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An Intelligent Speed Controller Design for Indirect Vector Controlled Induction Motor Drive System

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Abstract

The aim of this paper is to present an Indirect vector control technique (Rotor- field Oriented) for a three phase Induction Motor drive using soft computing technique. Intelligent Speed Controller is being designed with Fuzzy Logic Controllers (FLC). Different Simulation experiments were carried out using MATLAB/SIMULINK to achieve at the best controller. The rules for the Fuzzy Controller were designed based on the dynamic behavior of the error signal. The performances of the proposed Fuzzy Logic Controller based Induction Motor drive are compared with that of the conventional PI controller based drive at different operating conditions.

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Keywords: vector control; Fuzzy Logic control; Rotor Field – oriented Control; Soft Control of Induction Motor

1. Introduction

Applications of three phase ac machines in different operating regimes are ever increasing. They have some limitations like production of harmonics, excessive drawl of reactive power and difficulty to control speed compared with DC drives. So, present day scenario demands an in depth study on these AC machines to analyze the behaviour and optimal performance in different operating regions. Of these AC drives, Induction motors are the most commonly used electric drives in the industries due to its robustness, small size, low cost and requirement of less maintenance[1].

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The difficulty in control of three phase Induction Motor lies in the fact that in Induction Motors the current responsible for producing the torque and the current responsible for producing flux are not decoupled. But this problem can be solved by the introduction of better control techniques using Vector Control. The underlying principle of vector control is to decouple the components and then control each component independently, in the same way as is done in a separately excited DC motor. Thus a drive system with a good dynamic response to the changes in load or in reference speed can be developed.

In conventional speed controller design of a Rotor Field Oriented Control (RFOC), a PI controller is used to control the speed of the induction motor drive. The use of PI controller induces many problems like high overshoot, oscillation of speed and torque due to sudden changes in load and external disturbances. The poor capability of dealing with system uncertainty, i.e. parameter variations and external disturbances, is a disadvantage of the PI controller. This behavior of the controller causes deterioration of drive performance. The conventional control methods depend on the accuracy of the mathematical model of the system developed [2]. Also, the expected performance is not met due to the load disturbance, motor saturation and thermal variations. Classical linear control shows good performance only at one operating speed. In this control, choosing the proper coefficients with varying parameters like set point is very difficult.

Advanced control based on artificial intelligence technique is called intelligent control. Intelligent control act better than conventional adaptive controls. Fuzzy logic is a technique to embody human-like thinking into a control system [3, 4 and 5]. Fuzzy Logic Control (FLC) approach is very useful for induction motor speed drives since it do not require exact mathematical model of the motor. A rotor-field oriented control of three phase Induction Motor with a Fuzzy Logic Controller is proposed in this paper.

2. Rotor Flux Field Orientation of Induction Motor

The field orientation was made according to the rotor flux vector. The magnitude of the rotor flux is obtained using a flux observer, but the frequency of the rotor field is neither computed nor estimated but it is imposed depending on the load torque value i.e. the slip frequency, and then integrated to obtain the imposed rotor flux position (angle θ_r). The mathematical model of induction motor is given by [1, 5, 6 and 7]:

$$\theta_e = \int \omega_e = \int (\omega_r + \omega_{sl}) = \theta_r + \theta_{sl} \quad (1)$$

The rotor circuit equations of the Induction Motor in d-q frame are given by:

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

$$\frac{d\psi_{qr}}{dt} + \frac{Rr}{Lr}\psi_{qr} - \frac{L_m}{L_r}R_r.i_{qs} - \omega_{sl}\psi_{dr} = 0 \quad (3)$$

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

$$\frac{L_r}{R_r}.\frac{d\psi_r}{dt} + \psi_r = L_m.i_{ds} \quad (4)$$

The slip frequency can be calculated as:

$$\omega_{sl} = \frac{L_m.R_r}{\psi_r L_r} i_{qs} \quad (5)$$

The decoupling can be achieved if the above slip angular speed command is used for making the field orientation.

The control rotor flux ψ_r and $\frac{d\psi r}{dt} = 0$ can be substituted in equation (4), so that rotor flux set as

$$\psi_r = L_m . i_{ds} \quad (6)$$

The electromagnetic torque developed in the motor is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(i_{qs}.\psi_{dr}) \quad (7)$$

But $\psi_{dr} = L_m . i_{ds}$. On substitution,

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(i_{qs}.i_{ds}) \quad (8)$$

Here, i_{qs} is the torque component of Stator Current and i_{ds} is the flux component of Stator current. In addition, rotor flux linkage is not affected by the change in I_{qs} (That is, decoupled)[1,8,9].

3. Fuzzy Logic Controller Design

Block Diagram of the proposed Fuzzy Logic Controller is shown in fig. 1. In this proposed model, the speed error signal and its time derivative are assigned as input variables. The speed error is computed by comparing the speed signal feedback and the reference speed. Appropriate normalizations are done which has a direct influence on the system response and algorithm optimality [10, 11].

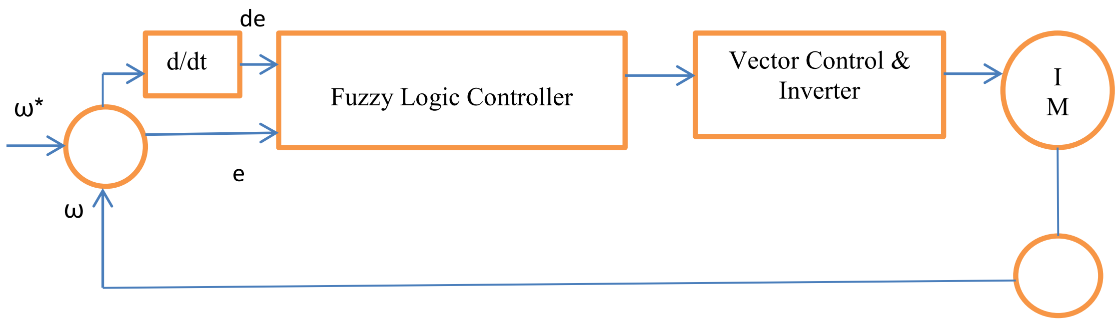


Fig 1 Block diagram of fuzzy logic based controller

Membership functions are defined within the normalized range for the two input variables as: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM(Positive Medium) and PB (Positive Big). Seven Membership Functions are chosen for e (pu) and de (pu) signals and seven for output. All the MFs are symmetrical for positive and negative values of the variables. Thus, 7x7 = 49 rules are formed.

The membership functions defined for the input and output variables are shown in figure 2(a), (b) and (c). Both utilize normalized universes of discourses to make the controller easier to port to different machine ratings. The fuzzification process will result in the activation of two membership functions. This is desirable to ensure the interpolation capability of the fuzzy controller. The output variable is also normalized and the rule base for the fuzzy controller is illustrated.

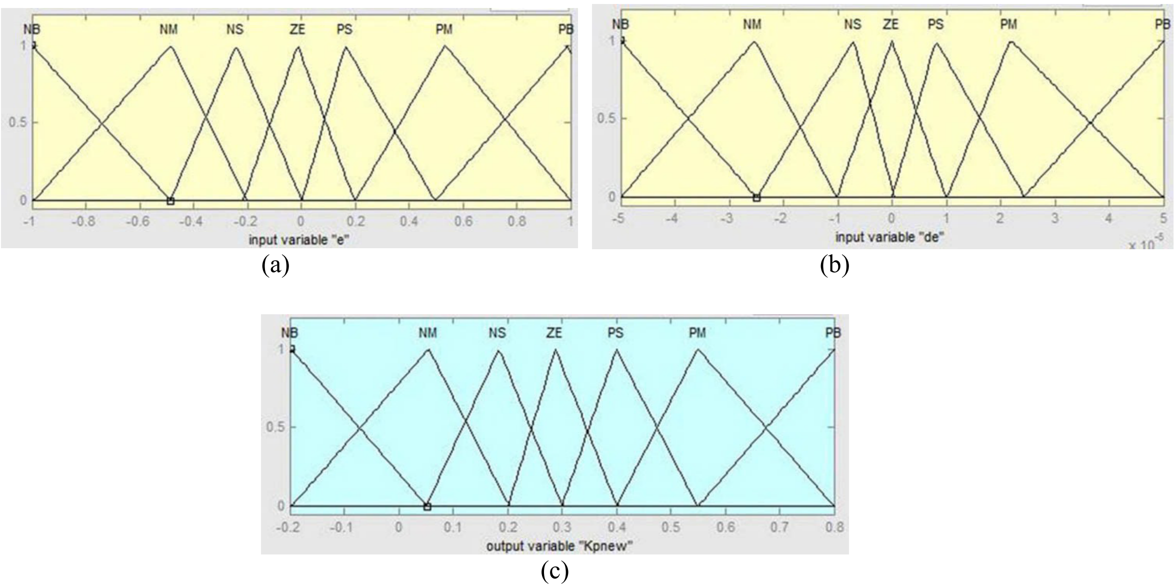


Fig 2 Membership functions for the input and output variables

The three dimensional control surface is shown in the figure 3. The rule base of the fuzzy controller is given in the table 1. However, the inference strategy is the 'mamdani algorithm', so the if-then rules for fuzzy control for the speed controlerl will be forty nine rules.

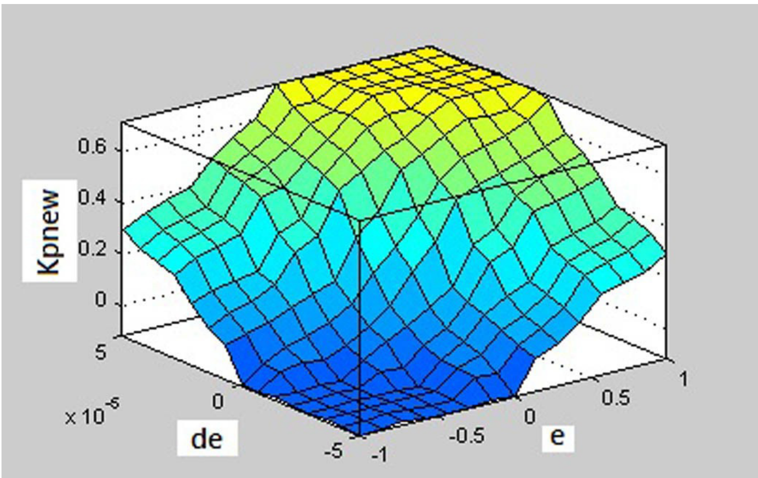


Fig 3 Three Dimensional Surface Plot of Control Variables

Table 1. The rule base of the fuzzy controller

de \ e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

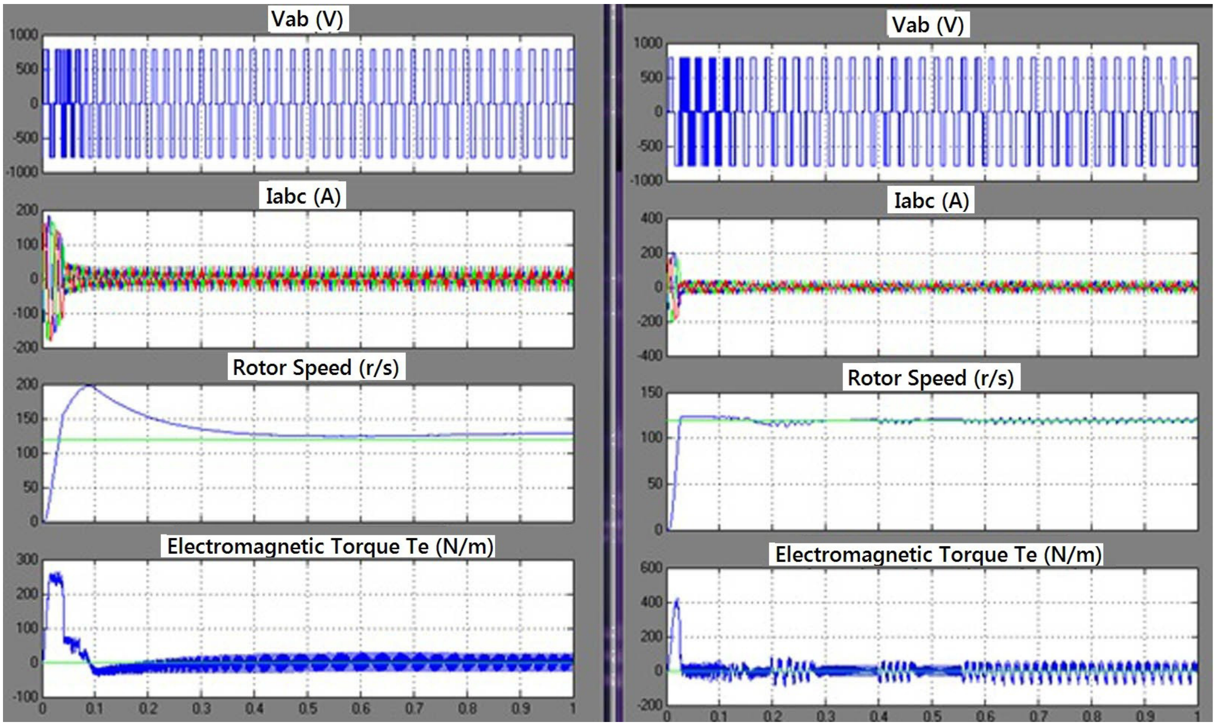
4. Results And Discussions

The Indirect Rotor Field Oriented Vector Control was implemented by Matlab/Simulink model. Simulations were carried out on both PI controller and the developed fuzzy logic controller on the indirect vector control of induction motor. The parameters of the Induction Motor used in simulation are shown in Table 2.

Table 2. Parameters of Induction Motor used in Simulation

HP	10
Supply Voltage, Line-to-Line, Vs	460
No.of Poles, P	4
Frequency, F	60
Stator Resistance, Rs(ohm)	0.6837
Stator Leakage Inductance, Lls (H)	0.004152
Rotor Resistance, Rr(ohm)	0.451
Rotor Leakage Inductance, Llr (H)	0.00415
Mutual Inductance, Lm (H)	0.1486
Inertia (Kg.m2)	0.05
Friction Factor (NmS)	0.00814
RPM	1760

Fig 4 shows the simulation results with PI Controller and FLC with a command speed of 120rad/sec applied with no load condition.



(a) (b)

Fig 4 (a) With PI Controller (b) Fuzzy Logic Controller

Fig 5 shows the variation of rotor speed for both PI and FLC for a step input of 120r/s. The results show that even though there is not much improvement in response time compared with PI controller, but the ripples in the torque developed as well as steady state speed and current are reduced much. The results could be improved by optimizing the membership functions and rule bases.

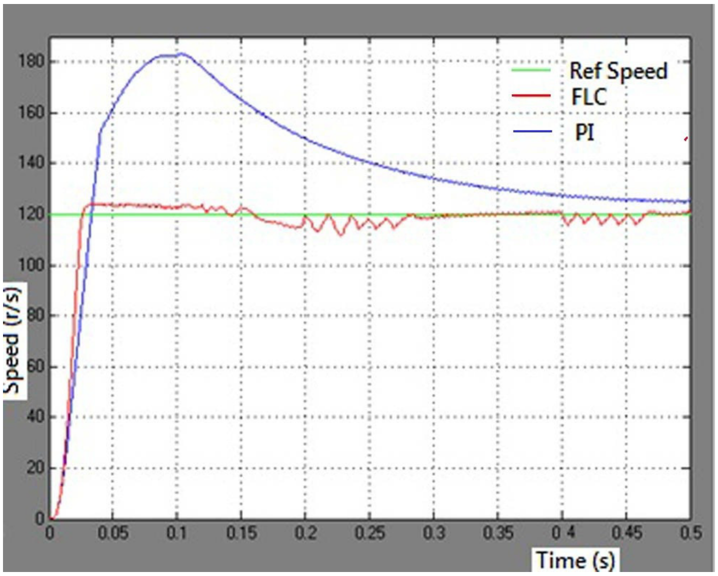


Fig 5. Variation of rotor speed for both PI Controller and FLC for a step input of 120r/s

The results obtained for the proposed model are shown in table 3:

Table 3

Response Parameters	PI	FLC
Rise Time (S)	0.06	0.03
Settling Time(S)	0.5	0.05

5. Conclusion

Matlab/Simulink Model of Rotor Field Oriented Control (RFOC) of Induction Motor was developed using PI Controllers and Fuzzy Logic Controllers. The FLC model results show improvement in ripple content of torque, stator current and steady state speed response and the dynamic response. From the results, it is observed that the stator current does not exhibit any overshoots or undershoots and the response of the speed curve takes only 10% of the settling time of the PI controller for the machine under consideration. A more generalized model with Fuzzy Logic Controller can be developed.

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