Indirect Vector Control of Induction Motor Using Fuzzy Logic Controller

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Abstract- **The paper presents a fuzzy logic speed control system based on fuzzy logic approach for an indirect vector controlled induction motor drive for high performance. The analysis, design and simulation of the fuzzy logic controller for indirect vector control induction motor are carried out based on fuzzy set theory. The proposed fuzzy controller is compared with PI controller with no load and various load condition. The result demonstrates the robustness and effectiveness of the proposed fuzzy controller for high performance of induction motor drive system.**

Keywords: **Indirect vector control, Fuzzy logic control, PI controller, induction motor, speed control**

I. INTRODUCTION

Ac motor drives are extensively used in industrial application requiring high performance. In high performance system, the motor speed should closely follow a specified reference trajectory regardless of any load disturbance, parameter variations and model uncertainties. In order to achieve high performance, field-oriented control of induction motor drive is employed [2].however the control design of such a system plays a role in system performance. The decoupling characteristics of vector-controlled induction motor are adversely affected the parameter changes in the motor.

The speed control of IM issues are traditionally handled by fixed gain PI and PID controllers. However the fixed gain controllers are very sensitive to parameter variations, load disturbances etc. Thus, the controller parameters have to be continuously adapted. The problem can be solved by several adaptive control techniques such as model reference adaptive control, sliding mode control smc,variable structure control VSC and self tuning PI controller etc. The design of the entire above controller depends on the exact system mathematical model. However it is often difficult to develop a accurate mathematical model due to unknown load variation and unavoidable parameter variations due to saturation, temperature variations and system disturbance. To overcome the above problems, Fuzzy logic controller (FLC) is being used for motor control purpose. There is some advantage of fuzzy logic controller as compared to conventional PI, PID and adaptive controller such as it does not require any mathematical model, it is based on linguistic rules within IF-THEN general structure, which is the basic of the human logic [3].

In this paper the configuration and design of fuzzy logic controller of indirect vector control of induction motor has been investigated. The performance of FLC has been successfully compared with conventional PI controller.

II. INDIRECT FIELD-ORIENTED INDUCTION MOTOR DRIVE

The indirect vector control method is essentially same as the direct vector control except the unit vector generated in an indirect manner using the measured speed ω_r and slip speed ω_{sl}. The following dynamic equations are taken into consideration to implement indirect vector control strategy [1].

$$\theta_e = \int \omega_e dt = \int \left(\omega_r + \omega_{sl}\right) = \theta_r + \theta_{sl} \tag{1}$$

The rotor circuit equation

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \tag{2}$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\psi_{dr} = 0 \tag{3}$$

For decoupling control $\psi_{qr} = 0$, So the total flux $\hat{\psi}_r$ directs on the d^e axis.

Now from equations (1) and (2) we get

$$\frac{L_r}{R_r}\frac{d\hat{\psi}_r}{dt} + \hat{\psi}_r = L_m i_{ds} \tag{4}$$

Slip frequency can be calculated as

$$\omega_{sl} = \frac{L_m R_r}{\hat{\psi} L_r} i_{qs} \tag{5}$$

For constant rotor flux ψ_r and $d\psi_r/dt=0$, substituting in equation (4) yields the rotor flux set as

$$\hat{\psi}_r = L_m i_{ds} \tag{6}$$

The electromechanical torque developed is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\hat{\psi}_r i_{qs} \qquad (7)$$

III. Design of Fuzzy Logic Controller for Induction Motor Drive

Fig. 1 shows block diagram of speed control system using fuzzy logic controller (FLC) [6].

Here the first input is the speed error 'e' and second is the change in speed error 'ce' at sampling time 't_s'. The two input variables $e(t_s)$ and $ce(t_s)$ are calculated at every sampling time as

$$e(t_s) = \omega_r^*(t_s) - \omega_r(t_s)$$
$$ce(t_s) = e(t_s) - e(t_s - 1) \qquad (8)$$

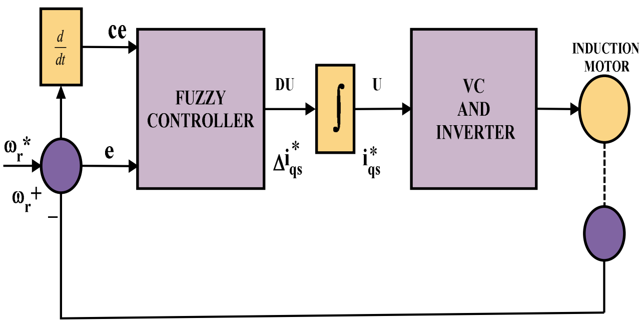

Fig.1 Functional block diagram of Fuzzy Logic Control

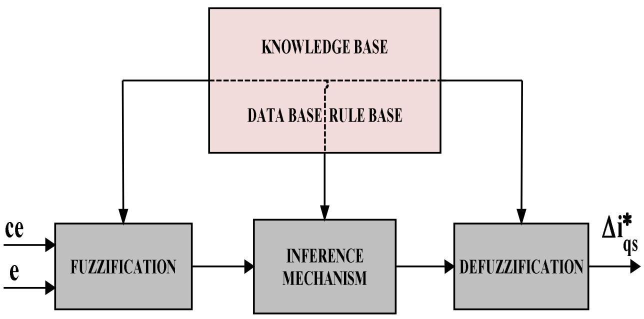

Fig.2 Fuzzy Logic Controller Internal structure

Where 'c_e' denotes the change of error 'e', $\omega_r^*(t_s)$ is the reference rotor speed , $\omega_r(t_s)$ is the actual speed, $e(t_s-1)$is the value of error at previous sampling time. The output variable is the change in torque ΔT which is integrated to get the reference torque as shown in the equation

$$T^*(t_s) = T^*(t_s - 1) + \Delta T \qquad (9)$$

As shown in Fig. 2, the fuzzy logic controller consists of four blocks, Fuzzification, inference mechanism, knowledge base and Defuzzification.

A. *Fuzzifications:*

In this stage the crisp variables of input $e(t_s)$ and $ce(t_s)$are converted into fuzzy variables. The fuzzification maps the error and change in error to linguistic labels of fuzzy sets. Membership function is associated to each label with triangular shape which consists of two inputs and one output.

The proposed controller uses following linguistic labels NB, NM, NS, ZE, PS, PM, PB. Each of the inputs and output contain membership function with all these seven linguistics.

B. *Knowledge base and inference stage:*

Knowledge base involve defining the rules represented as IF-THEN rules statements governing the relationship between input and output variables in terms of membership fuction.In this stage the input variables $e(t_s)$and $ce(t_s)$are processed by the inference mechanism that executes 7*7 rules represented in rule table shown below. Considering the first rule, it is represented as IF change in speed error is NB and change in speed is NB, THEN the output will be NB.Here Mamdani's algorithm for inference mechanism used.

C. *Defuzzification:*

This stage introduces different methods that can be used to produce fuzzy set value for the output fuzzy variable ΔT.

Here the centre of gravity or centroids method is used to calculate the final fuzzy value $\Delta T(t_s)$.Defuzzification using COA method means that crisp output of $\Delta T^*(t_s)$ is obtained by using centre of gravity, in which the crisp output $\Delta T(t_s)$ variable is taken to be the geometric centre of the output fuzzy variables value $\mu_{out}(\Delta T)$area, where $\mu_{out}(\Delta T)$ is formed by taking the union of all the contributions of rules with the degree of fulfilment greater than zero. Then the COA expression with discretised universe of discourse can be written as

$$\Delta T = \frac{\sum_{i=1}^{n} \Delta T_i . \mu_{out}(T_i)}{\sum_{i=1}^{n} \mu_{out}(\Delta T_i)} \qquad (10)$$

Then T_e^* obtained by integration which is used to calculate i^*_{qs}

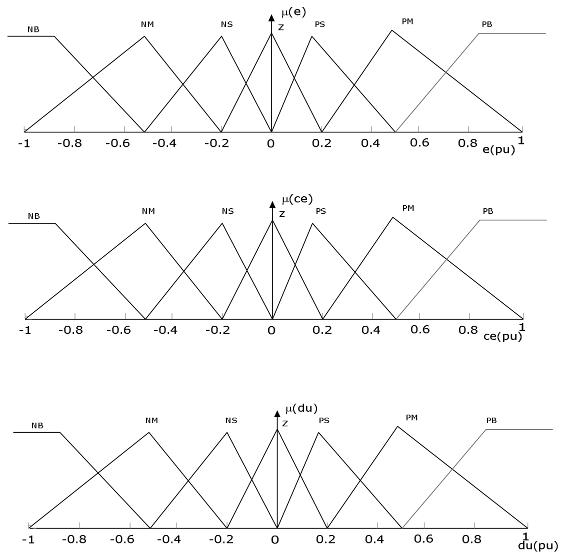

Fig.3. Membership Function of Fuzzy Variables μ_e, μ_{ce} and $\mu(du)$

TABLE: 1 Fuzzy Controller Rule Base

e(pu) ce(pu)	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
ZE	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

IV. SIMULATION RESULTS AND DISCUSSION

The machine is initially at stand still with no load. The reference speed is linearly increased from zero its rated value 500 rpm with FLC and PI controller. Various simulation were carried out on both PI controller and fuzzy logic controller on the indirect-vector control of Induction motor.

Fig.4 and fig.5 shows The PI and FLC with a step command of Speed are applied with no load condition. In case of PI Controller the rise time is in between t_s=0.5 to t_s=0.6 , but in case of FLC rise time is in between t_s=0.3 to t_s=0.4 .It is conclude that FLC offers faster response as compare to PI. Hence FLC based drive system is superior to PI based drive system in all respect rise time, settling time and overshoot.

Fig. 6 and Fig. 7 shows the PI and FLC at load condition. Here the PI controller was affected by change in load, but FLC have no affect by the change in load. Fig. 7shows that the proposed FLC is more robust to load disturbance as compared to PI controller.

Fig. 8 and Fig. 9 shows the X-Y plot of variation of rotor flux, where it is observed that in case of PI controller it will take more time to reach to steady state value but in case of fuzzy controller it will take less time to reach steady value.

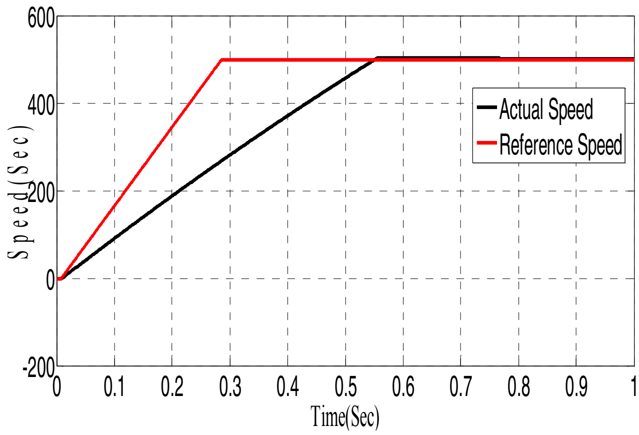

Fig.4. Speed response of PI controller at no load

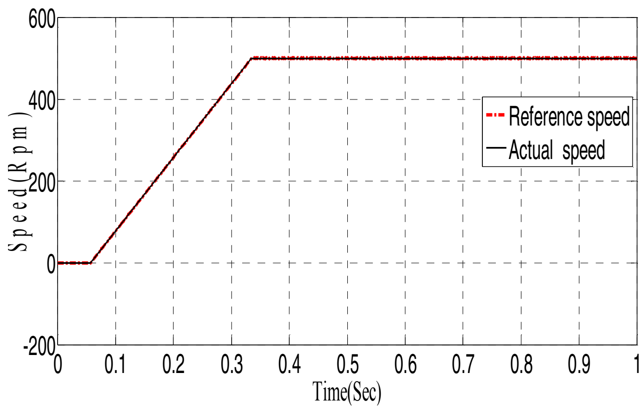

Fig.5. Speed response of Fuzzy logic controller at no load

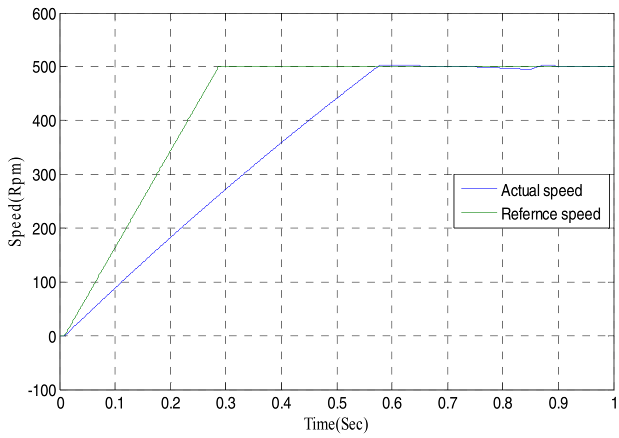

Fig.6. Speed response of PI controller at load

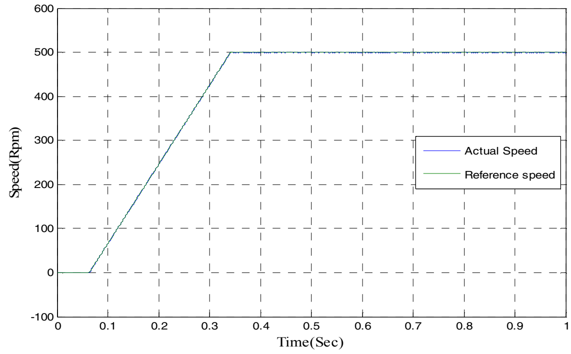

Fig.7. Speed response of Fuzzy logic controller at load

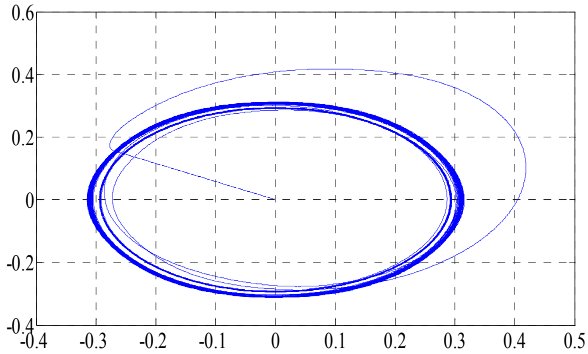

Fig.8. X-Y plot of Rotor flux of PI controller

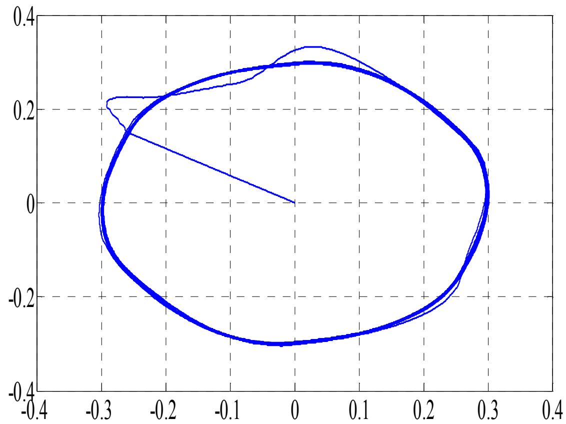

Fig.9. X-Y plot of Rotor flux of Fuzzy logic controller

V. CONCLUSIONS

In this paper fuzzy logic controller for the control of an indirect vector-controlled induction motor was described. The drive system was simulated with fuzzy logic controller and PI controller and their performance was compared. Here simulation results shows that the designed fuzzy logic controller realises a good dynamic behaviour of the motor with a rapid settling time, no overshoot and has better performance than PI controller. Fuzzy logic control has more robust during change in load condition.

APPENDIX

Specification of Induction Motor:
Machine type-3 phase induction motor
Rotor type-squirrel cage
Reference type-Stationary
5HP,1445 rpm,415V,50 hz,4 poles
R_s=7.34Ω,R_r=5.64Ω,
L_s=0.521H,L_r=0.521H,L_m=0.5H
J=0.16Kg.m^2,B=0.035kg.m/s

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