INDUCTION MOTOR CONTROLLER USING FUZZY LOGIC

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ABSTRACT

Induction Motor is widely used in general industry applications focusing on production area. Induction motor speed control is becoming very important due to increase the profit to the industries with increase efficiency, reliability and performance of induction motor. Due to the problem facing in induction motor that require complex mathematical model and varying parameters, Fuzzy Logic Controller (FLC) is applied to overcome this problem. The FLC based on the concepts of an artificial intelligence and attractive alternatives method to tackle the problem of controller design for complex mathematical model of system. This project used FLC Sugeno types. The purpose used FLC is to control speed and increase the efficiency of IM. While, the conventional controller only works well for linear system and their performances will decrease for nonlinear system. To make an induction motor operates such as Direct Current (DC) motor, Field Oriented Control (FOC) drives is applied for Induction Motor drive. FOC also offering a fast dynamic response and a high precision ability for IM drive. This project is implemented using Simulink Matlab. Based on the test results show the response of the speed curve takes less time to settle and reach the desired value.

ABSTRAK

Induction Motor (IM) sangat meluas penggunaanya umumnya dalam bidang industri dengan tumpuan lebih kepada industri pembuatan. Pengawalan kelajuan motor aruhan menjadi penting bagi tujuan meningkatkan keuntungan dalam industri dengan cara meningkatkan kecekapan, kebolehpercayaan kebolehgunaan dan prestasi motor aruhan tersebut. Disebabkan masalah yang dihadapi dalam motor aruhan yang memerlukan model matematik yang kompleks dan pelbagai parameter, *Fuzzy Logic Controller* (FLC) digunakan untuk mengatasi masalah ini. FLC adalah berdasarkan konsep kecerdasan tiruan dan merupakan satu kaedah alternatif yang menarik untuk menangani masalah reka bentuk pengawal bagi model matematik yang kompleks. Projek ini menggunakan FLC jenis Sugeno. Tujuan penggunaan FLC adalah untuk mengawal kelajuan dan meningkatkan kecekapan IM. Lagi pula penggunaan pengawal konvensional terhad pada pengawal yang menggunakan sistem kawalan linear dan keupayaan pengawal menjadi berkurang apabila sistem kawalan bukan linear diaplikasi padanya. Bagi memastikan IM beroperasi seperti motor *Direct Current (DC), Field Oriented Control (FOC)* digunakan sebagai pemacu IM. FOC juga menawarkan tindakbalas dinamik yang cepat dan keupayaan ketepatan pemacuan IM. Projek ini dilaksanakan dengan menggunakan Matlab Simulink. Berdasarkan keputusan ujian menunjukkan lengkungan laju mengambil masa yang kurang untuk selesai dan mencapai nilai yang diingini.

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LIST OF TERMINOLOGY

AC	Alternated Current
IM	induction motor
FOC	Field Oriented Control
FLC	Fuzzy Logic Controller
S	Sugeno
FIS	Fuzzy Inference System
VFD	Variable Frequency Drive
PWM	Pulse Width Modulator
IMC	Induction Motor Control
SCIM	structure to give the overall Squirrel Cage Induction Motor
v/f	Volts per Hertz
DTC	Direct Torque Control
MIN	Minimum
DSC	Direct Self-Control
SVM	Space Vector Modulation
NEG	Negative
POS	Positive.
MUX	Multiplexer
DE-MUX	Demultiplexer,
d-q	direct-quadrature

CHAPTER 1

INTRODUCTION

1.1   Project Background

An induction motor (IM) is an asynchronous Alternated Current (AC) motor where power is transferred to the motor by electromagnetic induction. It is much like transformer action. An induction motor has an advantage like simplicity, reliability, low cost and virtually maintenance-free electrical drives. It also characterized by highly common-linear, complex and time varying dynamics and inaccessibility of some of the states and outputs for measurements [1]. It can be considered as a challenging engineering problem.

Variable speed motors help improve efficiency and reduce noise. There are various speed control techniques available like:

1. Direct control torque control
2. Vector Control
3. Volts/Hertz control scheme
4. Field Oriented Control

There are many others that can apply then listing above. In this project the induction motor speed control applies is Field Oriented Control (FOC) [2]. It is because their ability to achieving high performance control of induction motor drives.

Previously the speed controls of Induction Motor are traditionally using fixed gain PI and PID controllers. However their sensitivity to parameter variations loads disturbances become their disadvantaged. Their disadvantaged can be solved using adaptive control technic such as self-turning PI controller. The design for the controller required the exact system mathematical model. Because of that an accurate mathematical modelling that depends unavoidable parameter variation need to be considered. The growing of Fuzzy control systems has sparked a flurry of activities in the analysis and design of fuzzy logic system.

Fuzzy logic approach allows the designer to handle efficiently very complex closed-loop control problems, reducing in many cases, engineering time and cost. It has the ability to distribute gain over a range of inputs in order to avoid the saturation of the control capability. Fuzzy logic shoved very useful to solved nonlinear control problems. It's also allows a simpler and more robust control solution whose performance can only be matched by a classical controller with adaptive characteristics. The advantages provided by a FLC is it operates in a knowledge – based way and its knowledge relies on a set of linguistic such as if-then rules like a human logic.

1.2 Problem Statements

In manufacturing nowadays the problem that manufactures always want to avoid is low efficiency and reduced cost. Because of that many manufactures are turning to variable speed motor technology to help increase efficiency, reduce noise and cut cost in product design. One of the focuses for energy efficiency is to control the motor speed. The good control in motor speed is important to achieve maximum torque and efficiency. The very overwhelmingly applications in industrial applications and for commercial and domestics application is AC motors. For solved that problem or reduces that problem AC induction motor were choose because of the distinct advantages over other types of motor. For that purpose Field oriented Control (FOC) techniques were used to control the motor flux and decompose the AC motor into torque producing component. The usual method of computation of mathematical model of the system is difficult. Fuzzy logic implements human logic

thinking into control system and more similar to human logic. For this case fuzzy learning used to enhanced speed control of an indirect FOC induction motor drive is proposed such that the machine can follow references model to achieve desired speed performance. FOC and Fuzzy logic controller were investigated.

1.3 Project Objectives

The major objective of this research is to improve performances of Induction Motor by developed fuzzy logic controller to control the speed of the Induction Motor. Its measurable objectives are as follows:

a) To derive mathematical model of Induction Motor.

b) To propose FOC method for induction motor.

c) To developed fuzzy logic controller based on Sugeno.

d) To investigate Sugeno fuzzy logic controller for control the speed of Induction Motor.

1.4 Project Scopes

This project is primarily concerned to the speed control of an IM. The scopes of this project are:

a) The IM variable that will control is the speed.

b) The IM use has input voltage 240- 460V.

c) Field Oriented Control (FOC) is used to control the motor flux.

d) The controller apply is fuzzy logic controller with Sugeno scheme.

e) The voltage and frequency input to the IM are to be controlled to obtain the desired speed response.

1.5   Report Outline

This project deals with the proposed idea of a fuzzy controller for a closed loop speed control of an induction motor. FOC control method is used for the speed control of the Induction Motor. This report is divided into six chapters. Chapter 1 is an introduction and gives an overview of the project and speaks about the scope and the main objective. Chapter 2 discusses briefly about the induction motor and scalar speed control or V/f control of the induction motor. Chapter 3 discuss a method used. It includes FOC, IM and fuzzy logic. Chapter 4 gives an overview of the fuzzy logic. It discusses about the fuzzy sets, their operation and membership functions. It also provides the design of the controller based on Sugeno architecture. Chapter 5 is dedicated to the simulation of the induction motor speed control system in MATLAB/SIMULINK®. The results obtained have been compared and discussed. Where is at Chapter 6 include conclusion and also includes information about the future scope of the designed controller.

CHAPTER 2

LITERATURE REVIEW

2.1   Induction Motor Theory and Design

An Induction Motor (IM) widely used in industry because of the advantages that it have.

IM have two main parts:

   a) Stator
   b) Rotor

The stator is the outer body of the motor which houses the driven windings on an iron core. It's made with aluminium or cast iron arranged up of a stack of round pre-punched laminations pressed into the frame. By the way the stator windings are arranged, the magnetic field appears to synchronously rotate electrically around the inside of the motor housing.

Rotor is a cylinder made from round laminations pressed onto the motor shaft and have a number of short-circuited winding. The rotor is built around a shaft, which transmits the mechanical power to the load. The rotor is equipped with cooling fins. At the back, there is another bearing and a cooling fan affixed to the rotor.Two types of construction are utilized for the rotor [3]:

a) Wound-rotor
b) Squirrel-cage rotor

A wound rotor is made of many turns of insulated wire and is connected to the slip ring on the motor shaft. The wound rotor IM is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range.
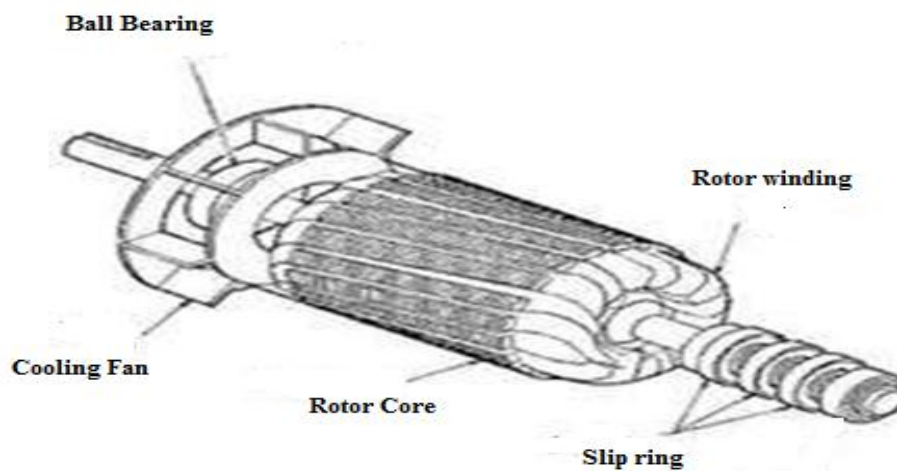
Figure 2.1: Wound Rotor Construction

Squirrel-cage rotor consists of a cylindrical laminated core with parallel slots for carrying the rotor conductors. It is not wires, but thick, heavy bars of copper, aluminums or its alloys. The conductor bars are inserted from one end of the rotor and as one bar in each slot. There are end rings which are welded or electrically braced or even bolted at both ends of the rotor, thus maintaining electrical continuity. These end rings are short-circuited. It looks similar to a squirrel cage.
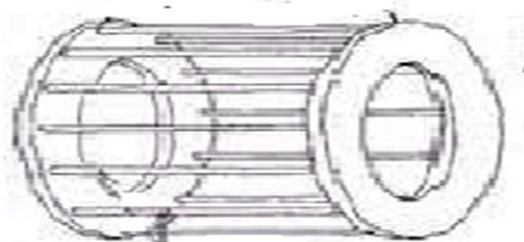
Figure 2.2: Squirrel Cage Construction

2.1.1 Speed Control of Induction Motor

Motor speed can be changed because the torque curve of the motor is effectively modified by the amount of resistance connect to rotor circuit. The speeds of maximum torque decrease if the values of resistance increase. Basically, by reducing the load will cause the motor to speed up and increasing the load will cause the motor to slow down until the load and motor torque are equal. When the load and torque are equal the slip losses are dissipated in secondary resistor. That causes the speed regulation and net efficiency poor.

The number of poles and frequency determines the speed of the IM. It can be proved with the formulae of a synchronous speed [4]:

$$N = 120 \, X \, \frac{f}{P} \tag{2.1}$$

Where N equal to speed in RPM, f is applied frequency in Hz and P is the number of magnetic poles.The difference between the synchronous speed and the full-load motor speed is called slip, *S* which is normally expressed in percent. *Ns* is synchronous spedd and *Nr* is rotor speed. The equation can be written as:

$$S = \frac{Ns - Nr}{Ns} X \, 100 \tag{2.2}$$

2.1.2   Induction Motor Dynamic Model

The IM were run with MATLAB/SIMULINK® program running under three phase sinusoidal symmetrical excitation. Synchronous frame is used where

a) Stator frame where $= \omega_k = 0$

b) Rotor frame where $= \omega_k = \omega_m$

c) Synchronous frame associated with frequency (conceivably time varying) of the stator excitation.

d) Rotor flux frame in which the d-axis lines up with the direction of the rotor flux vector.

ω denotes the rotational speed or angular frequency of a frame (in electrical rad/s) with respect to the stationary rotor. The angular position is obtained by integrating speed over time. That is the choice of the common *d-q* frame is usually prescribed by the symmetry constraints levied by the construction and excitation of the machine [5].

$$\theta = \int \omega \, dt \tag{2.3}$$

2.2   Field Oriented Control (FOC)

FOC is a very popular control technique use to control the IM applications. FOC also called Vector control. Vector control is a Variable Frequency Drive (VFD) control method which controls three-phase AC electric motor output by means of three controllable VFD inverter output variables such as:

a) Voltage magnitude

b) Voltage angle

c) Frequency.

AC drives that use Pulse Width Modulator (PWM) techniques have varying levels of performance based on control algorithms. There are four basic types of control for AC drives today. These are:

a) Volts per Hertz

b) Sensor less Vector Control

c) Flux Vector Control

d) Field Oriented Control.

Volts/Hertz control is a basic control method, providing a variable frequency drive for applications like fan and pump. It provides fair speed and starting torque, at a reasonable cost. Sensor less vector control provides better speed regulation and the ability to produce a high starting torque. Flux vector control provides more precise speed and torque control with dynamic response. Field Oriented Control drives provide the best speed and torque regulation available for AC motors [6]. It provides DC like performance for AC motors, and is well suited for typical DC applications.

In this cases FOC is chosen because it capability to combine with Fuzzy logic controller. It's also has an ability to separate and independently control (or regulate) the motor flux and torque [7].

Figure 2.3 show block diagram of FOC. A high bandwidth current regulator that separates and controls the components of stator current replaces the volts/hertz core. The high bandwidth characteristics of this control help eliminate nuisance trips due to shock-loads and will continuously adapt to changes in the motor and load characteristics. A separate adaptive controller uses information gained during auto tuning, actual reference information, and motor feedback information to give independent torque and flux control. This allows continuous regulation of the motor speed and torque. Also notice that Force Technology generates separate flux and torque references to improve the overall control of those quantities.
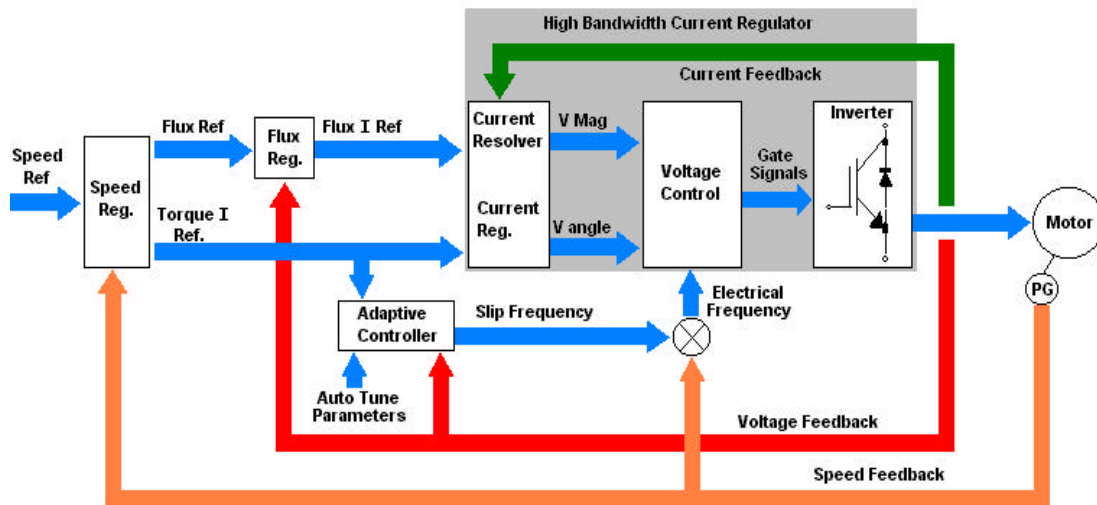
Figure 2.3: Field Oriented Control Block Diagram

2.3 Sugeno Fuzzy Logic Control

In the real world the system cannot be represented by linear differential equations and have a nonlinear nature. Because of that Fuzzy logic controller based on human logic thinking and natural language is propose to be the best solutions to nonlinearity system today.

A fuzzy controller uses fuzzy rules which are linguistic if-then statements. It is involves fuzzy set, fuzzy logic and fuzzy inference. It also represents expert control or modelling knowledge and experiences. There are three types of fuzzy rules:

a) Mamdani fuzzy
b) Sugeno fuzzy rules.
c) Takagi Sugeno

2.3.1 Fuzzy Rule Based System

Fuzzy rule based system consists of 5 conventional blocks. They are built to solve a complex problem. It show in figure 2.4.
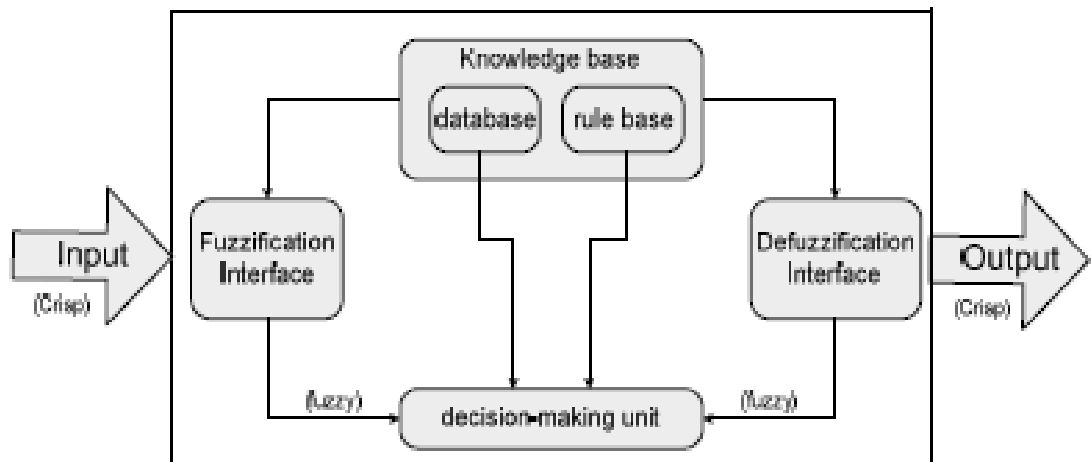
Figure 2.4: Fuzzy Rule Based System

Every block has their own function. Here list down 5 conventional blocks with their function:

a) A rule-base containing a number of fuzzy if-then rules

b) A *database* which defines the membership functions of the fuzzy sets used in the fuzzy rule.

c) A *decision-making unit* which per- forms the inference operations on the rules

d) A *fuzzification interface* which transform the crisp inputs into degrees of match with linguistic values

e) A *de-fuzziffication interface* which transform the fuzzy results of the inference into a crisp output.

2.3.2 Construction of Fuzzy Models

To design an S fuzzy controller, an S fuzzy model for a nonlinear system is needed. Therefore the construction of a fuzzy model represents an important and basic procedure in this approach [8]. Generally there are two approaches for constructing fuzzy models:

   a) Identification (fuzzy modelling) using input-output data

   b) Derivation from given nonlinear system equations.

   c) Identification (fuzzy modelling) using input-output data mainly consist of two parts:

      i) Structure identification

      ii) Parameter identifications.

2.3.3　Mathematics Expression of the S Fuzzy Model

S fuzzy model consist of R rules where the *i-th* rule can be represented as:

$$\text{Rule } i: \text{if } z_1 \text{ is } A_1^{i,k_1}, z_2 \text{ is } A_2^{i,k_2}, \cdots, \text{and } z_m \text{ is } A_m^{i,k_m}$$
$$\text{then } y^i = a_1^i x_1 + a_2^i x_2 + \cdots + a_q^i x_q$$
$$i = 1,2,\cdots,R.\, k_j = 1,2,\cdots,r_j. \tag{2.4}$$

It also described the parameter varying systems which possess m working state characteristic variables, q inputs and single output. R is the number of rules in the S fuzzy model. $z_j \ (j = 1,2,\cdots,m)$ is the *j-th* characteristic variable, which reflects the working state of the systems. It can be selected as input, output or other variables that affecting the parameters of system dynamics. $x_l \ (l = 1,2,\cdots,q)$ is the l-*th* model input. y^i is the output of the *i-th* rule.

For the *i-th* rule, A_j^{i,k_j} is the k_j-th fuzzy subset of z_j. a_l^i is the coefficient of the consequent. r_j is the fuzzy partition number of z_j. For simplicity of induction, $r_j = r$ and r is determined by both the complexity and the accuracy of the model.

Once a set of working state variables $\left(z_{10}, z_{20}, \cdots, z_{m0}\right)$ and model input variables $\left(x_{10}, x_{20}, \cdots, x_{q0}\right)$ are available, then the output of the S model under such working states is calculated by the weighted-average of each y^i:

$$y = \sum_{i=1}^{R} \mu^i y^i \bigg/ \sum_{i=1}^{R} \mu^i \qquad (2.5)$$

Where, y^i is determined by consequent equation of the *i-th* rule. The truth-value μ^i of the *i-th* rule is determined with below equation:

$$\mu^i = \bigwedge_{j=1}^{m} A_j^{i,k_j}\left(z_{jo}\right) \qquad (2.6)$$

Furthermore, equation (2.7) can be rewritten as:

$$y = \left(\sum_{i=1}^{R} \mu^i a_1^i x_1 + \cdots + \sum_{i=1}^{R} \mu^i a_q^i x_q\right) \bigg/ \sum_{i=1}^{R} \mu^i \qquad (2.7)$$

Equation (2.7) illustrated that the S fuzzy model can be expressed as an ordinary linear equation under certain working states since the truth-value μ^i is only determined by the working state variables. As μ^i varies with working state, S fuzzy model is a coefficient-varying linear equation. For all possible varying ranges of working states, the S fuzzy model reflects the relationships between model parameters and working states. Therefore, the global dynamic characteristics of the parameter varying systems can be represented.

2.4   Matlab Overview

Matlab originally wrote by Dr Cleve Moler, Chief scientist at MathWorks, Inc. The purpose of Matlab development is to use in courses in matrix theory, linear algebra and numerical analysis. The first version was written in the late 1970s.

Matlab is a high-performance technical computing language. Typical Matlab are used for:

a) Math and computation

b) Algorithm development

c) Data analysis

d) Exploration

e) Visualization

f) Modelling, simulation and prototyping

g) Scientific and engineering graphics

h) Application development, including graphical user interface building and etc.

Matlab also has both an environment and programming language. Matlab also allows user to build own reusable tools known as M-files. Since the M-files can be open it is easy to modify the M-files. One of the main features of Matlab are used in this project is a two and three dimensional graphics for plotting and displaying data and ability to cooperate with programs written in other languages and for importing and exporting formatted data.

The major usable for Matlab in this project is a SIMULINK. SIMULINK include in a Matlab toolbox for the dynamic simulation of linear and nonlinear systems. Matlab toolboxes consist of:

a) Signal processing-contains function to design analogue and digital filters and apply these filters to data and analyse the results.

b) Image processing-Provide access to a wide variety of functions for reading, writing and filtering images of various kinds in different ways.

c) Control system-Provides several features for advanced control system design and analysis.

d) Optimization-Contains basic tools for use in constrained and unconstrained minimization problems.

e) Neural networks-Allows you to simulate neural networks.

f) Communications-Provides functions to model the components of a communication systems physical layer.

g) Robust control-Allows users to create robust multivariable feedback control system design based on the concept of the singular value Bode plot.

h) Statistics-Include a wide variety of system analysis tools for varying data.

i) Splines-Used to find approximate functional representations of data sets.

j) Simulink-Allow users to model dynamic systems graphically.

k) Fuzzy logic-Allows for manipulation of fuzzy systems and membership functions.

This project required the optimized used of Matlab to achieve the desired output. That why Matlab becomes one of the powerful software.

2.5 Various Controller Method

There is much controller method design to achieve the optimum control evaluable use to Induction Motor. Recent controller that have been used such as:

a) Fuzzy Logic Controller (FLC)

b) Proportional Integral Controller (PI)

c) Genetic Algorithm Controller (GAs)

d) Neural Network Controller (NN)

Fuzzy Logic Controller is a main focus in this project. FLC is applied to keep the motor speed to be constant when the load varies. In this section FLC is not to be discussing because it already discuss in chapter 4 briefly.

2.5.1 Proportional Integral Controller (PI)

Proportional Integral Controller (PI) is a very classic controller. It can be used for high applications in the electric motor drive. The motor-control is traditionally handled by fixed-gain PI controller. However, the fixed-gain controllers are very

sensitive to such as parameter variation, load and disturbances. This is because the controller parameter has to be continually adapted or tuned.

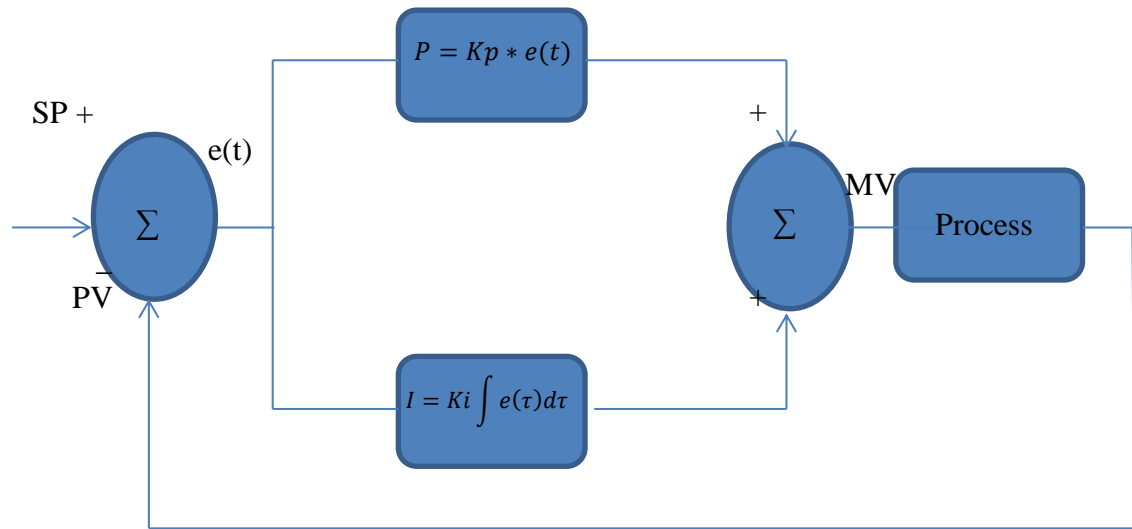Figure 2.7 shows basic block diagram of PI controller.

Figure 2.6:   Basic block of PI Controller

PI controller is a feedback controller. PI drives the plant to be controlled with comparison between the output and desire set point and the integral of that value. PI controller can reduce steady state error to zero. The derivation action makes the system steadier in steady state in case of noisy.

2.5.2   Genetic Algorithm Controller (GAs)

This project does not use Genetic Algorithm Controller (GAs). For study purpose GAs controller were discuss here. It is because one of the famous controller developments today is Genetic Algorithm Controller (Gas). GA successful applies in optimization technique based on the mechanism of natural selection. Recently GA is recognized as an effective and efficient technique to solve optimization problems. It can produce better performances compare to PI controller.

GA concept is to survival of the fittest. The founders of GAs were first suggested by John Holland and his colleagues in 1975. The main operators of GA are selection, reproduction and mutation. It works with a population of solution

called chromosomes. Fitness of each chromosome is determined by evaluating it against an objective function.

The main operators of GA are selection that represents initial generation. Its begin by randomly generating an initial population of the long real-valued strings. Selections direct the search of GAs toward the best individual. Reproduction is a process by which parent structures are selected to form new offspring. For the mutation the breeder genetic algorithm is used to implement the mutation operator for the real-coded GA which uses a nonlinear term for the distribution of mutation range applied to gene values. This mutation algorithm is able to generate most point in the hypercube defined by the variables of the individual and range of the mutation.

Figure 2.7 shows flowchart of Genetic Algorithm. This algorithm is repeated for many generations and finally stops when reaching individuals that represent the optimum solution for the problem. The algorithm different from more traditional search and optimization methods [9]. The optimization methods are listed below:

a) GA searches a population of point in parallel instead of searching for a single point.

b) GA does not require auxiliary knowledge even require derivative information. The objective function and corresponding fitness levels influence the direction of search.

c) The GA method used probabilistic transition rules.

d) The nature of the functions being optimized is immaterial.

The main operation of GA is the selection, crossover and mutation. Its allows the creation of new individuals which may be better than their parents.
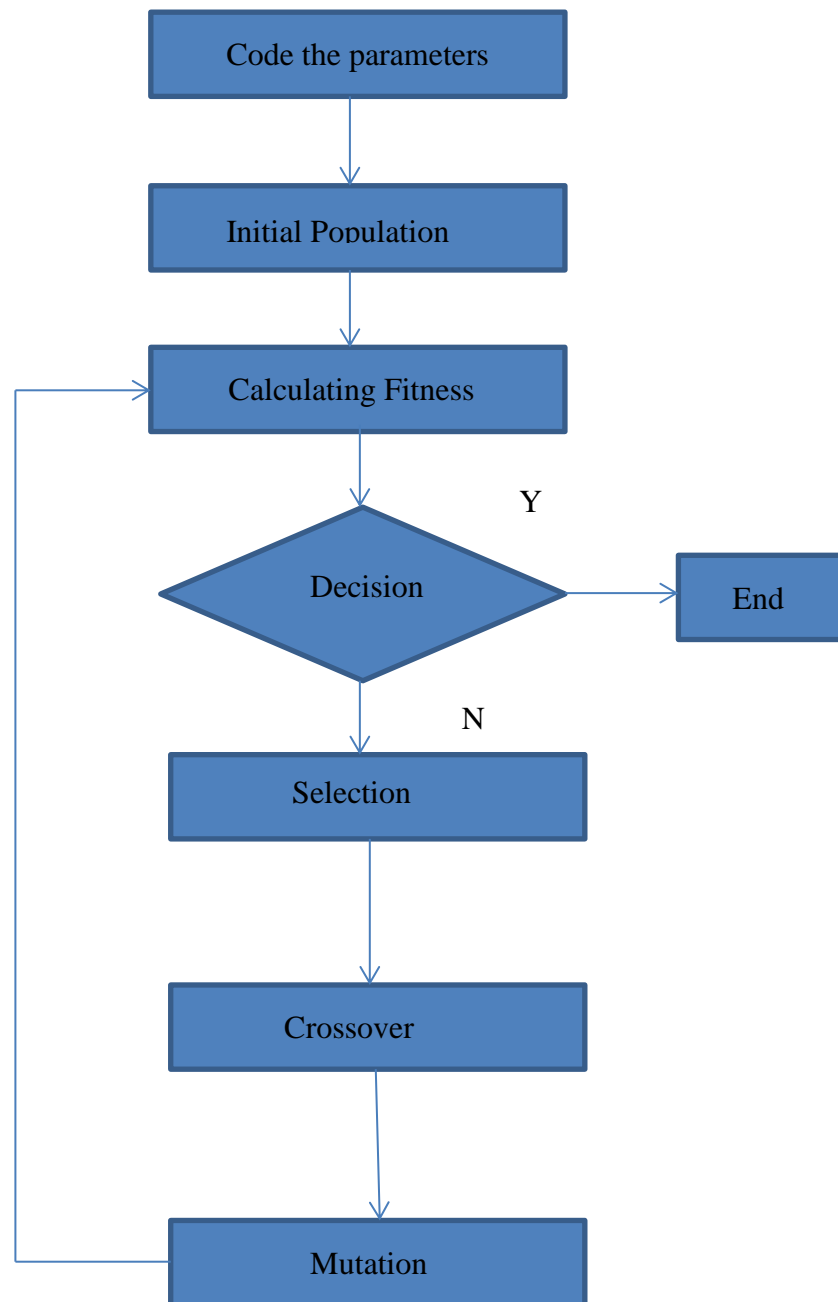
Code the parameters

Initial Population

Calculating Fitness

Decision

Y

End

N

Selection

Crossover

Mutation

Figure 2.7: Flowchart of Genetic Algorithm

2.5.3   Neural Network Controller (NN)

One of the controller method designs is neural networks controllers (NN). ANN's also are potential candidates for approximating complex non-linear process dynamics and have been used to formulate a variety of control strategies [10]. There are two basic design approaches:

    a)   Direct design

    b)   Indirect design

Direct design is when the neural network is itself the controller. The most fundamental method is termed *direct inverse control*. It uses a trained inverse model of the process as a controller. Meanwhile indirect design is the controller uses a neural network to predict the process output.

In the following, ANN's are used in combination with an Induction Motor Control (IMC) structure to give the overall Squirrel Cage Induction Motor (SCIM) control system depicted in Figure 2.8. Here Net 1 and Net 2 are neural networks.
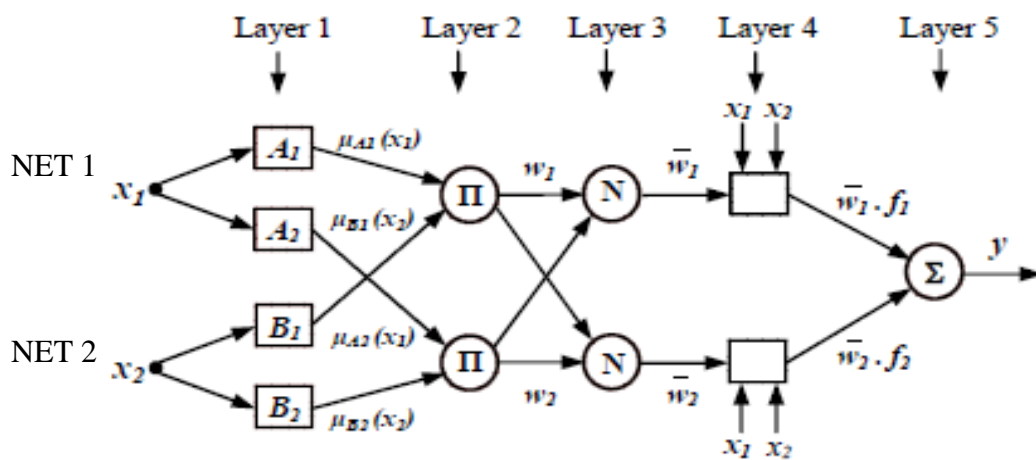

Figure 2.8: Neural fuzzy network ANFIS configuration

The NN control techniques studied are very suitable for real time implementation due to their simplicity, robustness and ease of tuning.

2.6   Various Speed Control

Variable speed drive system using various control technique have been widely used in many application. Figure 2.9 show overview of key competing VFD control Platforms with sensor or sensor less. Speed drive includes:

   a) Field oriented control or vector control
   b) Direct torque control
   c) Sensor less scalar control.
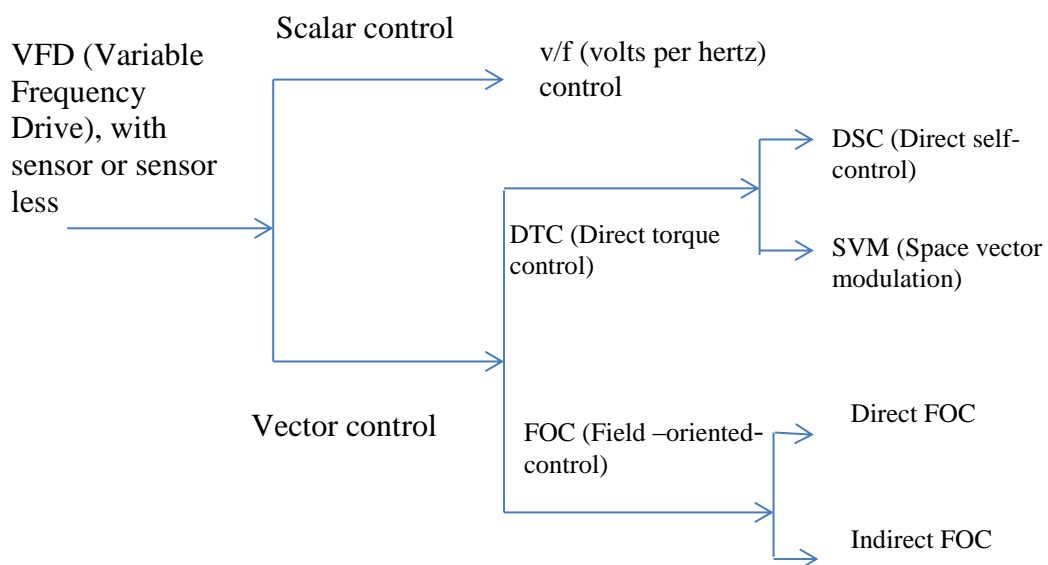
Figure 2.9: Overview of key competing VFD control Platforms

2.6.1   Direct Torque Control

Direct Torque Control (DTC) consists of DTC controller, torque and flux calculator and VSI. DTC method selects one of the inverter six voltage vectors and two zero vectors in order to keep the stator flux and torque within a hysteresis band around the demand flux and torque magnitudes. The torque produces by IM is determined using equation (2.10).

$$Tem = \frac{3}{2}\frac{P}{Ls}\frac{Lm}{Lr}|\bar{\lambda}r||\overline{\lambda s}|sin\alpha \qquad (2.8)$$

Equation (2.10) shows that the torque produce is dependent on the stator flux magnitude, rotor flux magnitude and the phase angle between the stator and rotor flux vectors.

DTC drives usually have two major problems. The first problem is variable switching frequency due to hysteresis comparators used for the torque and flux estimators and inaccurate stator flux estimations which can degrade the drive performance. The changes in the stator flux vector shown in figure 2.10 [1].
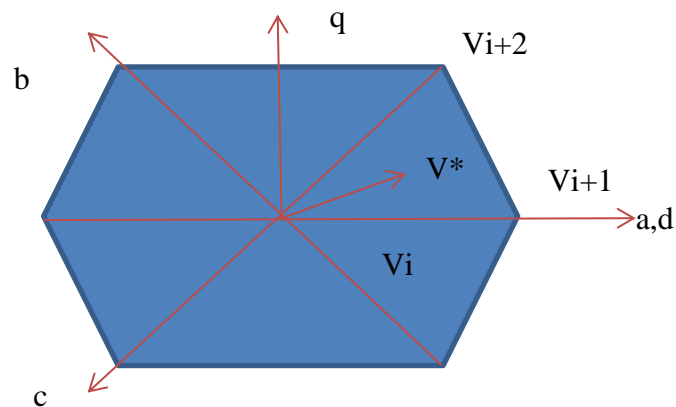

Figure 2.10: Changes in the stator flux.

2.6.2   Scalar Control (V/f Control)

Scalar Control (Voltage/frequency Control) technique for variable frequency drive (VFD) is type of control that functions with fed variable frequency signals generated by the Pulse Width Modulation (PWM) control from an inverter to the motor. The V/f ratio is maintained constant in order to get constant torque over the entire operating range. Since only magnitudes of the input variables - frequency and voltage - are controlled, this is known as *scalar control*. Generally, the drives with such a control are without any feedback devices that mean the controller has an open-loop control. Hence, this type of a control offers low cost and is an easy-to-implement solution.

Because of a little knowledge of the motor is required for frequency control scalar control (v/f Control) is widely used. A disadvantage of scalar control (v/f control) is that the torque developed is load dependent, as it is not controlled directly. Also, the transient response of such a control is not fast due to the predefined switching pattern of the inverter.

If there is a continuous block to the rotor rotation, it will lead to heating of the motor regardless of implementation of the overcurrent control loop. By adding a speed or position sensor, the problem relating to the blocked rotor and the load dependent speed can be overcome. However, this will add to the system cost, size and complexity. Figure 2.11 show control loop of an AC drive with frequency control using PWM.
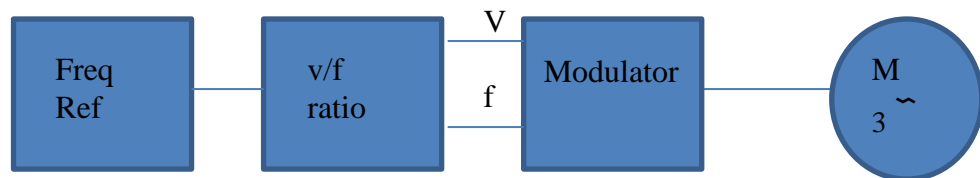

Figure 2.11: Control loop of an AC Drive with frequency control using PWM

2.7   Description of Previous Methods

There are many approach used to developed method for Induction Motor as explain on the previous sub chapter. The simplification or linearization of the non-linear system under consideration has to be performed by the conventional control methodologies like PI, PD and PID since their construction is based on linear system theory. Hence, these controllers do not provide any guarantee for good performance [11]. They require complex calculations for evaluating the gain coefficients. These controllers however are not recommended for higher order and complex systems as they can cause the system to become unstable.

Fuzzy logic is a suitable strategy for controlling nonlinear systems. The controller design is based on expert information or human experiences. The fuzzy

logic controller (FLC) based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy. It can be a good controller to replace a classical controller that used mathematical model in each design [12].

CHAPTER 3

METHODOLOGY

3.1   Introduction of Method Used in This Project

To achieve these project objectives the project must organize well. Figure 3.1 show block diagram of Fuzzy FOC controller of IM. Start with reference input voltage (ωa). Then design the FLC and used FOC to drives IM. The idea is to build a closed loop speed control system of IM with the element such as sensor as their feedback system.

Phase 1: Fuzzy Logic Controller Design.
First phase is to design a Fuzzy Logic Controller. The membership functions are built. The input is speed error (e) and change in error (Δe) or derivative of speed error. Then the memberships function for the output design was chosen. From the membership function the rules are decided.

Phase 2: Apply IFOC Method
IFOC is to make a condition that AC motor work similar to DC motor and produces optimal torque to control motor speed.

REFERENCES

[1] R. P. V.Chitra, "Induction Motor Speed Control Using fuzzy logic Controller," in *world academy of science Engineering and technology 23*, 2006.

[2] M. S. P. P. Bharat Bhushan, "Performance Analysis of Field Oriented Induction Motor using Fuzzy PI and Fuzzy Logic based Model Reference Adaptive Control," *International Journal of Computer Applications ,* vol. Volume 17, no. No.4, p. (0975 – 8887), March 2011.

[3] D. K. a. I. Nagrath, Electrical Machines, Tata Mc Graw Hill Education Limited, 2004.

[4] T. Wildi, Electrical Machines drives and Power Systems, International Edition, Prentice Hall, 2006.

[5] V. V. a. G. B. a. S. Nayak, Speed Control of Induction Motor Using Fuzzy Logic Approach, Roukela: National Institute of Technology, 2012.

[6] A. Bradley, AC Drive Using PWM Technic, USA: Rockwell International Corporation. All rights reserved, June 2000,© 2000 .

[7] P. M, "Induction Motor Modelling for Vector Control Purposes," University of Technology, Laboratory of Electromechanics, Helsinki, 2000.

[8] K. Mehran, "Takagi Sugeno Fuzzy Modelling for Process Control," Industrial Automation and Artificial Intelligent (EE8005) School of Electrical, Electronic and Computer Engineering, New Castle , 2008.

[9] R.Arulmozhiyal and Dr K. Baskaran, "Speed Control of Induction Motor Using Fuzzy PI and Optimized Using GA," *International Journal of Recent Trends in Engineering,* vol. Vol 2, no. No. 5, 2009.

[10] Hunt K.J and Sbarbaro D, "Neural Networks for nonlinear model control," *IEE Proc,* vol. 138, pp. 431-438, 1991.

[11] C.-T. S. E. M. J.-S. R. Jang, "Neuro-Fuzzy and Soft Computing," Pearson Education Pte. Ltd, ISBN 81-297-0324-6, 1997, chap. 2, chap. 3, chap. 4.

[12] S. M. I. M. M. G. S. J. Faiz, "Performance Improvement of a Linear Permanent Magnet Synchronous Motor Drive using Fuzzy Logic Controller," *International Conference on Power System Technology,* 2010.

[13] Surajit Chattopadhyay, Madhuchhanda Mitra and Samarjit Sengupta, Electric Power Quality Power System, Netherlands: Springer Netherlands, 2011.

[14] S.N Sivanandam, S.Sumathi and S.N Deepa, Introduction to Fuzzy Logic Using Matlab, Verlag Berlin: Springer-Verlag Berlin Heidelberg, 2010.