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A Fuzzy Pre-Compensated-PI Controller for Indirect Field Oriented Controlled Induction Motor Drive

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Abstract— **This paper presents design, analysis and simulation of fuzzy logic controller for indirect field oriented control (FOC) of induction motor drives. The induction motor drive is controlled using a FOC, which allows a fast transient response of the system by controlling a decoupled flux and torque components. Moreover, a fuzzy pre-compensated proportional-integral (PI) controller is used for attaining a better dynamic performance of the proposed drive system. The performance of the proposed fuzzy controller is compared with the conventional-PI controller for the operation of the induction motor drive at rated load and light loading conditions. The obtained results demonstrate effectiveness and robustness of the proposed fuzzy logic controller.**

*Keywords—**Indirect vector control; field oriented contro; induction motor; fuzzy logic; PI control; speed control; induction motor.***

I. INTRODUCTION

Because of low cost and ease of implementation, indirect vector control IMD finds large number of industrial applications. The indirect field oriented control has two feedback loops. The inner loop is a current synchronization loop, where the feed-forward current synchronizer is mostly used. With precise slip computation, the disunited control of flux and torque can be easily acquired. For the speed control, the outer loop is used. The outer loop consists of a proportional-integral (PI) controller which produces a dominating current i_{qs}^*, which is directly proportional to the related torque. PI-controllers are often used for their simplicity. The dominating currents i_{ds}^* and i_{qs}^* depends upon the performance of the PI-controller and the preciseness of the slip computation. But the slip computation depends upon the rotor time constant which deviates according to the operational conditions. The-PI controller does not compensate for the change in parameter of the plant as it is not a knowledge-base controller [4].

In the indirect vector control approach, the shaft speed is commonly achieved, and the slip speed is computed which is established upon the motor parameters which defines the angular frequency of the rotor flux.

The field orientation control of IMD method is suitable as a major candidate in high-version motor drive approach. The fast transient response is formed feasible through disunited torque and flux control [1].

Conventionally, FOC uses a three-phase uncontrolled diode bridge rectifier with a capacitor filter at the front end, which converts the three-phase AC mains input into a smooth dc voltage. The speed control issues of induction motors are generally governed by stable gain PI or PID controllers [3]. However, the stable gain controllers are very delicate to load disturbances and change in parameters. In conventional PID controllers there is a inconvenience with firm speed tracking, change in parameter and load disorders. Due to which, the motion control scheme performance degrades with some level [6]. Thus, a continuous adaptation of control parameters should be there. There are various control techniques to solve this problem such as MRAS, sliding mode control, self tuning PI controller etc. These systems require a exact mathematical model due to unaware load disorders and change in parameters. To overbear the above issues, Fuzzy logic controller (FLC) is used, as it does not need a mathematical model and depends upon linguistic rules within IF-THEN configurations [2].

Fuzzy control provides an organized approach which uses individual's proficiency in the controller. The application of fuzzy controller in the machine drive application has been potentially increased. The author of [10] and [11] presents a specific FLC for a doubly excited reluctance machine and a standard fuzzy controller for the same machine. In [11], the popular MRAS scheme is grouped with the fundamentals of fuzzy logic. Fuzzy logic is employed to an IMD in [12] in which the gain of PI controller is changed by the fuzzy controller. This approach shows better performance. However, it is extra complicated as it uses two controllers.

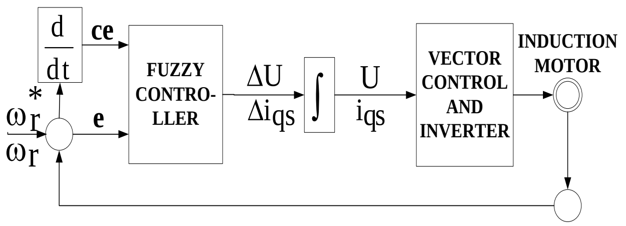


Figure 1. Operational block diagram of Fuzzy Logic Controller.

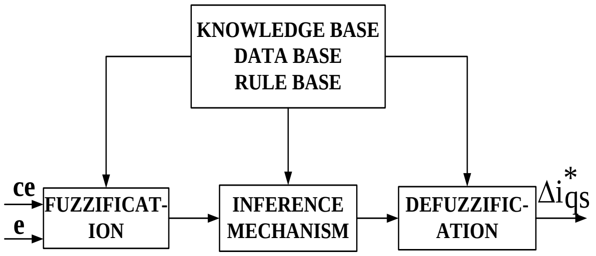


Figure 2. Internal configuration of Fuzzy Logic Controller.

In this paper, a FLC in the indirect vector control of IMD has been successfully examined. The implementation of the FLC is thus related with the standard PI controller. It is found that FLC is unfriendly to load torque disorders. Thus, FLC is a good alternate for the standard PI controller.

II. FUZZY CONTROLLER: FUNDAMENTALS AND DESIGN

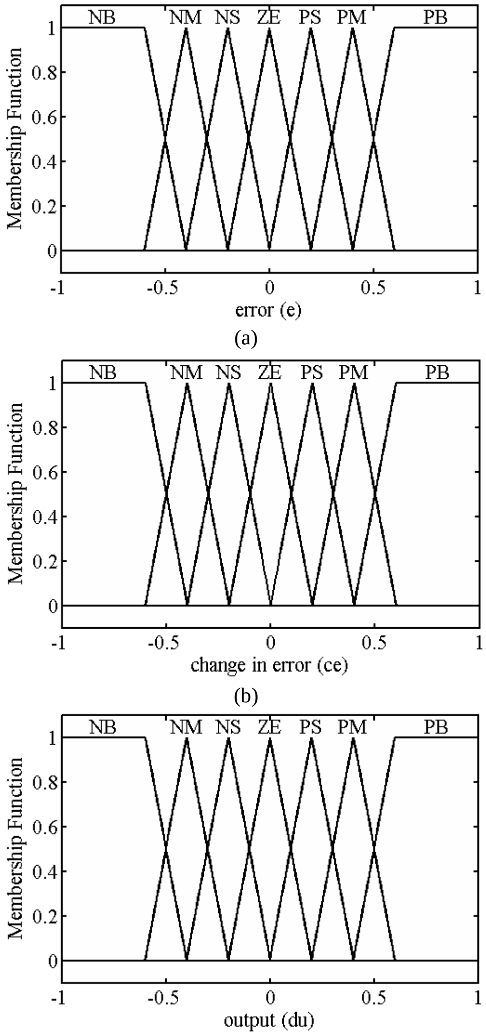
Fuzzy logic offers an easiest approach of scheming controller deviations from individual’s knowledge and expert knowledge about the method to be controlled. This approach enhances the reworking, dependability and wellness of the closed loop system.

In the induction motor drive techniques, the optimization problems are solved by the fuzzy logic technique. In this proposed technique, the speed of rotor can be treated as a optimization problem [5].

The proposed FLC is a Mamdani-type rule based system, the error in speed and change in speed error are considered as the input linguistic variables, and the output linguistic variable is the torque producing current component. The functional relationship can be explained by the equation below [2].

$$i_q(k) = \int \Delta i_q(k) = f\left\{\Delta e(k), \Delta\omega_r(k)\right\} \qquad (1)$$

where, $\Delta e(k) = \Delta\omega_r(k) - \Delta\omega_r(k-1)$ is the change in error of speed , $\Delta\omega_r(k) = \Delta\omega_r^*(k) - \Delta\omega_r(k-1)$ is the recent selection of the speed error, $\Delta\omega_r(k-1)$ is the previous speed error, $\Delta\omega_r(k)$ is the recent selection of actual speed, $\Delta\omega_r^*(k)$ is the recent sample of the reference speed, and f denotes the non linear function.



(a)

(b)

(c)

Figure 3. Membership Functions; (a) for error; (b) for change in error; (c) output

The major aim of this control scheme is to trace the dominating speed by delivering the torque yielding current component i_{ds}^* appropriately, which depends upon the functional conditions. In real time, the information regarding motor situation and output of the fuzzy logic controller, which is q-axis current i_{qs}^*, and the d-axis current are used to calculate the dominating currents i_a^*, i_b^*, i_c^*. The position of the motor is expressed by the relation $\theta_e = \theta_r + \theta_{s1}$ where θ_e is the circulating angular position, θ_r is the position of rotor and θ_{s1} is position of slip, due to slip speed [2].

Each variable consists of seven membership functions. Following are the fuzzy sets which are used: NB= NEGATIVE BIG, NM= NEGATIVE MEDIUM, NS= NEGATIVE SMALL, ZE= ZERO, PS= POSITIVE SMALL, PM= POSITIVE MEDIUM, PB= POSITIVE BIG. Table 1 shows the fuzzy rule base and has 49 rules [5].

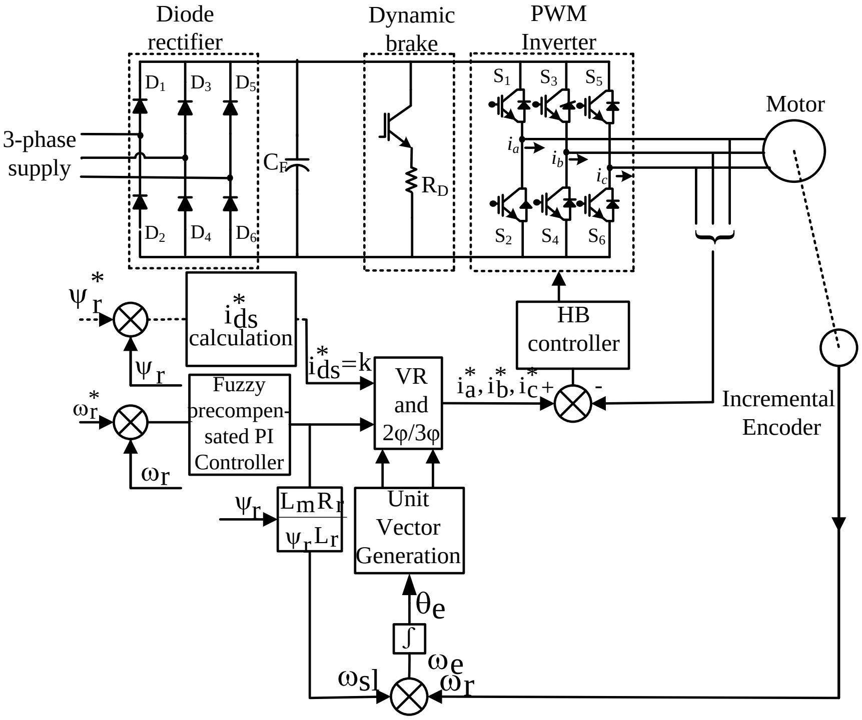


Fig. 4. Block diagram of indirect vector control utilizing fuzzy logic controller.

III. INDIRECT FIELD ORIENTED CONTROL

The indirect field oriented control technique is same as direct vector control, but with a difference that the unit vectors $\cos\theta_e$ and $\sin\theta_e$ are generated in indirect manner [9]. The phasor diagram shown in Fig. 5 explains the basic principle of indirect field oriented control technique. The rotor axes d^r-q^r are rotating with a speed ω_r as shown, while the stator axes d^s-q^s are fixed. The axes d^e-q^e are rotating synchronously rotating and are ahead of the rotor axes with angle θ_{sl} which has a slip frequency ω_{sl} [7] . The equations for implementing indirect field oriented control are shown as [8]

$$\theta_e = \int \omega_e dt = \int(\omega_r + \omega_{sl})dt = \theta_r + \theta_{sl} \tag{2}$$

The rotor current equations are

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

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} - \omega_{sl}\psi_{dr} = 0 \tag{4}$$

For disuniting control $\psi_{qr} = 0$, the whole flux ψ_r directs on the d^e axis.

Substituting this condition in equations (3) and (4), we get

$$\frac{L_r}{R_r}\frac{d\psi_r}{dt} + \psi_r = L_m i_{ds} \tag{5}$$

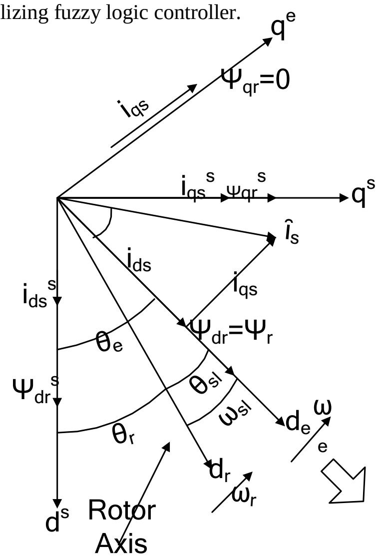


Fig. 5. Phasor diagram explaining the indirect vector control

The slip frequency may be computed as

$$\omega_{sl} = \frac{L_m R_r}{\psi_r L_r} i_{qs} \tag{6}$$

As the rotor flux ψ_r is constant then $\frac{d\psi_{qr}}{dt} = 0$, using this in equation (5) gives

$$\psi_r = L_m i_{ds} \tag{7}$$

TABLE I. LINGUISTIC RULE BASE FOR PI-TYPE FUZZY LOGIC CONTROLLER

E → ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NM	NM	NS	NS	NS	ZE
NM	NM	NM	NS	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PM
ZE	NS	NM	NS	ZE	PS	PM	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PS	PM	PM
PB	ZE	PS	PS	PM	PM	PB	PB

TABLE II. COMPARATIVE PERFORMANCE OF PI AND FLC OVER DIFFERENT LOADING CONDITIONS.

Load Condition	**Performance Comparison**		
	Peak Overshoot %	**Settling Time Sec**	**Steady-State Error %**
PI on No Load	23.42	2.37	0.7936
PI on Load	5.97	2.73	0.1426
Fuzzy on No Load	1.81	1.19	0.7655
Fuzzy on Load	0.57	1.41	1.6853

The electromechanical torque equation is given by

$$Te = \frac{3}{2}\left(\frac{P}{2}\right)\frac{Lm}{Lr}\psi_r i_{qs} \tag{8}$$

The schematic of the proposed system is displayed in Fig. 4. In the proposed method, the conventional PI controller is replaced by the Fuzzy pre-compensated-PI Controller (FLC). In this method, there is a power circuit with diode bridge rectifier and a PWM voltage source inverter. In this scheme a hysteresis-band current control PWM is used. The torque component of current $i_{qs}^*$is generated by output of the fuzzy logic controller which is the speed control signal. The flux component of the current i_{ds}^* for the desired rotor flux is calculated with the help of equation (8).

IV. SIMULATION RESULTS

Operation of the indirect vector control based IMD is studied for both the configurations namely, the PI controller and the FLC, as the speed controller. Fig. 6 shows the dynamic working of the indirect vector control technique with PI controller for load operation. Waveforms consists of rotor speed (N_r), stator currents (i_{abc}), motor line voltage (V_{ab}), and electromagnetic torque (T_e) [13]. The waveforms of the indirect vector control induction IMD with the Fuzzy pre-compensated-PI Controller are shown in Fig. 7. It can be noted from Fig. 7 that the FLC is showing smooth performance.

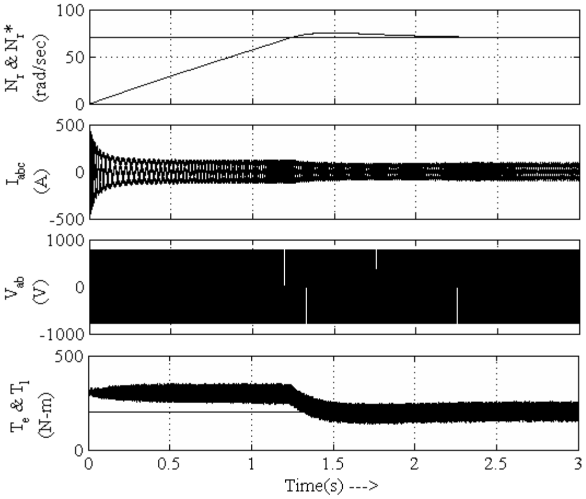


Fig. 6. Dynamics of IFOC based IMD with PI controller.

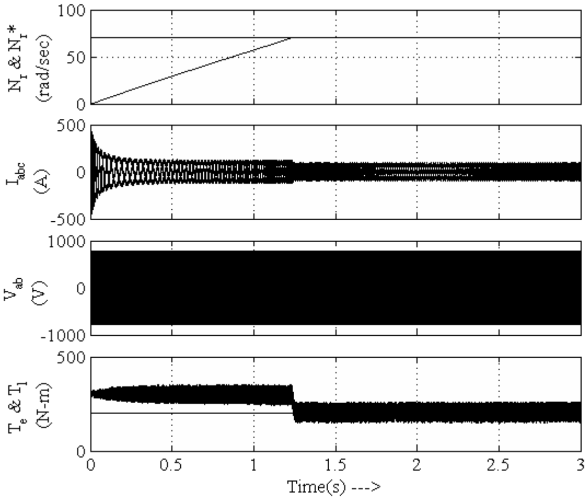
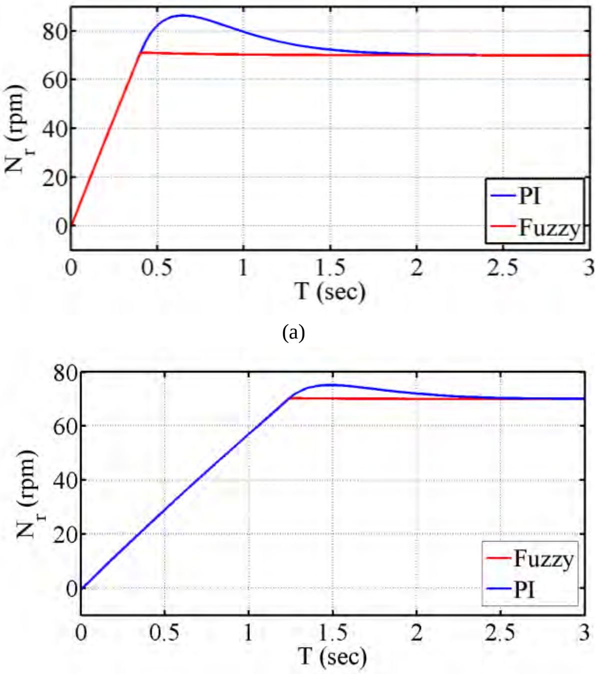


Fig. 7. Dynamics of IFOC based IMD with Fuzzy Logic controller.

The Fig. 8 shows the comparative performance of the PI and Fuzzy pre-compensated-PI controller. The result is shown for the reference speed of 70 rad/s. Fig. 8(a) shows the operation of PI and FLC at No-Load condition. In this, the PI controller is showing a overshoot of 23.42% whereas the FLC is showing a smoother response. The overshoot of the FLC is 1.81% which is very less as compared with the response of PI controller. Fig. 8(b) shows the operation of PI and FLC at loaded condition. In this, the PI controller is showing a overshoot of 5.97% whereas the FLC is showing a very smooth response.



(a)

(b)

Fig. 8. Speed response of PI and Fuzzy controller at (a) No Load, (b) On Load

The overshoot value of the FLC is 0.57% which is very less as related with the PI controller. In both the operations, the FLC settles down in very less time. Overall, the FLC is showing better performance over the PI controller. Table II shows the correlation of the PI and Fuzzy pre-compensated-PI Controller over the No-Load and On-Load condition.

V. CONCLUSION

A Fuzzy Logic based indirect vector control of IMD drive with improved speed performance has been designed for a 50HP motor. The simulation results of the fuzzy pre-compensated-PI controller shows a improved and better dynamic behavior of the motor which settles down very fast, very less overshoot response and has better operation than the PI controller. In all, the fuzzy pre-compensated-PI controller found to be a practical solution for the speed control operation of induction motor drive.

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