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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FACULTY OF ELECTRICAL ENGINEERING

FUZZY LOGIC SPEED CONTROL FOR INDUCTION MOTOR DRIVES

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FUZZY LOGIC SPEED CONTROL FOR INDUCTION MOTOR DRIVES

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A report submitted in partial fulfillment of the requirements for the degree of Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2018

APPROVAL

I hereby declare that I have read through this report entitled “Fuzzy Logic Speed control of induction Motor drives” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering

Signature: ....

Supervisor’s Name: Prof Dr Zulkifilie Bin Ibrahim

Date : 6/6/2018

DECLARATION

I declare that this report entitles “Fuzzy Logic Speed control of induction Motor drives” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ………………………………………

Name: OSAMA ABDUL QADIR

Date : 6/6/2018:

DEDICATION

To my beloved father and mother

Acknowledgment

In preparing this report, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thought. In particular, I wish to express my sincere appreciation to my main project supervisor, Prof Dr Zulkifilie Bin Ibrahim, for encouragement, guidance critics and friendship. I am also very thankful to my friends for their guidance, advices and motivation. Without their continued support and interest, this project would not have been same as presented here.

ABSTRACT

In recent years, the application of high performance Induction Motor Drives has become a great attention of motor drive player. The demand of robustness controller is necessary to meet satisfactory performance cover various speed demand and other variation such as parameters and load. The conventional controllers of motor drive such PI controller can’t handle non-linearity of the drive as well as sensitive to parameters change. In this project fuzzy logic controller FLC is utilized to drive the induction motor to enhance the speed performance of the motor. The FLC is robust controller that can handle non-linearity of the motor parameters unlike the conventional controllers. The principle of fuzzy logic is to drive the IM system based on the speed error produced in which the fuzzy membership function is designed to effectively reduce the error as much as possible in order to produce optimum performance. The IM model was designed using Matlab/Simulink environment. Three different rules selection of fuzzy logic controller were considered which are 9,25 and 49 rules. The drive performance was investigated without load disturbance and under load disturbance. The settling time rise rime and percent overshoot of the speed response in forward and reverse operation was analyzed a compared in order to validate the performance of the fuzzy logic controller. Therefore, the objective of this project was successfully achieved by designing Fuzzy logic speed controller based induction motor drive system.

ABSTRAK

Dalam beberapa tahun kebelakangan ini, penerapan pemacu Motor Induksi prestasi tinggi telah menjadi perhatian utama pemacu motor. Permintaan pengawalan keteguhan diperlukan untuk memenuhi prestasi yang memuaskan meliputi pelbagai permintaan laju dan variasi lain seperti parameter dan beban. Pengawal konvensional pemacu motor pengawal PI tersebut tidak dapat mengendalikan linieriti pemacu serta sensitif terhadap perubahan parameter. Dalam projek ini fuzzy logic controller FLC digunakan untuk memacu motor induksi untuk meningkatkan prestasi kelajuan motor. FLC adalah pengawal teguh yang dapat menangani non-linearity parameter motor tidak seperti pengendali konvensional. Prinsip logik fuzzy adalah untuk memacu sistem IM berdasarkan ralat kelajuan yang dihasilkan di mana fungsi keahlian fuzzy direka untuk mengurangkan kesilapan secara berkesan sebanyak mungkin untuk menghasilkan prestasi yang optimum. Model IM direka menggunakan persekitaran Matlab / Simulink. Tiga pilihan pemilihan pengawal logik fuzzy telah dipertimbangkan iaitu 9,25 dan 49 peraturan. Prestasi pemacu disiasat tanpa gangguan beban dan di bawah gangguan beban. Masa penyelesaian, kenaikan harga dan peratus overshoot terhadap tindak balas kelajuan operasi ke hadapan dan terbalik dianalisis berbanding untuk mengesahkan prestasi pengawal logik kabur. Selain itu, matlamat projek ini berjaya dicapai dengan merancang pengawal kelajuan logik Fuzzy sistem pemacu motor induksi berasaskan.

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CHAPTER 1

1. INTRODUCTION

1.1 Background

The usage AC motors increases largely because of their features and application in industrial field and house equipment (single phase). The induction motor considered as one of the well-known used type of ac motor due to their robust and less maintenance characteristics. (IMs) have been widely known as key element in the industry for long time because of its less cost, simple and robust construction. However, the drive of IM is complex because of its non-linear attributes in nature and the parameters changes with several operating conditions. Normally, the conventional fixed-gain (PI) and (PID) and their controlled classes have been widely used for IM drive. However, the fixed-gain and controlled drives mostly encounter smatter in the steady-state, parameters variations and output disturbance. Lately, researchers and industry are concerning in utilizing intelligent methods for IM drive due to their characteristics compared to the conventional PI, PID and their controlled classes. The crucial characteristics are that the construction of these drive does not depends on efficient designing mathematic model and their performance.

The recent drives area has contributed widely to provide various sets of drivers that have made it simple to alter the speed with a huge operating range. However, the big non-linear method of the IM control mechanical methods needs efficient drive method for driving speed. The conventional driver’s types that are used for the aims of motor control are may be numeric or neural or fuzzy. The driver's types that are normally used are: PI, PD, PID, FLC or a combination of two of them. In this project fuzzy logic controller FLC is utilized to drive the induction motor to enhance the speed performance of the motor. The FLC is robust controller that can handle non-linearity of the motor parameters unlike the conventional controllers.

1.2 Problem statement

In the past decades, proportional integral (PI, PID) have been utilized as speed controllers in IM drive system. These controllers drive the speed of induction motor in accordance to the speed error. The issues with such controllers can be visualized by their incapacities on handling parameters changes. These controllers are considered non-linear controllers with fixed gains vales in which they must be retuned if any changes occurred to the system [1].

However, with the rapid advancement in technology and industrial application, the fuzzy logic controllers have been proposed as an alternative effective approach to drive the IM system. Fuzzy logic controllers in IM drives have received a great attention by numerous researchers in the past few decades due to the robustness and enhanced performance compared to the conventional PI controller. The principle of fuzzy logic is to drive the IM system based on the speed error produced in which the fuzzy membership function is designed to effectively reduce the error as much as possible in order to produce optimum performance.

1.3 Objectives

The main aim of this project is to design an induction motor drive system based on fuzzy logic controller, hence these objectives to be achieved:

i. To build and design vector control of induction motor drive.
ii. To design hysteresis current control of induction motor drive.
iii. To design Fuzzy Logic Speed Controller FLC of induction motor drive to overcome the shortcomings of conventional controllers.

1.4 Scopes

The scope of this project includes designing and simulating induction motor drive system-based speed control fuzzy logic control. The scope of the project covers the following:

i. Mathematical modelling of 3 phase induction motor drive.
ii. Hysteresis current controller of induction motor drive.
iii. Fuzzy logic controller speed control of induction motor drive.
iv. Implementation of fuzzy logic speed controller of induction motor using Matlab/Simulink.

1.5 Expected Outcomes

The expected outcomes of this project are as follow:

i. Study the behavior of variable induction motor drive.
ii. Improved overall performance with fuzzy logic controller.
iii. Variable speed operations with better speed characteristics under load disturbance.
iv. Different rules design of Fuzzy Logic Controller (FLC).

1.6 Report Organization

This report consists of five chapters which are presented as below:

Chapter 1: Introduction-This chapter provide introduction and illustration of the project background, problem statement, scope and objectives

Chapter 2: Literature Review – presents the theoretical background of the ac motor drive including the conventional drives. Previously published work is also analyzed and investigated.

Chapter 3: Methodology- The project flow and steps are presented in thus chapter including the project flow chart and design procedures of the fuzzy rules and membership function.

Chapter 4: Result and discussion- the simulation results of the IM drive system obtained from Matlab/Simulink are presented. No load operation and with load operation were analyzed considering different speed range.

Chapter 5: Conclusion and recommendation- summary of the project finding and outcomes and future work suggestion are presented in this chapter.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Introduction

AC motors are getting into the industrial field of motor control, in which DC motors were always used. Sophisticated inverter methods have led the AC power source very adjustable. Varied frequency power source enabled the ac motor to get rid of from the constant synchronizing speed and tend to be controllable speed motors [2]. It is proving that the determination of IM is of huge essentiality in various industry implementations. From all the sets of ac motors, the cage type IM is largely utilized in industrial field. The IM is also referred as the asynchronous motor [3][4]. The induction motor has numerous advantages such as simple construction and robustness. The induction motor is very popular in industry due to its advantages and robustness and less maintenance [5][6]. The squirrel cage induction motor is mostly used in most application [7].

2.2 Conventional AC Motor Drive

For long time, the Ac motor has been controlled by conventional methods. One of the ancient methods used to control the Ac motor is the V/F or scalar control.

2.2.1 Scalar control (V/F)

In the scalar control, the speed of AC motor is driven by the controlled value of stator voltages and frequency in a method which the air gap flux is usually kept at the required amount at the steady-state. This control method is named the scalar control due to its concern on the steady state conditions. It might be illustrated the way this control method operates by considering the basic equivalent model motor at steady state operations, the stator resistor (Rs) is expected to be zero and the stator leakage inductor (Lls) is incorporated into the rotor leakage inductor (Llr) and the magnetic inductor (Lm), which represents the value of air gap flux, is placed in front of the overall leakage inductor (Ll = Lls + Llr). Based on this the magnetic current that produces the air gap flux might roughly the stator voltage to frequency ratio. Thus, the phasor equivalent circuit can be analyzed as follow [9]:

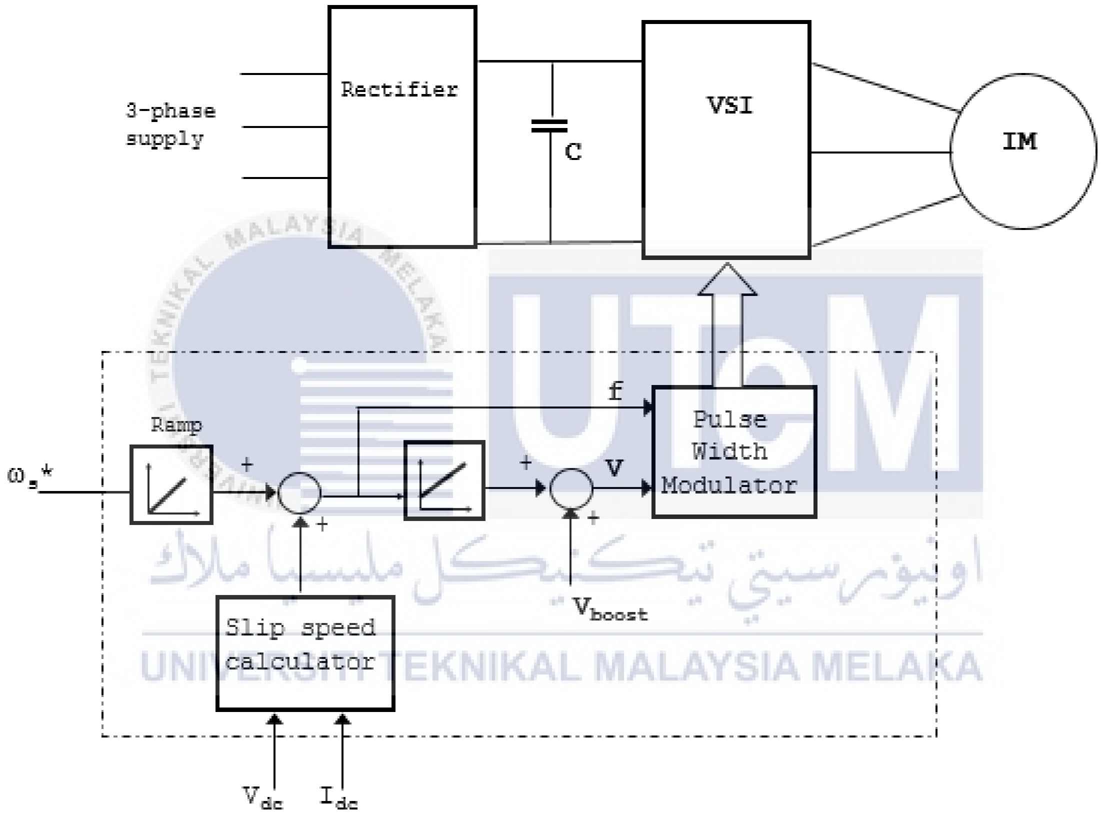


Figure 2.1: Constant V/f – open-loop with slip compensation and voltage boost

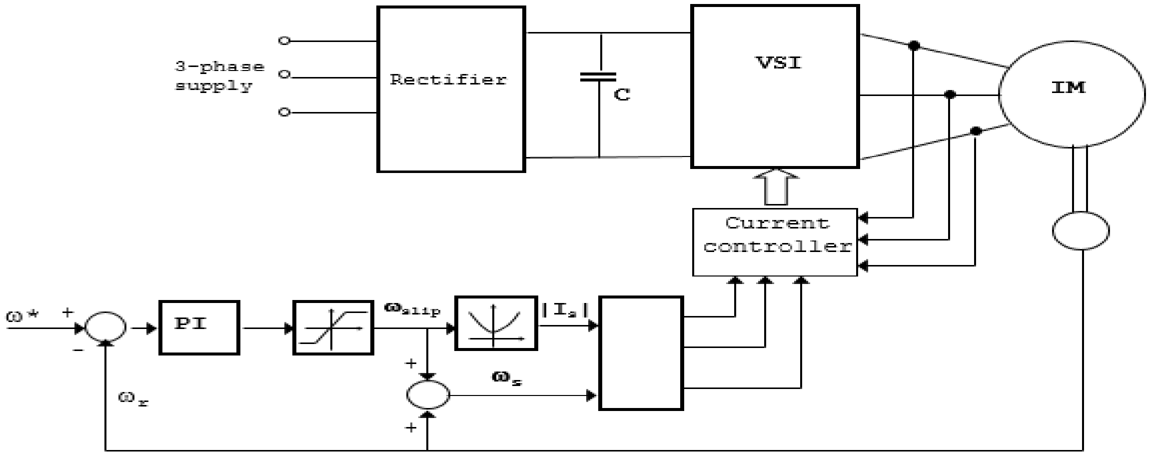


Figure 2.2: V/F scalar control

$$I_m = \frac{V_s}{j\omega L_m} \qquad 2.1$$

If the motor is working in the linear magnetized area, the Lm is fixed. So, equation 2.1 could be presented as follow:

$$I_m = \frac{\Lambda \mathrm{M}}{Lm}\frac{V_s}{2\pi f L_m} \qquad 2.2$$

V and Λ are their values of stator voltage and stator flux, and Ṽ is the phasor value.

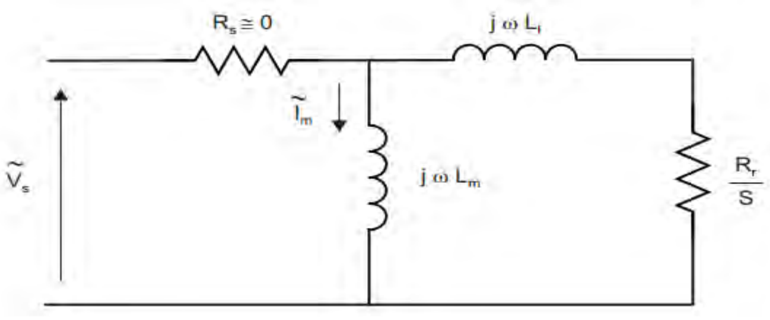


Figure 2.3 Equivalent circuit of motor in steady state condition

Based on equation 2.2, it shows that if the V/f kept fixed for any changes in frequency, so flux kept fixed and the torque doesn’t rely on the frequency of the supply. For maintain ΛM fixed, the ratio of frequency / voltage would as well be fixed at the various speed. As the speed rises, the voltages should, hence, be increasing in proportional way so that the voltage/ frequency ratio of Vs/f maintain fixed. But, the frequency is not the actual speed due to the slip as a part of the load. With no- load, a small value of the slip is obtained, and the speed is almost the synchronizing speed. Therefore, the basic open-loop scalar control system will not effectively drive the speed with the existence of load torque. The slip compensating could be easily attached in the drive. The closed-loop scalar control (V/f) with a speed encoder can be presented in Figure 2.3.

In reality, the v/f ratio is normally in accordance to the rated magnitudes of such parameters. The basic V/Hz profile can be presented in Figure 2.4. Simply, three speed ranges in the v/f profile is presented

Range 1: From 0- cutoff frequency (Hz), a voltage is needed, so any decrease in the voltage along the stator resistor will not be ignored and should have compensation by the increment of voltage. Hence, the V/Hz profile is non-linear.

Range 2: from cutoff frequency (Hz), -F rated (Hz); it acts similarly to the fixed V/Hz relation. The curve normally shows the air gap flux magnitude as presented in equation 2.2.

Range3: At high rated frequency (Hz), the fixed Vs/f relationship cannot be followed due to the voltages will have limitation up to the rated amount, to prevent insulating breaking down at stator windings. Hence, the produced air gap flux will be minimized, and then consequently make the developed torque decrease. This range is normally referred as “field-weakening range”. To prevent such this from occurrence, fixed V/Hz principle is not followed at such range [10].

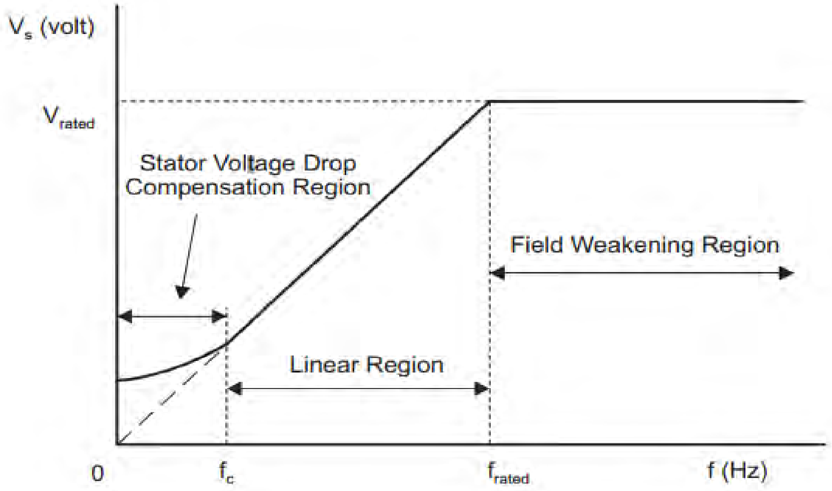


Figure 2.4 Voltage Vs frequency under V/F control

Because of the value of the flux is continuously kept constant, the developed torque relies on the slip speed. It is presented in Figure 2.4. By controlling the slip, the torque and speed of the motor can be driven by the fixed V/Hz control method. Open and closed-loop drive of the speed of an AC motor can be utilized in accordance to the fixed V/Hz method. Open-loop speed drive is utilized if efficiency in speed performance is not a required like HVAC (Heating, Ventilation and air conditions), fan or blower implementations. In such situation, the frequency of the supply is identified in accordance to the required speed and the expectation which assumes the motor would approximately acts with its synchronizing speed. This method however only provides satisfactory performance during steady-state condition but not in transient. The scalar control method does not achieve a good accuracy in speed and torque responses because the stator flux and torque are not directly controlled. Thus, this method only suitable for applications which does not required high accuracy and crucial transient behaviors [11] [12].

2.2.2 Vector control of AC Drives

The demands of high performance motor drive which have good transient and steady state performances introduce the vector control methods. FOC and DTC method is the most well-known vector control methods. It is become the standard control method for high performance motor drive system. This vector control methods directly control the instantaneous position of the voltage, current and flux vectors. The invention of the FOC and DTC solved the problem of scalar control method. This method independently controls the flux and torque component in a similar fashion of separately excited Direct Current (DC) machine [13].

In the past decades, the area of control electrical drives has experienced fast extension because of primarily, the features of power electronics. This rapid technology enhancement had allowed the construction of actual efficient AC drive system with ever less power losses porotype and ever much precise drive configuration. The electric drive controls tend to be much precise in the concept that not just are the DC current and voltage driven but also the 3- Ø currents and voltages are controlled by as referred vector control.

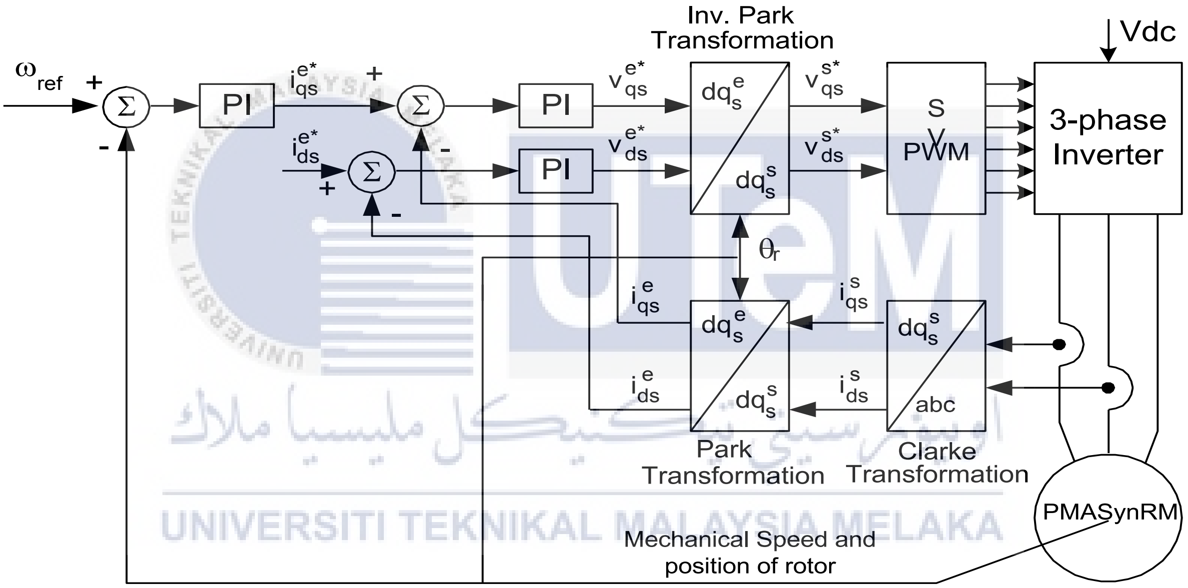


Figure 2.5: Vector control of induction motor

The Field Orientated Control (FOC) is one of the most well-known type of vector control of AC drive. It worked in accordance to three essential points: the motor current and voltage space vectors, the transforming of a 3-phase speeds and times reliable model to a 2-phase. The FOC is in accordance to projections by transforming a 3-phase quantities system into 2-phase quantities system (d-q system). . These transformations produce a structure same like that of a DC motor control. FOC requires two parameters as input references: the torque parameter (q quantity) and the flux parameter (d- quantity) [14].

FOC is closed loop control system of ac motor, which compares the actual speed of the motor with standard reference speed utilizing a speed controller to produce the reference torque quantity (q-component). Then, it transforms the q-component and referenced d-component (d-q) into the three-phase system. The result of the phase transformation is then applied to a current controller (hysteresis controller) to generate the switching pulses for voltage source inverter (VSI) which will control the AC motor. The block diagram showed in Figure 2.6 present the basic construction of Field Oriented Control (FOC) including its main components.

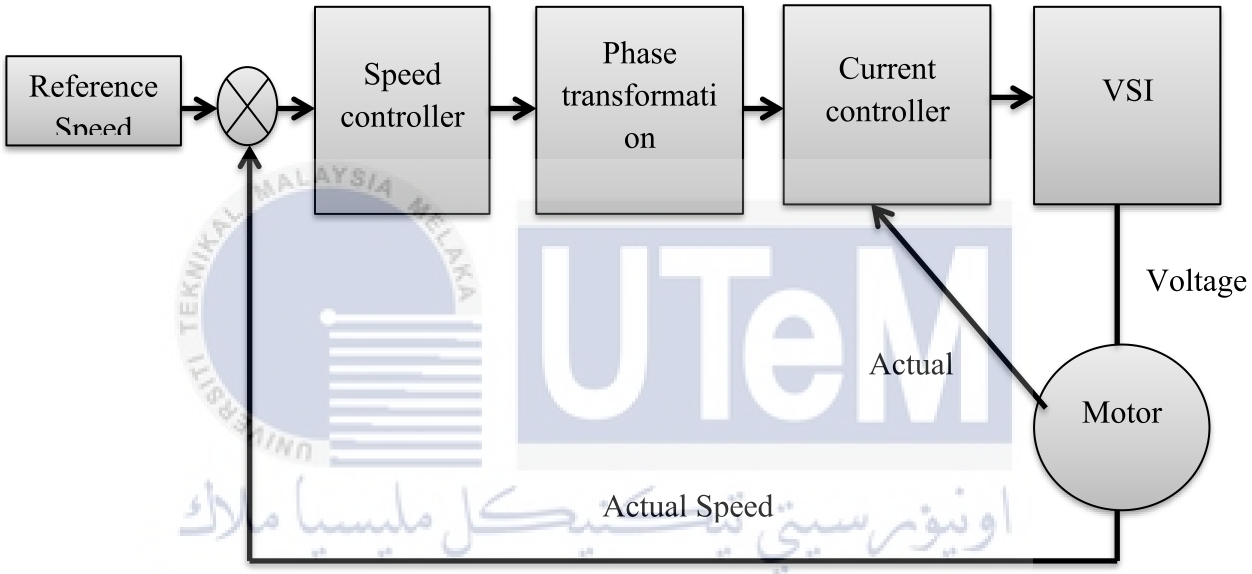


Figure 2.6 Basic block diagram of FOC

2.2.2.1 Speed control

The speed control is the one of the main components of Field Oriented Control of induction motor drive. The working principle of speed control in the motor drive is illustrated such that, the actual speed of the motor is measured and compared with standard reference speed. The resultant error of the speed comparison is fed into the speed control system which produce the reference current (iq) . Different method can be used to construct the speed control system such as the conventional PI controller, or intelligent control method such as Fuzzy logic controller [15].

Conventional PI speed Controller

Since the development of vector control method as a reliable alternative for the traditional scalar control, conventional PI controller has aged for long as speed controller in the vector control. Various studies as well as industries have developed AC motor drive system utilizing PI controller as the speed controller. The simplicity and easy construction of the PI controller made it as dominant speed controller for considerable period of time.

The construction of PI controller is quite simple and straightforward; it combines the proportional and integral part to result in analytic expression which can drive a control process. The working concept of PI is to control a resultant error utilizing the derivative and integral part to produce a controlled variable. Figure 2.7 shows the block diagram of PI controller visualizing its proportional and integral components [16].

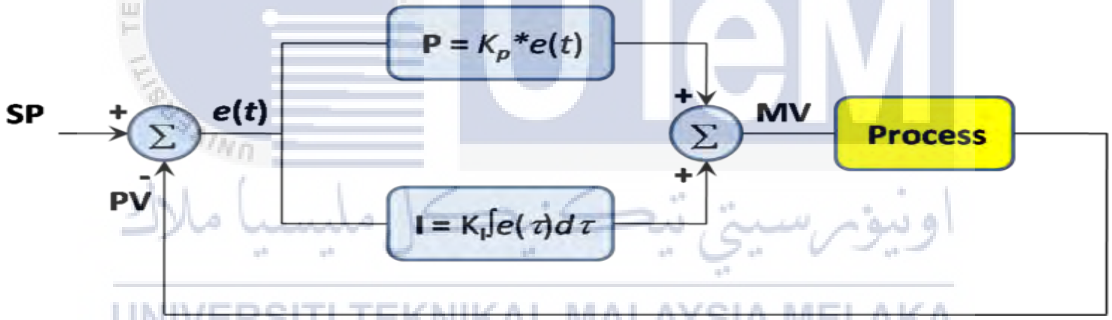


Figure 2.7 PI controller structure

In AC motor drive, PI controller is utilized as speed controller. The resultant error of speed comparison is fed into the PI controller to produce the controlled variable (iq). Proportional and integral gain of the PI controller is tuned to produce the best performance of the drive system. The features of the PI are that it can be changed practically by varying the gain amounts and noticing the alterations in system performance. It is expected that the PI controller is performing frequently sufficient; hence, the drive can be effectively driven. The resultant error is obtained by comparing the standard speed of motor to the practical obtained speed of the motor. The value of the error shows the direction of changes to be implemented by the control signal, leaving a smaller remained steady state error. The Integral (I) part of the PI is utilized to overcome smaller steady state disturbance. The I part compute a constant running overall of the error. Hence, a smaller steady state error combines to a big mount of error with time. Such combined error values are proceeded by a gain I and obtained the I output part of the PI. The PI speed controller used in the AC motor drive is presented in Figure 2.8[16].

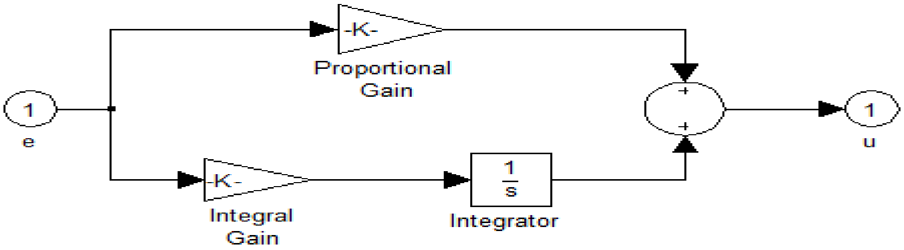


Figure 2.8 PI speed controller used in AC motor drive

Fuzzy Logic Speed Controller

Fuzzy Logic Controller has been proposed as an alternative speed controller of the conventional PI speed controller. Due to the non-linearity and less sensitivity of the Fuzzy controller it becomes a better alternative for the speed control of the AC drive. The fuzzy controller acts as human behavior, which can be updated in response to system changes accordingly. In AC motor drive, the Fuzzy Logic Controller with two input and one outputs can be implemented to control the speed of the motor. The resultant error of the speed comparison is fed into the fuzzy speed controller which has a specific range for the error and changes of error. Hence any changes of the motor parameter will results in increase in the errors signal, however, the fuzzy controller has specific range for the error, so that any change will be compensated accordingly. The basic block diagram of the Fuzzy Logic Speed controller implemented in the AC motor drive can be presented in Figure 2.9[17].

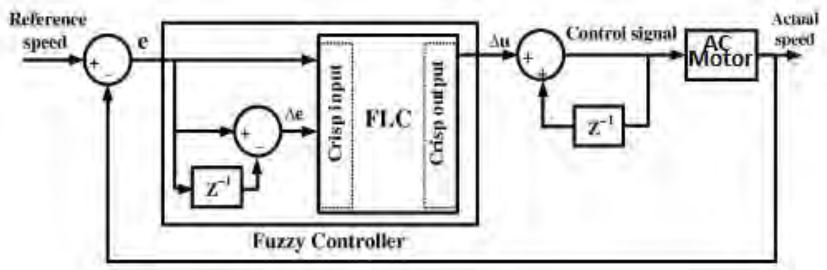


Figure 2.9 Fuzzy Logic speed controller in AC drive

Neural Network Speed Controller

Neural network essential component is a feedforward NN with 2 inputs and one output. NN is splitted into 3 regions, called the input region with 2 neurons, the covered region with ten neurons, and the output region with 1 neuron. The activating functioning of the input neurons is linearly, whereas the output region and covered region is sigmoidal. The inputs are the error, and change of error, they are functioned by the scaling gains and have a limit prion entrance to NN. A scaling gain also set as the product of the output and must be tuned to obtain the desired speed performance. The block diagram of the Neural Network Speed Controller in AC motor drive is presented in Figure 2.10[18].

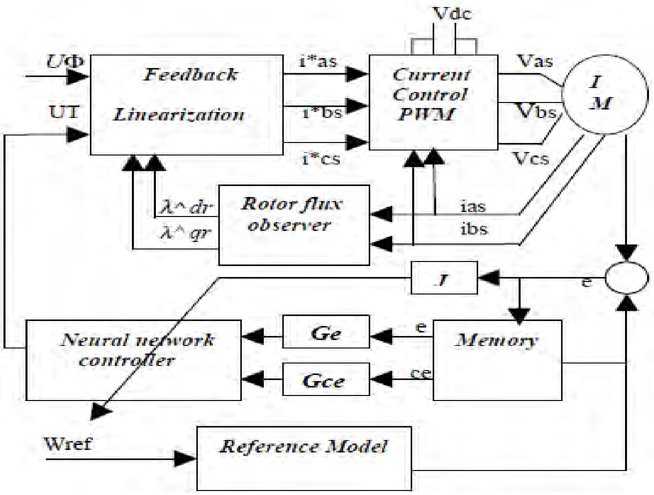


Figure 2.10 Neural network speed controller for AC motor drive [15]

2.3 Application of Induction motor drives

Induction motor is one of the most widely used types of Ac motor drive due to its robustness, efficiency and less maintenance. The utilization of induction motor can be ranged from a simple house appliance such as fan to large industrial equipment. Electric Vehicle (EV) is one the most sophisticated application that utilized AC induction motor.

2.3.1 Electric Vehicle (EV)

In an electric vehicle, selecting the proper motor is very crucial as it primarily identifies its effectiveness, cost and workability. A certain motor might perform in different way when subjected to various driving situations. The power train of EVs contains of electrical motor (EM). The first stage of designing of the power train is to opt the motor to be utilized in the EV driving train. Selecting the motors are identified by utilizing the driving cycle the EV works on and the vehicle mechanical model for traction force computation [19].

The induction motors are ideally suitable for vehicle application because of its torque speed performance. Induction motors have the capabilities to deliver highly starting torque. The IM in its typical condition offer fixed torque higher than its base speed. At such speed, the IM get to reach its rating capability. The operations after the base speed higher than the largest speed is taken into account as fixed power condition.

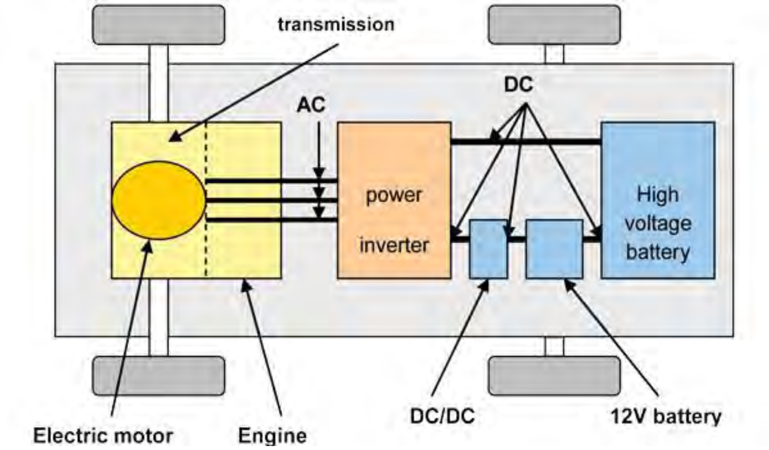


Figure 2.11 Electric Vehicle (EV)

2.4 Review of Previous Studies

Previous studies have contributed largely to offer various driver system of the induction motor. A study as in [20], has introduced a design approach of PI controller of induction motor with respect to parameters changes. This study introduces a new design approach of speed controller for an induction motor with the changes of design parameters. The aim of the study was to create a credible and settled PI gain opting steps versus the mechanic and the electric parameter changes of an induction motor. The proposed design of PI controller in this study has been verified by simulation and experimental approach.

Another study as in [21], has proposed a smart speed control design in accordance to fuzzy logic for a voltage source inverter-connected to Indirect Vector Control of induction motor. The fuzzy logic controller comes as replacement of PI controller. The performance of the introduced fuzzy logic controller has been tested with software simulation utilizing MATLAB-SIMULINK environment for various operation states like immediate variation in reference speed and output torque. The obtained results illustrate that the performance of the designed controller is superior in comparison to the conventional PI controller.

The principle of fuzzy logic is to drive the IM system based on the speed error produced in which the fuzzy membership function is designed to effectively reduce the error as much as possible in order to produce optimum performance [22] [23][24]. The fuzzy parameters or scaling factors are fixed to a value that can produce optimum performance, however with fixed parameters, the performance might be degraded when load applied, or disturbance occurred. In order to overcome such issues associated with fuzzy controller, Self-Tuning mechanism have been introduced in order to tune the fuzzy parameters online in case of any effects occurred [25].

Fuzzy logic controller of induction motor has been discussed by many researchers, (Masiala, 2008) has proposed a fuzzy self-tuning mechanism of field-oriented control of induction motor drive. The outstanding outcomes of this study is that, the fuzzy parameters can be tuned online accordingly based on the comparison of actual speed and reference model. The study was validated by simulation and experimental setup and shows the abilities of the proposed mechanism to adjust the fuzzy gains online [26].

A proposed method to simplify the fuzzy rules has been done in [27], the study has present the approach of simplifying 25 rules to 7 rules and implement it in IM drive system. The significance of rule reduction has improved the performance of the IM drive in terms of overshoot, rise time, settling time as well as reduction of the system overall computational time.

CHAPTER 3

3. METHODOLOGY

3.1 Introduction

This chapter will present the producers and steps undertake to accomplish the project. The first step is to conduct a literature review about the induction motor drive modelling, speed control hysteresis control and fuzzy logic control. The second step is to implement the concept obtained in Matlab/Simulink. The fuzzy rules designed and implemented to the speed controller of induction motor.

3.2 Induction Motor Model

A dynamic model of the machine subjected to a control must be known in order to understand and design the vector-controlled drives. Such a model can be obtained by means of either the two-axis theory or spiral vector theory of electrical machines. Three phase squirrel cage induction motor in rotatory referencing frame can be showed as in Figure 3.1. In accordance to the circuit of induction motor represented in rotary reference frame, the voltage quantities can be expressed as follow:

$$\psi_{dr} = L_{lr} i_{dr} + L_m (i_{ds} + i_{dr}) \qquad (1)$$

$$V_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_e \psi_{ds} \qquad (2)$$

$$V_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} + \omega_e \psi_{ds} \qquad (3)$$

$$V_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_e - \omega_r)\psi_{dr} \quad (4)$$

$$V_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} + (\omega_e - \omega_r)\psi_{qr} \quad (5)$$

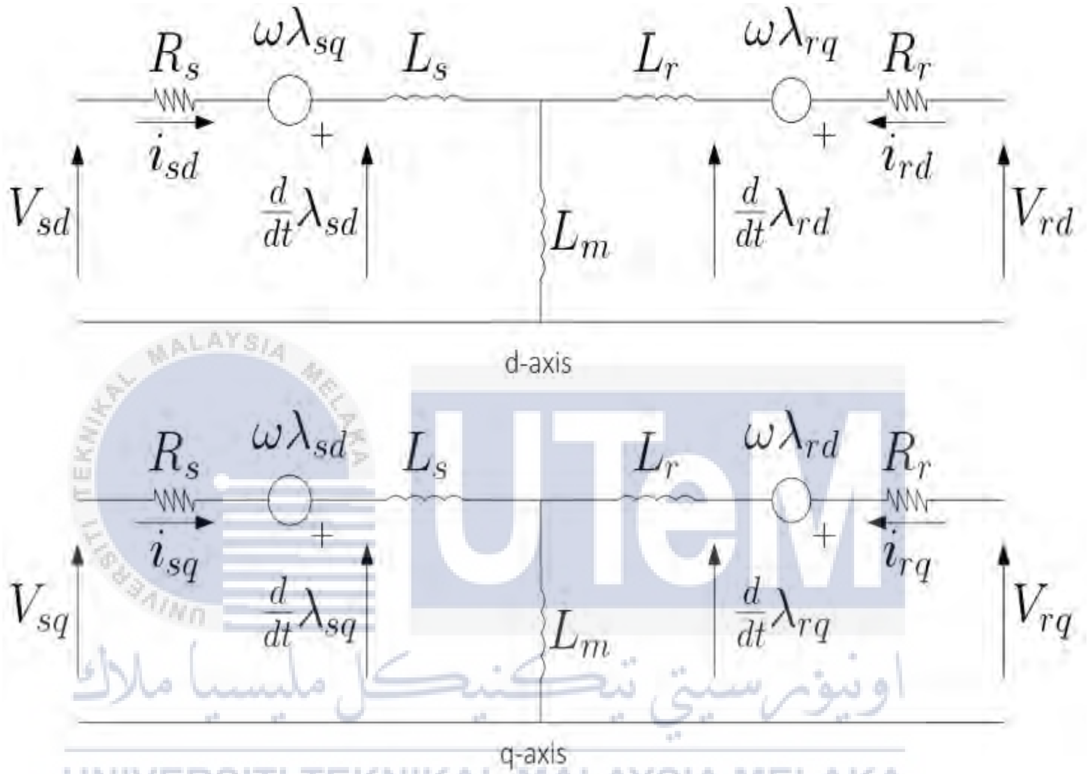


Figure 3.1 Induction motor equivalent circuit, q-axis frame, d-axis frame

And V_{qr}, V_{dr}=0 and the flux equation as follow:

$$\psi_{qs} = L_{ls} i_{qs} + L_m (i_{qs} + i_{qr}) \quad (6)$$

$$\psi_{qr} = L_{lr} i_r + L_m (i_{qs} + i_{qr}) \quad (7)$$

$$\psi_{ds} = L_{ls} i_{ds} + L_m (i_{ds} + i_{dr}) \quad (8)$$

The electromagnetic torque can be expressed as follow:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(\psi_{dr} i_{qs} - \psi_{qr} i_{ds}) \qquad (9)$$

P represent the pole number of the motor. When the vector control is accomplished, the d frame of the rotor field can be zero. So that the torque is driven by q frame of stator current as expressed in equation 10:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(\psi_{dr} i_{qs}) \qquad (10)$$

3.3 Fuzzy Logic Controller

Fuzzy logic concept is identical to the human behavior and inferencing operation. Not like conventional control method, fuzzy logic is a range-to- ranges control methods. The output of a fuzzy is obtained from fuzzicating of the inputs and outputs utilizing the corresponding membership functions. A crisp input is converted to the various ranges of the corresponding membership functions in accordance to their values

Fuzzification, fuzzy inference and defuzzification are the three main process of the fuzzy logic controller.

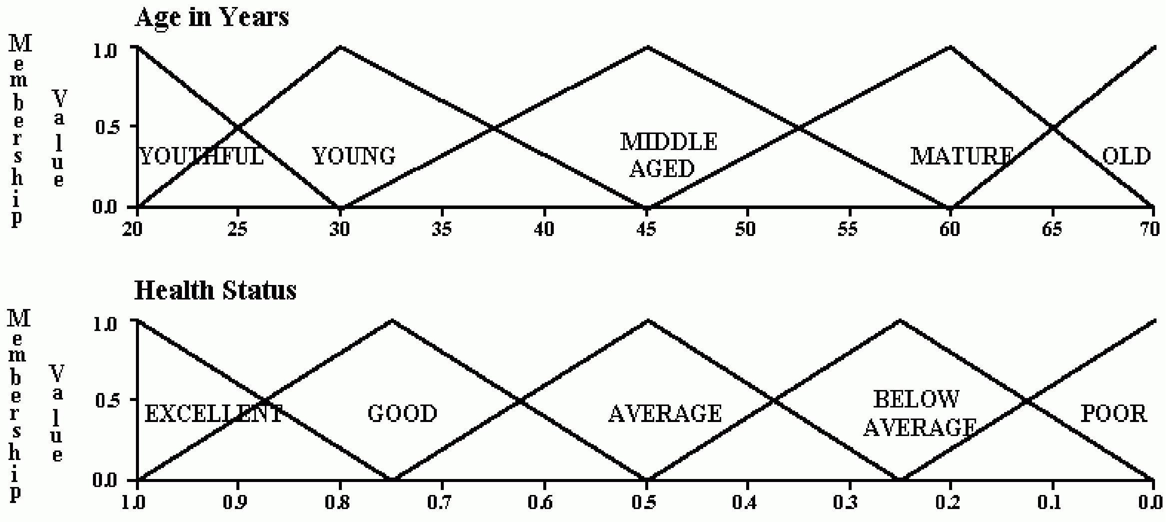


Figure 3.2 Membership function of the input and output

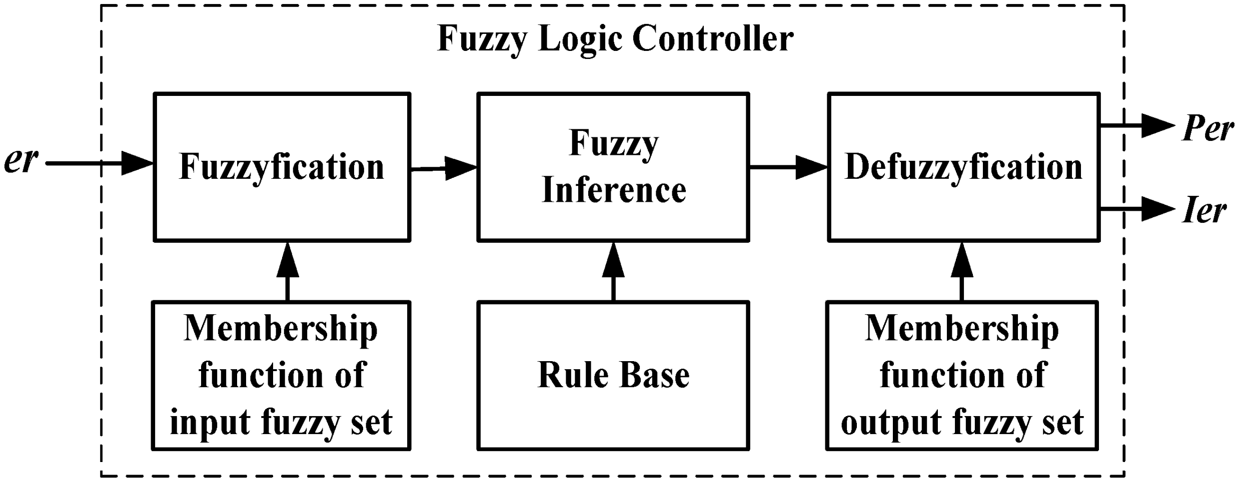


Figure 3.3 Fuzzy logic block diagram

3.4 Project Flow Chart

Figure 3.4 the proposed system flow in which the project implementation phases are organized in sequence. The project starts by gathering relative information and compare it with existing system, then the software simulation is done using Matlab/Simulink. The implementation of this project involves several steps comprising different techniques used to obtain the final system design and record its results. The process includes reviewing various research studies achieved in the project field in order to develop the proposed IM vector control system with fuzzy logic. The drive system has operated applying three standard fuzzy logic speed controller designs (9,25,49). For performance improvement ,25 rules size was selected to be subjected to further tuning and adjusting techniques. The 25 rules fuzzy logic controller three parameters (scaling factors, Membership functions, rules) have been subjected to tuning and reduction techniques in order to improve the performance of the IM drive .25 rules have been reduced to 7 rules and scaling factors have been tuned accordingly to obtain optimum results. In addition, the membership functions have been adjusted accordingly to obtain zero overshoot and faster settling time.

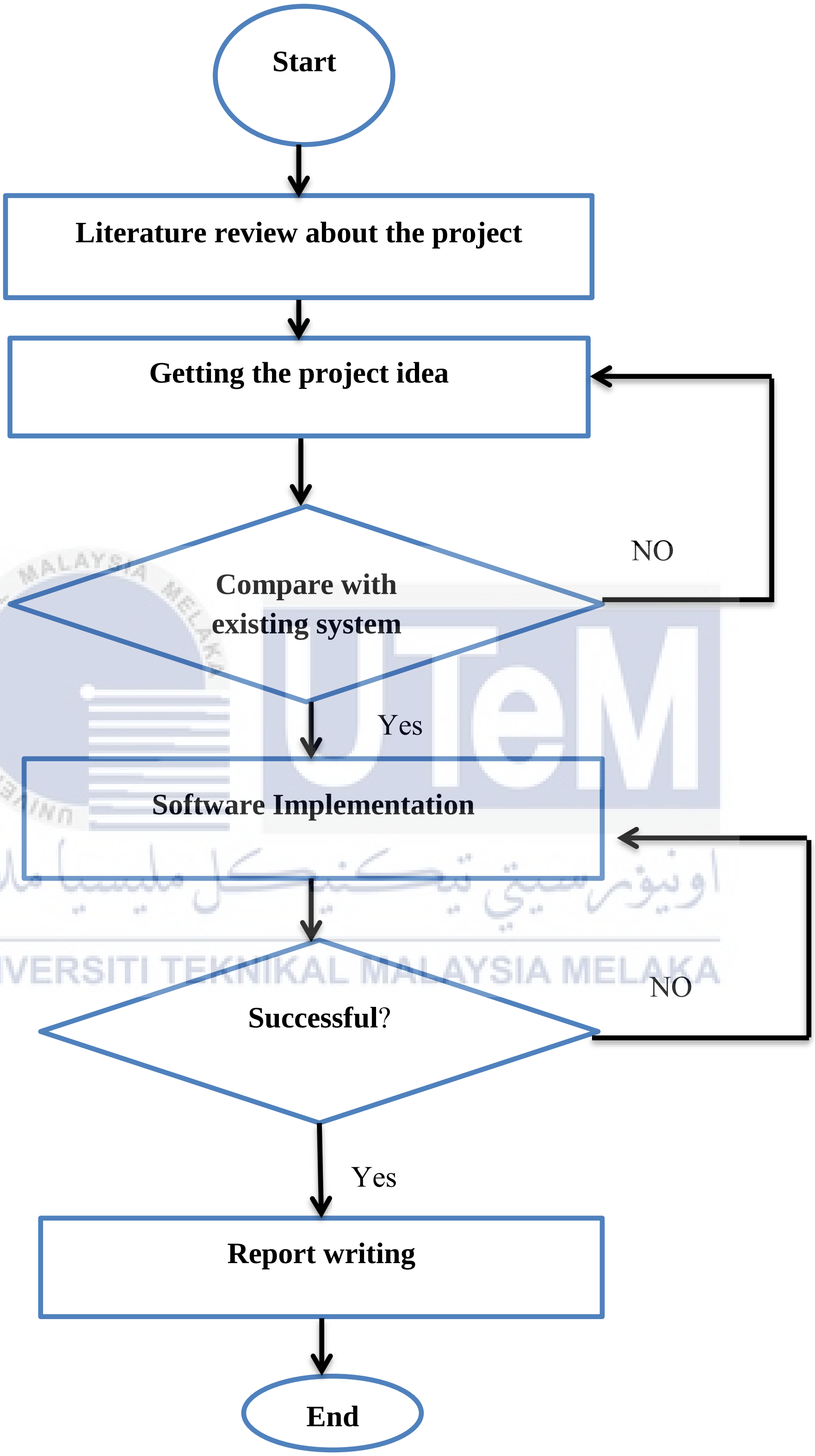


Figure 3.4 Project Flow chart

3.5 Field Oriented Control (FOC)

Field Oriented Control (FOC) of induction motor are most widely used in high performance application due to robustness and better performance that can be obtained. FOC which comprises of controlling the stator currents represented by a vector. This control is based on projections which transform a three-phase time and speed dependent system into a two axis (d and q axis) time invariant system. These projections lead to a control mechanism like that in DC motor drive. Voltage Source Inverter (VSI) is one of the essential components of the FOC system. Figure 3.5 shows the block diagram of FOC system which consists of speed controller, phase transformation, hysteresis controller, and VSI inverter and induction motor model. Fuzzy logic controller is utilized as speed controller.

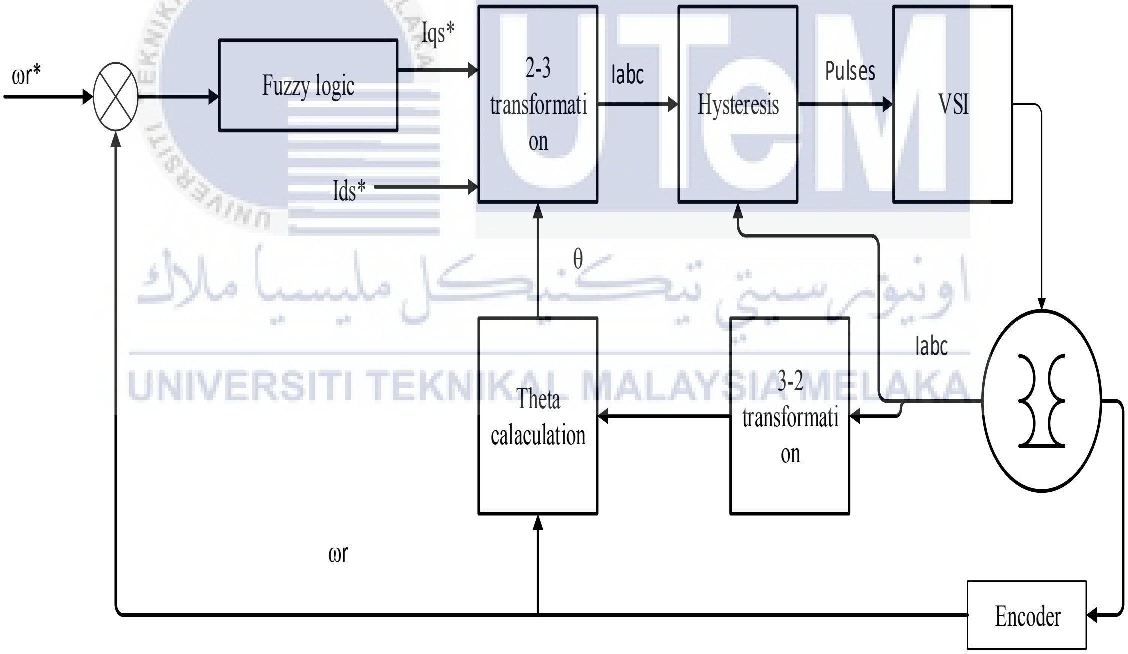


Figure 3.5 FOC of induction motor drive

3.6 Fuzzy Logic Speed Controller design

The speed control working principle is to compare the actual speed of the motor with reference speed and the produced error is fed into the controller to generate the reference based on the error. PI, fuzzy or Hybrid PI-fuzzy can be utilized as speed controller to compensate the error and produce the appropriate torque. Fuzzy controllers proved to have the superiority in terms of performance and flexibility to parameters variation so that various studies as well as industries prefer the fuzzy logic over other conventional controllers.

The block diagram of fuzzy logic controller which has two input and one output is presented in Figure 3.6. The fuzzy system consists of two stage fuzzifier and defuzzifier process.

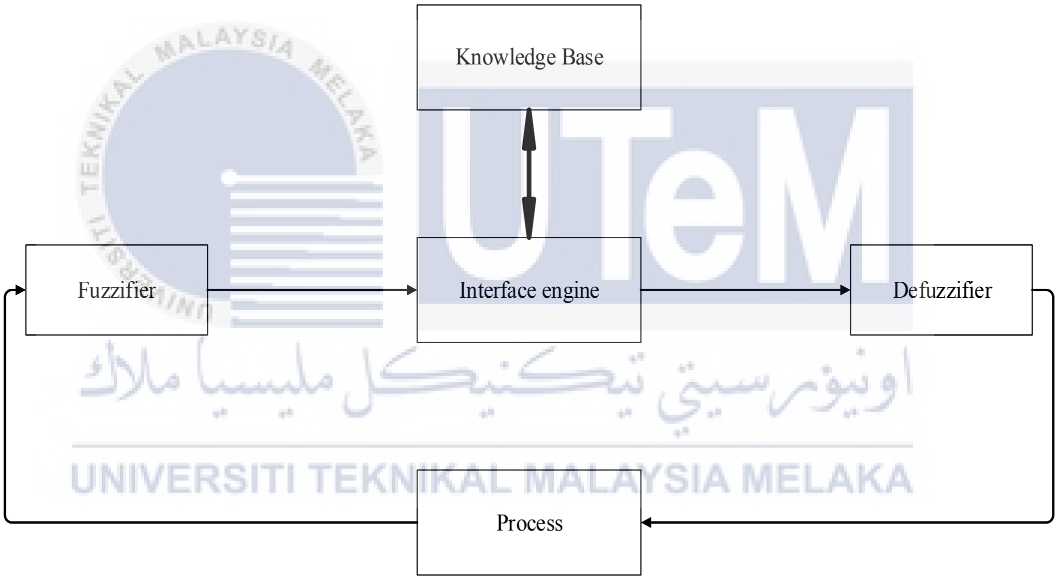


Figure 3.6 Fuzzy logic block diagram

The standard FLC for induction motor can be identified by two inputs fuzzy and one output, each input and output has a scaling factor. The block diagram of fuzzy logic controller for speed control of induction motor drive is presented in Figure 3.7.

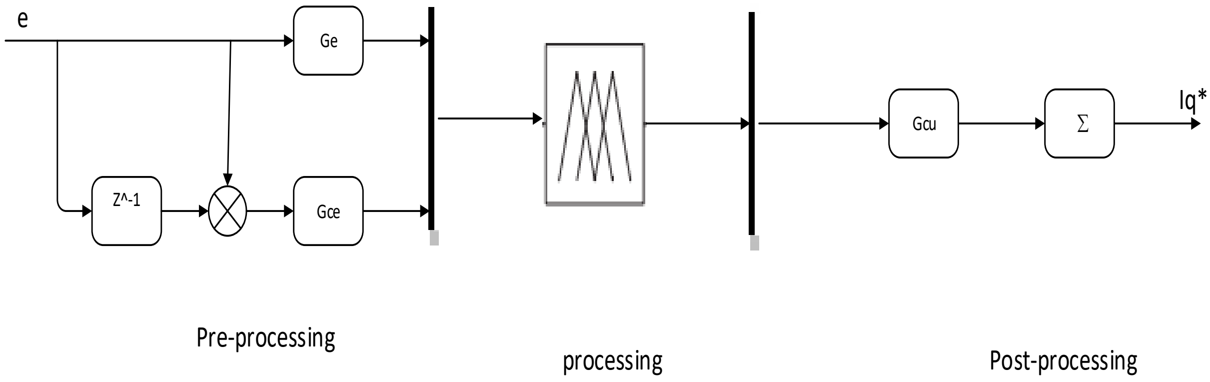


Figure 3.7 Standard FLC for IM drive

In the preprocessing part, two inputs variable are generated for the FLC, which are the speed error, e and its change of speed error Δe , they are defined as:

$$e(k) = G_e\left(\omega_r{}^*(k) - \omega_r(k)\right) = G_e(k)$$

$$\Delta e(k) = G_{ce}\frac{(e(k) - e(k-1)}{T_s}$$

From the above equation, ωr * and ωr stand for reference and actual speed respectively. Meanwhile, (k) and (k-1) represent the current and previous state of the error. Ts represents for the sampling time. The Ge and Gce denote the error and the change of error gain scaling factor. Where ωr * and ωr are speed reference and actual speed respectively. The maximum Ge gain is determined to cover the rated speed using the following equation.

$$G_e = \frac{1}{|\omega_{e\,max}|}$$

Where, $\omega_{e\,max}$ is the maximum error for the rated speed operation to ensure high enough gain applied to cover the rated speed operation. For the change of error Δe and output gain Gcu the membership function range opted to fit the rated speed operation. The membership function for error (e) and change of error Δe and output fuzzy are presented in Figure 3.8

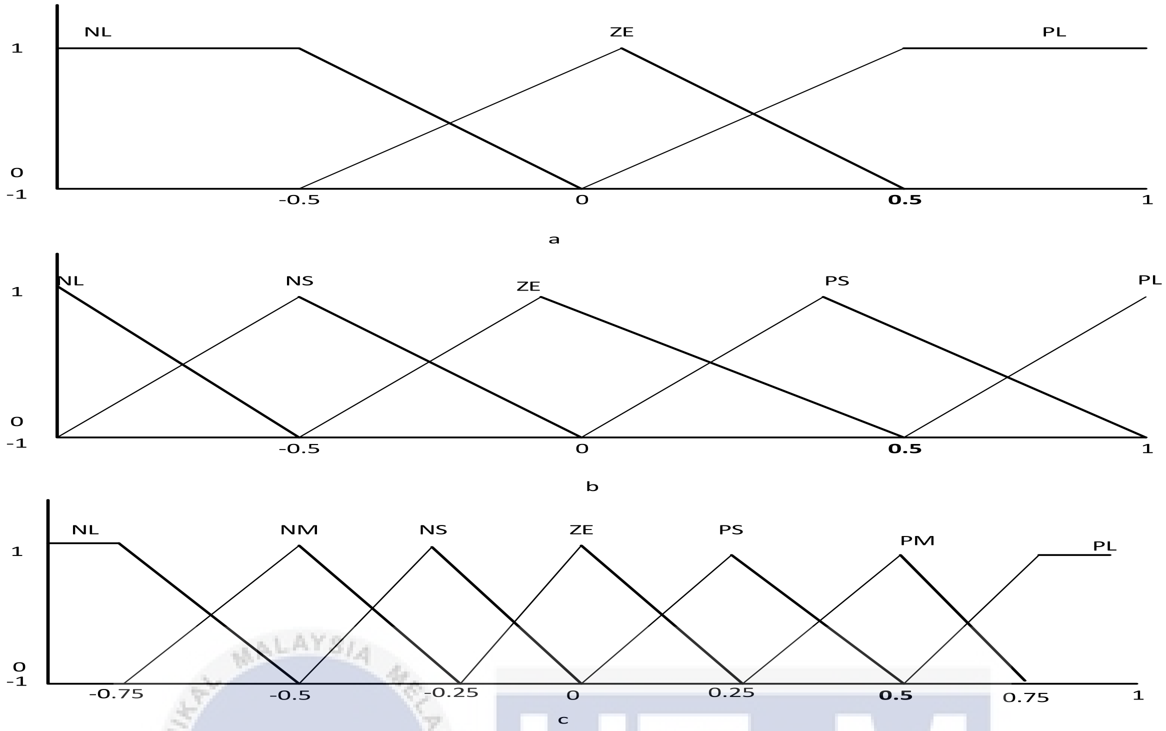


Figure 3.8 Ge, Gce and Gcu membership function design (a) 9 rules, (b) 25 rules and (c) 49 rules.

Three different fuzzy logic membership functions have been presented in which three different rule selections is utilized. The fuzzy rules utilized to obtain are presented in table 3.1, 3.2 and 3.3 for 9, 25 and 49 rules respectively. Increasing the number of rules contribute to enhance the performance of the motor.

Table 3.1: fuzzy rule (9)

e ∇e	NL	ZE	PL
NL	NL	NL	ZE
ZE	NL	ZE	PL
PL	ZE	PL	PL

Table 3.2: fuzzy rule (25)

e ∇e	NL	NS	ZE	PS	PL
NL	NL	NL	PS	NS	ZE
NS	NL	NS	NS	ZE	PS
ZE	NL	NS	NS	PS	PL
PS	NS	ZE	ZE	PS	PL
PL	ZE	PS	PS	PL	PL

Table 1: fuzzy rule (49)

e ∇e	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	NL	PL	PL	PL

Through defuzzification, the output current ΔIq^* is computed using the center of gravity (COG) algorithms. For post-processing part, the final crisp output for the torque current Iq* is obtained by the following equation:

$I^*_q(k) = I *_q (k-1) + Gcu(\Delta Iq^*(k))$

3.7 Fuzzy Logic Controller Tuning

Fuzzy Logic Controller consists of three tunable parameters which are scaling factors, membership function and fuzzy rules. In this project, these three parameters will be tuned utilized 25 rules of FLC.

3.7.1 Scaling factor

Fuzzy Logic Controller used in the IM drive system has two inputs and one outputs. Each input and output are adjusted via constant gain called scaling factor, error input scaling factor (Ge), change of error scaling factor (Gce) and output scaling factor (Gcu). The value of the Ge scaling factor is constant which determined via the motor maximum speed to be 0. 00334.While Gce and Gcu scaling factors are initially set to 1. Hence, the Gce and Gcu can be tuned accordingly to improve the performance of the IM drive system. Table 3.4

Table 3.4: Gce and Gcu scaling factors variations

Gce	Gcu	Gcu	Gce
1	1	1	1
0.9	1	0.9	1
0.8	1	0.8	1
0.7	1	0.7	1
0.6	1	0.6	1
0.5	1	0.5	1
0.4	1	0.4	1
0.3	1	0.3	1
0.2	1	0.2	1
0.1	1	0.1	1

3.7.2 Fuzzy Rules Reduction

The 25 rules table is presented in table 3.5 in which these rules matrix has been designed utilizing knowledge-based expert and phase plane approach. In according to these method, 25 rules have been developed for 5 x 5 triangular membership functions which are nominated from Negative Large (NL) to Positive Large (PL). based on the system experience and error, change of error range investigation, the 25 rules have been reduced from 25 to 7 rules. This is done by selecting only the dominant rules as can be seen in table 3.5 in which the selected rules are highlighted.

Table 3.5 : Selected 7rules of 25 rules

e ∇e	NL	NS	ZE	PS	PL
NL	NL	NL	PS	NS	ZE
NS	NL	NS	NS	ZE	PS
ZE	NL	NS	NS	PS	PL
PS	NS	ZE	ZE	PS	PL
PL	ZE	PS	PS	PL	PL

The new dominant 7 rules out 25 selected are:

1. NL and ZE, then NL
2. NS and ZE. then NS
3. ZE and NS then NS
4. ZE and ZE then NS
5. ZE and PS then ZE
6. PS and ZE then PS
7. PL and ZE then PL

3.7.3 Membership function

The triangular membership function utilized for common 25 rules FLC comprise five triangular membership functions to represent the input and output fuzzy parameters. The width and position of these membership functions are normally symmetrically designed. In order to improve the performance of the speed of IM motor, the width and peak position of the MFs can be changed. The speed error MFs are adjusted to enhance the drive performance particularly in the proximity of the origin point. adjusting the width and changing the peak values position of the MFs to the ZE position will make the speed controller to be highly sensitive to smaller variation in speed error and obtain an effective control mechanism. Apart from that, changing the peak values and position of the MFs toward the NL will produce speed controller highly sensitive to small error negative variation. The proposed tuned 5 x 5 MFs are presented in Figure 3.9 and 3.10 for MFs tuned to ZE and MFs tuned to NL respectively.

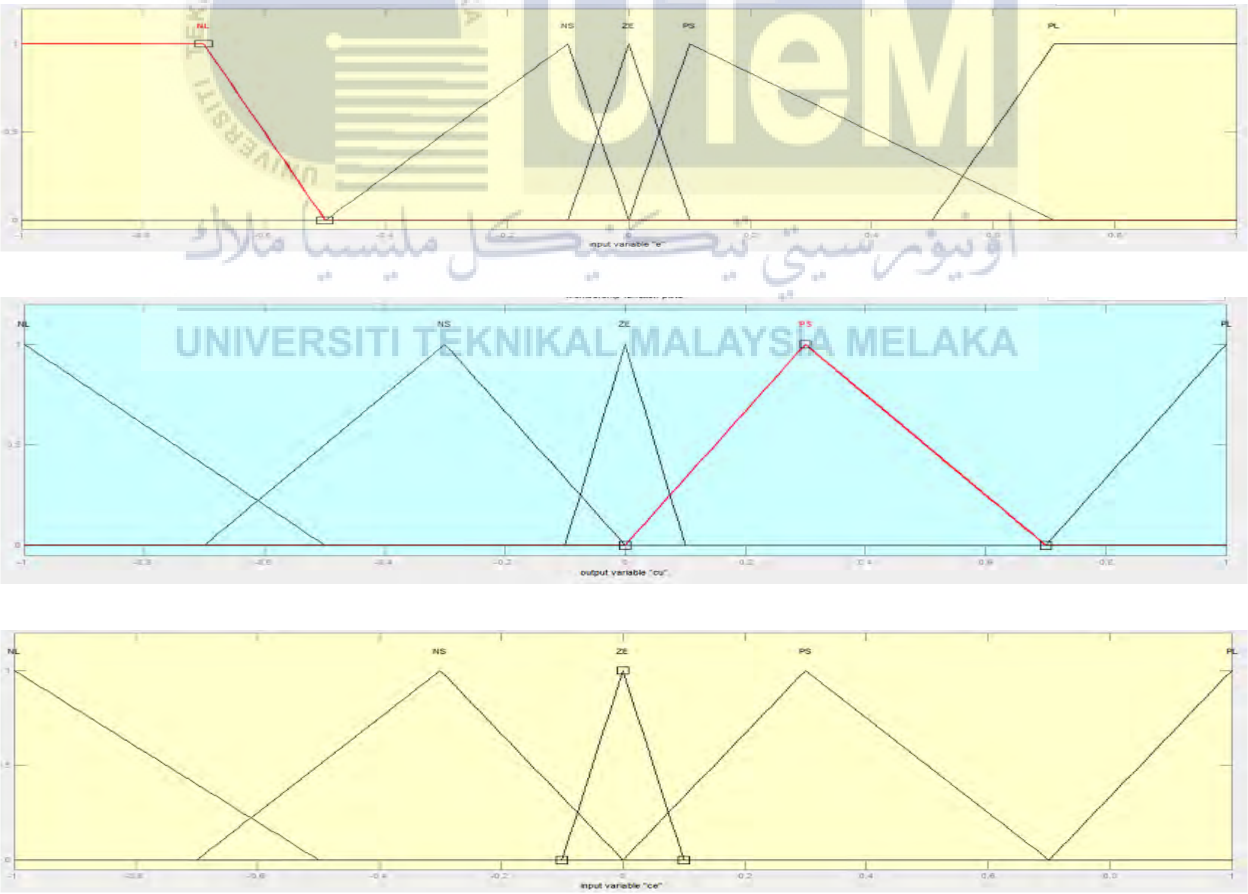


Figure 3.9:Tuned MFs toward ZE for error, change of error and output fuzzy

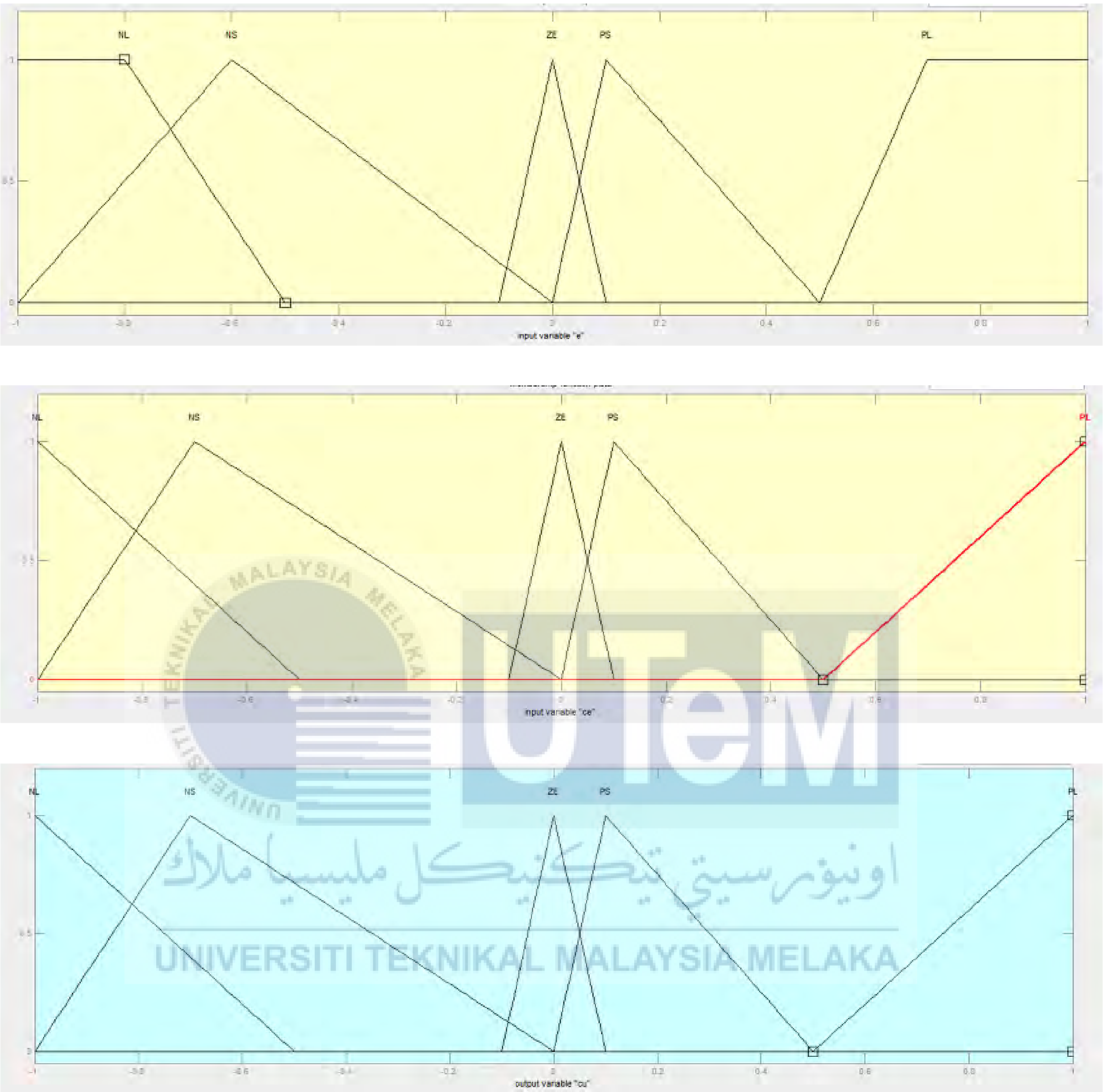


Figure 3.10: Tuned MFs toward NL for error, change of error and output fuzzy

3.8 Simulink Model of Induction Motor Drive

MATLAB/SIMULINK environment is utilized to design and simulate the induction motor drive system. Field Oriented Control (FOC) is constructed with three phase induction motor. The conventional Fuzzy Logic Controller (FLC) has been applied as speed control with three different rules selections.

Table 3.6: simulation parameter

Vs(rated)	380v	Fs(rated)	50Hz
P(poles)	4	ω (reference speed)	1400rpm
Rs (stator resistance)	3.45Ω	Rr (rotor resistance)	3.6141Ω
Ls (stator inductance)	0.3252H	Lr (rotor inductance)	0.3252H
Lm(magnetic inductance)	0.3117H	J	$0.02kgm^2$
Bandwidth	0.2	Simulation with load	10
Sampling time	$50x10^{-6}$	Frequency	50
Vdc	537		

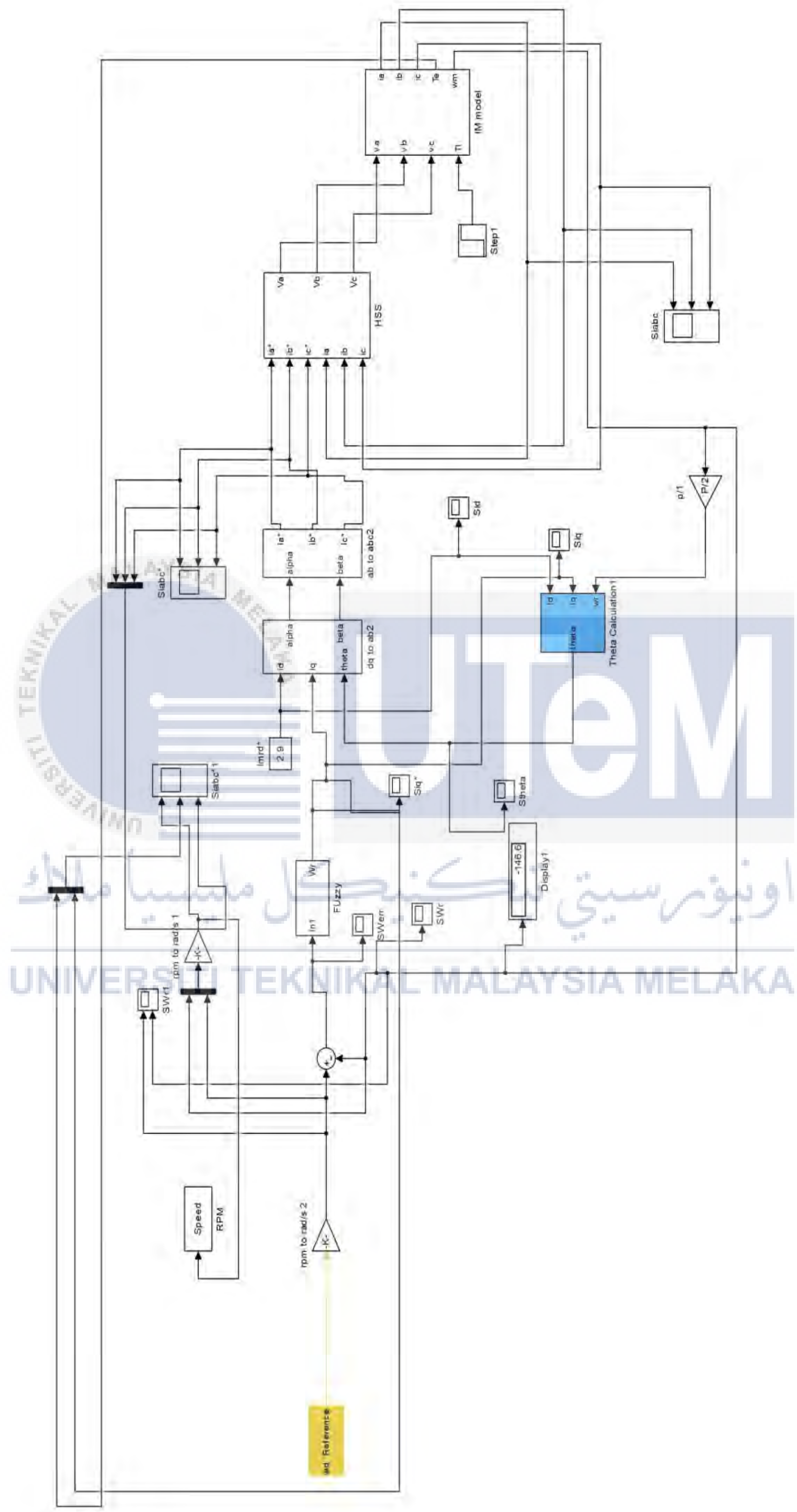


Figure 3.11 Simulink model of the IM drive system

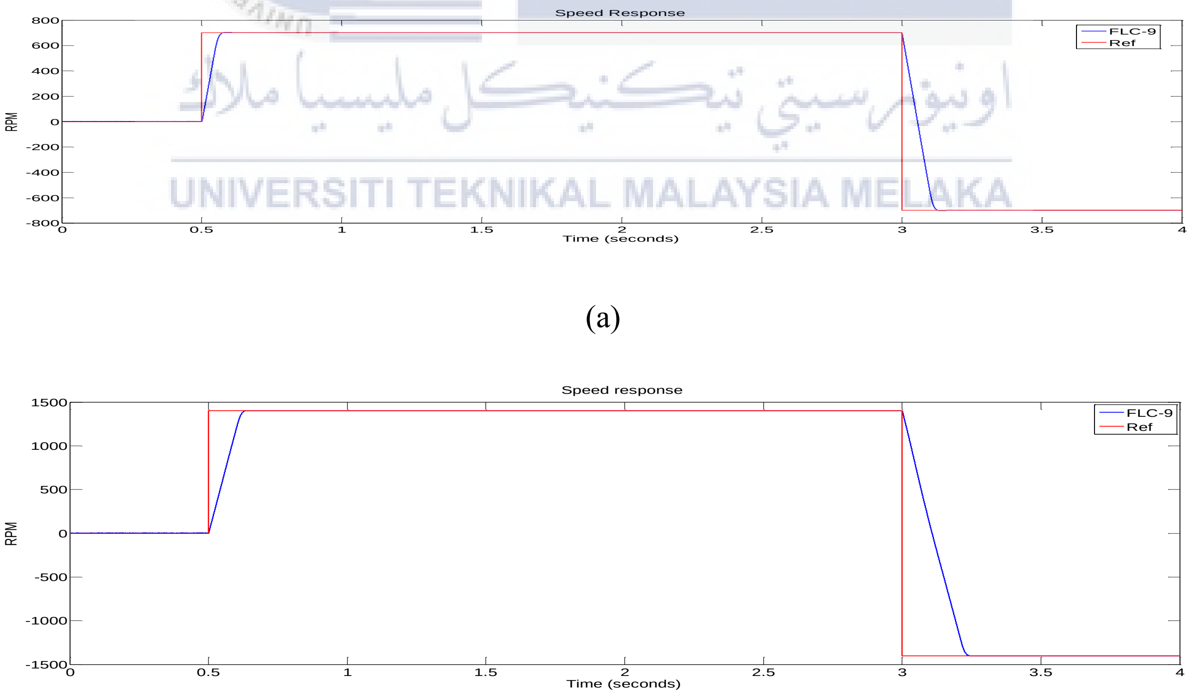
CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Simulation Results

4.1.1 No-load operations

The results of the FLC are obtained at different speeds as well as with different rules selections without load. The speed response at two different speed operations is considered the torque and current waveforms. The speed response at 700 and 1400 rpm with 9 rules FLC are plotted in Figure 4.1a, b.



(a)

(b)

Figure 4.1 Speed response with 9 rules at (a) 700 rpm (b) 1400 rpm

The torque response of the induction motor drive is presented in Figure 4.2, also the three-phase current are plotted in Figure 4.3.

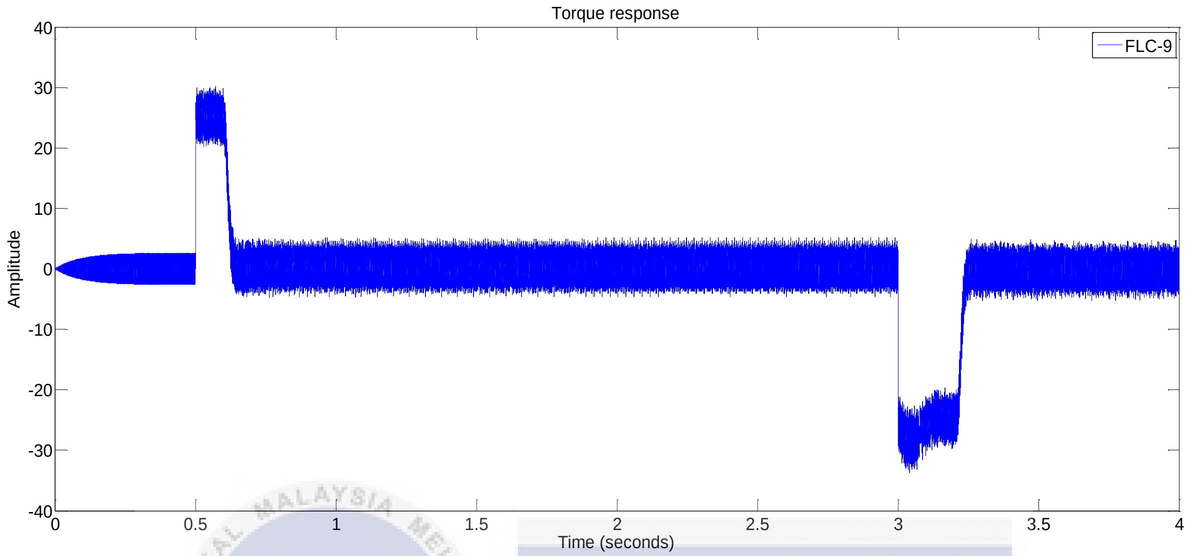


Figure 4.2 Torque response of 9 rules FLC of IM drive

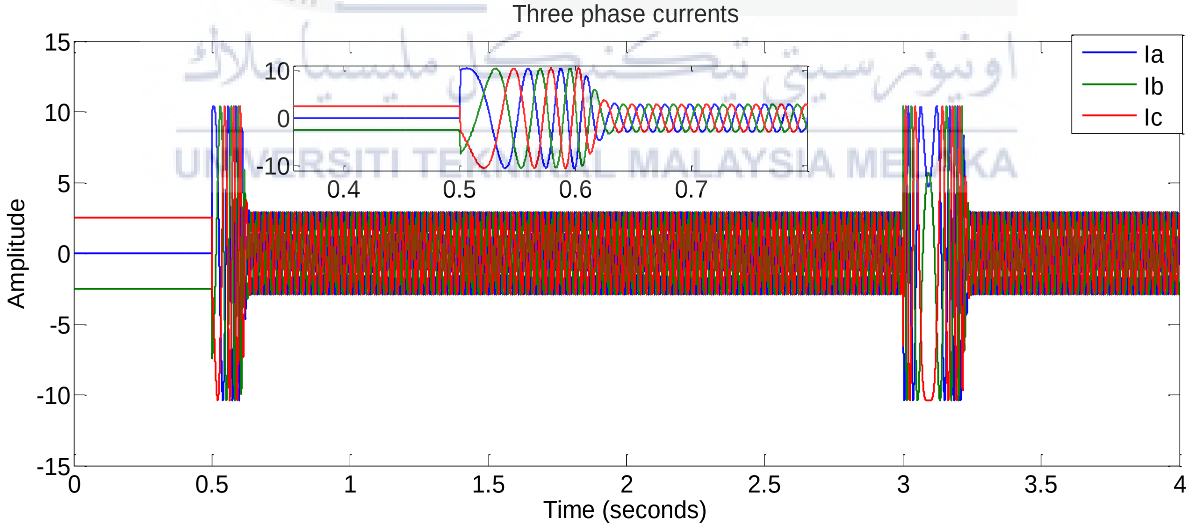
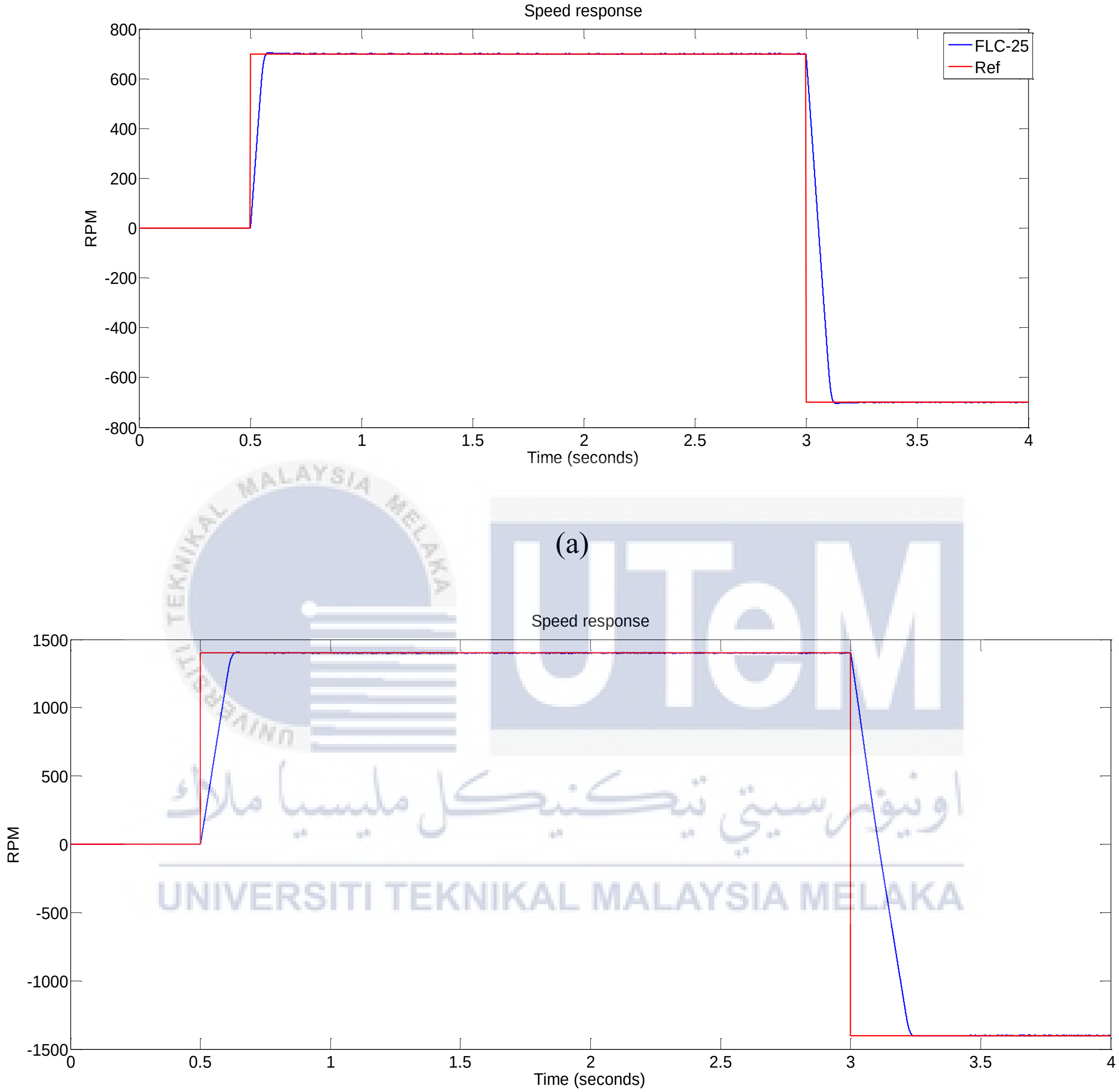


Figure 4.3 Current response of 9 rules FLC of IM drive

Moreover, the speed response of the induction motor drive with 25 rules FLC at 700 and 1400 rpm are presented in Figure 4.4 a, b.



(a)

(b)

Figure 4.4 Speed response with 25 rules at (a) 700 rpm (b) 1400 rpm

The torque response of the induction motor drive is presented in Figure 4.5; also the three phases current are plotted in Figure 4.6.

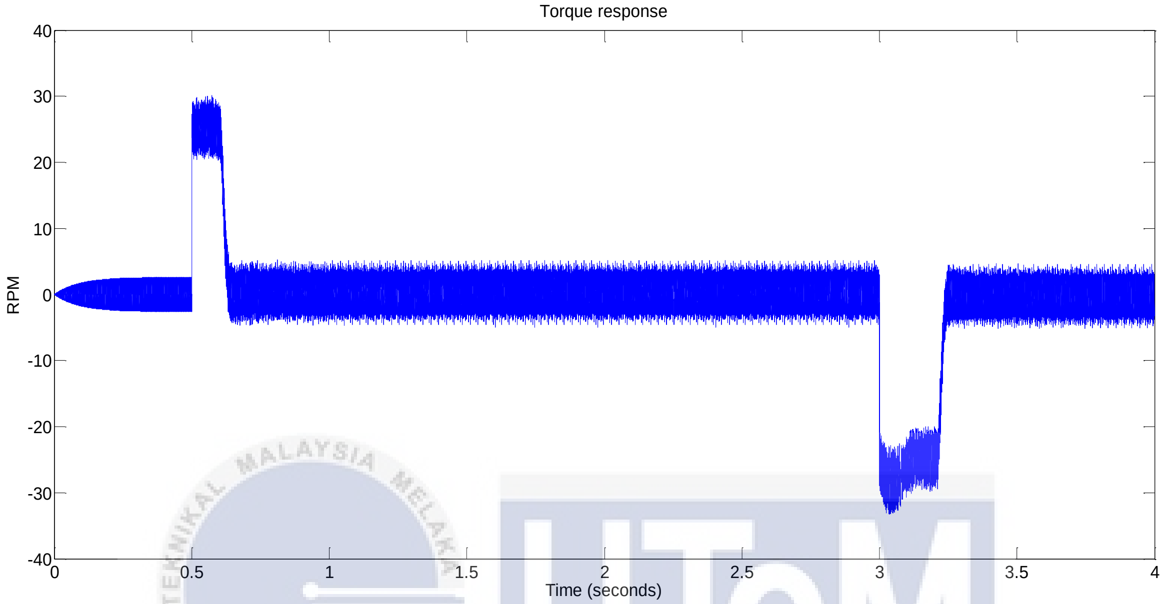


Figure 4.5 Torque response of 25 rules FLC of IM drive

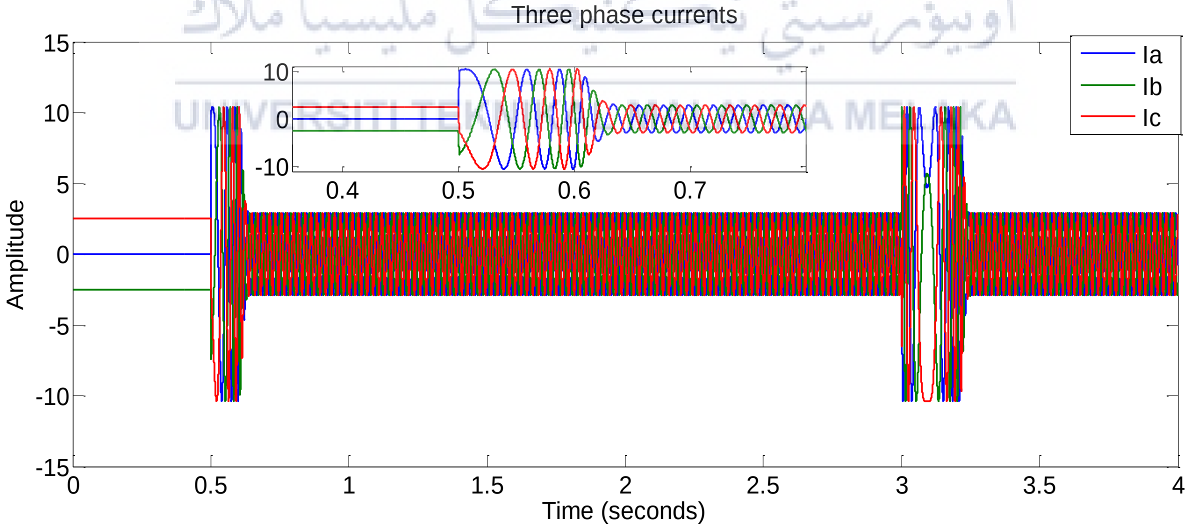
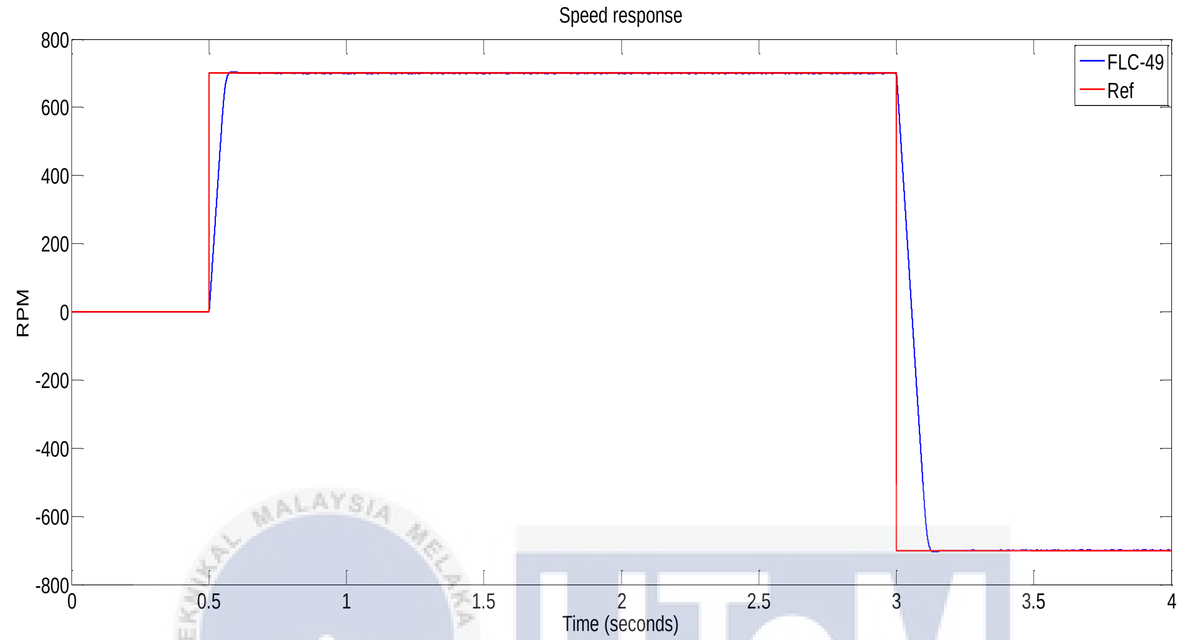
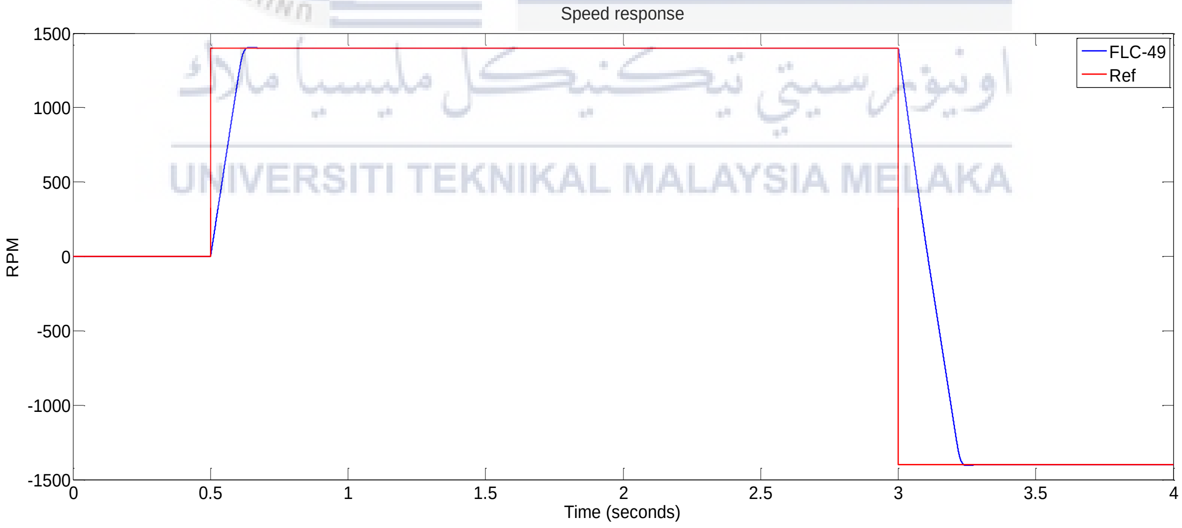


Figure 4.6 Current response of 25 rules FLC of IM drive

Moreover, the speed response of the induction motor drive with 49 rules FLC at 700 and 1400 rpm are presented in Figure 4.7 a, b.



(a)



(b)

Figure 4.7 Speed response with 49 rules at (a) 700 rpm (b) 1400 rpm

The torque response of the induction motor drive is presented in Figure 4.8, also the three-phase current are plotted in Figure 4.9.

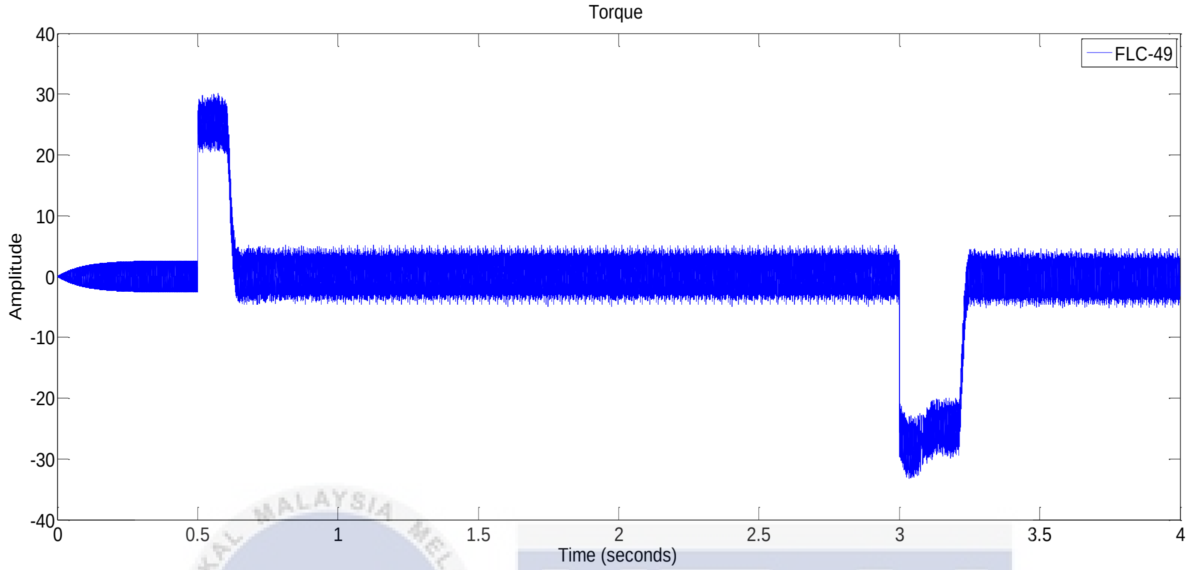


Figure 4.8 Torque response of 49 rules FLC of IM drive

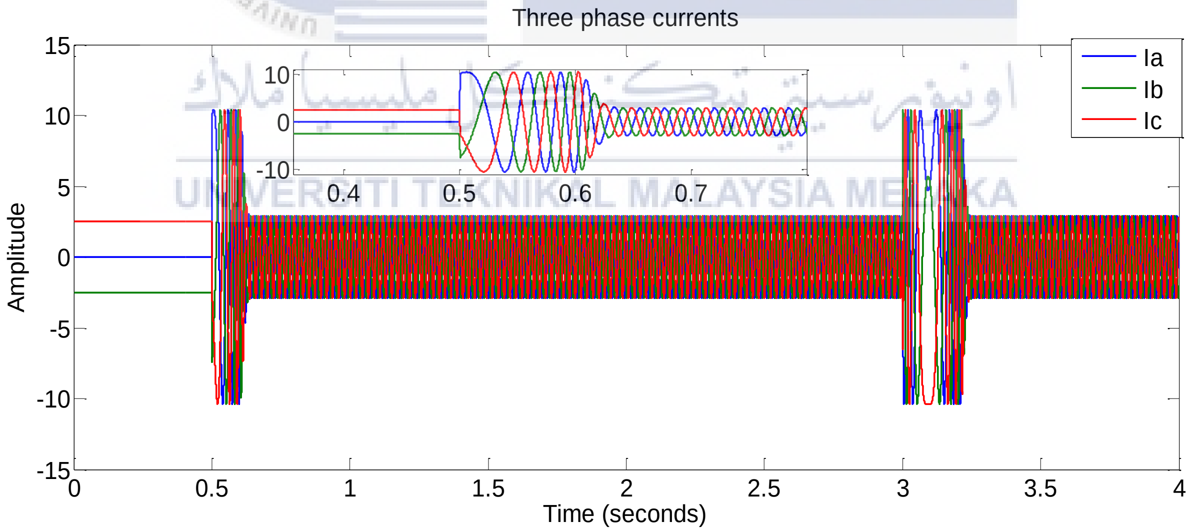
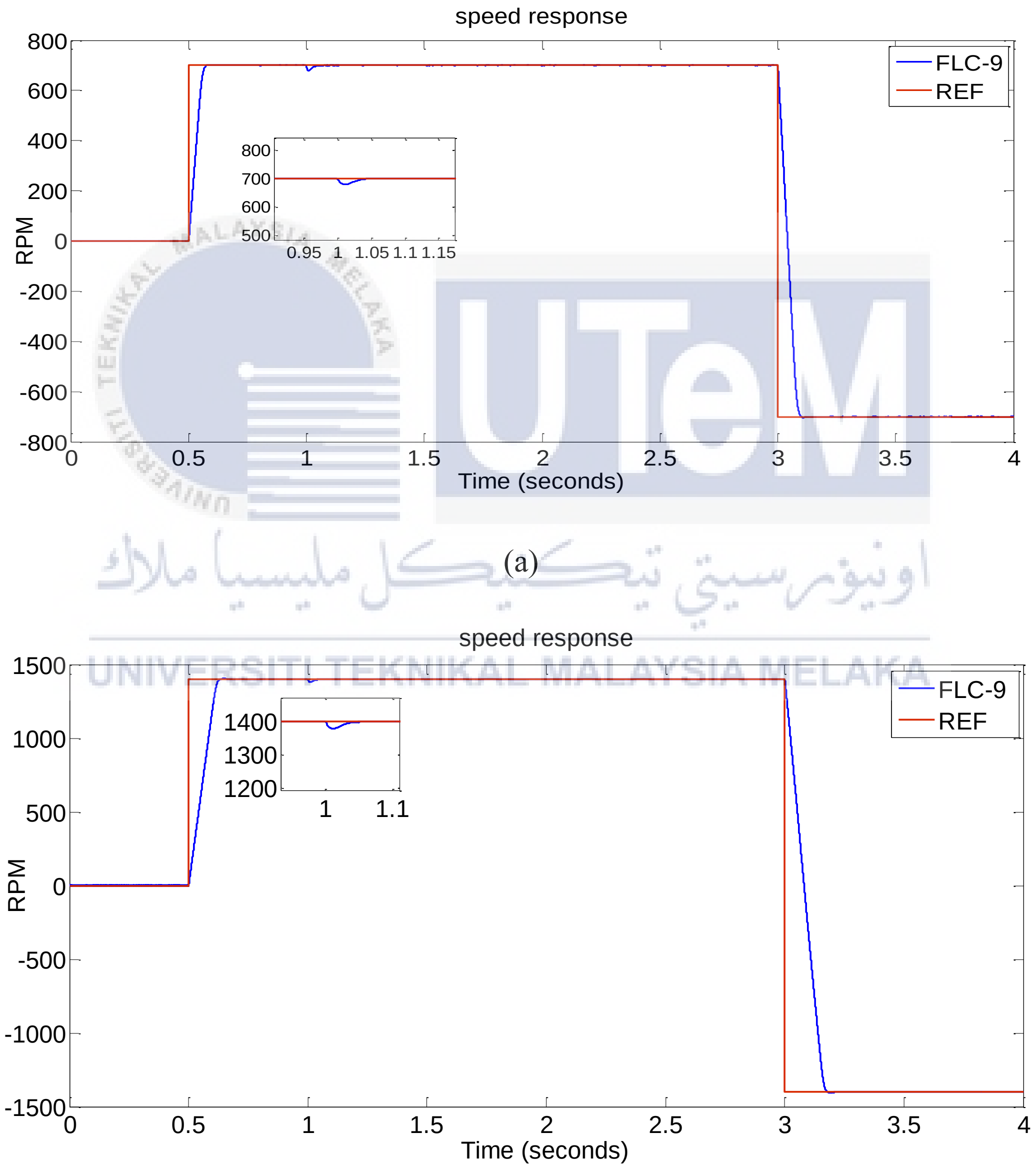


Figure 4.9 Currents response of 49 rules FLC of IM drive

4.1.2 Load Operation

The results of the FLC are obtained at different speeds as well as with different rules selections with load. The speed response at two different speed operations is considered the torque and current waveforms. The speed response at 700 and 1400 rpm with 9 rules FLC are plotted in Figure 4.10a, b. A small speed drop is recorded during load with 9 rules FLC. In addition, as the motor operates at lower speed than the rated speed, the speed drop increase.



(a)

(b)

Figure 4.10 Speed response with 9 rules at (a) 700 rpm (b) 1400 rpm

The torque response of the induction motor drive is presented in Figure 4. 11, also the three phase currents are plotted in Figure 4.12.

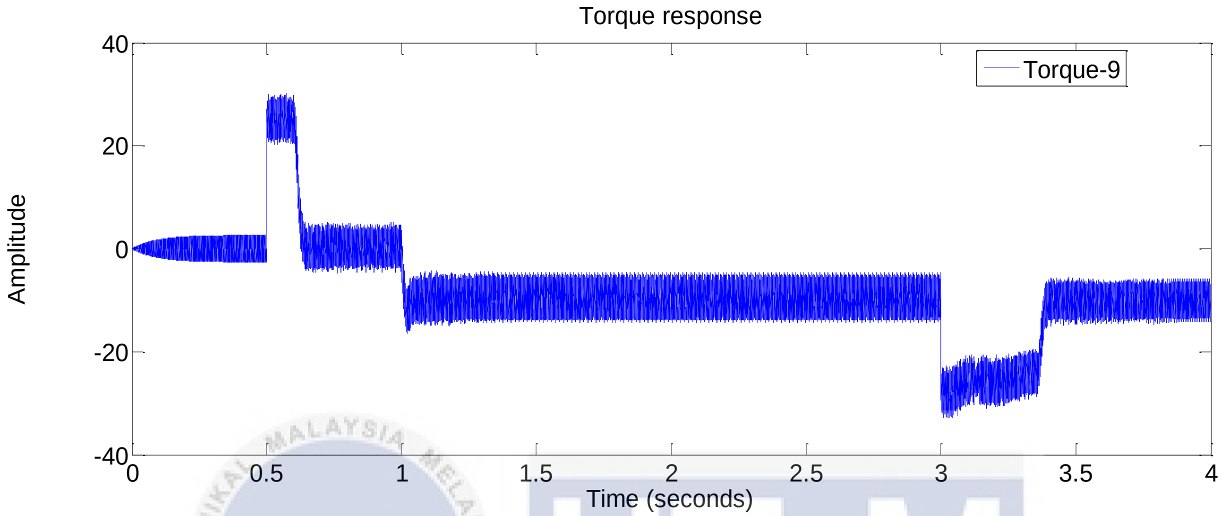


Figure 4.11 Torque response of 9 rules FLC of IM drive

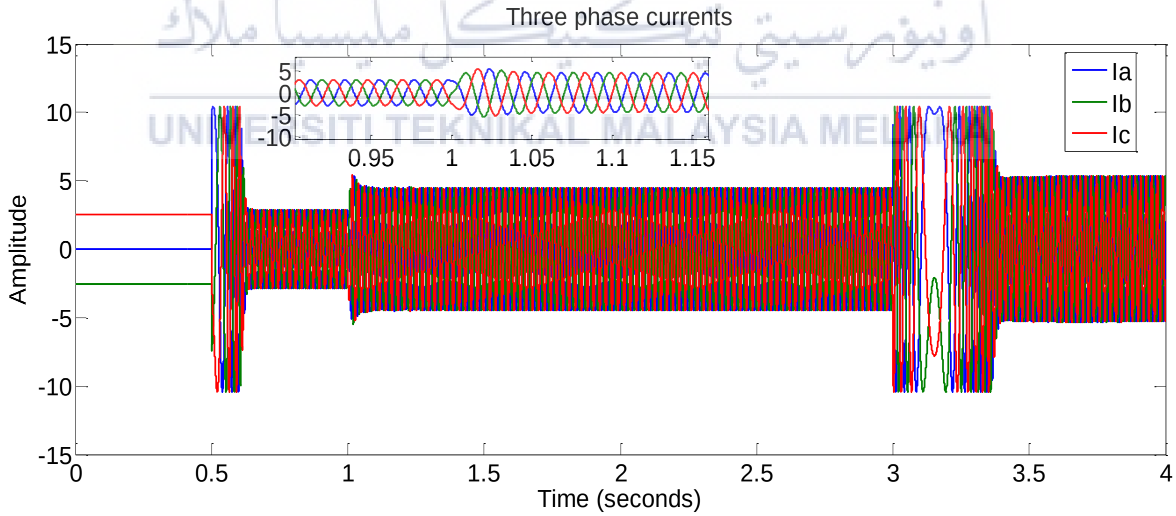
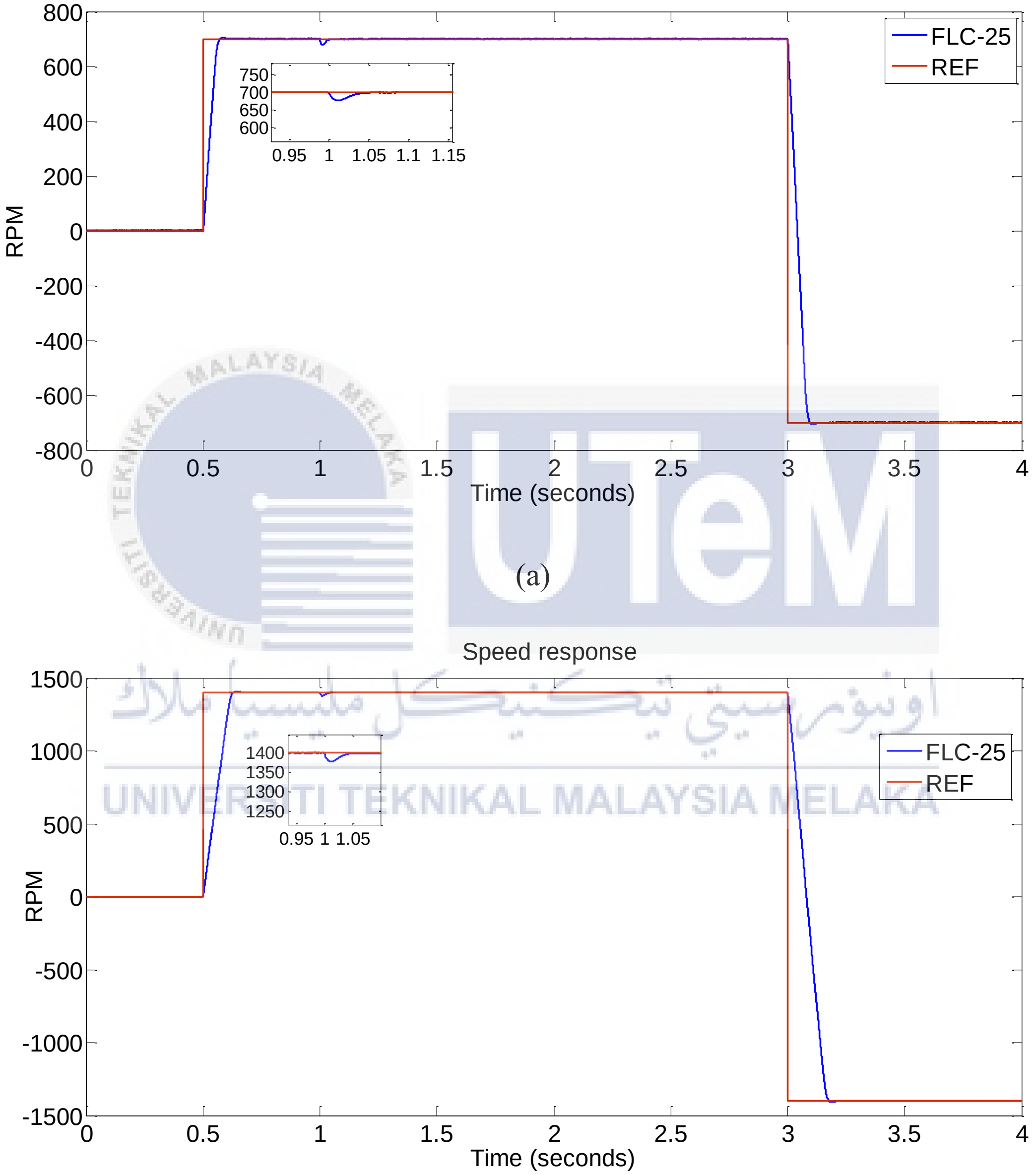


Figure 4.12 Current response of 9 rules FLC of IM drive

Moreover, the speed response of the induction motor drive with 25 rules FLC at 700 and 1400 rpm are presented in Figure 4.13 a, b. A small speed drop is recorded during load with 25 rules FLC. In addition, as the motor operates at lower speed than the rated speed, the speed drop increase.



(a)

(b)

Figure 4.13 Speed response with 25 rules at (a) 700 rpm (b) 1400 rpm

The torque response of the induction motor drive is presented in Figure 4,14, also the three phase current are plotted in Figure 4.15.

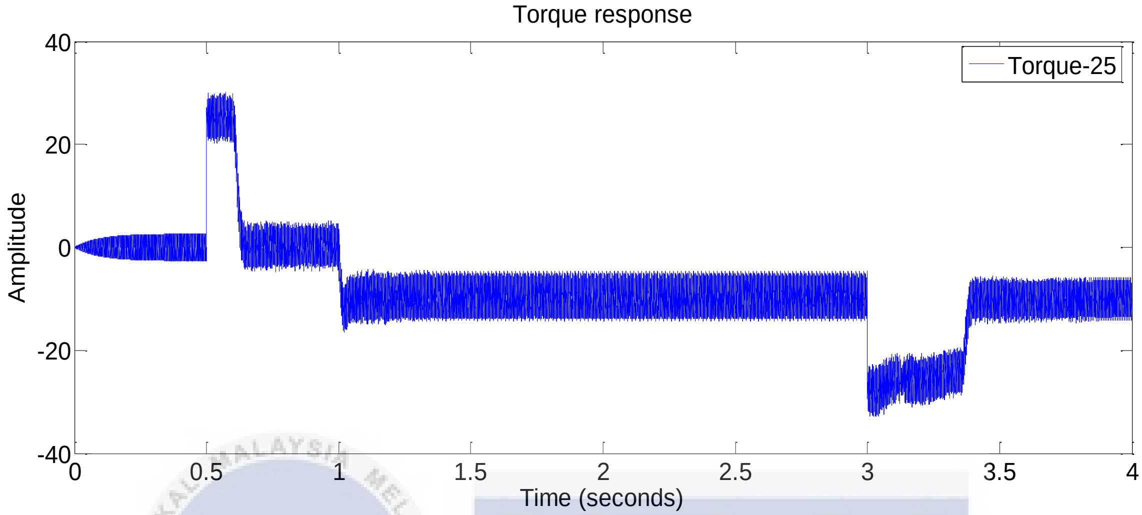


Figure 4.14 Torque response of 25 rules FLC of IM drive

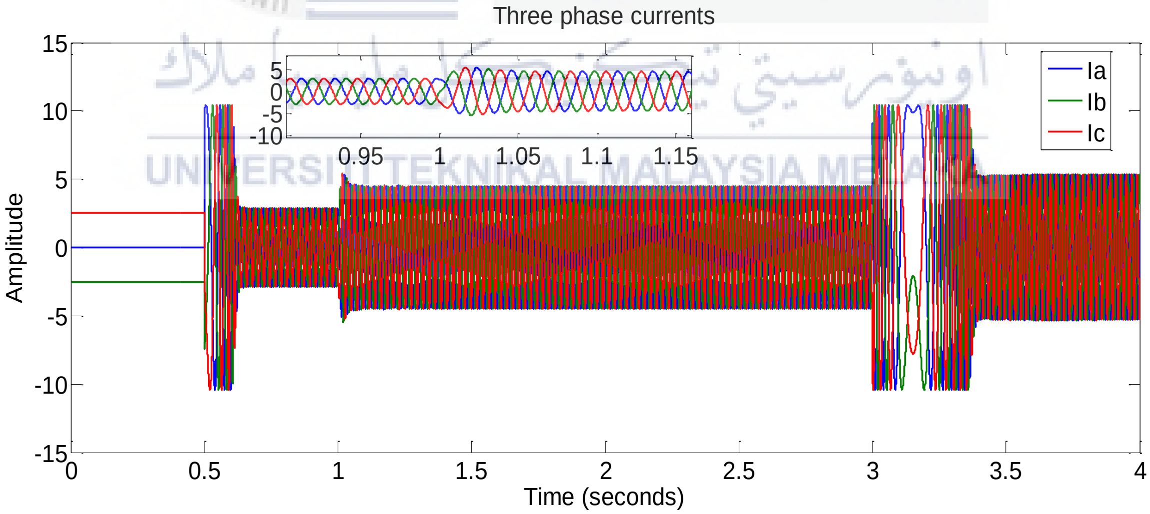
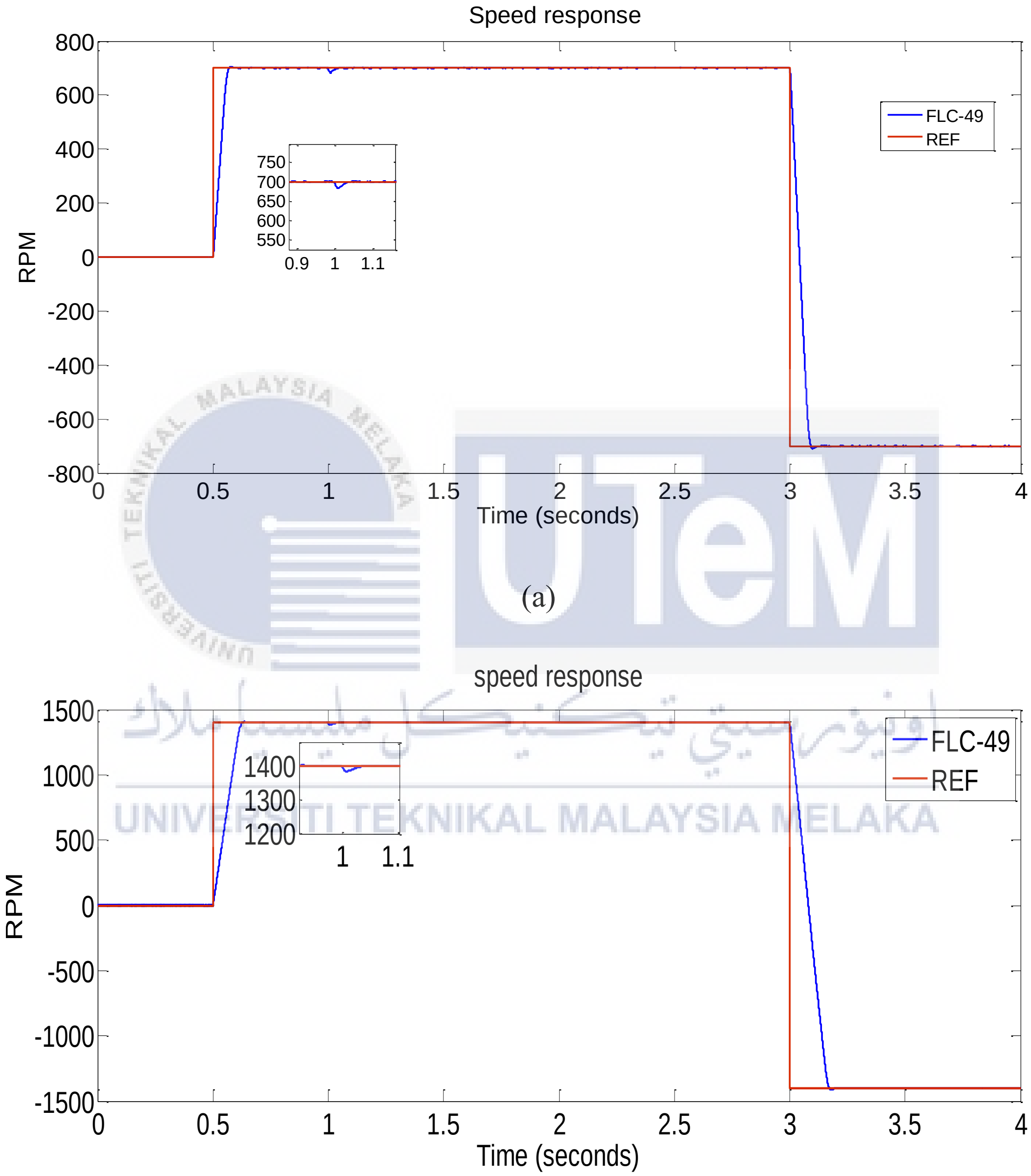


Figure 4.15 Current response of 25 rules FLC of IM drive

Moreover, the speed response of the induction motor drive with 49 rules FLC at 700 and 1400 rpm are presented in Figure 4.16 a, b. A small speed drop is recorded during load with 49 rules FLC. In addition, as the motor operates at lower speed than the rated speed, the speed drop increase.



(a)

(b)

Figure 4.16 Speed response with 49 rules at (a) 700 rpm (b) 1400 rpm

The torque response of the induction motor drive is presented in Figure 4.17, also the three phase current are plotted in Figure 4.18.

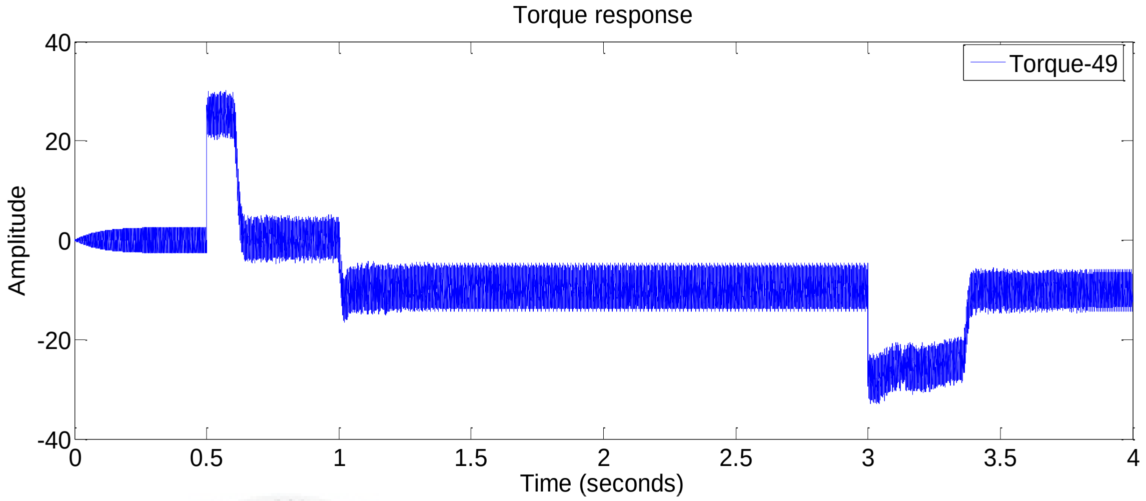


Figure 4.17 Torque response of 49 rules FLC of IM drive

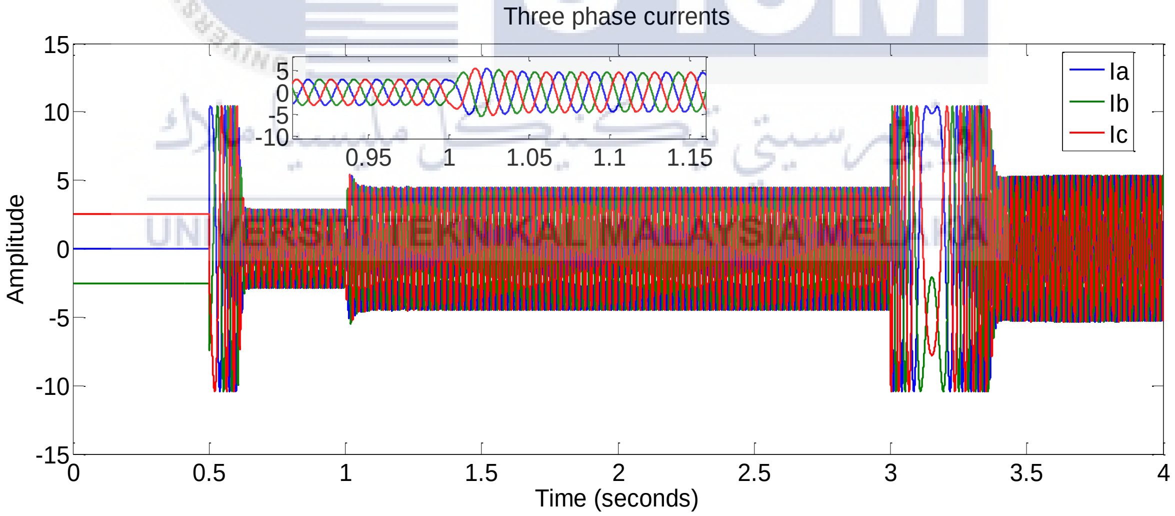


Figure 4.18 Currents response of 49 rules FLC of IM drive

4.2 Tuned 25 rules Fuzzy Logic controller

In this project 25 rules fuzzy logic controller is selected to perform tuning of scaling factors, membership function and rules reduction. The change of error and output scaling factors have been varied accordingly to observe their impacts on the overshoot of the output speed, applying various scaling factors to the FLC the overshoot behavior has been recorded and plotted as in Figure 4.19.

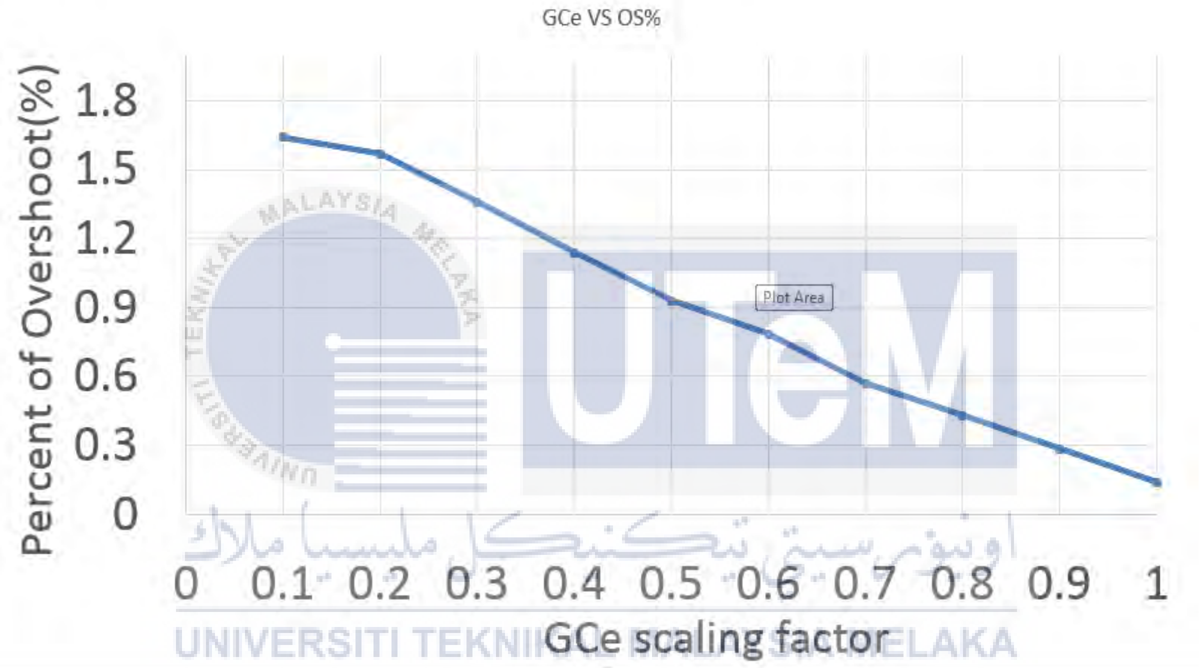


Figure 4.19: Overshoot response with scaling factor variations

The membership functions of triangular 5 x5 are adjusted toward zero ZE and alternatively tuned to the negative side NL. The amount of shit in the MFs in the two cases are presented in Figure 4.20 in which the shift percentage of NS, ZE and PS are presented with reference to the original peak value of these membership functions. The shift value of NS to zero compared to the original MF is computed and the percentage value of the shit is computed as well. In addition, for NS shift value toward negative side (NL) is computed and compared with original MF and percentage value of shit compared to main MF is obtained. The same scenario was adopted for ZE and PS as well.

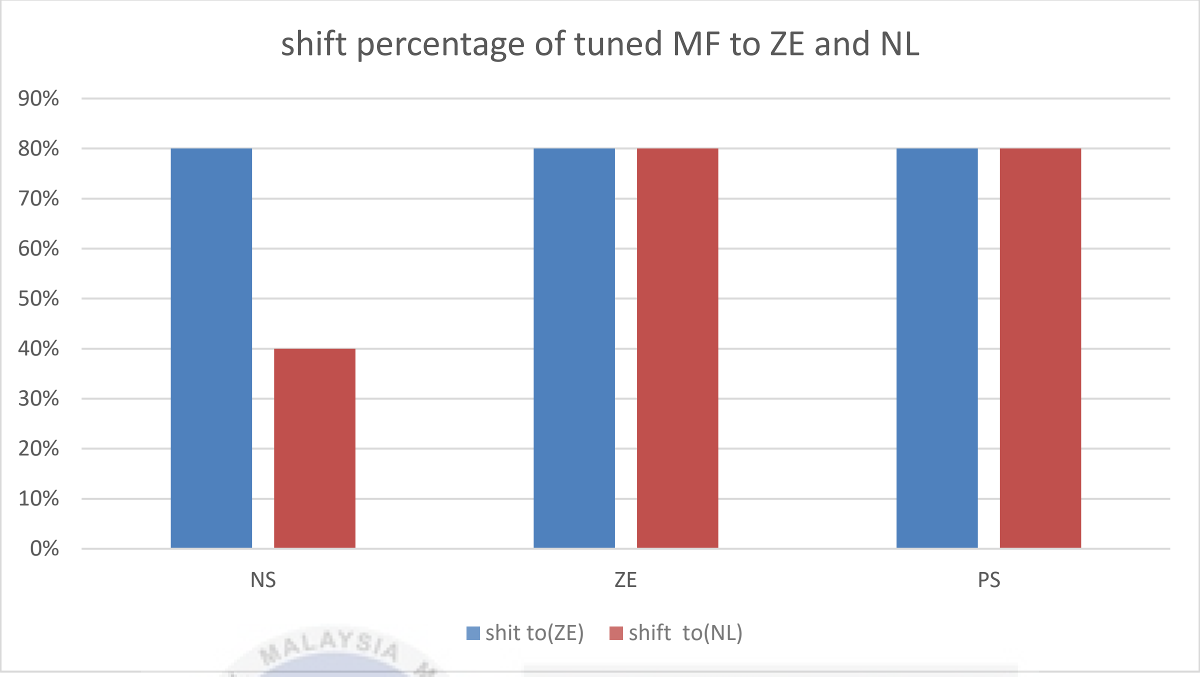


Figure 4.20: The shift value of each MF to ZE and PL compared to the original MF

The two tuned MFs, 7rules FLC and standard 25 FLC have been simulated in IM drive system considering different conditions. Firstly, all of the designs are simulated without load applied to the system at rated speed and the output speed performance comparison of these four schemes are plotted in Figure 4.21. In addition, load was applied to the system and performance comparison of loaded speed operation is presented in Figure 4.22. Apart from that, inertia was increased to be 1.5 of the initial value and the performance comparison with 1.5 (0.03) inertia is presented in Figure 4.23. Moreover, torque and phase current performance comparison are presented in Figure 4.24 and 4.25 respectively.

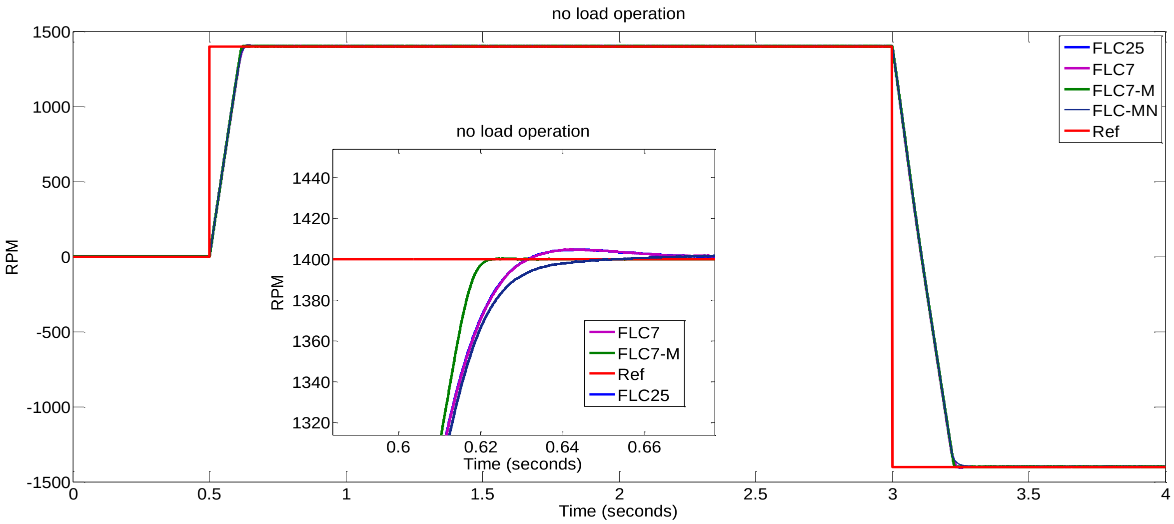


Figure 4.21: Speed performance comparison with no load operation

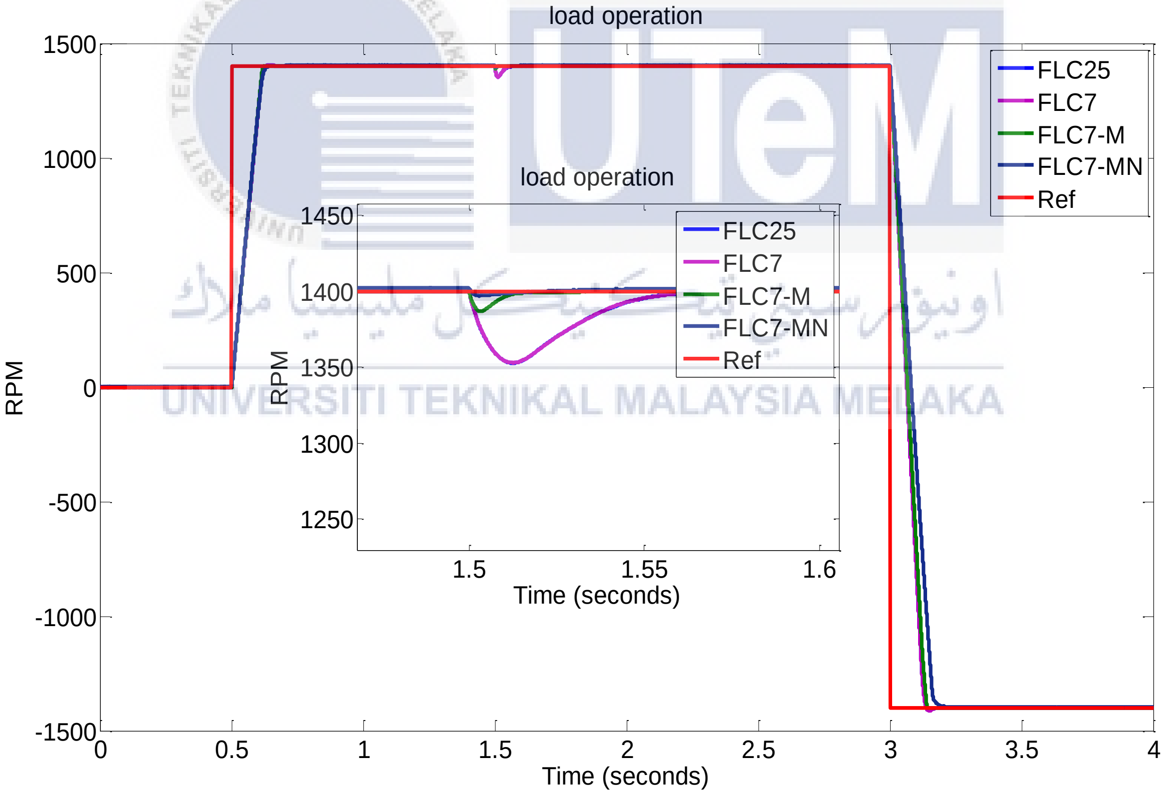


Figure 4.22: Speed performance comparison with load operation

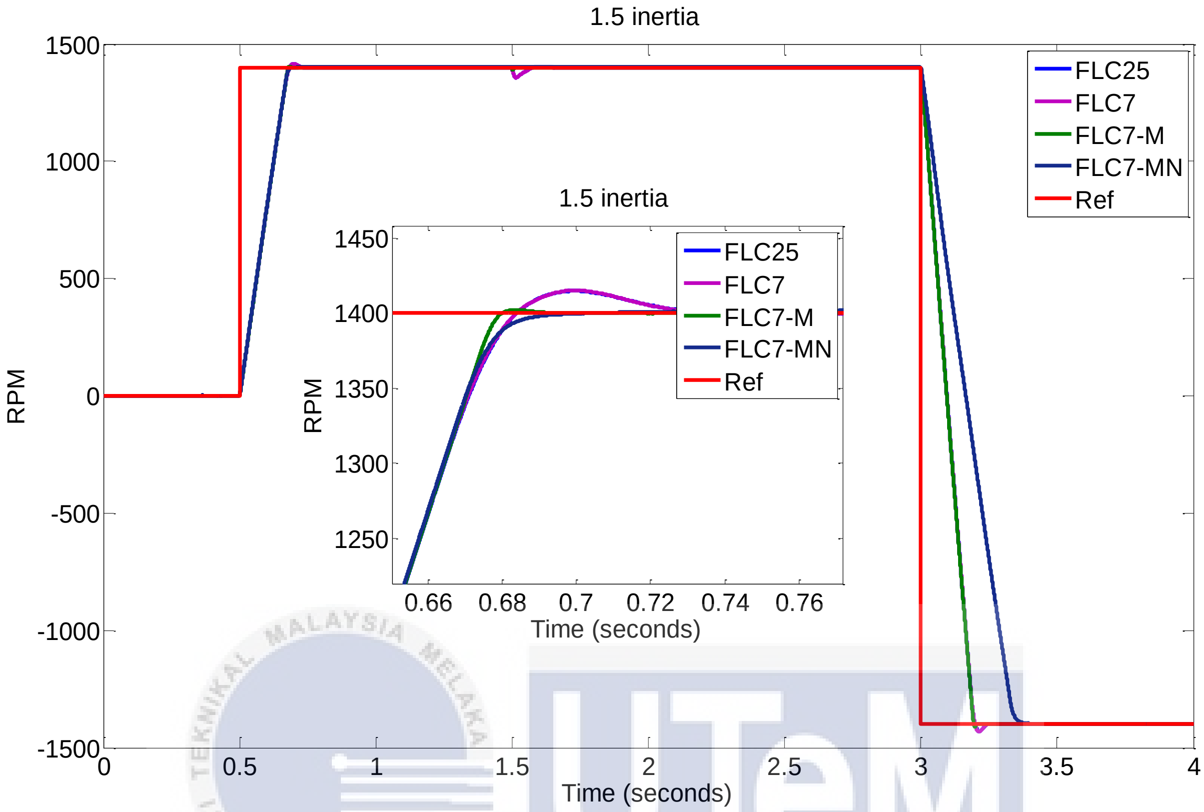


Figure 4.23: Speed performance comparison with variation of inertia

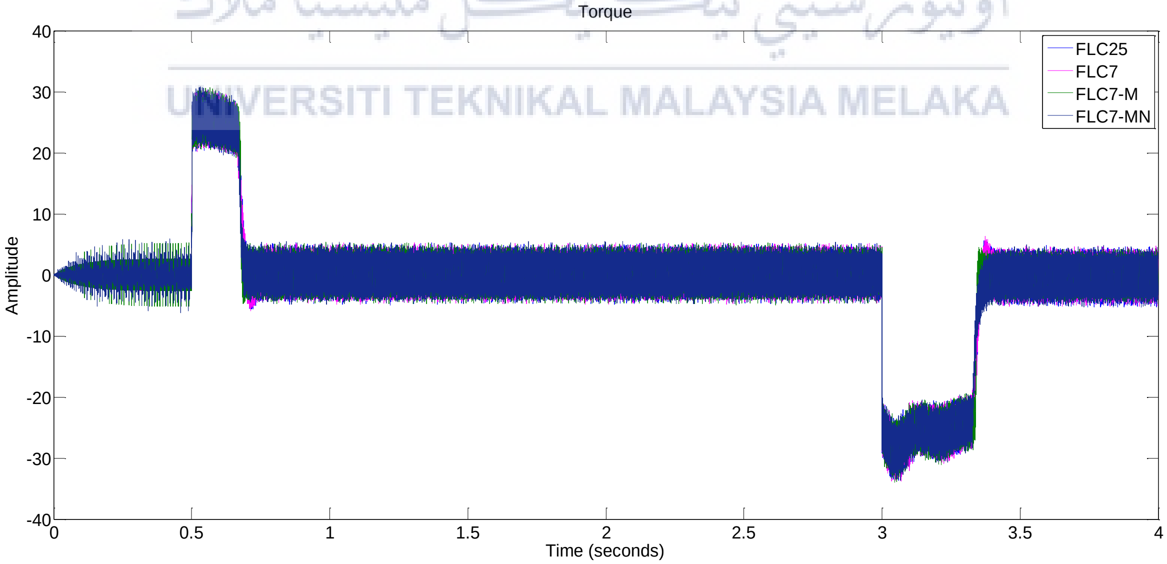


Figure 4.24: Torque performance comparison

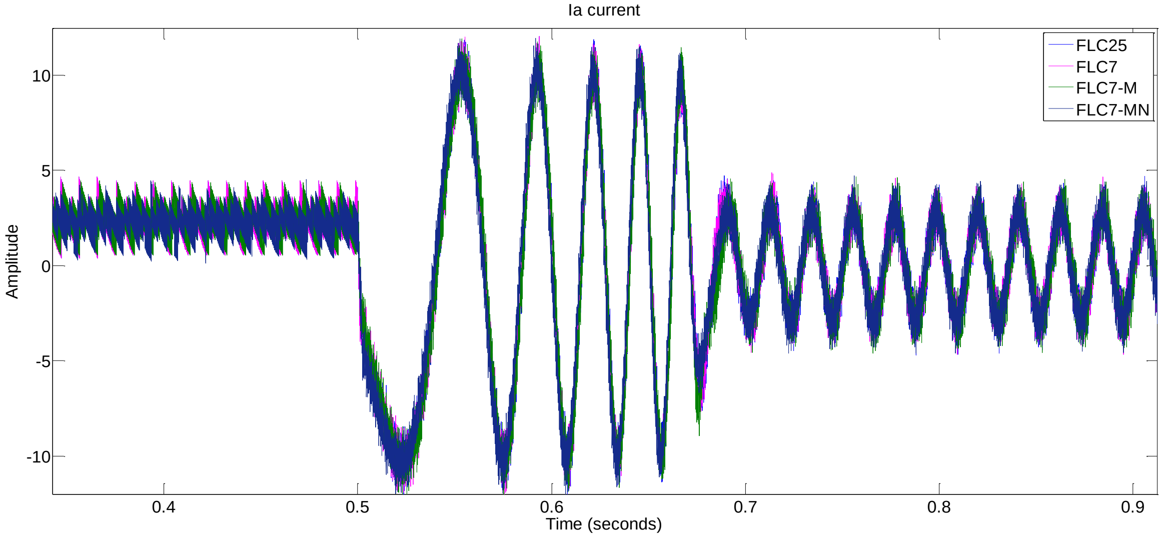


Figure 4.25: Phase A current performance comparison

4.3 Discussion

MATLAB/SIMULINK environment was utilized to perform the simulation of the IM drive system with three different fuzzy rules size of speed control. Both fuzzy sets designed to achieve almost zero overshoot; however as can be seen from the speed response, there is a slight difference in performance between the three different rules size during forward and reverse speed operation. Table 4 summarizes the rise time (Tr) and settling time (Ts) of the 9, 25 and 49 rules at 1400rpm. In addition, different speed ranges were considered in order to investigate the motor performance at high, medium and low speed operations. The performance of the speed operations is depended on the distribution and gradient of the membership function shape. The simulation results demonstrate the workability of the three different rules under forward and reverse speed operation.

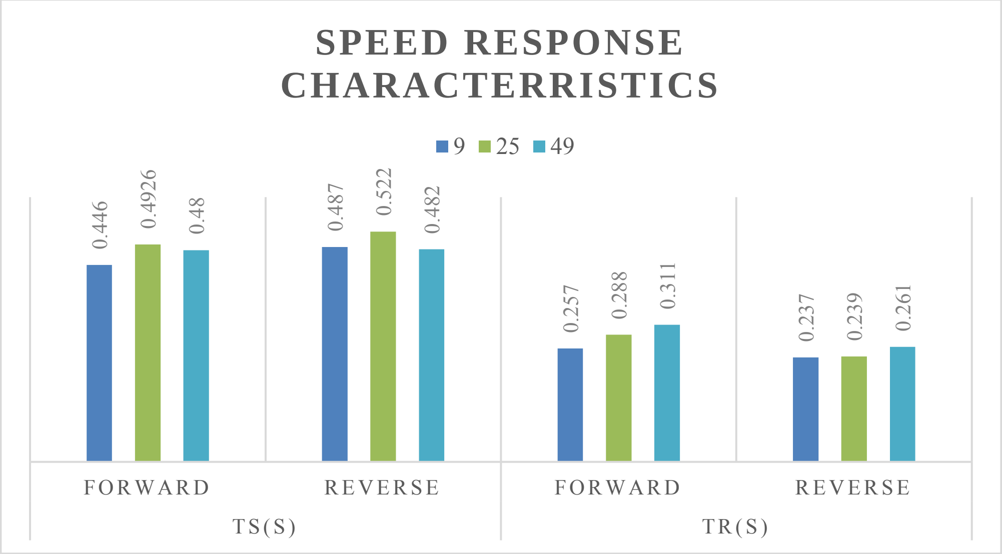


Figure 4.26: Speed response characteristics

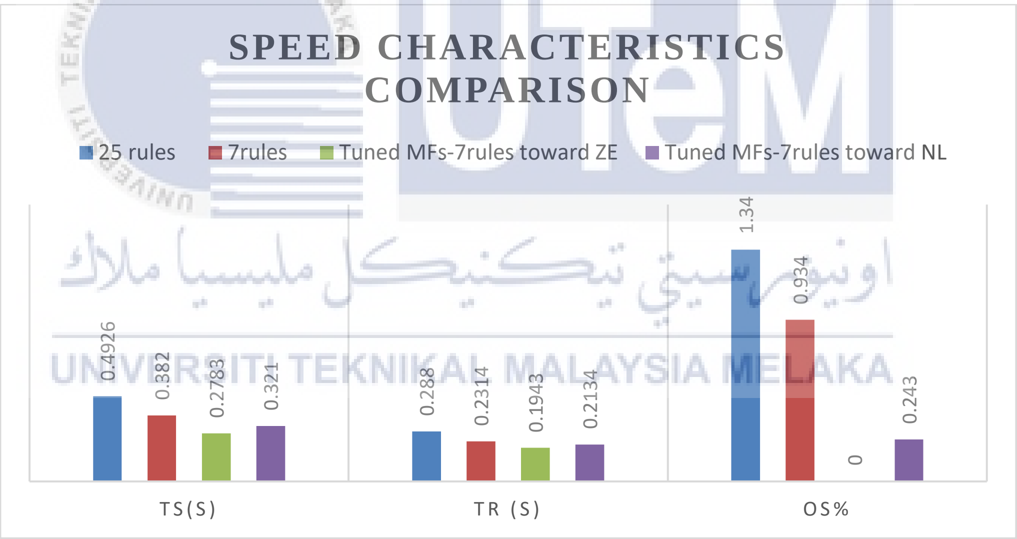


Figure 4.27: Speed characteristics comparison

The speed performance when load applied is significantly affected and experienced much rpm drop for different rules size. When 9-rule FLC is implemented with load, small effects in the speed performance occurred, while the speed drop with 25, 49 rules are higher. Avery fast recovery with a small rpm drop is noticed for 9-rules while the rpm drop increased as the number of rules increased.

CHAPTER 5

5. CONCLUSION

5.1 Conclusion

The use of induction motor involves in most applications ranging from simple electric fan to large factory applications. The robustness, easy to make, less maintenance as well as cheaper costs make the induction motors preferred in most of applications. Vector control is utilized to control the induction motor drive efficiently just like dc motor control. Conventional controllers like PI and PID can control the speed of induction motor with much sensitivity to motor parameters however; fuzzy logic controllers can be utilized to control the speed efficiently with less sensitivity to motor parameters changes. In this project three different rules 9, 25 and 49 selections have been utilized. In addition, 25 rules were selected and to tune its scaling factors, fuzzy rules and membership functions. Performance comparison of 9, 25 and 49 rules fuzzy logic speed controller have been presented considering different speed range. The simulation results of the tuned 25 FLC have been presented and compared. It was concluded that, FLC with tuned MFs produced superior performance in terms of overshoot, rise time and settling time.

5.2 Recommendation for Future Work

The future works recommended for this project are:

i. Implement different rules selection for the IM drive.
ii. Implement hybrid controllers for IM speed drive.
iii. Design self-tuning controllers for speed controller of fuzzy logic.
iv. Verify the proposed simulation models with hardware implementation.

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APPENDICES

Appendix A: Gant chart

Progress	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Selection of the topic & writing of the proposal	■													
Overview of Induction motor drive		■	■	■										
Literature review understanding IM modelling		■	■	■										
PI and fuzzy speed controller					■	■	■							
Matlab/Simulink Design of the system								■	■					
Testing the system with Fuzzy logic different rules										■	■			
Review the system												■		
FYP1 Report													■	■

Appendix B: Gant chart

Progress	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Review of the designed system in FYP 1	■													
Select 25 rules for tuning process		■												
Simplify the fuzzy rules from 25-7 rules		■	■	■										
Membership functions tuning					■	■	■							
Scaling factors tuning								■	■					
Performance comparison of the different design										■	■			
Analysis and discussion												■		
FYP2 Report													■	■