

**A STATOR RESISTANCE ESTIMATION OF INDUCTION
MOTOR USING FUZZY LOGIC**

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**A STATOR RESISTANCE ESTIMATION OF INDUCTION
MOTOR USING FUZZY LOGIC**

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**A thesis submitted in partial fulfillment of the
requirements for the awarded of the Degree of Bachelor of Electrical &
Electronics Engineering**

**Faculty of Electrical & Electronics Engineering
University Malaysia Pahang**

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I declare that this thesis entitled “A STATOR RESISTANCE ESTIMATION OF INDUCTION MOTOR USING FUZZY LOGIC” 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 : MOHD AKMAL BIN ROHANI

Date : 29 NOVEMBER 2010

To my beloved mother and father and those who have guided and inspired me
throughout my journey of learning.

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ABSTRACT

During the operation of induction motor, stator resistance changes incessantly with the temperature of the working machine. This situation may cause an error in rotor resistance estimation of the same magnitude and will produce an error between the actual and estimated motor torque which can lead to motor breakdown in worst cases. Therefore, this project will propose an approach to estimate stator resistance of induction motor using fuzzy logic. Then, a correction will be made to ensure the stabilization of the system.

Generally, this project can be divided into three parts which are design the induction motor by using the mathematical equation, design Fuzzy Logic estimator to estimate the value of stator resistance R_s , and make the correction of stator resistance, R_s . The MATLAB simulink is used in order to design the induction motor. Secondly, Fuzzy Logic Toolbox is used to design fuzzy logic estimator and finally the correction of R_s is made.

ABSTRAK

Semasa operasi motor induksi, perubahan rintangan stator berkadar terus dengan suhu. Situasi ini boleh menyebabkan gangguan bagi menganggar jarak dan arah bagi rotor dan akan menghasilkan kesilapan antara kekuatan motor sebenar yang boleh menyebabkan kerosakan motor dalam keadaan amat teruk. Oleh itu, projek ini akan mencadangkan suatu pendekatan untuk meramal ketahanan stator motor induksi menggunakan Logic Fuzzy. Kemudian, pembedahan akan dilakukan untuk memastikan kestabilan sistem.

Umumnya, projek ini boleh dibahagikan kepada tiga bahagian iaitu merekabentuk motor induksi dengan menggunakan persamaan, mencipta anggaran Logik Fuzzy untuk menganggarkan nilai rintangan stator R_s , dan membuat pembedahan bagi stator, R_s . Perisian MATLAB digunakan untuk merekabentuk motor induksi. Kedua, Fuzzy Logic Toolbox digunakan untuk mereka anggaran logik fuzzy dan akhirnya pembedahan R_s dibuat.

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LIST OF ABBREVIATIONS

GUI	Graphical User Interface
CCE	Change Current Error
CE	Current Error
RC	Resistance Change
NL	Negative Large
NM	Negative Medium
NS	Negative Small
Z	Zero
PS	Positive Small
PM	Positive Medium
PL	Positive Large

LIST OF SYMBOLS

V_{ds}	-	<i>direct</i> component of the stator voltage vector
V_{qs}	-	<i>quadrature</i> component of the stator voltage vector
I_{ds}	-	<i>direct</i> component of the stator current vector
I_{qs}	-	<i>quadrature</i> component of the stator current vector
λ_{ds}	-	<i>direct</i> component of the rotor flux vector
λ_{qs}	-	<i>quadrature</i> component of the rotor flux vector
L_s	-	Stator inductance
L_r	-	Rotor inductance
L_m	-	Mutual inductance
R_s	-	Resistance of a stator phase winding
R_r	-	Resistance of a rotor phase winding
T_s	-	Stator time constant
T_r	-	Rotor time constant
σ	-	$1 - \frac{L_m^2}{(L_s L_r)}$ total leakage factor
ω_r	-	Rotor electrical angular velocity

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CHAPTER 1

INTRODUCTION

1.1 Background

Asynchronous motors, particularly the squirrel-cage induction motor, enjoy several inherent advantages like simplicity, reliability, low cost and virtually maintenance-free electrical drives. These facts are due to the induction motor advantages over the rest of motors. The main advantage is that induction motors do not require an electrical connection between stationary and brushes. Induction motor also has low weight and inertia, high efficiency and high overload capability.

However, for high dynamic performance industrial applications, their control remains a challenging problem because they exhibit significant non-linearity and many of the parameters, mainly the stator resistance, vary with the operating conditions such as the temperature.

The problem is overcome by adding another on-line estimation for R_s to the system using a fuzzy non-linear observer, giving the indirect vector control system, total immunity to resistance variations. The stator resistance identifier uses the error between a discrete estimate of stator current and the measured stator current, to map the change in stator resistance, using a fuzzy non-linear mapping.

The proposed fuzzy logic estimator, which is designed to estimate the change in stator resistance during the drive, is in operation. A fuzzy logic real time estimator is used as the stator resistance observer, to eliminate the error in rotor resistance estimation.

Once the stator resistance is estimated, the new of stator resistance R_s is added to eliminate the error in rotor resistance and give same magnitude and same torque to the induction motor.

1.2 Problem Statement

A mismatch between the real rotor flux and the estimated rotor flux, leads to error between the real motor torque and the estimated torque and hence poor dynamic performance. The error in stator resistance R_s , leads to errors in rotor resistance R_r .

1.3 Objectives of the project

The vital objective of this project is to estimate stator resistance R_s in induction motor by using fuzzy logic estimator to eliminate an error of rotor resistance R_r estimation in order to get the right magnitude and torque during the operation of induction motor.

1.4 Scopes of the project

The scopes of the project are:

- Design an estimated of induction motor.
- Design Fuzzy Logic estimator to estimate stator resistance R_s .
- Make the correction of stator resistance R_s .

1.5 Thesis outline

This thesis contains five chapters. Which are introduction, literature review, methodology, result and discussion, conclusion and recommendations.

Chapter 1 is explaining about the background, objectives, and scopes of the project and overview of the whole chapter. This chapter explains more about the outcomes and introduction about this project.

Chapter II provides a literature review on stator resistance overview in general. Other than that, this chapter also discusses about the methods used today to estimate stator resistances.

Chapter III focuses on the methods that are used for this project including flow chart, and circuit design of the system. Other than that, it also discusses about software used for this project. The part of software can be divided into three parts which are designing estimated induction motor, design fuzzy logic estimator, and make the correction of stator resistance.

Chapter IV discusses about the result obtained from the simulation. The results obtained are explained more detail part by part. The explanation includes equation, graph and theory of the whole project while Chapter V covers the conclusion, problems encountered and future recommendations about this project.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter presents an overview of stator resistance R_s estimation of induction motor, and types of method that used for estimate the value of the stator resistance in induction motor.

2.2 Stator Resistance Estimation Overview

The stator resistance changes due to the temperature variations and stator frequency variation that deteriorate the drive performance by introducing errors in the estimated magnitude and position of the stator flux vector.

2.3 Types of Stator Resistance Estimation

Direct torque control (DTC) of induction machines presents a good tracking for both electromagnetic torque and stator flux [1]. This control scheme, shown in Figure 2.10, depends only on stator measurements.

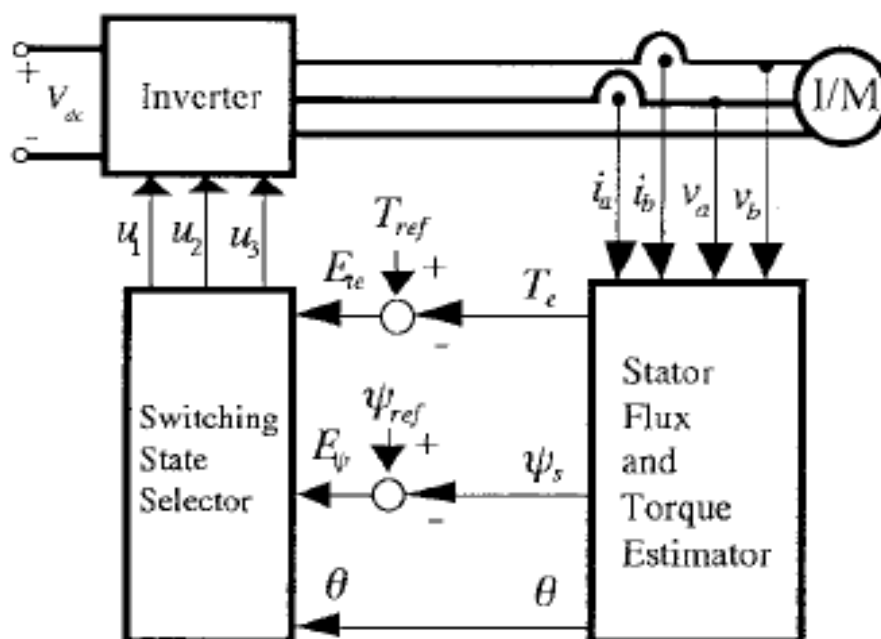


Figure 2.1 Direct Torque Control (DTC) [1]

Here [1] an artificial neural network (ANN) is used to accomplish tuning of the stator resistance of an induction motor. The parallel recursive prediction error and back propagation training algorithms were used in training the neural network for the simulation and experimental results, respectively. The neural network used to tune the stator resistance was trained on-line, making the DTC strategy more robust and accurate. Simulation results are presented for three different neural-network configurations showing the efficiency of the tuning process.[1]

This paper [2] describes a Quassi-Fuzzy method of online stator resistance estimation of an induction motor, where the resistance value is derived from stator winding temperature estimation as a function of stator current and frequency through an approximate dynamic thermal model of the machine. The estimator has been designed and iterated by simulation study and then implemented by a digital signal processor on a 5 horse power stator flux oriented direct vector controlled drive. [2]

In [3] presents application of Adaptive Neuro-fuzzy inference system (ANFIS) into a squirrel cage induction machine towards modeling, control and

estimation. This paper contributes (i) Development of a simple and more realistic model of the induction motor. Using ANFIS, the parameter sets of the motor model are estimated. The simplified model contains eleven estimated parameters. The identified model can be utilized for electric drives. (ii) Speed, torque and flux control using direct torque control (DTC) algorithm with ANFIS (iii) Design of Estimator through ANFIS which estimates the stator resistance with reference to the temperature when the DTC algorithm is involved. Better estimation of stator resistance results in the improvements in induction motor performance using DTC thereby facilitating torque ripple minimization. The values of stator voltage (V_s), stator current (I_s) and rotor angular velocity (ω_r) are taken. [3]

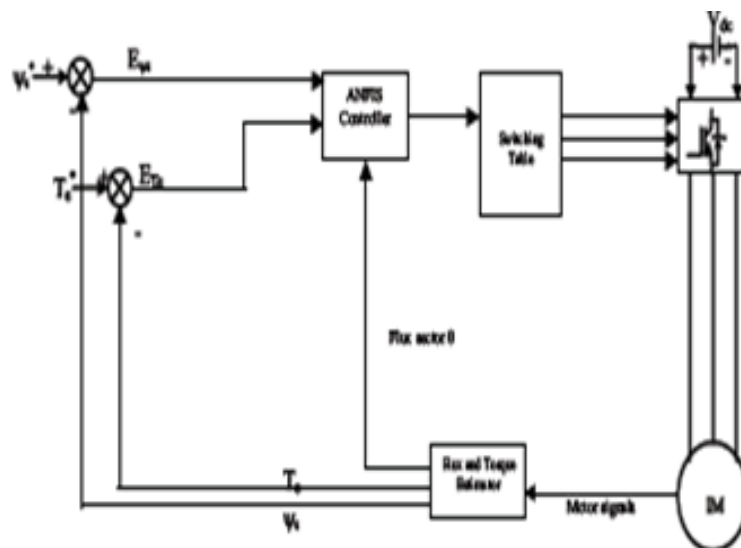


Figure 2.2 Adaptive direct torque neuro fuzzy control [4]

Figure 2.2 shows the block diagram of direct torque neuro fuzzy control (DTNFC) of induction motor. Torque and stator flux are estimated mathematically from the motor signals. Adaptive Neuro-fuzzy inference system (ANFIS) is used as controller to which the torque and flux errors along with position of stator flux are given as inputs and from which inverter-switching states are estimated.

A ninth-order estimation algorithm is designed which provides on-line exponentially convergent estimates of both rotor and stator resistance for induction motors, when persistency of excitation conditions are satisfied and the stator currents

integrals are bounded, on the basis of rotor speed, stator voltages, and stator currents measurements. Rotor flux is also asymptotically recovered. The proposed estimation scheme is intended to improve performance and efficiency of currently available induction motor control algorithms. [4]

A fuzzy logic real time estimator is used as the stator resistance observer, to eliminate the error in rotor resistance estimation. The performance of the induction motor drive with the above rotor and stator resistance estimators is investigated for torque and flux responses, to analyze the effects of stator resistance observer on rotor resistance identification, for variations in the stator and rotor resistances from their nominal values. Both these resistances are estimated experimentally, in a vector controlled induction motor drive and found to give accurate estimates. [5]

A stator and rotor resistance estimation technique for the purpose of stator winding and rotor conductor temperature monitoring is presented in this paper. [6] The proposed estimation scheme is a two-step procedure based on the voltage, current, and speed measurements. The first step is to estimate the rotor resistance and rotor flux linkage simultaneously based on a Model Reference Adaptive System (MRAS) structure that is independent of R_s . In the second step, the stator resistance is updated based on the estimated rotor flux linkage using the q-axis stator voltage equation in the synchronous reference frame. [6]

A novel motor stator estimation scheme for the purpose of monitoring the temperature in steady state is proposed in this paper [7] and the feasibility of wavelet network-based estimation of the stator resistance. The occurring instants of the signal change can be identified by the multi-scale representation of the signal. The improved least squares algorithm transform is used to fulfill the network structure initialization and parameter identification. The corresponding temperature is calculated according to the principle that the metal resistance depends on its temperature. [7]

The proposed scheme in this paper [8] is based on both a rotor resistance estimation technique and a lumped thermal model of an induction machine.

Temperature estimation based on a parameter model that determines the rotor resistance is quite accurate under rated load conditions. Therefore, rotor temperature of a slightly loaded induction machine may be better approximated by a thermal model which evaluates the losses of the induction machine. [8]

This paper [9] studies the influence of the stator resistance variation on MRAS speed estimation. It has been shown that when a motor is running at high speed, the effect of error in stator resistance is usually quite negligible. But as the frequency approaches zero, this becomes more serious because the voltage drop on stator resistance becomes relatively larger as the frequency decreases. Under this reference scheme, one component of flux can be decoupled from the corrupting effects of the stator resistance and the other quadrature component can provide a near-instantaneous estimate of the stator resistance.

CHAPTER III

METHODOLOGY

3.1 Introduction

This chapter discusses about the methods that are used for this project. It includes overview of the whole system, design the estimated of induction motor using the equation, design Fuzzy Logic estimator, and make the correction of stator resistance, R_s .

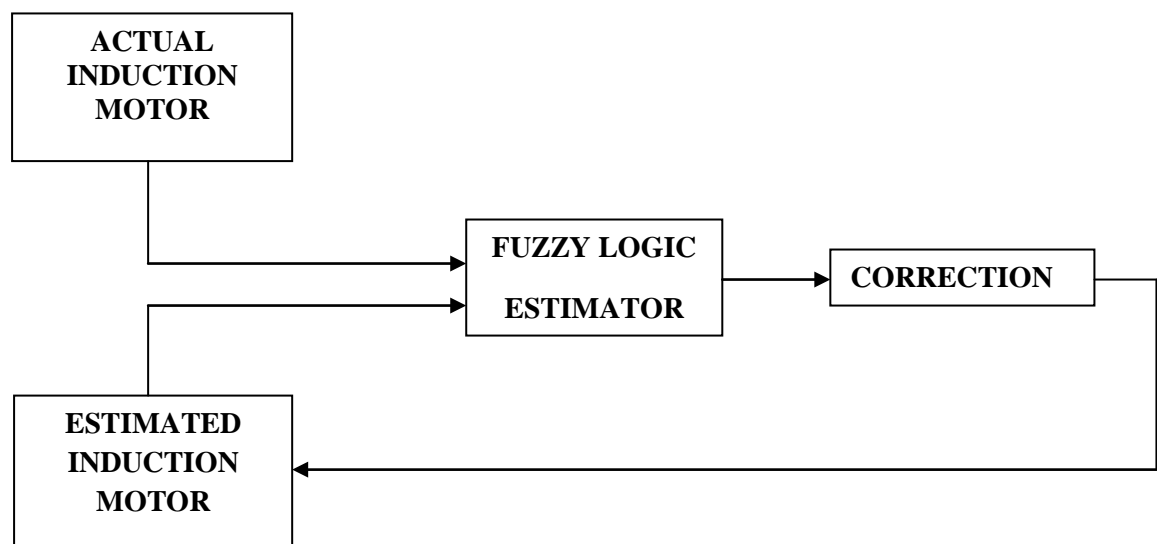


Figure 3.1 Flow of Stator Resistance Estimation of Induction Motor Project

Figure 3.1 above shows the flow of project a stator resistance estimation of induction motor. There are two induction motor that needs to be designed. First is estimated induction motor will be design by using the equation of induction motor's in MATLAB and real induction motor is designed by using Newcastle University Drive Simulation Library (NUDSL). Both stator resistances, R_s of induction motor will estimate using Fuzzy Logic estimator. Then the correction will make to the stator resistance of estimated induction motor.

3.2 Graphical User Interface (GUI)

The main reason graphical user interface (GUI) are used is because it makes things simple for the users. User can choose any topics above by clicking the subtopic, and a modeling will appear at the screen. This GUI is created using M-File in MATLAB.

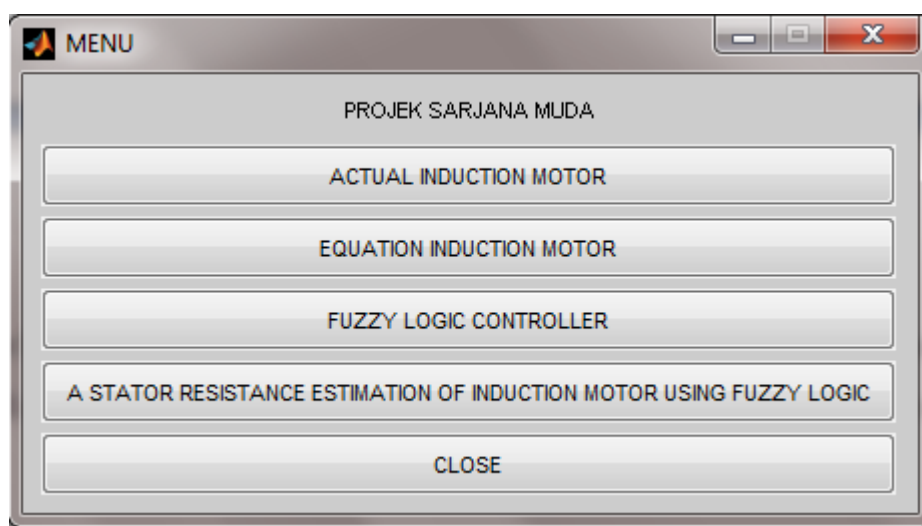


Figure 3.2 GUI Topics

Figure 3.2 consists of GUI topics which are actual induction motor, equation or estimated induction motor, fuzzy logic controller, and a stator resistance estimation of induction motor.

3.3 Actual Induction Motor

For actual induction motor, it focuses on (NUDSL). Actual induction is simulated using simulink block from this library. Here, there are two conditions should be considered in designing induction motor, no load and on load conditions.

3.3.1 Newcastle University Drives Simulation Library (NUDSL)

The Newcastle University Drives Simulation Library consists of seven sub-libraries. The seven sub-libraries are accessed from the DRIVES block which is located in the main simulink window. This induction motor acted as actual motor in the simulation.

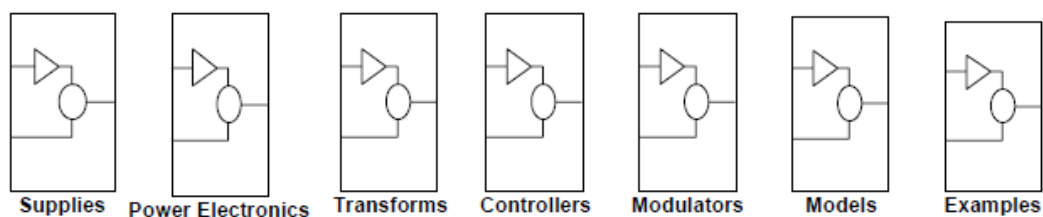


Figure 3.3 NUDSL Library

Figure 3.3 shows (NUDSL) Version 1.0. The first six sub-libraries contain simulation blocks which can be used to build up and simulate various drives. All blocks are fully compatible with other standard SIMULINK blocks. The seventh sub-library contains simulations built using various blocks from the other sub-libraries, these examples can be used to become familiar with the MATLAB simulink environment.

3.3.2 No Load

The no load test of an induction motor measures the rotational losses of the motor and provides information about its magnetization current. The only load on the motor is the friction and winding losses.

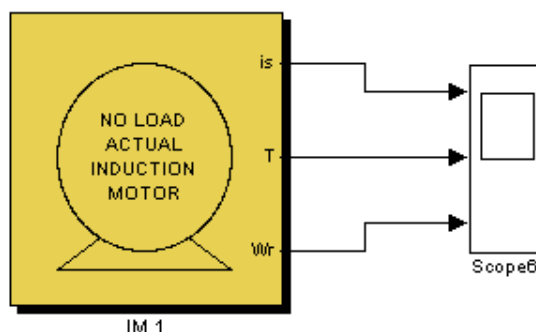


Figure 3.4 Masked No Load Actual Induction Motor

Figure 3.4 shows the block diagram of actual induction motor during at no load. The scope can display stator current, torque value and speed of rotor.

Table 3.1: Rate Data of the Simulated Induction Motor at No Load

Power	4kW
Frequency	50 Hz
Voltage	220/380
Current	15/8.6 A
Rpm	1440
Connection	Δ / Y
Power factor	0.8
Stator Resistance, R_s	1.2 Ω
Rotor Resistance, R_r	1.8 Ω
Stator Inductance, L_s	0.156 H
Rotor Inductance, L_r	0.156 H
Mutual Inductance, L_m	0.143 H

The value in Table 3.1 above is used as the parameter of induction motor during at no load.

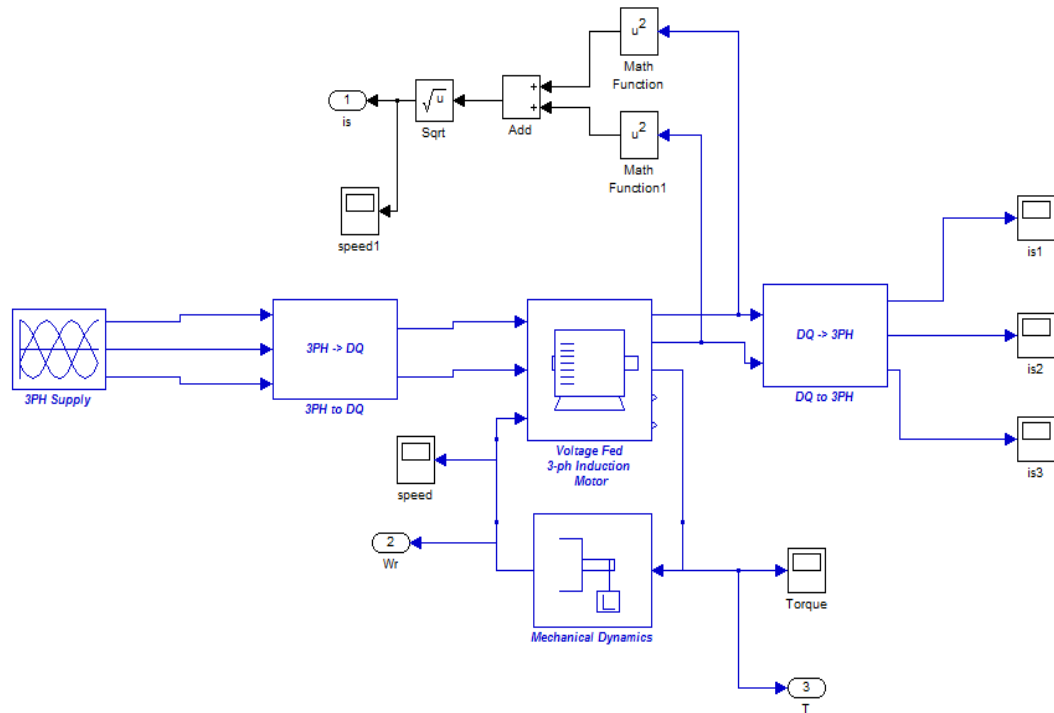


Figure 3.5 Unmasked Actual Induction Motor at No Load.

Figure 3.5 shows overall system of actual induction motor during at no load. This system started with three phase power supply is converted to DQ transform. Then, DQ transformation is supplied 3 phase induction motor to run the motor.

Synchronous Speed

$$\begin{aligned} n_{sync} &= \frac{120 f_e}{P} \\ &= \frac{120 \times 50}{2} \\ &= 3000 \text{rpm} \end{aligned}$$

$$\begin{aligned} \omega_{sync} &= 3000 \text{rpm} \times \frac{2\pi \text{ rad}}{1 \text{ r}} \times \frac{1 \text{ min}}{60 \text{ s}} \\ &= 314.1592 \text{ rad / s} \end{aligned}$$

Rotor Speed

$$\begin{aligned} \omega_r &= \frac{2\pi f}{P} \\ &= \frac{2\pi \times 50}{2} \\ &= 157.0796 \text{ rad / s} \end{aligned}$$

3.3.3 On Load

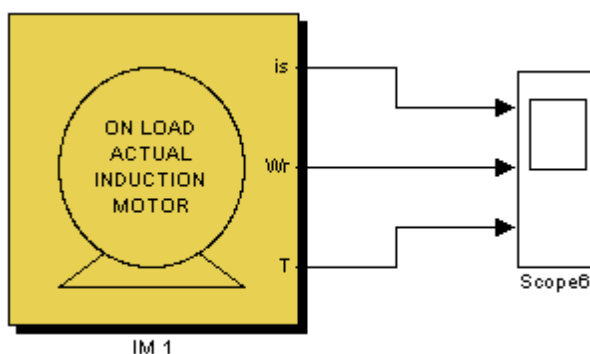


Figure 3.6 Masked On Load Actual Induction Motor

Figure 3.33 shows the block diagram of actual induction motor during at on load. The scope can display stator current, speed of rotor and torque value.

Table 3.2: Rate Data of the Simulated Induction Motor at On Load

Power	4kW
Frequency	50 Hz
Voltage	220/380
Current	15/8.6 A
Rpm	1440
Connection	Δ / Y
Power factor	0.8
Stator Resistance, R_s	1.2 Ω
Rotor Resistance, R_r	1.8 Ω
Stator Inductance, L_s	0.156 H
Rotor Inductance, L_r	0.156 H
Mutual Inductance, L_m	0.143 H
Moment Inertia, J	0.024 kgm^2

The value in Table 3.2 above is used as the parameter of induction motor during at on load.

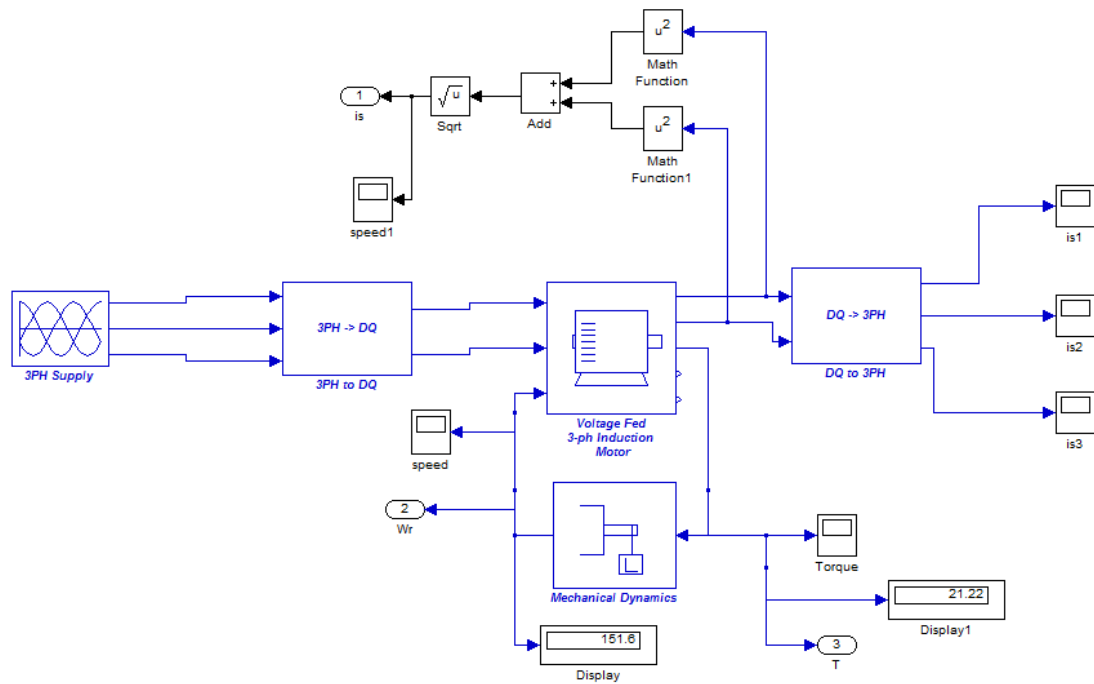


Figure 3.7 Unmasked Actual Induction Motor Block with load

Figure 3.7 shows overall system of actual induction motor during at on load. This system started with three phase power supply is converted to DQ transform. Then, DQ transformation is supplied 3 phase induction motor to run the motor. Here, the motor operates with the load.

From display block, $\omega_r = 151.6 \text{ rad / s}$

Synchronous speed, $\omega_{sync} = 314.1592 \text{ rad / s}$

$$\begin{aligned} Slip &= \frac{\omega_{sync} - \omega_r}{\omega_{sync}} \\ &= 0.5174 \end{aligned}$$

Torque rated

$$\begin{aligned} T_{rated} &= \frac{P_{out}}{\omega_r} \\ &= \frac{4000 \text{ W}}{151.6} = 26.385 \text{ Nm} \end{aligned}$$

Torque load

$$\begin{aligned}
 T_L &= \frac{80}{100} \times T_{rated} \\
 &= \frac{80}{100} \times 26.525 \text{ Nm} \\
 &= 21.108 \text{ Nm}
 \end{aligned}$$

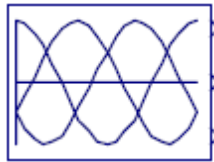


Figure 3.8 Three Phase Supply

Figure 3.8 shows the three phase supply has no inputs and three outputs which are 'A' Phase voltage, 'B' Phase voltage and 'C' Phase voltage.

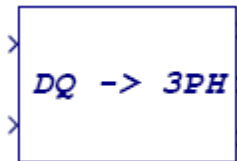


Figure 3.9 DQ to 3PH

Figure 3.9 shows the DQ to 3PH block has two inputs, D-Axis Value, Q-Axis Value. Three outputs are Phase 'A' Value, Phase 'B' Value, and Phase 'C' Value.

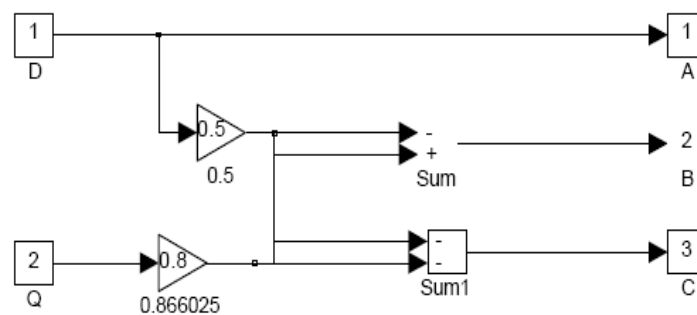


Figure 3.10 DQ to Three Phase Block

Simple gains are use to simulate the following equations which perform the transform.

$$A = D$$

$$B = 0.5D + 0.866025D$$

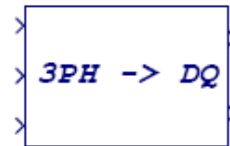


Figure 3.11 3PH to DQ

Figure 3.11 show the 3PH to DQ block has three inputs which are Phase 'A' Value, Phase 'B' Value, Phase 'C' value. The outputs are D-Axis Value, Q-Axis Value.

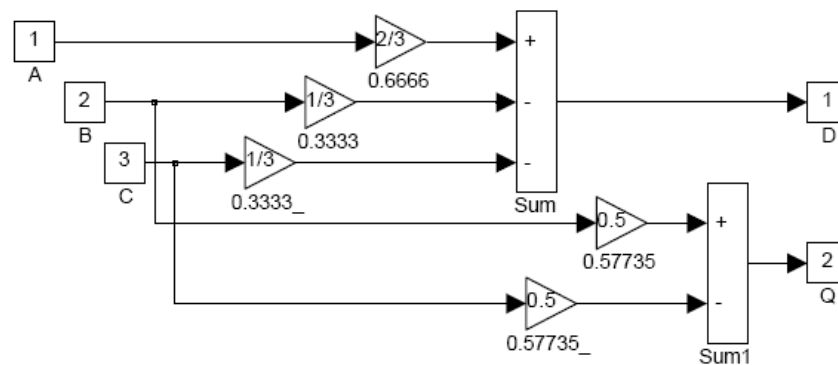


Figure3.12 Three Phases to DQ Block

Simple gains are use to simulate the following equations which perform the transform.

$$D=0.66666A - 0.333333B - 0.33333C$$

$$Q=0.57735B - 0.57735C$$

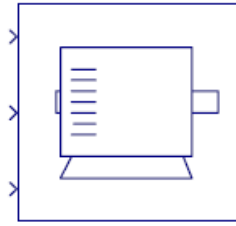


Figure 3.13 Voltage Fed

Figure 3.13 explain about the Induction Motor Model block has three inputs which are D-Axis Stator Voltage, Q-Axis Stator Voltage (stator ref. frame) and Rotor Speed (rads/sec). The outputs are D-Axis Stator Current (stator ref. frame), Q-Axis Stator Current (stator ref. frame), Electromagnetic Torque, D-Axis Rotor Current (stator ref. frame), and Q-Axis Rotor Current (stator ref. frame).

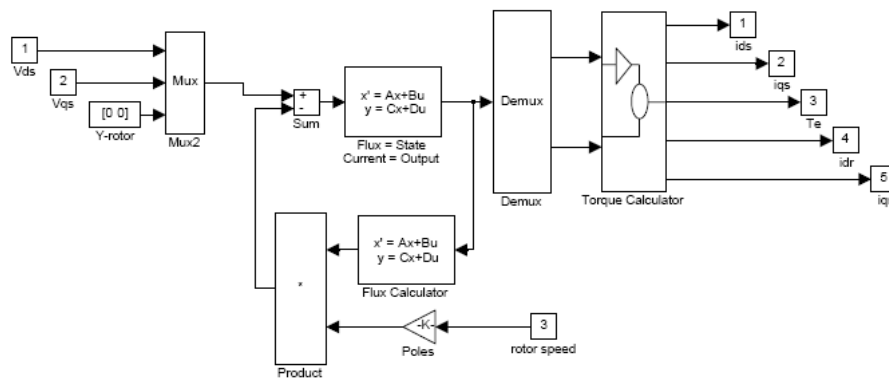


Figure 3.14 Voltage Fed Induction Motor Block

Consider, as a suitable starting point the following equations, which can be derived from the classic, twin coil DQ model of the induction motor.

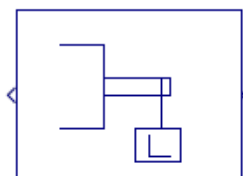


Figure 3.15 Mechanical Dynamic

Figure 3.16 shows the Mechanical Dynamics block one input, electromagnetic torque and one output, rotor speed (rads/sec).

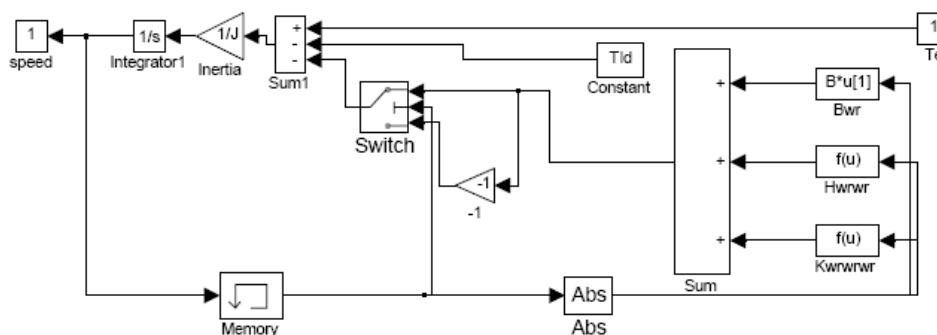


Figure 3.16 Unmasked Mechanical Dynamic Block

J, T_{ld}, B, H and K represent the various mechanical parameters and are user defined by entering their values via the block's dialogue box. There is a direction sensor switch which modifies the equation when the motor is rotating backwards, this overcomes any need to enter negative numbers for the load parameters. This is due to the fact that friction forces oppose the direction of rotation, however T_{ld} is an applied shaft torque independent of rotational direction.

3.4 Estimated Induction Motor

Here, estimated induction motor is designed using the equation. The equation got from IEEE Library. There are two equations involved which are based on stator voltages and stator currents and another one is stator currents and rotor speed.

This induction motor was designed refer to dq frame model. The choice of the common dqframe is usually dictated by the symmetry constraints imposed by the construction and excitation of the machine.

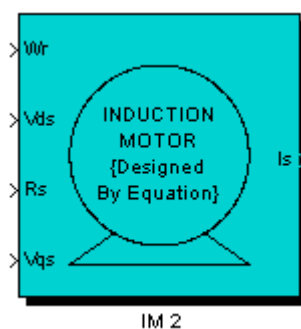


Figure 3.17 Masked Estimated Induction Motor

Figure 3.17 show block diagram of estimated induction motor. This induction is designed using mathematical model equation.

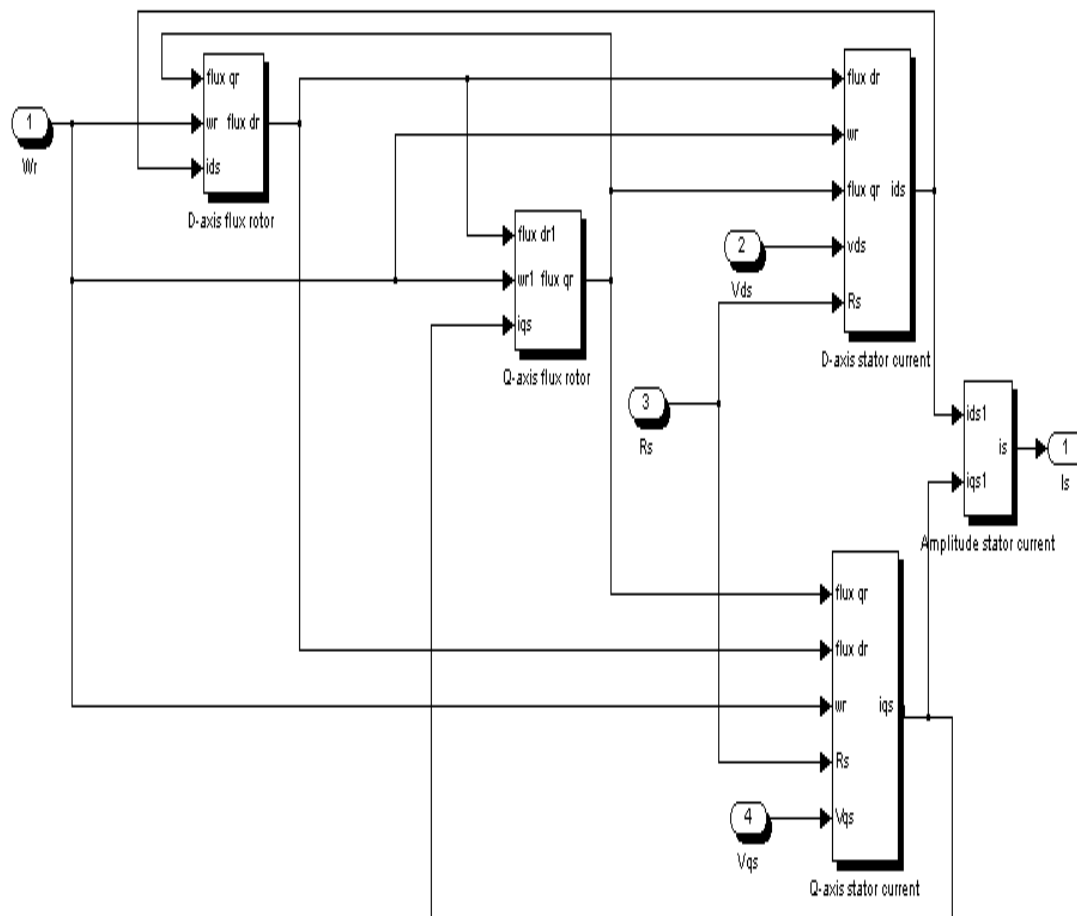


Figure 3.18 Unmasked Estimated Induction Motor

Figure 3.18 shows the block diagram of overall system estimated induction motor. This induction motor is constructed from D-axis flux rotor, Q-axis flux rotor, D-axis stator current and Q-axis stator current.

3.4.1 D-Axis Flux Rotor Model

The block showed below is for equation of D-axis flux rotor model. This block model designed using stator currents and rotor speed equation matrix.

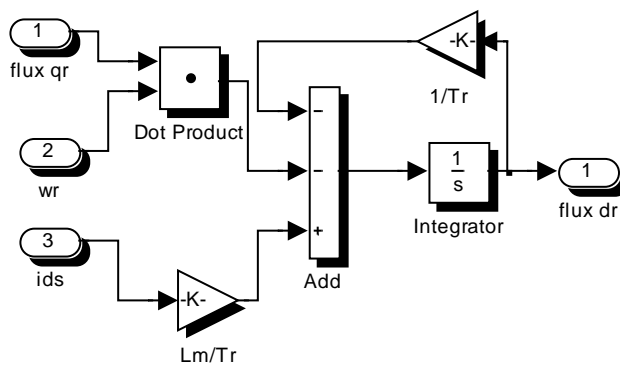


Figure 3.19 Unmasked D-axis flux rotor

$$\frac{d\lambda_{dr}^{im}}{dt} = -\frac{1}{T_r}\lambda_{dr}^{im} - \omega_r\lambda_{qr}^{im} + \frac{L_m}{T_r}i_{ds}^s \dots\dots\dots (1)$$

Figure 3.19 shows the block diagram of D-axis flux rotor. The block diagram is constructed from the equation 1.

3.4.2 Q-Axis Flux Rotor Model

The block showed below is for equation of Q-axis flux rotor model. This block model designed using stator currents and rotor speed equation matrix.

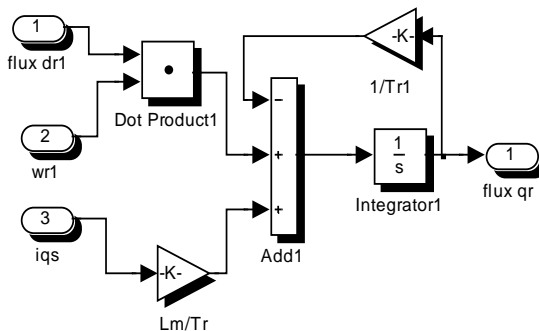


Figure 3.20 Unmasked Q-axis flux rotor

$$\frac{d\lambda_{qr}^{s\prime im}}{dt} = \omega_r \lambda_{dr}^{s\prime im} - \frac{1}{T_r} \lambda_{qr}^{s\prime im} + \frac{L_m}{T_r} i_{qs}^s \dots\dots\dots (2)$$

Figure 3.20 shows the block diagram of Q-axis flux rotor. The block diagram is constructed from the equation 2.

3.4.3 D-Axis Stator Current

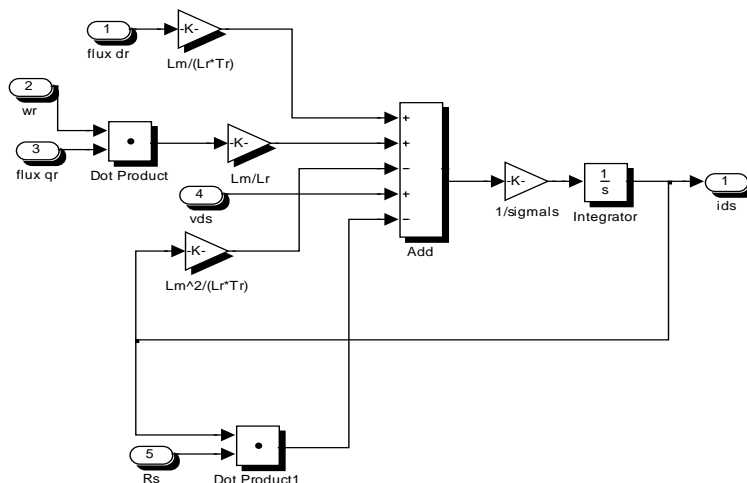


Figure 3.21 Unmasked D-axis stator current

$$\sigma L_s \frac{di_{ds}^s}{dt} = \frac{L_m}{L_r T_r} \lambda^s i_{dr}^{im} + \frac{L_m}{L_r} \omega \lambda^s i_{qr}^{im} - \frac{L_m^2}{L_r T_r} i_{ds}^s + v_{ds}^s - R_s i_{ds}^s \dots\dots\dots (3)$$

Figure 3.21 shows the block diagram of D-axis stator current. The block diagram is constructed from the equation 3.

3.4.4 Q-Axis Stator Current

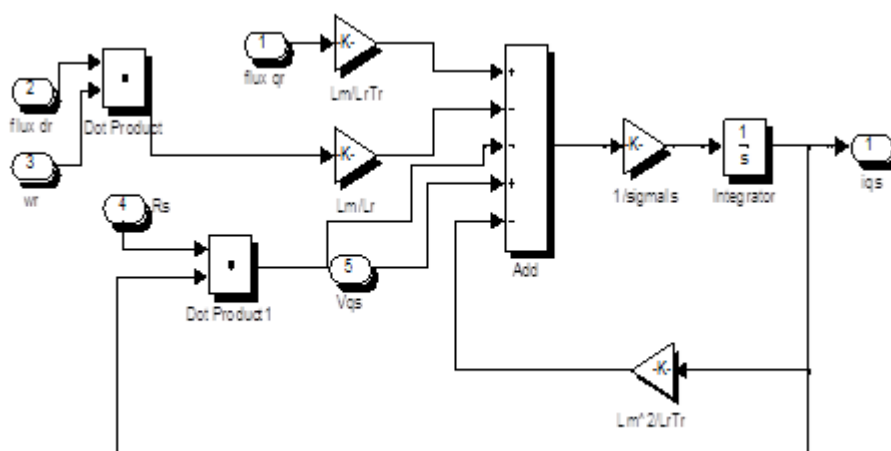


Figure 3.22 Unmasked Q-axis stator current

$$\sigma L_s \frac{di_{qs}^s}{dt} = \frac{L_m}{L_r T_r} \lambda^{sim} i_{qr}^{sim} - \frac{L_m}{L_r} \omega \lambda^{sim} i_{dr}^{sim} - \frac{L_m^2}{L_r T_r} i_{qs}^s + v_{qs}^s - R_s i_{qs}^s \dots\dots\dots (4)$$

Figure 3.22 shows the block diagram of Q-axis stator current. The block diagram is constructed from the equation 4.

3.5 Fuzzy Logic Estimator

Fuzzy logic estimator designed using fuzzy logic toolbox in MATLAB. The Fuzzy Logic Toolbox is a collection of functions built on the MATLAB numeric computing environment. It provides tools to create and edit fuzzy inference systems within the framework of MATLAB.

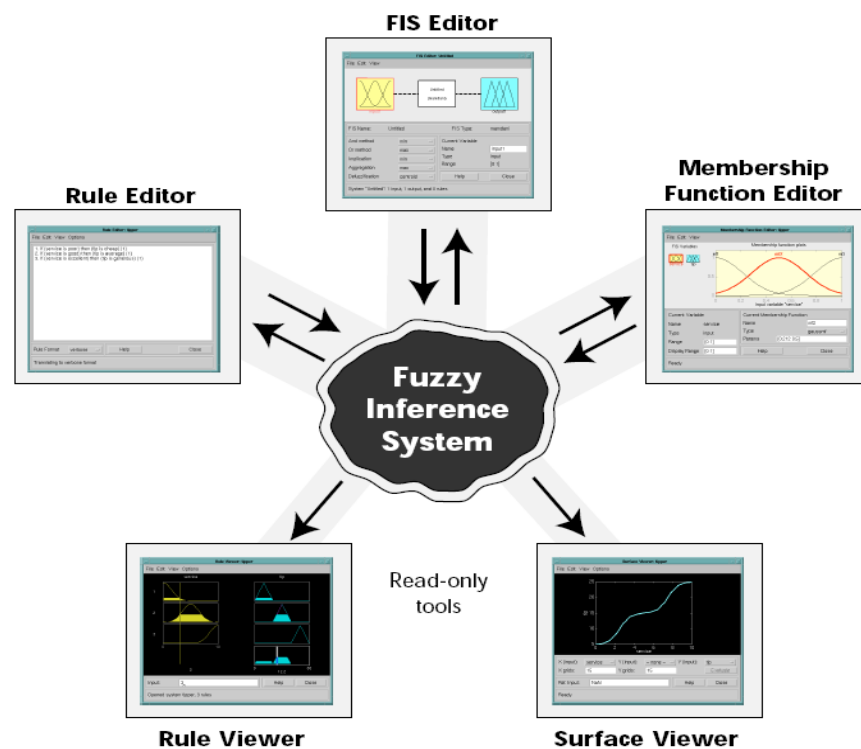


Figure 3.23 Fuzzy Inference System

Figure 3.23 shows the step to construct fuzzy logic system. The step started with fis editor, membership function, rule editor, surface viewer, and rule viewer.

3.5.1 FIS Editor

When creating a new fuzzy inference system from scratch, the place to start is the FIS Editor. To do that, type

```
>> fuzzy
```

This will call up a window that acts as the high-level view of a FIS. At the top of the figure, there's a diagram that shows inputs on the left and outputs on the right. The system that is displayed is a default start-up system, since didn't specify any particular system. The FIS Editor displays general information about a fuzzy inference system. There is a simple diagram at the top that shows the names of each input variable and each output variable.

In this project, user constructs two-input, and one output system. The two inputs are current error (CE) $e(k)$, and change in current error (CCE) $\Delta e(k)$. The one output is change in stator resistance ΔR_s .

To add a second input variable and change the variable names to reflect these designations:

1. Select Edit > Add variable > Input. A second yellow box labelled input2 appears.
2. Click the yellow box input1. This box is highlighted with a red outline.
3. Edit the name field from input1 to $e(k)$, and press enter.
4. Click the yellow box input2. This box is highlighted with a red outline.
5. Edit the Name field from input2 to $\Delta e(k)$, and press enter.
6. Click the blue box output1.
7. Edit the name field from output1 to ΔR_s , and press enter.
8. Select File > Export > To File.
9. Enter the File variable name fuzzy logic, and click OK.

The diagram is updated to reflect the new names of the input and output variables. There is now a new variable in the file called fuzzy logic that contains all the information about this system. By saving to the file with a new name, you also rename the entire system. The window looks like the following diagram.

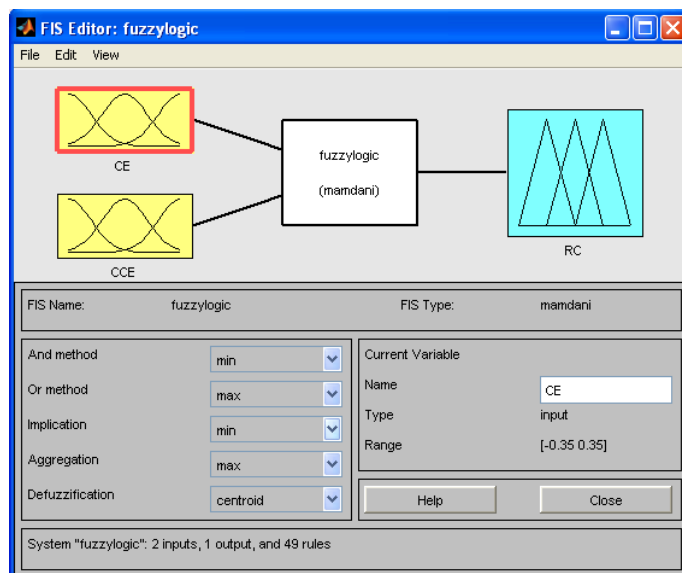


Figure 3.24 FIS Editor

Figure 3.24 shows the fis editor of fuzzy logic inference system. Here Mamdani type of fuzzy is used.

3.5.2 Membership Function Editor

The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. Here, triangle and trapezoidal function are used. Next, define the membership functions associated with each of the variables. User can open the Membership Function Editor in one of three ways:

1. Within the FIS Editor window, select Edit > Membership Functions.
2. Within the FIS Editor window, double-click the blue icon called tip.
3. At the command line, type mfeedit.

When user open the Membership Function Editor to work on a fuzzy inference system that does not already exist in the file, there are no membership functions associated with the variables that user defined with the FIS Editor. The membership functions associated with an input or an output variable for the FIS is setup. A FIS variable in this region is selected by clicking it. Next the Edit pull-down menu, and choose Add MFs is selected. A new window appears which allows user to select both the membership function type and the number of membership functions associated with the selected variable. In the lower-right corner of the window are the controls that let user change the name, type, and parameters (shape), of the membership function, after it is selected.

The process of specifying the membership functions for this project is as follows:

1. Double-click the input variable service to open the Membership Function Editor.
2. In the Membership Function Editor, enter [-0.35 0.35] in the Range and the Display Range fields.
3. Create membership functions for the input variable $e(k)$.
 - a. Select Edit > Remove All MFs to remove the default membership functions for the input variable service.
 - b. Select Edit > Add MFs. to open the Membership Functions dialog box.
 - c. In the Membership Functions dialog box, select trapmf and trimf as the MF Type.

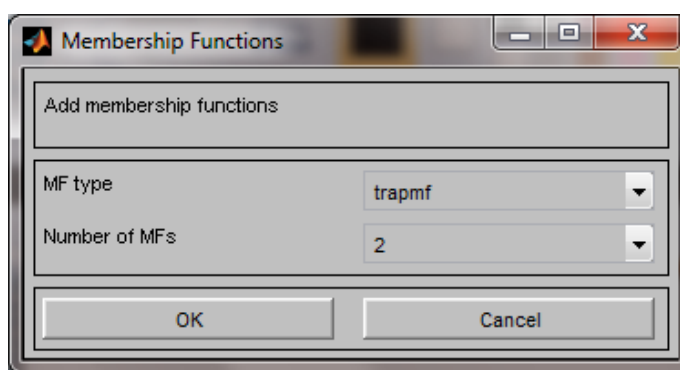


Figure 3.25 Trapezoidal membership function

Figure 3.25 shows the trapezoidal membership function. In this project, two membership functions used to create fuzzy logic estimator. This membership function used in input change current error, current error, and output, change in stator resistance.

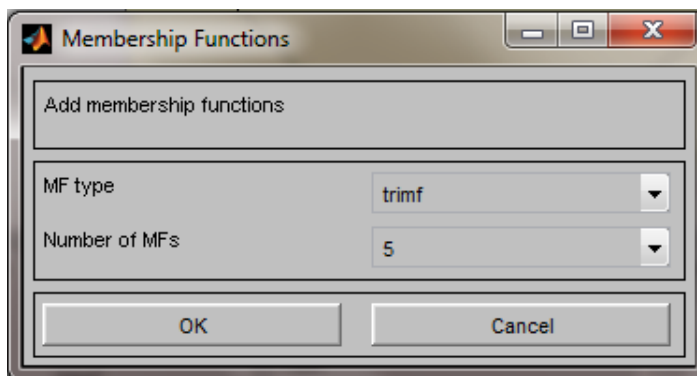


Figure 3.26 Triangular membership function

Figure 3.26 shows the trapezoidal membership function. In this project, two membership functions used to create fuzzy logic estimator. This membership function used in input change current error, current error, and output, change in stator resistance.

- d. Verify that 2 for trapmf and 5 for trimf are selected as the number of MFs.
 - e. Click OK to two curves to the input variable $e(k)$.
4. Rename the membership functions for the input variable, and specify their parameters.
 - a. Click on the curve named mf1 to select it, and specify the following fields in the Current Membership Function (click on MF to select) area:
 - In the Name field, NL.

The Membership Function Editor: fuzzylogic window looks similar to the following figure.

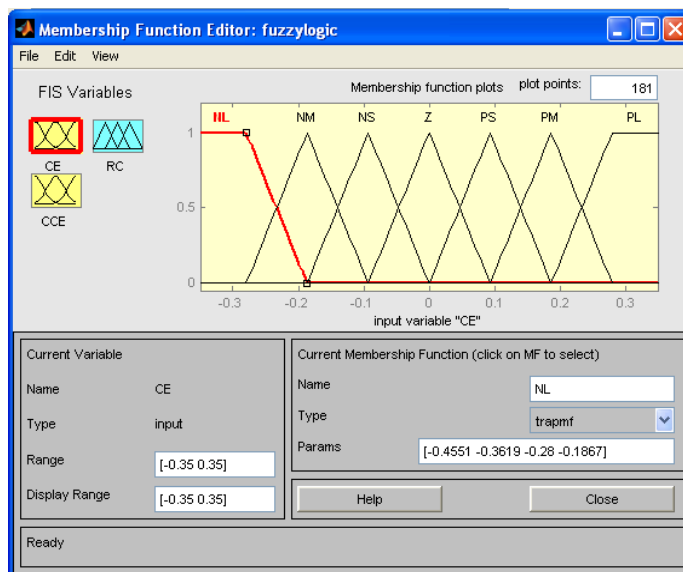


Figure 3.27 Membership Function Editor for $e(k)$

Figure 3.27 shows the membership function of current error. User can update the membership function by change the range of universe discourse, and move the membership function.

- b. Click on the curve named mf2 to select it, and specify the following fields in the Current Membership Function (click on MF to select) area:
 - In the name field, enter NM. Repeat this step for mf3, mf4, mf5, mf6, and mf7 with NS, Z, PS, PM, PL.
5. Repeat step 1 until 4b to create variables membership function for $\Delta e(k)$ and ΔR_s with different range.
6. Enter [-0.3 0.3] and [-0.2 0.2] in the Range and the Display Range fields for $\Delta e(k)$ and ΔR_s .

The window looks like the following diagram.

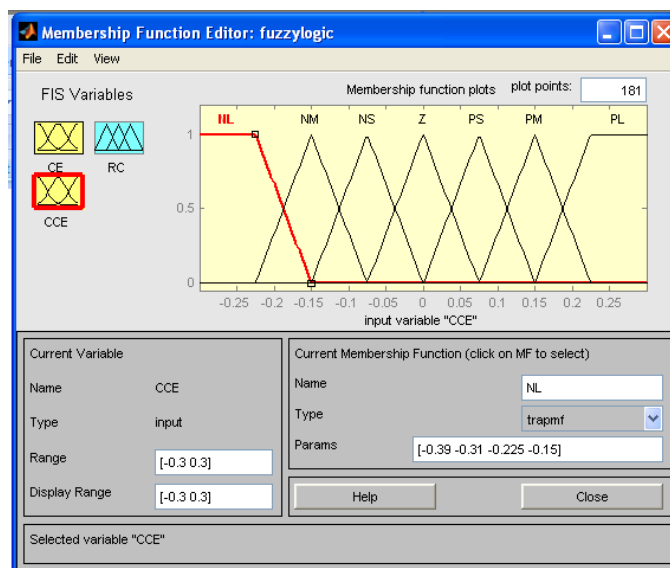


Figure 3.28 Membership Function Editor for $\Delta e(k)$

Figure 3.28 shows the membership function of input change current error. User can update the membership function by change the range of universe discourse, and move the membership function.

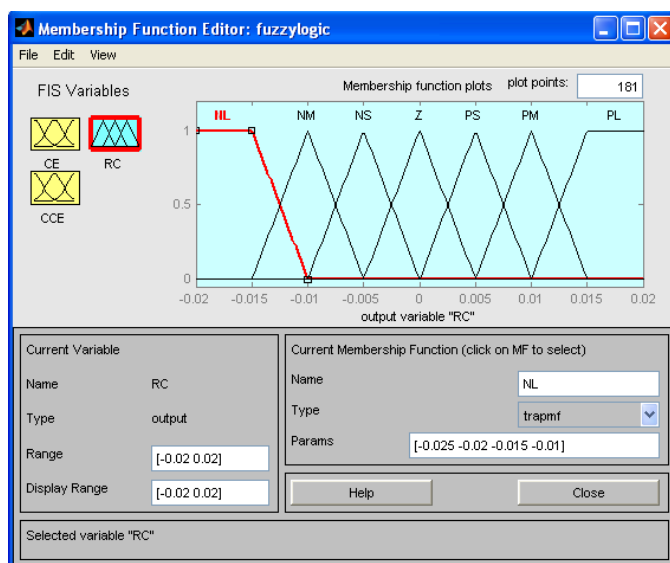


Figure 3.29 Membership Function Editor for ΔR_s

Figure 3.29 shows the membership function of output change in stator resistance. User can update the membership function by change the range of universe discourse, and move the membership function.

Now that the input and output variables have been named, and the membership functions have appropriate shapes and names, the next step is to create the rules of Fuzzy Logic. To call up the rule editor, **View** menu is gone and **Edit rules** is selected.

3.5.3 The Rule Editor

The Rule Editor contains a large editable text field for displaying and editing rules. It also has some by now familiar landmarks similar to those in the FIS Editor and the Membership Function Editor, including the menu bar and the status line. The Rule Editor is for editing the list of rules that defines the behaviour stator resistance estimation. The Rule Editor allows user to construct the rule statements automatically. Here, there are seven rules involved which are NL, NM, NS, Z, PS, PM, and PL.

1. To insert the first rule in the Rule Editor, select the following:
 - NL under the variable CE.
 - NL under the variable CCE.
 - The and radio button, in the Connection block.
 - NL under the output variable, RC.
2. Then, click Add rule.

The resulting rule is

>> If (CE is NL) and (CCE is NL) then (RC is NL) (1)

3. Repeat the step 1 until 2 to create another rule by referring the Table 3.3
The rules can reach until 49 of rules.

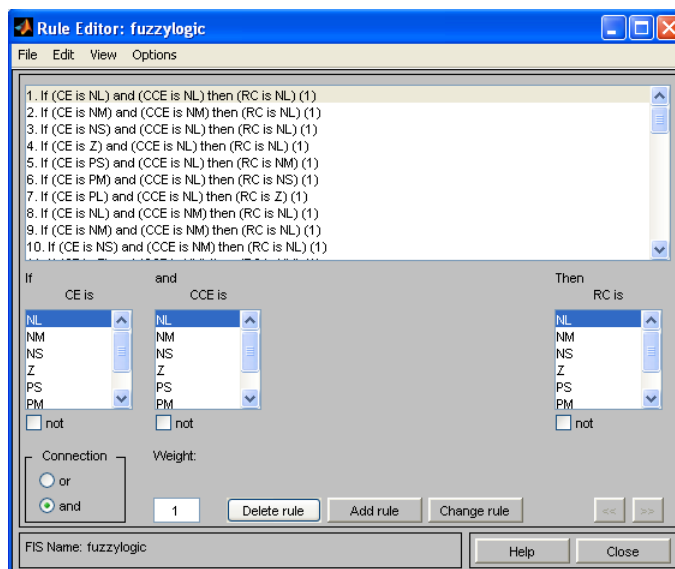


Figure 3.30 Rule Editor

Figure 3.30 shows the rule editor of fuzzy logic estimator.

Table 3.3: Rule base for the fuzzy stator resistance estimator

		Current Error						
		NL	NM	NS	Z	PS	PM	PL
Change In Current Error	NL	NL	NL	NL	NL	NM	NS	Z
	NM	NL	NL	NL	NM	NS	Z	PS
	NS	NL	NL	NM	NS	Z	PS	PM
	Z	NL	NM	NS	Z	PS	PM	PL
	PS	NM	NS	Z	PS	PM	PL	PL
	PM	NS	Z	PS	PM	PL	PL	PL
	PL	Z	PS	PM	PL	PL	PL	PL

3.5.4 The Rule Viewer

The Rule Viewer displays a roadmap of the whole fuzzy inference process. It is based on the fuzzy inference diagram described in the previous section. User can see each rule is a row of plots, and each column is a variable. The rule numbers are displayed on the left of each row. User can click on a rule number to view the rule in the status line.

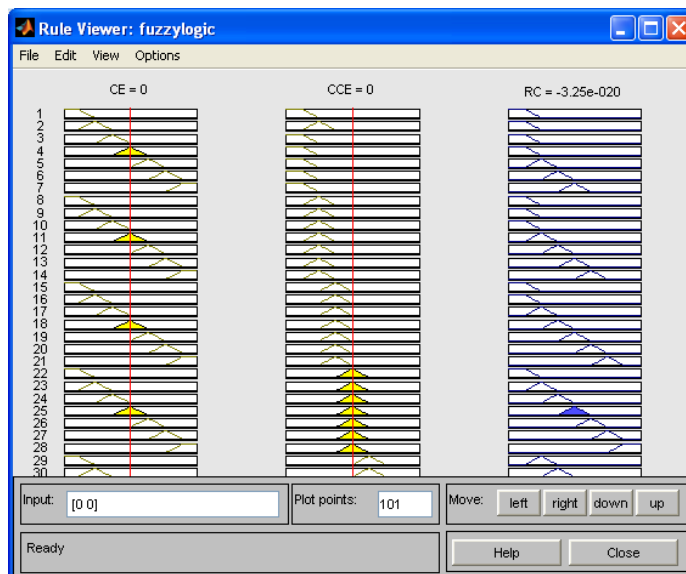


Figure 3.31 Rule Viewer

Figure 3.31 shows the rule viewer. The first two columns of plots (the six yellow plots) show the membership functions referenced by the antecedent, or the if-part of each rule. The third column of plots (the three blue plots) shows the membership functions referenced by the consequent, or the then-part of each rule.

User can shift the plots using left, right, down, and up. The menu items allow user to save, open, or edit a fuzzy system using any of the five basic GUI tools. The Rule Viewer also shows how the shape of certain membership functions influences the overall result. Because it plots every part of every rule, it can become unwieldy for particularly large systems, but, for a relatively small number of inputs and outputs, it performs well (depending on how much screen space devote to it) with up to 30 rules and as many as 6 or 7 variables. The Rule Viewer shows one calculation at a time and in great detail. In this sense, it presents a sort of micro view of the fuzzy inference system.

3.5.5 The Surface Viewer

Upon opening the Surface Viewer, three-dimensional curve that represents the mapping from current error, change in current error and change in stator resistances is seen. Because this curve represents a two-input and one-output case, user can see the entire mapping in one plot.

Clicking Evaluate initiates the calculation, and the plot is generated after the calculation is complete. To change the x-axis or y-axis grid after the surface is in view, change the appropriate input field, and press Enter. The surface plot is updated to reflect the new grid settings.

The Surface Viewer has a special capability that is very helpful in cases with two (or more) inputs and one output. User can grab the axes, using the mouse and reposition them to get a different three-dimensional view on the data. When user move beyond three dimensions overall, user can start to encounter trouble displaying the results.

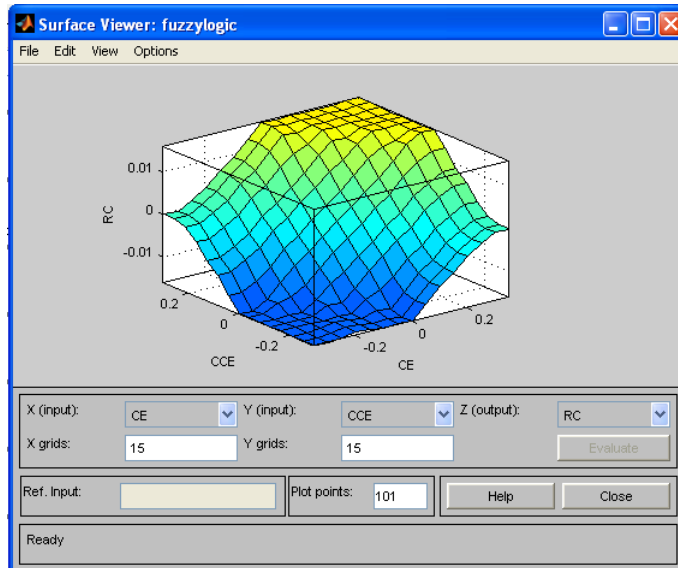


Figure 3.32 Control surface of fuzzy stator resistance estimator

Figure 3.32 tools can display how change in stator resistance as the output depends on two of the inputs which are current error and change in current error.

CHAPTER IV

RESULT & DISCUSSION

4.1 Introduction

This chapter discusses all the results obtained from the simulation using MATLAB software. The discussions included no load, on load, and stator resistance estimation of induction motor and resistance estimation of induction motor using fuzzy logic.

4.2 No Load Analysis

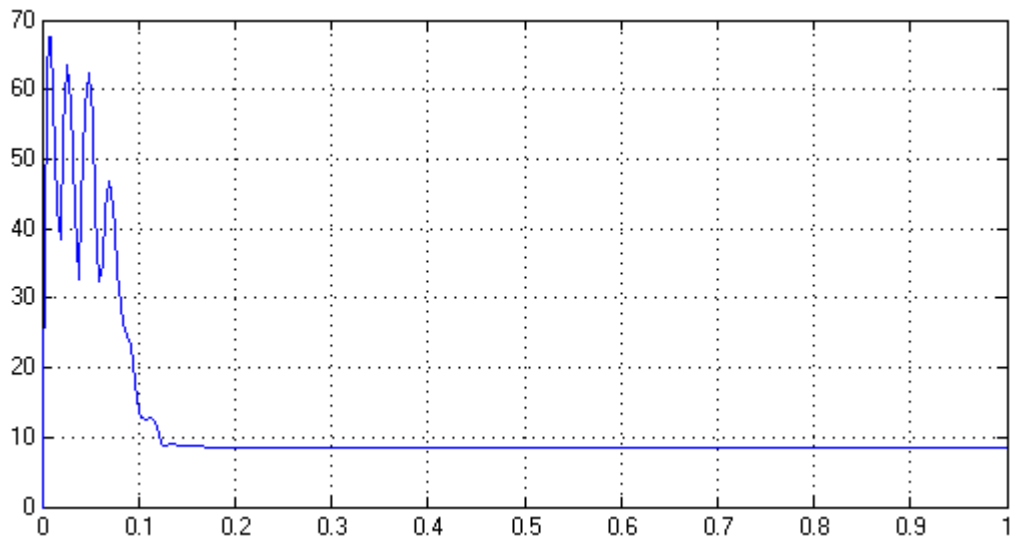


Figure 4.1 Stator Current $I_s(k)$ at no load

Figure 4.1 shows maximum current achieved by induction motor is 68 A at 0.025 seconds. The induction motor needs high starting current during turned on. After 0.025 seconds, the current of stator is slowly decreased. At the same time, the current induced at rotor also slowly down. After 0.2 seconds the current is constant, which is 8.5 A. The current is still needed even though there is no load at induction motor. The magnetizing current needed to establish a magnetic field is quite large in an induction motor, because of the high reluctance of its air gap. Here, there is no load at induction motor. The only load on the motor is the friction and winding losses.

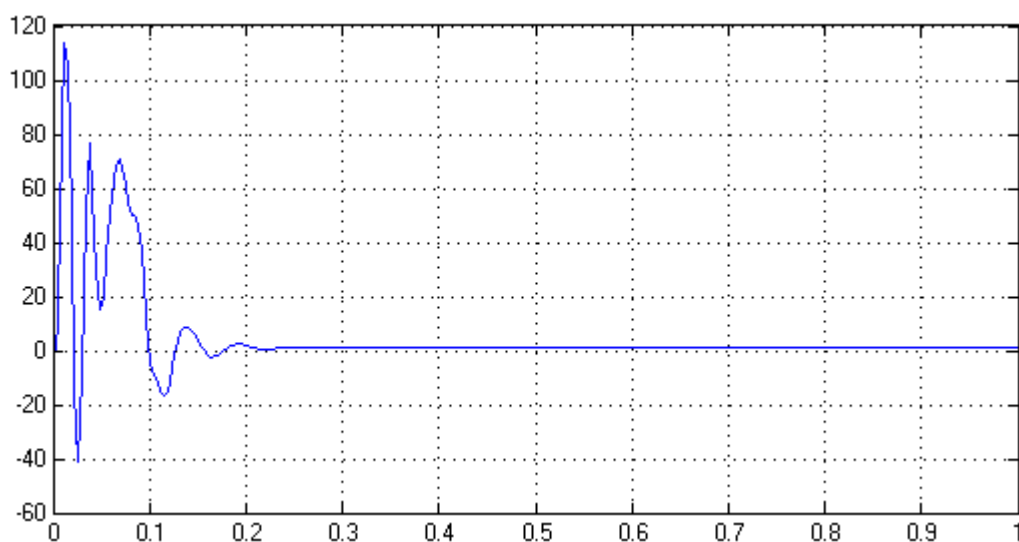


Figure 4.2 Torque at no load

A figure 4.2 show maximum (pullout) torque achieves is 118 N-m. Here, the maximum torque occurs when the rotor is in stationary condition. At this time, the relative positions of the rotor and the stator field are as different as possible. Maximum voltage is induced into the rotor, and the larger amount of torque is created. At 0.05 seconds until 0.2 seconds, the value of torque is slowly decreased. At this time, the speed of rotor is slowly increased. When speed of rotor is increased, the voltage induced to rotor is decreased and the torque produced is also reduced. At 0.22 seconds, the torque is zero. At this moment, the synchronous speed and speed of rotor have reached the same speed. There is no load during this time.

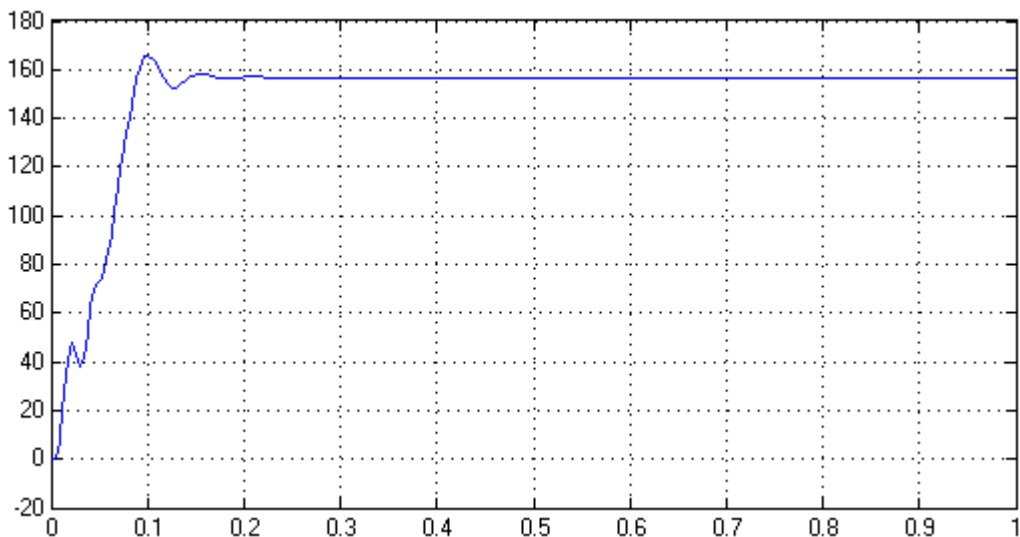


Figure 4.3 Speed of rotor at no load

Figure 4.3 show speed of rotor is increased starting from 0 rad/s to 116 rad/s. At 0.2 seconds until 0.4 seconds, the speed is constant which is 157 rad/s. Here, the speed of rotor is constant. There is no load during the operation starting 0.2 seconds.

4.3 On Load Analysis

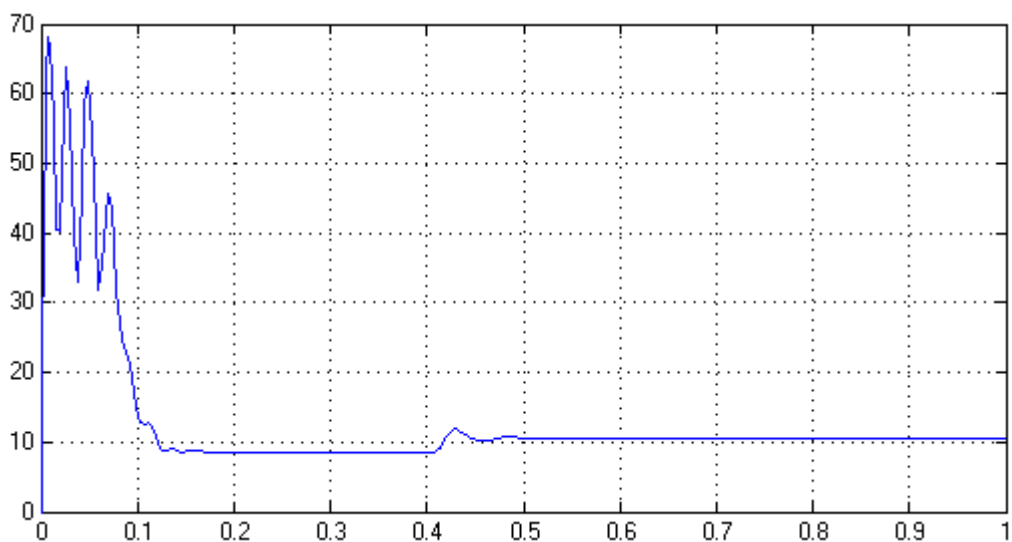


Figure 4.4 Stator Current $I_s(k)$ at on load

Figure 4.4 explain about the maximum current achieved by induction motor is 68 A at 0.025 seconds. The induction motor needs high starting current during turned on. After that, the current of stator is slowly decreased. This happened because the speed of rotor is slowly increased. At the same time, the voltage induced also slowly down. At 0.2 until 0.4 seconds, the value of current is constant which is 8.5 A. Here, the speed of rotor and revolution per minute of stator is almost being the same. Initially, the three-phase induction motor runs on no-load and after 0.41 second, it runs on full-load. At 0.41 seconds the current start increased again which is 11.8 A. At this moment, rotor need more induced current to pull the inertia of load. When the speed of rotor stabled, the induced current being constant, which is 10.5 A.

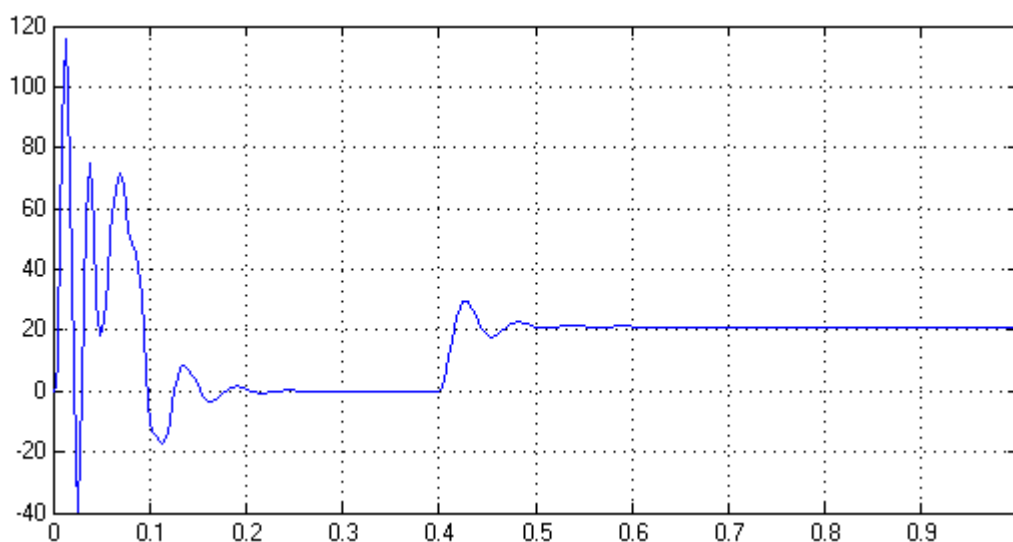


Figure 4.5 Torque at on load

Figure 4.5 show maximum (pullout) torque archived is 118 Nm. Here, the maximum torque occurs when the rotor is in stationary condition. At this time, the relative positions of the rotor and the stator field are as different as possible. Maximum voltage is induced into the rotor, and the larger amount of torque is created. At 0.05 seconds until 0.2 seconds, the value of torque is slowly decreased. At this time, the speed of rotor is increased. The torque produced is reduced. At 0.22 seconds until 0.4 seconds, the torque of induction is zero. At this moment, the synchronous speed and speed of rotor have reached the same speed. The slip is equal to zero. Initially, the three-phase induction motor runs on no-load and after 0.4 second, it runs on full-load. At 0.4 second, the torque rise again until 30 Nm. At this

time, the speed of rotor is slow down, and larger amount of voltage is developed. The rise of torque is needed to overcome the static inertia of load.

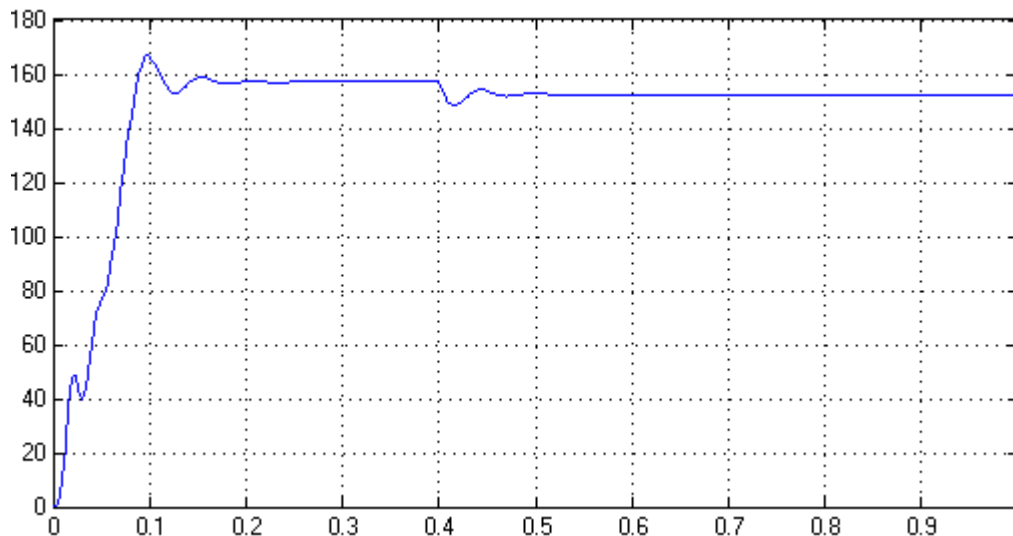


Figure 4.6 Speed of rotor at on load.

Figure 4.15 explain about speed of rotor is increased starting from 0 rad/s to 116 rad/s. At 0.2 until 0.4 seconds, the speed is constant which is 157 rad/s. Here, the speed of rotor is constant. There is no load during the operation start 0.2 until 0.4 seconds. Initially, the three-phase induction motor runs on no-load and after 0.4 second, it runs on full-load causes the speed of rotor is decreased to 148.3 rad/s at 0.4 seconds.

4.4 Stator Resistance Estimation Analysis

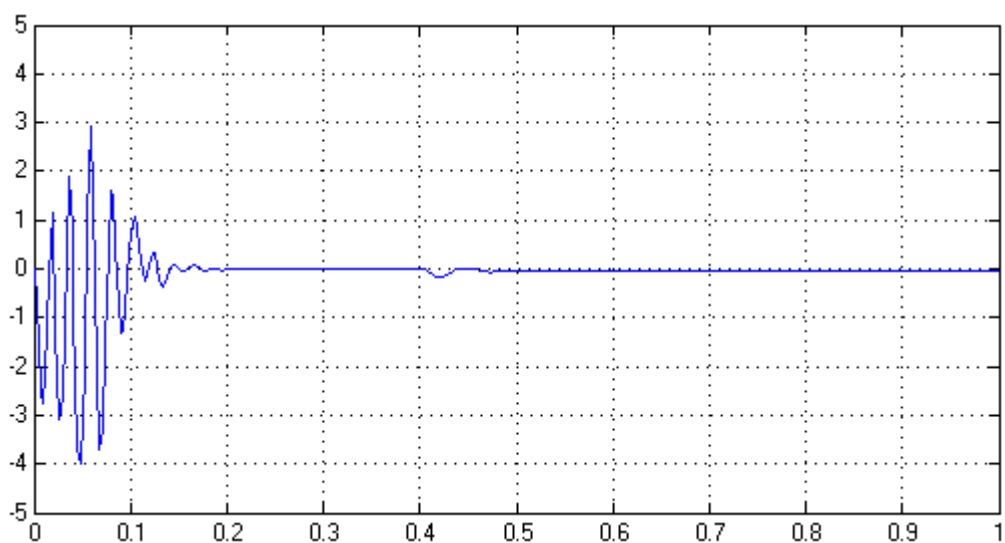


Figure 4.7 Current error between actual and estimated induction motor

Figure 4.7 shows the differences between the actual stator current with estimated stator current of induction motor. The error between the estimated stator current $I_s(k)$ and the measured stator current $I_s(k)$ is used to determine the incremental value of stator resistance (ΔR_s) through a fuzzy estimator.

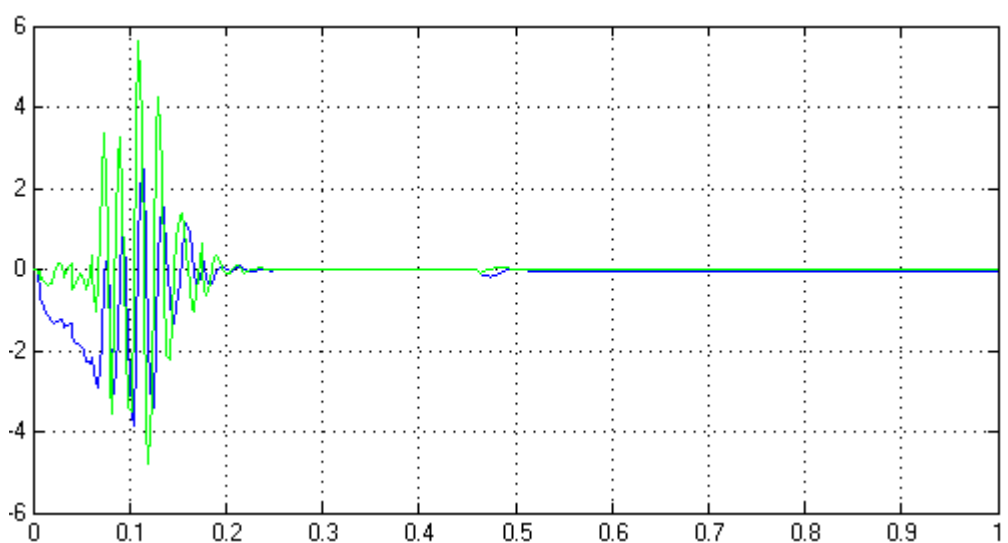


Figure 4.8 Combination of current error $e(k)$, and change in current error $\Delta e(k)$

Figure 4.8 shows the current error $e(k)$ and change in current error $\Delta e(k)$. The green colour representative of $e(k)$, while blue colour representatives of $\Delta e(k)$. Both these error are inputs to the fuzzy estimator. The change in current error is created using unit delay in MATLAB software.

$$e(k) = \Delta I_s(k) = I_s^k(k) - I_s(k)$$

$$\Delta e(k) = e(k) - e(k-1)$$

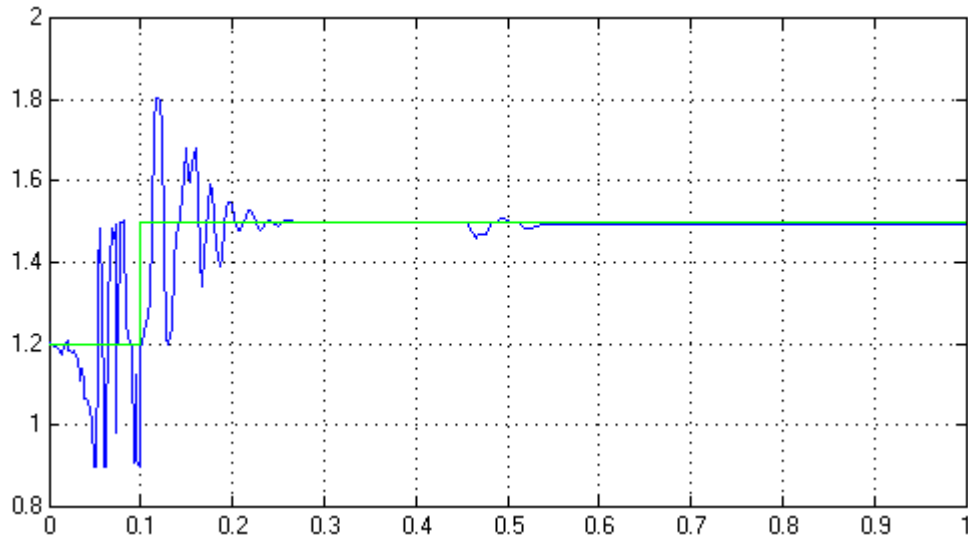


Figure 4.9 Stator Resistance at 1.5

Figure 4.9 show the stator resistance and estimated stator resistance of induction motor during 1.5 Ω . To test the stator resistance estimation, an additional 0.3 Ω is added in series with the induction motor stator. At 0 until 0.12 seconds, the value of estimated R_s is increased till 1.8 Ω . After that, the estimated R_s is dropped to 1.5 Ω . The stator resistance estimators can converge in a short time, as low in 50 milliseconds. However there are some small errors between the measured and estimated stator resistance.

The Simulations are also executed in different initial values of stator resistance, R_s which are 1.6 Ω and 1.7 Ω . These simulations showing the differences of stator resistance between estimated and actual induction motor of stator resistance.

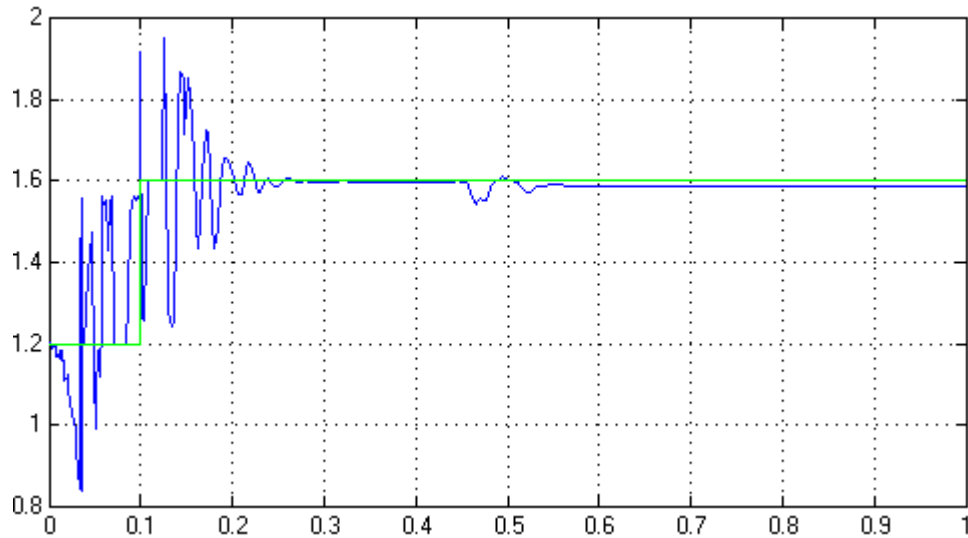


Figure 4.10 Stator Resistance at 1.6Ω

Figure 4.10 show the stator resistance and estimated stator resistance of induction motor during 1.6Ω . To test the stator resistance estimation, an additional 0.4Ω is added in series with the induction motor stator. At 0 until 0.12 seconds, the value of estimated R_s is increased till 1.95Ω . After that, the estimated of R_s is dropped to 1.6Ω . After that, the estimated stator resistance follow the measured of stator resistance.

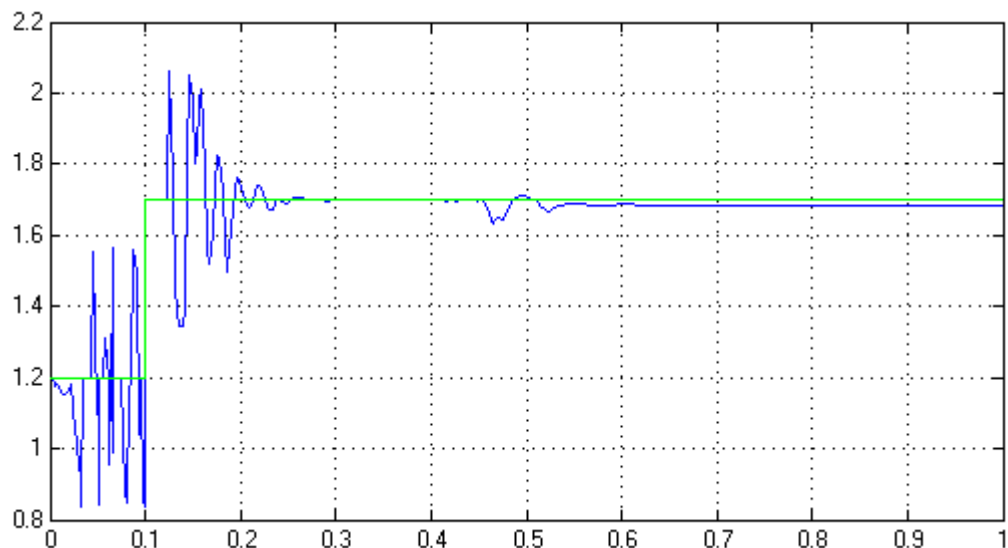


Figure 4.11 Stator Resistance at 1.7Ω

Figure 4.11 shows the stator resistance and estimated stator resistance of induction motor during 1.7Ω . To test the stator resistance estimation, an additional

0.5 Ω is added in series with the induction motor stator. At 0 until 0.12 seconds, the value of estimated R_s is increased till 2.1 Ω . After that, the estimated of R_s is dropped to 1.7 Ω . After that, the estimated stator resistance follow the measured of stator resistance.

CHAPTER V

CONCLUSION & RECOMMENDATION

5.1 Conclusion

The main objective of this project is to develop stator resistance estimation by using Fuzzy Logic. Fuzzy Logic acted as an observer for stator resistance to eliminate the error in rotor resistance estimation.

All objectives and scopes in this project have been covered and the system is properly running. By using MATLAB the simulation running as desired. When the stator currents on both induction motors are compared, the Fuzzy Logic observer will act as estimator to estimate the value of stator resistance produced by the induction motor. The increasing of stator resistance is measured and then the correction is made to stabilize the system.

Hopefully, this project can be a platform for electrical engineer in our industry to solve the problem about error in rotor resistance that can leads the induction motor from the breakdown in worst cases.

5.2 Problem Encountered

There are few problems that had been encountered while doing this project such as the correction of stator resistance and rule of fuzzy logic.

i) Correction of Stator Resistance

Stator resistance should be corrected to stabilize the system. Here, closed loop transfer function must be used to improve the system stability. However, during closed loop transfer function is applied, the simulation is failed to debug. There is have clashed between the closed loop transfer function from adding R_s and input of R_s .

ii) Rule of Fuzzy Logic

User need to try and error to develop the suitable rule of fuzzy logic according the problem faced. Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than accurate. The problem in applying this is that the appropriate fuzzy operator may not be known.

5.3 Future Recommendations

For further research, there are two recommendations to enhance and improve this project:

i) Use Neural Network and Neurofuzzy as other methods.

Neural Network and Neurofuzzy also are modern artificial intelligent same goes to fuzzy logic that can act as observer in estimating stator

resistance. From the result obtained, student can compared which one among those methods is the best.

ii) Combination of Software And Hardware

Combination of software and hardware can make this project more realistic in the real world. The software can use to control an induction motor by online tuning method of stator resistance, and the hardware is use to prove the simulation that error in rotor resistance depends on the stator resistance of induction motor.

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APPENDIX A

Mathematical Expressions for Estimated Induction Motor

Stator voltage and current model equation

$$\begin{bmatrix} \frac{d\lambda^{s\ vm}_{dr}}{dt} \\ \frac{d\lambda^{s\ vm}_{qr}}{dt} \end{bmatrix} = \frac{L_r}{L_m} \left\{ \begin{bmatrix} v^s_{ds} \\ v^s_{qs} \end{bmatrix} - R_s \begin{bmatrix} i^s_{ds} \\ i^s_{qs} \end{bmatrix} - \sigma L_s \begin{bmatrix} \frac{di^s_{ds}}{dt} \\ \frac{di^s_{qs}}{dt} \end{bmatrix} \right\}$$

Stator current and rotor speed model equation

$$\begin{bmatrix} \frac{d\lambda^{s\ im}_{dr}}{dt} \\ \frac{d\lambda^{s\ im}_{qr}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_r} & -\omega_r \\ \omega_r & -\frac{1}{T_r} \end{bmatrix} \begin{bmatrix} \lambda^{s\ im}_{dr} \\ \lambda^{s\ im}_{qr} \end{bmatrix} + \frac{L_m}{T_r} \begin{bmatrix} i^s_{ds} \\ i^s_{qs} \end{bmatrix}$$

D-Axis Flux Rotor Model

$$\frac{d\lambda^{s\ im}_{dr}}{dt} = -\frac{1}{T_r} \lambda^{s\ im}_{dr} - \omega_r \lambda^{s\ im}_{qr} + \frac{L_m}{T_r} i^s_{ds}$$

Q-Axis Flux Rotor Model

$$\frac{d\lambda^{s\ im}_{qr}}{dt} = \omega_r \lambda^{s\ im}_{dr} - \frac{1}{T_r} \lambda^{s\ im}_{qr} + \frac{L_m}{T_r} i^s_{qs}$$

D-Axis Stator Current

$$\begin{aligned} \frac{L_m d\lambda_{dr}^{s\ vm}}{L_r dt} &= v_{ds}^s - R_s i_{ds}^s - \sigma L_s \frac{di_{ds}^s}{dt} \\ \sigma L_s \frac{di_{ds}^s}{dt} &= -\frac{L_r d\lambda_{dr}^{s\ vm}}{L_m dt} + v_{ds}^s - R_s i_{ds}^s \\ \frac{d\lambda_{dr}^{im}}{dt} &= \left(-\frac{1}{T_r} \lambda_{dr}^{s\ im} \right) + \left(-\omega \lambda_{qr}^{s\ im} \right) + \frac{L_m}{T_r} i_{ds}^s \\ \sigma L_s \frac{di_{ds}^s}{dt} &= -\frac{L_m}{L_r} \left[\left(-\frac{1}{T_r} \lambda_{dr}^{s\ im} \right) + \left(-\omega \lambda_{qr}^{s\ im} \right) + \frac{L_m}{T_r} i_{ds}^s \right] + v_{ds}^s - R_s i_{ds}^s \\ \sigma L_s \frac{di_{ds}^s}{dt} &= \frac{L_m}{L_r T_r} \lambda_{dr}^{s\ im} + \frac{L_m}{L_r} \omega \lambda_{qr}^{s\ im} - \frac{L_m^2}{L_r T_r} i_{ds}^s + v_{ds}^s - R_s i_{ds}^s \end{aligned}$$

Q-Axis Stator Current

$$\begin{aligned} \frac{L_m d\lambda_{dr}^{s\ vm}}{L_r dt} &= v_{qs}^s - R_s i_{qs}^s - \sigma L_s \frac{di_{qs}^s}{dt} \\ \sigma L_s \frac{di_{qs}^s}{dt} &= -\frac{L_m d\lambda_{dr}^{s\ vm}}{L_r dt} + v_{qs}^s - R_s i_{qs}^s \\ \frac{d\lambda_{qr}^{im}}{dt} &= \left(-\frac{1}{T_r} \lambda_{qr}^{s\ im} \right) + \left(\omega_r \lambda_{dr}^{s\ im} \right) + \frac{L_m}{T_r} i_{qs}^s \\ \sigma L_s \frac{di_{qs}^s}{dt} &= -\frac{L_m}{L_r} \left[\left(-\frac{1}{T_r} \lambda_{qr}^{s\ im} \right) + \left(\omega_r \lambda_{dr}^{s\ im} \right) + \frac{L_m}{T_r} i_{qs}^s \right] + v_{qs}^s - R_s i_{qs}^s \\ \sigma L_s \frac{di_{qs}^s}{dt} &= \frac{L_m}{L_r T_r} \lambda_{qr}^{s\ im} - \frac{L_m}{L_r} \omega_r \lambda_{dr}^{s\ im} - \frac{L_m^2}{L_r T_r} i_{qs}^s + v_{qs}^s - R_s i_{qs}^s \end{aligned}$$

D-axis stator current

$$\begin{aligned} \frac{di_{ds}^s}{dt} &= \frac{L_m}{\sigma L_s L_r T_r} \lambda_{dr}^{s\ im} + \frac{L_m}{\sigma L_s L_r} \omega_r \lambda_{qr}^{s\ im} - \frac{L_m^2}{\sigma L_s L_r T_r} i_{ds}^s + \frac{v_{ds}^s}{\sigma L_s} - \frac{R_{ds}^s}{\sigma L_s} i_{ds}^s \\ \int \frac{di_{ds}^s}{dt} &= \int \frac{L_m}{\sigma L_s L_r T_r} \lambda_{dr}^{s\ im} dt + \int \frac{L_m}{\sigma L_s L_r} \omega_r \lambda_{qr}^{s\ im} dt - \int \frac{L_m^2}{\sigma L_s L_r T_r} i_{ds}^s dt + \int \frac{v_{ds}^s}{\sigma L_s} dt - \int \frac{R_{ds}^s}{\sigma L_s} dt \end{aligned}$$

$$\begin{aligned}
i_{ds}^s(k) &= \frac{L_m T_s}{\sigma L_s L_r T_r} \lambda^{s\ im}(k-1) + \frac{L_m T_s}{\sigma L_s L_r} \omega_r \lambda^{s\ im}_{qr}(k-1) + \frac{v_{ds}^s T_s}{\sigma L_s}(k-1) - \frac{R_{ds}^s T_s}{\sigma L_s} i_{ds}^s(k-1) + \left(1 - \frac{L_m^2 T_s}{\sigma L_s L_r T_r}\right) i_{ds}^s(k-1) \\
i_{ds}^s(k) &= \left(1 - \frac{L_m^2 T_s}{\sigma L_s L_r T_r} - \frac{R_{ds}^s T_s}{\sigma L_s}\right) i_{ds}^s(k-1) + \frac{L_m T_s}{\sigma L_s L_r T_r} \lambda^{s\ im}(k-1) + \frac{L_m T_s}{\sigma L_s L_r} \omega_r \lambda^{s\ im}_{qr}(k-1) + \frac{v_{ds}^s T_s}{\sigma L_s}(k-1) \\
i_{ds}^{*s}(k) &= \left(1 + \frac{L_m^2 T_s}{\sigma L_s L_r T_r} + \frac{R_{ds}^s T_s}{\sigma L_s}\right) i_{ds}^s(k-1) + \frac{L_m T_s}{\sigma L_s L_r T_r} \lambda^{s\ im}(k-1) + \frac{L_m T_s}{\sigma L_s L_r} \omega_r \lambda^{s\ im}_{qr}(k-1) + \frac{v_{ds}^s T_s}{\sigma L_s}(k-1) \\
i_{ds}^{*s}(k) &= W_4 i_{ds}^{*s}(k-1) + W_5 \lambda^{s\ im}(k-1) + W_6 \omega_r \lambda^{s\ im}_{qr}(k-1) + W_7 v_{ds}^s(k-1)
\end{aligned}$$

Q-axis stator current

$$\begin{aligned}
\frac{di_{qs}^s}{dt} &= \frac{L_m}{\sigma L_s L_r T_r} \lambda^{sim}_{qr} - \frac{L_m}{\sigma L_s L_r} \omega_r \lambda^{sim}_{dr} - \frac{L_m^2}{\sigma L_s L_r T_r} i_{qs}^s + \frac{v_{qs}^s}{\sigma L_s} - \frac{R_{qs}^s i_{qs}^s}{\sigma L_s} \\
\int \frac{di_{qs}^s}{dt} &= \int \frac{L_m}{\sigma L_s L_r T_r} \lambda^{sim}_{qr} dt - \int \frac{L_m}{\sigma L_s L_r} \omega_r \lambda^{sim}_{dr} dt - \int \frac{L_m^2}{\sigma L_s L_r T_r} i_{qs}^s dt + \int \frac{v_{qs}^s}{\sigma L_s} dt - \int \frac{R_{qs}^s i_{qs}^s}{\sigma L_s} dt \\
i_{qs}^s(k) &= \frac{L_m T_s}{\sigma L_s L_r T_r} \lambda^{s\ im}_{qr}(k-1) - \frac{L_m T_s}{\sigma L_s L_r} \omega_r \lambda^{s\ im}_{dr}(k-1) + \frac{v_{qs}^s T_s}{\sigma L_s}(k-1) - \frac{R_{qs}^s T_s}{\sigma L_s} i_{qs}^s(k-1) + \left(1 - \frac{L_m^2 T_s}{\sigma L_s L_r T_r}\right) i_{qs}^s(k-1) \\
i_{qs}^s(k) &= \left(1 - \frac{L_m^2 T_s}{\sigma L_s L_r T_r} - \frac{R_{qs}^s T_s}{\sigma L_s}\right) i_{qs}^s(k-1) + \frac{L_m T_s}{\sigma L_s L_r T_r} \lambda^{s\ im}_{qr}(k-1) - \frac{L_m T_s}{\sigma L_s L_r} \omega_r \lambda^{s\ im}_{dr}(k-1) + \frac{v_{qs}^s T_s}{\sigma L_s}(k-1) \\
i_{qs}^{*s}(k) &= \left(1 + \frac{L_m^2 T_s}{\sigma L_s L_r T_r} + \frac{R_{qs}^s T_s}{\sigma L_s}\right) i_{qs}^s(k-1) + \frac{L_m T_s}{\sigma L_s L_r T_r} \lambda^{s\ im}_{qr}(k-1) - \frac{L_m T_s}{\sigma L_s L_r} \omega_r \lambda^{s\ im}_{dr}(k-1) + \frac{v_{qs}^s T_s}{\sigma L_s}(k-1) \\
i_{qs}^{*s}(k) &= W_4 i_{qs}^{*s}(k-1) + W_5 \lambda^{s\ im}_{qr}(k-1) - W_6 \omega_r \lambda^{s\ im}_{dr}(k-1) + W_7 v_{qs}^s(k-1)
\end{aligned}$$

Coefficients

$$W_4 = 1 + \frac{T_s}{\sigma L_s} \frac{L_m^2}{L_r T_r} + \frac{T_s}{\sigma L_s} R_s, \quad W_5 = \frac{T_s}{\sigma L_s} \frac{L_m}{L_r T_r}, \quad W_6 = \frac{T_s L_m}{\sigma L_s L_r} \omega_r, \quad W_7 = \frac{T_s}{\sigma L_s}$$

The amplitude of the stator current

$$i_s^*(k) = \sqrt{i_{ds}^{*s}(k)^2 + i_{qs}^{*s}(k)^2}$$

APPENDIX B

M-File for Graphical User Interface (GUI)

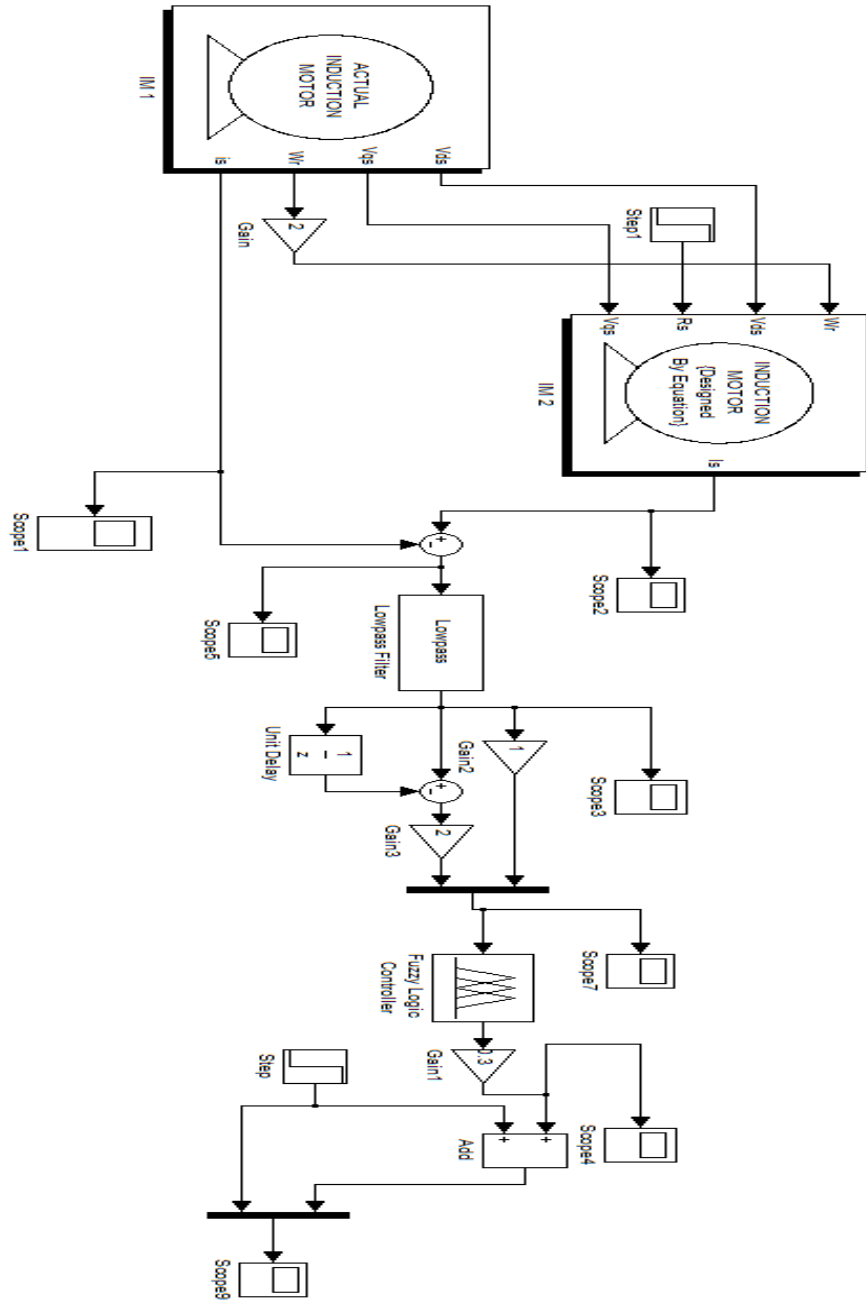
```

% PROJEK SARJANA MUDA
clc,clear,close all
mohdakmal=menu('PROJEK SARJANA MUDA',...
    'ACTUAL INDUCTION MOTOR',...
    'EQUATION INDUCTION MOTOR',...
    'FUZZY LOGIC CONTROLLER',...
    'A STATOR RESISTANCE ESTIMATION OF INDUCTION MOTOR USING
FUZZY LOGIC',...
    'CLOSE');
mohdakmal1=num2str(mohdakmal);
switch mohdakmal1
    case '1',
        mohdakmal2=menu('ACTUAL INDUCTION MOTOR:',...
            'ACTUAL INDUCTION MOTOR NO LOAD',...
            'ACTUAL INDUCTION MOTOR ON LOAD',...
            'RETURN');
        mohdakmal3=num2str(mohdakmal2);
        switch mohdakmal3
            case '1',noload;
            case '2',hasload;
            case '3',clc,PSM,close all
        end
        case '2', equationimpsm;
        case '3', fuzzylogic;
        case '4', aimeim;
        case '5',clc,clear, break
    end
end

```

APPENDIX C

Block Diagram of Stator Resistance Estimation of Induction Motor



This simulation simulates A Stator Resistance Estimation of Induction Motor Using Fuzzy Logic.