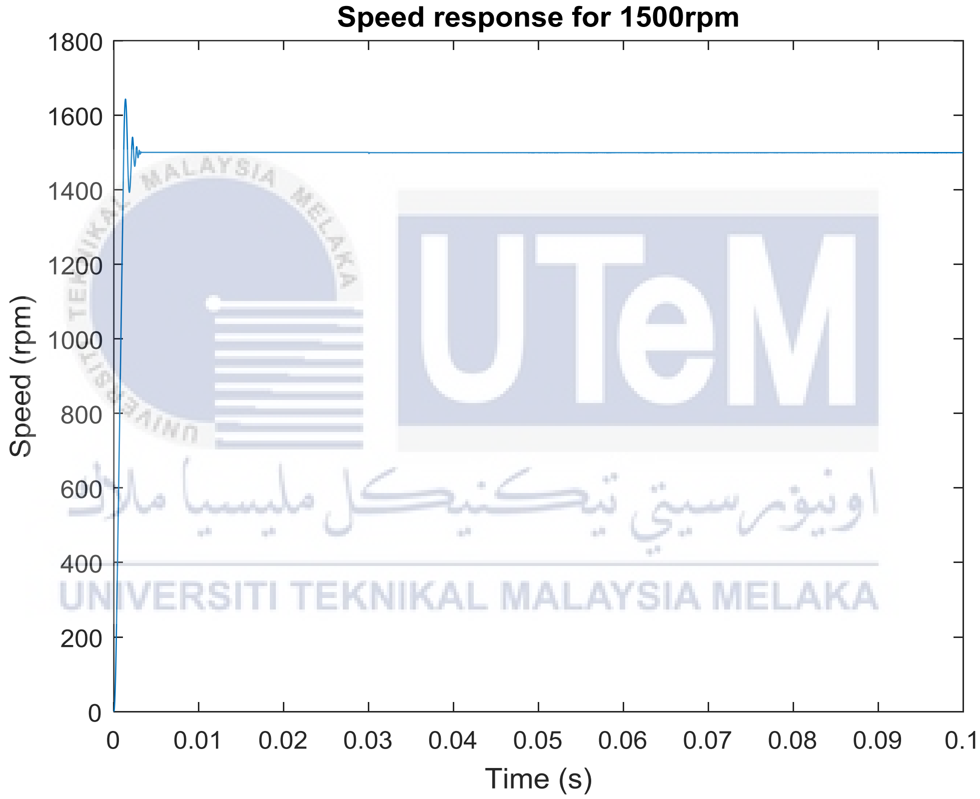


Figure 4.6

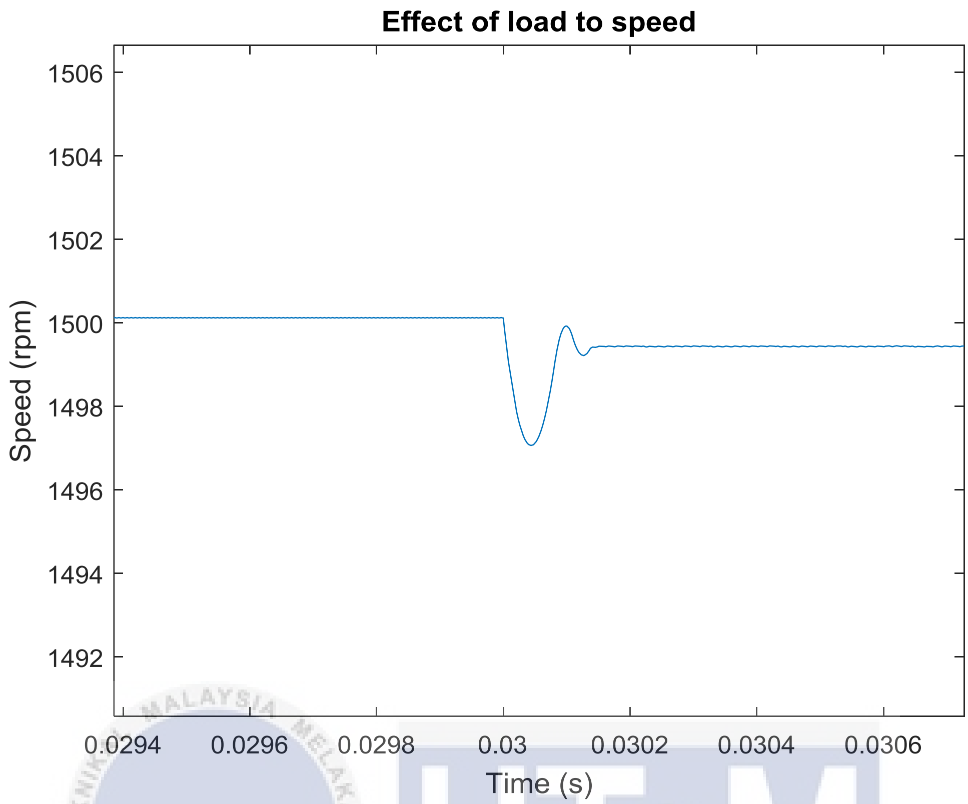


Figure 4.7

Table 5: Speed response at 1500rpm

Types	***Tr (μsec)***	***Ts (ms)***	**OS (%)**
Value	603.044	1.774	12.319

4.3.2 Result for *iabc* during no load and full load

Figure 4.8 shows the signal of *iabc* for no load and full load. From t = 0s until t = 0.03s the signal of *iabc* current is close to zero. This is because no load was applied at that time. While at t = 0.03 until t = 0.1, the waveform of *iabc* current has maximum and minimum values 3 and -3. This is because the *iabc* current influenced by the existence of load 3 N.m.

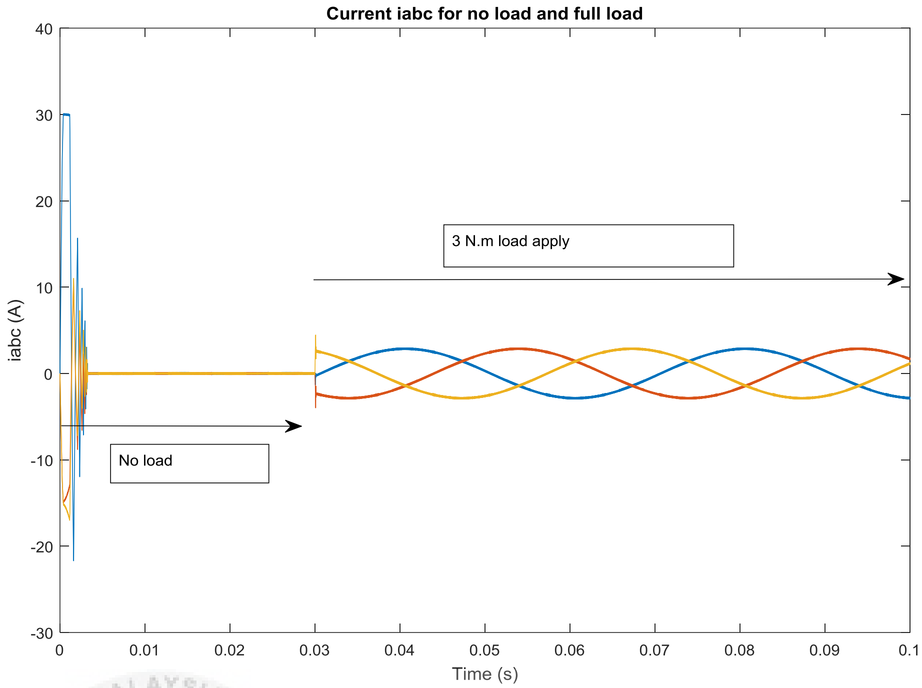


Figure 4.8

4.3.3 Result for stator current *id* during no load and full load

Figure 4.9 shows the stator current *id* for no load and full load. At the beginning, the stator current *id* experienced a sharp rise and a sharp decrease with the amplitude around 5A and -4A. But the increase is in a small time range. From the diagram below, the stator current id is not affected by the existence of the load. This is because when the load is applied, stator current id value is still approaching to zero. But when the load is applied at t = 0.03s, the value of stator current *id* increase about to 1 A. But the decrease is in a small time range.

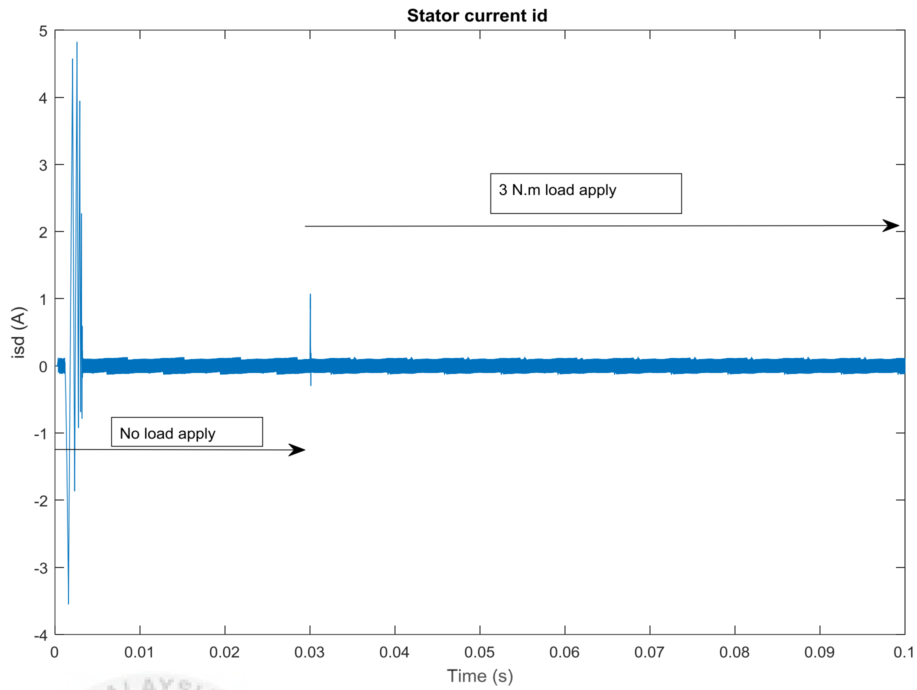


Figure 4.9

4.3.4 Result for stator current *iq* during no load and full load

Figure 4.10 shows the stator current *iq* for no load and full load. At the beginning, the stator current *iq* experienced a sharp rise and a sharp decrease with the amplitude around 30A and -20A. The property of stator current *iq* is same with *iabc*, which is the stator current *iq* influenced by the existence of load 3 N.m.

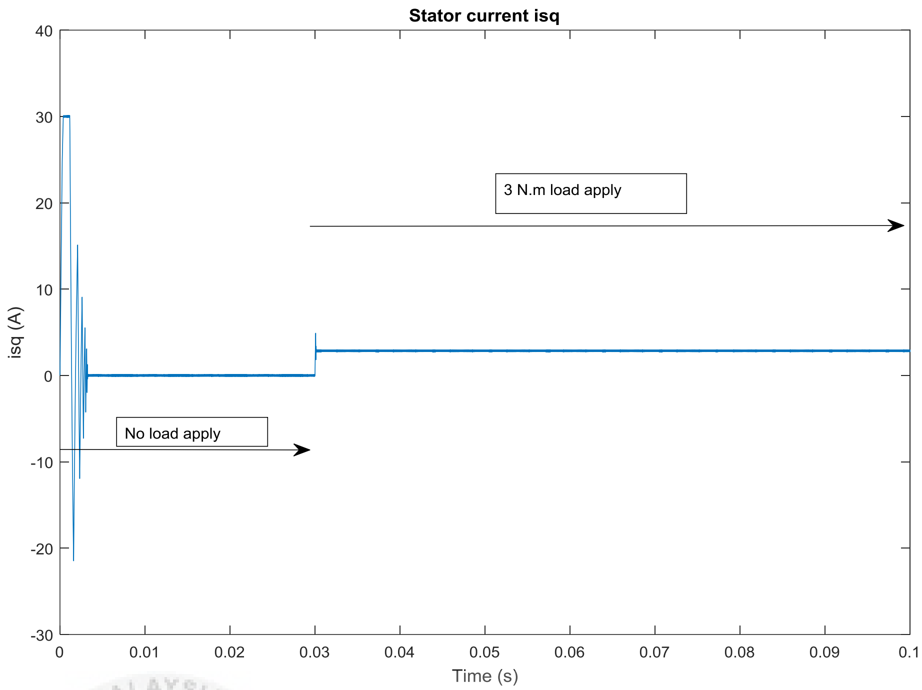


Figure 4.10

4.4 Performance PMSM by applying PSO

In this subtopic, the comparison of performances by using different tuning error is performed to identify the ability of the PSO to optimize the PMSM drive. Comparisons are made at different speeds which is at 3000 rpm and 1500 rpm.

4.4.1 Performance PMSM by applying PSO at 3000 rpm

Figure 4.11 shows the comparison speed responses using different tuning method. The detail of values of overshoot, rise time, and settling for both technique methods are show in table 6. Comparison that can be derived from the value obtained is value of overshoot and settling time for PSO technique has lower than trial and error method, except value of rise time. Moreover, the system that applying PSO technique has more stable compare to conventional method.

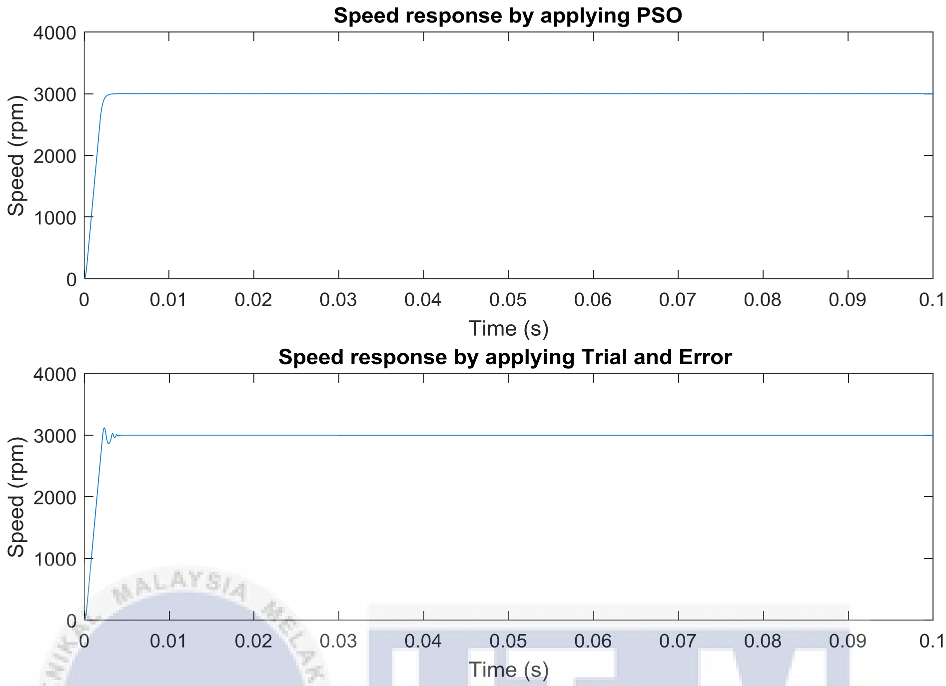


Figure 4.11

Table 6: Comparison tuning method at speed = 3000rpm

Types	***Tr (msec)***	***Ts (ms)***	**OS (%)**
PSO	1.192	1.042	0.703
Trial and Error	1.148	2.200	5.072

Figure 4.12 shows the bestcost of the system for 10 iteration. The value of bestcost is 4381. The *Kp* and *Ki* values obtained from PSO are 0.7757 and 31.6215

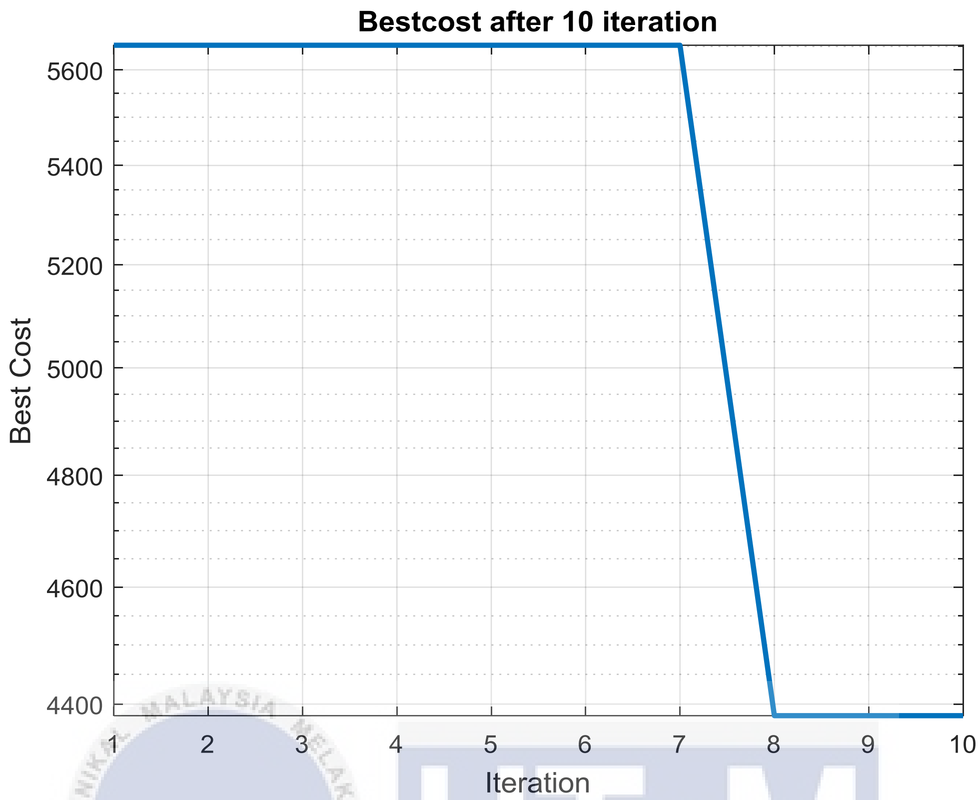


Figure 4.12

4.4.2 Performance PMSM by applying PSO at 1500 rpm

Figure 4.13 shows the comparison speed responses using different tuning method. The detail of values of overshoot, rise time, and settling for both technique methods are show in table 7. Comparison that can be derived from the value obtained is value of overshoot and settling time for PSO technique has lower than trial and error method except the value of rise time. Moreover, the system that applying PSO technique has more stable compare to conventional method.

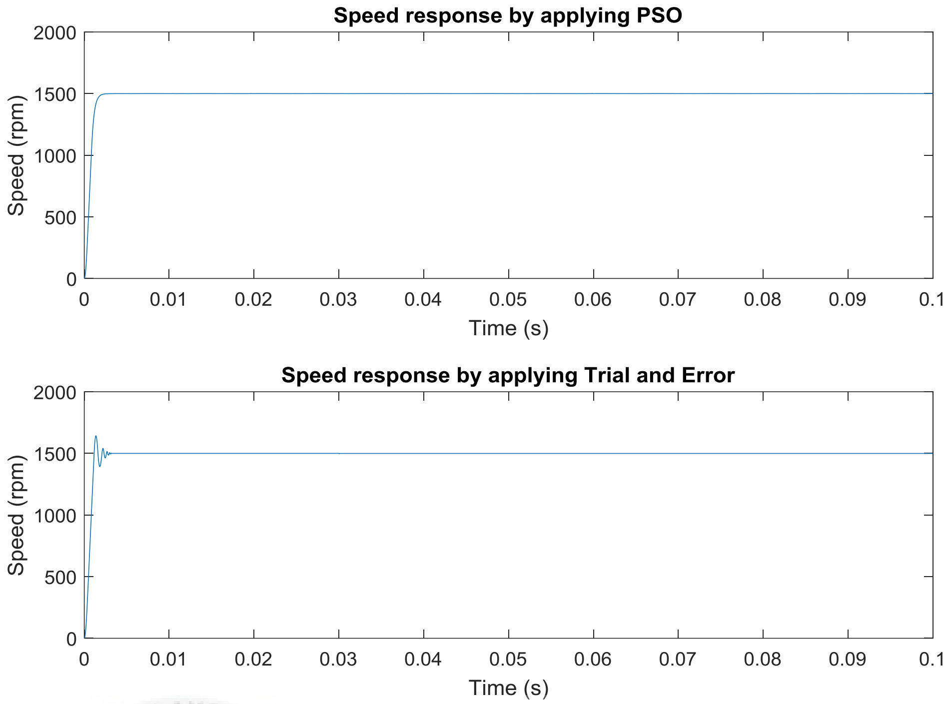


Figure 4.13

Table 7 Comparison tuning method at 1500rpm

Types	***Tr (μsec)***	***Ts (ms)***	**OS (%)**
PSO	706.650	0.873	0.819
Trial and Error	603.044	1.774	12.319

Figure 4.14 shows the bestcost of the system for 10 iteration. The value of bestcost is 5150. The *Kp* and *Ki* values obtained from PSO are 37.44 and 35.71

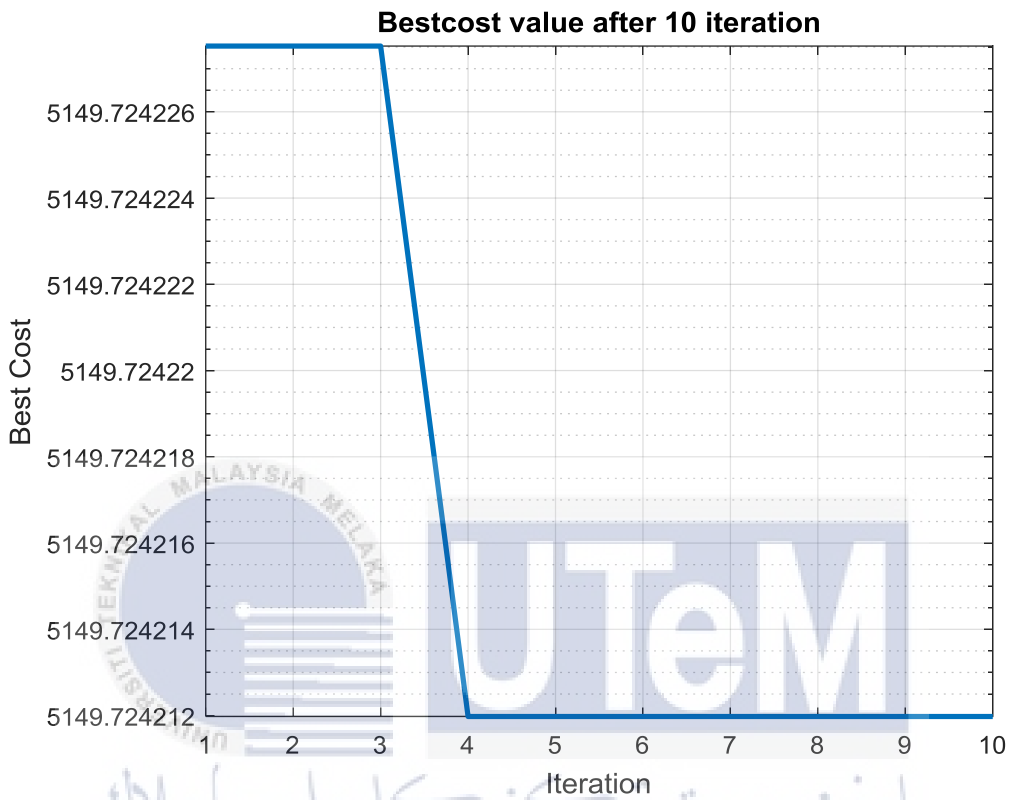


Figure 4.14

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In this project, vector control techniques have is applied to PMSM drives. Vector control or known as Field Oriented Control has is successfully applied in this project by using hysteresis as a current controller.

This project is successfully implemented PI controller as a speed controller for PMSM drive. PI was chosen in this project because it is simple, low cost, and high efficiency. Its function is to stable the system the input to the output so that it can be used to control the speed of PMSM motor. The feedback needed in a system to produce a good transient response and zero-steady-state error. Without feedback control strategy, the transient response of this system will not be good and steady-state-error will occur.

In addition, the technique used for tuning PI controller are by using conventional methods and PSO. The system for PMSM drive has successfully developed by using Simulink/MATLAB.

Furthermore, the results of this project were analysed by comparing the performance of PMSM drives by using different tuning techniques such as conventional methods and PSO techniques.

The execution of the PSO calculation technique for tuning a PI controller has been ended up being superior to the conventional method. From the outcomes, the outlined PI controller utilizing the PSO calculation demonstrates better execution over the customary technique for conventional method, as far as the framework overshoot, settling time and rise time.

As a suggestion, PI controller is a controller that has some weaknesses. To get the best performance for PMSM, Fuzzy logic is the best alternative as a replacement for PI controller.

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