Design and Simulation of Indirect Vector Control Scheme for Traction Motor Drive

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Pankaj Kumar
(2K12/PSY/15)

Under The Esteemed Guidance of

Mrs. Priya Mahajan

DEPARTMENT OF ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

BAWANA ROAD, DELHI-110042

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DELHI TECHNOLOGICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL ENGINEERING

<u>CERTIFICATE</u>

This is to certify that the thesis entitled, " **Design And Simulation Of Indirect Vector Control Scheme For Traction Motor Drive**" has been done in partial fulfillment of the requirements for award of the degree in M.Tech in Electrical Engineering (Power System) under my supervision by Pankaj Kumar (2K12/PSY/15), at the Delhi Technological University.

This work has not been submitted earlier in any university or institute for the award of any degree to the best of our knowledge.

Mrs. Priya Mahajan
Assistant Professor & Supervisor
Department of Electrical Engineering
Delhi Technological University

Prof. Madhusudan Singh
HOD (Deptt. Of Electrical Engg)
DTU, Delhi

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Pankaj Kumar
M.Tech(PSY)

Abstract

Induction motor of large rating are used in traction. This work is focused on developing the effective control strategies and configuration for control of Traction Motor Drive. This work is extended to control the speed and torque of traction motor using current control hysteresis loop controller. The proposed control strategy is analyzed and confirmed by simulation studies of mathematical models used. This work is carried out on 220 kW Traction Motor.

Further, indirect vector control for the control of speed of traction motor is used in the present study Much attention has been given to the motor torque and speed control. At the present time, the Vector control has widespread use in high performance traction motor drives. It allows, by means of a co-ordinate transformation, to decouple the electromagnetic torque from the rotor flux, and hence manage speed control of traction motor. The decoupling control between the flux and torque allows traction motor to achieve fast transient response. Field orientation control can be obtained using hysteresis current controller.

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F	Frequency (Hz)
I_f	Machine field current.
I_s	Rms stator current.
i_{dr}^s	d^s axis rotor current
i_{ds}^s	d^s axis stator current
i_{qr}	q^e - axis rotor current
i_{qs}	q^e - axis stator current
L_m	Magnetizing inductance
L_r	Rotor inductance
L_s	Stator inductance
L_{lr}	Rotor leakage inductance
L_{ls}	Stator leakage inductance
L_{dm}	d^e- axis magnetizing inductance
L_{qm}	q^e axis magnetizing inductance
N_e	Synchronous speed (rpm)
N_r	Rotor speed
P	Number of poles
S	Slip
T_e	Developed torque
V_d	DC voltage
φ_{dr}^s	d^s- axis rotor flux linkage
φ_{ds}^s	d^s- axis stator flux linkage
φ_{qr}	q^e - axis rotor flux linkage
φ_{qs}	q^e- axis stator flux linkage
ω_e	Stator or line frequency (r/s) Rotor mechanical speed
ω_r	Rotor electrical speed
ω_{sl}	Slip frequency
R_s	Stator Resistance
R_r	Rotor Resistance

i_a*, i_b*, and i_c*	Stator current reference
i_{qs}*	Stator quadrature-axis reference current
i_{ds}*	Stator direct-axis reference current
$\mid \psi_r \mid$*	Sotor flux reference input
T_e*	Torque reference
$\mid \psi_r \mid_{est}$	Estimated rotor flux linkage
θ_e	Angle of synchronously rotating frame
θ_r	Rotor angle
θ_{sl}	Slip angle

CHAPTER 1
INTRODUCTION

1.1 Introduction

Electric railway traction is a transportation system which is significantly used for transportation in urban, sub urban areas for very fast land and freight transportation. The main objective of electrification is to achieve high efficiency, compact and simple structure**,** good reliability and low cost drive locos but it requires heavy capital expenditure for installation. It basically constitutes of the power transmission lines, including the railway track lines, pantograph-catenary system, traction transformer, switch gear and electric drive system.

The traction sub-stations transmit power through the contact wire (also known as catenary system). Then the supply voltage is stepped down to the desired value depending upon the converter inverter system. Afterwards the power is passed to the converter inverter system where the AC voltage supply is converted to DC and then again converted to AC supply for motors operation. The conversion of AC to DC is done in order to maintain constant DC link voltage irrespective of the fluctuations occurring in AC supply .Then this controlled AC supply is fed to the traction motors for faithful operation.

Following types of electrical traction system exists:-

(i) 3-phase AC 3.7 kV system
(ii) Single phase AC 15/16 kv -161/25 Hz
(iii) Single phase AC 20/25 kV – 50/60 Hz
(iv) 600 V DC
(v) 1200 V DC
(vi) 1500 V DC
(vii) 3 kV DC

Depending upon the traction systems the different type of traction motors are:-

(i) D.C series motor supplied with dc or rectified D.C
(ii) A.C series motors single phase

(iii) Repulsion motor
(iv) Three phase induction motor
(v) Linear induction motor

Table no 1.1: Efficiency of different traction system

Traction System	Efficiency
Steam locomotive	5-7%
Gas turbine electric locomotive	10%
Diesel electric locomotive	26-30%
Electric locomotive with thermal power plant	34-36%
Electrical locomotive with Hydroelectric power plant	40-42%

Table 1.1 specifies the different traction system with their efficiency.

Now a days DC traction motor are not used in railways because of three major reasons:

(i) There is more power loss in the speed control of DC traction motor
(ii) There is also the commutation problem in the DC traction motor
(iii) In dc machine, we observe that if there is a little difference in the speed brings about very large difference in the torque developed. So that there is an unequal loading of the motor. Therefore motor having shunt characteristics are not used for parallel operation.

Also the DC locomotive has a variety of control settings with set power level for each settings. This technique is quite simple and effective. Due to power is a product of torque and speed that's why it does not produces a constant motor torque. Depending on speed, the tractive effort varies effectively for every control settings, making it impossible to obtain maximum adhesion.

When the power Electronics device like converter, inverter, IGBT come into existence use of AC traction motor increased widely. However, power electronic devices and microcontroller; embedded systems generate harmonics and reactive power and thereby distorting the signal. The AC traction system is also called variable frequency drive and it is used as standard in traction applications. Major advantages of AC system are higher reliability, less maintenance requirement and adhesion level up to 100% more than DC system.

AC traction offers so much attention because of three basic reasons. Firstly in standard DC drive, there is a tendency in traction motor to increase speed and run away even if the load is not immediately reduced. When slip of wheel increases the coefficient of friction rapidly drops up to 0.10 due to connections of all motors are together, the load of whole locomotive is decreases.

Tractive effort = Weight on drivers x Adhesion

Adhesion = Coefficient of friction x Locomotive adhesion variable

The AC system works in a very dissimilar manner. The variable frequency drive produces a rotating magnetic field which spins about 1% faster than the motor is turning. Since the rotor cannot exceed the field speed, any wheel slip is less than 1% and is rapidly sensed by the drive which shortly reduces load to the axle.

Regenerative braking is an important parameter for consideration with AC traction. Braking is a function of weight on drivers. The braking capability of the locomotive is directly proportional to the weight of locomotive, when we uses the standard friction braking. In Regenerative braking, traction drive transition from the motoring operation to generating mode occurs and the electricity produced is degenerated in the braking resistors or it can be fed back to the system thereby increasing the power factor of the system. This property is not in case of DC traction system**.**

1.2 Traction Motor Drives

Electric traction has been using DC motor drives fed by 25kV single-phase AC supply rectified by an AC-DC uncontrolled converter [1]. This converter draws an AC current waveform in the form of narrow pulses, which is rich in harmonics. These harmonics result in decreased rectifier efficiency, input AC mains voltage distortion (because of the associated peak currents) leading to frequent failure of auxiliary motors, malfunction of sensitive electronic equipment due to electromagnetic interference (EMI) etc.

With the advent of power electronics, the use of variable frequency ac motor drives has increased tremendously. Among ac motors, three-phase squirrel cage induction motors have always attracted the attention of research engineers due to their property of robustness, reliability and freedom from regular maintenance. When squirrel cage induction motors operate in vector control mode, their response improves substantially as this mode of operation enables them to act as a better substitute of DC motors. Such type of control when applied to induction motors combines the advantage of flexibility present in dc motors with the inherent advantages present in induction motors. Also their simple, less expensive, more robust framework, induction motors are more suitable for industrial environments.

Fig 1.1shows the block diagram of indirect vector control of Induction Motor drive. A 25 KV voltage is stepped down with the help of step-down transformer (3-winding transformer). This step down voltage is given to converter input. The scheme shown in figure is used to maintain the dc link voltage at converter and control the speed and torque of high rating Induction motor at load side with vector control tchnique. There are four induction motor are connected in parallel so that used for traction. In this thesis control at load side only with the help of Indirect vector control

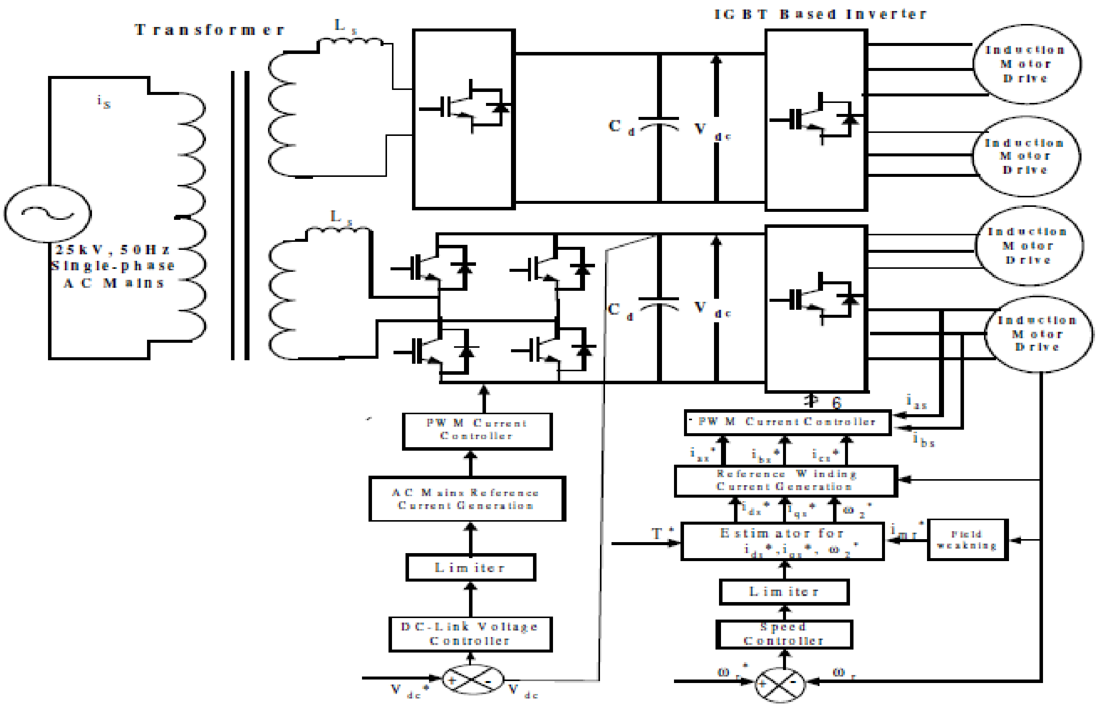

Figure 1.1: Block diagram of indirect vector control of Induction motor drive.

.1.3 Motivation of Work

In recent year there is an explosive growth in the field of traction drive system. Also the demand of ac drive system reaches its peak value as the additional services are add in present infrastructure. The estimation and control of IM drive establish vast subject. Also in recent year the technology has been improved continuously. In industries for the variable speed application in wide range of power sequiral cage IM drive has been used that’s cover the fractional horsepower to multi megawatts. Also in traction large rating induction motor is used (220 Kw) and application in pump and air conditioners, subway and locomotive propulsion, rolling mills, machine tools and robotic, electrical and hybrid vehicles, fans, wind generation system. In addition to these application drives are used to process control, and energy saving feature of variable frequency drive is getting a lot of attention nowadays.

Motivation of work is to control the 3- phase traction motor drive with indirect field oriented control using hysteresis PWM switching of inverter. Here conventional PI, Fuzzy logic Control and Fuzzy PI control and controllers are used for controlling the speed and torque characteristics of induction motor.

1.4 Outline of Thesis

The whole work of dissertation is organized in 7 chapters.

Chapter 1 presents the general introduction of traction, induction motor drive and motivation of work.

Chapter 2 presents the literature review of the thesis for control technique i.e DTC FOC and indirect vector control of induction motor.

Chapter 3 presents the induction motor drive system followed by dynamic modelling of induction motor and design consideration of different control technique of vector control

Chapter 4 presents different controller used in the speed control of traction motor drive i.e PI, Fuzzy, Fuzzy tune PI controller.

Chapter 5 presents Simulink model for controller design for indirect vector control to traction motor drive and different control blocks.

Chapter 6 presents Simulink results are presented and analysed in this chapter

Chapter 7 contains the conclusions based on the Simulink results. It also includes the further improvements in controllers such as design of active power filters to minimize the harmonics.

Conclusion

This chapter presents a brief introduction about traction motor, and different type of motor used in traction. Here DC traction motors are then compared with AC traction motors and Traction motor drives are explained thoroughly.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter contains a brief review of previous work on topics dealt within this thesis without trying to be exhaustive in anyway. The dissertation review deals with the studies of drives and associated related work being carried out on different types of control schemes of induction motor drives during last few decades

2.2 FOC (field oriented control) of Induction Motor Drives

The direct vector control also known as feed- forward control was discovered by Blaschke (1972)[2] and Hasse (1969)[3] respectively. In Field oriented indirect control, we obtained the field angle by the use of motor parameter and the rotor position measurement. This control scheme have been widely used in electric drive [4].

Gabriel et. al.[5] implemented the technique by the use of power electrical device, such as microprocessor and microcontroller. Also the research on design of flux and current regulator, simplification of circuit with advanced microprocessor has continued.

In 2005 Epaminondas D. Mitronikas and Athanasios N. Safacas,[6] presents the sensorless vector control for IM motor drive. This technique mainly based on the dynamic model of induction motor, and improved closed loop stator flux which gives exact stator flux estimation over wide range of operation. Stator flux estimator confirms the stability over a wide range of speed operation area. The rotor speed estimation technique based on the MARS (model reference adaptive system) theory. This control strategy mainly based on the direct vector control using stator flux where the speed and flux controller are optimal tuned. Also this implementation of proposed technique is based on simple algorithm to be used in the low-cost microcontroller [7].

The vector and field oriented control of sequiral-cage induction motor offers the high level dynamics performance and provided long term stability of system by closed loop associated with induction motor drive. Induction motor drive also used in the process control and industrial application. To achieve the high performance of IM drive the motor speed should track the specified path nevertheless of any disturbance, model uncertainty, and parameter variation. Also to design of controller of induction motor drive play important role in system performance. We can change the parameter of motor drive by the variation in the decoupling characteristics of motor. So that vector control also known as decoupled or independent control [8].

There are two type of field oriented control, the control strategies can be defined according to how we calculated the field angle. The field angle can be calculated by sensing the flux of winding or by use of the terminal voltage and current this technique under direct control. Also the field angle can be calculated partly use of machine parameter and the rotor position but no other parameter like current and voltage are used, this scheme come under the control scheme of indirect vector control. So these control scheme has derived out as inverter fed IM drive[9].

In field control, the pulse pattern feeding to inverter connected to induction motor drives mainly determined the performance of machine. A control technique to control the current using hysteresis loop control can applied to gating the pluses pattern of induction motor drive. We can obtain the fast control of current loop in hysteresis control also has no requirement of the parameter of load. But in this control scheme there is variable frequency leads to more harmonics in the system [10].

Vector control of induction motor drive a very high torque and wide speed range can be established. The characteristic of vector controlled induction motor is same as like of separately excited DC machine. We can attained the rapid torque response of induction motor drive to estimate the rotor flux estimation to use of Extended Kalman filter. The vector control is used to calculate the rotor resistance and estimation of the parameter calculation algorithm [11].

There are twofold techniques in which vector-controlled induction motor drive evaluation system can be implemented. Real machine methodology and simulation of system with suitable vector controller with a current-regulated pulse width modulation (PWM) inverter are the twofold techniques [12].

2.3 Direct Torque Control Induction Motor Drives

Thkahashi (Japan) [13]and Depenbrock (Germany) was introduced the direct torque control of induction motor drive. Because of simple construction and rapid response of torque and flux, it is used in the industries. Direct torque control technique was implemented to inverter fed IM drive. It can be possible because the direct torque control is less dependent on machine parameter and the control can be achieved with the help of switching table. In this technique the stator flux is only the factor to estimate the speed and torque control.

In conventional direct vector control, to select of optimum inverter switching the flux and torque can independently controlled. In this method there is problem to control the flux and torque at the low speed and also high torque ripple present. So a very high switching frequency and variable frequency for the implementation of digital hysteresis controller using DTC control [14].

In 1992 the direct vector control technique of induction motor drive was introduced based on the analytical, flux and torque deadbeat control. When there is a change in flux and torque , the over switching period is calculate by accessing the synchronous speed also stator voltage and voltage behind transient reactance which is to be required to cause flux and torque equal to their value of respective reference frame. Then PWM space vector described the switching state of inverter fed induction motor [15].

Vector control of induction motor without encoder was proposed by **James N Nash** [16] in **1997.** Here an explanation of direct self-control and the field orientation concept, implemented in adaptive motor model is presented and also the reliance of the control method on fast processing techniques has been stressed.

In 2004 M. vasudevan[17] and R. Arumugan was proposed the new technique for electrical vehicles drives (direct torque control). The electric vehicle drive involves the three level IGBT inverter, rewound induction motor, direct torque control , field oriented control and the DTC control with space vector technique and also DTC with space vector modulation are examined here, comparison between these technique are studied also. DTC using space vector modulation is better in them for application.
The difference among DTC and Field Oriented Control is analysed by Shauder C. Even factor sensitivity, dynamic show and control methodologies comparison was also analysed by him [18].

Control technique for reducing flux ripple and torque was given by L Tang et al which utilising space vector modulation [19]. Difference among DTC and FOC with predictable manner was also analysed by him.

In 2005 M. vasudevan and S. Paramasivam studied the detailed comparison between the adaptive intelligent strategies of torque control and emphasizing its advantage and disadvantage. The genetic algorithm based torque controller and performance of neural network is evaluated as the sensorless DTC control of induction motor. To achieve the high performance torque and decoupled flux control, these adaptive intelligent technique are used [20].

In 2011, S.L Kaila and H.B. jani described the DTC of induction motor drive using the space vector pulse width modulation. In this research, the switching instant of different space vector was determined [21].

C.Martins, proposed ripple reduction techniques and switching frequency imposition. This approach utilised converter of multilevel in DTC drives to diminish torque ripples. Performance of DTC also analysed by him by utilising PI stator resistance comparator. This approach rough and ready for stator resistance [22].

2.4 Indirect Vector Control of Induction Motor

In 2002 A. Miloudi and A draou present the indirect vector control by using the varible gain PI (VGPI) controller to control the speed and rotor resistance estimation of induction motor drive. First they designed the VGPI speed controller and simulate the speed control and rotor resistance estimation are compared to theclassical PI controller. Simulation of Indirect vector control of induction motor drive using variable control of PI give promising result. The motor drive reaches to its reference speed very fast and also without overshoot, trapezoidal command under no load tracks with zero steady state error, and the load disturbance are rejected, the motor parameter are fairly dealt also. If there is variation of the integrator gain from zero to its tuned value results of no trasient state error, for the rotor resistance estimation. So variable gain PI resitance estimator gives the outstanding traction performance [23].

Now the vector control technique have gained the wide acceptance in appliction of high performance machine. In vector control the control is transform, the induction motor drive to sepratly excited dc machine by crearting the separate channel for torque and flux contol. Essential for the better contol algoritm for vector control we have to known the position of rotor flux. We can evaluate the indiect vector control technique to measured the position of rotor by direct vector control. This also required the knowledge of the machine parameter which make the indirect vector control depends on machine parameter. When there is change in the saturation level and temperature of machine drive, this effect the dynemic opretion and the steady state of drive system. The parameter sensitivity effect on the dynemic performance and the stady state of indirect vector control can be stdied by Hebertt Sira-Ramírez.[24] The parameter sensitivity technique is sensitive to resistance of stator instrumented in the controller. The change in the resistance of stator a wide variation (0.75 to 1.7 times from is minimal value) due to varaition in temparture also small variation in frequancy. Only if there is large varaition in tempreture.

Norman morium, samsual Bhhari Mohd nour described the indirect vector control using fuzzy logic controller of three phase induction motor drive. The FLC algorithm has been simulated on Simulink Toolbox in Matlab. The performance of the proposed FLC has been investigated and compared to the results obtained from the conventional PI controller based drive at different operating conditions such as sudden change in load. The simulation results demonstrate that the performance of the FLC is better than that for the conventional PI controller [25].

The indirect vector control of induction motor (IM) drive associates the decouling of the stator current into flux and torque genreting component. Also in this reseach they implement the fuzzy logic control techinique useful to d-q component current control techinique of drive. Nitin R patel and kaushik devloped the fuzzy efficient logic controller with the help of knowledge of rule base in terms settling time and dynemic response with sudden varaition can compaired of Fuzzy logic controller with PI controller. The harmonic of the output current is calculated with both the fuzzy logic controller and PI controller. The steady and the trasient state performance of induction machine drive have been also studied [26].

Now, there is more demand in the high performance electrical drive system adept of accuratetly achieved the speed control command. Vector control of IM drives with high performance are widly used because of cost, size and efficiency. In dc machine we can contol the torque by controlling the flux and torque independently. The closed loop control technique for matrix converter fed IM drive is described. A prototype drive of 2.5 kw is used to described with closed loop control using indirect vector control. An induction motor of varible speed opration required a three phase source of variable frequancy Which can be achieved by using the power converter system with dc link connected between a rectifier connected to inverter. In many control technique to follow the input reference (sinusoidal), a three phase current control loops added to force the motor current. Depending upon the application we can control the inverter fed induction motor drive. The most utilized technique is V/F contol, direct torque control, field oriented control , open loop flux control [27].

In 2011, Biranchi Narayan Kar and Kanungi Barada Mohanty described the indirect vector control using sliding mode controller. The vector control or field oriented control methods have been proposed so that the induction motor can be controlled like a separately excited dc motor. Indirect vector control has been applied in wide range of industrial application. In order to accomplish variable speed operation, conventional PI controllers have widely used. By applying this controller induction machine achieves control performance similar to separately excited dc machine. Due to non linear characteristic of induction motor, linear controller such as PI controller fails to give optimum performance. This controller is also sensitive to parameter Variation, external disturbance, loads change. To solve these problems, recently intelligent controller such as sliding mode controller (SMC), Fuzzy logic Controller (FLC) etc. have been applied to drive systems [28].

2.5 Conclusion

A survey of several power circuit configurations and control approaches has been conceded out and presented in this chapter. Vector control of induction motor acting an important role in designing a traction motor drives. The review of two control schemes of vector control named: field oriented control and direct torque control has been performed. The induction motor drive control to indirect vector can achieved by the help of machine parameter and Direct Torque Control with the help of switching table and the stator flux

CHAPTER 3

INDUCTION MOTOR DRIVES CONTROL SCHEME

3.1 Introduction

Here in this chapter traction motor drives using induction motor is described. Speed control of induction motor drive is explained thoroughly and the vector control techniques namely direct, indirect vector and direct torque control is explained.

3.2 Feature of Traction Motor Drive

Traction motor drive with FOC or vector control offers a high-level dynamic performance and long term stability with closed loop control. Also we get the suitable torque-slip characteristics and speed control for traction motor drive. Below some desirable characteristics for traction motor are given

The desirable characteristics for traction motor:-

(i) There is a suitable torque speed characteristics for traction motor. The tractive effort required is maximum during the starting period

(ii) In traction work normally more than one motor are used. These motor should be capable of operating in parallel for which they should have suitable toque speed and current torque characteristics. For small difference in the speed of various motor, there should not occur wide difference in the torque i.e speed-current and speed-torque curve should not be flat

(iii) There should be voltage fluctuation feature in traction drive. In traction work, heavy current inrush at starting and considerable voltage fluctuations of supply line is a normal feature. Traction motor should be capable of withstand voltage fluctuation without undue effect on their performance.

(iv) In traction system, temporary interruption in a supply to the motor occur when cross over and the section insulator are crossed with controller on. Motor should be in position to withstand temporary interruption in the supply without very much undue of inrush current.

(v) Motor selection should be capable of taking heavy load without flash over. This property of motor is overload capacity.

(vi) Traction motor should have Self relieving property. Motor has speed torque characteristics such that torque is inversely proportional to speed, the product be always be constant. This gives the motor self-protective property against excessive overloading.

(vii) Traction motor should be amenable to simple speed control methods.

(viii) Motor should be amenable to easy and simple methods of rheostatic and regenerative breaking.

(ix) There should be limitation of weight and size of traction motor. In case of all transport vehicles, every kg. Weight require expenditure of energy. So that high power/weight ratio is aimed at in the design of traction motor.

(x) Robustness:- motor are subjected to service vibration. As such they should be robust enough to withstand any service condition

(xi) Traction motor should have high mechanical and electrical efficiency.

Based on these characteristics, three phase Induction motor is found to be more suitable than the dc series motor.

3.2.1 Induction Motor Working Principle

In three phase induction motor drive consists of slots on stator where three phase balance winding (120 degree electrically apart) are placed. Also three phase balance current is provided to stator so that resulting in a sinusoidal flux distribution in the air gap i.e rotating magnetic field is produced on stator because the prime condition for production of magnetic field is that there is three phase balance winding excited by three phase balance current. This flux links the rotor circuit also, we have three phase balanced winding on rotor so rotating magnetic produced in the rotor circuit. As the flux cuts across these conductors, an EMF is induced across the rotor bars which results in current flow in the rotor because the ends of the rotor are short circuited at the end. The direction of induced current is given by Lenz law, the direction of current is such that it opposes its cause (relative speed between stator magnetic field and rotor field). So that rotor starts rotating in the direction of stator magnetic field to overcome the relative motion of stator magnetic field and rotor magnetic field. Rotor always move less than the magnetic field of stator (N_s). If the rotor will move to synchronous speed then there is no relative motion so no torque will produced. Stator and rotor mmf are stationary in space from a result of this, induction motors is classified as a asynchronous motors. So Induction motor is self-starting in nature. The difference of rotational speed between stator and rotor is called slip. If more torque is required from the rotor shaft, the slip frequency increases.

3.2.2 Model Of Induction Motor

Generally induction machine also called Generalised transformer because its equivalent circuit is same as that of transformer. Dynamic model of the induction motor is to bred rived from two phase machine in the direct and quadrature axis. This is desirable to achieve the simplicity obtained to the two set of winding first on rotor and second one on the rotor. Equivalence between two and three phase motor model derived by the simple observation, and this approach suitable extended the model for multi- phase machine model. This concept introduced power must be equal in 3- phase machine model and this will equal to 2-phase machine. It said that the dynamic model of the induction machine is a good approximation of the real plant. The dynamic model of induction motor can be derived either by 2- axis theory or space vector theory. But space vector is better option to drive the model of induction machine and control point

The following condition are to be assumed for deriving the dynamic model for induction motor drive:-

(i) The rotor and stator winding are to be balanced, also MMF should be stationary

(ii) Air gap will be uniform

(iii) Rotor vs inductance position sinusoidal

(iv) Parameter & saturation are be neglected.

(v) No fringing in magnetic circuit

(vi) The effect of the slots of stator are neglected

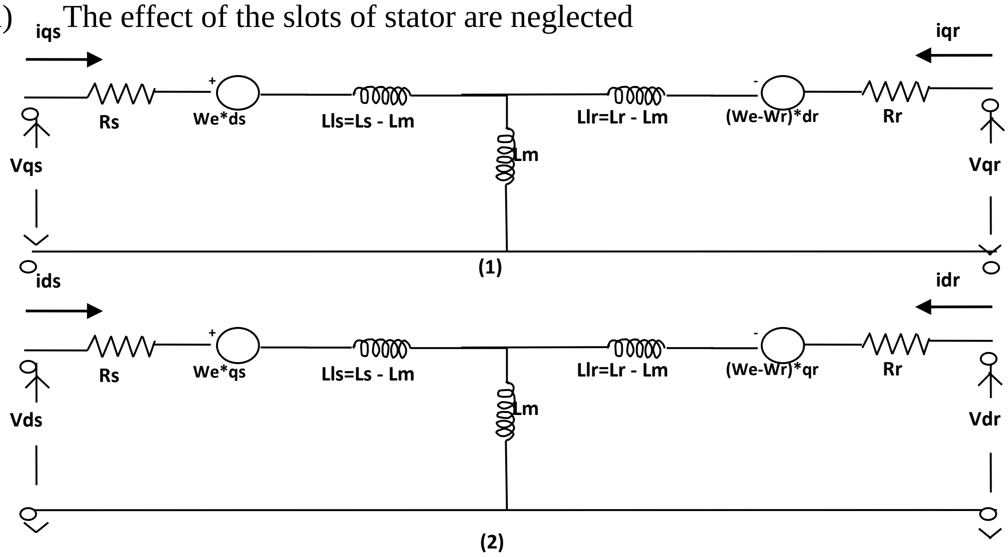

Figure No-3.1 Equivalent ckt of induction motor in the synchronous rotating ref. frame,

1) q-axis ckt 2) d-axis ckt

The various parameters are calculated as under:

Here below we explain the Voltage equation(3.1)-(3.4):-

$$V_{qs} = R_s * i_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_e \varphi_{ds} \quad (3.1)$$

$$V_{ds} = R_s * i_{ds} + \frac{d\varphi_{ds}}{dt} - \omega_e \varphi_{qs} \quad (3.2)$$

$$V_{qr} = R_r * i_{qr} + \frac{d\varphi_{qr}}{dt} + (\omega_e - \omega_r)\varphi_{dr} \quad (3.3)$$

$$V_{dr} = R_r * i_{dr} + \frac{d\varphi_{dr}}{dt} - (\omega_e - \omega_r)\varphi_{qr} \quad (3.4)$$

Below Flux equations are explain (3.5)-(3.8):-

$$\varphi_{qs} = L_{ls} * i_{qs} + (i_{qs} + i_{qr})L_m \quad (3.5)$$

$$\varphi_{qr} = L_{lr} * i_{qr} + (i_{qs} + i_{qr})L_m \quad (3.6)$$

$$\varphi_{ds} = L_{ls} * i_{ds} + (i_{ds} + i_{dr})L_m \quad (3.7)$$

$$\varphi_{dr} = L_{lr} * i_{dr} + (i_{ds} + i_{dr})L_m \quad (3.8)$$

Where V_{ds}& V_{qs}; i_{qr} , i_{qs}, i_{dr} & i_{ds} are voltage and currents corresponding d & q axis $\varphi_{qr}, \varphi_{qs}, \varphi_{dr}$ & φ_{ds} are the rotor and stator flux component; R_s, R_r are the stator & rotor resistances; L_{lr} and L_{ls} symbolizes the inductances, where L_m also denotes inductance.

The equation (3.9) of Electromagnetic torque is given below:-

$$T_e = \frac{3*P*L_m}{2*2*L_r} * (\varphi_{dr} i_{qs} - \varphi_{qr} i_{ds}) \quad (3.9)$$

Here *P* denotes number of pole the motor
In vector control the *q axis*-component the rotor field φ_{qr} should be zero. So Electromagnetic torque given by equation (3.10)

$$T_e = \frac{3*P*L_m}{2*2*L_r} * (\varphi_{dr} i_{qs}) \quad (3.10)$$

3.3 Type of Speed Control of Three Phase Induction Motor Drives

We have various control scheme for induction motor drive. But induction motor control drives are approximately classified in these two categories such as vector control and scalar control. There are two measure step to design the control system drive:-

(i) To accomplish the evaluation & analysis of the system, first we convert the system in mathematical model.

(ii) If there are external perturbations present in the system, then optimal regulator imposed response will obtained from the system.

There are two fundamental direction for induction motor drive:-

(i) Analogue (ii) Digital

(i) In analogue we will direct measured the parameter of the drive (rotor seed mainly). This will compared with the reference speed

(ii) Also in digital estimate the machine drive parameter (without measure the rotor speed)

The following method can be used for measured the parameter of the drive (induction motor)

- (i) Calculate the slip frequency
- (ii) Estimate speed using state equation
- (iii) Direct controlling the flux and torque
- (iv) Observer based sensorless speed control
- (v) Model adaptive reference system
- (vi) Parameter adaption with sensor less control
- (vii) Sensor less control of Neural network
- (viii) Fuzzy logic based sensor less control

Cataloguing of control techniques of induction motor from the point of view of the control signal

- (i) Scalar control of induction motor
- (ii) Vector or Field oriented control(FOC)
- (iii) Direct torque control

3.4 Scalar Control

Scalar control is based on the relationship effective in study state, here only the magnitude and frequency of flux and voltage linkage space vector are control. Neglects the coupling effect of the machine. As the name suggests the scalar control is due to the variation in the control variable only. Such as to control the flux of drive by controlling the voltage of drive & slip or frequency can be control by controlling the torque. Also the torque and flux are the function of frequency and voltage respectively. A scalar control drive given better performance. It is easy to be implemented so that widely used in industries. But the inherent coupling effect of both flux and torque are the function of frequency and voltage give very sluggish response and the system will easily disposed to instability because of the order of harmonics(5^{th} order) is larger effect the system. If we want to increase the torque by increasing the slip or frequency, so that flux will decreased. It is also noted that flux varied very slow rate i.e sluggish response. Here decrease in the flux will be compensated by the slow response of the flux control loop feeding the extra voltage.

.3.5 Vector or Field-oriented Control (FOC) of the Induction Motor Drives

Vector control made alternating current (ac) drive equal to the direct current (dc) drive in independent control of the flux and torque and superior to them in their dynamic performance. These developed positioned ac machine for high power performance application, yet reserved for separately excited DC motor machine. The design of speed controller for induction motor are explained in his chapter

3.5.1 Principle of vector control for drive:-

For explain the vector control principle, we have to be assumed that known the position of rotor flux linkage phasor (λ_r), θ_f is the angle between the stationary reference frame and θ_f Denotes the field angle then three phase stator current are transformed to the d and q axes current in synchronous reference frames using transformation

$$\begin{bmatrix} i_{qs}^e \\ i_{ds}^e \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\theta_f & \sin(\theta_f - \frac{2\pi}{3}) & sin(\theta_f + \frac{2\pi}{3}) \\ \cos\theta_f & \cos(\theta_f - \frac{2\pi}{3}) & \cos(\theta_f + \frac{2\pi}{3}) \end{bmatrix}\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \tag{3.11}$$

From equation (3.11) which the stator current phasor, i_s is derived as

$$i_s = \sqrt{(i_{qs}^e)^2 + (i_{ds}^e)^2} \tag{3.12}$$

And the stator phasor angle is given by equation (3.13)

$$\theta_s = \tan^{-1}\left\{\frac{i_{qs}^e}{i_{ds}^e}\right\}, \tag{3.13}$$

Figure 3.2 explain the phasor diagram of vector controller. Here i_{ds}^e and i_{qs}^e are the d and q axis current synchronous reference frame that will obtained to projecting stator current phasor on q and d axes respectively. The rotor flux λ_r and torque T_e produced by the stator current phasor i_s. The component of current that will produced rotor flux phasor and rotor flux are in phase. If we resolves the stator current along λ_r Reveals the field producing component is i_T.

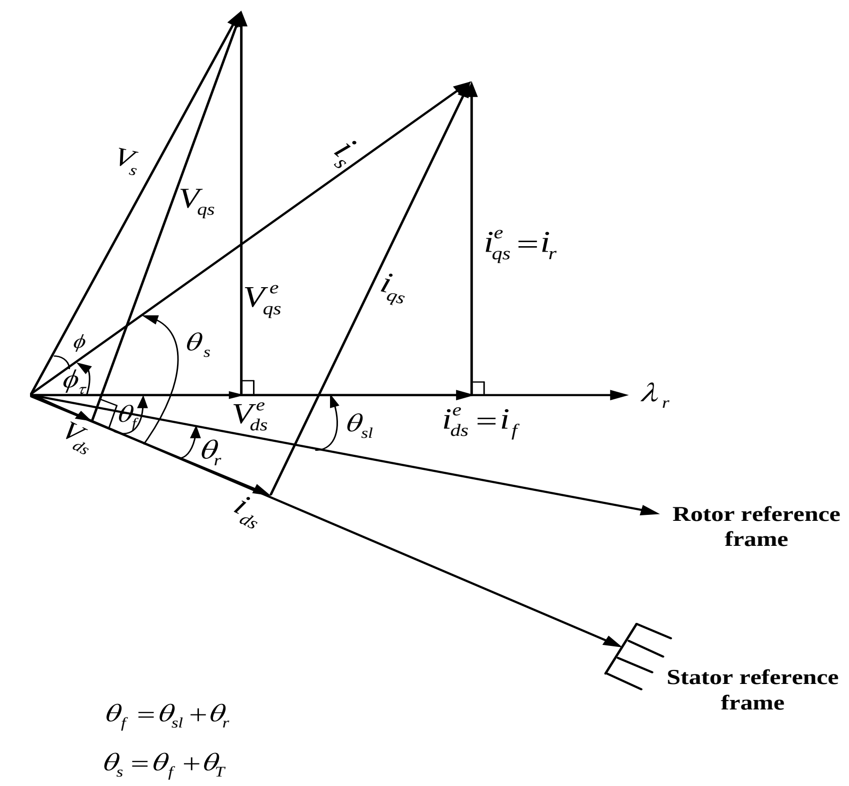

Figure No 3.2: phasor diagram of vector controller

The torque producing component is basically the perpendicular component i_T. Writing the flux linkage and torque equation (3.14)-(3.15) in relations with these component.

$$\lambda_r \propto i_f \tag{3.14}$$

$$T_e \propto \lambda_r i_T \propto i_f i_T \tag{3.15}$$

Vector control to be classified according to how we calculated the field angle acquired. If we can calculate the field angle by the use of terminal current and voltage or sensing the flux winding then this scheme is called direct vector control

We can also calculate the field angle by the use of position of rotor and partially estimate the parameter of machine but none other variable such that current and voltage using this scheme calculate the field angle leads to the class of indirect vector control.

Vector control is can be explained by the following algorithm:-

(i) First the field angle obtain

(ii) Estimate the flux producing component i_f for required rotor flux linkage λ*r .we can control the rotor flux linkage by controlling the field control.

(iii) Torque generating component can be calculated by the λ*r and required T_e^*. the controlling of toque generating component of current and the rotor flux linkage phasor constant give the independently controlled electromagnetic torque. This is the same effect like in dc machine there torque will controlled by the current.

(iv) The magnitude of Stator current phasor is given by the vector sum of i_T^* and i_f^*

(v) Torque and flux generating component of the stator current commands give the torque angle $\theta_T = \tan^{-1}\left[\frac{i_T^*}{i_f^*}\right]$

(vi) Stator current phasor angle θs is to be calculate by adding θ_f and θ_T

(vii) By the use of the magnitude and angle of stator current phasor θs.and i_s^* we can obtained the required stator current commands to going through qd0. Transformation to abc variable. Equation from (3.16)-(3.18) give the stator reference current.

$$i_{as}^* = i_s^* \sin \theta_s \quad (3.16)$$

$$i_{bs}^* = i_s^* \sin(\theta_s - \frac{2\pi}{3}) \quad (3.17)$$

$$i_{cs}^* = i_s^* \sin(\theta_s + \frac{2\pi}{3}) \quad (3.18)$$

(viii) Synthesize current by use of inverter; when these are supply to induction motor stator finally we obtained the required rotor flux linkage and torque.

These are two scheme under the vector control of induction motor drives

(a) Direct or feed- back control

(b) Indirect or feed forward control

These two scheme explained below

3.5.2 Direct vector control:-

In block diagram (figure 3.3) direct vector control explain with current source inverter. Here reference speed and the rotor speed is compared. This produced the error and error amplified used to generates reference torque T_e^* the rotor flux linkage reference λ*r is to be derived from the rotor speed through absolute value of function generator.

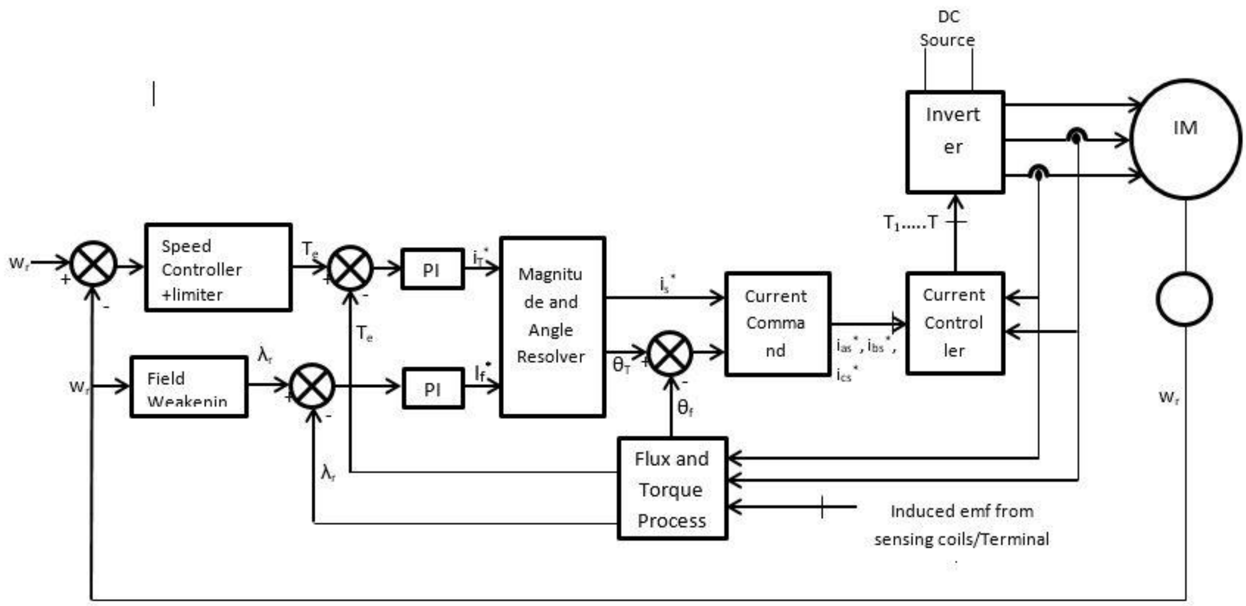

Figure No 3.3: Block diagram of direct vector control of IM Drives

Rotor flux linkage is to be kept at 1 p.u and the rotor speed will lies between 0 to 1 p.u. to be varied as a function of rotor speed. This ensure that the speed will not extended beyond the base speed with the variable voltage (dc) to inverter by weakening the rotor flux linkage. We reduced the induced EMF to lower that's of the output voltage available from the inverter. To reduce the rotor flux linkages the torque generating component of stator current and the electromagnetic torque will reduced. The flux-linkage and torque reference are to be compared torque T_e^* and rotor flux linkage λ_r respectively. This will generate the error and this error will amplified and limited to produce the reference flux and torque producing component of the stator current i_T^* and i_f^* , respectively, the phasor summation of the flux and torque generating component of stator will give the stator current phasor reference i_s^*.and the angle between i_T^* and i_f^* give the torque angle reference, θ_T^*,the addition of the field angle and torque angle give the position of the stator current reference i_{as}^* , i_{bs}^* and i_{cs}^* these current requests are simplified by use of the current and inverter feedback loops. These phase current control loops can be used in one of the technique given below

(i) PWM (pluse width modulation)

(ii) Hysteresis loop control

(iii) Space vector modulation (SVM)

By the use one of above control scheme the inverter current are made correspond to the reference input and the feedback variable θf, T_e .and λr can be obtained from the bock of torque and flux processor. This will be the key to direct vector control.

3.5.3 Indirect vector control of induction motor drive

The indirect vector control calculate the field angle is calculated by the use of position of rotor and partially estimate the parameter of machine but none other variable such that current and voltage. This scheme is same as the direct vector control, difference is only the unit vector signal are garneted in the feed-forward manner. In industries, the indirect vector control is widely used. The phasor diagram explain the principle of indirect vector control. The stator axes (d^s and q^s) are fixed on stator. But the rotor axes ($d^r - q^r$) are rotating with the speed ω_r. But rotor axes are fixed on rotor. The positive slip angle θ_{sl} crossponding to the slip frequencyω_{sl} is the angle between the synchronous rotating axes d^e-q^e and the rotor axes d^r–q^r. Rotor pole directed towards d^e axis. θ_e Can be gives by equation (3.19) as

$$\theta_e = \int \omega_e dt = \int(\omega_r + \omega_{st})dt = \theta_r + \theta_{sl} \tag{3.19}$$

The position of rotor is not absolute but is slipping w.r.t rotor at frequencyω_{sl} . The torque component of current i_{qs} should be aligned on q^e axes and the stator flux component of current i_{ds} on d^e axis. Where figure 3.4 shows the phasor diagram of vector control. The rotor equation expressed (3.20)-(3.21) as

$$\frac{d\Psi_{dr}}{dt} + R_i i_{dr} - (\omega_e - \omega_r)\Psi_{\mathrm{qr}} = 0 \tag{3.20}$$

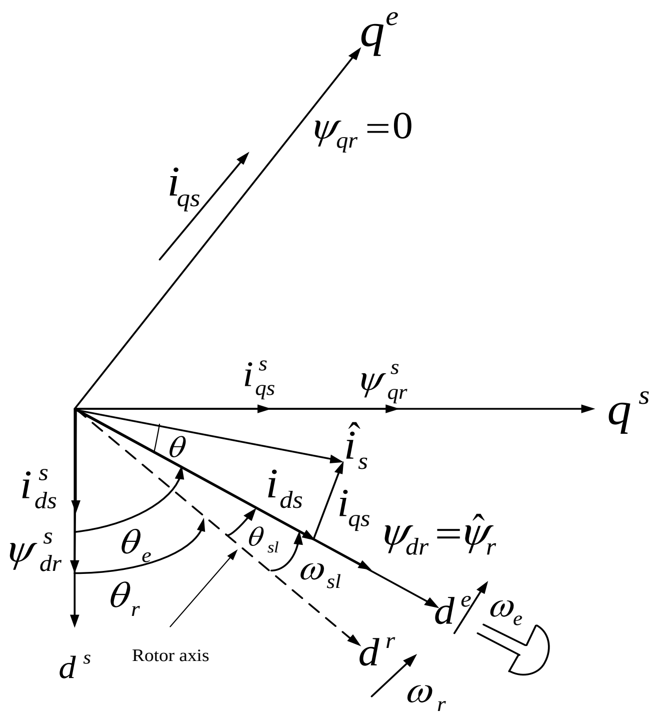

Figure No 3.4: Phasor diagram of indirect vector control

$$\frac{d\Psi_{qr}}{dt} + R_i i_{qr} + (\omega_e - \omega_r)\Psi_{\mathrm{dr}} = 0 \tag{3.21}$$

The rotor flux linkage expressions (3.22)-(3.27) can be given as

$$\Psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{3.22}$$

$$\Psi_{qr} = L_r i_{qr} + L_m i_{\ qs} \tag{3.23}$$

$$i_{dr} = \frac{1}{L}\Psi_{dr} - \frac{L_m}{L_r} i_{ds} \tag{3.24}$$

$$i_{qr} = \frac{1}{L}\Psi_{qr} - \frac{L_m}{L_r} i_{qs} \tag{3.25}$$

$$\frac{d\Psi_{dr}}{dt} + \frac{R_r}{L_r}\Psi_{dr} - \frac{\mathrm{L}_m}{L_r} R_r i_{ds} - \omega_{sl}\Psi_{qr} = 0 \tag{3.26}$$

$$\frac{d\Psi_{qr}}{dt} + \frac{R_r}{L_r}\Psi_{qr} - \frac{\mathrm{L}_m}{L_r} R_r i_{qs} - \omega_{sl}\Psi_{dr} = 0 \tag{3.27}$$

Where $\omega_{\mathrm{sl}} = \omega_{\mathrm{e}} - \omega_{\mathrm{r}}$ has been submitted.

$$\Psi_{qr} = 0 \tag{3.28}$$

$$\frac{d\Psi_{qr}}{dt} = 0 \tag{3.29}$$

So that the total rotor flux $\widehat{\Psi_r}$ is directed on the d^e axis.

$$\frac{L_r}{R_r}\frac{d\widehat{\Psi_r}}{dx} + \widehat{\Psi_r} = L_m i_{ds} \tag{3.30}$$

$$\omega_{sl} = \frac{L_m R_r}{\widehat{\Psi_r} L_r} i_{qs} \tag{3.31}$$

Where $\widehat{\Psi_r} = \Psi_{dr}$ has been substituted .

$$\widehat{\Psi_r} = L_r i_{ds} \tag{3.32}$$

For the implementation of indirect vector control the equation (3.19) (3.30) and (3.31) are necessary required. Figure 3.5 Show Block diagram of the indirect vector control of four quadrant position of servo system. A hysteresis band current controller with PWM shown in figure 3.5. The torque component of current i_{qs}^* is generated by the speed control loop. Equation (3.32) determined the flux component of current i_{ds}^* for the desired rotor flux, and is maintained constant in open loop for simplicity. There is a drift in the flux to vary the magnetizing inductance L_m. ω_{sl}^*(Slip frequency) is generated from i_{qs}^* in the feed-forward manner. The slip gain given below equation (3.33):-

$$K_s = \frac{\omega_{sl}^*}{i_{qs}^*} = \frac{L_m R_r}{\widehat{\Psi_r} L_r} \tag{3.33}$$

The speed signal ω_r added with signal ω_{sl}^* to generate the frequency signalω_e . Integration of frequency signal generate the unit vector $\sin\theta_e$and $\cos\theta_e$. In indirect vector control, the speed signal from incremental position encoder is must needed because slip signal locate the pole w.r.to axis of rotor (dr) in feed-forward manner, which is moving with a speed of ω_r

In the indirect vector control, the speed control range can be easily extended between the zero speed (stand–still) and field weakening region. The field weakening region is shown in figure 3.5. The flux is constant in constant torque region. But flux is always programmed such that inverter operate in PWM mode in the field weakening region. Same technique for field weakening is used for direct vector control.

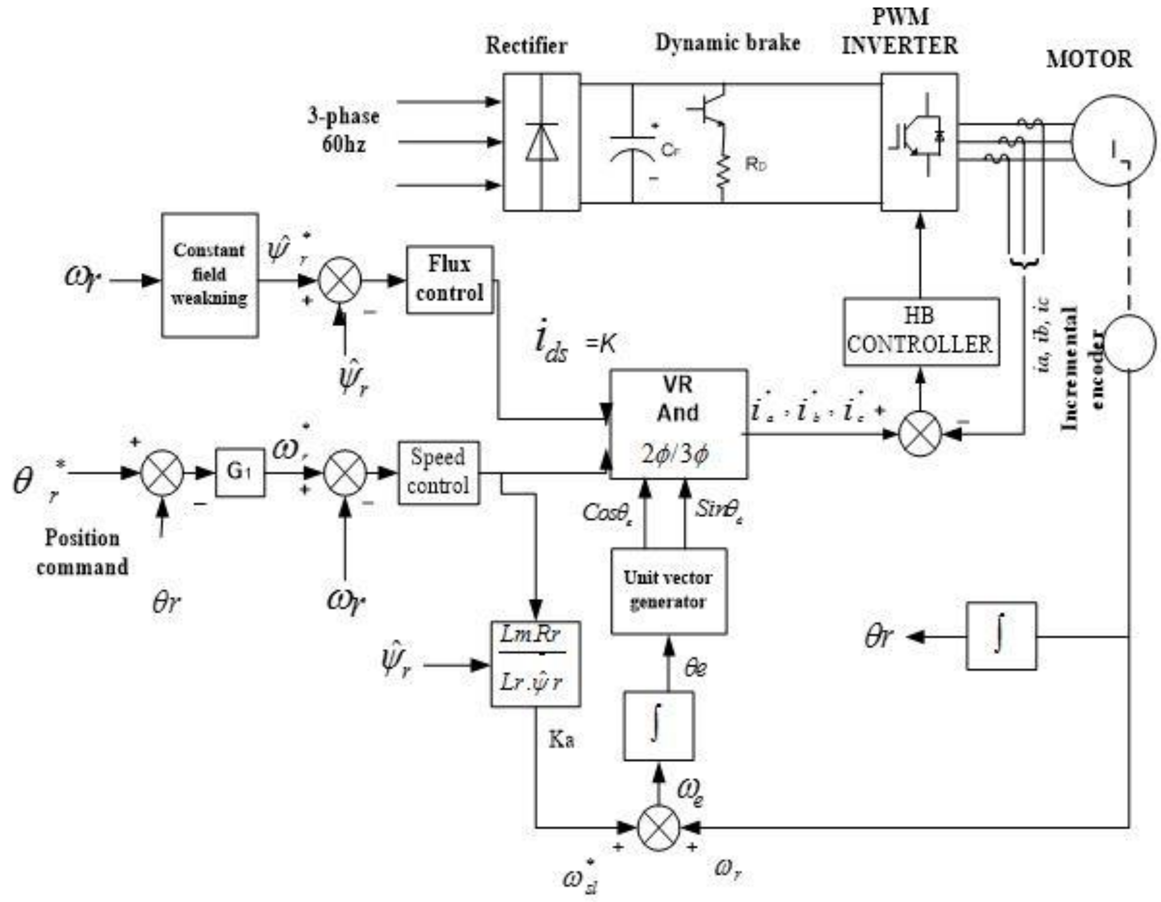

Figure No-3.5 Block diagram of indirect vector control

Variable (d^s-q^s) variables and then transform these to synchronously rotating reference frame (d^e-q^e).and following transformation equations (3.34) and (3.35)are used.

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta & 1 \\ \cos(\theta - 120°) & \sin(\theta - 120°) & 1 \\ \cos(\theta + 120°) & \sin(\theta + 120°) & 1 \end{bmatrix} \begin{bmatrix} v_{qs}^s \\ v_{ds}^s \\ v_{os}^s \end{bmatrix} \tag{3.34}$$

The corresponding inverse relation is given by eqn (3.20)

$$\begin{bmatrix} v_{qs}^s \\ v_{ds}^s \\ v_{os}^s \end{bmatrix} = \frac{2}{3} \begin{bmatrix} cos\theta & \cos(\theta - 120°) & \cos(\theta + 120°) \\ sin\theta & \sin(\theta - 120°) & \sin(\theta + 120°) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} \tag{3.35}$$

Where v_{os}^s is added as the zero sequence component, which may or may not be present. We have considered voltage as the variable

The current and flux linkage can be transformed by similar equations (3.36)-(3.38).

$$\begin{bmatrix} v_{qs}^s \\ v_{ds}^s \\ v_{os}^s \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} \quad (3.36)$$

$$\theta = \int_0^t \omega_1 \, t + \theta_0 \quad (3.37)$$

$$\begin{bmatrix} v_{qr}^s \\ v_{dr}^s \\ v_{or}^s \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\omega_e - \omega_r)t & \cos((\omega_e - \omega_r)t - 120°) & \cos((\omega_e - \omega_r)t + 120°) \\ sin(\omega_e - \omega_r)t & \sin((\omega_e - \omega_r)t - 120°) & \sin((\omega_e - \omega_r)t + 120°) \\ 0.5 & 0.5 & 0.5 \end{bmatrix}\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix}$$

(3.38)

It should be noted that the difference $\omega_e - \omega_r$

$$\theta_e = \int(\omega_m + \omega_{sl})dt \quad (3.39)$$

$$\omega_{sl} = \frac{L_m}{|\psi_r|_{est}} \frac{R_r}{L_r} i_{qs}^* \quad (3.40)$$

Equation 3.39 and 3.40 are used for calculation of theta

$$i_{ds}^* = \frac{|\psi_r|^*}{L_m} \quad (3.41)$$

Equation 3.41 used for calculation of direct axis reference current of stator

$$i_{qs}^* = \frac{2}{3} . \frac{2}{p} . \frac{L_r}{L_m} \frac{T_e^*}{|\psi_r|_{est}} \quad (3.42)$$

Equation 3.42 is used for the calculation of quadrature axis stator current

Where L_r is the rotor inductance, L_m is the mutual inductance, and $|\psi_r|_{est}$ is the estimated rotor flux linkage.

3.6 Direct torque control of induction motor drive:-

3.6.1 Principle of direct torque control for IM drive:-

Electromagnetic torque of induction motor drive can be given by (3.43)

$$T_e = \frac{3}{2} P\Psi s \, . \, is \quad (3.43)$$

Here ψs is stator flux, i_s is stator current (both are static stationary reference frame) and P denotes number of poles. The above Equation can be improved as equation(3.44).

$$T_e = \frac{3}{2}\, P|\Psi s|.|is|.\sin(\alpha s - \rho s) \quad (3.44)$$

Where ρs is angle of stator flux and the stator current angle is αs, both denoted the horizontal axis of stationary reference frame fixed to stator. The angle ρs will change if the stator flux modulus is to be kept constant. So that electromagnetic torque can directly controlled. Electromagnetic torque also given from below equation (3.45).

$$T_e = \frac{3}{2}\, P \frac{Lm}{LsLr - Lm^2} |\Psi r|.|\Psi s|.\sin(\rho s - \rho r) \quad (3.45)$$

Because of rotor time constant is greater than stator one, the rotor flux variations are slowly compared to stator flux; rotor flux assumed to be constant.(rotor flux assumed to be constant if the response time of control system is more than the time constant of rotor).Time from which As long as, the modulus of flux stator remain constant, electromagnetic torque changed quickly and controlling is done by the change of angle(ρs – ρr).

3.6.2 DTC (direct torque control) technique:-

In field oriented control technique have faced some problems like complexity in its implementation due to dependency of machine parameter, also the transformation of reference frame. After that direct torque control can be introduced. This technique only required the stator resistance to calculate the torque and stator flux.

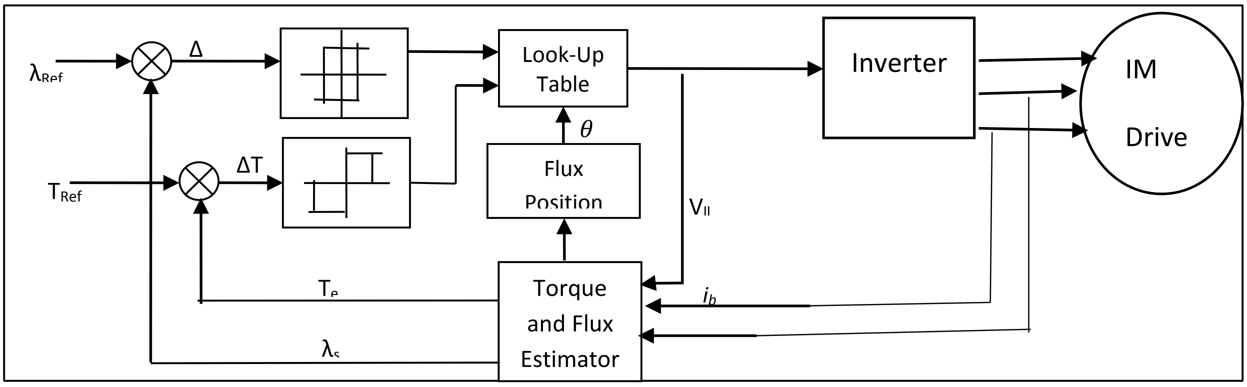

Figure No-3.6 Block diagram direct torque control

Figure 3.6 shows the block diagram of direct torque control. In conventional direct torque control, the flux and electromagnetic torque controlled independently by selection of optimum switching of the inverter modes. For the selection of inverter switching modes is made to limit the flux and torque errors within the flux and torque hysteresis bands. In basic circuit of direct torque control consists two comparators within specified bandwidth, voltage source inverter, switching table, torque and flux blocks. There is some advantage and some disadvantage of every control scheme. DTC also have advantage like less parameter dependency, making the system more robust and easier to implements and some disadvantages are difficult to control torque and flux at low speed, there is distortion in the torque and current during change of the sector, frequency will be variable, a very high sampling frequency needs for the digital implementation of hysteresis controller, a high torque ripple.

The main feature of direct torque control is to control directly the flux and torque, and indirectly control of stator currents and voltage to give the sinusoidal stator flux and current. These feature leads to absent the co-ordinate axis transformer in control technique. The block of Voltage modulation and PID controller for flux and torque of motor are needed in control algorithm.

3.6.3 DTC-SVC Control of IM drive:-

The output voltage vector pluses duration is determined from the torque ripple minimum condition. This improvement can reduced the ripple present in torque, but also increase the complexity in algorithm of direct torque control. An alternative technique which reduced the ripple is to be based on space vector modulation. DTC-SVC technique is used to determine the reference vector of stator voltage and modulate this by SVM method in power gates of inverter with constant switching frequency, such that every sampling time voltage will produced by the inverter.

DTC based on the space vector modulation DTC transient merits, moreover the steady state transient performance will better in a wide speed range. In each cycle, DTC-SVM technique used to attain the reference voltage space vector to compensate the error of torque and flux. So that the ripple in torque is sufficiently improved at low speed

3.7 Conclusion

This chapter, we studied different controller design for speed control. The outline of the vector or field oriented and torque of IM drive is well- known. Torque and flux calculation block of field oriented control with associated equation described. The space vector and the switching table of direct torque control is explained.

CHAPTER 4

CONTROLLER FOR TRACTION MOTOR DRIVE

4.1 Introduction

Induction motors of high rating are used for traction motor drive. Here in this chapter vector control techniques of traction motor drive is described using PID, Fuzzy logic and Fuzzy PI controllers. Also all these controllers are explained in detail in this chapter.

4.2 Controllers for induction motor drive System

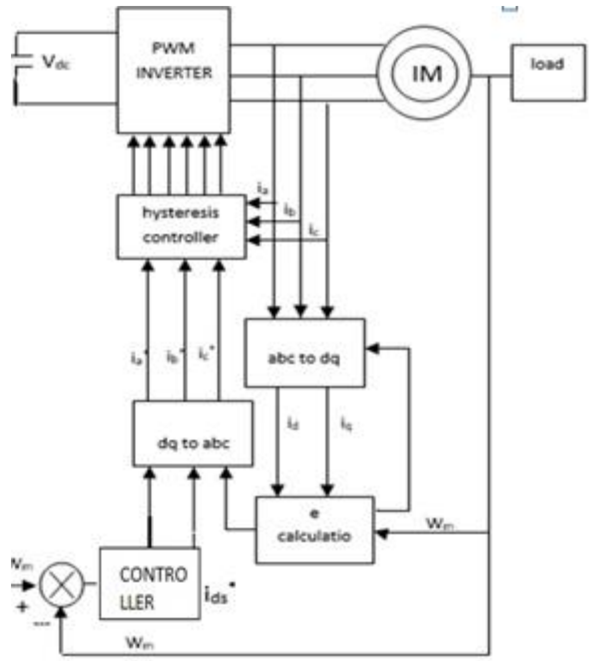

Figure No-4.1 Indirect vector controller diagram

In fuzzy logic and Fuzzy Tuned PI controllers different membership functions comprising and designed and compared with conventional PID controller. Main emphasis is kept on the peak overshoot and settling time of the current and speed. We use different controller in place of the block controller as shown in figure 4.1. Further intelligent controllers namely Fuzzy Logic Controller, and Fuzzy PID for induction motor drive system are designed and then simulated using MATLAB-Simulink.. All controllers are compared and suitable results are obtained.

4.2.1 PID Control

PID controllers are used because of its simplicity and easier design in control loops. It minimize the settling time and gives better steady state response. The PID controllers made up of following control actions;

1) The Proportional
2) The Derivative
3) The Integral

The transfer function of the PID controller is given by equation (4.1);

$$K_p e(t) + K_i \int_0^t e(t)\, dt + K_d \frac{de(t)}{dt} \quad (4.1)$$

Here (t) is error w.r.t. reference input signal and K_p, K_i and K_d are control parameters i.e. proportional constant, integral constant and constant of derivative respectively. The proportional constant is accountable for following the desired set-point, while the integral and derivative part account for the accumulation of past errors and the rate of change of error in the process. PID controller is used the weighted sum of these three controls. The controller can provide control action designed for exact process requirements by tuning of these controls. Figure 4.2 shows the block diagram of PID controller.

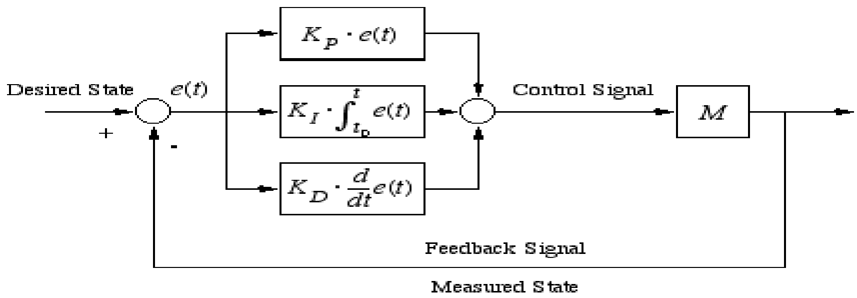

Figure No-4.2 Block diagram of a PID controller in a feedback loop

4.2.2 Fuzzy Logic Control

It is a mathematical tool for analysis and management of doubts in a specific system. It is a nonlinear adaptive control method based on artificial intelligence. The fuzzy logic control is used to control the speed using indirect vector control. The main components of a fuzzy logic system are:

(i) Fuzzifier

(ii) An inference engine (a knowledge base comprising of data base and rules base)

(iii) Defuzzifier.

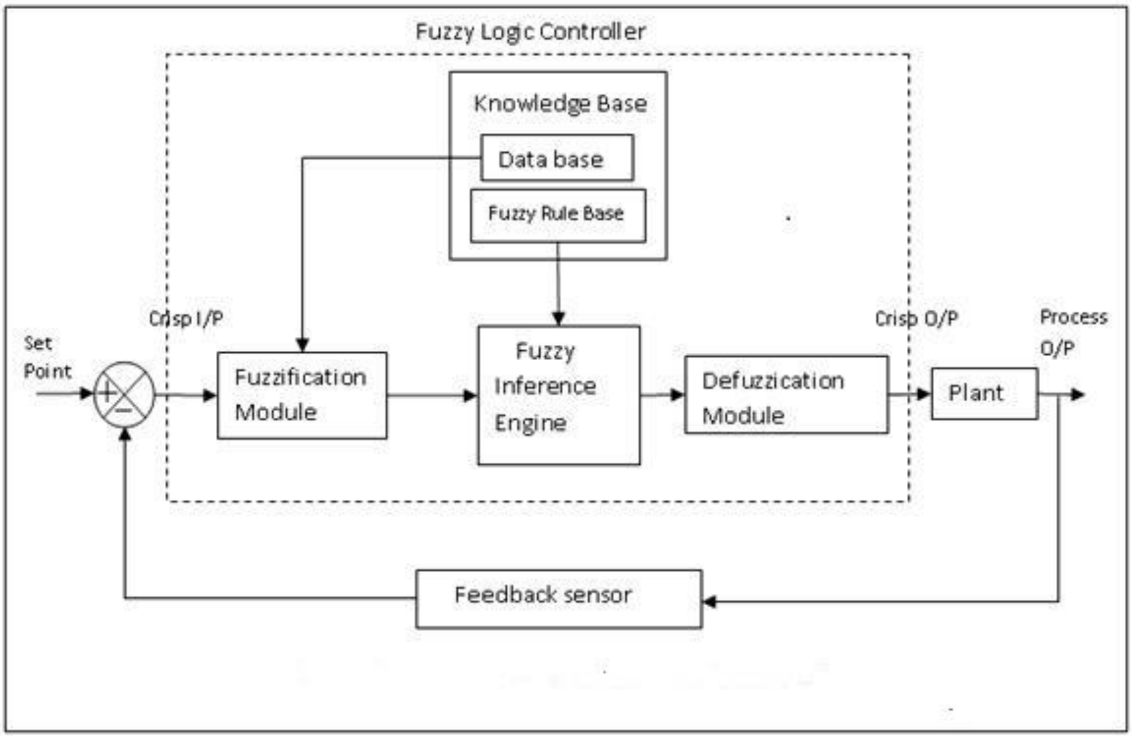

Figure No-4.3 Block diagram of Fuzzy logic controller

Fuzzification is the conversion process of uncertain crisp parametric value into corresponding fuzzy set values. It should be first normalized to the range of universe of discourse and expressed in terms of membership function before the parameters fuzzification. It is a graphical representation of the magnitude of participation of each input. It relates a weight with each of the input that are processed, defining functional overlap between inputs and ultimately regulating an output response. The rules use the input sets of values as a weighting factor to regulate their influence on the fuzzy output sets of the output conclusion. Once the functions are inferred, scaled and combined, they are de-fuzzified into a crisp output, which is then used to compute the final output. Fig. 4.3 shows the block diagram for fuzzification.

FLC is recently becoming common with the systems requiring of robust control i.e. where load and process parameters vary. Zhao and Bose imply that triangular mfs are easy to implement and the response of trapezoidal also follows triangular response closely. They performed the vector control of induction motor with different FLC mfs but stated that it can be generalized to other control systems also. Here fuzzy logic controller is designed with single where error is single output. All membership function are continuous in nature. Since all information contained in a fuzzy set is described by its membership function, it is useful to describe various special features of these functions.

A Fuzzy logic controller is designed to control the speed of traction motor as shown in Figure 4.4. Here G Bell membership function are used to design the fuzzy logic control as shown in figure 4.5

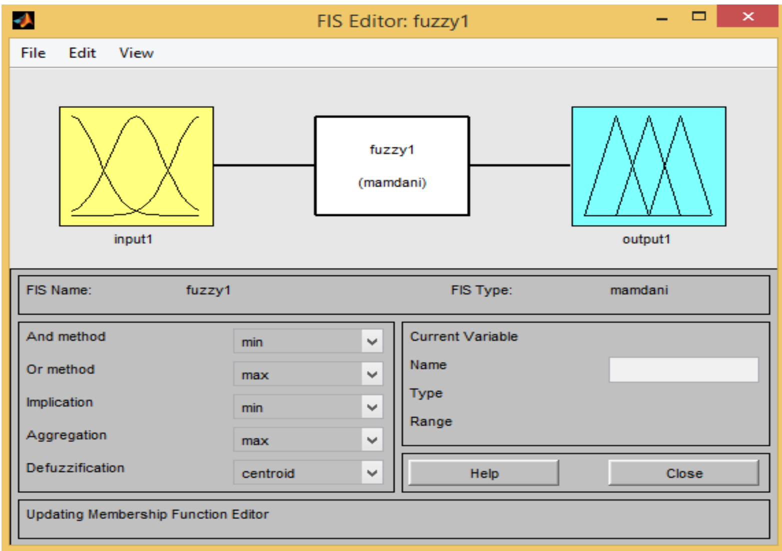

Figure No-4.4 fuzzy logic control for speed control of traction motor

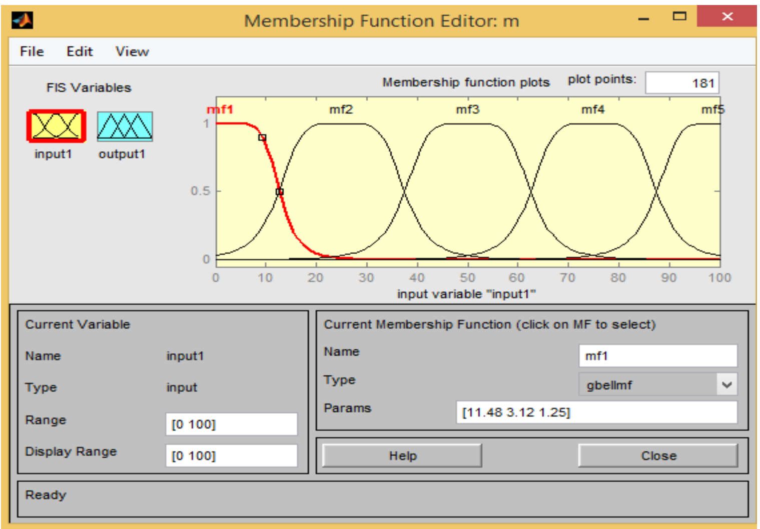

Figure No-4.5 Input and output membership function for Fuzzy logic controller

4.2.3 Fuzzy tuned PI

Fuzzy logic is a powerful tool to validate the ad-hoc methodology of PID control. It uses the conventional PID controller as the basis and takes the fuzzy reasoning and variable universe of discourse to regulate the PID parameters. For better tuning of PID parameters robustness and adaptability is used in the controlling method.

Self-tuning discusses to the characteristics of the controller to tune its controlling parameters on-line automatically, most appropriate values of those parameters which result in optimization of the process output. It works on the control rules designed on the basis of theoretical and experience analysis and can tune these parameters Kp, Ki, and Kd by adjusting the other controlling parameters and factors on-line. It shows the precision of overall control higher and gives a better performance without self-tuning ability. Figure 4.6 shows the block diagram of Fuzzy tuned PI controller.

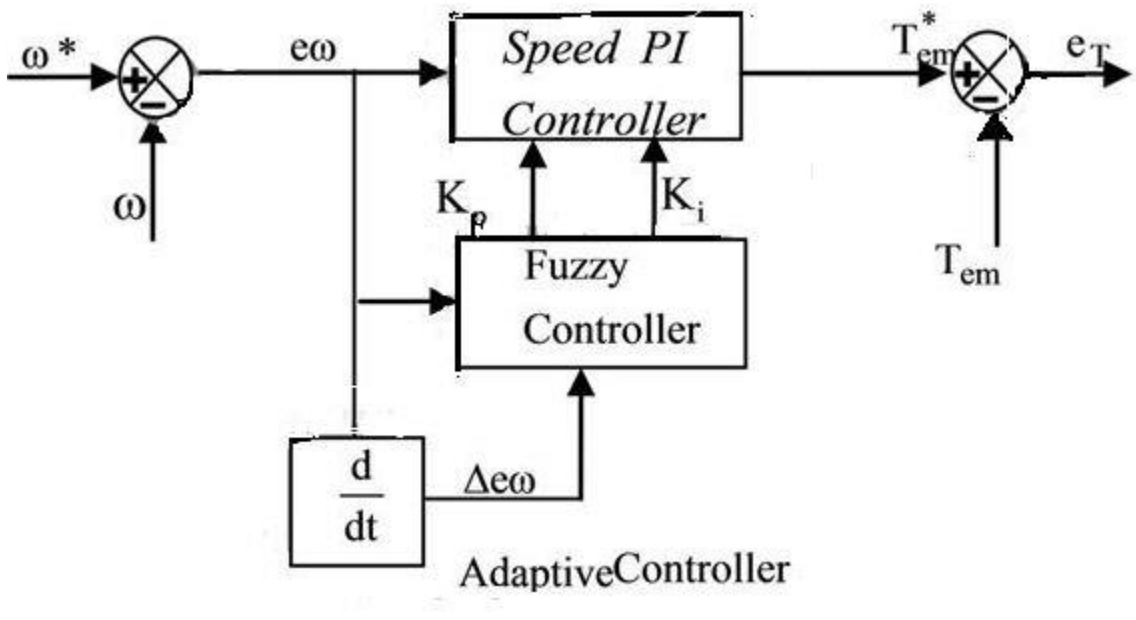

Figure No-4.6 Block diagram of Fuzzy tuned PID

(1) Advantages of fuzzy self-tuning PID controller

The followings are the advantages of fuzzy self-tuning PID controller over the conventional PID controller:

i) The traditional PID controller cannot self-tune parameters K_p, K_i and K_d while operating.

ii) Combining fuzzy inference with traditional PID method, self-tuning of PID parameters can be realized.

iii) The decisions can be made through fuzzy reasoning rules according to the size, direction and the changing tendency of the system error.

iv) In railway traction system, the variability of parameters and the uncertainty of model are very high, thus using conventional PID control the precise control of the process cannot be achieved.

v) The fuzzy control has a good robustness and adaptability thus the precise mathematical model of the process is not necessary.

A fuzzy tuned PI controller is designed for speed control of traction motor as shown in figure 4.7

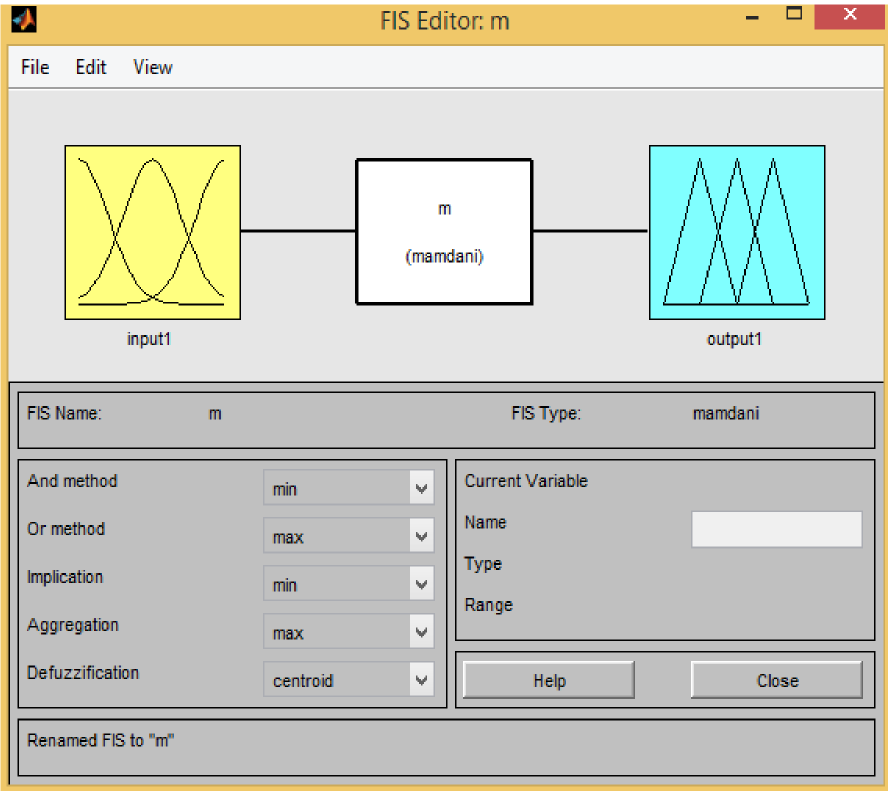

Figure 4.7 fuzzy tuned PI controller for speed control of traction motor.

For the design of fuzzy tuned PI controller, we use the triangular membership function as shown in figure 4.8

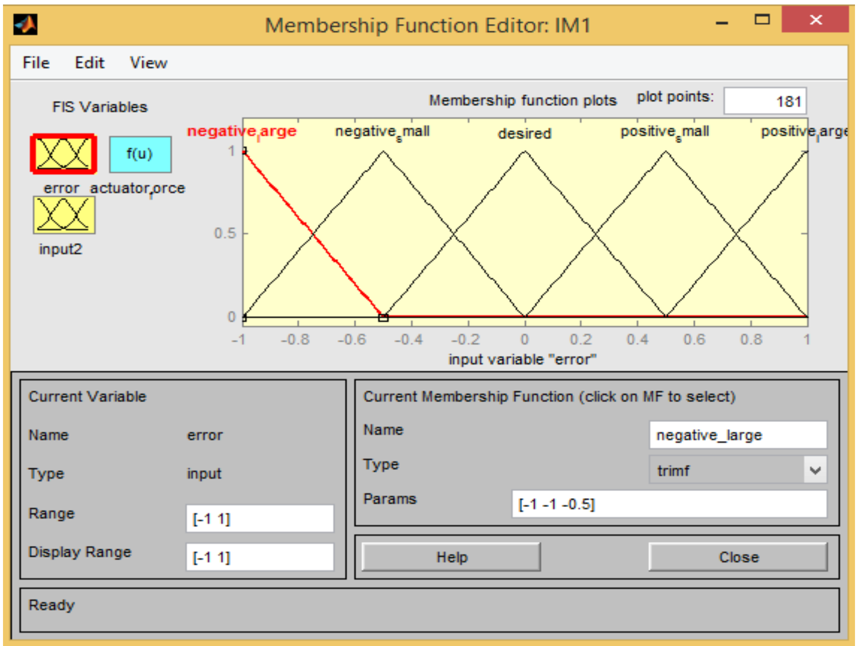

Figure No-4.8 input and output membership function for fuzzy tuned PI controller

Table No-4.1 Rule based for tuning of fuzzy tuned PI and fuzzy logic controller

$\Delta\omega$ / $\Delta\dot{\omega}$	-ve big	-ve small	desired	+ve small	+ve big
-ve big	-ve big	-ve big	-ve big	-ve small	desired
-ve small	-ve big	-ve small	-ve small	desired	-ve small
desired	-ve big	-ve small	desired	+ve small	+ve big
+ve small	-ve small	desired	+ve small	+ve small	+ve big
+ve big	desired	+ve small	+ve big	+ve big	+ve big

Rule base for K_p, K_i, K_d based on fuzzy tuning

4.3 Conclusion:-

Here vector control of traction motor drive is described. Here different controllers are designed namely PID, fuzzy logic and fuzzy PI for comparison w.r.to the performance of the motor.

CHAPTER 5

CONTROLLER DESIGN USING SIMULINK

5.1 Introduction

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time.

A computer simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to .see how the system works. By changing variables in the simulation, prediction may be made about the behaviour of the system. It is a tool to virtually investigate the behaviour of the system. Fig 5.1 shows the various Simulink block of induction motor drive that is to be explained in this chapter.

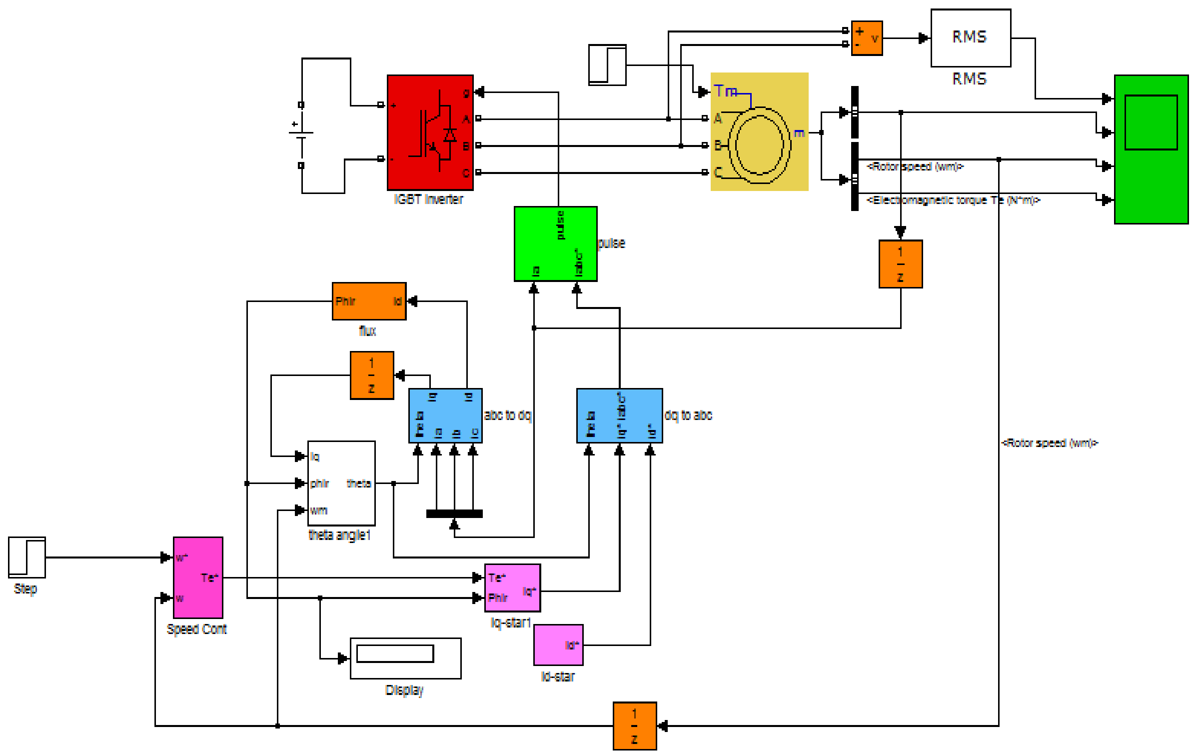

Figure No-5.1 Indirect vector control Simulink block diagram

5.2 Simulink Model Of Hysteresis Current Regulator

The current regulator, which consists of three hysteresis controllers, is built with Simulink blocks. The motor actual currents are provided by the measurement output of the Asynchronous Machine block. The actual motor currents and reference current are compared in hysteresis type relay.

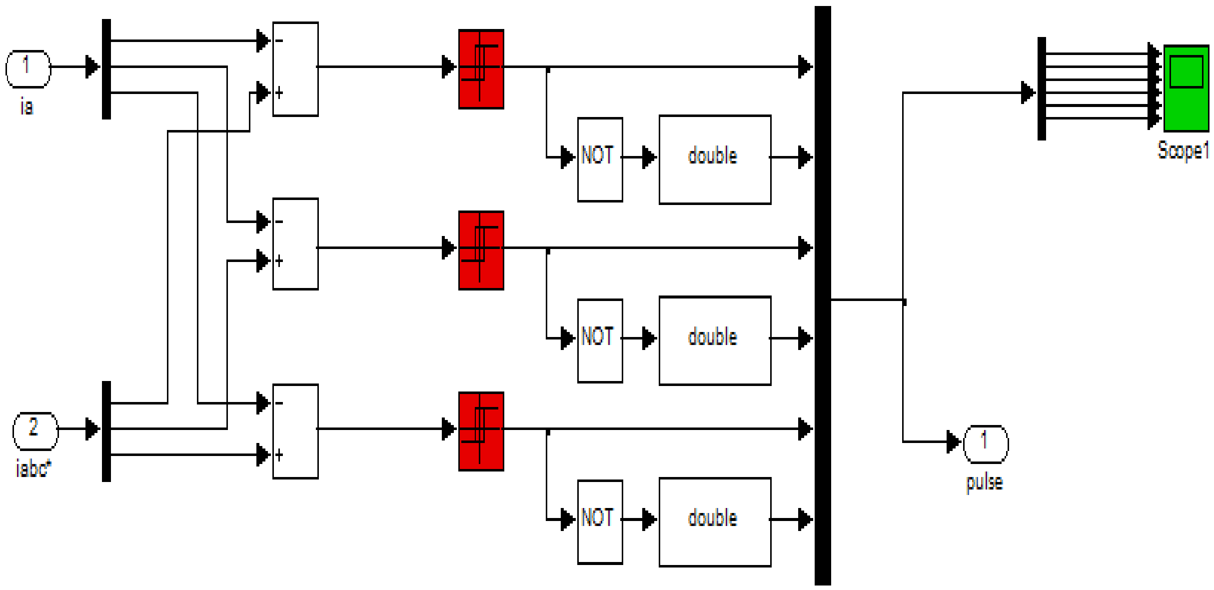

Figure No-5.2 Hysteresis Current Regulator-simulink model

5.3 Universal Bridge:

The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration is selectable from the dialog box. Power Electronic device and Port configuration options are selected as IGBT/Diode and as output terminals respectively. Set the snubber capacitance Cs to infinite to get a resistive snubber.

5.4 Flux Calculation Simulink Model

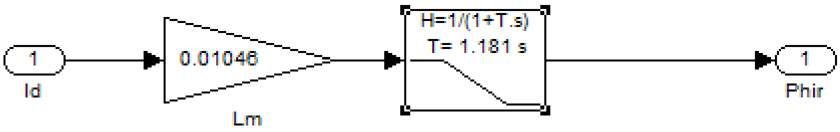

Figure No- 5.3 Flux Calculation Simulink Block

$$\varphi_{dr} = \frac{L_m * i_d}{1+T_r s} \quad (5.1)$$

$$L_r = Ll'_r + L_m \quad (5.2)$$

L_r= 0.000327+0.0106 = 0.010957 H

L_m = 0.0106 H

R_r = 0.00929 Ω

$$T_r = L_r / R_r = 1.181 \text{ sec} \quad (5.3)$$

Put the value of L_m and T_r in flux equation

5.5 Theta Calculation Simulink Model

Theta calculation block is used to calculate the rotor flux position (θ_e).

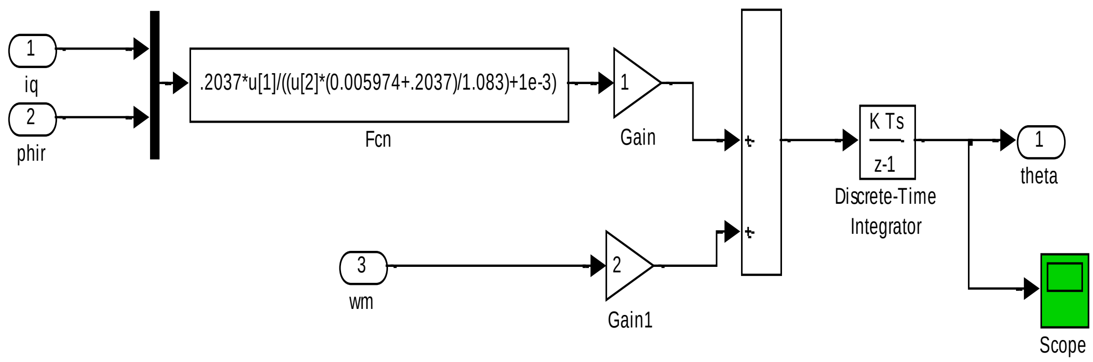

Figure No-5.4 Theta Calculation Simulink block

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \quad (5.4)$$

$$\omega_r = \frac{L_m * i_{qs}}{T_e * \varphi_{dr}} \quad (5.5)$$

$$\omega_{sl} = \frac{P * \omega_m}{2} \quad (5.6)$$

Equation (5.4)-(5.6) used for calculation of theta

5.6 d-q to abc Transformation Simulink Model

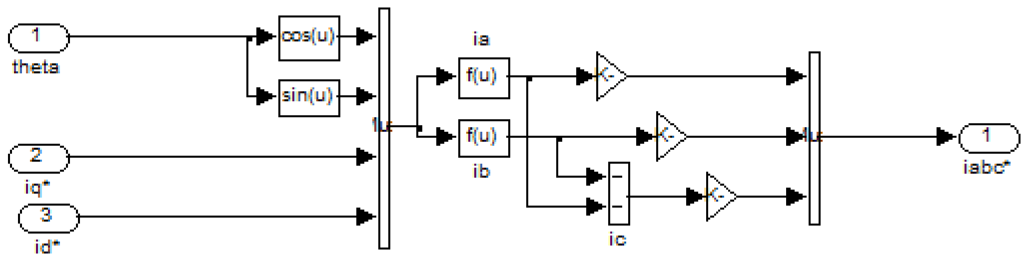

Figure No- 5.6 d-q to abc transformation Simulink Block

$$I_{abc} = Te^{-1} I_{dqo} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_o \end{bmatrix} \quad (5.7)$$

Equation (5.7) sows the dq-abc transformation

5.7 abc to d-q Transformation Simulink Model

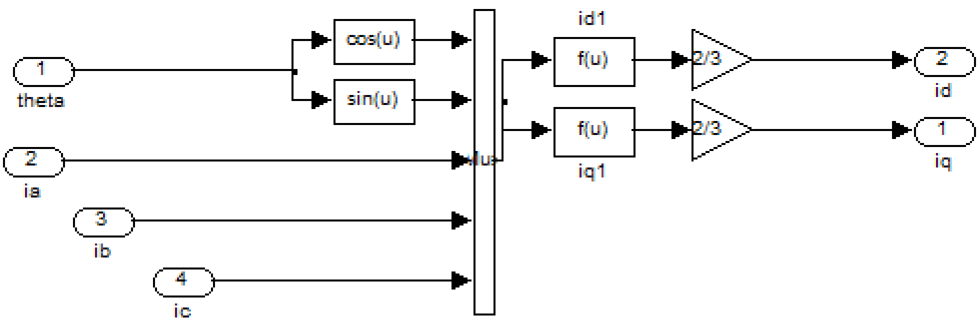

Figure No- 5.7 abc to d-q Transformation Simulink Block

$$I_{dqo} = TI_{abc} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (5.8)$$

Equation (5.8) shows the abc to dq transformation.

5.8 PI Controller

Figure 5.8 shows the Simulink diagram of PI controller. The speed of the drive can be control using PI controller. The difference between the reference speed ω^* and given speed ω is the input of PI controller. To limit the output saturation block is used.

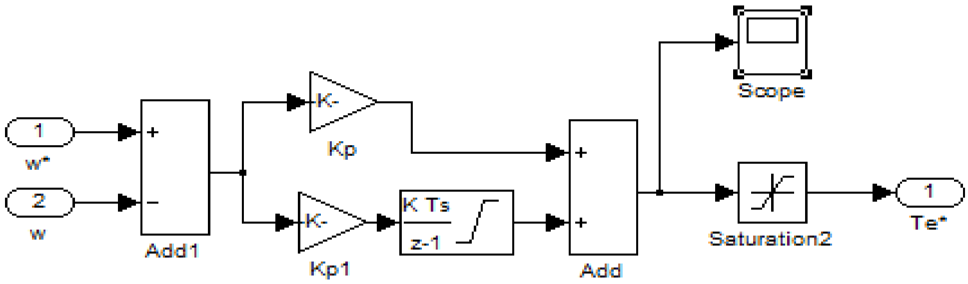

Figure No-5.8 Simulink block of Proportional Integral Controller

There are different method to tuned the PI controller with best possible value of K_p and K_i . Here Zieglar method is use to find the value of K_p and K_i.

5.9 Fuzzy logic controller

Figure 5.9 shows the Fuzzy logic controller Simulink diagram. Fuzzy controller is used in place of PI controller. Difference between the reference speed ω^* and given speedω is the input of fuzzy controller. This gives the torque component.

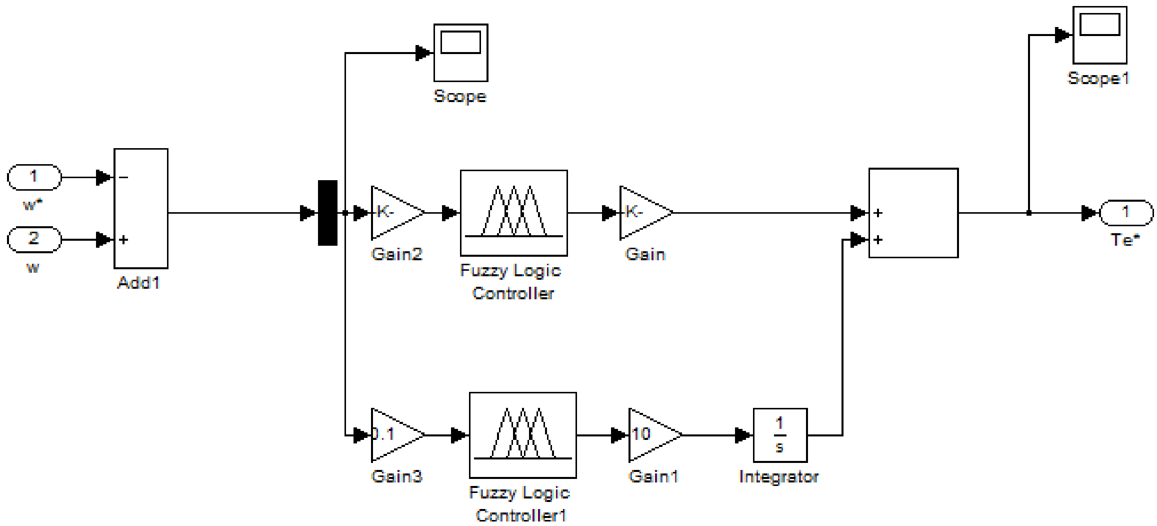

Figure No- 5.9 Fuzzy logic controller Simulink block diagram

5.10 Fuzzy tuned PID controller

Figure 5.10 shows Simulink block of Fuzzy tuned PI controller. Difference between reference speed ω^* and given speed ω is the input of fuzzy controller. Then the output of fuzzy controller is tune with the help of PI controller. This give better tuned result than PI controller.

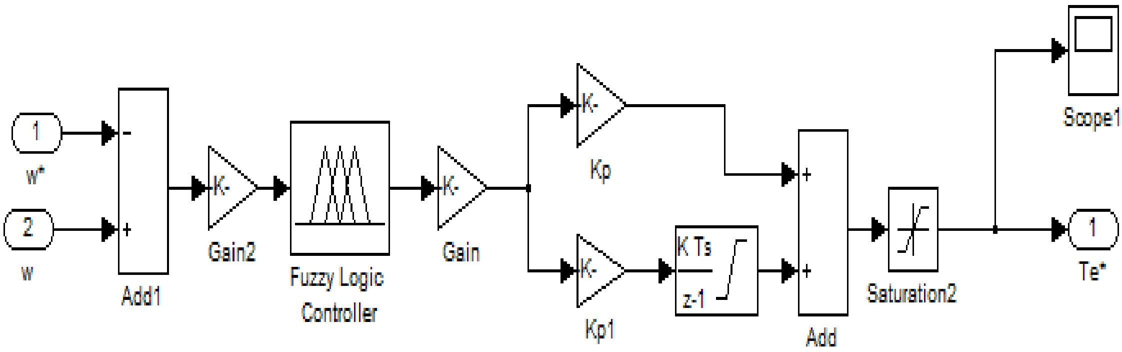

Figure No-5.10 tuned PI Simulink block diagram

5.11 Conclusion

One of the primary advantages of simulation is that they are able to provide users with practical feedback when designing real world systems. This allows the designer to determine the correctness and efficiency of a design before the system is actually constructed. Simulation is extensively used for educational purposes. In this chapter Simulink model of induction motor drives has been presented, different Simulink block such as hysteresis current regulator, flux calculation block, theta calculation block, PI controller, fuzzy controller, fuzzy tuned PID , abc to d-q and d-q to abc has been discussed and explained

CHAPTER 6

SIMULATION RESULTS

6.1 Introduction

There are two big advantages to performing a simulation studies rather than actually design and testing it. The biggest of these advantages one is money. Designing, testing, redesigning, retesting for anything can be an expensive project. Most of the time the simulation testing is cheaper and faster than performing the multiple tests of the design each time.

The second biggest advantage of a simulation studies is the level of detail that you can get from a simulation. A simulation can give you results that are not experimentally measurable with our current level of technology. A simulation can give these results when a problem such as it's too small to measure.

6.2 Implementation In Matlab

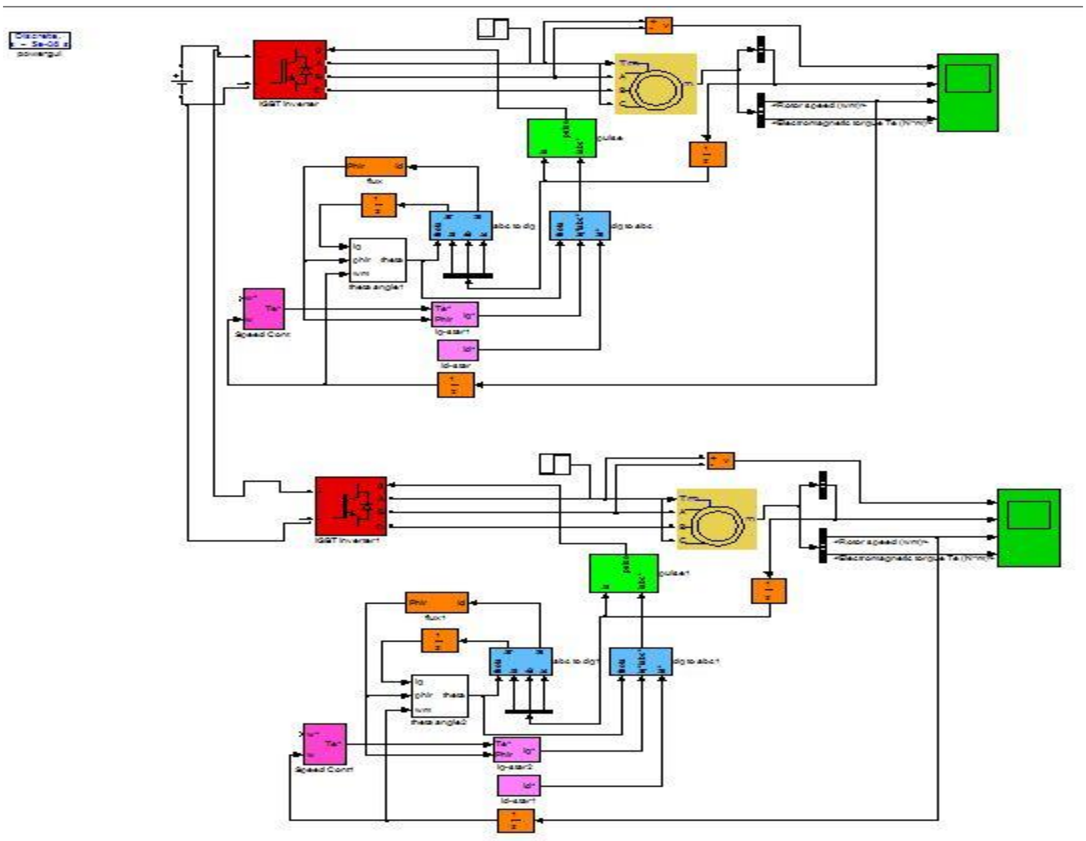

Figure No- 6.1 Simulink block diagram for traction drive connected to DC link voltage

Figure 6.1 shows the complete simulation block for two traction motor. Here two traction motor are connected in parallel. The control of both the motors is same. The motor stator current is provided by the measurement output of the traction motor block. The reference current and the motor current are compared in hysteresis loop controller to generate the switching pulses. The torque and speed are controlled with the help of PI , Fuzzy and Fuzzy tuned PI controller. This simulation has also been carried on the 3-phase 220KW, 2088 rpm (218rad/sec), and 72.5Hz rating squirrel cage induction motor. The rating and the parameter are shown in the appendix.

All the Simulink result shows below are taken at reference speed of 218 rad/sec and the reference torque of 1000 Nm.

6.3 Simulation Result

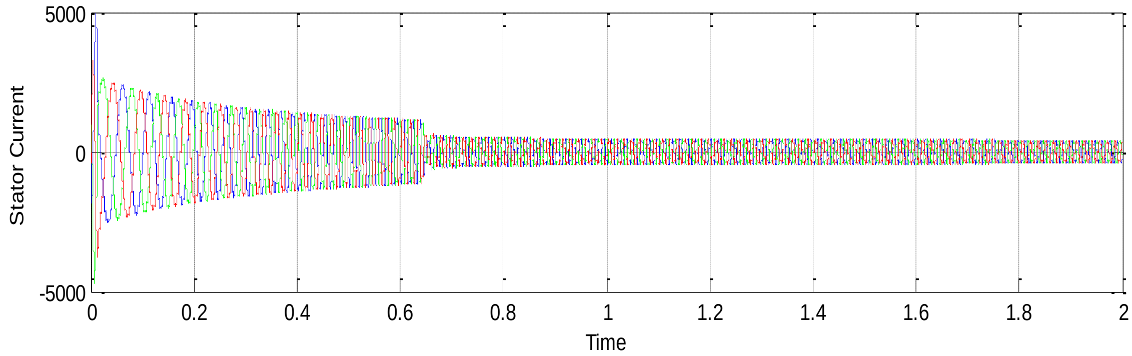

figure No- 6.2 (a)

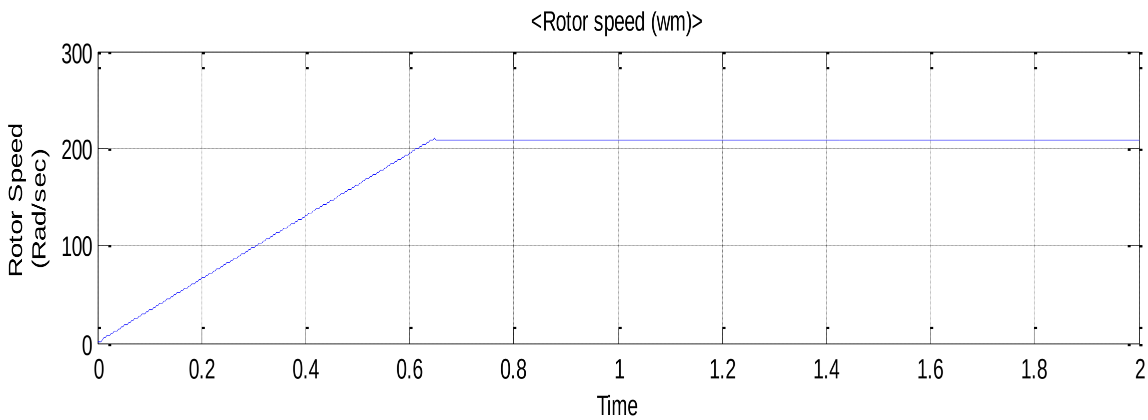

figure No- 6.2 (b)

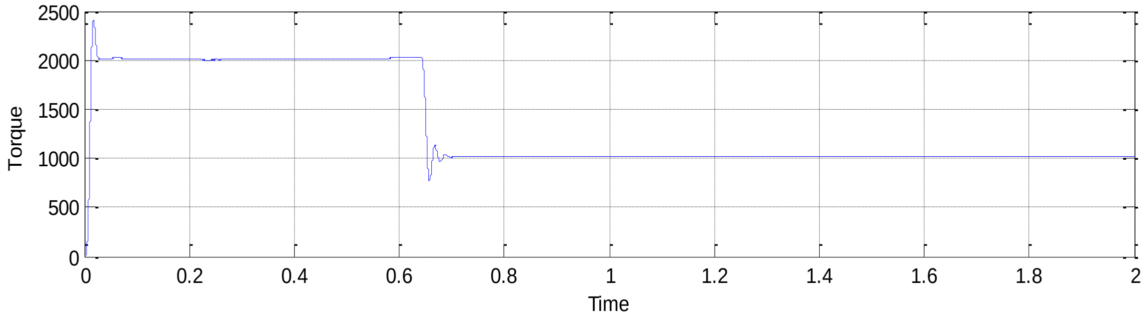

figure No- 6.2 (c)

Figure 6.2 (a) (b) and (c) show the simulink plot of three phase stator current, rotor speed at 218 rad/sec and torque

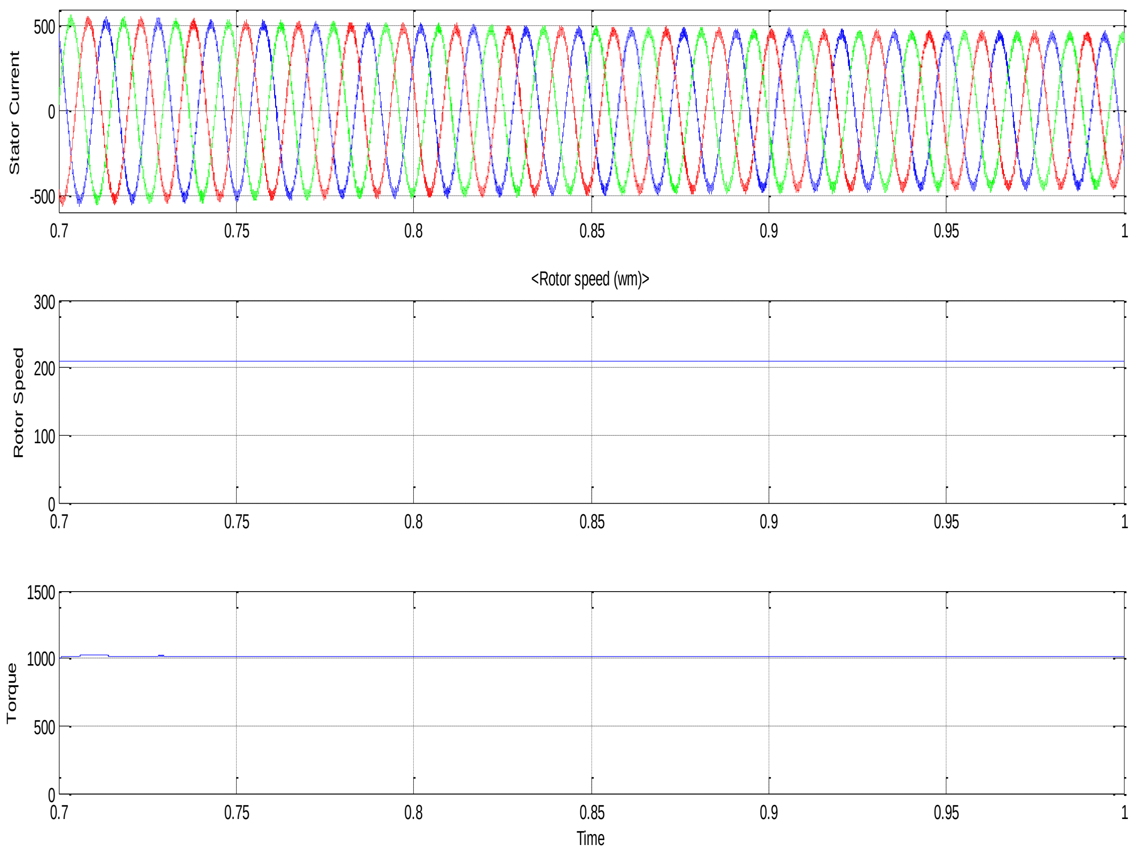

figure No- 6.3 the simulink plot of steady state of three phase stator current, Rotor speed(rad/sec), Torque using PI controller

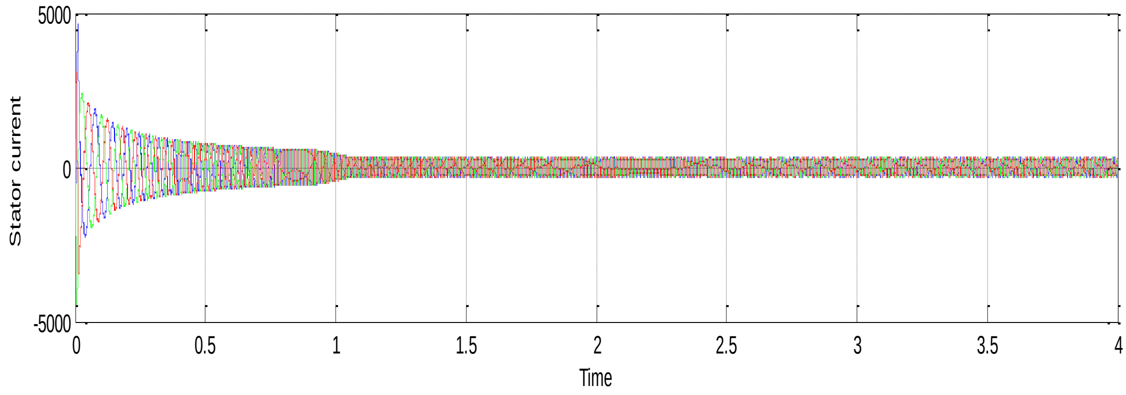

figure No- 6.4 (a)

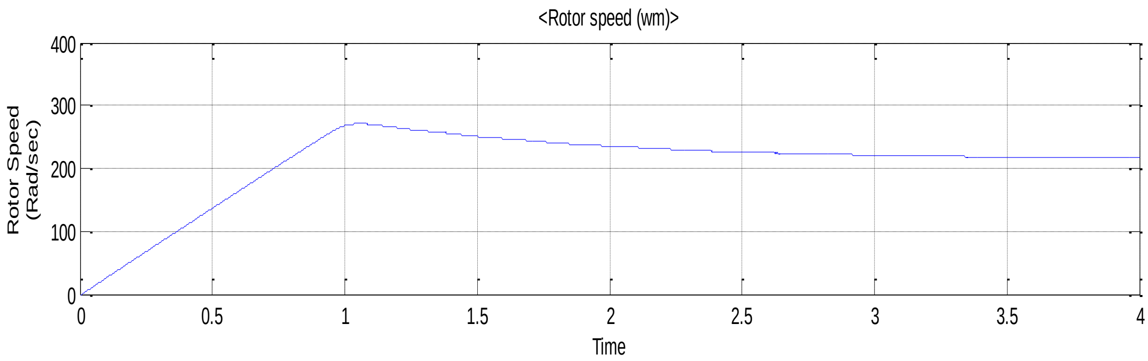

Figure No- 6.4 (b)

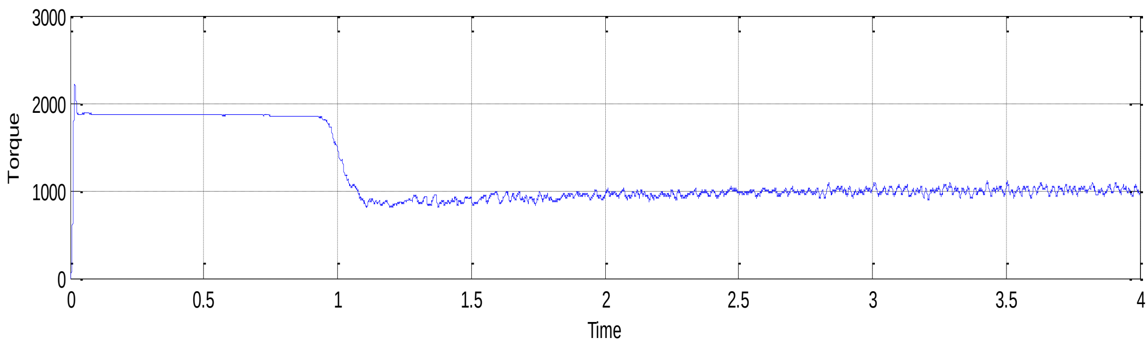

Figure No- 6.4 (c)

Figure No- 6.4 (a) (b) (c) shows the Simulink plot three phase stator current, rotor speed (rad/sec), and torque using Fuzzy logic controlle

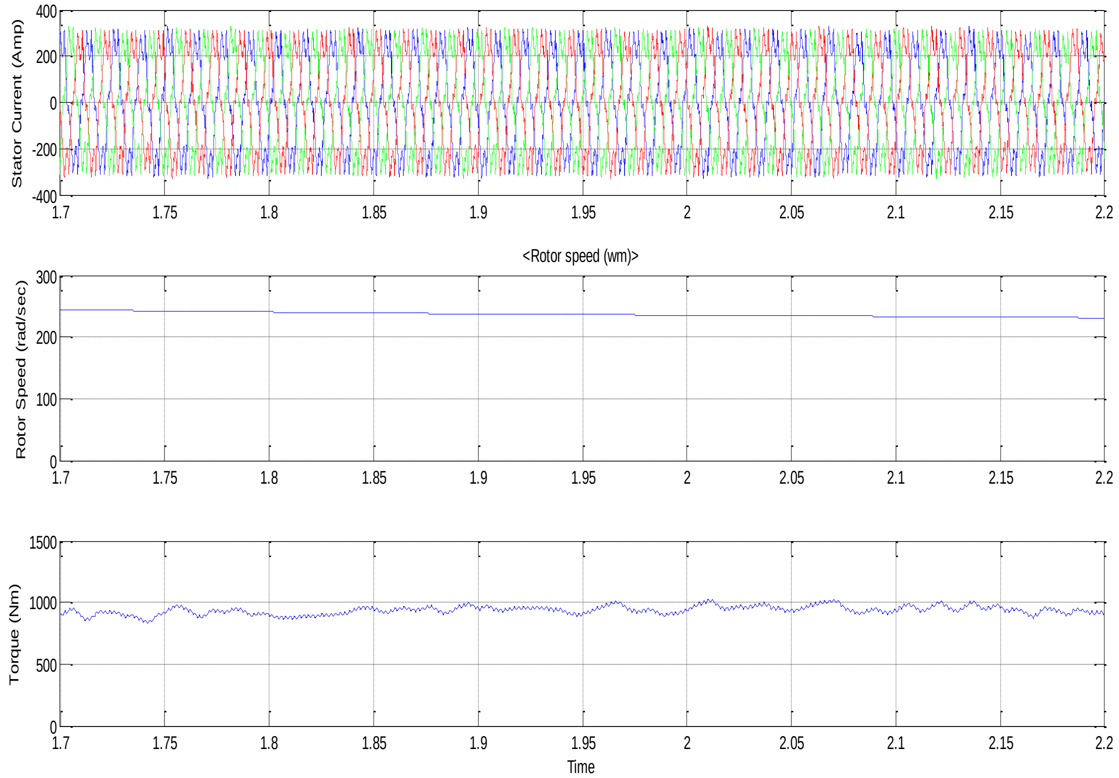

Figure No- 6.5 shows the Simulink plot of steady state of three phase stator current, rotor speed (rad/sec), and torque using Fuzzy logic controller

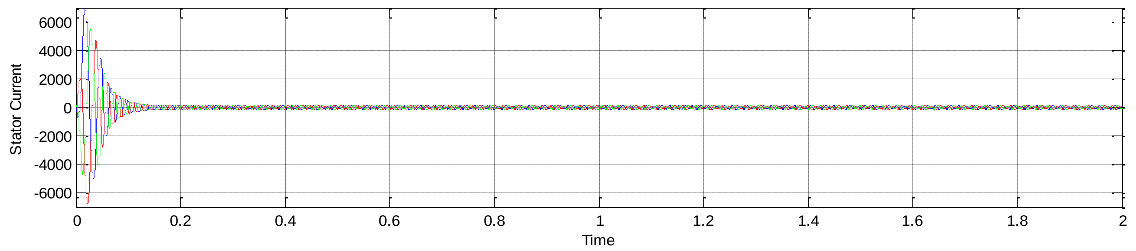

figure No-6.6 (a)

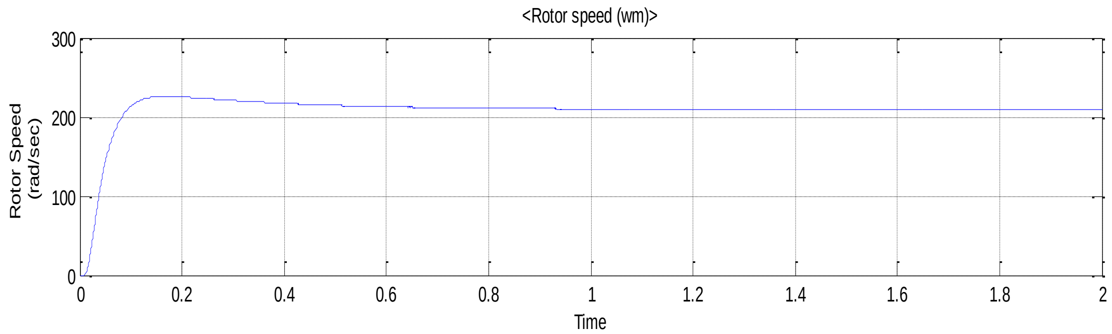

figure No-6.6 (b)

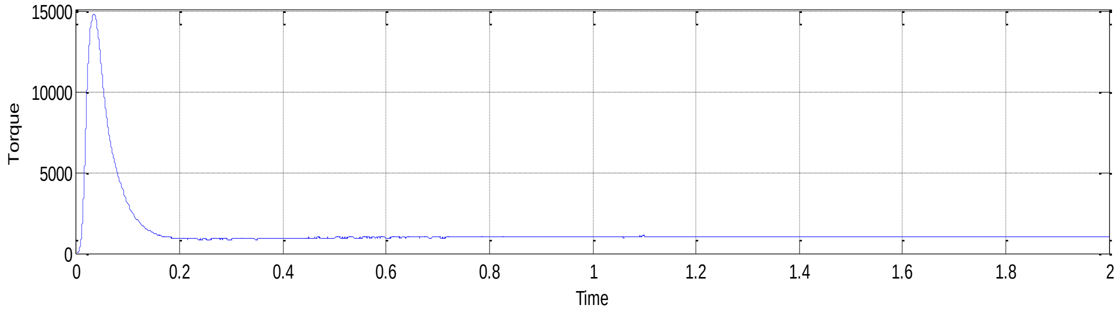

Figure No-6.6 (c)

Figure No- 6.6 (a) (b) (c) shows the Simulink plot three phase stator current, rotor speed (rad/sec), and torque using Fuzzy tuned PI logic controller

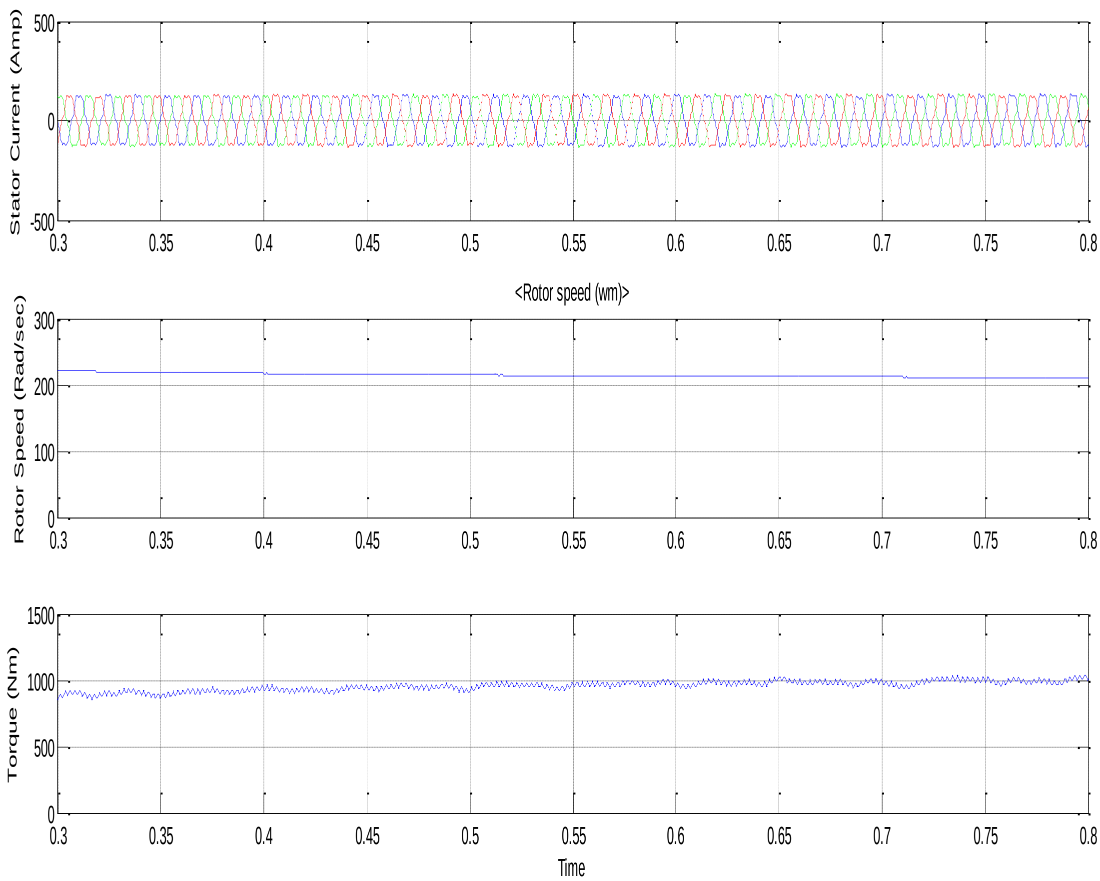

Figure No- 6.7 (a) (b) (c) Simulink plot of steady state of three phase stator current, rotor speed (rad/sec), and torque using Fuzzy tuned PI controller

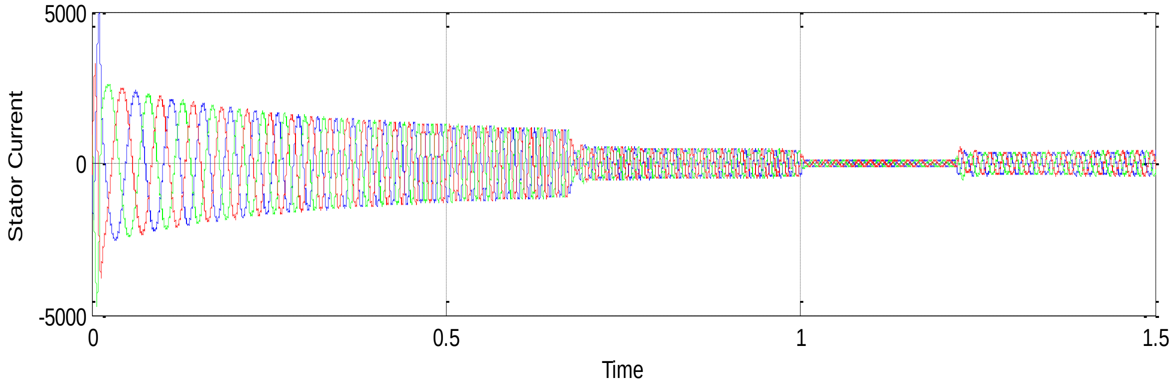

figure No- 6.4 (a)

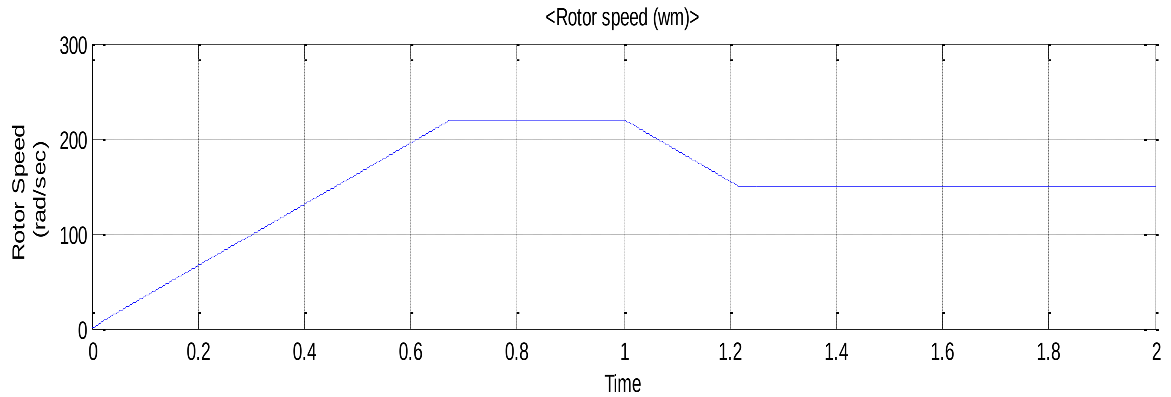

figure No- 6.4 (b)

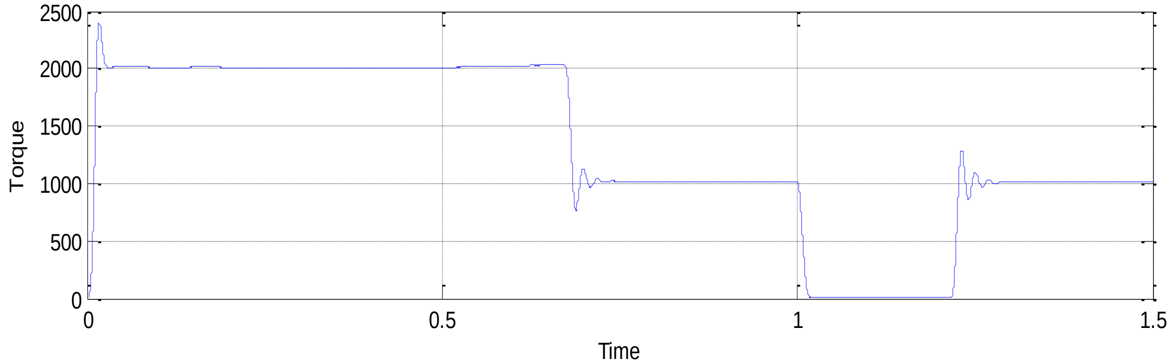

figure No- 6.4 (c)

figure No- 6.8 (a) (b) (c) is Simulink plot of three phase stator Current, Rotor speed, and Torque of step applied at 1 sec of PI controller.

6.3 Analysis of Result:-

(i) Figure 6.2 (a) (b) (c) shows the Simulink result of stator current, rotor speed, and torque of steady and transient state using PI controller of 220 kw traction motor on full load of 1000 Nm. Fig 6.2 (a) show the peak current of 5000 Amp during transient state and settle at 500 Amp. Figure 6.2 (b) show the speed reaches equal to its reference speed 218 rad/sec after 0.7 sec. figure 6.2 (c) show the steady and transient state of torque i.e torque during transient is 2500 Nm and settle at its full load value (1000 Nm) after 0.7 sec.

(ii) Figure 6.3 shows the Simulink plot of steady state of three phase stator current, Rotor speed (rad/sec), and Torque using PI controller. Figure 6.3 shows the stator current 500 Amp, rotor speed 218 rad/sec and torque 1000 Nm of 220 Kw traction motor during steady state on full load of 1000 Nm is applied. Also show the motor is attained its reference speed during steady state in nearly 0.7 sec. and current drawn by motor contain less harmonics (nearly sinusoidal waveform)

(iii) Figure No- 6.4 (a) (b) (c) shows Simulink transient plot three phase stator current, rotor speed (rad/sec), and torque using Fuzzy logic controller. Figure shows that during transient period, the peak stator current of 4500 Amp and peak torque of 2200 N/m.

(iv) Figure 6.5 shows Simulink plot of steady state of three phase stator current, rotor speed (rad/sec), and torque using Fuzzy logic controller. Figure shows the peak current of 400 Amp during steady state. More harmonics are present in stator current when motor will operate at full load of 1000 Nm . Motor attained its steady state near to 1.7 sec

(v) Figure - 6.6 (a) (b) (c) shows the Simulink plot three phase stator current, rotor speed (rad/sec), and torque using Fuzzy tuned PI logic controller during transient . The peak current and torque during transient is 7000 Amp and 15000 Nm respectively. So during starting, motor draws more current but for a very small duration of approximately 0.3s and also large torque can produce. F

(vi) Figure - 6.7 (a) (b) (c) shows the Simulink plot of steady state of three phase stator current, rotor speed (rad/sec), and torque using Fuzzy tuned PI controller of 220 Kw traction motor. It is observed that current during steady state is 220 A and less harmonics are present in current in steady state than the fuzzy logic controller. Further, steady state can be achieved faster than fuzzy and PI controller. Table no

6.1 shows the comparison between different type of controller i.e PI, Fuzzy and Fuzzy tuned PI.

(vii) Figure 6.8 (a), (b) and (c) shows Simulink plot of stator current, rotor speed, and torque using PI controller when there is a speed perturbation is given after 1 sec. In starting speed is 218rad/sec and after 1 sec (150 rad/sec)and figure 6.8 (a) (b) (c) also shows that motor attained its steady state after 0.7 sec and remain constant stator current, rotor speed (218 rad/sec) and torque (1000 Nm) up to 1 sec and time between 1 sec to 1.3 sec is transient period, after 1.3 sec motor attained its reference value of 150 rad/sec and load torque of 1000 Nm and remain in steady state.

TABLE NO-6.1 COMPARISON OF DIFFERENT CONTROLLER USED

TYPE OF CONTROLLER USED	PEAK OVERSHOOT IN TORQUE(NM)	PEAK OVERSHOOT IN STATOR CURRENT(AMP)	SETTLING TIME OF ROTOR SPEED (SEC)
PI	2500	5000	0.7
FUZZY LOGIC	2200	4500	1.7
FUZZY TUNED PI	15000	6000	0.3

6.4 Conclusion

In this chapter Simulink plot of PI, Fuzzy and Fuzzy tuned PI controller have been studied. From table 2 we conclude that the peak overshoot in three phase stator current is case of Fuzzy controller but settling time is more. In case of fuzzy tuned PI the transient state is improved i.e motor attain its steady rapidly state in 0.3 sec but the over shoot in torque and current is more. We give the load perturbation in PI controller because there is fewer harmonic in steady state and observe the result.

CHAPTER 7

CONCLUSIONS AND FURTHER SCOPE OF WORK

7.1 Conclusion

This thesis presents the algorithm for indirect vector control of traction motor drive using hysteresis current control. The simulation studies are carried out on 220 Kw traction motor.

Simulink model of traction motor drives has been presented, and different Simulink block such as hysteresis current regulator, flux calculation block, theta calculation block, , abc to d-q and d-q to abc, PI controller, fuzzy logic controller, fuzzy tuned PI controller has been discussed and explained. To improve the performance of the system, advanced AI technique like Neurofuzzy can be used.

In indirect vector control scheme, the speed control using fuzzy tuned PI attains its steady state much faster than the Fuzzy logic controller and PI controller but the overshoot in the torque and current waveform is large. So depending upon the needs of a particular application the appropriate control scheme can be chosen.

7.2 Further Scope

A number of control techniques are available today that can be implemented to improve the performance of the traction motor. The control of the traction drive should be such as to maintain power factor on supply side as unity and minimize the harmonics. For this different configurations of converters like H-Bridge converter, can be studied.

Besides using the hysteresis current control techniques, the SVPWM technique can also be studied to obtain better control in the circuit. A synchronous current control voltage PWM can also be used.

Sensorless Speed vector control is an emerging technology. A number of speed estimation techniques are being reviewed. However, very low-speed operation including start-up at zero frequency remains a challenge. Besides Sensorless Vector Control Scheme, Direct Torque Control Scheme can also be studied and the response of two techniques can be compared.

APPENDIX

Motor Parameters

The simulation has also been carried on the 3-phase 220KW, 1750rpm (218rad/sec), and 72.5Hz rating squirrel cage induction motor with following parameters:

Stationary reference frame

Y- Connected

Power output = 220 Kw

Voltage rating = 1040 V

R_s (stator resistance) = 0.01485Ω

R_r (rotor resistance) = 0.009295Ω

L_s (stator inductance) = 0.0003027H

L_r (rotor inductance) = 0.0003027H

L_m (magnetizing inductance) = 0.010.46H

J (moment of inertia) = 3.1Kg m^2

P (number of poles) = 4

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