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Modeling and Implementation of fuzzy vector control for Induction motor Drive

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Abstract: This thesis presents a methodology for implementation of a rule based fuzzy logic controller applied to a closed loop vector speed control induction motor. The induction motor is modeled using a dq axis theory. The designed Fuzzy Logic controller's performance is weighed against with that of PI controller. The proc of Fuzzy Logic controllers (FLCs) over the conventional controllers are: (i) they are economically advantageous to develop (ii) a wide range of operating conditions can be covered using FLCs, and (iii) they are easier to adopt in terms of natural language .Another advantage is that, an initial approximate set of fuzzy rules can be impulsively refined by self-organizing fuzzy controller. For Vector speed control of the induction motor, the reference speed has been used and the control architecture includes some rules. These rules portray a nonchalant relationship between two inputs and an output. The errors are evaluated according to the rules in accordance to the defined membership functions. The membership functions and the rules have been defined using the FIS editor given in MATLAB. Based on the rules the surface view of the control has been recorded. The results obtained by using conventional PI controller and the designed fuzzy logic controller has been studied and compared.

KEY WORDS:

Mathematical model, Induction motor Drive, vector control, fuzzy logic controller,membership function, PI controller, self-organizang.

1.INTRODUCTION:

Induction motor (IM) can be considered as the workhorse of the industry because of its special features such as low cost, high reliability ,low inertia, simplicity and ruggedness. Even today IMs especially the squirrel cage type ,are widely used for single speed applications rather than variable speed applications due to the complexity of controlling algorithm of IM variable speed drives. However, there is a great interest on variable speed operation of IM within the research community mainly because IMs can be considered as a major industrial load of a power system. It is well known fact that electric energy consumption of the appliances can be reduced by controlling the speed of the motor [1].

However the highly nonlinear nature of induction motor control dynamics demands strenuous control algorithms for control of speed. The conventional controller types that are used for controlling the torque and speed are may be numeric or neural or fuzzy. The controller types that are regularly used are Proportional Integral (PI), Proportional Derivative (PD), Proportional Integral Derivative (PID), and Fuzzy logic controller or blend between them. The PID controller offers very efficient solution to numerous control problems in the real world. If the PID controllers are tuned properly they can provide robust and reliable control. This very feature has made PID controller exceedingly popular in industrial applications. The only problem associated with the use of conventional PI, PD and PID controllers in speed control of induction motors is the complexity in design arising due to the non-linearity of induction motor dynamics. Variable speed drives for induction motors require wide operating speed range along with fast torque response irrespective of the variation in load, there by leading us towards more advanced methods of control so as to meet real demand.

Advanced control based on artificial intelligence technique is called intelligent control[2]. The fuzzy logic controller is the most efficient controller because of its non-linearity handling features and it is independent of plant model. The technique to embody human-like thinking into a control system is fuzzy control. A fuzzy controller can be designed to emulate human deductive thinking that is the process people use to infer conclusions from their knowledge .Fuzzy control has been primarily applied to the control of process through linguistic descriptions.

Fuzzy vector control is usually realized with PWM controller in rotating (d-q) reference. In fuzzy vector control stator current is controlled instantaneously which reduces the torque ripples and improves overall performance of machine. In this paper fuzzy vector control of IM is implemented and verified in MATLAB SIMULINK environment.

This paper is organized as follows: section 2 presents the modeling of IM. Section 3 develops the implementation of vector control. Section 4 describes the fuzzy logic controller. Section 5 provides the simulation results and analysis of fuzzy vector controlled IM drive. Section 6 concludes the paper.

2. MATHEMATICAL MODELING

Mathematical modeling is required for simulation and analysis of Drive system.IM equations are represented in d-q reference frame[3].

2.1 Axes Transformation

Consider a symmetrical three –phase induction machine with stationary as-bs-cs axis at 2π/3 angle apart. Our goal is transform the three-phase stationary reference frame (as-bs-cs) variables into two-phase stationary reference frame (d^s - q^s) variables [2, 3].Assume that d^s - q^s

Axes are oriented at θ angle as shown in fig .1.

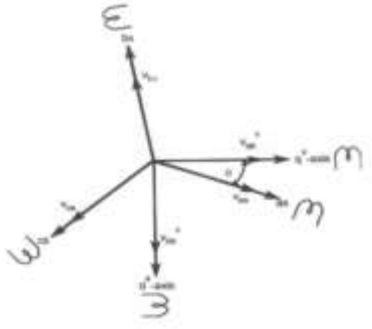


Fig.1. 3-Φ to 2-Φ transformation

The voltages v_{as}, v_{bs}, v_{cs} can be resolved into v_{ds}^s and v_{qs}^s components and can be represented in the matrix form as:

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 120^o) & \sin(\theta - 120^o) & 1 \\ \cos(\theta + 120^o) & \sin(\theta + 120^o) & 1 \end{bmatrix} \begin{bmatrix} v_{qs}^s \\ v_{ds}^s \\ v_{0s}^s \end{bmatrix} \qquad (1)$$

The corresponding inverse relation is as follows

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

Here v_{os}^{s} is the zero sequence component, convenient to set θ=0, so that q^{s}-axis is aligned with as-axis. Therefore ignoring zero sequence components[2],it can be simplified as

$$v_{qs}^{s} = \frac{2}{3}\, v_{as} - \frac{1}{3}\, v_{bs} - \frac{1}{3}\, v_{cs} \qquad (3)$$

$$v_{ds}^{s} = \frac{-1}{\sqrt{3}}\, v_{bs} + \frac{1}{\sqrt{3}}\, v_{cs} \qquad (4)$$

Equations 3 and 4 consecutively called as Clark transformation

Fig.2. shows the synchronously rotating d^{e} - q^{e} axes, which rotate at synchronous speed w_{e} with respect to the d^{s} - q^{s} axes and the angle θ= $w_{e}\, t$ .The two phase d^{s} - q^{s} windings are transformed into hypothetical windings mounted on the d^{e} - q^{e} axes. The voltages on the d^{s} - q^{s} axes can be transformed into the d^{e} - q^{e} frame as follows.

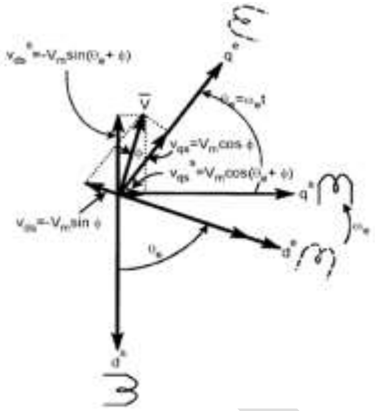


Fig.2.stationary frame to rotating reference frame transformation

$$v_{qs}^{e} = v_{qs}^{s}\cos\theta_{e} - v_{ds}^{s}\sin\theta_{e} \qquad (5)$$

$$v_{ds}^{e} = v_{ds}^{s}\cos\theta_{e} + v_{qs}^{s}\sin\theta_{e} \qquad (6)$$

Equation 5 and 6 consecutively called as park equation

Again resolving the rotating reference frame parameters into stationary frame, the relation are

$$v_{qs}^{s} = v_{qs}^{e}\cos\theta_{e} + v_{ds}^{e}\sin\theta_{e} \qquad (7)$$

$$v_{ds}^{s} = -v_{qs}^{e}\sin\theta_{e} + v_{ds}^{e}\cos\theta_{e} \qquad (8)$$

Equations 7 and 8 are known as inverse park equations.

2.2 Induction motor Dynamic model

The following assumptions are made to derive the dynamic model

1. Uniform air gap

2. Balanced rotor and stator windings, with sinusoidally distributed mmf.

3. Inductance vs. rotor position is sinusoidal.

4. Saturation and parameter changes are neglected.

Fig.4. shows the d-q equivalent circuits for a three symmetrical squirrel cage motor in synchronously rotating frame with zero sequence component neglected [2, 4, 5, 7]. From the dynamic equivalent circuit, the induction motor parameters can expressed in matrix equation (9),assuming that the rotor bars in squirrel cage induction motor are shorted out and the rotor voltages equal to zero.

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{qr} \\ v_{dr} \end{bmatrix} = \begin{bmatrix} R_S + PL_S & w_e L_s & L_m P & w_e L_m \\ -w_e L_s & R_s + L_s P & -w_e L_s & L_m P \\ L_m P & (w_e - w_r) L_m & R_r + PL_r & (w_e - w_r) \\ -(w_e - w_r) L_m & PL_m & -(w_e - w_r) L_r & R_r + PL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \qquad (9)$$

Where R_s and R_r are the stator and rotor resistance per phase respectively, Ls and Lr are the stator and rotor inductances per phase respectively p=d/dt operator, we and w_r are the synchronous and rotor speed respectively.

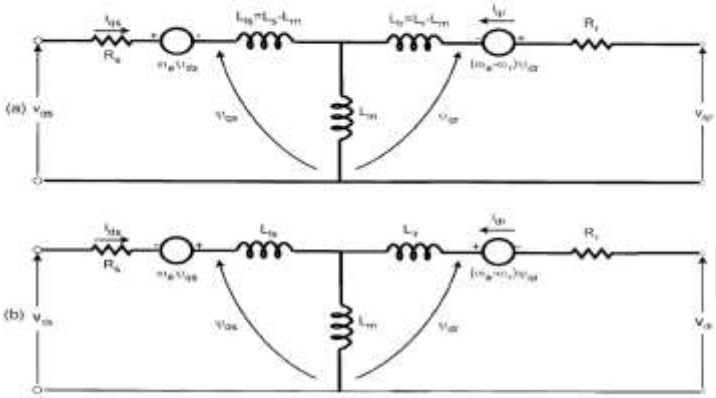


Fig.3. Dynamic d^e-q^e equivalent circuit of machine (a) q^e-axis circuit (b) d^e-axis circuit

3. VECTOR CONTROL

3.1.Principle of vector control

The fundamentals of vector control implementation can be explained with the help of Fig.4

Where the machine model is represented in synchronously rotating reference frame. The inverter has unity gain, that is ,it generates the currents i_a,i_b,i_c as dictated by corresponding command currents i_a^*, i_b^*, i_c^* from the controller. The machine terminal phase currents i_a,i_b and i_c are converted into i_{ds}^s and i_{qs}^s components by 3-phase to 2-phase transformation. These are then converted to synchronously rotating reference frame by unit vector control components cosθ_e and sinθ_e before applying them to the d^e-q^e machine model as shown. The controller makes two stages of inverse transformation, as shown so that the control currents i_{ds}^* and i_{qs}^* correspond to the machine currentsi_{ds} and i_{qs} respectively. In addition the unit vector assures correct alignment of i_{ds} currents with flux vector ψ_r and i_{qs} perpendicular to it as shown in Fig.4.

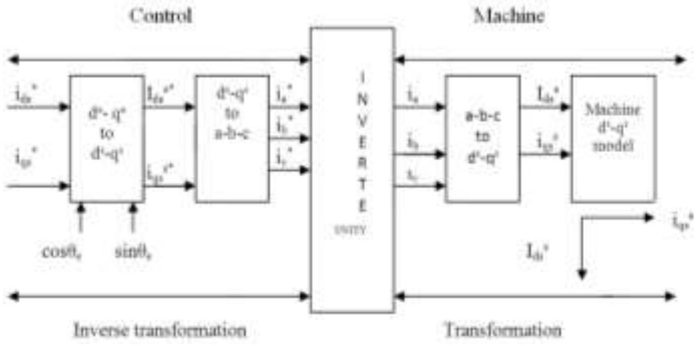


Fig.4.vector control implementation principle with d^e-q^e reference model

3.2. Direct or Feedback vector control

The basic block diagram of the direct vector control method for PWM voltage inverter is shown in Fig.5.we developed strategy for rotor flux oriented direct vector control by manipulating equations derived from d^e-q^e equivalent circuit.

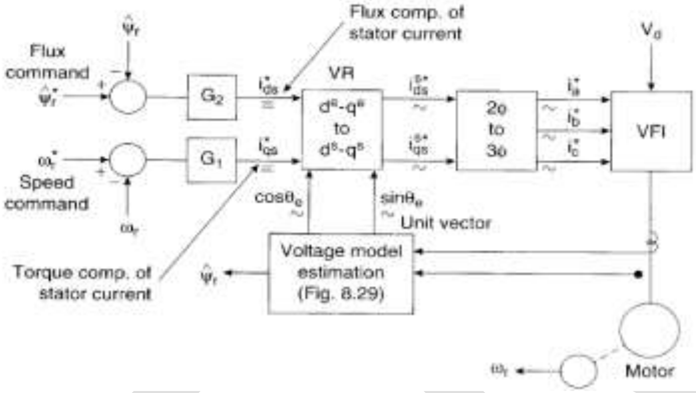


Fig.5.Blockdiagram of direct or feedback vector control

The key estimation equations can be summarized as follows

$$\Psi_{dr}^{s} = \hat{\Psi}_r \cos\theta_e \qquad (10)$$

$$\Psi_{qr}^{s} = \hat{\Psi}_r \sin\theta_e \qquad (11)$$

$$\cos\theta_e = \frac{\Psi_{dr}^{s}}{\Psi_r} \qquad (12)$$

$$\sin\theta_e = \frac{\Psi_{qr}^{s}}{\Psi_r} \qquad (13)$$

$$\Psi_r = \sqrt{\Psi_{dr}^{s^2} + \Psi_{dr}^{s^2}} \qquad (14)$$

Where vector $\overline{\Psi_s}$ is represented by magnitude Ψ_s, signals $\cos\theta_e$ and $\sin\theta_e$ have been plotted in correct phase position in Fig.6(b).These unit vector signals when used for vector rotation in Fig.5.give a ride of current i_{ds} on the d^e-axis (direction of) $\overline{\Psi_s}$ and i_{qs} on the q^e-axis as shown .

At this condition ψ_{qs} =0, and $\psi_{ds}=\psi_s$ as indicated in the figure. when the i_{qs} polarity is reversed by the speed loop the i_{qs} position in the Fig.6(a).is also reverse giving negative torque. The generation of unit vector signals from feedback flux vectors gives the name direct vector control [2, 6, 7, 8, 9, and 10].

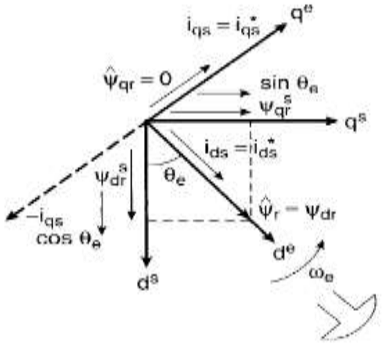


Fig.6 (a).

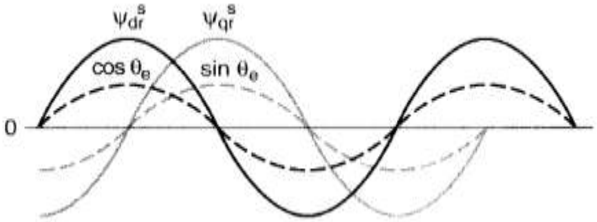


Fig.6 (b).

Fig. 6(a).d^s-q^s and d^e-q^e phasors showing correct rotor flux orientation.(b) plot of unit vector signals in correct phase position

4. FUZZY LOGIC CONTROLLER

D.D.Neema, R.N.Patel, A.S.Thoke represented the fuzzy set theory and applications of FLC in IM[3].Fuzzy logic controller has found robust and is suitable for controlling the system. The fuzzy theory has the better performance than that a PID controller.[11,12,13,14,15].Fig.7 shows the structure of fuzzy logic controller.

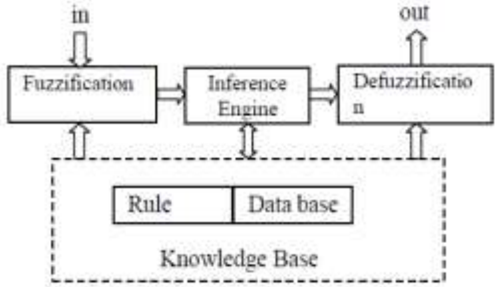


Fig.7.structure of fuzzy logic controller

4.1.Structure of fuzzy logic controller

The structure of fuzzy logic controller in general contains four main parts which are:

1. Fuzzification
2. Knowledge Base
3. Inference Engine
4. Defuzzification

The input variables go through the fuzzification interface that inform to linguistic variables. The rule base holding the decision-making logic used to infer the fuzzy output, a defuzzification converts fuzzy output into signal output.

4.1.1.Fuzzification

A fuzzification interface ,the fuzzy control initially converts the crisp error and its rate of change in error into fuzzy variables ,then they are mapped into linguistic labels Membership functions are defined within the normalized range and associated with each label.NB(Negative Big),NS(Negative Small),ZE(Zero),PB(Positive Big),PS(Positive small).Five MFs are chosen for e(pu) and ce(pu) and five for output. Thus maximum 5x5=25 rules can be formed as tabulated below in Table.1.

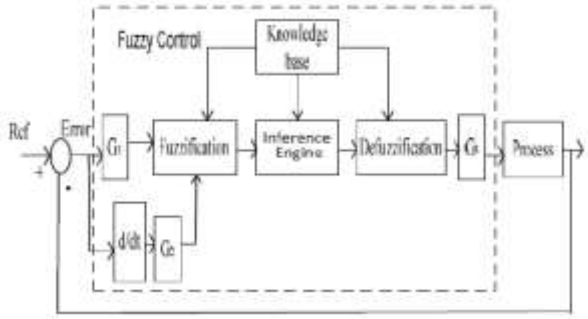


Fig.8.Connection diagram of fuzzy logic controller

4.1.2.Knowledge Base

A knowledge base (a set of IF and THEN rules) which contains the definition of fuzzy subsets, their membership functions, universe of discourse and the whole of the rules of inference to achieve good control.

4.1.3.Inference Engine

An inference mechanism (also called inference engine or fuzzy inference module),which is heart of fuzzy control, poses the capacity to feign the human decisions and emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.

4.1.4.Defuzzification

A defuzzification interface, which converts the conclusions of interface mechanism into actual inputs for the process. In this work; Centre Of Area (COA) is used as a defuzzification method, which can be presented as:

$$X^{crisp} = \frac{\sum_{i=1}^{n} x_i \mu_A(x_i)}{\sum_{i=1}^{n} \mu_A(x_i)}$$

Where

n= no. of discrete variables

x_i=The value of discrete element

$\mu_A(x_i)$=The corresponding MF value at the point x_i

4.2 Design of fuzzy speed controller

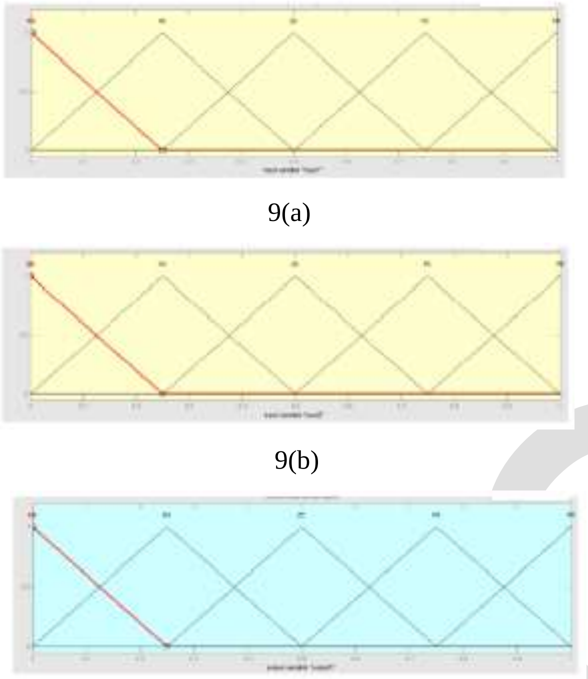
The error e(pu) and change in error ce(pu) and output u are represented as linguistic values as follows.

4.2.1 Fuzzy Number

1.PB(Positive Big)2.PS(Positive Small)3.ZE(Zero)4.NB(Negative Big)5.NS(Negative Small)

4.2.2 Membership Function

In this paper triangular shaped functions were selected. The number and membership function is shown in Fig.9.



9(a)

9(b)

9(c)

Fig.9 (a).Membership function of error (b) Membership function of change in error
(c)Membership function of output

4.2.3Quantization levels

Fuzzy sets of FLC shows the corresponding rule table for speed control. There are 5x5=25 rules are possible as follows.

	Δe					
E	O/P	NB	NS	ZE	PS	PB
NB		NB	NB	NS	NS	ZE
NS		NB	NS	NS	ZE	PS
ZE		NS	NS	ZE	PS	PS
PS		NS	ZE	PS	PB	PB
PB		ZE	PS	PS	PB	PB

Table.1.Rules for fuzzy logic controller

The fuzzy inference process to calculated fuzzy output. The Mamdani's method that found suitable for DC machine or Induction machine. The Mamdani's method converts fuzzy output value into the crisp value of the output variable. The centre Of Area (COA) defuzzification method is generally used.

5.SIMULATION AND ANALYSIS

Simulation is performed in MATLAB-SIMULINK to investigate the performance of fuzzy vector controlled induction motor drive. In this section electromagnetic torque, speed and stator currents of proposed motor drive has been studied and compared with PI vector controlled induction motor drive

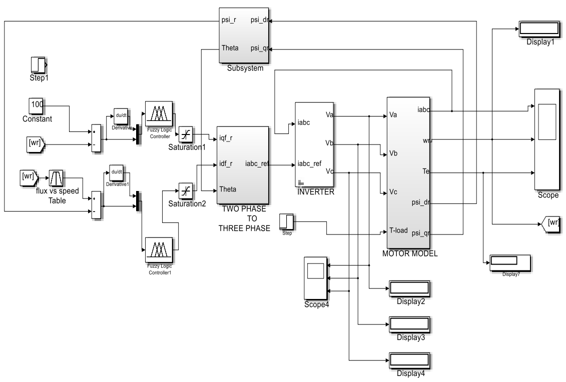


Fig10.Block diagram of fuzzy vector controlled induction motor drive

Fig.11. shows the electromagnetic torque response of both fuzzy and PI controlled Induction motor drive. We can say that the torque response of fuzzy vector controlled IM drive has less transient ripples or less overshoot and it is smoothly following the load torque and it reaches the desired torque. The torque response of PI vector controlled IM drive has spikes or transient ripples when the motor is starting and suddenly loaded condition.

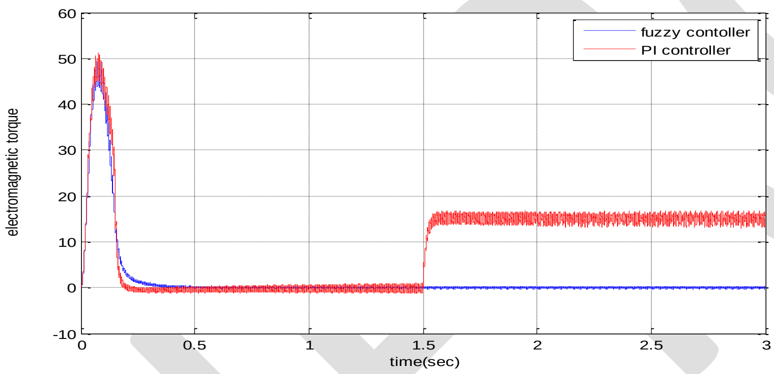


Fig.11. Torque response of both fuzzy and PI vector controlled IM drive.

The bad effect of that spiky transient torque is that the motor is forced to draw a higher current especially, when we have load torque which has to be applied for certain time and then switched off and so on and if the motor is over load even for short time, the drive will effect dangerously.

Fig.12.shows the NO load speed response of both fuzzy and PI vector controlled induction motor drive. We noticed that while using fuzzy vector control the overshoots obtained in speed response are very less as compared to the case when PI controller is used. We can also noticed that fuzzy vector controlled IM drive reaches desired speed in 0.5 sec where as PI controlled drive takes 1 sec to reach the desired speed.

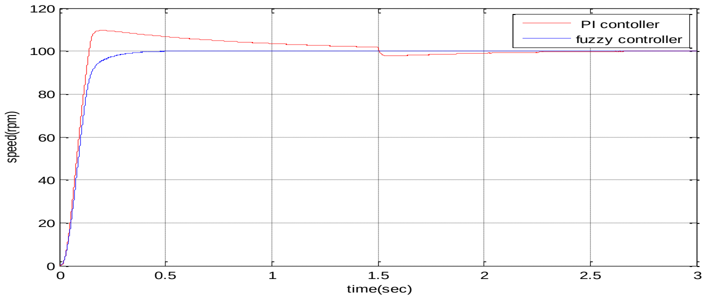


Fig.12.Speed response of both fuzzy and PI vector controlled IM drive.

Fig.13. shows the speed response of IM drive at loaded condition. The IM drive speed set as 100 rad/sec and the load of 15Nm is applied at 1.5 seconds.The PI vector controlled drive speed is decreased during loaded condition. The fuzzy vector controller has very less effected as compared to the PI controlled drive .And also we noticed that fuzzy vector controlled drive gives slight decrease in steady state speed response.

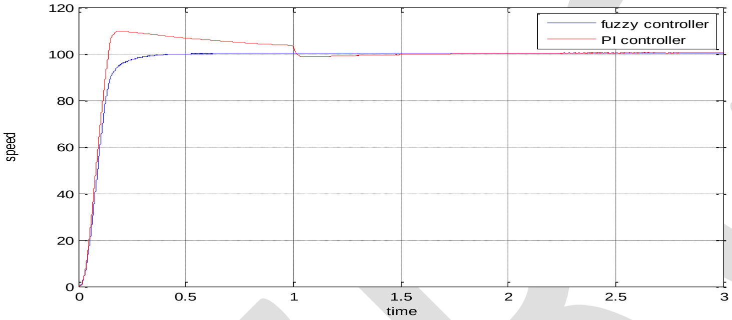


Fig.13.speed response of both fuzzy and PI vector controlled IM drive on load.

Fig.14. shows three phase currents of fuzzy vector controlled IM drive fed space vector pulse width modulated inverter at step change in 0-15Nm

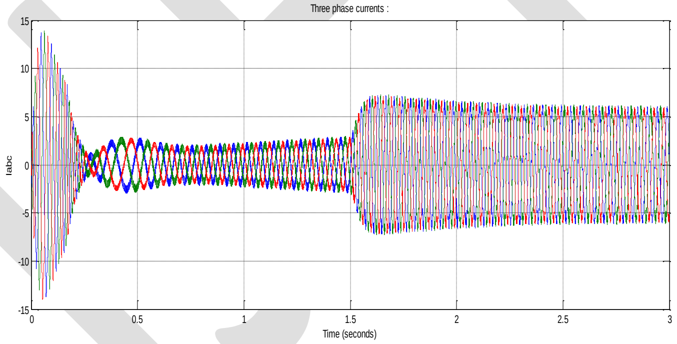


Fig.14.Three phase currents of fuzzy vector controlled IM drive at step change in 0-15 Nm

Fig.15.shows the simulation results for the IM drive speed 100 rad/sec and 6 rad/sec under constant load torque 15 Nm ,like DC machine speed control is possible in four quadrants.

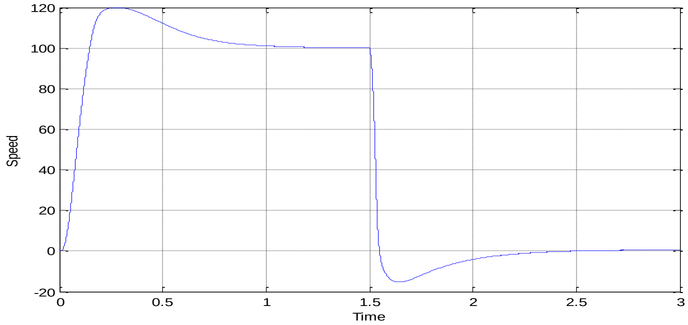


Fig.15 (a). speed response of fuzzy vector controlled IM drive.

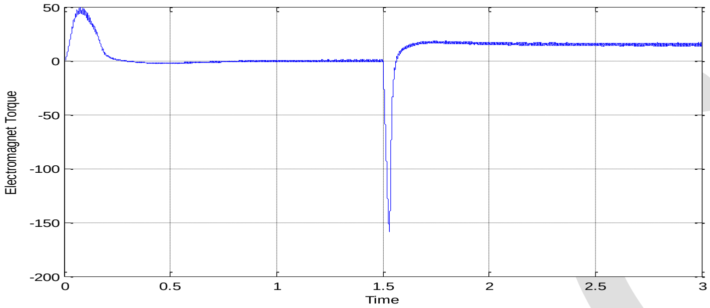


Fig.15 (b).torque response of fuzzy vector controlled IM drive.

As mentioned before, and from the simulation results the fuzzy vector controlled IM drive having good dynamic response, speed and torque of fuzzy vector controlled drive are separately controlled like DC machine which is not possible with scalar control.

6.CONCLISION

Fuzzy logic controller shows fast response with vector controlled IM drive. This controller give maximum torque over the entire speed range. Linguistic rules control the speed .This speed controller shows fast response smooth performance and high dynamic response with changing and transient condition. The fuzzy vector controller proves robustness against rotor resistance variation and insensitivity to load torque disturbance as well as faster dynamics with negligible steady state error at all dynamic operating conditions. Simulation results have shown correct stator flux oriented control behavior and speed tracking performance.

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