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# Performance Evaluation of Vector Controlled Induction Motor Using Self-tuned Fuzzy Logic controller

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***Abstract***
*The need to control the speed of an induction motorto enhanced steady speed response is the aim of this paper.In process control, the motor is sometimes applied in multifunction processes and variable speed operation, hence, the need for system control. The design and simulation of a conventional PI and Fuzzy logic is developed and implemented in MATLAB/SIMULINK environment to control the speed and flux of an induction motor. The proposed design is a modified control model of a proportional integral (PI) for optimal control of induction motor on-load and on no-load operations. Using the conventional PI, the system experiencesspeed and flux oscillation, overshoot, long settling time, and rise time.For this reason, a self-tuned Fuzzy logic PI controller is designed. The output scaling factor (SF) of the controller is modified on-line by Fuzzy rules according to the current trend of the controlled process. The rule base for tuning the output SF is defined as error (e) and change in error ($\Delta e$) of the controlled variable. The simulation results show that the Fuzzy logic controller has a better performance compared to the PI controller.*

***Keywords:*** *Induction motor, self-tuned Fuzzy logic,PI controller, vector control.*

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## I. Introduction

An induction machine is dependable in industrial processes and position control. This is due to the advantages such as; rugged construction, high efficiency, less maintenance operation, etc. However, the induction motor response characteristics when driving mechanical load and influenced by some environmental conditions, experience high overshoot, speed oscillations, long settling time, and rise time which affects the motor performance. Therefore, there is need to incorporate a control system during motor operation. The optimal control of induction motor speed, using self-turned PI and Fuzzy Logic Controller is of great concern to researchers in recent times. The focus is mainly to achieve optimal performance in the present of perturbation. The induction motor is an important class of electric machines which finds wide applicability as a three phase motor in the industry and in its single phase form in several domestic uses, [1, 2]. Also, the motor is distinguished from other motors by the mode of excitation. The rotor of the machine with a spinning coil passing electromagnet magnets, which at steady state, the rotation of the shaft is synchronized with the supply current and the resulting magnetic field that drives it. The relationship between the speed and the synchronous speed is usually express in term of the frequency and pole.

Speed control is one of the various application that imposed difficulties on the choice of motor. However, in the past years, studies and implementation of various methods have been carried out. The speed control mechanisms as provided, shows that the Volts/Hertz control scheme is very popular, hence it provides a wide range of speeds with good performance during transients.

The control mechanism in which both the input and output commands are speed is referred to as scalar control, whilevector controlis when torque/flux and reference current variable of control. Vector control design provider better performance in terms of dynamic speed regulation, but difficult in implementation, due to on-line coordinate transformations that covert line current into two axis representation, [3]. The non-linear nature of the induction motor control dynamics demands better control strategy for the control of speed. The controllers that are regularly used for motor speed control applications are: Proportional Integral (PI), Proportional Derivative (PD), Proportional Integral Derivative (PID), Fuzzy Logic Controller (FLC) or a blend between them. The PID controller, if properly tuned, offers an efficient solution to several control problems, [4]. However, this feature has made the PID controller more popular in industrial application. However, the common problem associated with the use of conventional PI, PD and PID controllers in speed control of induction motor, is the complexity in design, due to non-linearity of induction motor dynamics. The non-linearity of the system can be linearize by the conventional controller in order to calculate the parameter, [5]. The conventional control strategy however, possess the following problem:

- ❖ Dependence on the actual mathematical model of the system.
- ❖ Unstable system due to load disturbance, motor saturation and thermal deviation.
- ❖ Effective performance can only be exhibited at one operating speed, when classical linear control is employed.
- ❖ Adopting the right coefficient for acceptable results.

Investigation had shown that, to overcome the complexity of conventional controller, the Fuzzy logic controller (FLC) is a good option. However, the Fuzzy Logic Controller (FLC) which uses a simple IF and THEN rules linguistic rules in some applications also have a drawbacks. This complexity and the drawbacks is overcome using self-tuned controller that is tuned in order to eliminate the steady state error.

A torque is produced as a result of the force that tends to move the rotor in the same direction as the rotating field. This was however, justified by Lenz law, according to which the direction of rotor currents will be such that they have a tendency to oppose the cause producing them. However, the relative speed between the rotating field and the standstill rotor conductors is that which generate the rotor currents. Meanwhile, to reduce this speed, the rotor starts running in the same direction as that of the stator field and tries to meet at a point. The speed control of induction motor is at some point complex to control than that of the D C motors, especially where comparable accuracy is required. However irrespective of the numerous advantages of induction motor, it also has disadvantages, such as complex, nonlinear and multivariable of mathematical model and that the induction motor is not inherently capable of providing variable speed operation, [8,9]

These problems can be solved through the use of smart motor controllers and adjustable speed controller, such as scalar and vector drive [10, 11]

The method of controlling AC machines, known as the vector control was invented by Blaschke and Hasse within 1970/1980 [12]. The vector control method is used when high performance of control is desired [13]. The vector control method is of two types known as: Direct Torque Control (DTC) and the Field Oriented Control (FOC). The DTC was invented by Blaschke in 1980 [14]. Hence the FOC was invented by Hasse in 1970 [15]. However, in direct vector control method, the rotor flux is estimated by using flux sensor in the air gab or by estimating the sensing stator voltages. Meanwhile, in an indirect vector control, the rotor flux is estimated by using the Field Oriented Control (FOC) equations, which at some point will need the instantaneous speed information. The direct vector control is difficult to implement practically at low speed application.

The Indirect Field Oriented Control (IFOC) is then preferred to the direct vector control due to accuracy over wide range of speed. More so, the direct method requires flux acquisition that is mostly obtained by computational techniques using terminal quantities. [15]. Meanwhile, the Indirect Field Oriented Control (IFOC) method does not require flux acquisition, rather uses the known motor parameter to compute the appropriate motor slip speed wd to obtain the desired flux position,[16]. The indirect vector control method is almost the same, but the unit (cosθ and sinθe) are generated in feed forward manner, using the measured rotor speed wr and the slip speed wsl. The indirect vector control is widely used in industrial application, due to accuracy over wide range of speed. In the recent time, the conventional control approach have been integrated into the induction motor speed control techniques, but observed that the conventional control of induction motor proved to be difficult due to strong non-linear magnetic saturation effect and temperature dependency of the motor's electrical parameters, [17]. In classical FOC, the PI control is designed to control the speed of the induction motor drive and reduces system transient behaviour

, but under sudden changes in mechanical load and external disturbances, the system experience high rise time, overshoot, undershoot and steady state error.[18]. The proportional integral (PI) controller is used mostly for systems that control the speed motor , due to its low cost, simple to use and easy to design. However, PI parameters have difficulty determining their best valves. Meanwhile, the Ziegler-Nichols and Cohen-coon technique is used to find PI best parameters, [19; 20]. However, these methods are difficult and have unsatisfactory results and depend on knowing the mathematical model of the plant. The PI controller can be achieved by providing a proportional gain (Kp) and the integral corrections component or gain (Ki) using the feed forward path.The fuzzy logic controller is a control technique that is based on linguistic control strategy, derived from expert knowledge into an automatic control strategy, [21].

## II. System Mathematical Modelling

The mathematical model of an induction machine can be obtain by first describing it as a coupled stator and rotor poly-phase circuit in terms of phase variable: that is stator current $i_{as}$, $i_{bs}$, and $i_{cs}$, also, rotor current $i_{ar}$, $i_{br}$, and $i_{cr}$, the rotor motor speed $w_m$, and the angular displacement $\theta$ between stator and rotor winding.

The a b c, d-q axis of induction machine model

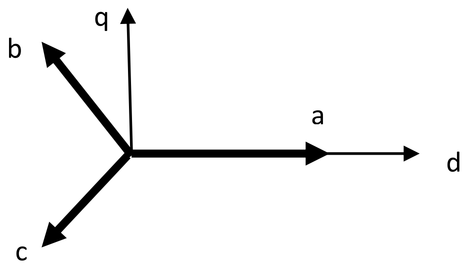


**Figure 1:** Diagrammatic representation of abc sequence and d-q axis.

$$V_d = R_1 i_d + \frac{d\Psi_d}{dt} - \omega_1 \Psi q$$
(1)
$$V_q = R_1 i_q + \frac{d\Psi_q}{dt} - \omega_1 \Psi d$$

But considering α, β, when $W_k = 0$ and d-q; when $W_k = w_{sin}$, then equation (1) can be written as:

$$\left.\begin{aligned} V_s &= R_s i_s + \frac{d\Psi_s}{dt} + j\omega_k \omega_s \\ V_r &= R_r i_r + \frac{d\Psi_r}{dt} - j(\omega_k - \omega_r)\Psi_r \end{aligned}\right\} \quad (2)$$

Where $W_k$ is the angular rotation speed of co-ordinate system and then the squirrel-cage rotor motor equations allowed for derivative flux linkage becomes:

$$\frac{d\Psi_s}{dt} = V_m \cos(\tau) - R_s \text{ls } \alpha$$

$$\frac{d\Psi_s\alpha}{dt} = -V_m \sin(\tau) - R_s \text{ls } \beta \quad (3)$$

$$\frac{d\Psi_s\alpha}{dt} = -R_r i_{r\alpha} + \text{Wr } \Psi r\beta$$

$$\frac{d\Psi_r\beta}{dt} = -R_r i_{r\beta} + \text{Wr } \Psi r\beta$$

Then $\frac{d\Psi_r}{dt} = (M_{em} - M_1)/T_m$ (4)

Where $V_m \cos(\tau) - V_m \text{ Sin }(\tau)$ is the voltage supply to the stator winding $M_{em}$ and $M_1$ is the torques electromagnetic and of load.

$T_m$, is the machine time constant measured in electrical radians.

## III. Simulink Model Of Vector Controlled Induction Motor Drive Using Self-Tuned Pi Fuzzy Logic Controller.

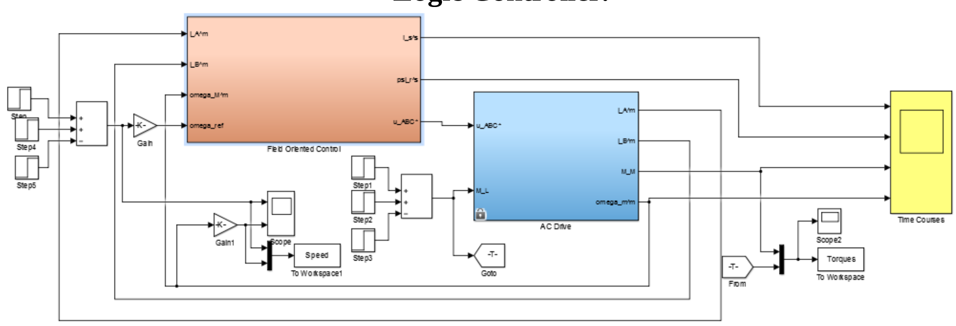


**Figure 2:** Simulink model of vector control using self-tuned PI Fuzzy controller.

The design of this Simulink block is embedded with subsystem block such as the PI Fuzzy block, PWM, and FOC. The FOC is made according to the flux vector. The figure below shows the complete FOC block.

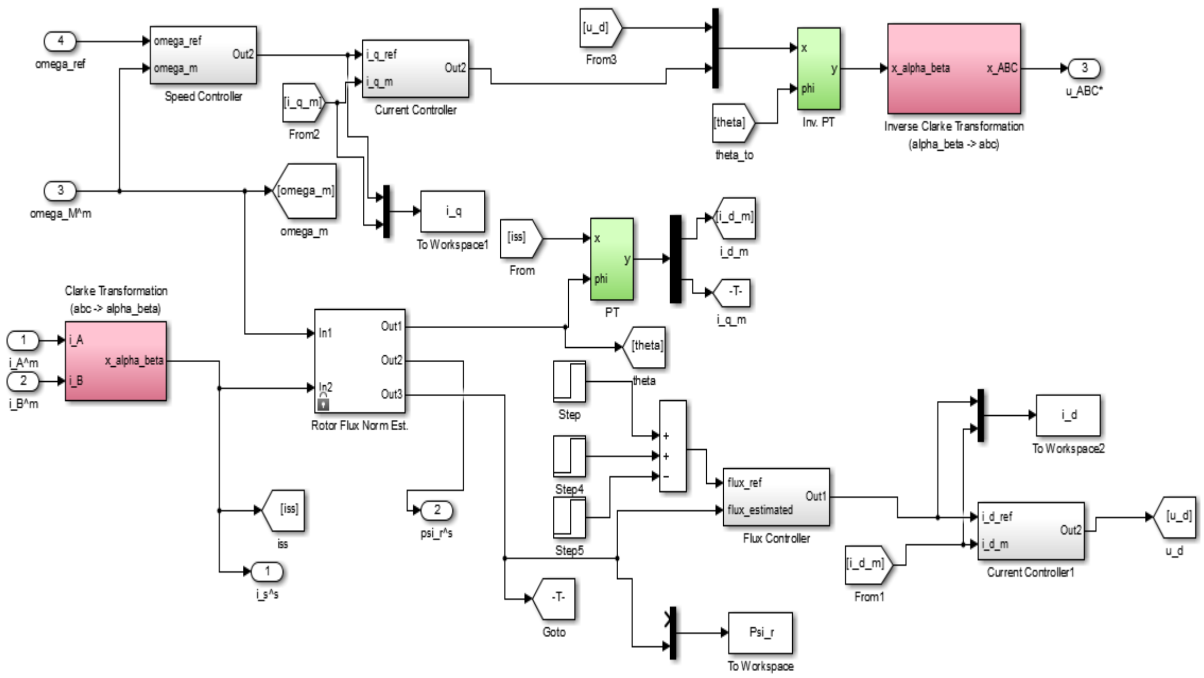


**Figure 3:** Simulink block of the FOC using PI Fuzzy controller

The reference current $i_r^*$ generated, decomposed into three phase (3∅) current with respect the rotor position$\theta$. The PWM inverter subsystem generates a 3-$\theta$ voltage that controls the motor speed and torque with respect to reference speed and load torque.

## IV. Simulation Results And Analysis

The simulation results of the motor response is shown in the figures below.

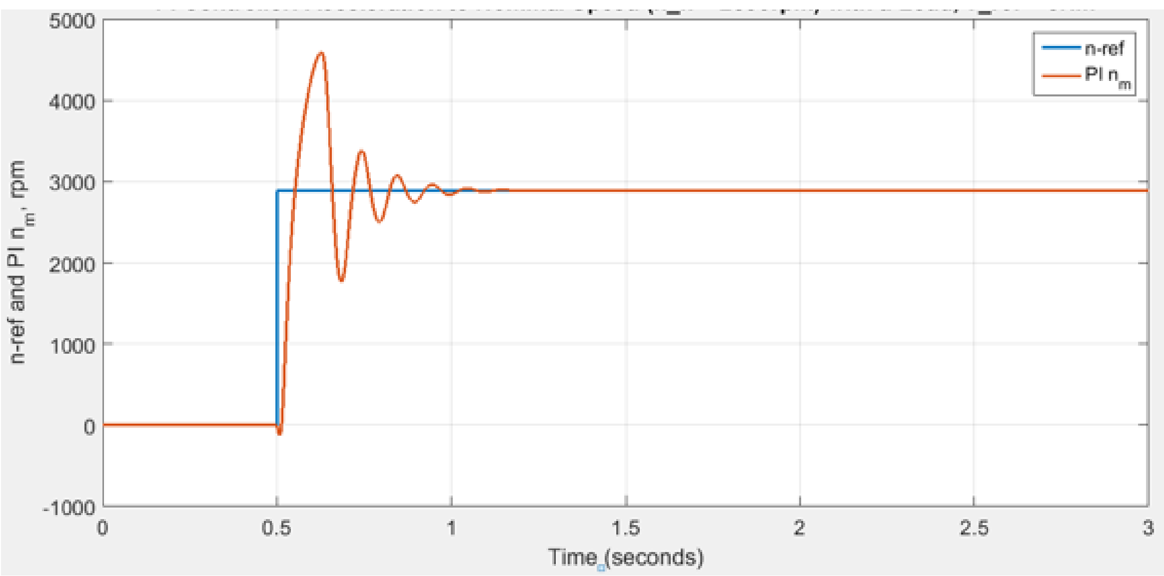


**Figure 4:** PI controller, acceleration to nominal speed of 2890 rpm with load torque of 5 Nm

The simulation results as shown for the conventional PI in figure 6 with the reference speed set to 2890 rpm with a load torque of 5 Nm. The response show high oscillation, rise time, overshoot and settling time. However, under change in reference speed and load torque, the controller response is quite appreciable with varying load. This shows that the PI controller are very sensitive to system parameter variations and any change in machine parameter results in unsatisfactory control over speed and generated electromagnetic torque. However, the system need to be self-tuned in order to obtained a better control response. The performance indices table as shown in table 1 and 2, is used to analysis the system performance characteristics response.

The conventional fuzzy logic controller of figure 5, give a good performance with a reference speed set to 2890 with a load torque of 5 Nm. The simulation results shows that the conventional fuzzy logic controller out-performs PI controller. However, when the induction motor is loaded, the rotor resistance increases due to heating, this increase in rotor resistance results in uncontrollable speed with PI controller. While fuzzy logic controller is very litter affected with this change, but give a best performance when self-tuned the controller.

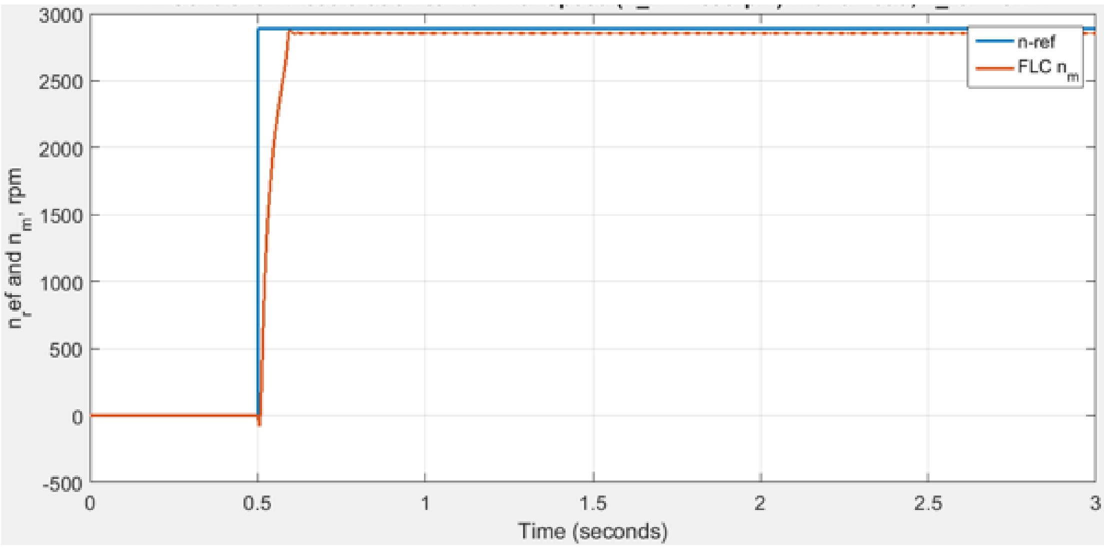


**Figure 5**: FL controller, acceleration to nominal speed of 2890 rpm with load torque of 5 Nm

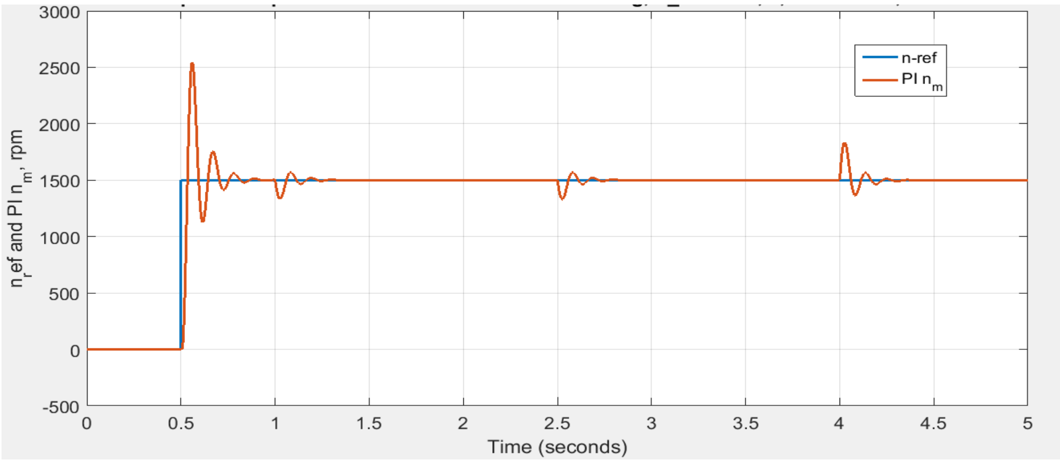


**Figure 6:** Self-tuned PI controller speed response under load tracking

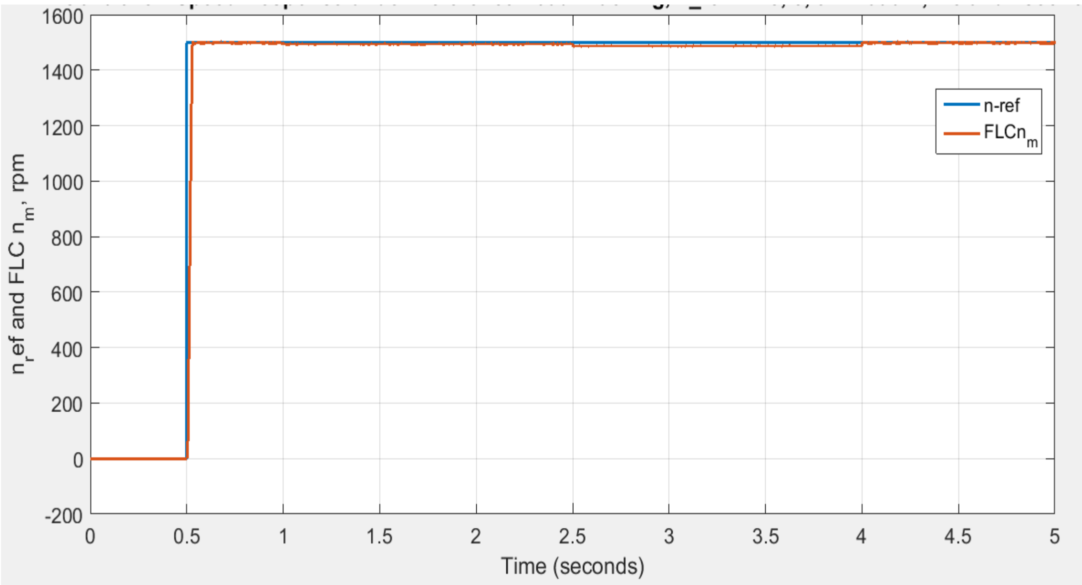


**Figure 7:** Self-tuned FL controller speed response under load tracking

**Table 1: conventional PI Fuzzy logic speed controller**

| S/N | Simulation Description | Controller | Rise Time [sec] | Settling Time [sec] | Maximum Overshoot [%] | Minimum Undershoot [%] | Steady State Error [%] |
|---|---|---|---|---|---|---|---|
| 1 | Acceleration to nominal speed under no load condition | FL | 0.057 | 0.062 | 0.173 | 0 | 0 |
| | | PI | 0.090 | 0.725 | 67.3 | 0 | 0 |
| 2 | Acceleration to nominal speed under a load of 5Nm | FL | 0.094 | 0.125 | 0 | -102.79 | 1.038 |
| | | PI | 0.127 | 0.85 | 59.13 | -104.35 | 0 |

**Table 2: self-tuned PI fuzz logic Flux Controller**

| S/N | Simulation Description | Controller | Rise Time [sec] | Settling Time [sec] | Maximum Overshoot [%] | Min. Undershoot [%] | Steady State Error [%] |
|---|---|---|---|---|---|---|---|
| 1 | Psi_r_ref = 0.5, 1, 0.75Wb at t=0.5, 2, 3.5sec resp.<br>T_ref = 5Nm at t=1sec<br>N_ref = 1000rpm at t = 0.5sec | FL | 0.01 | 0.02 | 0.758 | 0 | 0 |
| | | PI | 0.022 | 0.94 | 3.68 | 0 | 0 |

## V. Conclusion

The investigation of vector controlled induction motor drive using self-tuned Fuzzy logic controller and PI controller is implemented using MATLAB Simulink model. The induction motor as model, is created with the aid of d-q synthesis. The propose technique for this paper work, is an effective control strategy for vector control of induction motor using Fuzzy inference system (FIS). The (FIS) is built with two input, (error and change in error) and with one output. The controller takes in crisp input, through speed error (e) and change in error (Δe) and give an output called change in control. The performance of the proposed technique was extremely good with respect to rise time, overshoot, steady state and settling time. Hence the performance has zero overshoot. The controller investigation was carried out by setting the reference speed to 2890 rpm for a load of 5Nm. While the flux controller is set at 0.5, 1, and 0.75 wb at, t= 0.5, 2, and 3.5 second respectively with a load of 5Nm for both PI and Fuzzy logic controller. The results as shown on the graphical response and the performance indices table shows that the Fuzzy logic controller have a better performance than the PI controller. However, the proposed scheme is better for speed control application

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