TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)

SCHOOL OF GRADUATE STUDIES

FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY AND INFORMATION AND COMMUNICATION TECHNOLOGY

(DEPARTMENT OF ELECTRICAL AND ELECTRONICS TECHNOLOGY)

SPEED CONTROL OF FIVE PHASE INDUCTION MOTOR VECTOR CONTROL USING ANFIS

MSc Thesis for the partial Fulfillment of

Master of Science in Electrical Automation and Control Technology Management

By,

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Supervisor,

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AUGUST 2022

ADDIS ABEBA, ETHIOPIA

SPEED CONTROL OF FIVE PHASE INDUCTION MOTOR VECTOR CONTROL USING ANFIS

A *Thesis submitted to*

TECHNICAL AND VOCATIONAL, TRAINING INSTITUTE (TVTI)

FACULTY OF ELECTRICAL AND ELECTRONIC AND INFORMATION COMMUNICATION TECHNOLOGY

(DEPARTMENT OF ELECTRICAL AND ELECTRONICS TECHNOLOGY)

In Partial Fulfillment for the Degree

MASTERS OF ELECTRICAL AUTOMATION AND CONTROL TECHNOLOGY

By,

Tadele Mengistie (MTR/305/12)

Supervisor,

Dr. Beteley Teka

DECLARATION

I, hereby declare that the work which is being presented in this thesis entitled *anfis based speed control of five phase induction motor vector control* is the original work of my own has not been presented for master of thesis in other universities and all source of materials used for this thesis work have been acknowledged.

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Place: Addis Abeba

Date of Submission 06-09-2022

This thesis has been submitted for examination with my approval as a TVTI advisor.

Dr. Beteley Teka

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Date 02-09-2022

TECHNICAL AND VOCATIONAL, TRAINING INSTITUTE (TVTI)

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Thesis on

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By

Tadele Mengistie (MTR/305/12)

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ACKNOWLEDGEMENT

First thanks is to God for helping me not only in this research but in every step of my life. Thanks to my advisor Dr. Beteley Teka provided critical comments and feedback throughout the writing of this paper. I thank my family's unwavering support.

ABSTRACT

This thesis presents design and simulation of Adaptive Neural Fuzzy inference system of five-phase induction machine speed control drives. For the modeling purpose five phase squirrel-cage induction motor is selected. In the past years research deal efforts in the area of IM control mechanisms that concentrated on identification and observation of this highly nonlinear dynamic plant. In order to reduce the torque ripple and harmonics for smooth operation of the machine and to reduce the amount of heat generated the motor has to be supplied with five-phase supply greater than three phase supply. A five-phase five leg 10 switch inverter fed five phase star connected load operating with five different excitation is simulated and compared with that of three phase conventional inverter. Many speed controller techniques have been proposed to cope up with speed controlling problem. Developed anfis based speed controlling algorithms are more or less parameter dependent and computationally time consuming. The conventional controller is replaced by an ANFIS which tunes the fuzzy inference system with hybrid learning algorithm. Data for training are obtained from conventional simulations when the motor drive was working with different load and without load values of speeds observation. The drive results have been analyzed for both steady state and dynamic conditions like speed capability, overshoot and undershoot behaviors, torque response quickness, step response of drive with speed reversal and sensitivity to motor parameter fluctuations. the drive results have been analyzed for both steady state and dynamic conditions such as of speed tracking capability, torque response quickness, low speed behavior, step response of drive with speed reversal and sensitivity to motor parameter uncertainty. It has observed from simulation results that five- phase SCIM that using ANFIS based controller produces the output current 6-8% higher than those of the three-phase and six- phase machines with the reference speed of 151rad/sec and ANFIS controller is much better than Fuzzy controller as it gives a percentage overshoot of 8.2% than that of fuzzy controller which is 14.4%.

Keywords: Five-phase Induction motor, Space Vector Modulation**,** d-q Transformation, voltage source invertor.

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ABBREVIATION'S

AC……………..........Alternative current

ANFIS……………….Adaptive Neuro-Fuzzy Inference System

ANN…………………Artificial Neural Network

ASICS………………..Application Specific Integrated circuits

DC…………………......Direct current

DFO…………………..Direct Field Orientation

DSP…………………...Digital signal processor

DTC…………………..Direct Torque control

EM…………………....Electromagnetic force

FLC…………………..Fuzzy Logic Controller

FOC…………………..Field oriented control

IFOC……...................Indirect Rotor Field Orientation

GUI………..………Graphical user Interface

IM……………………Induction motor

Kd……………………Derivative gain

Ki………….................. Integral gain

Kp……………………Proportional gain

MRAS…………..... ……Reference Model adaptive system

NNs………………..…Neural Networks

RMS………................Root mean squared

PID…………..……....Proportional Integral Derivative

PWM……….................Pulse width modulation

SISO…………………..Single input single output

SCIMS…......................Squirrel Cage Induction Motor

SVPWMS…..…………pace Vector Pulse Width Modulation

TL………..…………Total load

V/F……………………Vector frequency

VFD…………………..Variable

VSI……….…………..Voltage source inverter

CHAPTER 1
INTRODUCTION

1.1. Background of Study

Since the first five-phase variable-speed drive was introduced in 1969, five-phase machines have been seen as a potential alternative to three-phase machines. This is true for high-power applications and safety-critical applications. In the industry application three- phase induction motor was the dominant one during the last century, their simple and robust design. But recently, the advancement of power electronics, multi-phase induction motors fed by power electronic converters offer more reliable operation under fault conditions. Its drives are many advantages, like lower torque pulsation, minimize harmonic current, voltage lacking a rise in phase voltage, and fault tolerant [1].

Induction motors, especially squirrel cage induction motors, were widely used industrial applications like pump drive, washing, cooling machine and heating machine, servo system, electric vehicles, paper and textile factories, and home appliances. Low cost, small size and light weight, robust and rugged design, commutators free and brushes less are main advantages of induction motors, once preferred in electric propulsion systems [2].

The open loop variable frequency, variable voltage amplitude induction motor controller provides a motor with variable speed sufficient to constant torque functioning without a speed limit adjustment needed. But when need to high performance drive situations such as high speed dynamic response of induction motors, accurate speed and torque control, these are difficult problems as a result of the highly linked nonlinear structure, some in terms of the parameters that depends on load torque, speed, as well as other operating circumstances of reference setting, Temperature and rotor resistance of the motor [3]. Different control mechanism has been developing to control induction motors in order to achieve optimal efficiency of IM, such as scalar and vector controls. The earliest induction motor control methods use scalar control. This type of technology maintains a consistent ratio between supply voltage's frequency and amplitude, which allows for direct torque control. Its controlled schemes were easy to implement, but the inherent coupling effect between torque and magnetic force slows the response and tends to make the system unstable, resulting in unsatisfactory results for high power applications. Direct torque control or field-oriented control can be used to solve this issue. The common strategy for industrial control purposes of controlling a Field-oriented or vector control was the foundation of induction motor operation principles. In this technique, the induction motor can be operated similarly to a separately excited DC motor by decoupling the magnetic flux and torque [4]. For many decades, traditional controls or conventional controller systems or hybrid of one to another has the dominant techniques that increasing the induction motors' speed. But, it has some drawbacks like the sensitivity of performance to changes in system characteristics and the possibility that, when utilizing fixed gain, the controller would not deliver the anticipated speed performance due to changes in motor specifications and operating circumstances.

To overcome these kind of challenges, the ANFIS controller was used for instead of these conventional motor speed controller [5]. Main advantage of ANFIS controller is the combination of artificial neural networks and fuzzy inference systems. These included the ability to understand non-linear structure of the process, adaptability, and learn quickly. It has been shown that by adopting nonlinear speed control techniques such as those provided by fuzzy control [6] and [7], the dynamic electric drive performance and their consistency with a parameter fluctuation can be made better. Recently, in order to improve control performance, IM has a hybrid control technique has been proposed. The method here proposes combines ANFIS, control techniques to benefit from what is good characteristics the two controls to eradicate shortcomings of traditional controls method like oscillation, large excess speed and long settling time.

1.2 Objectives

1.2.1 General Objective of thesis

General objective this thesis has speed controlled of five-phase induction motor vector controlled by using ANFIS controller.

1.2.2 Specific Objective of the thesis

- Designing and model five-phase voltage source invertor.
- Model induction motor Simulink block diagram by using matlab/Simulink.
- To study dynamic model performance of anfis based five-phase induction motor.

1.3 Statement of Problem

Induction motor is backbone of industries, for the last many years up to now and it is played a vital role in industries activity. But the efficiency of this machine has some problems, due to perfection of the drives or controlling mechanism. Most familiar controlling technique in industries are conventional (PI, PD, PID), fuzzy and cascaded one another have some known limitations efficiency of the motor. These controllers` mechanisms has full of very large overshoot and it takes very long settling time, in the transient performance analysis. This brings the reduction of induction motor efficiency. Such kind of problems avoid by using ANFIS controller instead of conventional controller's in order to improve the performance limitations associated with very large overshoot, minimize settling time and give fast response. ANFIS control techniques created and used to select appropriate rule base. This strategy enhances the system's effectiveness, efficiency, dynamics, and dependability of the created controller.

1.4 Significance of Study

ANFIS based speed control of five phase induction motor vector control is provide to achieve better speed performance and increase up motor efficiency.

1.5 Scope

The scope of thesis has to model and simulate five-phase induction motor speed control (Specifically squirrel cage) using ANFIS controller by matlab/Simulink and this paper has only full digital simulation.

1.6 Limitations

Speed control of induction motors are always difficult, this is the main disadvantages of induction motors. Hence for fine speed control applications dc motors are used in place of induction motors. Three-phase induction motors have poor starting torque and high inrush currents. Five phase supply is not a general supply scheme on a commercial level, so this motor would need a phase changer or phase splitter for its operations. This will also pose problems with others components which are used for speed control of motor. Now you would be needing five phase inverter for that, thus spilling up the cost. In the process of five-phase induction motor anfis based speed controller design process it takes time when configured to the anfis designing terminology.

1.7 Methodology

It is possible to control an AC motor in a way that is comparable to controlling a separately excited DC motor due to vector control or field-oriented control (FOC) of AC machines. The interaction of current and flux results in the development of torque in AC machines. Only the stator power supply in an induction motor because it is difficult to distinguish between the currents that produce flux and torque. Separating the stator current components that produce the flux and the torque is the primary requirement of vector control. The magnitude, frequency, and phase of the stator current are controlled by an inverter control scheme to produce the vector control in an AC machine. As, the control of the motor is obtained by controlling both magnitude and phase angle of the current, this control method is given a name i.e. vector control. In order to achieve independent control of flux and torque in induction machines, the stator (or rotor) flux linkages phasor is maintained constant in its magnitude and its phase is stationary with respect to current phasor.

To perform vector control of induction motor drive the following steps should be

- Dynamic modelling of induction motor in dq frame
- Measuring the motor quantities (phase voltages and currents).
- Transforming them to the 2-phase system (α, β) using a Clarke transformation.
- Calculating the rotor flux space vector magnitude and position angle
- Transforming stator currents to the d-q coordinate system using a Park transformation
- The output stator voltage space vector is calculated using the decoupling block.
- Using the space vector modulation, the output 3-phase voltage is generated.

For AC induction motor vector control, knowledge of the rotor flux space vector's magnitude and position is crucial. It is possible to establish the rotating coordinate system (dq) using the space vector of the rotor magnetic flux. The rotor magnetic flux space vector can be obtained using a number of different techniques. To determine the size and location of the rotor flux, the flux model makes use of stator voltages and currents as well as observed rotor speed. In this thesis, anfis and IFOC control mechanism is used to determine the position of the rotor flux.

A controller is a device that handles every action taken by the system while making decisions. When there is a disturbance, the control system's perspective is that it stabilizes the system, protecting the equipment from further harm. It could be a software-based controller, a hardware-based controller, or a hybrid of the two.

Fuzzy Logic Control (FLC) has now shown to be successful for complex, nonlinear, and vaguely defined systems as compared to conventional model-based control strategies. Impossible or impracticable Fuzzy logic addresses issues that are ambiguous. Employ membership functions with values ranging from 0 to 1 and uncertainty. If the data what is readily available is unreliable or the system is too complicated to arrive at the necessary judgment. The creation of a fuzzy logic controller becomes quite challenging when there are no rules. In this scenario, the utilization of expert knowledge can be used to create appropriate guidelines that can be employed in the future to adjust the controller for a better outcome.

Artificial neural fuzzy inference system (ANFIS) have strong learning, adaptability, resilience, and speed capabilities. Therefore, using an adaptation and learning method that refer to as the ANFIS controller, the advantages of ANFIS have been used to frame the right rules of the fuzzy logic controller.

Expert control is the design paradigm used for ANFIS-based speed controllers, which simulates a human expert. The goal of control is to create a controller function that allows the plant state to as closely resemble the desired trajectory as possible. The proposed neurofuzzy controller's inputs are the normalized speed error and the rate of change of the real speed error.

The design parameters required for any ANFIS controller are:

- ❖ Number of data pairs,
- ❖ Training data set,
- ❖ Checking data sets,
- ❖ Fuzzy inference systems for training and,
- ❖ Number of epochs to be chosen to start the training, learning results to be verified after mentioning the step size.

This thesis presents a method of induction motor control with ANFIS controller for improving the transient response, when subjected to parameter variations and load torque disturbances. The required data for training of ANFIS controller is obtained by simulation of the closed loop system with PI and FLC controllers respectively.

1.8 outline of thesis

This paper is organized into five chapters. Chapter 1The background of the general structure of the thesis. Below we describe his ANFIS speed control and various controllers for a five-phase vector controlled induction motor. Chapter II Literature Review this section provides a searching to different articles that is important to this paper. It builds the theoretical theory upon which the thesis is based. Introduce the principles of modeling and indirect field-oriented control. Describes the background and structure of the ANFIS controller in Chapter III. Chapter IV also introduces the design and model of the ANFIS controller, in, SIMULINK models are presented and simulation results were discussed and compared with different kinds of control technics. Chapter V summarizes conclusions and recommendations for the inclusion of future work depending on the work completed.

CHAPTER 2

LITERATURE REVIEW

Induction machines are broadly utilized in industrial purpose across the world. Therefore, much attention has paid to controlling different mechanisms with various control specifications. Currently utilizing intelligent scheme like FL, NN, and hybrid control has to develop in order to improve the characteristics of IM. The following literature reviews describe various control methods for regulating the speed of five-phase induction motors vector control techniques.

Many researchers have studied over the last 50 years traditional variable speed drives that used three-phase induction motor to drive loads in many areas such as factories, vehicles, and propulsion ships. These loads are limited to hundreds of kilowatts, making applications beyond traditional mega drives unable to handle accidents such as failures, increased loads, and stress on power electronics [8].

To solve these problem, a new generation of multi-phase induction motor drives for machines was introduced. The word multi refers to any number of more than three and has brought many benefits to the drive system. Such applications with different loads and operating conditions may need to adjust the speed of these drives, for voltage / frequency control, change the number of stator poles and adjust the supply voltage. These methods can be implemented using one of the following techniques: Proportional gain Kp, integral gain Ki, and derivative gain Kd and PID controller gains. For single-input, single-output systems, (SISO) these gains are typically found using Cohen Coon and Ziegler-Nichols model tuning techniques [9].

PI and PID controllers have typically been used to address motor control concerns. But such kind of, controllers with fixed gain were extremely sensitive to variable changes and some disturbance of load. Therefore, always should be adjusted controller parameters.

In order to avoid such challenges different control mechanisms must be developing, including (adaptive model reference, sliding mode, variable structure, self-tuning PI) controller [10-12]. The procedures of designing all mentioned controllers type its system depending on the mathematical model. But it’s always challenging to developing a precise mathematic modeling systems, given the load fluctuations, parameter variations in the saturations, temperature and system disturbance [13].

To solve such problem, it is developing Fuzzy logic controller (FLC) or artificial neural networks (ANN) or adaptive neuro fuzzy inference system controller (ANFIS) and cascaded one to another. Each one of them characterized by their properties differs from one another, where PID is sensitive to any change of circuit so it needs to know exact parameter of the system, while fuzzy logic controller (FLC) gave fast response with approximate mathematical model of system, and artificial neural network depends on volume of training data. ANFIS controller represent a combination both last schemes with their properties [14].

The proposed an induction motor with five phases and anfis-based control system. The thesis presents two types of control strategies: direct torque control and vector control. This method could be widely applied to a fully digital implementation of five-phase induction motor operating. The direct torque control of a five-phase induction motor reduces the magnitude of the flux and torque of the stator ripple, allowing better control of the torque and flux. The TMS320C32 32b A digital signal processor (DSP) that supports floating point easy implementation of this two complex high-precision control strategies. When used to five phase induction motor, experimental results demonstrate that both control approaches achieve optimum controllability [15].

Gebrihans Yehdego, proposed to regulation DC of the motor. Using spatial vector modulating, five-phase induction motor. Outputs show an oscillating transient response of 0.03s with a rise of 0.004s, and a steady-state torque value that tracks load torque less than 2% error. Finally, authors have achieved high efficiency of fast response, precise torque, flux control, torque and flux becomes small for five-phase induction machines than for three-phase induction machines [16].

Typically, PI controllers are used in motor control drives. However, this controller was system-sensitive, nonlinearities, parameter modifications as well as any unwanted noise. This kind of limitations could be improved by using AI based controllers. Fuzzy logic and artificial neural networks are two of the most recent popular systems used as intelligent controllers and have shown improved performance of the motor when compared to conventional controllers [17].

Amanulla et al. [18] proposes an updated recognition technique based on a simple structured neural network for the estimation of flux position, vector, and stator voltage selection for IM by using the control methods DCT. This techniques, has advantages of DTC like flux and torque ripple has enhanced. Then results indicates DTC based on ANN has better performance than the modified DTC. Many recently developing computer control techniques were grouping into a field of study known as intelligent control, which is the result of integrating FL mechanisms into system for automatic control. Fuzzy logic always it needs expert when try to define membership functions and rules this is the problems of fuzzy logic. This problem can be solved by designing adaptive neuro-fuzzy inference system (ANFIS) [19].

Another high performance most recently popular hybrid controller is called ANFIS (Adaptive Neural Network Fuzzy Inference System). The conventional type controller that were using in DTC techniques has replace by ANFIS speed controller.

In comparison between three-phase and five phase induction motors systems are, five-phase IM system having greater space voltage vectors. The more vectors available, the more complex switching vector tables can be made, with voltage vector selection based on real-time stator flux and torque fluctuation values. This document's goal is to design and put into practice a speed control strategy using an ANFIS controller for a five-phase induction motor drive system.

2.1 Summary of the literature review

Many researchers have studied over the past years traditional variable speed drives that used three-phase induction motor to drive loads in many areas such as factories, vehicles, and propulsion ships. These loads are limited to hundreds of kilowatts, making applications beyond traditional mega drives unable to handle accidents such as failures, increased loads, and stress on power electronics.

Currently utilizing intelligent scheme like FLC, NN, and hybrid control has to develop in order to improve the performance of IM. The above literature reviews was describe various control methods for regulating the speed of five-phase induction motors vector control techniques.

The vector control or field-oriented control (FOC) of AC machines makes it possible to control AC motor in a manner similar to the control of a separately excited DC motor. In AC machines, the torque is developed by the interaction of current and flux. In induction motor the power is given to the stator only, the current responsible for flux production, and the current responsible for torque production are not easily separate. The main criterion of vector control is to separate the components of stator current responsible for flux production, and also the torque. The vector control in an AC machines is obtained by controlling the magnitude, frequency, and stator current phase, by inverter control scheme. As, the control of the motor is obtained by controlling both magnitude and phase angle of the current, this control method is given a name i.e. vector control. In order to achieve independent control of flux and torque in induction machines, the stator (or rotor) flux linkages phasor is maintained constant in its magnitude and its phase is stationary with respect to current phasor.

This thesis focused on design of an ANFIS based speed controlled of induction motor to handle the short comings of conventional control schemes such as parameter sensitivity, high computational efforts, and very high overshoot, undershoot, and the proposed ANFIS controller to control the speed of induction motor drive to minimize the problems related to conventional controllers.

CHAPTER 3

MTHEMATICAL MODEL OF FIVE PHASE INDUCTION MOTOR AND CONTROLLER DESIGN

3.1. Introduction

Multi-phase induction motors are normally constructed with a squirrel-cage rotor and multi-phase stator windings. Its structure and operating principle are the same to three-phase induction machines. Similar to three-phase induction machines, multiphase machines are modeled in mutually perpendicular arbitrary frames of reference with constant Lumped parameters [20].

Multi-phase machine has many advantages over a three-phase machine such us higher torque density, higher efficiency, reduced torque spikes, greater fault tolerance, in the required rating per inverter leg. The noise characteristics of multi-phase drives are better than those of three-phase drives. Due to the simultaneous increase in the frequency of the torque pulse and decrease in the amplitude of the torque ripple, a higher phase number results in a smoother torque. The squirrel cage induction motor (SCIM) that presented figure 3.1, has been selected by many industrial applications such as vehicles, paper and textile factories, robotics system, and wind turbine generation due to their many advantages like simple design, robustness, reliability, low price, brushless, commutator-free and less maintenance requirements. In order to obtain the requirement of the application of industries it must be proper control. Light weight and size, sturdy and robust construction, no commutator and most popular in electric drive systems, squirrel cage induction motors provide a number of particular advantages, including brushes less.

Figure 3. 1 shows one squirrel cage induction motor [21].

3.2 WORKING PRINCIPLE OF MULTI-PHASE INDUCTION MOTORS

Five-phase induction motor has the same operation that of three-phase induction motor, both of them that operates depending on how Lorentz force and Faraday's law are applied to the conductor. As soon as a five-phase AC machine providing power to the stator windings which is temporally spatial displacement of 72°, generated magnetic field that is revolving at a synchronous speed. An EMF has develops in the rotor conductor when a short squirrel cage rotor putting a revolving magnetic field as a result of electromagnetic induction. Through the rotor conductor, current starts to flow due to the EMF principle, creating their own magnetic field. The interacting of two magnetic fields, a conductor producing torque and it moves. The five-phase motor driving diagram shown in figure (3.2) [22]. When a five-leg inverter is used to excite the stator that has the IM field winding installed. The n-phase machine's stator windings can be designed, the displacement in space between two successive stator phases is equal to, $\alpha = 2\pi/N$ where N indicates number of phase, which is multiple symmetrical phases machine. If prime odd number has the phase number then, this will always be the case. Compared to a five phase machine72 degree, a three phase IM's are spatially displaced by 120 degrees' figure (3.2-3.3).

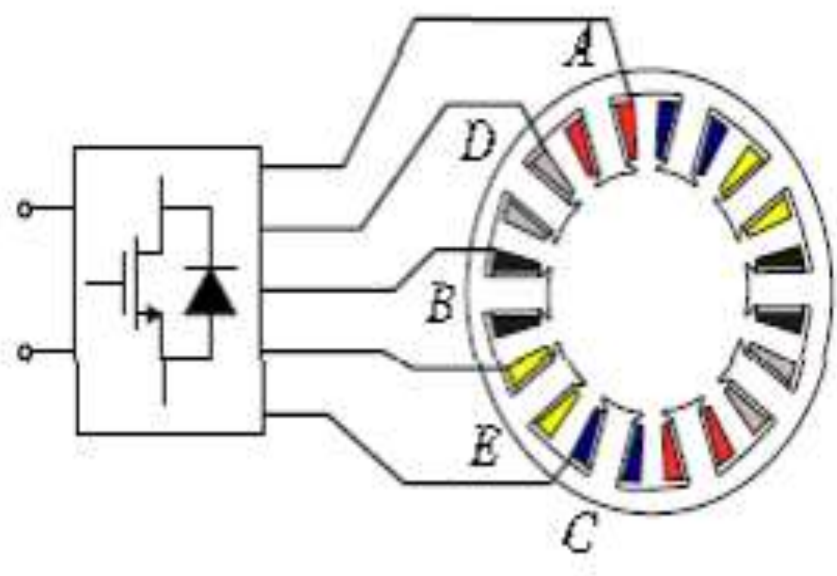

Figure 3. 2 the five-phase motor drive diagram [23].

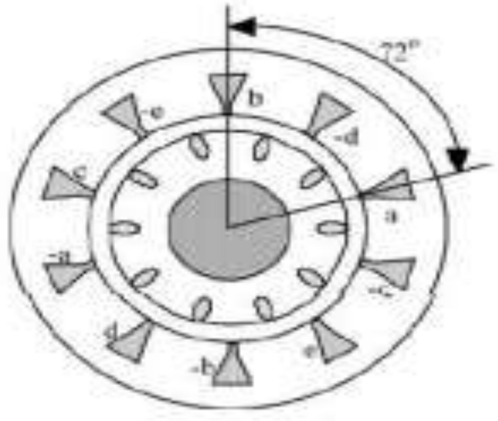

Figure 3. 3 Diagram of five phase motor

3.2 Mathematical Model

The five-phase squirrel cage IM was represented in its d-q synchronous frame. The winding axes of five-phase stator windings were displaced by 72°. If increasing the number of phases, it is also possible to increase torque/ampere for the same machine volume. In this analysis, iron saturation was ignored. The quadrature axis voltage of the stator shaft is given by a five-phase VSI model implemented in ten steps. The five-phase IM model was originally developed as a variable phase. Transformation was applied to the model known as the “dqxy0” model design or manufactured machine to modify the developed model by eliminating fluctuation of time and the term of inductance [24]. Only the current in d-q axis does, the remaining x-y components and the zero-order components do not contribute to the torque and flux creation; Five-phase induction machines are built using ten-phase belts, 36^0 degrees each in along the stator's perimeter, these phases. Consequently, the distance between the phases in space is $\alpha = 2\pi/N$. Where N is phase number N = 5 and 72 phase angle. Assume that the rotor windings has been called the stator windings, using the windings' turns’ ratio. The equations for the x-y component pairs are completely separated from all other components and stator-rotor coupling is also absent, the d-q components and the rotor x-y components are entirely isolated from one another. The stator and rotor has been disregarded to zero-sequence component equation, since the rotor windings are short circuited and the stator winding is connected in a star connection, allowing for the existence of both an x-y component and an irregular-sequence component [25].

Any star-connected multi-phase system without a neutral conductor cannot have a zero-order component, but a zero component can only be present in an even number of phases. The equations for the *x-y* components can also be omitted from farther consideration. This means that the model of the five-phase induction machine in an arbitrary frame of reference becomes identical to the model of three-phase induction machine [26].

3.3 Direct-Quadrature-Zero Transformation to Five Phase Systems

The *dq0* models may be viewed as a natural extension of time-varying phasor models, and are used extensively for modeling and analysis of fast transient phenomena in power systems.

The dq0 transformation and its inverse are defined as follows:

$$T_\theta = \frac{2}{3}\begin{bmatrix} \cos(\theta) & cos(\theta - \frac{2\pi}{3}) & cos(\theta + \frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad 3.1$$

$$T_\theta^{-1} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 1 \\ cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & 1 \\ cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \quad 3.2$$

Where the angle θ is the reference angle or the reference phase. Direct multiplication of these matrices reveals that $T_\theta T_\theta^{-1} = T_\theta^{-1} T_\theta = I_{3\times3}$.

Three-phase signals in the *abc* reference frame are transformed into new quantities in the rotating dq0 reference frame via the dq0 transformation. Indicate $x_{abc} = [x_a, x_b, x_c]^T$ and $x_{dq0} = [x_d, x_q, x_0]^T$

$$x_{dq0} = T_\theta x_{abc},$$

$$x_{abc} = T_\theta^{-1} x_{dq0} \quad 3.3$$

Where the direct, quadrature, and zero components are denoted by the subscripts *d*, *q*, and 0 respectively.

This all the above descriptions that has three phase systems, but when we consider about n phase system, transformation results in a number of N sequences. The first sequence is $\frac{2\pi}{N}$ apart and the second is $2x\frac{2\pi}{N}$. The last sequence will results in spacing of 2π which means all phases are in the same direction, this is called the sequence of zero. A five phase system will result in five sequences these five sequences will be spaced by $\frac{2\pi}{5}, \frac{4\pi}{5}, \frac{6\pi}{5}, \frac{8\pi}{5}$ and 2π

It is clear that a sequence 1 and 4 are equivalent; same sequence in the opposite direction. The same is true for sequences 2 and 3. Therefore, only sequence 1, 3, and 5 will be used.

2.4 Transformation of model

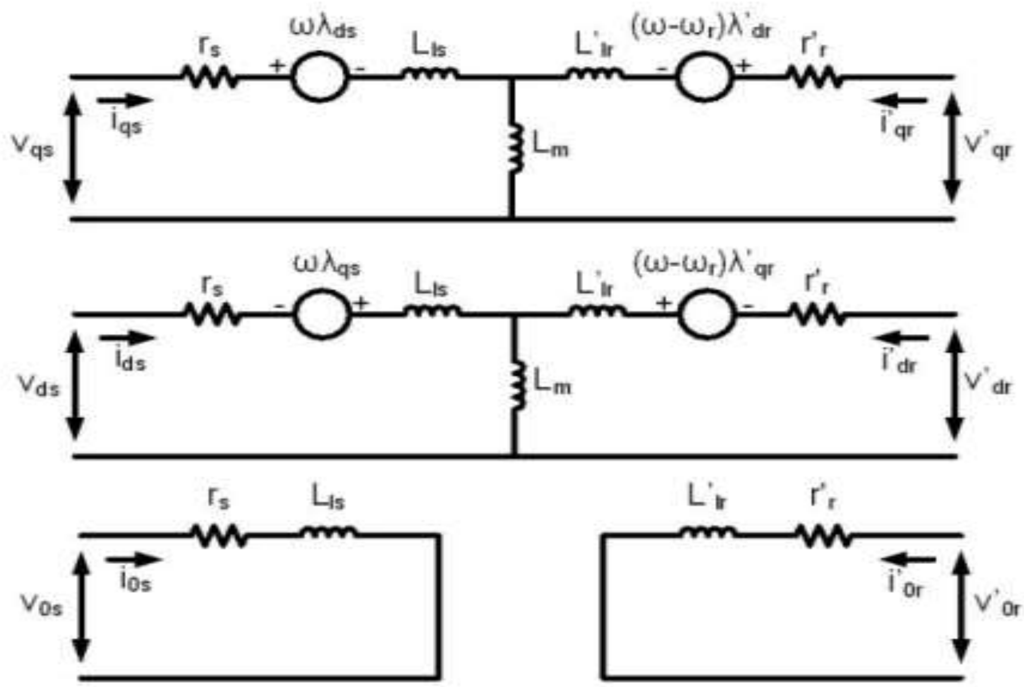

Figure 3. 4 Five phase IM equivalent circuit on the dqo axis in any reference frame.

The induction motor's five phase stator voltage is represented as follows when it is balanced.

$$V_a = \sqrt{2V_{rms}}\sin(\omega_t) \quad 3.4$$

$$V_b = \sqrt{2V_{rms}}\sin(\omega_t - \frac{2\pi}{5}) \quad 3.5$$

$$V_c = \sqrt{2V_{rms}}\ \sin(\omega_t - \frac{4\pi}{5}) \qquad 3.6$$

$$V_d = \sqrt{2V_{rms}}\ \sin(\omega_t + \frac{4\pi}{5}) \qquad 3.7$$

$$V_e = \sqrt{2V_{rms}}\ \sin(\omega_t + \frac{2\pi}{5}) \qquad 3.8$$

The decoupling transformation matrix, which replaces the original sets of n variables with new sets of n variables, transforms the modeling machine in to original form. The following matrix shows decoupling transformation form.

$$\begin{bmatrix} V_d \\ V_q \\ V_x \\ V_y \\ V_o \end{bmatrix} = \frac{2}{5}\begin{bmatrix} 1 & \cos\alpha & \cos 2\alpha & \cos 3\alpha & \cos 4\alpha \\ 0 & -\sin\alpha & -\sin 2\alpha & -\sin 3\alpha & -\sin 4\alpha \\ 1 & \cos 3\alpha & \cos 6\alpha & \cos 9\alpha & \cos 12\alpha \\ 0 & -\sin 3\alpha & -\sin 6\alpha & -\sin 9\alpha & -\sin 12\alpha \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} \qquad 3.9$$

Where $\alpha = \frac{2\pi}{5}$

The results of simulating and transforming the five phase voltages specified in equations (3.4) through (3.8) using MATLAB/Simulink are displayed in figure 3.5 and figure 3.6 The five-phase sinusoidal voltages supply provided to the motor are shown in figure 3.5 and the transformed q- and d-axis stator voltages are shown in figure 3.6

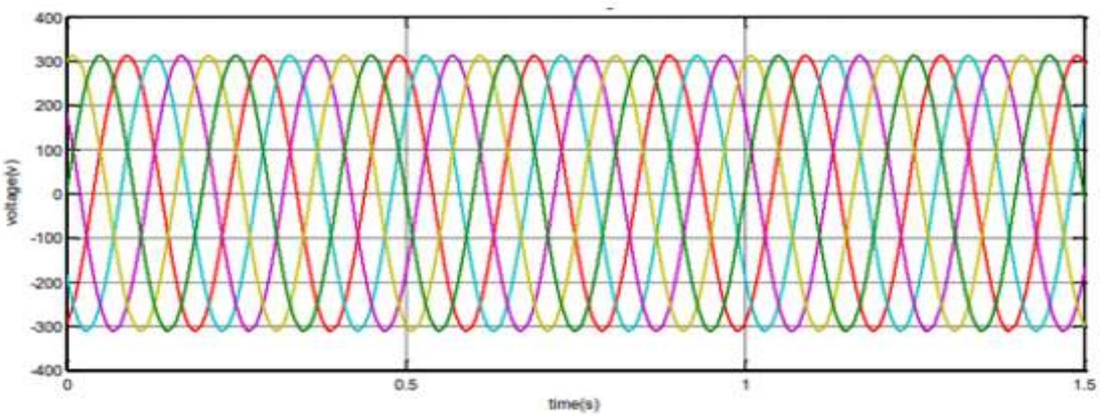

Figure 3. 5 Five phase supply voltage

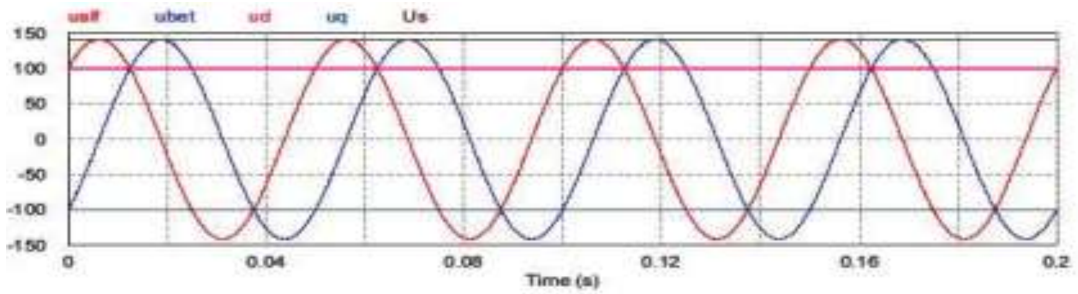

Figure 3. 6 q-d axis stator voltage

Since the stator-rotor coupling occurs only in the rotating transformation has applicable to that of *d-q* equations. This question structure is the same as that of three-phase mechanical equation. Suppose the equation of a machine is transformed into any frame of a reference that rotates at an angular velocity ω_a. The model of the five-phase inducer is given by the following is the stator side voltage equation for the d and q reference frame.

$$V_{ds} = R_s i_{ds} - \omega_a \varphi_{qs} + \rho \varphi_{ds} \quad 3.10$$

$$V_{qs} = R_s i_{qs} + \omega_a \varphi_{ds} + \rho \varphi_{qs} \quad 3.11$$

$$V_{xs} = R_s i_{xs} + \rho \varphi_{xs} \quad 3.12$$

$$V_{ys} = R_s i_{ys} + \rho \varphi_{ys} \quad 3.13$$

$$V_{os} = R_s i_{os} + \rho \varphi_{os} \quad 3.14$$

Here under the voltage rotor side questions in the d- and q- reference frames:

$$V_{dr} = R_r i_{dr} - (\omega_a - \omega) \varphi_{qr} + \rho \varphi_{dr} \quad 3.15$$

$$V_{qr} = R_r i_{qr} - (\omega_a - \omega) \varphi_{dr} + \rho \varphi_{qr} \quad 3.16$$

$$V_{xr} = R_r i_{xr} + \rho \varphi x_r \quad 3.17$$

$$V_{yr} = R_r i_{yr} + \rho \varphi y_r \quad 3.18$$

$$V_{or} = R_r i_{or} + \rho \varphi_{or} \quad 3.19$$

The five-phase induction motor's stator side flux equation is as follows:

$$\varphi qs = (L_{ls} + L_m)i_{ds} + L_m i_{dr} \quad 3.20$$

$$\varphi ds = (L_{ls} + L_m)i_{qs} + L_m i_{qr} \quad 3.21$$

$$\varphi xs = L_{ls} + i_{xs} \quad 3.22$$

$$\varphi ys = L_{ls} + i_{ys} \quad 3.23$$

$$\varphi os = L_{ls} + i_{os} \quad 3.24$$

The five phase induction motor's rotor side flux equation is as follows:

$$\varphi qr = (L_{lr} + L_m)i_{dr} + L_m i_{ds} \quad 3.25$$

$$\varphi dr = (L_{ls} + L_m)i_{qr} + L_m i_{qs} \quad 3.26$$

$$\varphi xr = L_{lr} i_{xr} \quad 3.27$$

$$\varphi yr = L_{lr} i_{yr} \quad 3.28$$

$$\varphi or = L_{lr} i_{or} \quad 3.29$$

Where M stands for highest value mutual inductance phase variable model of the stator to rotor. And L_m = (n/2) *M*. Resistance and inductance are represented by the symbols *R* and *L*. Voltage, current, and flux linkage are represented by the symbols *v, I* and *φ*. Stator and rotor variables and parameters are represented by the indices *s* and *r*. Leakage inductances are identified by index l. The torque and rotor speed can be calculated using the aforementioned equations as,

$$T_e = \frac{5}{2}(\frac{p}{2})\frac{1}{W_b}(\phi_{ds}\, i_{qs} - \phi_{qs}\, i_{ds}) \quad 3.30$$

$$W_r = \int p/2J(T_e - T_L) \quad 3.31$$

J stands for moment of inertia and *P* stands for number of poles. Load torque on T_L; Rotor Speed; ω_r *Te*, Electromechanical Torque.

Model equations in mathematics and torque equations of *d-q* component are the same as three-phase induction machine has the present of x-y component voltage and flux equations is the only distinction between the five-phase machine and the related three-phase machine model. *X-Y* of Rotor component is completely separate from d-q component. When rotor winding were shorted then, *X-Y* component does not appear. Due to the stator and rotor zero component equations could be excluded based on further analysis because the rotor windings are short-circuited and the stator windings are star-connected.

$$\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \\ i_{ds} \\ i_{es} \end{bmatrix} = \sqrt{2/5} \begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ \cos\alpha & \sin\alpha & \cos 2\alpha & \sin 2\alpha & 1 \\ \cos 2\alpha & \sin 2\alpha & \cos 4\alpha & \sin 4\alpha & 1 \\ \cos 3\alpha & \sin 3\alpha & \cos 6\alpha & \sin 6\alpha & 1 \\ \cos 4\alpha & \sin 4\alpha & \cos 8\alpha & \sin 8\alpha & 1 \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{xs} \\ i_{ys} \\ i_{os} \end{bmatrix} \qquad 3.32$$

Stator voltages *Va, Vb, Vc, Vd,* and *Ve* have been converted into d-q form, flux linkages, current, torque, and rotor speed equations are used to derive the currents as i_{qs}, i_{ds}, i_{qr}, and $i_{dr,}$ respectively. Finally, inverse transformation are used to derive stator current like machine variables. To examine the nature of the current in the stator, inverse transformation equations are available to convert the current any reference frame to the current machine.

3.3 Inverter Modeling

3.3.1 Five-Phase VSI Space Vector Representation

Modeling voltage source inverter (VSI) on a two-level inverter gives a 2^n space vector magnitude. Thus, a five-phase VSI generates 32 space vector, only 10 space vectors were generated, resulting in a method of operating with 10 steps, 22 more space vectors generated when the inverter operates in PWM mode. Of these 22 states, two do not result in a zero neutral phase voltage. The model first expands to a stationary reference frame in the dq plane and then expands to spanning the x-y plane. The developed method can be extended to higher numbers of phases. For a five-phase motor, the stator phases are 72^0 apart. Figure 3:4 shows the basic power circuit topology for a five-phase VSI. Five-phase VSI and multi-phase inverters can generate multiple phases since each leg of the inverter represents one phase. We can increase the number of phases by adding more branches to the inverter. We require a five-leg inverter to power a five-phase motor.

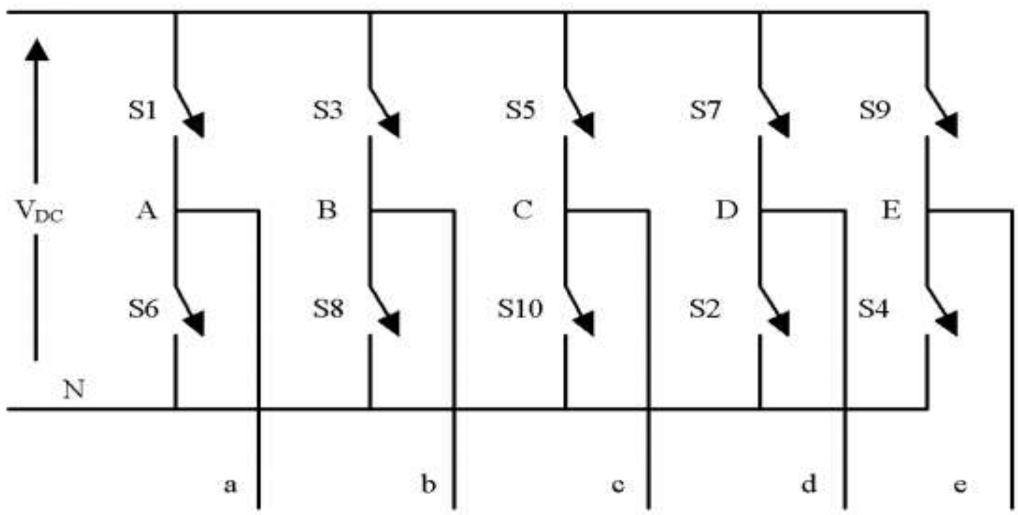

Figure 3. 7 Five phase VSI power circuit [27]

When switch S1 is on, terminal 'A' is connected to the positive terminal of the V_{DC} input voltage (V_{DC}). When switch S1 is off, terminal 'A' is connected to the negative terminal of the DC input voltage (V_{DC}). There are 10 operating modes in one cycle, and the duration of each mode is 36°. Switches any one leg of the inverter (S1 and S6, S3 and S8, S5 and S10, S7 and S2, or S9 and S4) cannot be on at the same time. This is to avoid shorting the V_{DC} supply voltage. Similarly, the branch of the inverter cannot be switched off at the same time to avoid an undefined state of the output AC voltage. The outputs of inverter are marked in Figure 3.7 with lower-case symbols (*a, b, c, d, e*), while the connection points of the outputs to the branches of the inverter are marked with upper-case symbols (*A, B, C, D, E*). Every switches were to conduct 180° resulting in ten-step mode operation. Phase delay between turnings on two switches in any two consecutive phases is equal to 360°/5 = 72°. For five-phase ten-level inverters, three switches off from the top and two switches turned on from the bottom at any time and the river is also true, each switch is conducting 36° apart [28].

3.3.2 Ten-Step mode of operation

The following figure 3.8 illustrates five-phase inverter's switching pattern and mode of operation figure 3.8.

Table 3. 1 Modes of operation for a voltage source inverter with five phases [29]

Modes	Terminal Polarity	Switches on
1	$E^+D^-C^-A^+B^+$	3, 2, 1, 9,10,
2	C-D-A+B+E-	2, 3, 10,1,4
3	B+D-C+A^+E^-	2,4,3,1,5
4	$A^-C^+B^+D^-E^-$	2,4,3,5,6
5	$E^-B^+D^+C^+A^-$	7,4,6,5,3
6	$E^-A^-B^-D^+C^+$	8,5,4,7,4
7	$B^-D^+A^-C^+E^+$	6,8,5,7,9
8	$A^-B^-E^+C^-D^+$	6,7,10,8,9
9	$A^+E^-B^-D^+C^-$	1,10,7,9,8
10	$A^+D^-C^-B^-E^+$	8,1,10,9,2

A complete drive cycle can be categorized as ten distinct modes shown in the figure 3.8 and summarized in the table above. From the figure and table tells that always, five switches "on" and the same time five switches "off".

Using a power invariant transformation, the following in a stationary frame of reference, the space vector of phase voltage is determined

$$V_S=\sqrt{\frac{2}{5}}(V_a + aV_b + a^2V_c + a*{}^2V_d + \alpha * V_e) \qquad 3.33$$

where * denotes a complex conjugate

a = exp(j2π/5), a2 = exp(j4π/5), a* = exp(-j2π/5), a*2 = exp(-j4π/5).

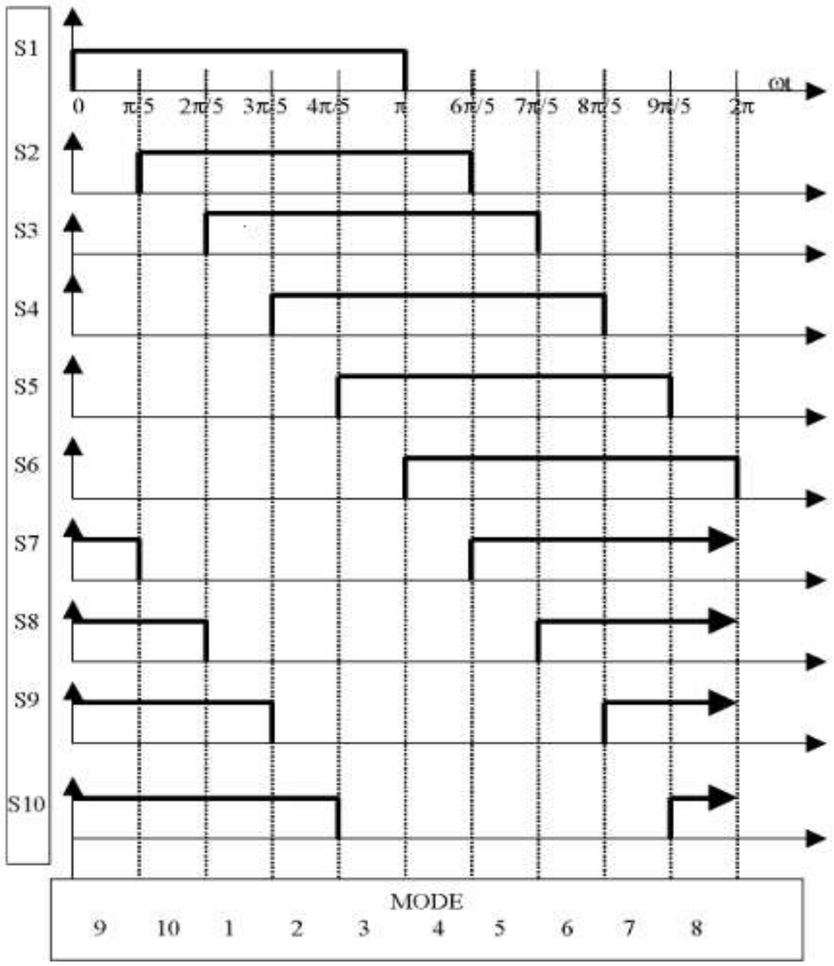

Figure 3. 8 driving of switch signals ten step mode of 5-∅ VSI [30]

Five phase VSI leg voltage space vectors

$$\begin{bmatrix} V_{1leg} \\ V_{2leg} \\ V_{3leg} \\ V_{4leg} \\ V_{5leg} \\ V_{6leg} \\ V_{7leg} \\ V_{8leg} \\ V_{9leg} \\ V_{10leg} \end{bmatrix} = \sqrt{\frac{2}{5}} V_{DC} 2Cose\left(\frac{\pi}{5}\right) \begin{bmatrix} e^{j0} \\ e^{j\pi/5} \\ e^{j2\pi/5} \\ e^{j3\pi/5} \\ e^{j4\pi/5} \\ e^{j\pi} \\ e^{j6\pi/5} \\ e^{j7\pi/5} \\ e^{j8\pi/5} \\ e^{j9\pi/5} \end{bmatrix} \quad 3.34$$

The magnitude of leg voltage has been given $\sqrt{\frac{2}{5}} V_{DC} 2Cose\left(\frac{\pi}{5}\right)$ and are 36^0 parts. At the same time, the easiest way to find voltages from phase-neutral of the load that is star-connection to define a voltage difference between the negative rail of the intermediate circuit *N* and the load's star point *n*, relationship then as follows:

$$V_A = V_a + V_N$$
$$V_B = V_b + V_{nN}$$
$$V_C = V_c + V_{nN} \quad 3.35$$
$$V_D = V_d + V_{nN}$$
$$V_E = V_e + V_{nN}$$

Because the phase voltages a load connected a star have sum to zero, summing the equations results in (3.35)

$$V_nN = (1/5)(V_A + V_B + V_C + V_D + V_E) \quad 3.36$$

The load's phase to neutral voltages were produced by substituting (3.36) for (3.35) the following way.

$$Va = (4/5)\ VA - (1/5)\ VD + VE + VC + VB$$

$$Vb = (4/5)\ VB - (1/5)\ VD + VE + VA + VC)$$

$$Vc = (4/5)VC - (1/5)\ VD + VE + VA + VB) \quad 3.37$$

$$Vd = (4/5)VD- ((1/5)\ (VC+ VB + VE+VA)$$

$$Ve = (4/5)\ VE-(1/5)\ (VD + VA + VB + VC)$$

Voltages in the legs are substituted into equation (3.37) to produce the phase voltages in various modes, and equation (3.38) is used to compute their space vectors (3.33). Phase to neutral voltage space vectors are identical to leg voltage space vectors. Figure 3.9 lists several modes has different phase to neutral voltages.

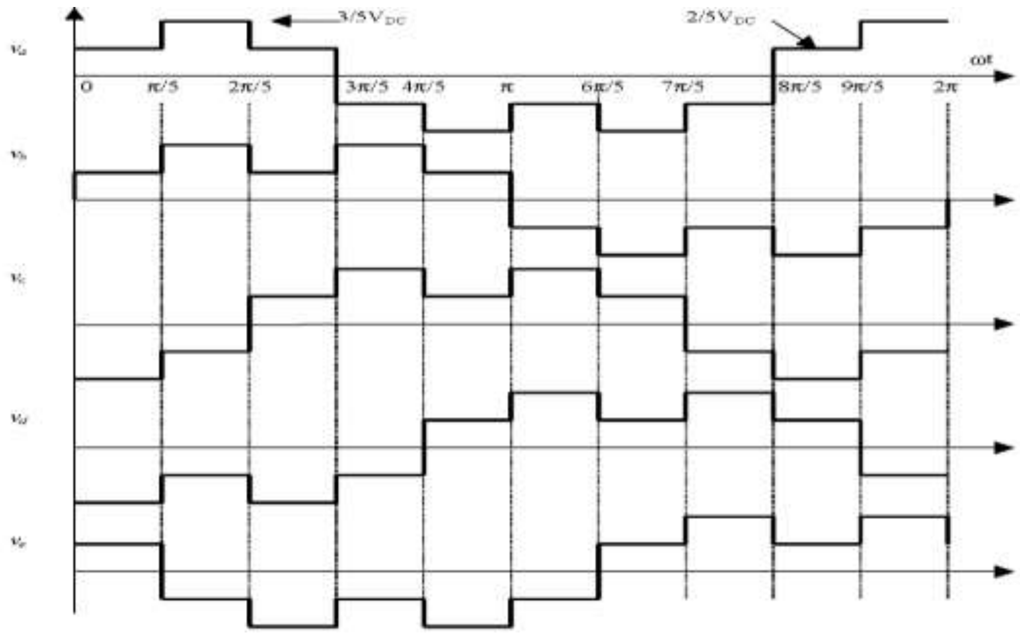

Figure 3. 9 voltages ten-step mode of operation phase of five phase VSI-neutral [31].

The Voltage waveform is subjected to fourier analysis in order to connect the inverter's input dc link voltage with the output phase to neutral. Using a periodic waveform to define the flourier series:

$$V(t) = V_0 + \sum_{k=1}^{\infty}(A_k cosk\omega t + B_k sink\omega t) \qquad 3.38$$

Where the coefficients are given

$$V_0 = \frac{1}{T}\int_0^T v(t)\,dt = \frac{1}{2\pi}\int_0^{2\pi} v(\theta)\,d\theta$$

$$A_k = \frac{1}{T}\int_0^T v(t) Cosk\omega t\,dt = \frac{1}{\pi}\int_0^{2\pi} v(\theta) Cosek\theta\,d\theta \qquad 3.39$$

$$B_k = \frac{1}{T}\int_0^T v(t) Sink\omega t\,dt = \frac{1}{\pi}\int_0^{2\pi} v(\theta) Sink\theta\,d\theta$$

Taking into account the waveforms' quarter-wave symmetry and practical ability to be interpreted as odd functions, the following formulas can be used to represent the phase to neutral voltages and line to line voltages.

$$V(t) = [\sum_0^{\infty} B_{2k+1} + Sin(2k+1)\omega t] = \sqrt{2\sum_{k=0}^{\infty} V_{2k+1} Sin(2k+1)\omega t}$$

$$B_{2k+1} = \sqrt{2v_{2k+1}} \quad = \quad \frac{1}{\pi}4\int_0^{\pi/2} V(\theta) Sin(2k+1)\theta d\theta \qquad 3.40$$

In the case of the phase to neutral voltage Vb, as shown in Figure 3.9, one must also account for the fourier series coefficients.

$$B_{2k+1}=\frac{1}{\pi}\frac{4}{5}V_{DC}\frac{1}{2k+1}[2+\cos(2k+1)\frac{\pi}{5}-\cos(2k+1)\frac{2\pi}{5}] \qquad 3.41$$

For any harmonics whose order is divided by five, the expression in the brackets of the second equation of (3.41) equals zero, it is 2.5 for all other harmonics.

Thus, the phase-to-neutral voltage's Fourier series can be expressed as follows:

$$V(t)=\frac{2}{\pi}V_{DC}\begin{bmatrix}\sin\omega t+\frac{1}{3}\sin\omega t+\frac{1}{7}\sin 7\omega t+\frac{1}{9}\sin 9\omega t\\ \frac{1}{11}\sin 11\omega t+\frac{1}{13}\sin 13\omega t+\frac{1}{15}\sin 15\omega t+\ldots\end{bmatrix} \qquad 3.42$$

The main components' The RMS value of the output phase to neutral voltage is equal to from (3.42) given:

$$V_1=\sqrt{2}/\pi V_{DC}=0.45V_{DC} \qquad 3.43$$

It is significant to remember that equation (3.33)'s description of the space vector maps the voltages from inverters into a two-dimensional space. Because the inverter with five-phases by its very nature demands a description in not all harmonics exist in five-dimensional space present in (3.42) are recorded by the space vector of (3.33). The space vector produced in (3.33) specifically only represents the order harmonics.

10k ± 1 *k= 0, 1, 2, 3…i.e*

Because of the isolated neutral point, order harmonics 5*k*, where *k*= 1, 2, 3, etc., cannot arise. Since the space vector formulation of (3.42) does not include harmonics of the order *5k* $\pm$*2*, where *k* = 1, 3, 5 and so on (3.33)

The five-phase's space vector is necessary since these harmonics effectively occur in second two-dimensional space.

3.3.3 PWM operating mode

When a five-phase VSI is set to PWM mode, there are 22 switching in addition to the ten states already described. In general, there are 2^n potential switching states, where n is the number of inverter legs (i.e. output phases). This correlation is true for any VSI with two levels.

The additional switching states related to the PWM way of operation that were not present, among ten step procedures were compiled in Table 3:2. Table 3:2 lists the switches that are "on" along with the associated connection polarity. It demonstrates that the rest switch states include there are three potentials scenarios: All states (11-20) when four switches from the top (lower) half of the inverter are on and one switch from the bottom (top) half; two states (31 and 32) when either all five upper (lower) switches are 'on'; and the remaining states when three switches from the upper (lower) half and two switches from the lower (upper) half are in conduction mode (21-30).

Table 3. 2 Additional five-phase VSI switching states in *PWM* mode.

State of Switching	Terminal Polarity	When Switches ON
11	$A^+E^-C^-B^-D^-$	1,10,4,2,8
12	$C^+B^+A^+E^+D^-$	3,2,1,9,5
13	$B^+A^-C^-E^-D^-$	3,2,4,10,6
14	$E^-B^+D^+C^+A^+$	7,3,5,4,1
15	$A^-B^-C^+E^-D^-$	2,4,5,8,6,
16	$A^-E^+D^+C^+B^+$	3,9,7,6,5
17	$A^-C^-B^-E^-D^+$	4,7,6,10,8
18	$A^+B^-D^+E^+C^+$	1,5,8,9,7
19	$C^-A^-B^-D^-E^+$	8,2,6,9,10
20	$A^+E^+C^-B^+D^+$	1,10,7,3,9
21	$E^-B^+C^-D^-A^-$	10,3 6 9 2
22	$B^+A^+C^-D^+E^-$	3,1,4,7,10
23	$C^+B^-A^+E^-D^-$	4,2,1,8,5
24	$A^-E^+C^+D^-B^+$	2,9,5,6,3
25	$E^-D^+C^-B^+A^-$	10,7,6,4,3
26	$A^+E^-C^+D^+B^-$	1,8,5,7,4
27	$B^-A^-E^+D^-C^+$	5,2,9,8,6
28	$C^-E^+A^-D^+B^+$	7,10,3,9,6
29	$D^+E^-C^-A^+B^-$	8,10,7,1,4
30	$C^+D^-A^+B^-E^+$	5,8,1,2,9
31	$A^+E^+D^+C^+B^+$	1,9,7,5,3
32	$E^-C^-B^-D^-A^-$	10,6,4,8,2 ,

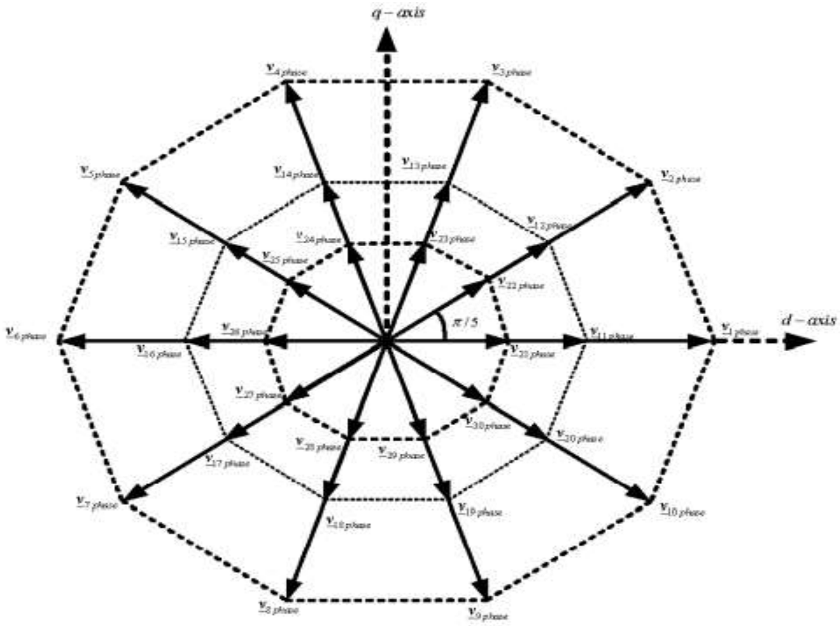

Figure 3. 10 State 1-32 space vector phase- neutral voltage (31-32 origin d-q p)[32].

To examine the mode of operation of a five-phase induction motor driven by a five-phase VSI, a simulation study is conducted. The five-phase VSI is managed utilizing the carrier-based PWM method. So results fully verify that developed model of the five-stage Voltage source inverter.

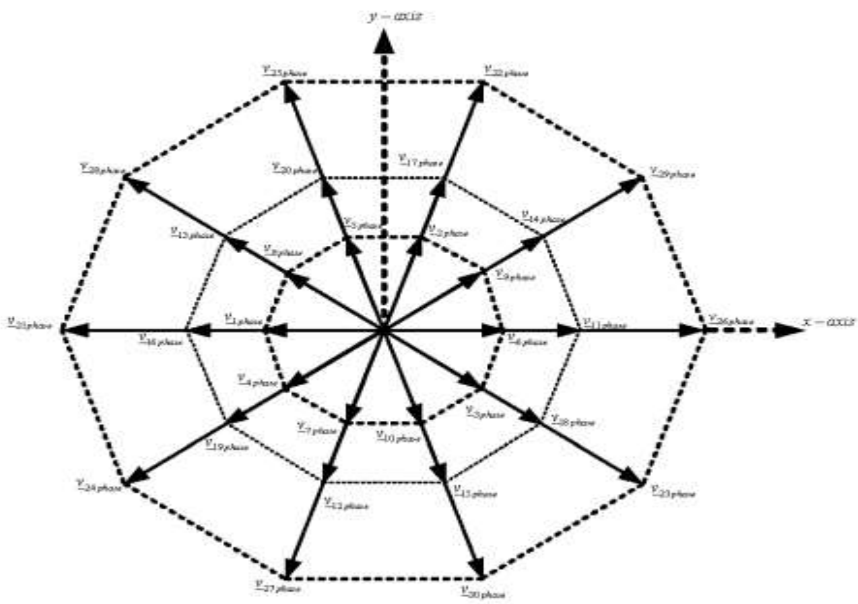

Figure 3. 11 Phase-neutral voltage space vectors states 1-32 (31-32 origin x-y plane)

3.4 FIELD ORIENTED CONTROL

3.4.1 Field Oriented Control Principle

An AC motor can be controlled in a manner similar to an independently excited DC motor thanks to vector control or field orientated control (FOC) of AC machines. The interplay of current and magnetic flux results in torque, AC machine. IM, power is only provided to the stator winding, and it is difficult to distinguish between the currents that produce the flux and the torque. Separating the stator current components that produce flux and torque from one another is the main requirement of vector control. By adjusting the stator current's amplitude, frequency, and phase using the inverter control method, vector control in AC machines is achieved. This form of control is known as vector control since it allows for the control of both the current's magnitude and phase angle. The phase of the stator (rotor) flux linkage is stable with respect to the current phasor and is kept constant within its amplitude in order to obtain separate torque and flux control induction machine.

The same IFOC technique as three-phase induction machines. The only distinction is that, depending on whether it is a current control in a fixed reference frame or in a revolving synchronous reference frame, coordinate transformation must create a set of n phases of the stator current (or stator voltage) reference. With the help of this control method, the induction machine's electromechanical torque may be quickly and accurately controlled. The interplay between the revolving magnetic fields of stator and rotor makes controlling rotor field more challenging, and it is difficult to regulate in a frame of reference that is stationary.

As a result, a transformation into a frame of reference that rotates synchronously and has the d-axis aligned with the rotor field is required. Among the controlling mechanism IFOC is one method it depends up on transformation of five- phase to two-phases in stationary reference frame and rotating reference frames. Figure 3.12 block diagram that represents indirect field oriented control.

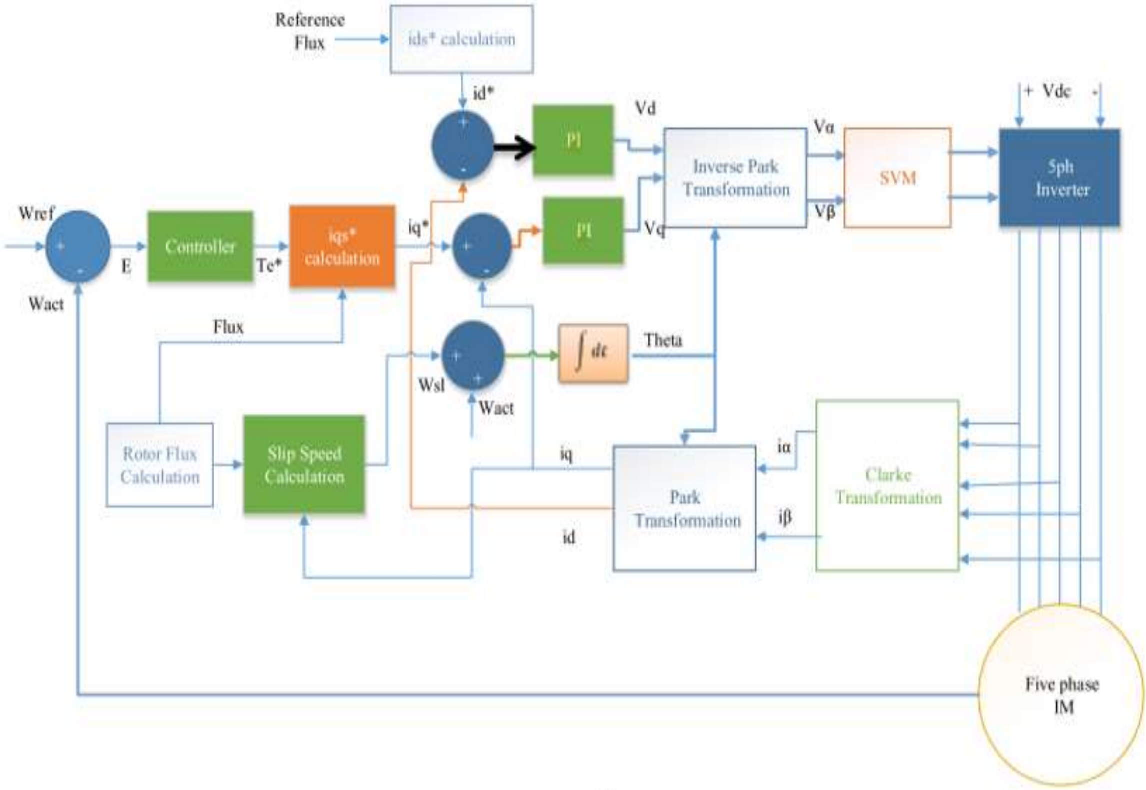

Figure 3. 12 An induction motor with a five-phase IFOC controller

Procedures of IFOC schem.

- Measure the stator currents and apply it to Clarke transformation to have two phase stationary reference frame.
- Apply two phase stationary reference frames are transformed by a park transformation into rotational reference frames.
- Compute rotor angle

In vector control topologies connected to asynchronous and permanent magnet synchronous machines (PMSM), Clarke and Park transforms are frequently employed.

Clarke Transformation

According to Figure 3.13, the Clarke transformation is used to convert three-phase variables from three-phase system coordinate for the two -axis Cartesian stationary system of co-ordinates. It’s given as follows.

$$I_{\alpha} = \frac{2}{3}(I_a) - \frac{1}{3}(I_b - I_c) \quad 3.44$$

$$I_{\beta} = \frac{2}{\sqrt{3}}(I_b - I_c) \quad 3.45$$

I_a, I_b, and I_c were three-phase quantities in this scenario. The stationary orthogonal reference frame values I_α and I_β are I_a, I_b, and I_c can be changed to I_α and I_β as follows when I_α is superposed with I_a and $I_a + I_b + I_c$ equals zero:

$$I_\alpha = I_{\mathrm{a}}$$

$$I_\beta = \frac{1}{\sqrt{3}}(I_a + 2I_b) \qquad 3.46$$

Where $I_a + I_b + I_c = 0$

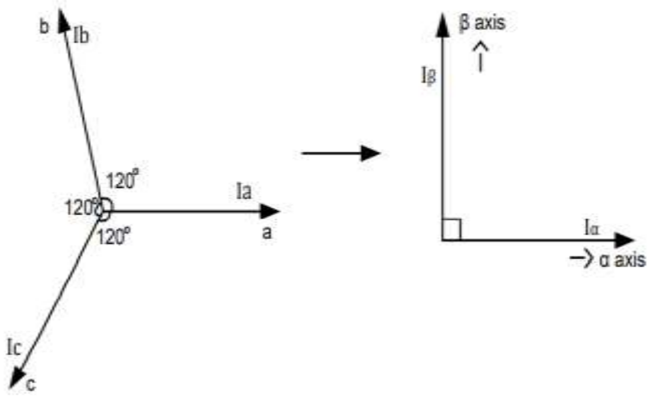

Figure 3. 13 Clark transformation

Park Transformation

As shown in figure 3.14, the Park transform is used to convert the 2-axis orthogonal stationary reference frame size according to the rotating reference frame size. Park transform the formula:

$$I_d = I_\alpha * \cos(\theta) + I_\beta * \sin(\theta) \qquad 3.47$$

$$I_q = I_\beta * \cos(\theta) - I_\alpha * \sin(\theta) \qquad 3.48$$

Where rotating reference frame quantities are I_d and I_q.

The stationary reference frame quantities I_α, I_β are orthogonal. θ is the angle of rotation

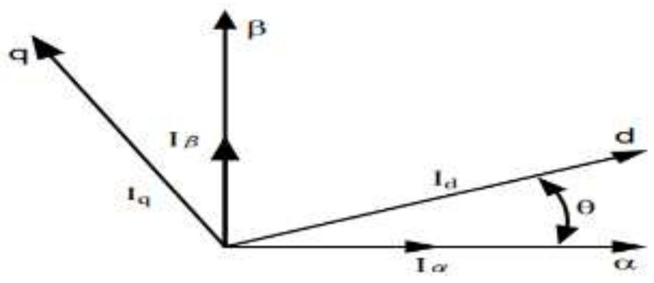

Figure 3. 14 transformation of park

Rotor angle is computed by

$$\theta=\int \boldsymbol{\omega_e\, dt} \qquad 3.49$$

Where $w_e = w_{sl} + w_{act}$

$$w_{sl} = \frac{M}{Lr} * \frac{Rr}{\varphi} * iq \qquad 3.50$$

Calculate quadrature stator current

$$I^*q = \frac{\mathbf{2}}{\mathbf{5}} * \frac{\mathbf{2}}{\boldsymbol{p}} * \frac{\boldsymbol{Lr}}{\boldsymbol{M}} * \frac{\boldsymbol{T^*}e}{\boldsymbol{\varphi}} \qquad 3.51$$

Calculate direct stator current

$$I^*_d = \frac{\boldsymbol{reference\ flux(\varphi *)}}{\boldsymbol{M}} \qquad 3.52$$

Apply inverse of both Clarke and park transformation.

Generally, IFOC undergoes the following transformations.

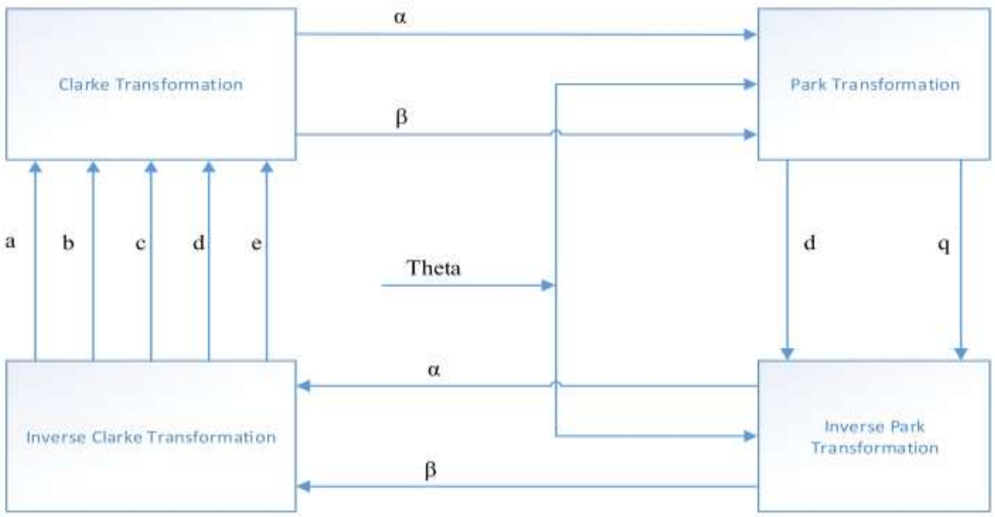

Figure 3. 15 Basic transformations in indirect field oriented control [33].

3.4.2 Realization of Space Vector PWM

Some steps for relization of space vector *PWM*

1, Determine V_α, V_β, and V_{ref} angle (θ)

2, Determine time duration T_0, T_1, T_2

3, Determine switching time of each transistor (S_1 through S_{10})

To obtaine the parameters of step-1, consider the following transformation.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} cos(\theta) & -sin(\theta) \\ sin(\theta) & cos(\theta) \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix} \quad 3.53$$

$$|V_{ref}| = \sqrt{(V^2{}_\alpha + V^2{}_\beta)} \quad 3.54$$

$$\alpha = \tan^{-1}\frac{V_\beta}{V_\alpha} \quad 3.55$$

Determine time duration T_1, T_2, T_0

Time duration for sector-1 is calculated using the figure below.

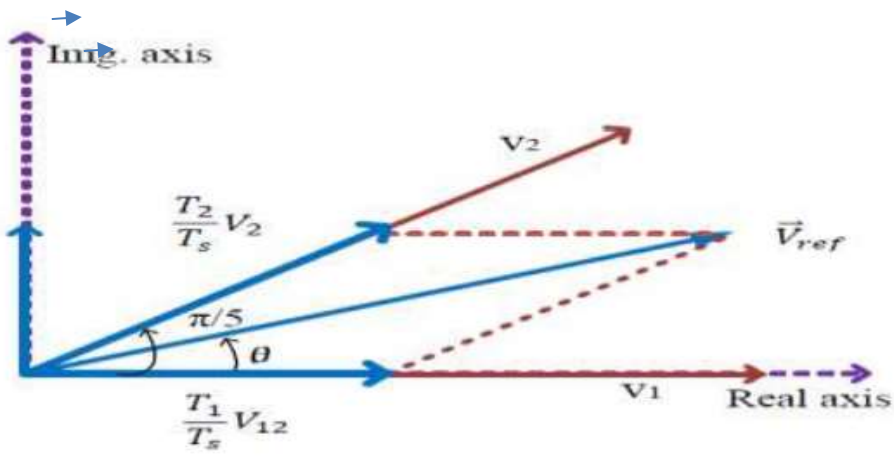

Figure 3. 16 space vector realization for sector-1

As shown from the above figure, $\vec{V}_{ref}$ is adjacent to $\vec{V}_1$ and $\vec{V}_2$ Therefore we express $\vec{V}_{ref}$ in terms of these adjacent voltages as follows

$$\int_0^{T_s} V_{ref}\, dt = \int_0^{T_1} V_1\, dt + \int_{T1}^{T_1+T_2} V_2\, dt + \int_{T_1+T_2}^{T_s} V_0\, dt \quad 3.56$$

From the above integration we get the following results

$$T_s\vec{V}_{ref} = T_1\vec{V}_1 + T_2\vec{V}_2 \quad 3.57$$

$$Ts = T_1 + T_2 + T_0 \quad 3.58$$

Where

$$\vec{V}_{ref} = \vec{V}_{ref}\, e^{j\alpha}$$

$$\vec{V}_1 = 2/5V_{dc}2\cos(\pi/5)\exp(j0) \quad 3.59$$

$$\vec{V}_2 = 2/5V_{dc}2\cos(\pi/5)\exp(j\pi/5) \quad 3.60$$

$$\vec{V}_0 = 0 \quad 3.61$$

3.5 ANFIS Speed Controller

3.5.1 Fuzzy Logic Controller Design

Design of fuzzy logic is the convenient way to mapping inputs to outputs. Conceptually easy to understand, it is a control algorithm based on a linguistic control strategy that attempts to provide human knowledge of how to control a system without the need for a mathematical model.

3.5.2 Fuzzy Logic Structure (FLC)

Knowledge base

The knowledge base contains database and rule base. Database consists of that provide clear input/output membership that operates operations involving fuzzing and defuzzing. Whereas a set of linguistic rules in the base that serves as the information source for the inference engine. This rule states as follows.

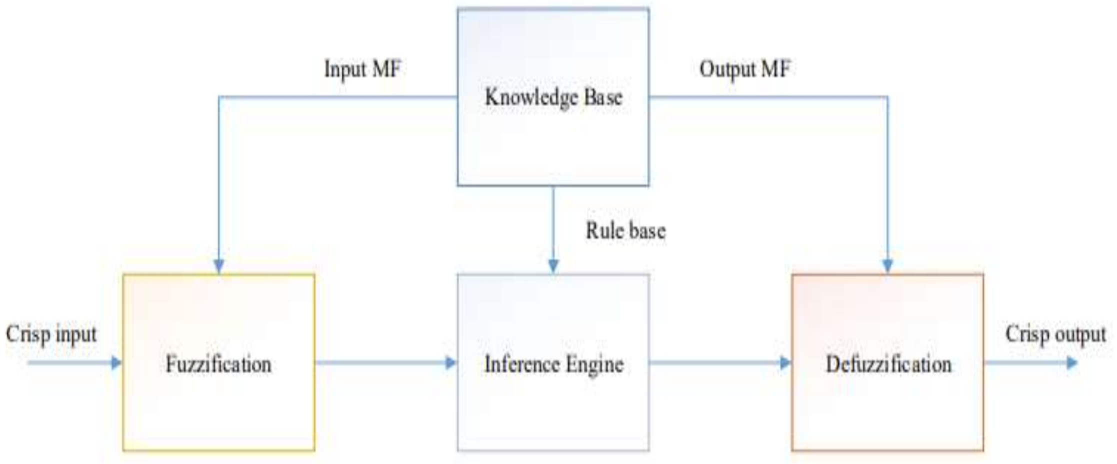

Figure 3. 17 Basic structure of fuzzy logic controller

Fuzzification

Procedures of converting crisp input value to a fuzzy number by using membership function.

Inference engine

A procedure relating to input and output fuzzy set by using if-then rules and the fuzzy operator that produce reasonable fuzzy output value, this is called as inference engine. Mamdani, Lusing Larson and Sugeno, are some of the known.

Defuzzification

Fuzzified output value that converting in the crisp control value by using membership function is known as Defuzzification. Centroid, height, mean of maxima and Sugeno are some of bet known defuzzification systems.

3.5.3. ANFIS Control structure

ANFIS has a hybrid system that combines ANN and FL. The intelligent power system's complexity can be decreased by combining the fuzzy logic with neural network concepts to create a better system with improved performance and design. A neural network called ANFIS is used to create fuzzy inference systems. The membership functions and rules table of a fuzzy model can be created using the neural network training approach, when input/output mappings for a fuzzy system are known. ANN, which is used to train the fuzzy inference system, is also based on the idea of input/output mapping. Trained to identify patterns in both the inputs and the outputs, much like the brain does. From a collection of input data, the network is trained to produce a corresponding output pattern. The speed controller in this thesis is based on ANFIS. The ANFIS controller gets a data set that includes input and target data based on a specified training scenario. The ANFIS controller uses this data set to train the fuzzy system. To start ANFIS learning; First, a training dataset is required that contains the desired input/output data pairs of the target systems to be modeled.

Generally, the following block diagram that represents Five-phase induction Motor Drive structure.

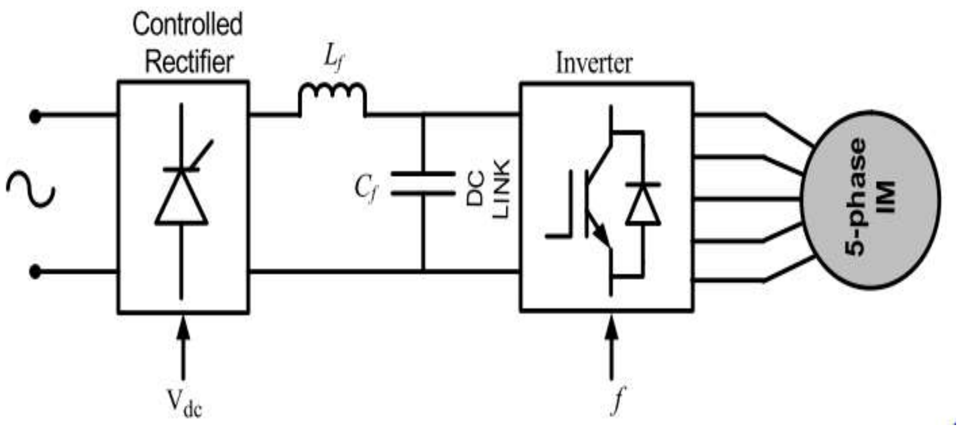

Figure 3. 18 Five-phase induction Motor Drive structure [34].

Four procedures of ANFIS controller design

Training Phase:

The training phase of ANFIS in the first stage and utilized to generate set of practice data. The suggested control techniques consider both actual torque and change motor values are generated as vectors and the applying data to the neural network. Data is the trained against the actual torque of the motor by a backpropagation training algorithm. This learned data set applying to fuzzy inference system can generate fuzzy rule. In interference method for controlling fuzzy rule base is generated automatically in ANFIS.

Testing Phase:

The investigation that produces the tested speed control system model is the next stage of ANFIS. The suitable electromagnetic control torque is obtained from the inference system during the test time by applying the motor's real torque and variable torque as inputs.

Features of ANFIS

For the feature set based on a neural network and a fuzzy system control mechanism has utilized, ANFIS. Neural network has a feed-forward network topology, and back-propagation is the network learning technique. The data is trained using the backpropagation learning algorithm based on network error. The discrepancy between the set point and the actual value is known as the grid error. A suitable control model can be created as a result. A collection of rules are contained in the suggested fuzzy inference system model, which is based on the Sugeno model.

Structure of ANFIS:

Output layer, rule layer, output members function layer, input membership function layer, and five levels that make up the ANFIS system's structure. In order to reduce the sum of squared errors (*SSE*), the data are classified using a fuzzy interference decision tree into one of 2^n (or P^n) linear regression models (*SSE*).

$$SSE = \sum_i er^2{}_i \qquad 3.62$$

Where er^2i has discrepancy between the desired and actual output and n is the number of input variables, P^n is the number of fuzzy divisions for each input variable. First order two input fuzzy model with sugeno is presented [29].

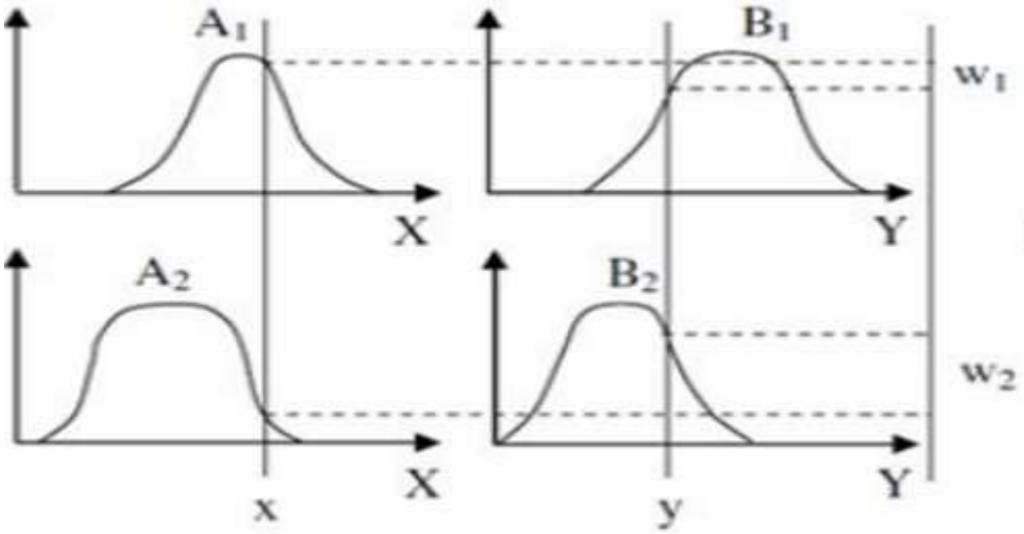

Figure 3. 19 two-dimensional first order Sugeno fuzzy model -inputs and two rule [35].

$f_1 = p_1x + q_1y + r_1$ Then

$f_2 = p_2x + q_2y + r_2$

$$Te = \frac{W1f2+W2\overline{f2}}{W1+W2} = W_1\overline{f_1} + W_2f_2 \quad 3.63$$

Standard fuzzy if-then logic established the first order. The Sugeno fuzzy inference model is described as follows:

If x_1 is B_1 AND x_2 is C_1, then $f_1 = p_1x + q_1y + r_1$

If x_1 is B_2 AND x_2 is C_2, then $f_2 = p_2x + q_2y + r_2$

Where parameters *pi, qi*, and *ri* are the fuzzy design parameters computed during the training process (i=1, 2,..*n*), and *Bi* and *Ci* are the antecedent fuzzy sets. The ANFIS structure's two inputs and one output are shown below.

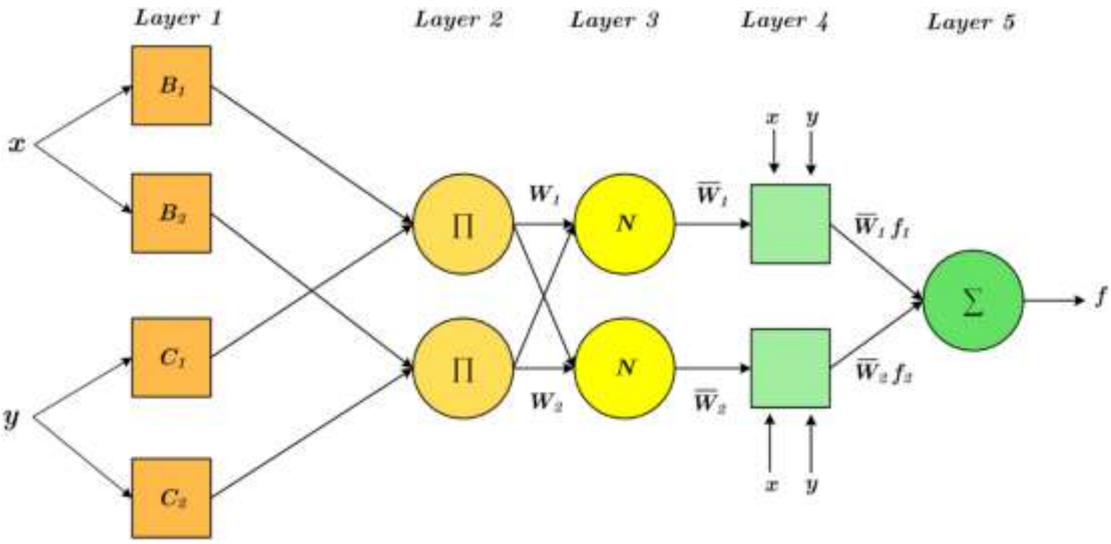

Figure 3. 20 The ANFIS diagram [36].

The accompanying picture shows the Sugeno model's technique for determining the motor's real torque (*f*) for a given input vector [*x, y*]. The ANFIS's structure and each layer's explanation are provided below.

Layer 1: Adaptive nodes with node functions are defined as follows in this layer:

$$Q_i^{L1} = \mu B_i\,(x) \qquad 3.64$$

$$Q_i^{L1} = \mu C_i\,(y) \qquad 3.65$$

Where, ω∗ input of *I* & B_i were node function connected to linguistic label. The membership function O_i^{L1} that indicates extent to which the specified *x* satisfied to quantifier *Bi*. A bell-shaped μB_i (x) that has a max1 and a min 0 is considered which is given below.

$$\mu B_i\,(x) = \frac{1}{1+\left|\frac{x-Ci}{ai}\right|2bi} = \exp\{-\left(\frac{x-C_i}{a_i}\right)2bi\} \qquad 3.66$$

When the parameter {a_i, b_i, c_i} to modify that linguistic label B_i membership functions is referred to as premise parameter. The same is true for the selected μ_{Ci} (y).

Layer 2: The firing strength of the rule is calculated by summing the input signals together before delivering the result to each layer node.

$$Q_i^{L2} = W_i = \mu_{Bi}(x)\ \mu_{Ci}(y),\ i = 1, 2, 3\ldots \qquad 3.67$$

Layer 3: The i^{th} node of this layer is used to determine the ratio between the firing strength of the i^{th} rule and the sum of firing strengths of all rules.

$$\overline{Q}iL3 = W1 = \frac{Wi}{W1+W2},\ i = 1,2 \qquad 3.68$$

Layer 4: The i^{th} node of layer calculates the i^{th} rule's contribution to total output as follows:

$$\overline{Q}_i^{L4} = W_i f_i = (P_i x) + q_i y + r_i \qquad 3.69$$

$\overline{Wi}$ is the layer 3 output, and p_i, q_i, and r_i are the parameter set.

The term consequent parameters are used to indicate the parameters of this layer.

Layer 5: The overall output is calculated by adding up all of the inputs at the single node in this layer designated as Σ.

$$\overline{Q}_i^{L5} = \sum_i W_i f_i = \frac{\sum_i W_i f_i}{\sum_i W_i} \qquad 3.70$$

The total output f for the ANFIS structure in figure 3.19 can be stated as a linear combination of the subsequent parameters for the situation with fixed premise parameters, which is most obvious from.

$$T_e = \overline{W}_1 f_1 + \overline{W}_2 f_2 \qquad 3.71$$

$$T_e = (\overline{W}_1 x)p_1 + (\overline{W}_1 y)q_1 + (\overline{W}_1)r_1 + (\overline{W}_2 x)p_2 + (\overline{W}_2 y)q_2 + (\overline{W}_2)r_2 \qquad 3.72$$

By using the vector as an input, the designed control system, of ANFIS structure, is trained. After that, the proper control output SVM is used to produce a control signal. The inverter receives a generated control signal that is used to regulate induction motor's speed. In general, the following block diagram depicting a hybrid neuro-fuzzy controller (Anfis) for induction motor speed control.

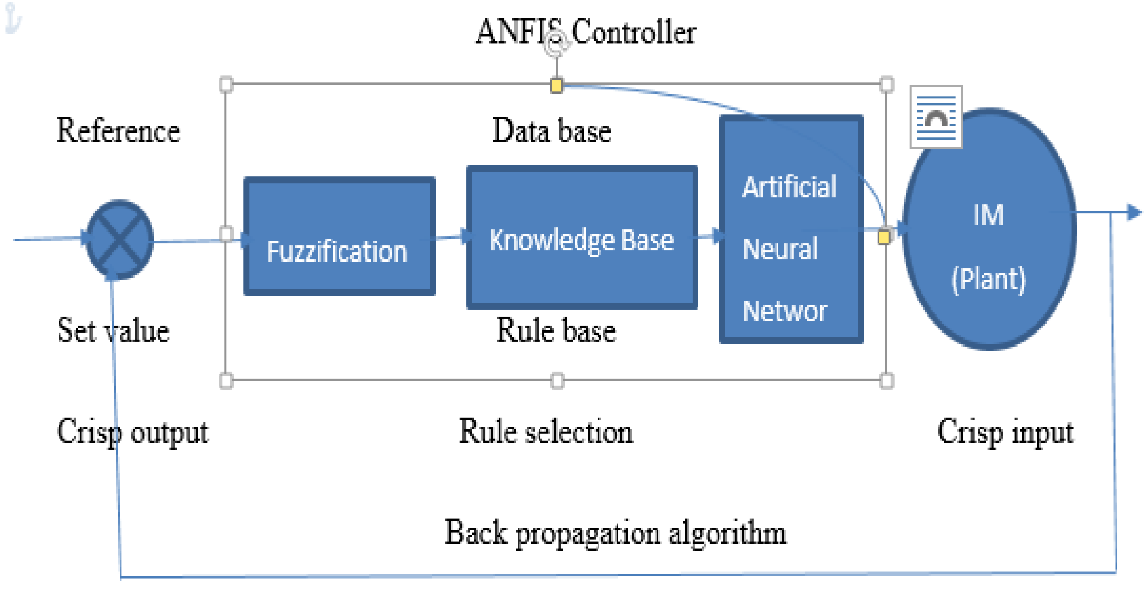

Figure 3. 21 Block schematic of the ANFIS control system for controlling IM's speed

CHAPTER 4
SIMULATION RESULTS AND DISCCUSIONS

4.1 Model, and Simulation of controller

Simulation modeling on computer is often used to examine how the proposed system behaves and determine if the modified control techniques has effective to avoid errors early in the simulation before going to implementation. There are many bundles of software simulation among these programs Simulink method is the popular one that suitable and strong methods because of its necessary to understand the characteristics and graphical user interface, for modeling dynamic systems. This thesis using Matlab/Simulink 2019a version to model, simulate and analyze the system responses. The proposed control system Simulink diagram of SCIM has shown in figure 4.1. Fuzzy neuron controller hereunder used to show speed response. The difference between the target speed and the actual speed is always called an error. This error acts as an input to the fuzzy controller and the electromagnetic torque is output from this controller.

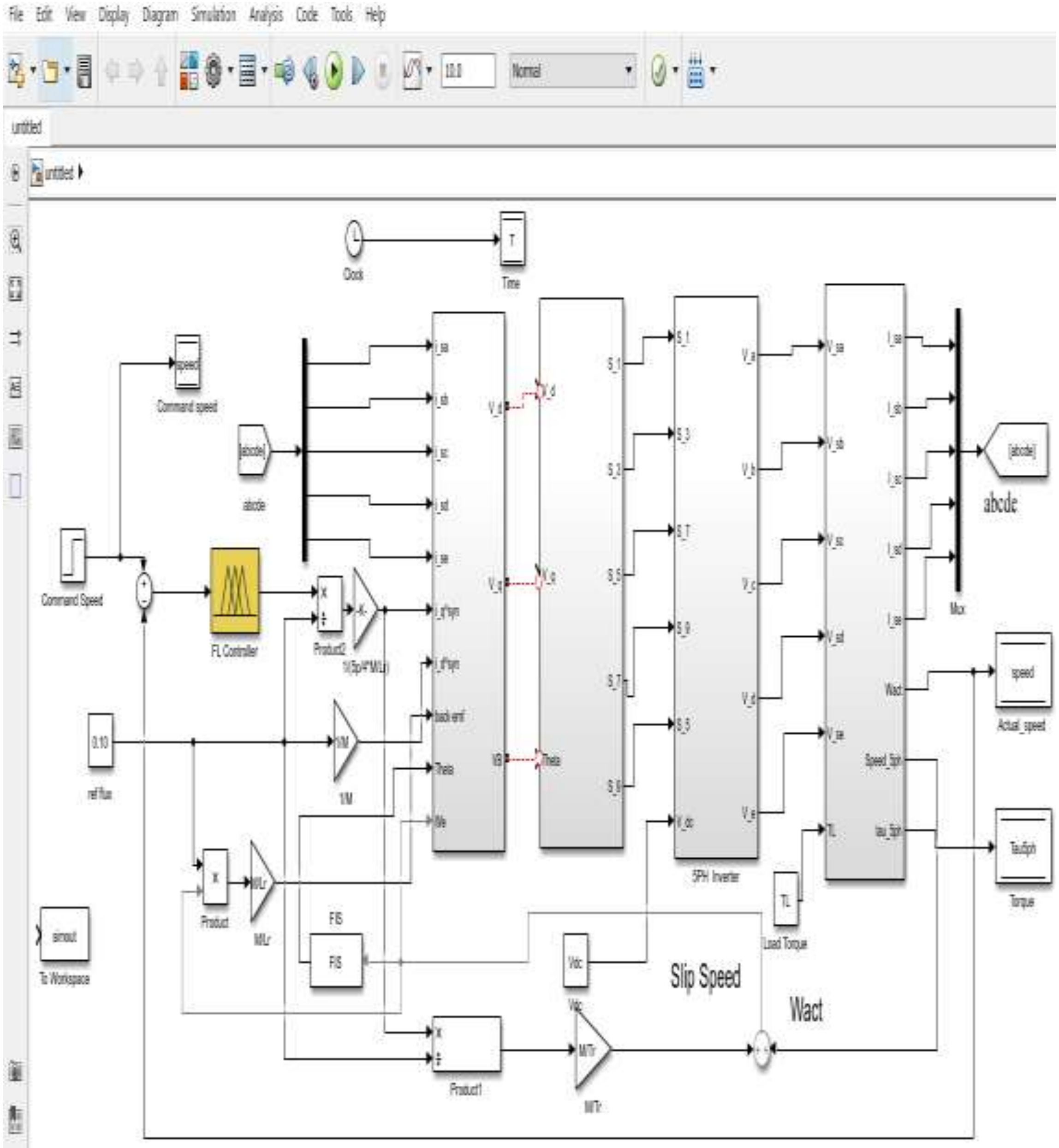

Figure 4. 1 Fuzzy neuron control Simulink block

An inverter for voltage source

By activating the switching states produced by space vector modulation techniques, to convert DC voltage into five-phase voltages, VSI blocks has been employed. Induction motors are powered by the phase voltage output of VSI, which is also used to measure specific flux and actual torque.

SVM Simulink block

Space vector modulation is another important functional block that can produces an appropriate duty cycle which controls working condition of VSI. Which have high dynamic response, interactions among current, fluxes, and speed must be incorporated in determining appropriate control strategies.

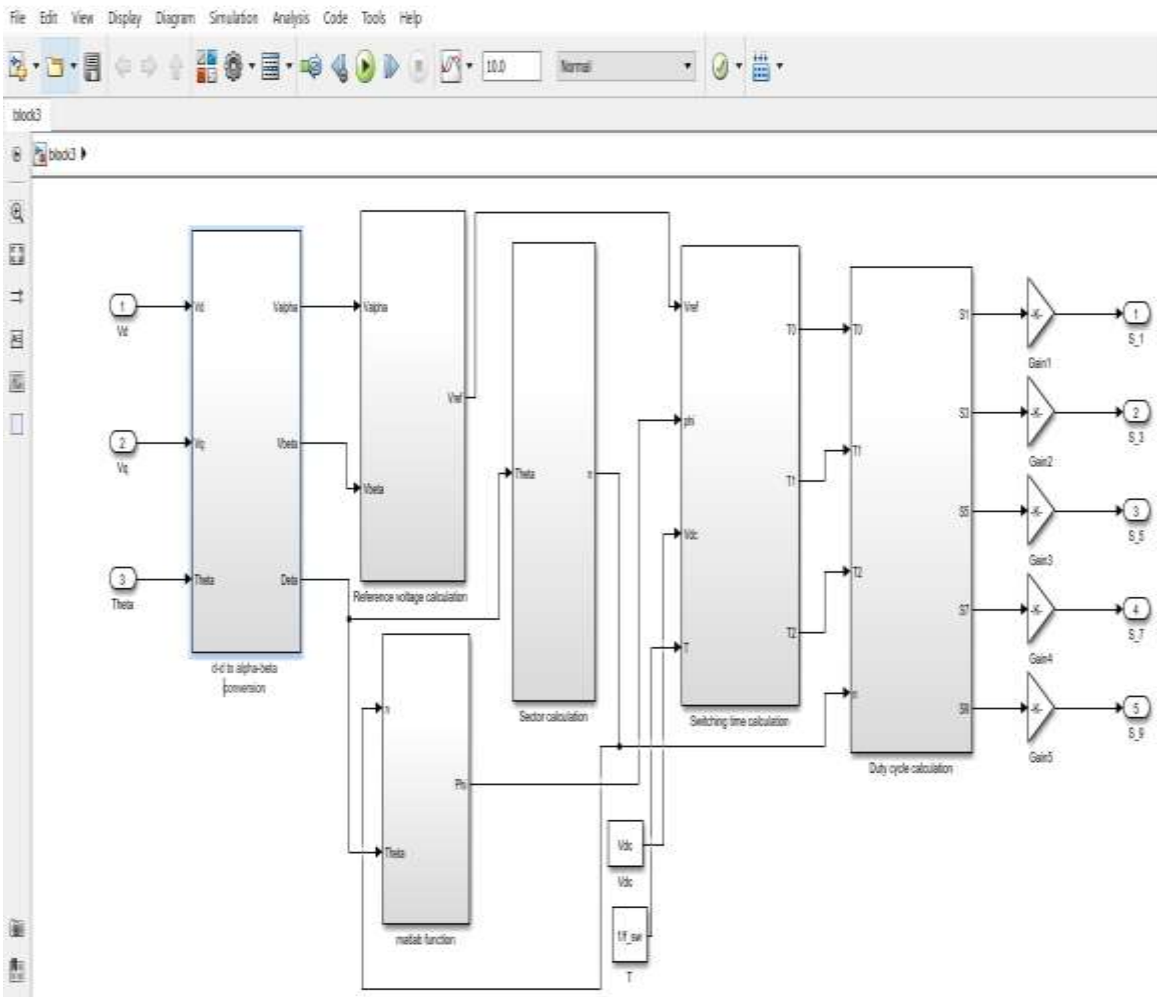

Figure 4. 2 Simulink model of SVM

IM simulation model

Here is the mathematical model of an induction motor based on the support of space vector theory and the principle of indirect field oriented control (IFOC). Induction motor drive simulation models have been developed using the indirect FOC principle. The Simulink blocks are based on rotation and static reference frames.

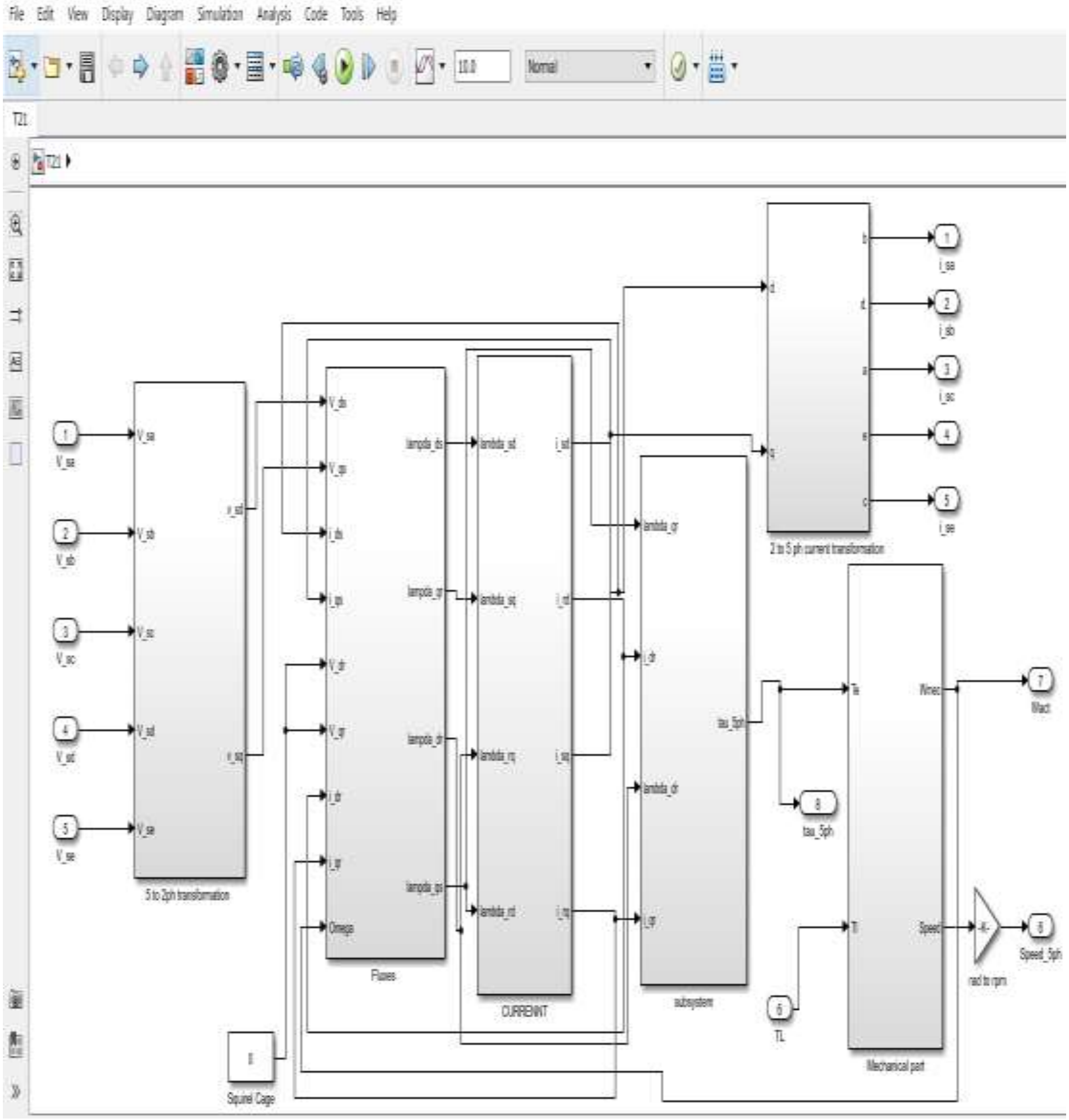

Figure 4. 3 Simulink model of five phase IM

4.2 Simulation Results of fuzzy controller

4.2.1 Simulation Results of IM

Simulation result discussed on the simulation results of different testing mechanism with the help matlab software to show what will happened five phase induction motor driving mechanism. Table 4.1 below lists the motor's parameters, which are utilized for the simulation. These parameters are obtained from matlab Simulink documentation.

Table 4. 1 based on a predetermined model in induction motor parameters

Name	Symbol	Unit	Value
Stator resistance	R_s	0.4	Ω
Rotor resistance	R_r	0.9	Ω
Stator inductance	L_s	5.25e-3	H
Rotor inductance	L_r	5.23e-3	H
Mutual inductance	M	5.2e-3	H
DC-Voltage	V_{dc}	1000	V
Kinetic energy	J	0.0032	$Kg.m^2$
Poles	P	4	

Fuzzy Logic Designer opens and displays a diagram of the fuzzy inference system with the name indicates each and every editor box. Figure 4.4 that clearly shows fuzzy logic designer, membership function editor, rule viewer and surface viewer. Fuzzy logic controller has passing all this processes in order to achieve the performance system design.

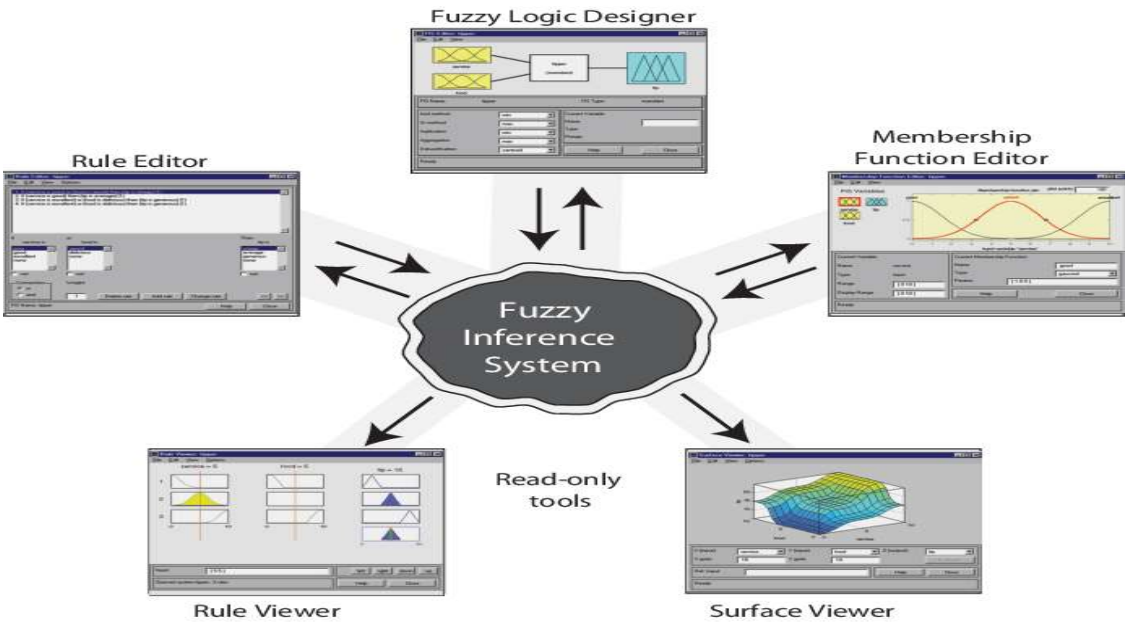

Figure 4. 4 the whole fuzzy logic editor window

Generally the overall steps of anfis controller of induction motor is given below in the figure 4.5 from the beginning of selecting input data up to the last results obtained in the anfis editor window

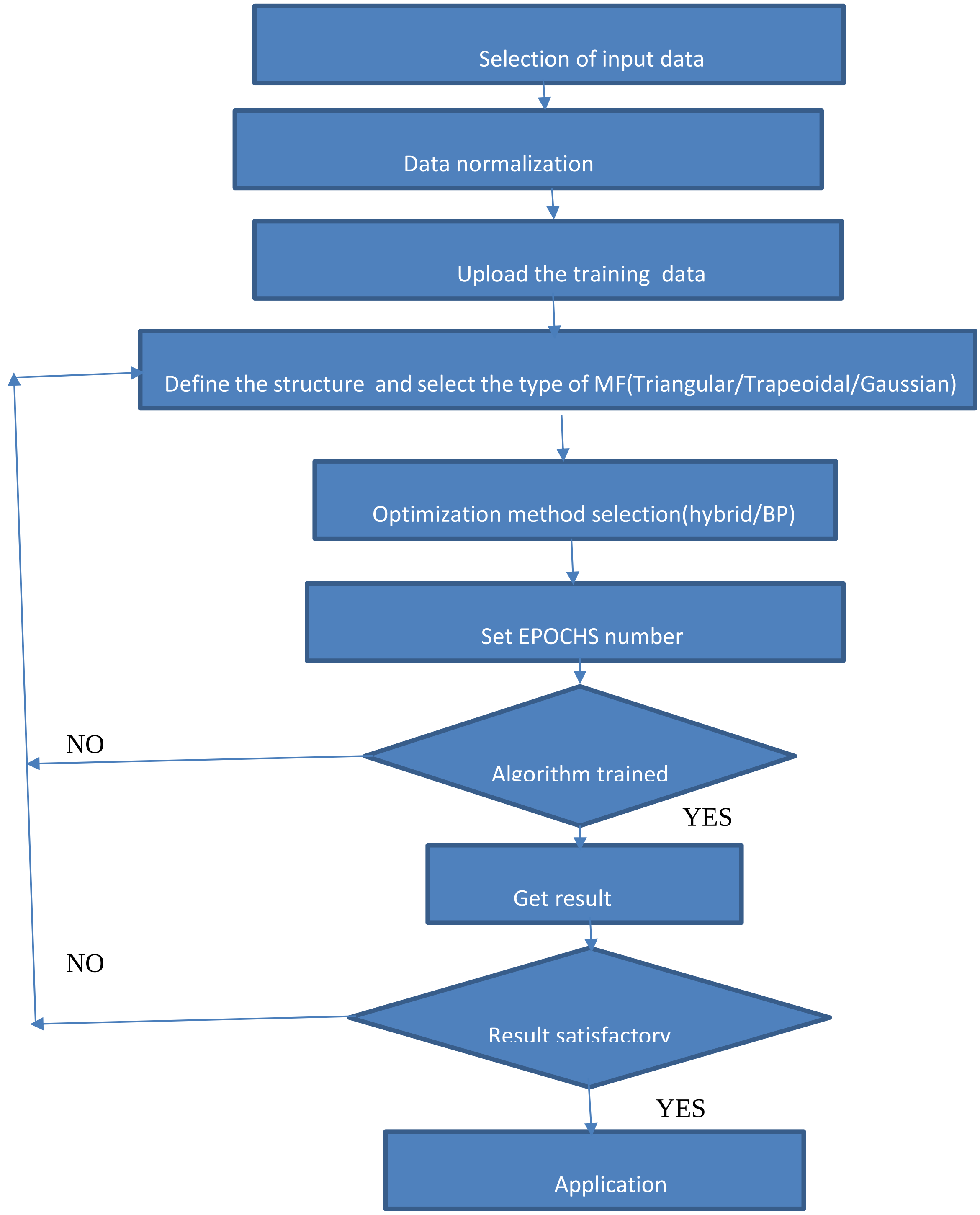

Figure 4. 5 Flow chart of anfis controller

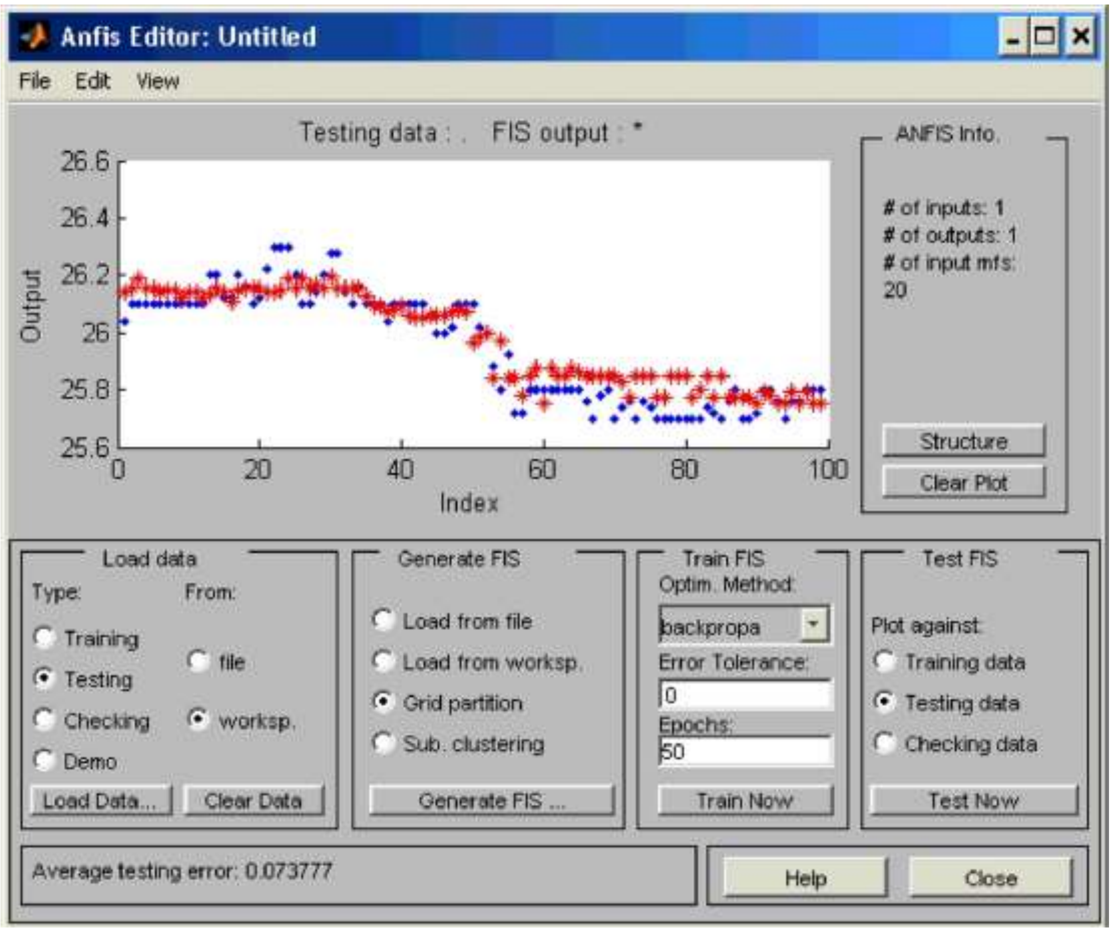

Figure 4. 6 The ANFIS editor, training, testing and checking data sets.

At each epoch, the generality of the fuzzy inference system is checked via data validation. The format of control data is the same as that of training data. The fuzzy inference model is validated using this dataset. This validation is carried out by feeding the model with verification data and observing how the model responds to that data. Test data is added to the model at each training epoch when the test data option is used in the ANFIS GUI. The training and verification data were loaded, and the FIS member function parameters were calculated using the ANFIS editor GUI. The verification data's error lowers towards the beginning of training because it is sufficiently comparable to the training data the control mistake is the deviation between the output value of the control data and output of the associated fuzzy inference system using the same input control data. Each epoch of error checking records the RMSE for test data.

Table 4. 2 The adaptive neuro-fuzzy inference system parameter that was built.

Name,of parameters	**Characteristics/ Value**	**Name of parameters**	**Characteristics /Value**
Optimization technique	Hybrid/combination	Number of training data pair	2,450,000
Structure of FIS	Sugeno first order	Number of data pairs being checked	1,150,000
Number of input value	2	linear parameters	148
Number of input MF	7	Non-linear parameters	47
Types of input MF	Universal bell	Total parameters	187
Number of out Put MF	Fortify nine(49)	Number of nodes	300
Numberof output	1	Number of rules	49
Output MF type	Linear	epoch/iteration	100

Effectiveness of five-phase IM function has discussed. According the statement or description of in previous portion formulas, figures and, Simulink models, the simulation is carried out for different load torque applications with no load to full load conditions are shown in the following.

Simulation result discussion

The model created in the preceding sub-sections is the foundation for the simulations described in this section. It is first assessed the conventional controllers such as fuzzy-PID, Fuzzy-PI. The values of the different performance parameters such as rise time (t_r), settling time (t_s), peak overshoot (M_p), and steady state error (e_{ss}) of each controller are shown in figure 4.7 and figure 4.8. According the results, it can be said that PID-Fuzzy has fast transient response and less overshoot than PI-Fuzzy controllers their Peak overshoot(M_p) and steady state error(e_{ss}) 0.0016, 0.0005 and 0.0994, 0.1100 at 100N.m respectively.

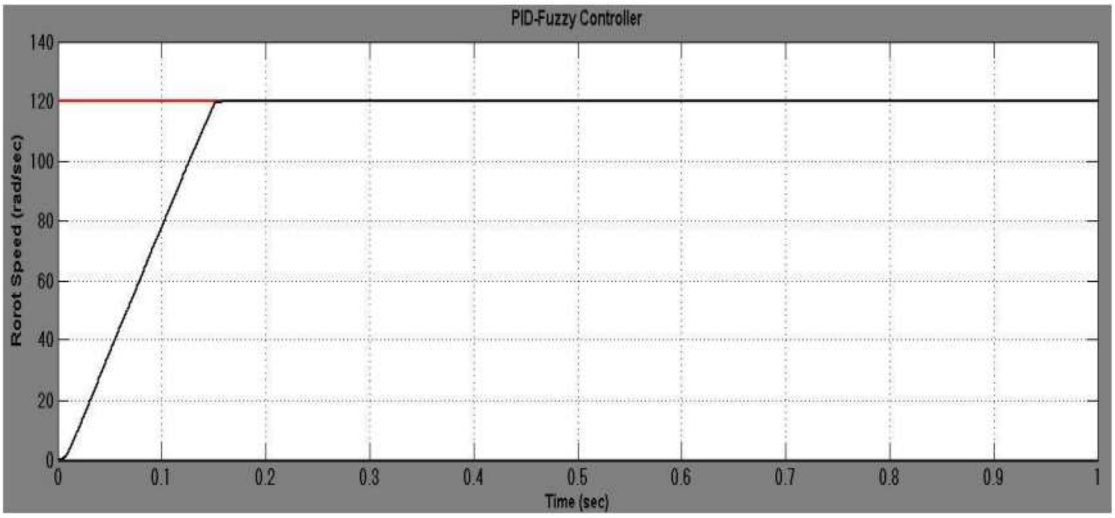

Figure 4. 7 speed of the fuzzy PID controller's

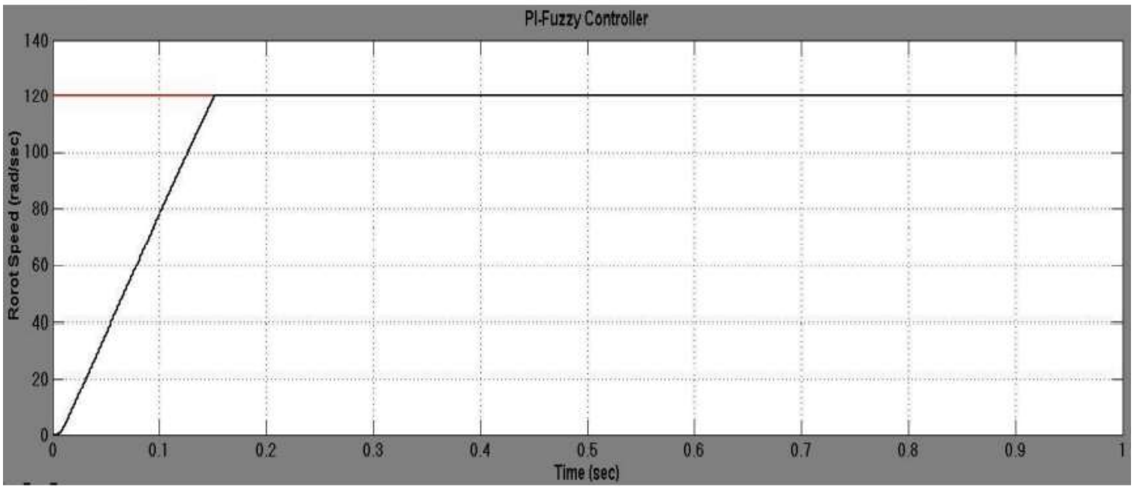

Figure 4. 8 shows the induction motor's fuzzy-PI speed response.

Another simulation result discussions first, it is evaluated the initial conditions, that is, when it is not applied any load torque. The results for this condition are presented in Figure 4.9, 4.10 and 4.11. Accordingly the result shows if the motor speed increases load-torque decreases sequentially, and vice versa.

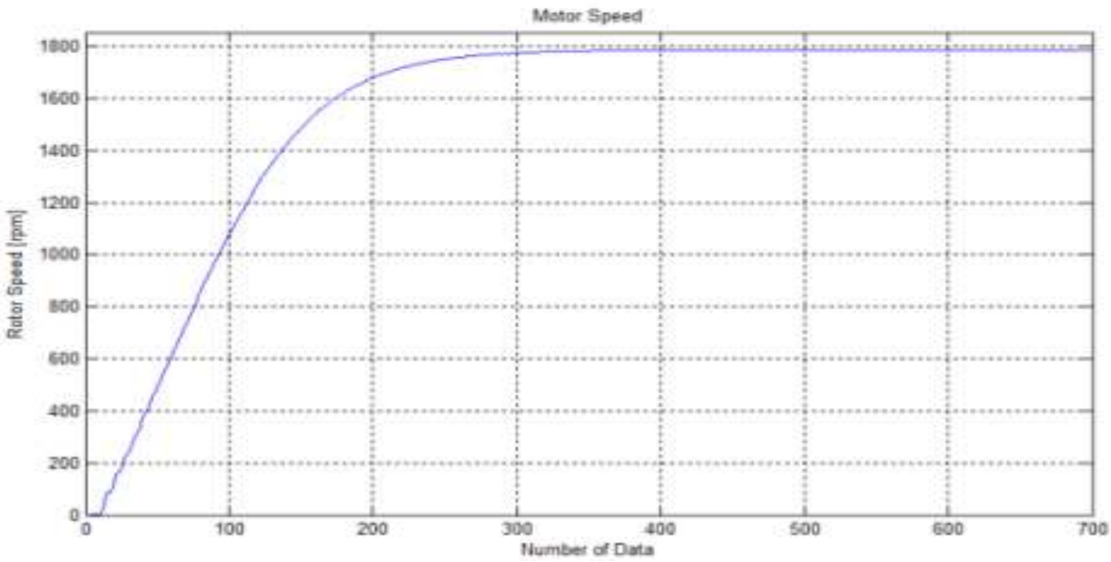

Figure 4. 9 Rotor Speed, TL = 0

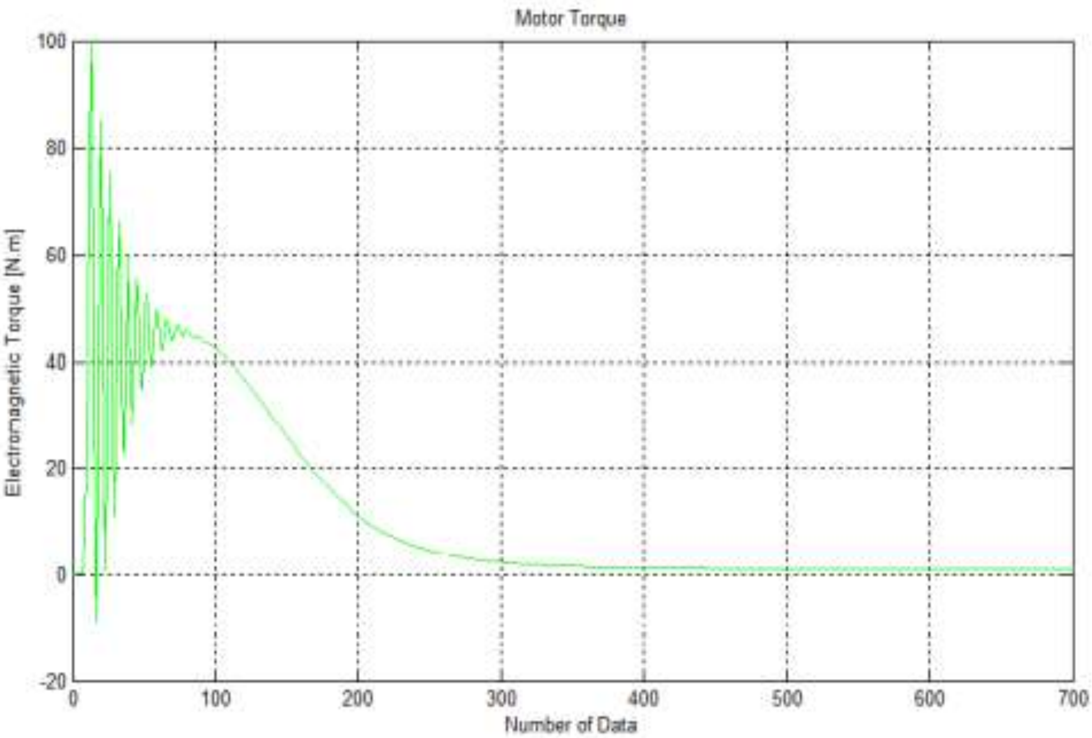

Figure 4. 10 Electromagnetic Torque, TL= 0

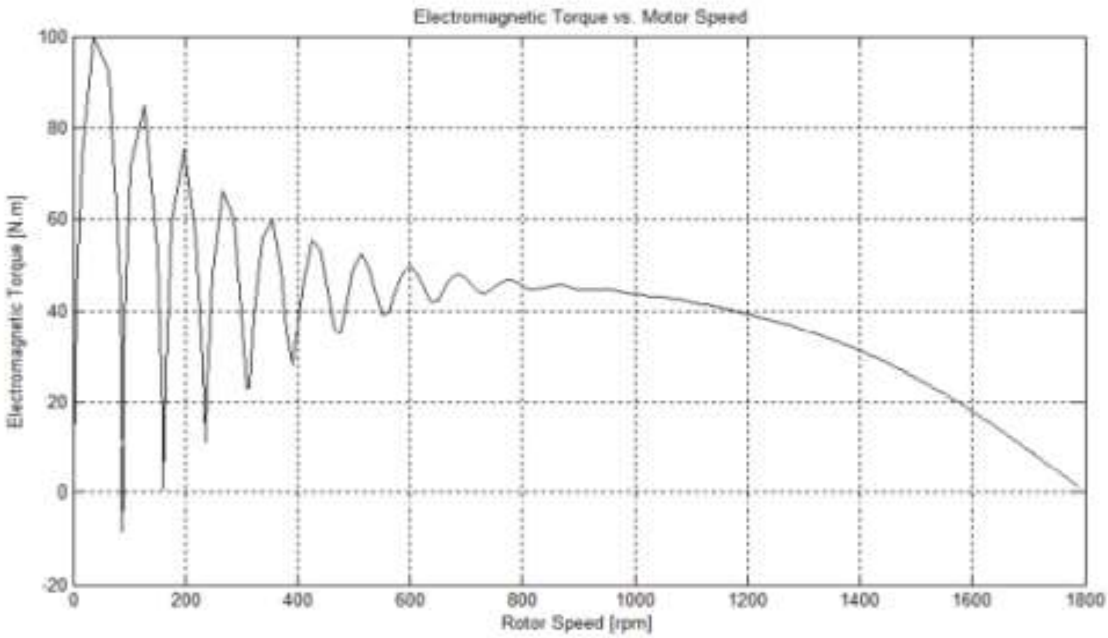

Figure 4. 11 Motor Speed versus electromagnetic Torque, TL = 0.

The second simulation is to evaluate the results in terms of electromagnetic torque, speed and the relation among torque and speed, when it is applied different load torque values to the induction motor. This is shown in figure 4.12 and 4.13.

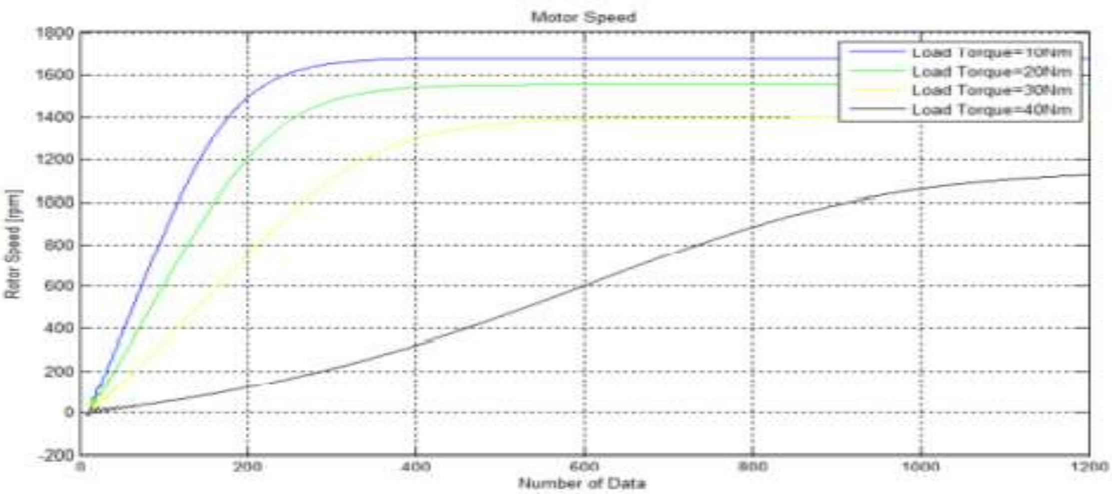

Figure 4. 12 Rotor Speed Results for different TL

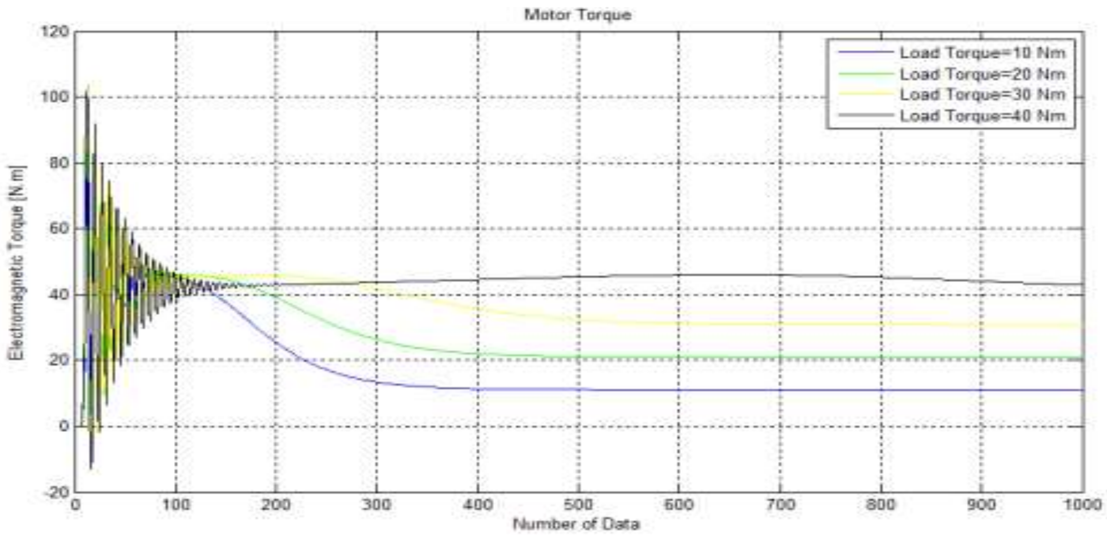

Figure 4. 13 Electromagnetic Torque Results for different TL

The speed control with applied to different load conditions and observe the characteristics of rotor speed, electromagnetic torque on the 10Nm, 20Nm, 30Nm and 40Nm load conditions. The speed error result and performance measures show that when the load increases peak overshoot and rise time takes less time, this is can be seen the load between 10Nm and 40Nm. Proposed scheme is far better than conventional controller.

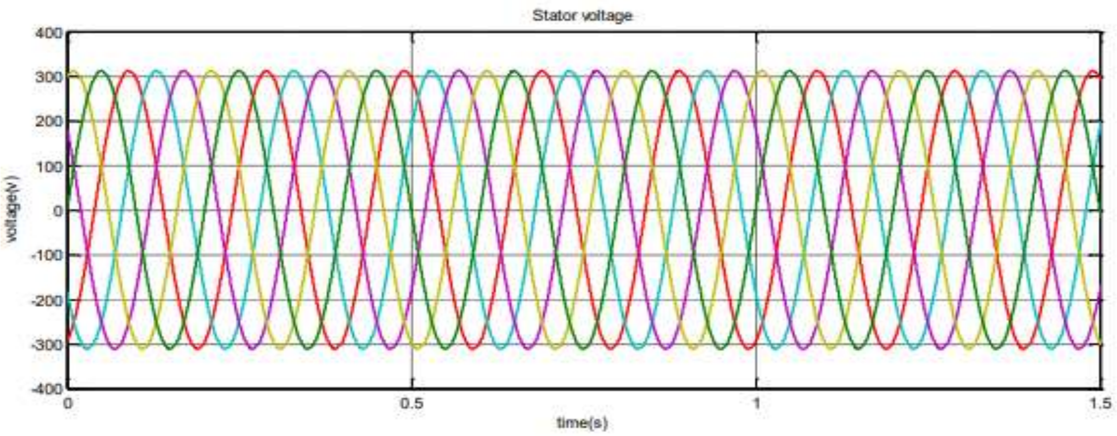

Figure 4. 14 five phase supply voltage

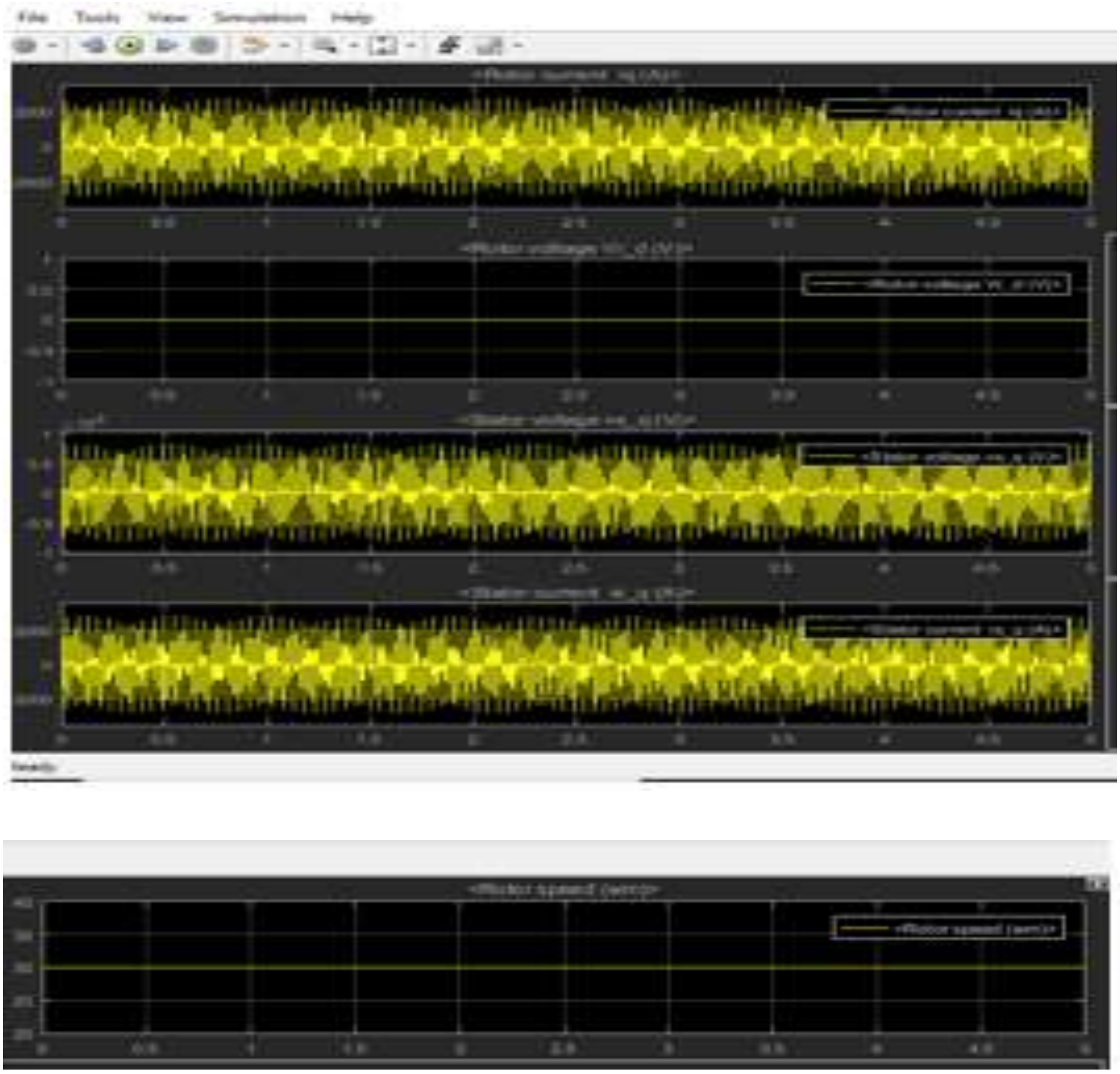

Figure 4. 15 Speed responses of motor with different parameters, torque speed, rotor and stator voltage

In figure 4.15 Simulation result that shows the characteristics curve of stator current, stator voltage, rotor current, rotor voltage and rotor speed (Wm).

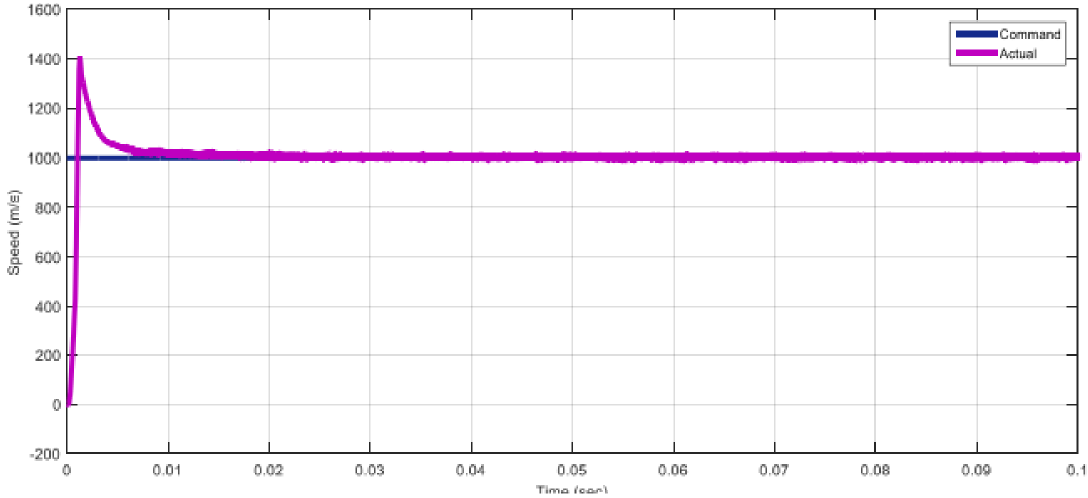

Figure 4. 16 Fuzzy based speed response induction motor

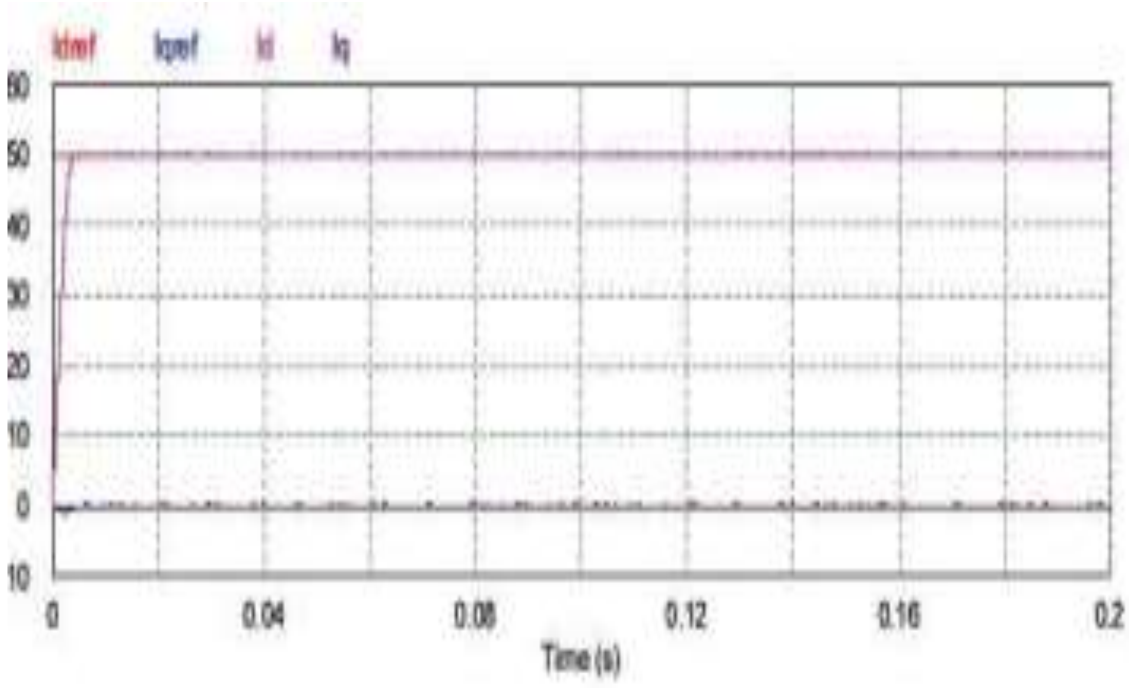

Figure 4. 17 ANFIS based speed response induction motor

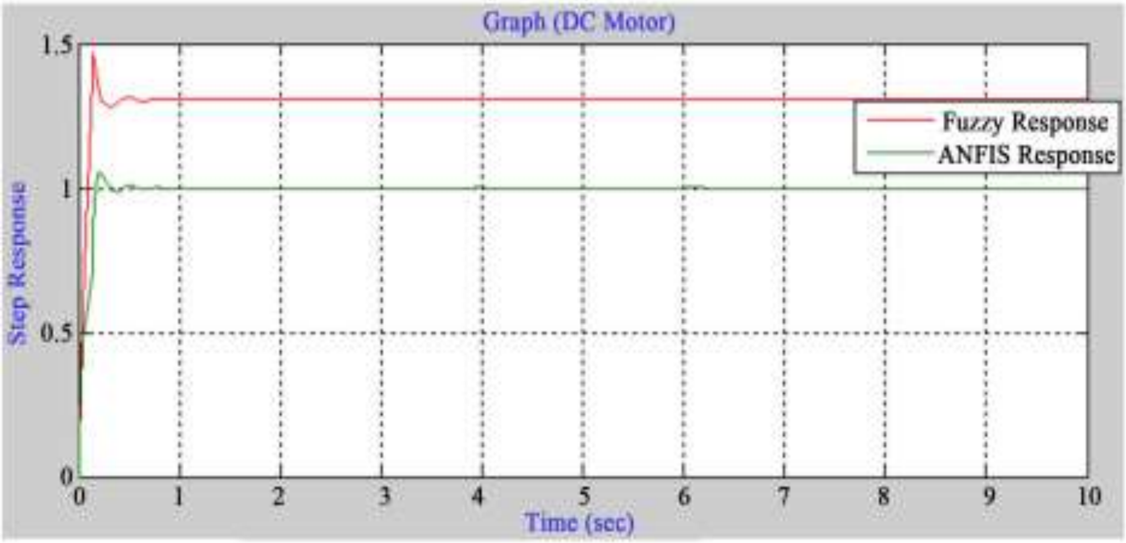

Figure 4. 18 out put response of fuzzy and anfis performance

Table 4. 3 Comparation between fuzzy and Anfis performance

Controller Type	Percentage overshoot	Rising time
FUZZY	14.4%	0.720 sec
ANFIS	8.2%	0.792 sec

Machine drives work when their speed is controlled precisely. For analysis a lot of issues come across such as changes in load dynamics, variable inputs, noise propagation and certain unknown parameters which result in unpredictable output of machines. Moreover, a reliable load regulating response with low and almost negligible noise propagation is necessary for a proficient system. In this thesis work has first analyzed Fuzzy and ANFIS controller separately and then interpreted both outcomes to show a comparison that which technique should be used in controlling speed of DC motor. A System should always be designed for less percentage overshoot and less rising time. Often there is a contradiction when adjusting percentage overshoot for minimum rising time. The study of this paper has shown that ANFIS controller is much better than Fuzzy controller as it gives a percentage overshoot of 8.2% than that of fuzzy controller which is 14.4%. Percentage overshoot indicates an outcome when a signal surpasses its steady-state value. ANFIS technique gives a lower percentage overshoot because of phases such as epoch and training involved in its simulation. Training phase repeats itself until and unless minimum error is reached. This minimum error limit reached is synchronized with given value of epoch which gives a low percentage overshoot then Fuzzy technique. However, a minimum adjustment of 0.072 sec rising time has to be made with ANFIS controller but due to less percentage overshoot, it should be considered a more adoptable technique.

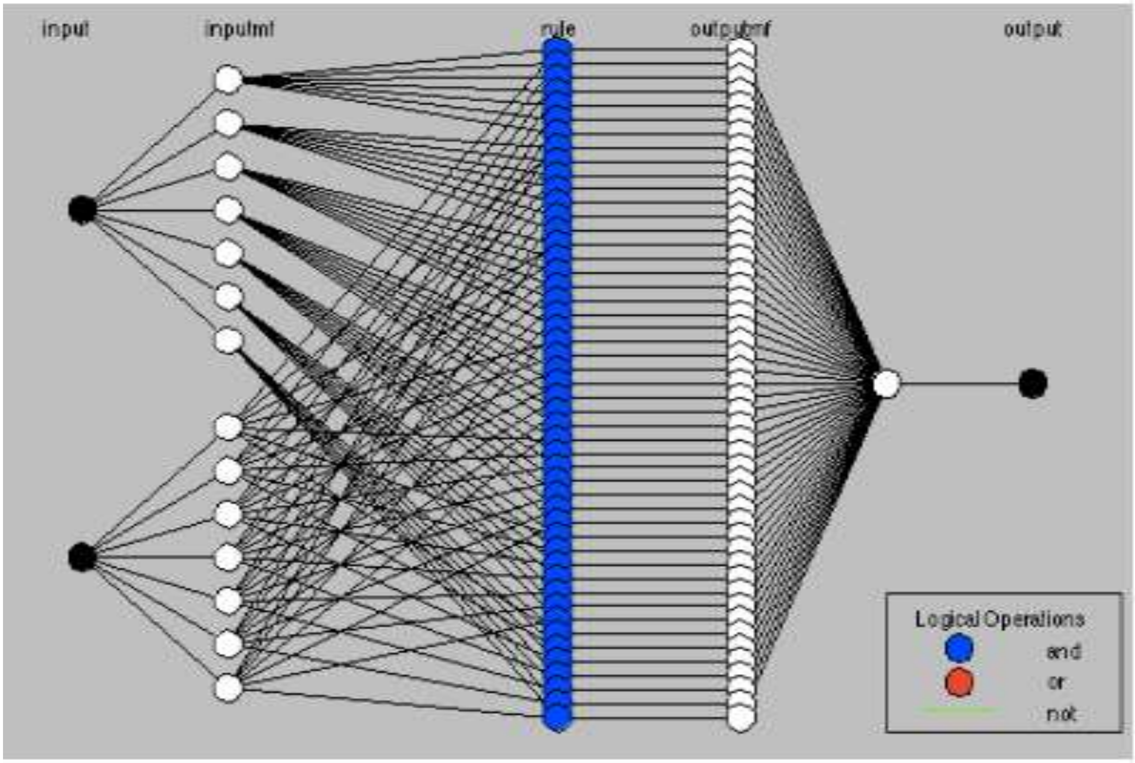

Figure 4. 17 ANFIS Structure

To establish a broad control strategy, a hybrid learning algorithm and a collection of 49 adaptive fuzzy rules were developed. Simulations ran for 3.1 seconds, and on the respective scopes inside the constructed model, typical curves for current, torque, and speed, time and load determined. They are simulation findings show that the characteristic curves of IM stabilize more quickly than those of other approaches, and the motor runs at its maximum speed. Much more rapidly when ANFIS controller is used. The extension of dynamic performance and good stabilization are the main benefits of the ANFIS coordinating approach.

The variables that affect induction motors are the variations in machine temperature, and saturation levels. The result, tells vector controlled induction motors are parameter sensitivity to treat as a secondary issue in the drive system. List of finding parameters of the detuning effect were Motor moment of inertia, stator resistance, rotor resistance, stator self-induction, and rotor self-induction. Among these specifications, it has been reported that the variation in stator and rotor resistances has a large impact on the speed performance. Other parameters have less impact, but as the variations become larger, the impact on the speed also becomes significant.

As shown the above designed figures 4.7 and 4.8 the speed response result with fuzzy-PID and Fuzzy-PI controller are shown large overshoot and very long settling time from the reference value, since the current also changes with a change in resistance and the torque deviates from its value as a result. But when the ANFIS controller are more resilient to parameter variations, it has zero overshoot and less time settling, and handle them correctly.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Tasks covered to the paper were designing and simulating a fuzzy IFOC-based controller for an inverter-fed SCIM, designing an investigation of alternatives using an ANFIS controller for vector control of an induction motor drive of the above controllers based on the output of MATLAB Simulink. Expressions for the rotor and stator speed of an induction machine's mathematical model are developed, and Also this paper that select five-phase SCIM that produces the output current 6-8% higher than those of the three-phase and six-phase machines. Most commonly used of multiphase system which is the smallest phase number, is five-phase.

It’s also shown that ANFIS controller is much better than Fuzzy controller as it gives a percentage overshoot of 8.2% than that of fuzzy controller which is 14.4%.

The performance and robustness of this proposed ANFIS controllers has been tested on simulation under different operating conditions, such us the speed response has tested by different load conditions and without load torques has been considered. Then, the simulation results demonstrate that the system is sufficiently robust for steady state operation in a variety of conditions, including no-load and load conditions, parameter fluctuation, and rotor resistance change. It has been possible to compare the controllers using performance metrics such overshoot and undershoot. And settling time based on simulation results, it is concluded that dynamic response and characteristics of anfis controller take much less overshoot and undershoot, when compared with the conventional controller and recently competitive fuzzy controller.

Accuracy, simplicity, and the possibility to create a better controller with fewer resources are the benefits of the ANFIS model proposed in this study. However, in order to achieve the desired control performance, a number of variables must be set. The training procedure requires a lot of time, but once the training results are put into practice, the system maintains its stability and operates more quickly, it can be inferred from the results.

Incorporation of general anfis controller has been spotted the speed reaching quickly the optimum value, it takes less time than that of the conventional controller. Another important feature of ANFIS is much faster operation speed the laborious job of training membership functions has been completed in ANFIS, making it more resistant to parameter fluctuations. Together, these findings demonstrate that the ANFIS controller offers a quicker settling time, a good dynamic response, and a fair level of stability. When concluding the proposed intelligent controller, it is perform better than traditional controlled drives.

5.2 Recommendation and future work

Due to the imperfect sinusoidal spatial distribution of the windings in multi-phase machines, undesirable spatial air-gap harmonics were produced. To develop suitable machine designs for five phase drive applications, this factor should be taken into consideration. A review of the proposed drive systems' general efficacy for the targeted applications.

Future research is advised to use derivative-free optimization techniques like evolutionary algorithms and sequential quadratic programming to identify the ideal parameters. Instead of using hybrid learning methods, layers numbers of one and four ANFIS Speed Controller Structures are optimized for the premise and consequential factors. Future work should focus on regulating the flux to increase motor efficiency and achieve a balance between the copper and aluminum. Hardware implementations utilizing Field-programmable gate arrays (FPGAs), application-specific integrated chips (ASICs), and digital signal processors (DSPs) (FPGAs).

REFERENCE

[1] Mitesh B. Astik, ’’Dynamic Modeling and Simulation of Five Phase Induction Motor’’, IJAREEIE, Vol. 4, Issue 4, April 2015.

[2] Ashok Kusagur, S. F. Kodad, and B. V. Sankarram, "Modelling of Induction Motor & Control of Speed Using Hybrid Controller Technology," Journal of Theoretical and Applied Information Technology, 2009.

[3] R.Rajendran and N.Devarajan, "FPGA Based Implementation of Space Vector Modulated *International Journal of Computer and Electrical Engineering, Vol. 2, No. 3, June, 2010 1793-8163*

[4] Mrinal Buragohain “Adaptive Network based Fuzzy Inference System (ANFIS) as a Tool for System Identification with Special Emphasis on Training Data Minimization.” Ph.D. dissertation, DECE, IIT Guwahati, India 2008

[5] MODELING AND DIRECT TORQUE CONTROL OF INDUCTION MOTOR BY USING FUZZY LOGIC CONTROL TECHNIQUE", International Journal of Computer and Electrical Engineering, Vol.2, No.3, pp.589- 594, June, 2010

[6] J. Martínez García, J.A. Domínguez, “Comparison between Fuzzy logic and PI controls in a Speed scalar control of an induction machine,” CIRCE ge3 – Departamento deIngeniería Electrical C.P.S., Universidad de Zaragoza, Conf.Paper

[7] F. Blaschke (1972) The Principle of Field Orientation as Applied to The New Transvector Closed Loop Control System for Rotating Field Machines. Siemens Review *IEEJ transactions on electrical and electronic engineering: official journal of the Institute of Electrical Engineering of Japan*

[8] K. Hasse (1968) On The Dynamic Behavior of Induction Machines Driven by Variable Frequency and Voltage Sources. ETZ Archive. 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI)

[9] M. Depenbrock (1988) Direct Self Control (DSC) of inverter-fed induction machines. IEEE Transactions on Power Electronics IEEE Power Electronics Specialists 1987 - ieeexplore.ieee.org

[10] Takahashi and T. Nogushi (1986) A New Quick Response and High Efficiency Control Strategy of an Induction Motor. IEEE Transactions on Industry Applications

[11] K. S. Narendra and S. Mukhopadhyay (1996) Intelligent Control Using Neural Networks. IEEE Press, New York.

[12] Bimal K. Bose (1997) Expert System, Fuzzy Logic and Neural Networks in Power Electronics and Drives. IEEE Press, New Jersey

[13] Tze-Fun Chan and Keli Shi (2011) Applied Intelligent Control of Induction Motor Drives. John Wiley and Sons.

[14] Seydi Vakkas Ustun a,1, Metin Demirtas b,* Modeling and control of V/f controlled induction motor using genetic-ANFIS algorithm

[15] Haungshang Xu;H.A. Toliyat;L.J.Petersen;''five phase induction motor drives with DSP based control system'' IJAET, August 2002

[16] Gebrihans Yehdego, 'direct torque control of five phase induction motor using space Vector modulation' 'AAU',June 2016.

[17] Sharda Patwa, "control of starting current in three phase induction motor using fuzzy logic controller," *International Journal of Advanced Technology in Engineering and Science", vol. 1, no. 12, pp. 27- 32, December 2013*.

[18] Amanulla and Manjunath Prasad, "Artificial Neural Network Based Speed and Torque Control of Three Phase Induction Motor," International Journal of Science and Research (IJSR), vol. 2, no. 8, pp. 462-465, August 2013.

[19] M. Ayyub. ANFIS based soft-starting and speed control of AC voltage controller fed induction motor. 2006 IEEE Power India Conference, 2006 - ieeexplore.ieee.org

[20] M.Sowmiya, G.Renukadevi IFOC of Five-Phase Induction Motor *Drive, 2013 International Conference on Power, Energy and Control (ICPEC).*

[21] Fattah, "Design and Analysis of Speed Control Using Hybrid PID-Fuzzy Controller for Induction Motors" (2015).

[22] Ashok Kusagur, Shankarappa Fakirappa Kodad, and Sanker Ram, "Modelling & Simulation of an ANFIS controller for an AC drive," World Journal of Modelling and Simulation, vol. 8, no. 1, pp. 36-49, March 2011.

[23] Amit Mishra and Zaheeruddin, "Design of Speed Controller for Squirrel-cage Induction Motor using Fuzzy logic based Techniques," International Journal of Computer Applications, vol. 58, no. 22, pp. 10-18, November 2012.

[24] Zhifeng Zhang, Renyuan Tang, BaodongBai and DexinXie, "Novel Direct Torque Control Based on Space Vector Modulation with Adaptive Stator Flux

Observer for Induction Motors", IEEE Transactions on Magnetics, Vol.46, No.8, pp.3133-3136, August 2010

[25] Kiran S.Aher et al.Int. Modeling and Simulation of Five Phase Induction Motor using MATLAB/Simulink Journal of Engineering Research and Applications ISSN: 2248-9622, Vol. 6, Issue 5, (Part-7) May 2016, pp.01-08

[26] E. Ward and H.Harer, "Preliminary investigation of an inverter fed five-phase induction motor", Proc. IEE 116 (6), 1969, pp. 980-984.

[27] Jyh-Shing Roger Jang. Input Selection for ANFIS Learning, Proc. 5th IEEE International Conference on Fuzzy Systems, 1996. 1493-1499.

[28] Mrinal Buragohain "Adaptive Network based Fuzzy Inference System (ANFIS) as a Tool for System Identification with Special Emphasis on Training Data Minimization." Ph.D. dissertation, DECE, IIT Guwahati, India 2008

[29] Mesfin Tilahun,''V/f control design and simulation for five phase induction motor','AAU', 'March 2015

[30] "D.CHANDRASEKHAR, G.V .MARUTHESHWAR" modeling and field oriented control of induction motor by using an adaptive neuro fuzzy interference system control technique

[31] "Shaikh Moinoddin, 2Atif Iqbal* and 3Elmahdi M. Elsherif" Five-phase induction motor drive for weak and remote grid system *International Journal of Engineering, Science and Technology*

[32] M.S.B. Zulkifli, W.N.B.W.A. Munim, H.C.M. Haris, "Five Phase Space Vector Modulation Voltage Source Inverter using large vector only," IEEE Symposium on Computer Applications and Industrial Electronics (ISCAIE), pp.5-9, Nov.2022

[33] "Biniam Abera" Design and Simulation of Speed Sensorless, FOC of Induction Motor Drive Using ANFIS Controller and ANN *http://etd.aau.edu.et/handle.*

[34] Fattah, "Design and Analysis of Speed Control Using Hybrid PID-Fuzzy Controller for Induction Motors" (2015). Master's Theses. 595.

[35] Mrinal Buragohain "Adaptive Network based Fuzzy Inference System (ANFIS) as a Tool for System Identification with Special Emphasis on Training Data Minimization." Ph.D. dissertation, DECE, IIT Guwahati, India 2008

[36] "Atif Iqbal Shaikh Moinuddin M. Rizwan Khan" Space Vector Model of A Five-Phase Voltage 'IEEE Transactions on Energy Conversion Published: 1995

Appendix

Table 4. 4 System parameters specifications

Parameter	Value	Parameter	Value
Rated power [kW]	2.5	Input Voltage [V]	415
Rated frequency [Hz]	50	No of Phases	5
Nominal speed [rpm]	1500	Frequency [Hz]	50
Pole pairs	2	DC link capacitance [µF]	2
Flux linkage [Wb]	0.175	Switching, frequency [kHz]	1-4
Stator resistance [Ω]	0.8	Rectifier ON resistance [Ω]	0.001
Armature,inductance [mH]	0.085	Rated Power [kW]	2.2
Torque constant	0.525	Rated Speed [rpm]	1500
Machine inertia [Kg-m2]	0.0008	Reference density [kg/m3]	1000
Viscous,coefficient [kg.m2/s]	0.00031	Rated Flow [m3/s]	15
Matlab simulation time	10 sec	Rated Head [m]	10
Solver used	Ode 45		

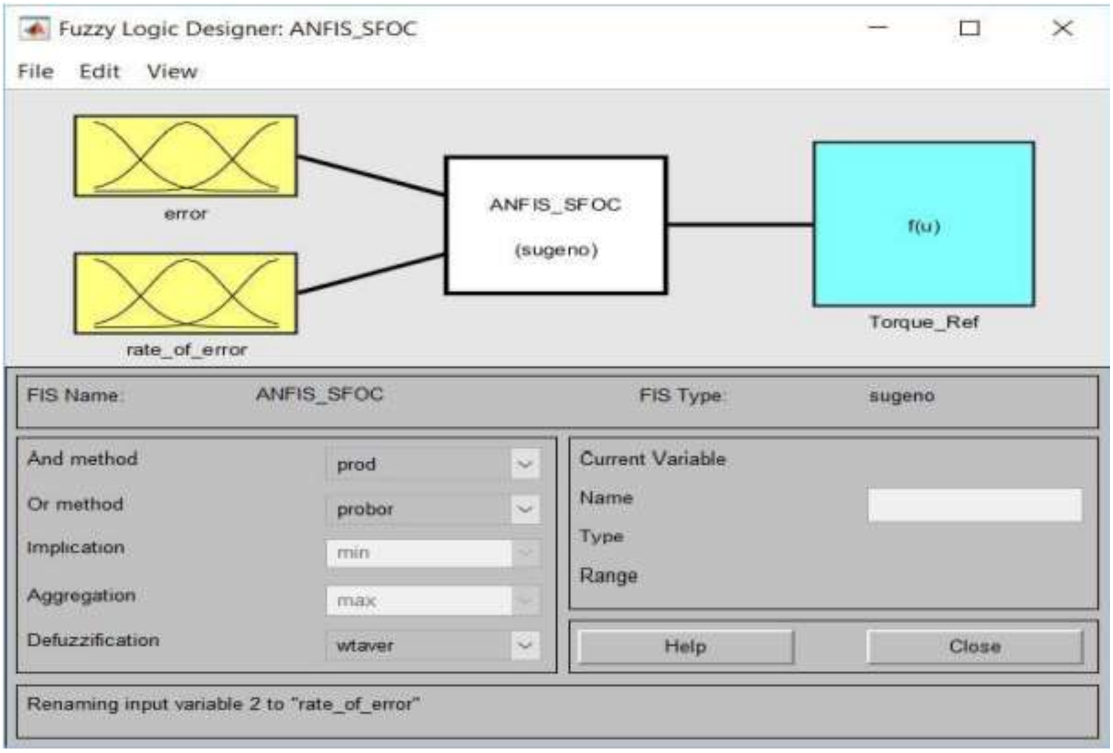

Figure A. 1 FIS Property Editor for Sugeno type Fuzzy Model with two inputs and one output

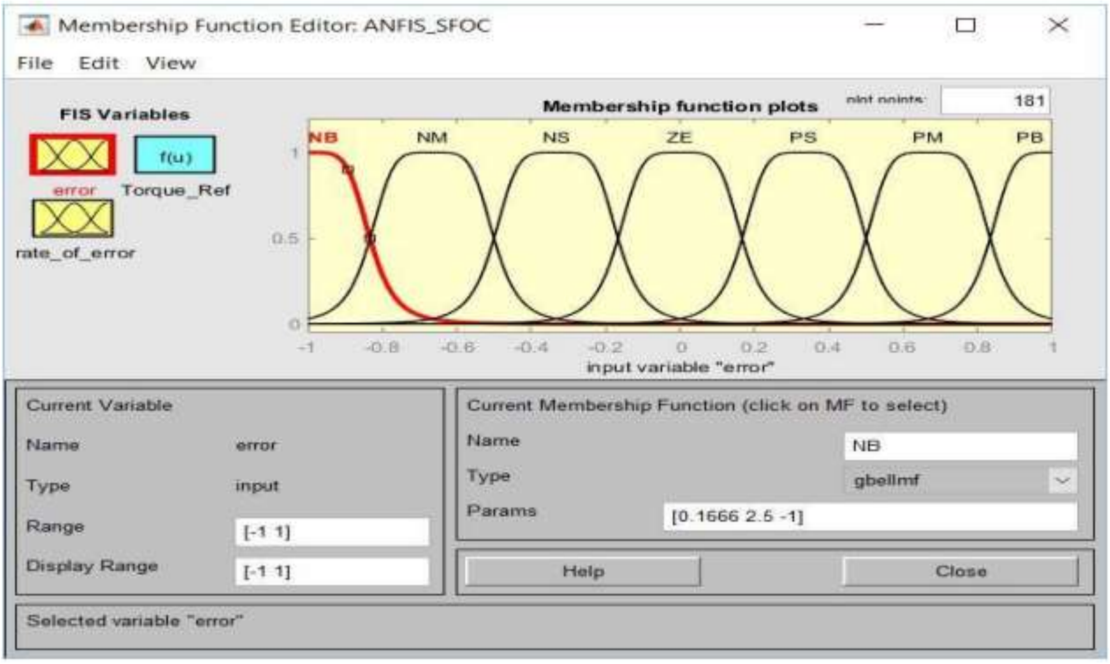

Figure A.2 Membership functions of input 1, error

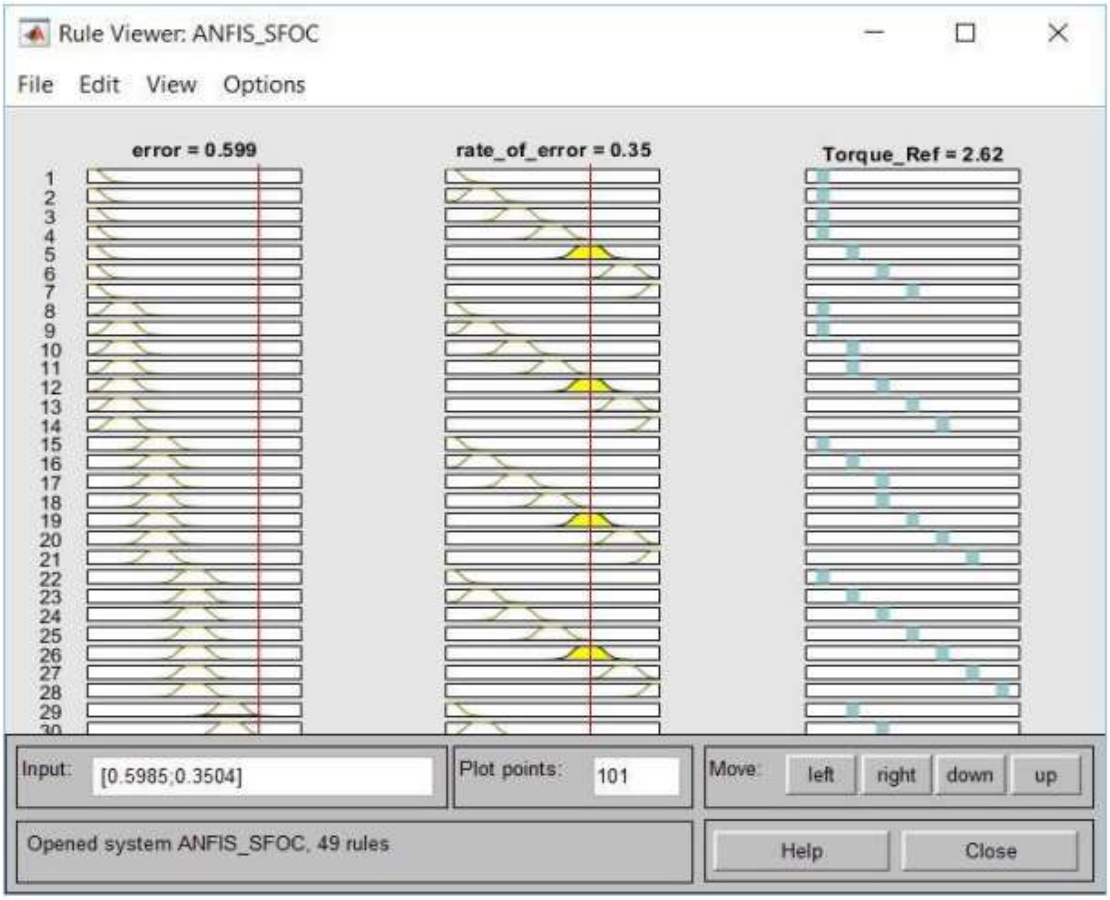

Figure A. 3 Rule Viewer

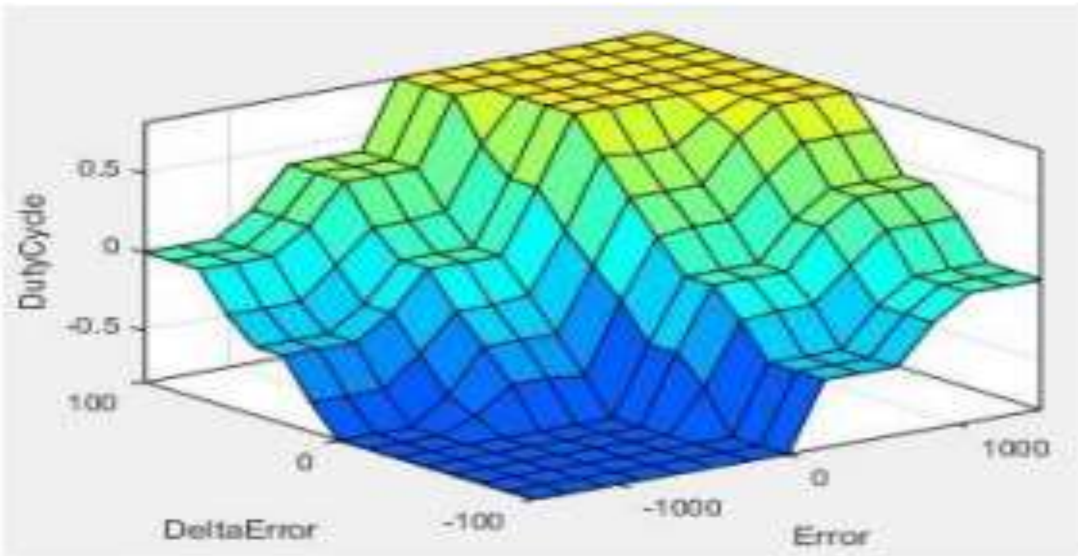

Figure A. 4 Surface viewer after ANFIS Training