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Design of Induction Motor Drive using Adaptive Fuzzy PI Controller

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ABSTRACT: This paper deals with the design and comparative performance of fuzzy PI controller with conventional PI controller to control the Induction Motor speed. As the conventional control not perform well for the complex system models during the load disturbances and set point variations, Fuzzy logic has met a growing interest in many motor control applications due to its non-linearities handling features and independence of the plant modelling. This paper presents a rule-based Mamdani type fuzzy logic controller applied to closed loop Induction Motor model. The results obtained in Simulation shows that the fuzzy PI controller is performing better than the conventional PI controller.

KEYWORDS: Induction Motor, Field oriented control, Fuzzy Logic Controller, PI-Controller, Simulink.

I.INTRODUCTION

In industrial application, PI controller schemes are still the most commonly used due to their simplicity in design and stability in performance. Besides, They facing the limitations as (i) Controller design depends on the mathematical model of the system (ii) Expected performance not met due to the load changes (iii) It gives acceptable results at single set point (iv) The coefficients must be choose properly for acceptable results, besides that choosing of proper gains is very difficult for varying parameters like set point. Numerous methods such as fizzy-logic control have been proposed to replace PI controller schemes. However, unexpected change in load conditions or environmental factors would produce overshoot, oscillation of motor speed, oscillation of the torque, long settling time and thus causes deterioration of drive performance. To overcome this, an intelligent controller based on Fuzzy Logic is proposed in the place of PI regulator.

In this paper application of fuzzy logic to the intelligent speed control of indirect vector controlled induction motor drive is investigated. The analysis, design and simulation of controller have been carried out based on the fuzzy set theory.

II.FUZZY CONTROLLER

A fuzzy controller employs a mode of approximate reasoning resembling the decision making route of humans, that is, the process people use to infer conclusions from what they know. Fuzzy control has been primarily applied to the control of processes through fuzzy linguistic descriptions stipulated by membership functions.

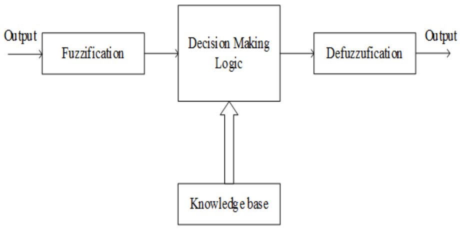

Fig. 1 Fuzzy control System

It has certain advantages compared to classical controllers such as ease of control, low cost, and the possibility to design without knowing the exact mathematical model of plant. The Controller architecture includes some rules which describe the casual relationship between two normalized input voltages and an output one. These are Error (e), that is speed error, Change-of-error (Δe), that is derivative of speed error, and Output, defined as the change-of-control (ΔT*).

III. DYANAMIC MODEL OF INDUCTION MOTOR

The dynamic modelling of Induction Motor is done in Simulink program of Matlab by utilizing its mathematical equations which are shown below. We have used synchronous frame of reference where:

$$v_{qs}{}^{c} = (R_s + pL_s)i_{qs}{}^{c} + \omega_c L_s i_{ds}{}^{c} + pL_m i_{qr}{}^{c} + \omega_c L_m i_{dr}{}^{c} \tag{1}$$

$$v_{ds}{}^{c} = -\omega_c L_s i_{qs}{}^{c} + (R_s + pL_s)i_{ds}{}^{c} - \omega_c L_m i_{qr}{}^{c} + pL_m i_{dr}{}^{c} \tag{2}$$

$$v_{qr}{}^{c} = pL_m i_{qs}{}^{c} + (\omega_c - \omega_r)L_m i_{ds}{}^{c} + (R_r + pL_r)i_{qr}{}^{c} + (\omega_c - \omega_r)L_r i_{dr}{}^{c} \tag{3}$$

$$v_{dr}{}^{c} = -L_m(\omega_c - \omega_r)i_{qs}{}^{c} + pL_m i_{ds}{}^{c} - L_r(\omega_c - \omega_r)i_{qr}{}^{c} + (R_r + pL_r)i_{dr}{}^{c} \tag{4}$$

And the Mechanical equation can be written as

$$T_e = J * \frac{d\omega_m}{dt} + B\omega_m + T_l \tag{5}$$

$$\begin{aligned} \frac{d\omega_m}{dt} &= \frac{1}{J} * (T_e - T_l - B\omega_m) \\ &= \frac{1}{J} * \{\frac{3}{2} * \frac{P}{2} * L_m\left[\left(i_{qs} * i_{dr}\right) - \left(i_{ds} * i_{qr}\right)\right] - T_l - B\omega_m \end{aligned} \tag{6}$$

ω_0 = base freq.; ω_r = rotor frame frequency
ω_s= synchronous frame frequency(Rad/sec)
R_s,R_r = Stator and Rotor resistances
L_s,L_r = Stator and Rotor inductances
L_m = Magnetizing inductance
V_{qs}, i_{qs} = q axis stator voltage and current
V_{ds}, i_{ds} = d axis stator voltage and current
V_{qr}, i_{qr} = q axis rotor voltage and current
V_{dr}, i_{dr} = d axis rotor voltage and current
ω_m = Rotor speed in mech. rad/sec
ω_r = Rotor speed in electrical rad/sec
p = Number of poles
T_e = Electromagnetic torque
T_l = Load torque
J = Load inertia coefficient
B = Friction coefficient

IV .PROPOSED CONTROL SCHEME

As shown in Figure2, set point is the desired speed of the motor, while the feedback signal is the measured value of the induction motor speed. The error signal and its derivative are used as input for FLC block. The output of FLC is the required change in reference torque (T^*) which will be integrated continuously and it will given to current generator and the generated reference current ($i_{qr}{}^*$, $i_{dr}{}^*$) will be compared with the actual motor current (i_{qr}, i_{dr}) and the difference will given to conventional PI controller. The reference voltages ($v_{qr}{}^*$, $v_{dr}{}^*$) of conventional PI controller is sent to 2/3 phase transformation block. These voltages (v_a, v_b, v_c) are used for PWM signal generation to control PWM inverter output voltages through which the speed of an induction motor is controlled. Feedback signal, which is the motor speed, will be sent again to FLC. So, the closed loop control system works continuously to achieve the desired motor speed.

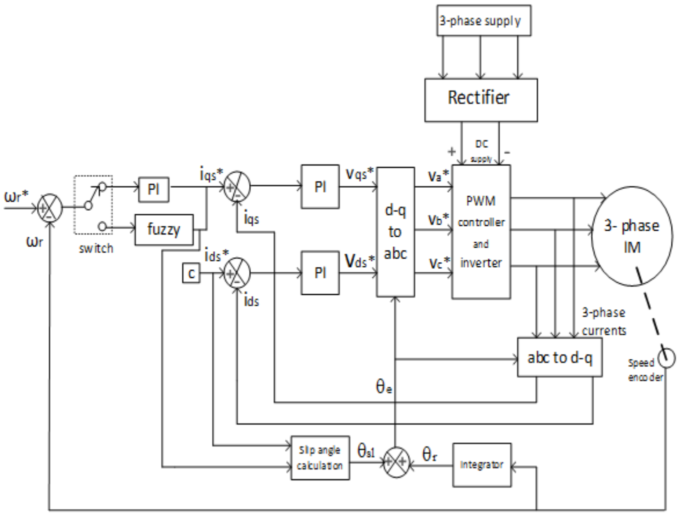

Fig. 2 Proposed block diagram

A. Field Oriented Control

Field oriented control (FOC) technique is intended to separate the stator currents into “flux producing (i_{ds})” and “torque producing (i_{qs})” components by utilizing transformation to the d-q coordinate system. These current components can be treated separately, and then recombined to create the actual motor phase currents. This gives a solution to the better control of the motor torque, which allows higher dynamic performance. For the high performance drives, the indirect Field oriented control is preferred choice. It is essentially same as the Direct Field oriented control, except that the rotor angle θ_e is generated in an indirect manner (estimation) using the measured speed ω_r and the slip speed ω_{sl}. To implement the indirect Field oriented control strategy, it is necessary to take the following dynamic equations into consideration.

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \tag{7}$$

For decoupling control, the stator flux component i_{ds} should be aligned on the d^e axis, and the torque component i_{qs} should be on q^e axis, that leads to $\psi_{qr} = 0$ and$\psi_{dr} = \psi_r$ then:

$$\frac{L_r}{R_r}\frac{d\psi_r}{dt} + \psi_r = L_m i_{ds} \tag{8}$$

As well, the slip frequency can be calculated as:

$$\omega_{sl} = \frac{L_m}{\psi_r}\frac{R_r}{L_r} i_{qs} \tag{9}$$

It is found that the ideal decoupling can be achieved if the above slip angular speed command is used for making field orientation.

The constant rotor flux ψ_r and $\frac{d\psi_r}{dt} = 0$ can be substituted in equation (8), so that the rotor flux sets as

$$\psi_r = L_m i_{ds}$$

The Simulink model for such an indirect vector control system is shown in the Fig. 3. This control technique operates the induction motor similar as separately excited DC motor so as to achieve high dynamic performance [2], [4].

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B. Design and Description of Fuzzy Controller

Fuzzy based controller has four major blocks one that computes the error into two input variables, a Fuzzification block, an inference mechanism, and the last step is Defuzzification.

1) Input/ Output variables

The design of the fuzzy logic controller requires predefined input and output variables. The variables entering the fuzzy logic speed controller has been selected as the speed error and its time variation. Two input variables $e(k)$ and $\Delta e(k)$, are calculated at every sampling instant as:

$$e(k) = \omega_r^*(k) - \omega_r(k)$$

$$\Delta e(k) = e(k) - e(k-1)$$

Where $\omega_r^*(k)$ is the reference speed, $\omega_r(k)$ is the actual rotor speed and $e(k-1)$ is the value of error at previous sampling time.

The output variable of the fuzzy logic speed controller is the variation of command torque, $\Delta T^*(k)$ which is integrated to get the reference command torque, $T^*(k)$ as shown in the following equation.

$$T^*(k) = T^*(k-1) + \Delta T^*(k)$$

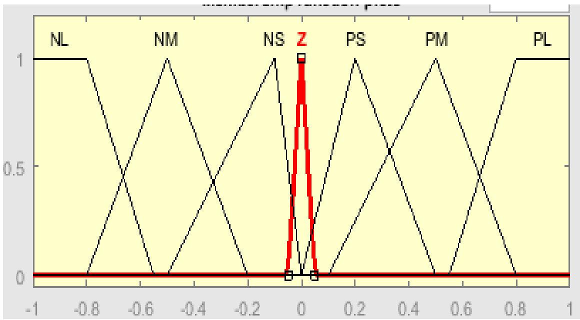
2) Fuzzification

In this stage, the crisp variables $e(k)$ and $\Delta e(k)$ are converted in to fuzzy variables e and Δe respectively. The membership functions associated with the control variables have been chosen with triangular and trapezoidal shapes as shown in Fig. 3.

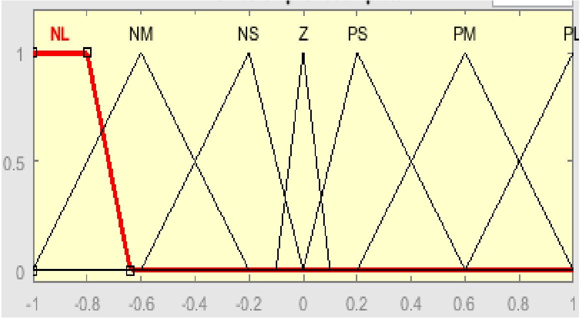
The universe of discourse of all the input and output variables are established as (-1, 1). The suitable scaling factors are chosen to brought the input and output variables to this universe of discourse. Each universe of discourse is divided into seven overlapping fuzzy sets:

Negative Large (NL), Positive Large (PL),
Negative Medium (NM), Positive Medium (PM),
Negative Small (NS), Positive Small (PS), Zero (ZE).

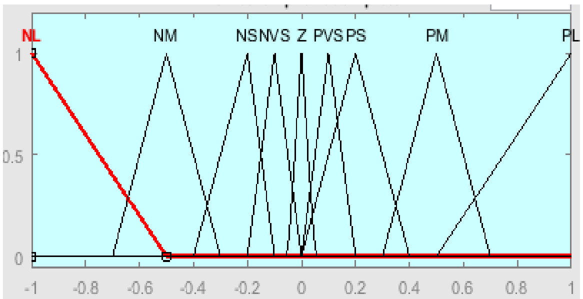
Each fuzzy variable is a member of the subsets with a degree of membership μ varying between 0 (non-member) and 1 (full-member).



(a)



(b)



(c)

Fig. 3 Membership functions for (a) speed error (b) change in speed error (c) Change in torque

3) Knowledge base and Inference Stage

It is the process that relates input fuzzy sets to output fuzzy sets using if-then statements to make the reasonable rules. In this stage, the variables e and Δe are processed by an inference engine that executes 49 rules as shown in Table I.

TABLE I. Fuzzy control rules

e	L	M	S	E	S	M	L
L	L	L	L	L	M	S	E
M	L	L	L	M	S	E	S
S	L	L	M	S	E	S	M
E	L	M	S	E	S	M	L
S	M	S	E	S	M	L	L
M	S	E	S	M	L	L	L
L	E	S	M	L	L	L	L

4) Defuzzification

In this stage a crisp value of the output variable T* is obtained by using Center Of Area (COA) is used as a deffuzification method, which can be presented as

$$\Delta T^*(k) = \frac{\sum_{i=1}^{n} \mu[(\Delta T^*)_i](\Delta T^*)_i}{\sum_{i=1}^{n} \mu[(\Delta T^*)_i]}$$

V. SIMULATION RESULTS AND DISCUSSION

At various set points simulation tests were carried out on induction motor drive using both conventional PI controller and fuzzy PI controller. The dynamic performance like settling time, raise time and peak overshoots for the proposed controller with conventional controller has compared.

In tth fig 4,5 we have set a speed of 300 rad/s to be fed so as to find out the performance with fuzzy PI controller and conventional PI controller at no-load condition.

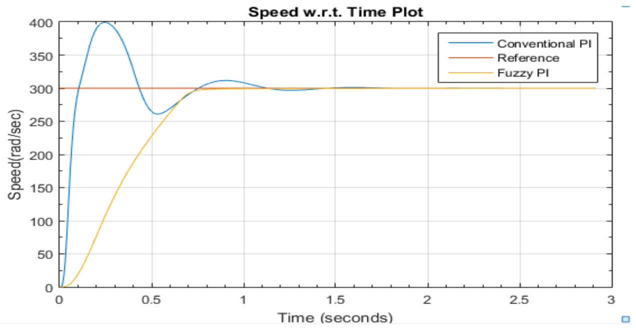


Fig. 4 Simulation result of I.M speed for ref. speed of 300(rad/sec) at no-load

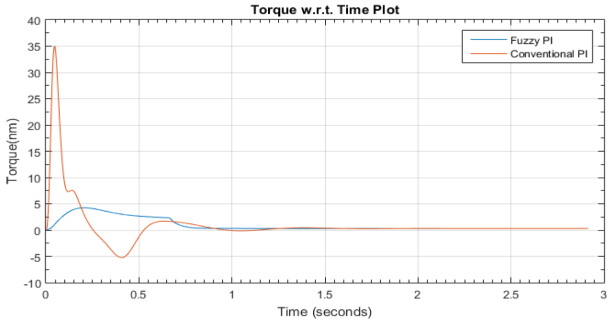


Fig. 5 Simulation result of I.M torque for ref. speed of 300(rad/sec) at no-load

In tth fig 6,7 we have set a speed of 300 rad/s to be fed so as to find out the performance with fuzzy PI controller and conventional PI controller with change in load 1N-m at 2.5 sec

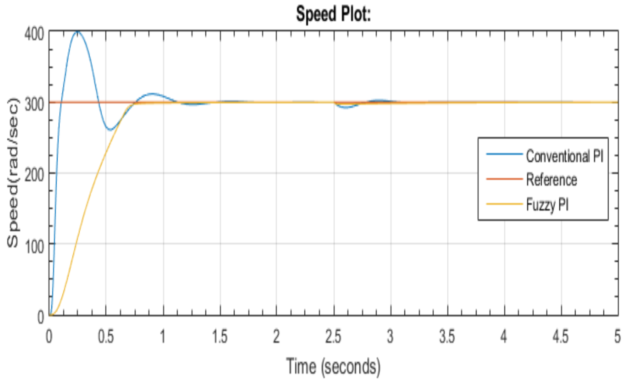


Fig. 6 Simulation result of I.M speed for ref. speed of 300(rad/sec) with change in load 1N-m at 2.5 sec.

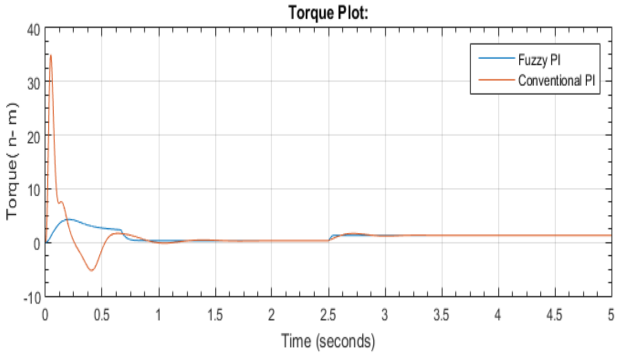


Fig 7 Simulation result of I.M torque for ref. speed of 300(rad/sec) with change in load 1N-m at 2.5 sec.

In tth fig 8,9 we have set a speed of 300 rad/s to be fed so as to find out the performance with fuzzy PI controller and conventional PI controller with change in load 1N-m at 2.5 sec

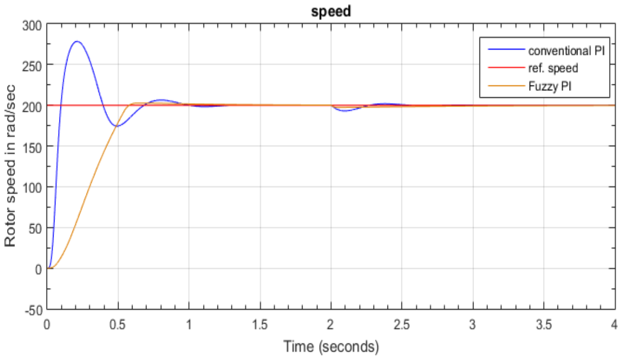


Fig. 8 Simulation result of I.M speed for ref. speed of 200(rad/sec) with change in load 1N-m at 2.5 sec.

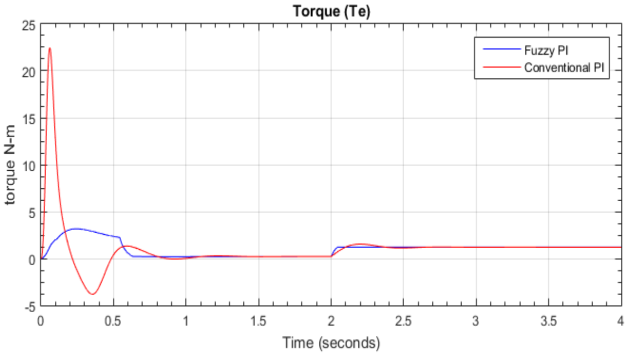


Fig. 9 Simulation result of I.M torque for ref. speed of 200(rad/sec) with change in load 1N-m at 2.5 sec.

TABLE II. Comparison of FLC and PI performance in multistep speed response

Reference Speed(rad/sec)	**Rise time (sec)**		**Settling time (sec)**		**Peak overshoot (rad/sec)**	
	FLC	PI	FLC	PI	FLC	PI
300	0.75	0.11	0.75	1.41	300	400
200	0.56	0.11	1.00	1.34	204	276

V. CONCLUSION

The performance of fuzzy logic based intelligent controller for the speed control of indirect vector controlled Induction motor drive has been verified and results were compared with that of conventional PI controller performance. The simulation results obtained have confirmed the very good dynamic performance and robustness of the fuzzy logic controller during the transient and steady state period. It is concluded that the proposed intelligent controller has shown superior performance than that of the parameter fixed PI controller.

APPENDIX

3-Phase Induction Motor Parameters
Rotor type: Squirrel cage,
Reference frame: Rotor
2.2KW, 50Hz, 4 Poles, Rs = 2.4Ω,
Rr = 1.452Ω , L_s,L_r =0.121H,
L_m=0.1H, J = 0.013Kg-m^2, B=0.002.

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