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Speed Control of an Induction Motor using Fuzzy Logic Controller

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Abstract: The classical approach of designing speed controllers for vector control of an induction motor have undergoes many problems like instability, rise time, settling time etc.., during load disturbances. In this paper, hybrid controller is designed for a 3 phase 50 HP, cage type induction motor through MATLAB/SIMULINK to decrease rise time, settling time etc. According to the simulation self tuning of fuzzy logic controller performs well and gives better response.

Keywords: Induction Motor, Vector Control, Fuzzy Logic Controller.

I. INTRODUCTION

An induction motor is an asynchronous AC (alternating current) motor. Induction motors plays a vital 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, etc.. Hence, they are often called the workhorse of the motion industry. Its main features are robustness, relatively low cost, reliability and efficiency. So, Induction motors have significant 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 FOC, 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 etc., 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 controller is designed based on fuzzy logic is employed in the place of the classical PI controller[1,2]. A Fuzzy Logic Controller (FLC) does not need complex mathematical algorithms and is based on the IF_THEN linguistic rules. This hybrid controller supresses 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 give a poor response for load transients and speed command variations[3]. But it will not give a good response during changes in load demand[1]. A self tuning fuzzy based hybrid controller is designed to reduce the overshoot, undershoot etc, during command speed variations and load transients.

II. INDUCTION MOTOR MODELLING

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

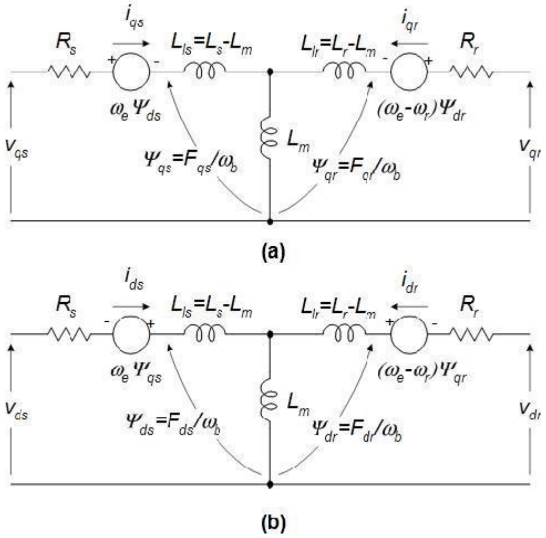


Fig.1. dynamic or d-q equivalent circuit of an induction motor.

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,
F_{mq} , F_{md}: q & d axis magnetizing flux linkages

R_r : rotor resistance,
R_s: stator resistance,
X_{ls}: stator leakage reactance (ωL_{ls}),
Xlr: rotor leakage reactance (ωL_{lr}).

The mathematical model of induction motor is given by

$$\theta_e = \int \omega_e \, dt$$

In this paper stationary reference frame is used for designing the motor. so three-phase (as-bs-cs) variables transformed into two-phase stationary reference frame(d^s-q^s) variables.

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 - 0.5 & -0.5 \\ 0 - 0.866 & 0.866 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

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

$$V_{ds} = R_s i_{ds} + \frac{d\Psi_{ds}}{dt} - \omega_e \psi_{qs} \quad (1)$$

$$V_{qs} = R_s i_{qs} + \frac{d\Psi_{qs}}{dt} + \omega_e \psi_{ds} \quad (2)$$

$$V_{qr} = R_r i_{qr} + \frac{d\Psi_{qr}}{dt} + (\omega_e - \omega_r)\psi_{dr} \quad (3)$$

$$V_{dr} = R_r i_{dr} + \frac{d\Psi_{dr}}{dt} - (\omega_e - \omega_r)\psi_{qr} \quad (4)$$

$$\Psi_{qs} = L_s i_{qs} + L_m i_{qr} \quad (5)$$

$$\Psi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (6)$$

$$\Psi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (7)$$

$$\Psi_{dr} = L_s i_{dr} + L_m i_{ds} \quad (8)$$

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. L_m is mutual inductance of stator and rotor. Rotor circuit equations are

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r} R_r i_{ds} - \omega_{sl}\psi_{dr} \quad (9)$$

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r} R_r i_{qs} - \omega_{sl}\psi_{qr} \quad (10)$$

For singly fed machines, such as a cage rotor $V_{qr}=V_{dr}=0$. For stationary referene frame and decoupling control $\omega_e=0$. So the stator flux component of current i_{ds} coincides with d^e axis and torque component of current i_{qs} coincides with q^e axis. Consequently $\Psi_{qr}=0$ and $\Psi_{dr}=\psi_r$.

$$\frac{d\Psi_{dr}}{dt} = 0 \quad (11)$$

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

$$T_e = \frac{3}{2}\frac{p}{2}\frac{1}{\omega_b}(\psi_{ds} i_{qs} - \psi_{qs} i_{ds})$$

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

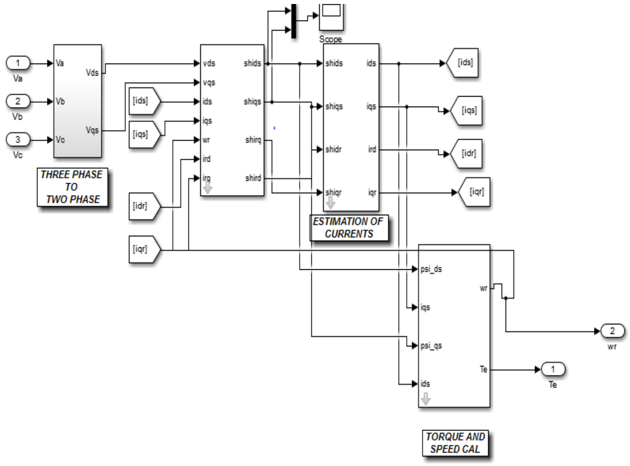


Fig.2. Subsystem for motor model.

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 The induction machine model implemented in this paper is shown in Fig.2. 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 as shown in Figs.3 and 4.

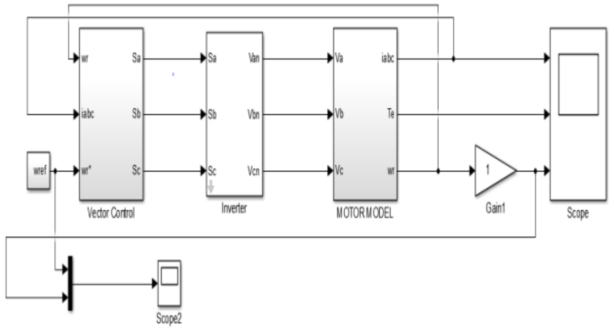


Fig.3. The developed simulink model for speed control of an induction motor.

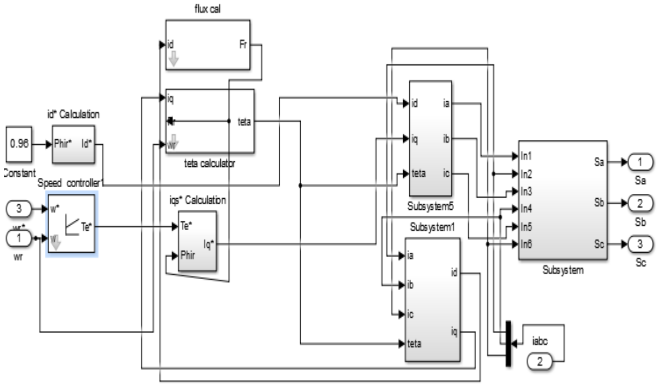


Fig.4 Subsystem for indirect vector control.

III. CONTROLLERS

A. Self Tuning Fuzzy Based 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[6].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 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 fig.5. 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 1. 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 PI controller [1].

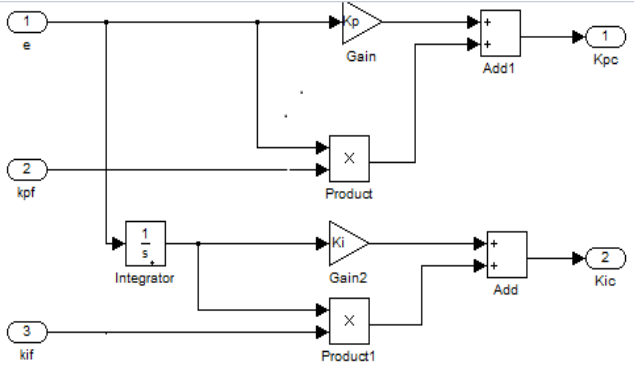


Fig.5.flow diagram of self tuning pi controller.

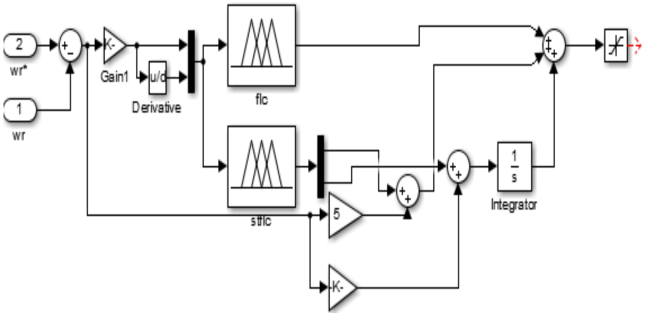


Fig.6. Subsystem for self tuning based hybrid controller.

This self tuning of pi block with FLC is added to the FLC shown in fig.6. 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.

TABLE I: Rule Base For Fuzzy Logic Controller

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

TABLE II: Rule base for k_{pf}

e / de	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

TABLE III: Rule base for k_{if}

e / de	N	N	P
N	N	Z	P
Z	Z	P	P
P	P	P	P

Membership functions for error(e) and change in error(de/dt) given to FLC used for self tuning Shown in fig.7.

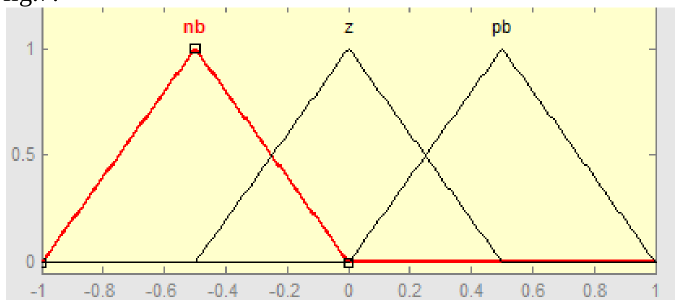
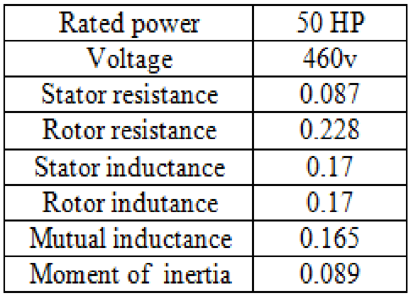


Fig.7. membership function for error and change in error.

IV. SIMULATION RESULTS

A complete mathematical model of FOC 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 IV: Parameters



Rated power	50 HP
Voltage	460v
Stator resistance	0.087
Rotor resistance	0.228
Stator inductance	0.17
Rotor indutance	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 increased from 100 to 120 rad/sec at 0.1sec and load applied at 0.5 sec with load torque T_l = 10Nm. At 0.7 sec load was removed. At 1.5sec braking was applied with T_l=-10nm.simulation were carried out with PI controller and FLC+self-tuning fuzzy PI controller on the indirect vector control of induction motor on various system disturbances shown in fig 4.1 and 4.2 respectively.

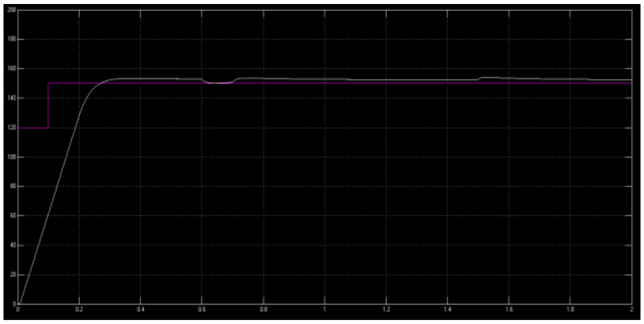


Fig.6. Forward motoring with load changes of an induction motor using conventional pi controller.

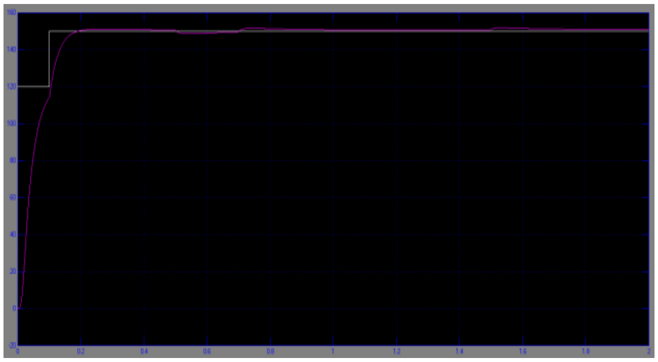


Fig.7. Forward motoring with load changes of an induction motor using self tuning fuzzy based hybrid controller.

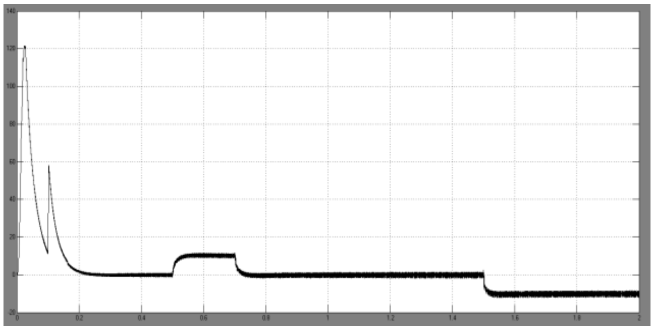


Fig.8. torque response with STPI+FL controller.

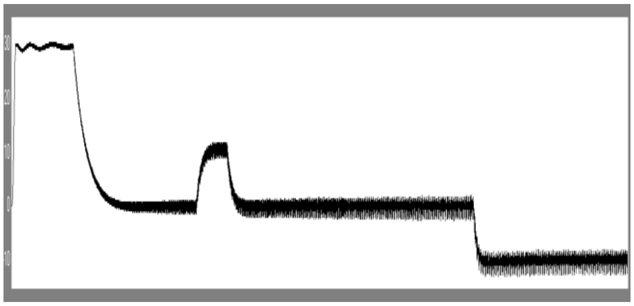


Fig.4. torque response with PI controller.

Table 5 shows the comparison results of PI and hybrid controller in terms of rise time, Settling time, overshoot and steady state value . By observing figures 4.3 and 4.4 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.

Table5. Time domain specifications

Specifications	Self tuned FLC
Rise time	0.09
Maximum peak overshoot	150.9
Steady state value	150.7
Settling time	0.3

V. CONCLUSION

The performance of 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 behavior 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+PI controller. Good torque response is obtained with self tuning of PI + FLC.

VI. REFERENCES

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