SPEED CONTROL OF INDUCTION MOTOR USING PROPORTIONAL INTEGRAL CONTROLLER PLUS FUZZY HYBRID CONTROLLER

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***ABSTRACT* :** The classical approach of manipulating speed controllers for vector control of an induction motor creates many problems like instability, rise time and settling time during load disturbances. In this paper fuzzy plus PI and self tuning of PI plus fuzzy hybrid controllers are used. To decrease rise time and settling time these controllers are designed in Matlab/Simulink and used for a 50 HP, 3 Phase cage type Induction motor. Hybrid controllers perform well and give improved response when compared with classical controller.

***KEYWORDS* -** Induction motor, vector control, hybrid controllers (STPI plus FLC), classical PI controller.

I. INTRODUCTION

An induction motor is an asynchronous alternating current motor. Induction motors plays a crucial role in industrial appliances like control and automation, pumps and fans, paper and textile mills, subway and locomotive propulsions, electric and hybrid vehicles, machine tools and robotics, home appliances, heat pumps and air conditioners, rolling mills, wind generation systems, hence they are often called the workhorse of the motion industry. Its main characteristics are robustness, relatively low cost, reliability and efficiency. So Induction motors have major importance and used more in the industrial variable speed drive system with the development of the field oriented control technology. Induction motor behaves like a separately excited DC motor using vector control technology.

In classical Field Oriented Control, a PI controller is designed to control the speed of the induction motor drive. It induces many problems like more rise time, settling time, overshoot, under shoot, steady state error. Oscillation of speed and torque due to sudden changes in load and external disturbances [1]. This behaviour reduces the performance of motor. To overcome these disadvantages an intelligent hybrid controllers are designed based on fuzzy logic is employed in the place of the classical controller [1, 2]. A Fuzzy Logic Controller (FLC) does not need complex mathematical algorithms and is based on the IF_THEN linguistic rules. The fuzzy controller reduces all the disadvantages of the classical controller. The fuzzy logic controller resembles a PI controller with high accuracy and efficiency. The fuzzy logic controller will awards poor response for load transients and speed command variations [3].

Hybrid fuzzy plus PI controller reduces rise time, settling time, steady state error but it will not give a good response during changes in load demand [7, 8]. A self tuning of PI plus fuzzy based hybrid controller is designed to reduce the overshoot, undershoot during command speed variations and load transients.

II. INDIRECT FIELD ORIENTED CONTROL OF AN INDUCTION MOTOR

The indirect vector control method is essentially the same as direct vector control, but the unit vector signals (cos and sin) are generated in feed forward manner using the measured rotor speed and the slip speed . Indirect vector control is widely used in industrial applications. The induction machine d-q or dynamic equivalent circuit is shown in Fig 1.

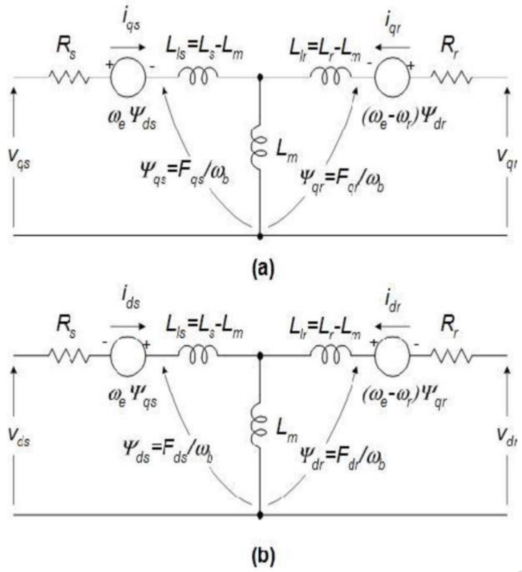

Figure 1. Dynamic or d-q equivalent circuit of an induction motor

Where

d: direct axis,
q: quadrature axis,
s: stator variable,
r: rotor variable,
V_{qs}, V_{ds}: q & d axis stator voltages,
V_{dr}, V_{qr}: q & d axis rotor voltages,
Ψ_{ds}, Ψ_{dr}, $\Psi_{qs,\ qr}$: q & d axis magnetizing flux linkages,
R_r : rotor resistance,
R_s: stator resistance,
X_{ls}: stator leakage reactance (ω L_{ls}),
X_{lr}: rotor leakage reactance (ω L_{lr}).

The mathematical model of induction motor is given by

$$\theta_e = \int \omega_e \ dt \tag{1}$$

In this paper stationary reference frame is designed so three-phase (*as-bs-cs)* variables transformed into two-phase stationary reference frame(ds-qs) variables.

$$\begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & -0.866 & 0.866 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{2}$$

By using fig 1, the electrical system equations can be written as follows:

$$\begin{aligned} v_{ds} &= R_s i_{ds} + \frac{d\varphi d_s}{dt} - \omega_e \varphi_{qs} \\ v_{qs} &= R_s i_{qs} + \frac{d\varphi q_s}{dt} + \omega_e \varphi_{ds} \\ v_{qr} &= R_r i_{qr} + \frac{d\varphi q_r}{dt} + (\omega_e - \omega_r)\varphi_{dr} \\ v_{dr} &= R_r i_{dr} + \frac{d\varphi d_r}{dt} - (\omega_e - \omega_r)\varphi_{qr} \\ \varphi_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \varphi_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \varphi_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \varphi_{dr} &= L_s i_{dr} + L_m i_{ds} \end{aligned} \tag{3}$$

Where $L_s=L_{ls}+L_m$, $L_r=L_{lr}+L_m$ L_{ls} and L_{lr} are self inductances of stator and rotor respectively. Lm is mutual inductance of stator and rotor. For singly fed machines, such as a cage rotor $v_{qr}=v_{dr}=0$. For stationary referene frame ωe=0.

Based on the above equations, the torque and rotor speed can be determined as follows

$$T_e = \frac{3}{2}\frac{p}{2}\frac{1}{\omega_b}\left(\varphi_{ds}i_{qs} - \varphi_{qs}i_{ds}\right) \tag{4}$$

$$\omega_r = \int \frac{p}{2J}(T_e - T_L)$$

The inputs of a squirrel cage induction machine are the three phase voltages, their fundamental frequency, and the load torque. The outputs, on the other hand, are the three phase currents, the electrical torque, and the rotor speed. The d-q model requires that all the three-phase variables be transformed to the two–phase stationary reference frame. Consequently, the induction machine model will have blocks transforming the three-phase voltages to the d-q frame and the d-q currents back to three-phase. It consists of five major blocks: the o-n conversion, abc-dq conversion, dq-abc conversion, unit vector calculation, and induction machine d-q model blocks shown in fig 2.

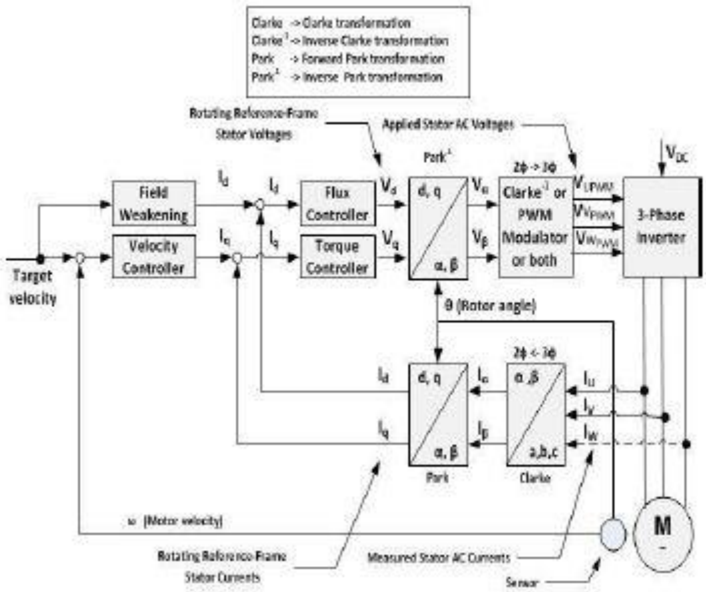

Figure 2. Flow diagram for indirect field oriented control of an Induction Motor

III. CONTROLLERS

3.1 PI Controller

Control signal used for this technique is given by

$$T_e = k_p e + k_i \int e\,dt \tag{5}$$

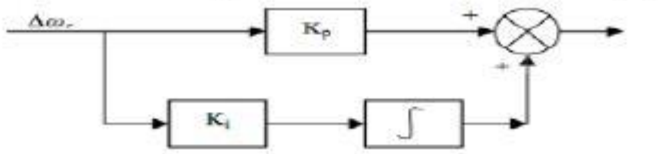

Figure 3. PI controller

The proportional controller is a device produces an output signal which is proportional to the input signal shown in fig 3. It improves the steady state response, disturbance signal rejection and relative stability. It also decreases the sensitivity of the system w.r.t parameters. The PI controller produces an output signal consisting of two terms- one proportional to input signal and the other proportional to the integral of input signal. If the gains of the controller exceed a certain value, the variations in the command torque become too high and will decrease stability of the system. To overcome this problem, a limiter ahead of the PI controller is used [6].

3.2 Fuzzy logic plus PI hybrid controller

The drawbacks of this PI controller are the occurrence of overshoot while starting, undershoot while load application and overshoot again while load removal [4,5]. In the fuzzification block, the inputs and outputs crisp variables are converted into fuzzy variables ‗e', ‗de' and ‗du' using the triangular membership function[1] shown in figure V. The fuzzification block produces the fuzzy variables ‗e' and ‗de' using their crisp counterpart. These fuzzy variables are then processed by an inference mechanism based on a set of control rules contained in (3*3) table as shown in Table I**.** The fuzzy rules are expressed using the IF-THEN form. The crisp output of the FLC is obtained by using MAX-MIN inference algorithm and the center of gravity defuzzification approach. The performance of the fuzzy controller depends on the membership functions, their distribution and the fuzzy rules that describe the control algorithm. There is no formal method to determine the parameters of the controller accurately. The speed error and the change in speed error are the inputs to the FL and speed error is input to PI controller [1].

TABLE 1
Rule base for fuzzy logic controller

de \ e	N	Z	P
N	NB	NM	Z
Z	NM	Z	PM
P	Z	PM	PB

TABLE 2
Rule base for K_{pf}

de \ e	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

TABLE 3
Rule base for K_{if}

de \ e	N	N	P
N	N	Z	P
Z	Z	P	P
P	P	P	P

3.3 Self tuning of PI plus Fuzzy Based hybrid controller

The drawback of FL based hybrid controller [9] shows overshoots and undershoots during load transients. PI control strategy is offline tuning so these parameters cannot be changed. The proposed self-tuning fuzzy PI controller is a combination of fuzzy logic concept and the conventional PI controller. The Self-tuning fuzzy PI controller [3] that employs the Fuzzy Interface System (FIS) to tune the parameters of Kp and Ki according to speed error (e) and the derivative of speed error (de/dt) shown in fig 4.

This self tuning of pi block with FLC is added to the existing FLC shown in fig 5. Fuzzy inference system for self tuning criteria is takagi sugeno fuzzy model. Rule base for this phenomenon is different for k_{pf} and k_{if} shown in table 2 and 3 respectively.

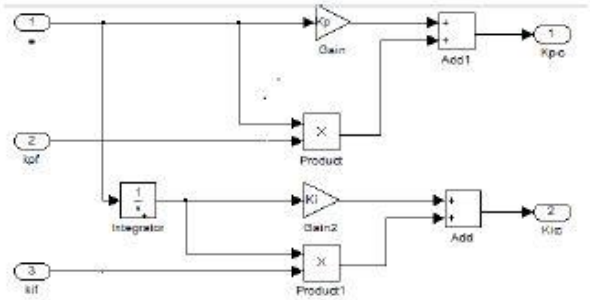

Figure 4. Flow diagram of self tuning pi controller

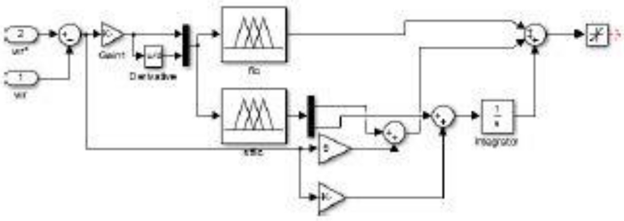

Figure 5. Subsystem for self tuning based hybrid controller

Membership functions for error (e) and change in error(de/dt) given to FLC used for self tuning criteria and FLC are shown in fig 6. Range of the kpf and kif parameters depends on the nature of the parameter characteristics.

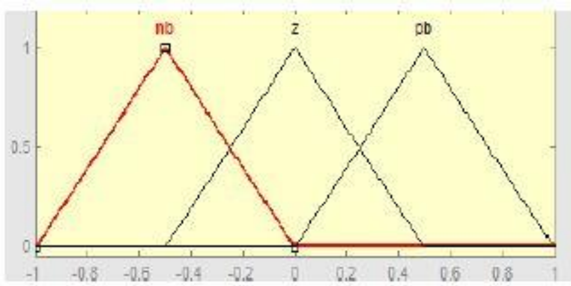

Figure 6. Membership functions for error and change in error

IV. RESULTS

A complete mathematical model of Field Oriented Control induction motor with a 50 HP (37KW) is simulated in MATLAB/SIMULINK. The Induction motor used in this is a 50 HP, 460 V, four-pole, 60 Hz motor having the following parameters.

TABLE 4
Parameters

Rated power	50HP
Voltage	460v
Stator resistance	0.087
Rotor resistance	0.22
Stator inductance	0.17
Rotor inductance	0.17
Mutual inductance	0.165
Moment of inertia	0.089

The machine is initially running at 100rad/sec with no load. The reference speed is linearly augmented from 100 to 120 rad/sec at 0.1sec and load applied at 0.5 sec with load torque Tl = 10Nm, at 0.7 sec load was removed and again load was applied at 1.5 sec with load demand Tl=10Nm. simulation were carried out with PI controller, FLC plus PI controller and FLC plus self-tuning fuzzy PI controller on the indirect vector control of induction motor on various system disturbances and speed waveform shown in fig 7,8 and 9 respectively. Torque response for FLC plus PI, FLC plus self tuning of PI and PI are shown in fig 10,11 and 12.

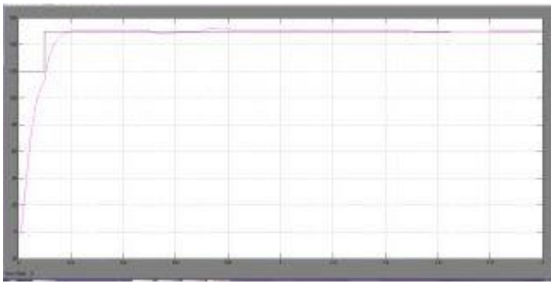

Figure 7. Forward motoring with load changes of an induction motor using conventional PI controller

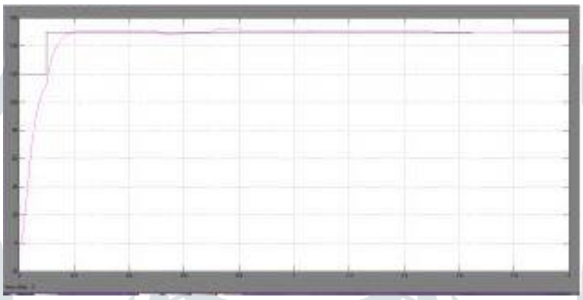

Figure 8. Forward motoring with load changes of an induction motor using fuzzy plus PI controller

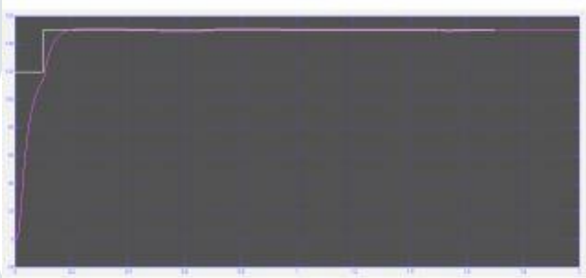

Figure 9. Forward motoring with load changes of an induction motor using self tuning fuzzy based hybrid controller.

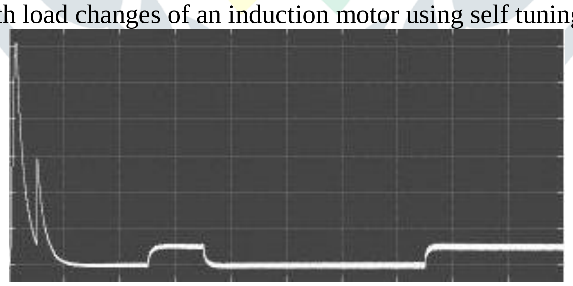

Figure 10. Torque response with PI plus FL controller.

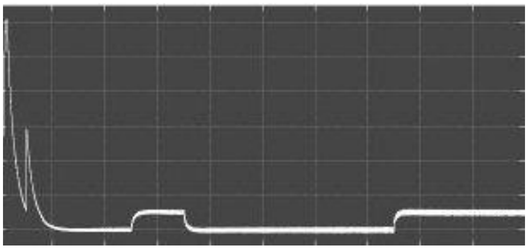

Figure 11. Torque response with STPI+FL controller.

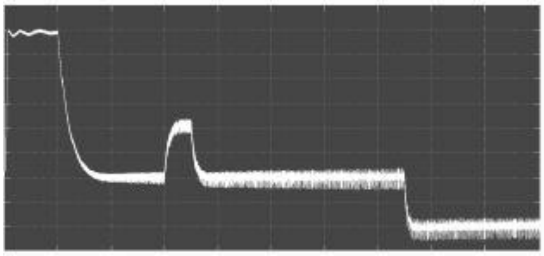

Figure 12. Torque response with PI controller

Table 5 shows the comparison results of PI and hybrid controllers in terms of rise time, Settling time, overshoot and steady state value. Good torque response is obtained with hybrid controller at all the instants. Less oscillation occurred in the torque response with Hybrid controllers compared to PI Controller.

TABLE 5

Time Domain specifications

Specifications	PI	FLC Plus PI	STPI Plus FLC
Rise time	0.17	0.1	0.09
Maximum peak overshoot	153.3	151	150.9
Steady state value	152.5	150.2	150.08
Settling time	0.46	0.25	0.3

5. CONCLUSION

The performance of the self-tuning of PI plus fuzzy logic controller for the indirect vector control PWM voltage fed induction motor drive has been simulated and compared with that of conventional PI controller‘s performance. The designed self-tuning fuzzy based PI controller was simulated for various load condition. The simulation results show that the designed self-tuning fuzzy PI controller realizes a good dynamic behaviour of the motor to sudden changes with a less rise time, less overshoot and less steady state value. So it has a better performance than PI controller and the fuzzy logic plus PI controller. Good torque response is obtained with self tuning of PI plus FLC.

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