FUZZY CONTROL OF FIELD-ORIENTED AC MOTOR DRIVES

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ABSTRACT

In this paper a fuzzy logic control of a field oriented ac motor drive using a dynamic drive model is investigated and simulation studies are performed with the matlab program. A mathematical model of the induction motor operating at constant speed and supplied from a symmetrical three phase supply is given. The dynamic model is simplified based on the reference frame theory and linearization technique. The fuzzy logic controller for speed loop is presented. The input variables to the controller are normalized by certain gain factors estimated by trial and error. The membership functions for the linguistic variables are represented by a symmetrical triangular shapes causing more crowding near the origin and precision control near the steady state operating point. The effectiveness of the proposed fuzzy controller is investigated and compared with an adjusted PI controller. The simulation and practical results are presented.

INTRODUCTION

Induction motors are the most preferable machines for industrial drives. This is entirely due to their robust construction, relatively low cost and reliability in service. They are available in sizes ranging from fractional h.p. machines to motors of rating exceeding 15 MVA [1]. One of the most important characteristics when considering industrial drive systems is that relating speed and torque and it is possible to shape the characteristic for a machine by various means to coincide with the requirements of a specific drive.

Field orientation has emerged as a powerful tool for controlling ac machines such as inverter-supplied induction motors. The complex functions required by field oriented control was executed by microprocessors on line, thus greatly reducing the necessary control hardware. The flux signals was drived from sensing coils or, with some compromise in performance, from the stator voltage and currents[2]. The speed signal is obtained from a digital tachometer. The concept of field orientation as proposed by Blaschke stands out as a fundamental method of controlling ac machines, essentially transforming their dynamic structure into that of dc machines [3,4].

In this paper a fuzzy control of a field oriented ac motor drive using a dynamic drive model is investigated and the simulation studies are performed with matlab program. Initial experimental results are also presented.

MATHEMATICAL MODEL OF THE INDUCTION MOTOR

The dynamic properties of an induction motor as a control plant can be described by a set of nonlinear differential equations linking the stator and rotor currents and voltages with the mechanical quantities: torque, speed, and angular position. Considerable simplifications result without noticeably affecting the validity of the control model if the stator and rotor windings are assumed to produce sinusoidal magnetomotive force (MMF) waves in the air gap of the machine, disregarding spatial harmonics of the windings as well as slot and end effects[3]. Additional minor inaccuracies are the assumption of infinite permeability of the iron core and the neglect of iron losses and eddy currents in the conductors.

The symmetry of the motor construction gives rise to complex current and voltage vectors defined in a plane perpendicular to the motor axis[3]:

$$i_S(t) = i_{S1}(t) + i_{S2}(t)\,e^{j2\pi/3} + i_{S3}(t)\,e^{j4\pi/3} \tag{1}$$

$$i_R(t) = i_{R1}(t) + i_{R2}(t)\,e^{j2\pi/3} + i_{R3}(t)\,e^{j4\pi/3} \tag{2}$$

The values $i_{S\nu}(t)$ are the stator-phase and $i_{R\nu}(t)$ are the rotor-phase currents.

The vector of the stator terminal voltages is defined accordingly:

$$u_S(t) = u_{S1}(t) + u_{S2}(t)\,e^{j2\pi/3} + u_{S3}(t)\,e^{j4\pi/3} \tag{3}$$

The stator and rotor inductances per phase are, converted to equal number of turns,

$$L_S = (1+\sigma_S)\,L_h\,, \qquad L_R = (1+\sigma_R)\,L_h \tag{4}$$

with

$$\sigma = 1 - 1/\,(1+\sigma_S)(1+\sigma_R) \tag{5}$$

being the total leakage factor. R_S and R_R are the winding resistance per phase, and L_h is the main inductance. With J as the total inertia of the drive, T_e and T_L the driving and load torque, respectively, ω the angular velocity, and ε the angle of rotation, the equations of the wound-rotor two-pole induction motor with shorted rotor windings can be written as follows [3]:

$$R_s i_s + L_s \frac{di_s}{dt} + L_h \frac{d}{dt}(i_R e^{j\varepsilon}) = u_s \tag{6}$$

$$R_R i_R + L_R \frac{di_R}{dt} + L_h \frac{d}{dt}(i_s e^{-j\varepsilon}) = 0 \tag{7}$$

$$J\frac{d\omega}{dt} = T_e - T_L = \frac{2}{3} L_h I_m\left[i_s(i_R e^{j\varepsilon})\right]^* - T_L - B\omega \tag{8}$$

$$\frac{d\varepsilon}{dt} = \omega \tag{9}$$

Equations (6) to (9) constitute a dynamic extension of the well-known stationary model of the induction motor, operating with constant speed of the symmetrical three phase line.

DYNAMIC DRIVE MODEL BASED ON FIELD ORIENTATION

The block diagram of an indirect field-oriented induction motor drive is shown in Fig(1a) [3]. It mainly consists of an induction motor, a dynamic load (a dc generator with switched resistors), a hysteresis current-controlled pulse width modulated (PWM) inverter, a slip angular speed estimator, a coordinate translator, and an outer speed feedback control loop. The torque component current command i_{qs} is generated from the speed error between the command and the measured rotor speed through the torque controller $G_c(s)$. The estimate of slip angular speed w_{s1} is obtained using the regulated stator torque component current i_{qs}, the preset stator flux component current i_{ds} and the rotor time constant L_r/R_r. Table I gives the parameters of the ac motor used in the simulation study [2].

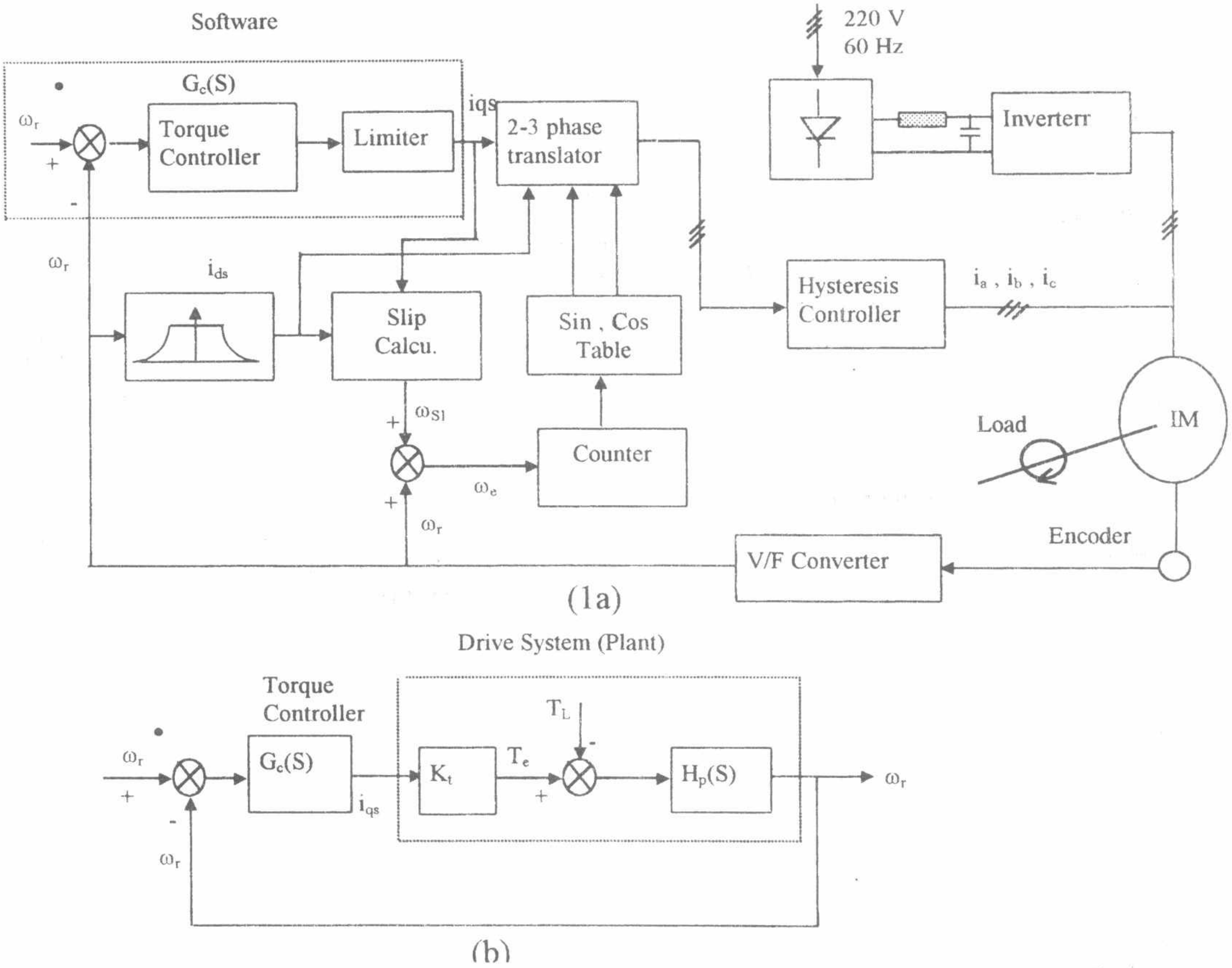

Fig.(1) (a) System configuration of the induction motor drive.
(b) Control system block diagram of the drive.

Table I Parameters of the ac motor

Rated voltage			220 V
Rated frequence			50 hz
Number of pole			4
Connection			Δ
Rated power			1 hp
L_r	0.04 H	L_h	1.233 mH
J	0.01339 kg-m^2	B	0.2409 N.m Sec./Rad
i_{ds0}	0.6 pu	i_{qs0}	0.8 pu

For performing the simulation of the proposed fuzzy controller, the dynamic drive model is necessary. Based on the reference frame theory and linearization technique, the drive system of Fig.(1a) can be reasonably represented by the block diagram shown in Fig.(1b) [5], where

$$\omega_r(s) = H_p(s)(T_e(s) - T_L(s)) \tag{10}$$

$$H_p(s) = \frac{1/J}{S + B/J} \cong \frac{b}{S + a} \tag{11}$$

$$T_e = K_t i_{qs} \tag{12}$$

$$K_t = (3P/4)(L_h^2 / L_r) i_{ds} \tag{13}$$

with

L_h	magnetizing inductance per phase.
R_r	rotor resistance per phase referred to stator side.
L_r	rotor inductance per phase referred to stator side.
P	number of poles.
B	damping ratio of the motor and mechanical load.
J	inertia constant of the motor and mechanical load.
i_{qs}	stator torque component current.
i_{ds}	stator flux component current.

The above equation is solved by using the Matlab program and Runge-Kutta 6 method[6]

FUZZY LOGIC CONTROLLER FOR SPEED LOOP

The fuzzy logic controller proceeds as follows to evaluate the desired output signal. First, input variables are normalized, then the membership functions of the fuzzy logic controller output signal is determined by linguistic variables. Finally, the numerical value of the fuzzy logic controller output signal corresponding to a specific linguistic variable is determined. In ac motor drives, based on previous experience, the motor speed error Eω and error derivative CE are chosen to be the input signals of the fuzzy controller.

The general input variables considered in the fuzzy rule base are:

$$E\omega(k) = \omega r(k) - \overset{*}{\omega} r(k) \qquad \text{For speed control loop} \qquad (14)$$

$$CE(k) = E(k) - E(k-1) \qquad \text{For change in error} \qquad (15)$$

Where for fuzzy speed controller, the error $E\omega(k)$ at sampling interval k, is the difference between the feedback angular velocity $\omega_r(k)$ and the reference angular velocity $\omega^*_r(k)$ and CE(k) is the error change. The input variables are normalized by division by gain factor as follows:

$$e(k) = E(k) \,/\, G1 \qquad (16)$$

$$Ce(k) = CE(K) \,/\, G2 \qquad (17)$$

where G1 and G2 are the respective gain factors of the controller. These gain factors are chosen by trial and error. It was found that, for fuzzy speed controller of the used motor G1= 60.5 and G2= 12.6 .Using these normalized quantities, the fuzzy logic controller input can be described by membership functions for the linguistic variables, which are divided into seven sections, this is called the fuzzification operation. Fig.(2) shows the membership functions of e(pu), ce(pu) and i_{qs}(pu) variables. Note that, the membership function for each linguistic variable is represented by a symmetrical triangular shape, and 50% overlap has been provided for the neighboring membership functions. The distance between the symmetrical axis of two successive membership function is called span. Since there is 50% overlap therefore, at any given point of the universe of discourse, no more than two membership functions will have non zero value. It is evident that for any input data of e(k) and ce(k), there will be four rules or less valid in the entire rule base given in Table II.

Table II Rule base for speed controller

e ce	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 structure of a general rule can be given as:
If e(k) is X AND ce(k) is Y THEN $i_{qs}(k)$ is Z
where $i_{qs}(k)$ is the change in control setting, X, Y and Z are the fuzzy subsets defined in the universe of discourse of e, ce and i_{qs}, respectively. Note that the fuzzy subsets for each variable have asymmetrical shape causing more crowding near the origin. This permits precision control near the steady state operating point, without unduly increasing the number of subsets. The parameters e1, e2, ..., c1, c2, ..., u1, u2, .. in Fig.(2) are iterated to tune the controller performance.
The basic structure for fuzzy speed control loop is shown in Fig.(3).

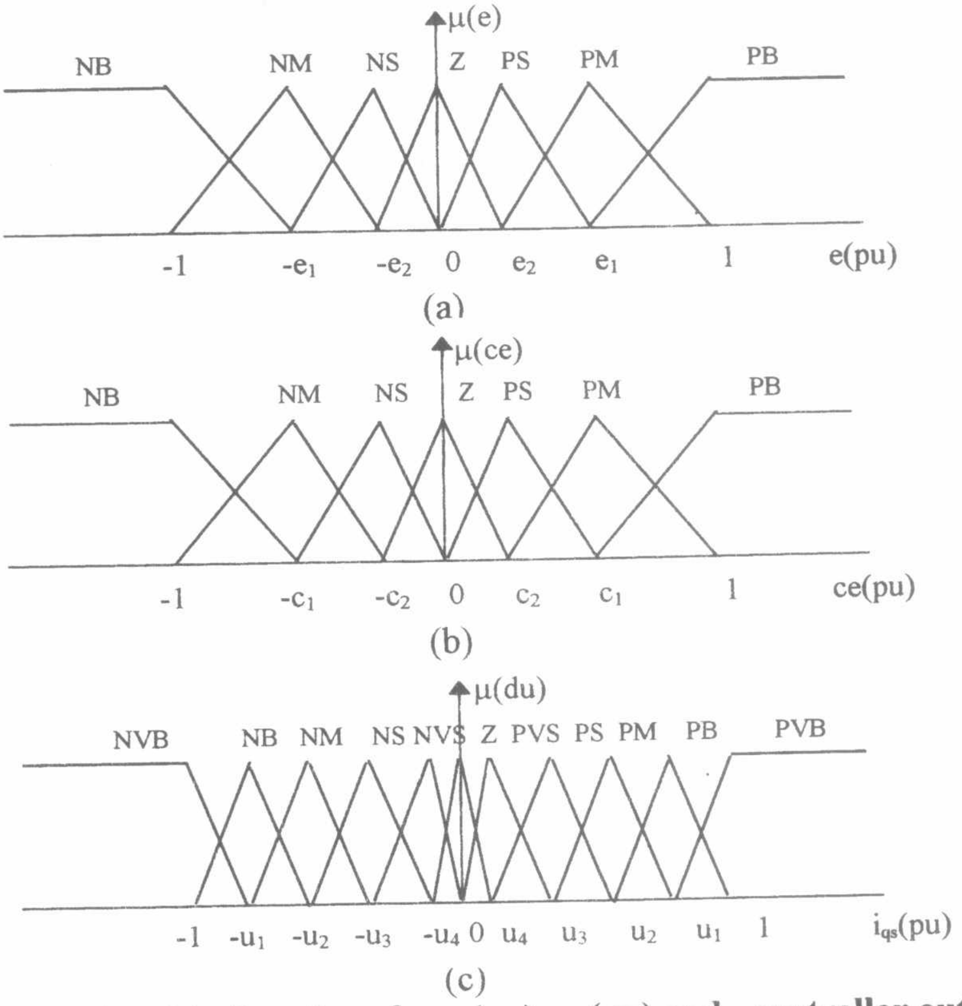

Fig.(2) Membership functions for e(pu), ce(pu) and controller output i_{qs}.

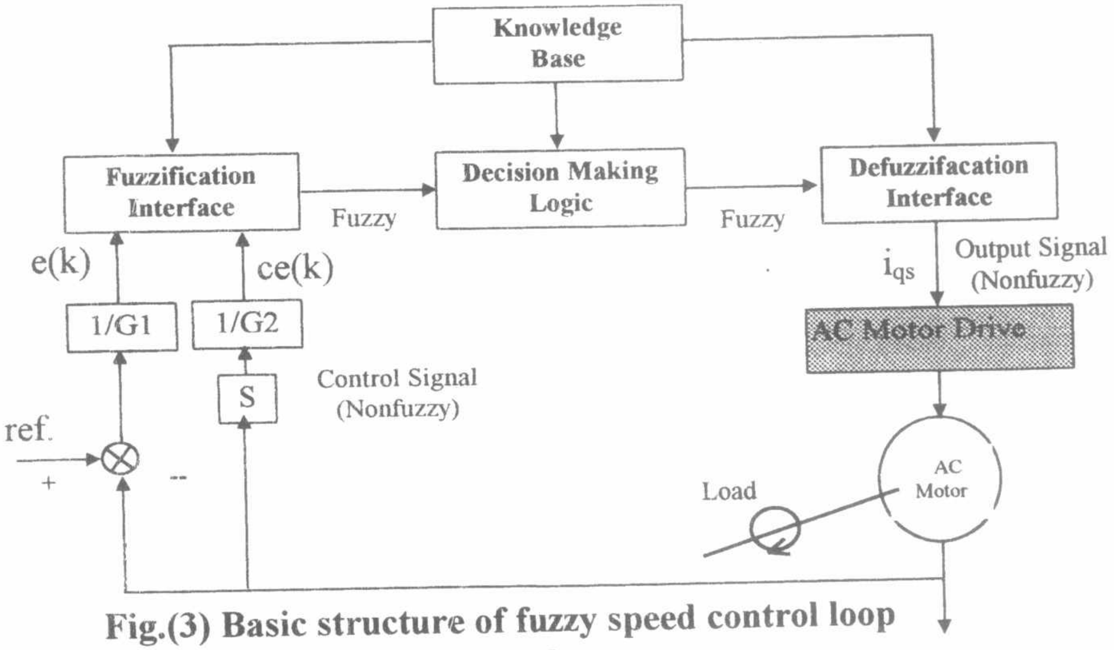

Fig.(3) Basic structure of fuzzy speed control loop for the controlled system .

SIMULATION RESULTS

The effectiveness of the proposed fuzzy logic controller on the transient and dynamic characteristics of the rotor speed of three phase induction motor is investigated. The speed control of the drive was also designed and simulated with PI control, in order to compare the performance with the respective fuzzy control. The induction motor was operated at full load for four seconds, then the load torque was increased to 130% of its full load value for a period of three seconds, and then the torque was returned to the full load value. The simulation results are shown in Fig.(4) to Fig.(7). Fig.(4) shows that the transient response using PI controller is approximately the same over a wide range of sampling times. This response is obtained by adjusting the PI coefficients by trial and error. The response using fuzzy controller at three different sampling times is shown in Fig.(5). The response is improved by decreasing the sampling time of the controller. Thus a fast computer is required to implement the fuzzy controller in order to obtain good response. Fig.(6) and Fig.(7) show that the PI controller is better than the fuzzy controller at large sampling periods, while the fuzzy controller is superior at small sampling periods. The obtained coeffiecients of fuzzy and PI controllers are shown in Table III.

Table III The coefficient for fuzzy and PI controller

Controller	PI		Fuzzy	
Sampling time (sec.)	KP	KI	G1	G2
0.03	0.549	0.001	1.5	30.92
0.01	0.189	0.001	2.5	40.5
0.006	0.119	0.001	4.5	40.5

EXPRIMENTAL RESULTS.

The PI and fuzzy controllers are implemented in a practical system composed of a 3-phase 2 pole squirrel-cage induction motor 1 hp connected to a voltage source inverter and the results are shown in Fig.(8) to Fig.(11). Fig.(8) and Fig.(10) show the speed and current response in case of fuzzy controller. The practical results reflects the validity of the previously stated simulation results.

CONCLUSION

Fuzzy logic and PI controllers for a field oriented ac motor drive using a dynamic drive model are investigated. The system response using fuzzy controller is greatly affected by changing the sampling time of the controller while that with the PI controller is slightly affected. The PI controller is found to be better than the fuzzy controller at large sampling periods while the fuzzy controller is superior at small sampling intervals.

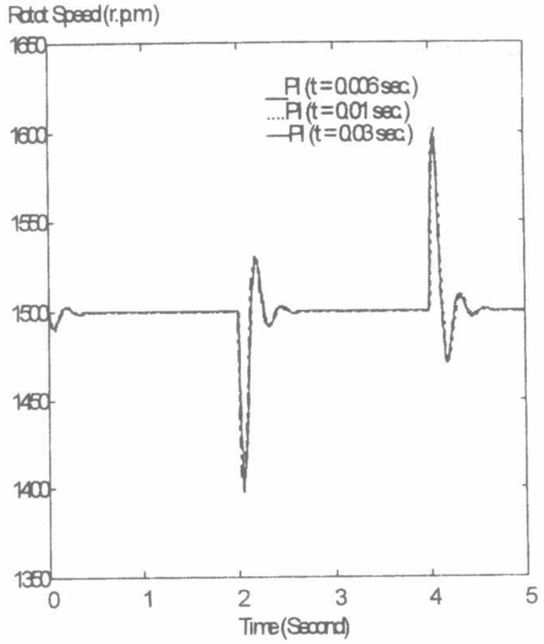

Fig.(4) PI controller at three different sampling times.

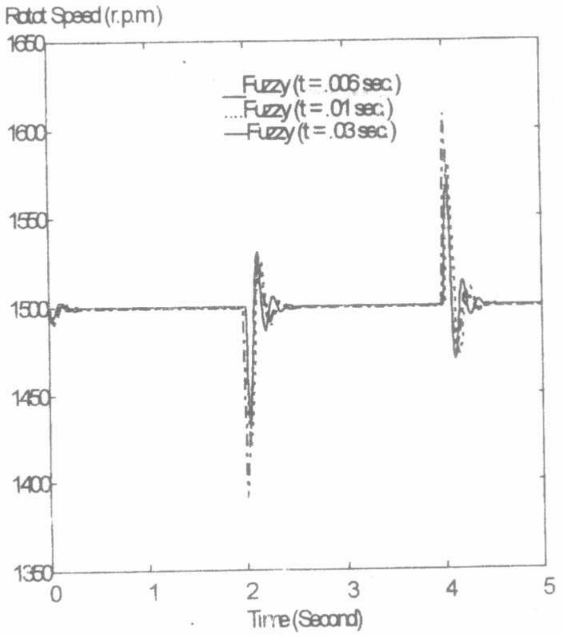

Fig.(5) Fuzzy controller at three different sampling times.

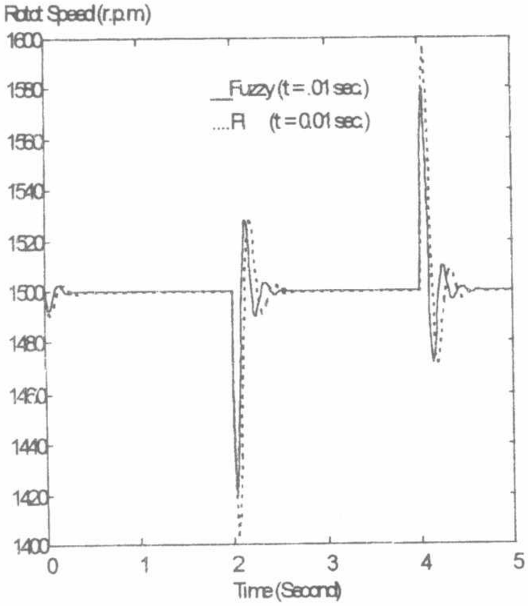

Fig.(6) Fuzzy and PI controllers at sampling sampling time = 0.01 sec.

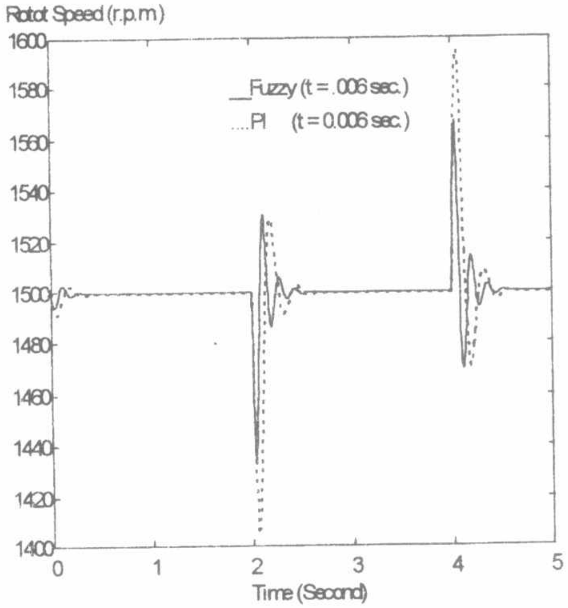

Fig.(7) Fuzzy and PI controllers at sampling time = 0.006 se.

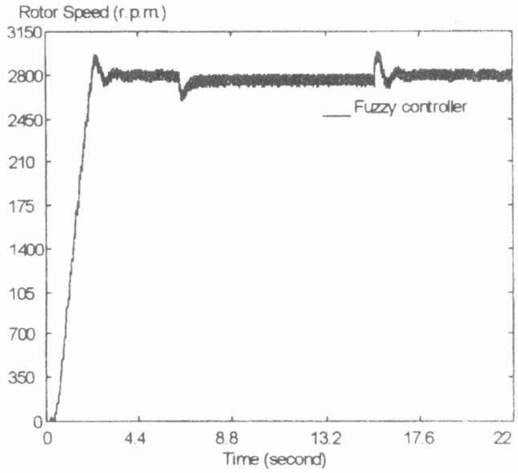

Fig.(8) Rotor speed with fuzzy controller

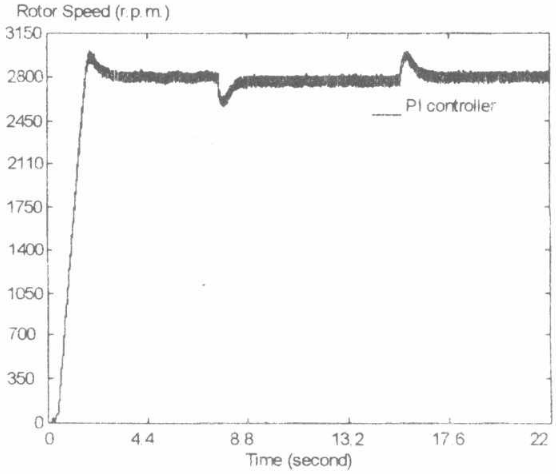

Fig.(9) Rotor speed with PI controller

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