AI BASED VECTOR CONTROL OF INDUCTION MOTOR

K.Padukolai
Electrical and electronics engineering
Sri Vidya college of Engineering and Technology, India
padukolaieee@gmail.com

Abstract- **In modern high performance ac drives usually the direct vector control schemes are used to achieve high dynamic operation. Vector control method has permitted fast transient response by decoupled torque and flux control. Now this scheme has become implementable with the advent of fast computing devices. The current regulative pulse width modulation inverter is regulating the output of the inverter current and also reduced the harmonics level The conventional controllers have trouble meeting a wide range of tracking performance even when proper vector control is achieved. The conventional controller's performance is severely degraded when detuning occurs. The conventional controllers are replaced by fuzzy controller. The over all performance of the drive can be improved by using AI based controller. It reduced the tuning effects associated with conventional controller and that will meet speed-tracking requirements even when detuning occurs. The fuzzy controller performance became superior to conventional controllers**

***Keywords*—vector conytol; conventional PI control; Fuzzy logic control;stability analysis;speed control.**

I. INTRODUCTION

Induction motor drives with cage type, is most commonly used in industry for constant speed application. These machines are very economical, rugged in construction and reliable Induction motor is becoming popular in variable speed applications.

The various control strategies for the control of the inverter-fed induction drive are scalar control and vector control. Scalar control provides good steady state response but poor dynamic response. This poor dynamic response can be attributed to variations in the air gap flux linkages. Scalar control is easy to implement, but because of the inherent coupling effect gives sluggish response and the system is easily prone to instability because of a higher-order system effect. For example, when the torque is increased by incrementing the frequency, the flux tends to decrease. This decrease in flux is compensated by feeding an additional voltage to the sluggish flux loop. These problems [B.K.Bose, 1997] can be solved by using vector or field oriented control

In the field oriented, control induction motor can be controlled as a separately excited dc motor. This brought a reaissance in the high-performance control of ac drives. In the case of dc motor torque and flux can be controlled separately. This performance can be extended to Induction motor by using direct vector control [Peneria 'et al'1998],

The performance of a dc motor can be extended to an induction motor if the machine control is considered in a synchronously rotating reference frame (d^e-q^e), where the sinusoidal variables appear as dc quantities in steady state. To understand the vector control, we have to be aware of dynamic d-q model of an induction machine. High performance induction machine drives require fast torque response below base frequency and constant power above base frequency. AC motor drives are used in industrial and process applications requiring high performances. In high performance drives, the motor speed should closely follow the specified reference trajectory regardless of any load disturbances and parameter variations. In order to achieve high performance, Field Oriented Control [Yen Shin Lai'1998] (direct Vector Control) is used.

The salient features of vector control are:

The frequency ωe of the drive is not directly controlled as in scalar control. In vector control frequency as well as the phase are controlled indirectly with help of unit vector.

Vector control normally working in stable region. Otherwise it automatically comes back to the stable region.

The torque control is like that of a DC machine.

Like a dc machine, speed control is possible in four quadrants without any additional control equipments.

This paper discusses the simulation of variable speed induction motor using fuzzy logic based vector control. The motor control issues are traditionally handled by fixed gain P and PI controllers.. This problem can be solved by several adaptive control techniques. The design of adaptive control techniques [M.A.Dental. 'et al'1997] depends on exact system mathematical model. But it is o ften difficult to develop an accurate system mathematical model due to unknown load variation and system disturbances.

The above problems can be by replacing traditional controller overcome by fuzzy logic controller [Brian Herber1995].

II. VECTOR CONTROL OF INDUCTION MOTOR

A. *DC DRIVE ANALOGY*

Ideally, a vector controlled induction motor drive operates like a separately excited DC drive, in a DC machine, neglecting the armature reaction effect and field saturation, the developed torque is

$T_e = K_t' \ I_a \ I_q$ (1)

Where I_a = armature current

I_f = field current

K'_t =torque constant

The construction of a dc machine is such that the field flux Ψ_f produced by the current I_f is perpendicular to the armature flux Ψ_a, which is produced by armature current I_a the space vectors, which are stationary in space, are orthogonal or decoupled in nature. This means that when torque is controlled by controlling a I_a, the flux Ψ_f is not affected. When the field current If is controlled, it affects the field flux Ψ_f only, but not the Ψ_a flux.

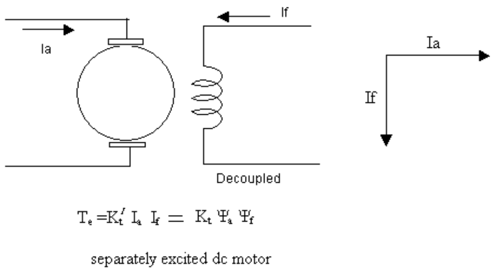

Fig. 1. separately excited dc motor

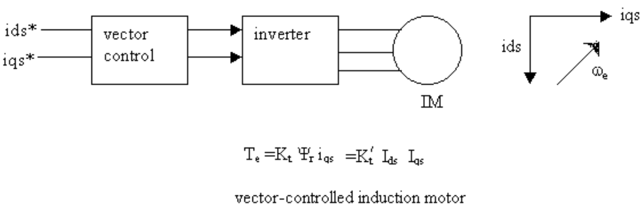

Fig. 2. vector control of induction motor

In vector control, ids is analogous to field current If and iqs is analogous to armature current Ia of a dc machine. The torque can be expressed as

$T_e = K_t' \ I_{ds} \ I_{qs}$ (2)

Where I_{qs} = torque component

I_{ds} = field component

This means that when i_{qs}* is controlled, it affects the actual iqs current only, but does not affect the flux ψ_r .similarly, when ids* current is controlled, it controls the flux only and does not affect the iqs component of current.

B. PRINCIPLES OF VECTOR CONTROL:

Representing machine model in a synchronously rotating reference frame by considering that inverter is having unity current gain. And it generates i_a, i_b and i_c currents depending upon the i_a^*, i_b^* and i_c^* command currents of the controller. The machine terminal phase currents i_a, i_b and i_c are converted to i_{ds}^s and i_{qs}^s by three phase to two-phase transformation. These are converted to synchronously rotating reference frame by three unit vector components $\cos\theta_e$ and $\sin\theta_e$. The control currents i_{ds}^{*} and i_{qs}^{*} correspond to the Machine control currents i_{ds} and i_{qs}. And also, the unit vector assures the correct alignment of i_{ds} current with the flux vector $\overline{\Psi}_r$ and i_{qs} perpendicular to it.

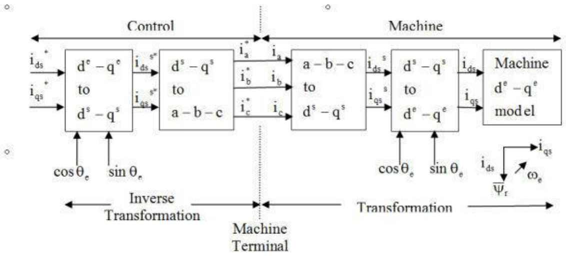

Fig. 3. vector control of induction motor

C. DIRECT OR FEED BACK CONTROL

Fig. 4 represents the block diagram of a direct vector control method for PWM voltage fed inverter drive. The control parameters i_{ds}^{s*} and i_{qs}^{s*} which are dc values in synchronously rotating reference frame converted to stationary frame by Using unit vectors generated from flux vector signals ψ_{dr}^s and ψ_{qr}^s.

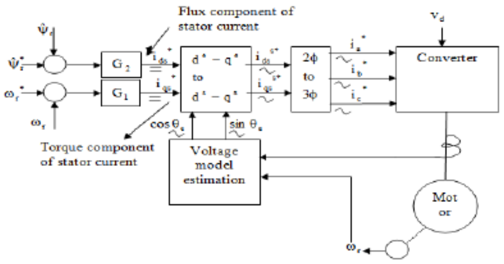

Fig. 4. Direct vector control block diagram with rotor flux orientation

The torque component of current i_{qs}^* is generated from the speed control loop through i_{qs}. Aligning of current i_{ds} in the direction of flux $\hat{\psi}_r$ and the current i_{qs} perpendicular to it is explained in Fig. 5. $d^e - q^e$ Will rotate at synchronous speed ω_e with respect to stationary frame $d^s - q^s$. The angular position of the d^e axis with respect to the d^s axis is θ_e.

By maintaining the amplitude of the rotor flux (Ψr) this means when i_{qs} is controlled, it affects the actual i_{qs} current only, but does not affect the flux Ψ_r. Similarly, when i_{ds} is controlled, it controls the flux only and does not affect the i_{qs} component of current.

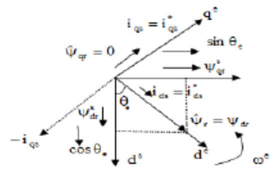

Fig. 5. $d^s - q^s$ and $d^e - q^e$ phasors & correct rotor flux

$$\psi^s_{dr} = \hat{\psi}_r \cos\theta_e \qquad (3)$$
$$\psi^s_{qr} = \hat{\psi}_r \sin\theta_e$$
$$\hat{\psi}_r = \sqrt{\psi^{s^2}_{dr} + \psi^{s^2}_{qr}}$$

D. AXIS TRANSFORMATION

The direct method of control the electrical angle is measured from the direct axis rotor flux ($\Psi_{dr}{}^s$), quadrature axis rotor flux ($\Psi_{qr}{}^s$) and rotor flux ($\Psi\hat{}_r$).

$$\Psi\hat{}_r = \mathrm{sqrt}\left((\Psi_{dr}{}^s \,\hat{}\, 2) + (\Psi_{qr}{}^s \hat{}\, 2)\right)$$

$$\mathrm{Cos}\theta e = \Psi_{dr}{}^s / \Psi\hat{}_r \qquad (4)$$

$$\mathrm{Sin}\theta e = \Psi_{qr}{}^s / \Psi\hat{}_r$$

$$i_{ds}{}^{s*} = \cos\theta_e\, i_{ds}{}^* - \sin\theta_e\, i_{qs}{}^*$$

$$i_{q\,s}{}^{s*} = \cos\theta_e\, i_{ds}{}^* + \sin\theta_e\, i_{qs}{}^* \qquad (5)$$

afterwards, the stationary variables are converted to phase variables using (2) to generate the three current commands for current regulated pulse width modulation inverter.

$$i_{as}{}^{s*} = \sqrt{(2/3)}\;\; i_{ds}{}^{s*}$$
$$i_{bs}{}^{s*} = \sqrt{(2/3)}*(-0.5\, i_{ds}{}^{s*} + \sqrt{(3/2)}\, i_{qs}{}^{s*}) \qquad (6)$$
$$i_{cs}{}^{s*} = \sqrt{(2/3)}*(-0.5\, i_{ds}{}^{s*} - \sqrt{(3/2)}\, i_{qs}{}^{s*})$$

E. CONVENTIONAL CONTROLLERS

1) Proportional controller

The proportional controller produces an output signal which is proportional to the input signal i.e. error. The equation describing the proportional controller is

$$U(t) = k_c\, e(t)$$
$$U(s) = k_c\, E(s) \qquad (7)$$
$$K_c = 100/PB$$

Where k_c = controller gain
PB = proportional band
E = error
U = perturbation in controller output signal from the base value corresponding to the normal operating conditions

2) Proportional integral controller

To remove the steady state error in controlled variable of a process, an extra amount of intelligence must be added to the proportional controller. The extra intelligence is the integral (or) reset action. The PI controller produces a output signal consisting of two terms- one proportional to error signal and other proportional to the integral of error signal. The equation describing a PI controller is

$$U(t) = k_c\, [e(t) + 1/T_1 \textstyle\int e(t)\, dt] \qquad (8)$$

$$U(s) = k_c\, [1 + 1/T_{1(s)}]\, E(s)$$

Where T_1 is integral (or) reset time

II. FUZZY LOGIC CONTROLLER

In recent years the fuzzy logic has become popular in many applications of electrical drives and control, where classical PI controllers were previously used. Several design techniques exist to tune the classical PI controller parameters, but they can be time consuming and moreover fixed controller settings cannot usually provide good dynamic performance over the whole operating speed range of the drive. [Longya xu 'et al'1993.

A. FUZZY LOGIC

Fuzzy logic (FL) is one of the artificial intelligent techniques. Fuzzy logic unlike Boolean logic, deals with problems that have fuzziness or vagueness.

A fuzzy set theory is based on fuzzy logic, where in a particular object has a degree of membership in a given set that may be anywhere in the range of 0 (completely not in the set) to 1 (completely in the set). For this reason, FL is often defined as multi-valued logic, compared to bi-valued Boolean logic [B.K. Bose, 1986].

B. FUZZY SYSTEM

A fuzzy inference system (or fuzzy system) basically consists of a formulation of the mapping from a given input set to an output set .

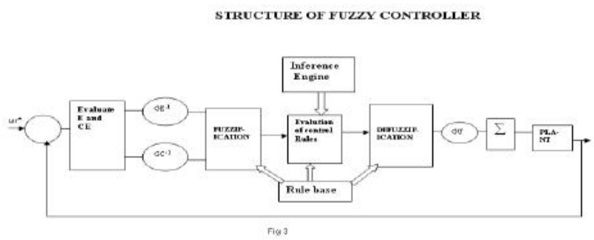

Fig. 6. Structure of fuzzy controller

The operation of fuzzification converts the actual input values into linguistic values or fuzzy sets fuzzy inference define as mapping from input fuzzy sets to output fuzzy sets based on the fuzzy IF-THEN rules and the compositional rule of inference and knowledge base contains information on fuzzy sets and a rule base with a set of linguistic conditional Statements based on expert knowledge. With the given inputs, fuzzy inference computes the fuzzy set C'_i ,having membership function $\mu_{c'i}(z) = \min[\mu_{Ci}(z)\,,\ \tau_i]$, induced by each rule , and aggregates all output fuzzy sets to obtain the global fuzzy output

$$\mu_{out}(z) = \max_i\{\min[\mu_{Ci}(z) , \tau_I]\}.$$

Finally the output fuzzy set $\mu_{out}(z)$ is converted into a crisp output value. This operation, called defuzzification, may be performed by several methods

C. SINGLETON FUZZIFICATION

Interprets an input a_0 as a fuzzy set with the membership function $\mu_A(a)$ equal to zero except at the point a_0 where $\mu_A(a_0)$ equals to one.

D. FUZZY IMPLICATION

It is a fuzzy set S with $\mu_s(x,y) = \mu_{A \longrightarrow B}(x,y) = \mu_A(x) * \mu_B(y)$ where A,B are fuzzy set on x,y respectively. When "*" represents a minimum operator, it implies that the conclusion is no more certain than the premise.

E. Normalization

Keeping all the universe of discourse fixed, the fuzzy system can be turned at its input and output with normalizing gains, making design easier and more flexible.

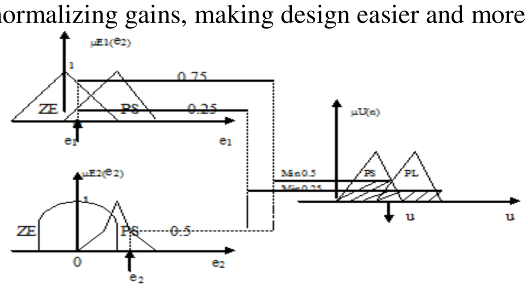

Fig. 7. Single rule fuzzy system using mamdani method

Fuzzification process maps them to associated fuzzy sets with membership values: e1 is mapped in to the fuzzy set representing "ZE" with the membership values of 0.75 and mapped in to the fuzzy set representing "PS" with the membership values of 0.25;

If e1 is ZE and e2 is PS, then u is PS;

If e1 is PS and e2 is PS, then u is PL;

F. FLC DESIGN FOR AN IM:

In this work two types of fuzzy controllers are used.

- Fuzzy speed controller.
- Fuzzy flux controller.

For the proposed FLC [Nasir 'et al'2002] , 'd' axis currents and the inner loop controller of flux of the IM drive are realized by incremental P fuzzy regulator. 'q' axis currents and the outer loop controller of speed of the IM drive are realized by incremental PI fuzzy regulator.

1. Fuzzy speed controller

The inputs to the speed controller are the speed error $e_\omega(n) = \omega_r^*(n) - \omega_r(n)$ between the reference and the actual speed , and the change of speed error $\Delta e_\omega(n) = e_\omega(n) - e_\omega(n-1)$ between two consecutive sampling time instants. The output variable of the speed controller is the reference of 'q' axis stator current component i_{qs}^* . The input and output linguistic variables of the three fuzzy controllers have been quantized in the following subsets [Cerruto 'et al' 1997].

NB- Negative big ; NS – Negative small; ZE – Zero ; PS – Positive small PB – Positive big ; NV – Negative ; PV – Positive ; NC – No change PM – Positive medium

TABLE I. SPEED CONTROLLER FUZZY RULES

ERROR (VS) CHANGE IN ERROR

de\e	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NVB	NB	NM	NS	Z
NM	NVB	NVB	NB	NM	NS	Z	PS
NS	NVB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PVB
PM	NS	Z	PS	PM	PB	PVB	PVB
PB	Z	PS	PM	PB	PVB	PVB	PVB

The membership function for fuzzy speed control is following

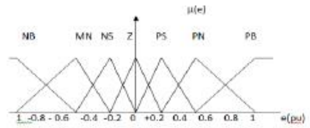

Fig. 8. Input membership function (Speed error)

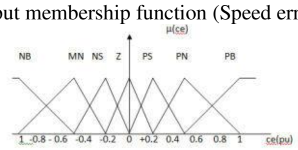

Fig. 9. Input membership function (Change in Speed error)

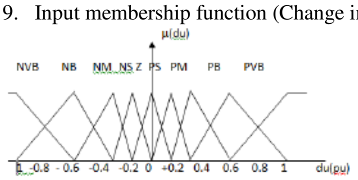

Fig. 10. Output membership function

2. Fuzzy flux controller

The inputs to the flux controller are the flux error $e_\Psi(n) = \Psi_r^*(n) - \Psi_r(n)$ between the reference and the actual speed , and the change of flux error $\Delta e_\Psi(n) = e_\Psi(n) - e_\Psi(n-1)$ between two consecutive sampling time instants. The output variable of the flux controller is the reference of 'd' axis stator current component i_{ds}^* .

The membership functions used for the input and outputs are shown in fig 8 and 9. The triangular membership functions are used for all the fuzzy set of the input vectors and all the fuzzy sets of the output vectors.

TABLE II. FLUX CONTROLLER FUZZY RULES

ERROR (VS) CHANGE IN ERROR

de\e	NB	NS	Z	PS	PB
NB	NVB	NVB	NB	NS	Z
NS	NVB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PM	PVB
PB	Z	PS	PB	PVB	PVB

The membership function for fuzzy flux control is following.

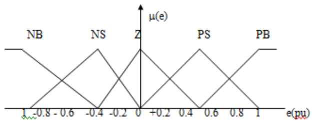

Fig. 11. Input membership function (Flux error)

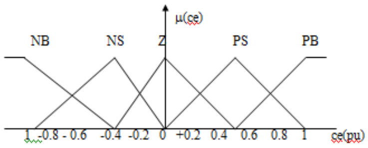

Fig. 12. Input membership function (change in flux error)

The triangular functions are used to reduce the computation for on line implementation. The triangular membership function can be obtained from the trapezoidal function by setting b = c.

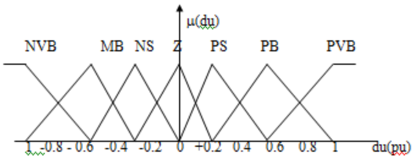

Fig. 13. Output membership function

The output function is given by

$$\text{Output i} = \frac{\sum_{k=1}^{N} i\mu_{c(k)}(i)}{\sum_{K=1}^{N} \mu_{cc(k)}(i)} \qquad (9)$$

The rules used for the proposed IM, FLC algorithm are shown in table 1 and 2.For this study , Mamdani type fuzzy inference and the centre of gravity defuzzication is used.

III. RESULTS AND DISCUSSION

The block diagram implementation of vector control with conventional PI controller is shown in fig 14

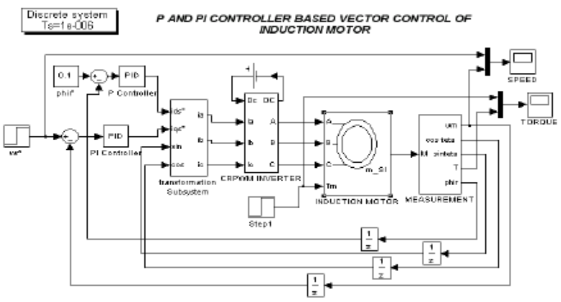

Fig. 14. PI Controller based vector control of induction motor

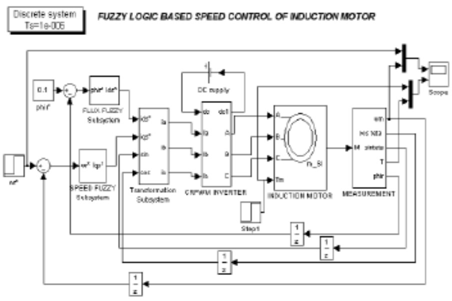

Fig. 15. fuzzy logic based vector control of induction motor.

Vector control of induction motor with conventional controllers and fuzzy controller was implemented in Matlab-Simulink. The results have been obtained for step change in speed and load. The performance of fuzzy controller has been compared with that of the conventional PI controller.

Three phase cage type induction motor the following parameter was used for simulation.

Rated power	:5h.p	Inertia	:0.1 kg m^2
Rated voltage	:415 v	Stator resistance	:0.5814 mohms
Rated current	:3.4 amps	Rotor resistance	:0.4165 mohms
Rated speed	:1420 rpm	Stator inductance	:3.979 mH
Frequency	:60 Hz	Rotor inductance	:4.15 mH
Pole pairs	:4	Magnetizing inductance	: 78.25 H

The Speed tracking ability of the conventional and fuzzy controller for given reference speed are shown in fig16 and 17 respectively. The nonlinear I/O capabilities of the fuzzy controller allows for the current to be changed very quickly resulting very accurate speed tracking. The conventional controller reacts slower causing inferior speed tracking.

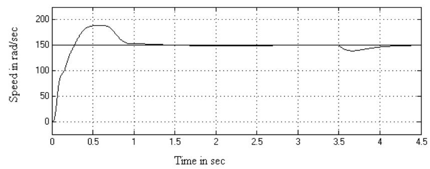

Fig. 16. Speed response using PI

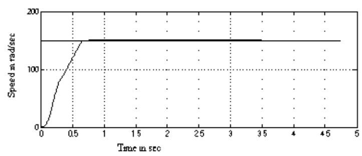

Fig. 17. Speed response using FLC

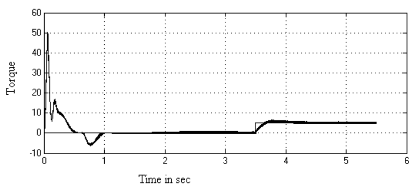

Fig. 18. Torque response using PI

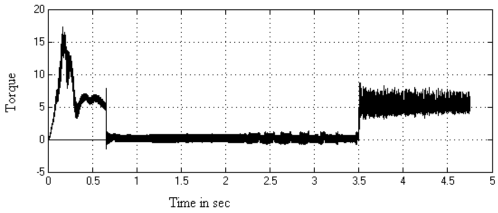

Fig. 19. Torque response using FLC

The torque response of two controller for a step change in load torque are shown in fig18 and Fig 19 shows the speed responses of the drive with a step change in the reference speed FLC based system is not affected by the sudden change of command speed. Thus a good tracking has been achieved for the FLC, whereas the PI controller is affected with the sudden change in command speed

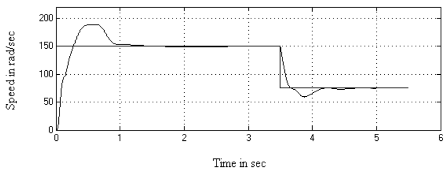

Fig. 20. speed response for step change in reference using PI

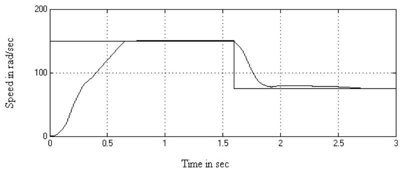

Fig. 21. speed response for step change in reference using FLC

In fig 20 step change in reference speed(150rad/sec to 75rad/sec) is applied at 3.5 sec
In fig 21 step change in reference speed(150rad/sec to 75rad/sec) is applied at 1.62sec

TABLE III. COMPARE THE PERFORMANCE OF THE TWO CONTROLLERS

Parameter	PI	FLC
Peak overshoot of speed	32 rad/sec	3to 5 rad/sec
Setling Time for step change in load	0.98sec	0.6 sec
Setling Time for step change in speed	1.4 sec	1.2 sec

IV. CONCLUSION

In this paper, principles and usefulness of fuzzy logic and fuzzy control has been illustrated through application for the intelligent control of a complex variable speed drive system.

The speed response has been are observed under different operating conditions such as sudden change in command speed and step change in load. The PI controller gives an optimum response at rated condition, but the fuzzy controller yielded better performances in terms of faster response time and lower starting current The proposed FLC can follow the command speed without any overshoot and 2% steady state error. It is to be noted that the speed response is affected by the load conditions. This is the drawback of PI controller with varying operating conditions. The torque response shows little ripples for FLS and large ripple content for PI controller respectively.

REFERENCES

1. Benoit .R , Federique. B, Jean. H and Herve.B (April 2000) , ‘ A Fuzzy Logic Based Multimodel Field Orientation in an Indirect Vector Control of Induction Motor’, IEEE Transactions on Industrial Electronics ,pp 380-388
2. 2. B.K.Bose, “An Adaptive Hysteresis – Band Current Controller Technique of a voltage fed – PWM inverter for Machine drive system,” IEEE Trans. Industrial Electronics, Vol. 37, No.5, October 1990, PP 402 -408.
3. 3. Bose. B.K, “Modern Power Electronics and AC Drives”, Pearson Education Asia, 2003.
4. 4. Cerruto. E, Consoli.A and Ricatti (Nov 1997).’Fuzzy Adaptive Vector Control Of Induction Motor Drives. IEEE Transactions of Power Electronics, pp1028-1039.
5. Joao O.Pinto, Bimal K.Bose and Marian P.Kazrnierkowski(November/December 2000), ‘Aneural network Based Space Vector PWM Controller for Voltage Fed inverter induction motor.’, IEEE Transactions 0n Industrial Applications, pp 1628-1636.
6. Nasir.M,Tawfik.S and Azizur.M (2002).’Performances Of Fuzzy Logic Based Indirect Vector Control For Induction Motor Drive, IEEE Transactions On Industry Applications, pp1219-1225
7. Miki .I,Nagai.N and Yamada.T ,(1992)’Vector Control Of Induction Motor With Fuzzy Pi Controller’, Ieeias Annu. Rec , pp 464-471
8. Marian P.Kazrnierkowski and Luigi Malesani(October 1998).’Current Control Techniques For Three Phase Sourse PWM Converter.’ IEEE Transactions 0n Industrial Applications, pp 628-634.
9. Tang.Y and Xu.L,(Dec1999).’Fuzzy Logic Application For Intelligent Control Of A Variable Speed Drive’,IEEE Transaction On Energy Conversion, pp679-685.
10. Vas.P (1990),’Vector and Direct torque Control of Ac Drives’, Oxford, and U.K: Clarendron.