A Novel Self - Tuning Fuzzy Based PID Controller for Speed Control of Induction Motor Drive

Arun Kumar R
PG Scholar, School of Electrical Engg.,
VIT University - Chennai Campus, India
arunkumarr.2012@vit.ac.in

Febin Daya J L
Assistant Professor (Sr), School of Electrical Engg.,
VIT University - Chennai Campus, India
febindaya.jl@vit.ac.in

Abstract: This paper presents a comparative study between a self-tuning fuzzy (STF) PID controller, Fuzzy Logic Controller and conventional PID controller based speed control system for a current source PWM inverter fed indirect field oriented control of Induction Motor (IM) Drives. In this work the conventional PI controller is replaced by self-tuning fuzzy PID based intelligent controller. The fuzzy logic controller employs different types of membership functions for each parameter for the efficient control of the drive system. The performance of the self-tuning fuzzy PID based controller is analyzed using digital simulation in MATLAB/Simulink. The results are compared with conventional PID and Fuzzy Logic Controller. The self-tuning fuzzy logic controller gives better results.

Keywords: - Self tuning, Fuzzy logic, Intelligent controllers, Field Oriented Control, Induction Motor drives

I. INTRODUCTION

Induction motors are the most commonly used electric drives in the industries due to its robustness, less maintenance, and low cost. The electric drives must possess good dynamic response for small changes in the load or in the reference speed. By using field oriented control of induction motors this requirement is achieved easily. The induction motor is run like a separately excited DC motor using the field oriented control [9]. The advantages of the AC drives over DC drives are unaltered. Thus a drive system with a good dynamic response is developed.

In conventional field oriented control, a PID controller is used to control the speed of the induction motor drive. The use of PID controller induces many problems like high overshoot, oscillation of speed and torque due to sudden changes in load and external disturbances [2, 11]. This behavior of the controller causes deterioration of drive performance. To overcome these disadvantages an intelligent controller based on fuzzy logic is employed in the place of the conventional PID controller [1, 4, 6, 7, 8]. The fuzzy controller reduces all the disadvantages of the conventional PID controller. The fuzzy logic controller resembles a PID controller with high accuracy and efficiency [2,12]. The fuzzy logic controller will give a poor response for load changes and speed command variations. To overcome this disadvantage a self-tuning method is incorporated with the fuzzy logic controller [3, 4, 5, 11]. This self-tuning controller will tune the PID controller to sudden disturbances in the load thus will give a better response.

The self-tuning fuzzy PID controller has all the advantages of a fuzzy logic based controller and PI controller like simplicity in control, and it can be designed without knowing exactly the mathematical model of the system to be controlled [11].

II. INDIRECT FIELD ORIENTED CONTROL OF INDUCTION MOTOR

The indirect vector control method is essentially same as the direct vector control except the unit vector is generated in an indirect manner using the measured rotor speed \( \omega_r \) and the slip speed \( \omega_{sl} \). 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 \( \lambda_e \)). A field weakening system is used to control the speed of the motor when the speed rises above the nominal value [1]. The mathematical model of induction motor is given by

\[
\theta_e = \int \omega_e = \int (\omega_r + \omega_{sl}) = \theta_e + \theta_{sl} \tag{1}
\]

where \( \theta_e \) is the rotor angle, \( \omega_e \) is the angular velocity of magnetic speed, \( \omega_r \) is the angular velocity of the rotor, \( \omega_{sl} \) is the angular velocity of the slip.

The rotor circuit equation:

\[
\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r} \psi_{dr} - \frac{L_m}{L_r} R_f i_{ds} - \omega_{sl} \psi_{qr} = 0 \tag{2}
\]

\[
\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r} \psi_{qr} - \frac{L_m}{L_r} R_f i_{qs} - \omega_{sl} \psi_{dr} = 0 \tag{3}
\]

Where, \( \psi_{dr} \) and \( \psi_{qr} \) are the rotor flux linkages in d and q axis, \( i_{ds} \) and \( i_{qs} \) are the stator currents in d and q axis, \( R_r \) and \( L_r \) are the resistance and inductance of the rotor circuit, \( L_m \) is the magnetizing inductance of the motor.

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

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

(4)

As well, the slip frequency can be calculated as:

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

(5)

It is found that the ideal decoupling could be achieved if the above slip angular speed command is used for making the field orientation. The control rotor flux $\psi_r$ and $\frac{d\psi_r}{dt} = 0$ can be substituted in equation (2), so that rotor flux set as

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

(6)

The electromagnetic torque developed in the motor is given by

$$T_e = \frac{3}{2} P L_m \psi_r i_{qs}$$

(7)

where $T_e$ is the electromagnetic torque developed in the motor, $P$ is number of poles of the induction motor [13].

The block diagram of the indirect field oriented control of induction motor is shown in Fig. 1.

![Fig. 1 Block diagram for indirect vector control of induction motor](image)

Fig. 1 Block diagram for indirect vector control of induction motor

### III. DESIGN OF SELF-TUNING FUZZY BASED PID CONTROLLER

Many researches are done on the new PID control strategies based on some intelligent algorithms especially using fuzzy logic concepts. The proposed self-tuning fuzzy PID controller is a combination of fuzzy logic concept and the conventional PID controller. The Self-tuning fuzzy PID controller that employs the Fuzzy Interface System (FIS) to tune the parameters of $K_p$, $K_i$, and $K_d$ according to speed error (e) and the derivative of speed error ($\frac{de}{dt}$). The structure of self-tuning fuzzy PID controller is show in the Fig. 2.

![Fig. 2 Block diagram of self-tuning fuzzy PID controller](image)

Fig. 2 Block diagram of self-tuning fuzzy PID controller

In self-tuning PID controller, the rules are designed based on the characteristics of the induction motor and the properties of the PID controller. The parameters of $K_p$, $K_i$, $K_d$ must be tuned according to load conditions by using fuzzy tuner. The fuzzy tuner has two inputs: error (e) and derivative of error ($\frac{de}{dt}$) and three outputs: $K_{pf}$, $K_{if}$, $K_{df}$ as shown in Fig. 2. The equations for the self-tuning process are given below.

$$T_e^* = K_{pnew} e(t) + K_{inew} \int e(t) + K_{dnew} \frac{de(t)}{dt}$$

(10)

$$K_{pnew} = (K_p + K_{pf}) * \alpha$$

(11)

$$K_{inew} = (K_i + K_{if}) * \alpha$$

(12)

$$K_{dnew} = (K_d + K_{df}) * \alpha$$

(13)

where $\alpha$ is the scaling factor, $K_{pf}$, $K_{if}$, and $K_{df}$ are obtained from the fuzzy controller.

The equations (8) to (13) are realized as shown in the figure 10. From the equations it is clear that the tuning of the PID controller is a function of the output variables of the fuzzy controller. The Simulink model of indirect vector control of induction motor is shown in Fig. 4.

The membership functions of the inputs and output fuzzy sets are shown in Fig. 5-8. The input fuzzy sets consist of seven linguistic variables and the output fuzzy set has 11 linguistic variables for the proper tuning of the PID controller [3, 7, 11]. The fuzzy rules base for each output variable $K_{pf}$, $K_{df}$, $K_{df}$ are shown in the tables below.
The rule base for $K_{pf}$ has only 7 linguistic variables and the other variables $K_{if}$ and $K_{idf}$ has 11 linguistic variables. The use of 11 linguistic variable for $K_{if}$ and $K_{id}$ is to increase the response of the self tuning fuzzy controller [11]. A scaling factor $\alpha$ is introduced in the control circuit. A variation in these linguistic variables adopted so that more accuracy can be obtained in the tuning of $K_i$ and $K_d$ so that the oscillations in the responses can be reduced. The scaling factor $\alpha$ makes the speed response of the induction motor to be faster and more reliable operation during loaded condition.

The fuzzified outputs are defuzzified using the COA method to obtain the true values of the output variables. Manmadi’s algorithm is used to interpret the rules of the fuzzy controller. This output variables are fed to the self-tuning PID controller and the torque signal $T_e^*$ for the motor is generated.
The torque signal is integrated for obtaining the torque-controlling element of current $i_{qs}^*$. The firing pulses to the inverter are generated according to the value of $i_{qs}^*$ [1].

![Fig. 9 Self-tuning PID controller](image)

**IV. SIMULATION RESULTS AND DISCUSSIONS**

The machine is initially at stand still with no load. The reference speed is linearly increased from zero to 100 rad/sec simulation were carried out on both PID controller, Fuzzy controller and self-tuning fuzzy PID controller on the indirect vector control of induction motor on various system disturbances.

Fig. 10 shows the no load response of the induction motor while the motor is run at a speed of 100 rad/sec. All controllers shows a similar response but it can be clearly seen the enlarged area shown in figure 11 of the response that STPID has a slight overshoot of 2 rad/sec. The settling time of the STPID is lesser than PID controller thus a better response is shown.

Fig. 12 and 14 shows the response of the motor to a variable speed command at no load condition. The motor speed varied from 60 rad/sec to 40 rad/sec and from 40 rad/sec to 60 rad/sec. Fig. 13 and 15 shows the enlarged figure of the corresponding responses of the controller. The STPID has an overshoot of 2 rad/sec in the response. The PID controller takes more time to settle down at the command speeds and it shows more steady state error than the STPID controller.

Fig. 16 shows the response of the controllers to a command speed of 100 rad/sec and a load of 15 Nm which is applied at 0.5 sec. The PID controller shows a considerable amount of decrease in speed of the motor when the load is applied. The Fuzzy controller shows a better response than that of the PID controller. The STPID shows a better response than the other controllers. The speed of the motor settles at 99.8 rad/sec.

The time domain specifications for each load conditions are tabulated in Table IV. The proposed self-tuning fuzzy PID controller has an overshoot of 2 rad/sec for all the system disturbances and the overshoot damps out in two cycles. The other time domain specifications steady state error ($e_{ss}$), settling time ($t_s$) for the proposed controller are better comparing to the conventional PID and Fuzzy logic controller.

![Fig. 10. No load response](image)

![Fig. 11 Enlarged version of Fig 10](image)

![Fig. 12 Speed response for step change in reference speed](image)
Table IV. Time domain specifications

<table>
<thead>
<tr>
<th>Time domain specifications</th>
<th>Controller</th>
<th>Disturbances</th>
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<tr>
<td></td>
<td></td>
<td>No load</td>
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<tr>
<td>Steady state error ($e_{ss}$)</td>
<td>PID</td>
<td>0.073</td>
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<td></td>
<td>STPID</td>
<td>0.0052</td>
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<tr>
<td></td>
<td>FLC</td>
<td>0.0439</td>
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<tr>
<td>Peak Overshoot ($M_p$)</td>
<td>PID</td>
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<tr>
<td></td>
<td>STPID</td>
<td>+2.43</td>
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<tr>
<td></td>
<td>FLC</td>
<td>-0.0763</td>
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<tr>
<td>Settling Time ($t_s$)</td>
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<tr>
<td></td>
<td>STPID</td>
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<tr>
<td></td>
<td>FLC</td>
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V. CONCLUSION

The performance of the self-tuning fuzzy PID controller for the indirect vector control PWM current fed induction motor drive has been simulated and compared with that of conventional PID controller’s performance. The designed self-tuning fuzzy controller was simulated for various load condition. The simulation results show that the designed self-tuning fuzzy PID controller realizes a good dynamic behavior of the motor to sudden changes with a rapid settling time, no overshoot and has a better performance than PID controller and the fuzzy logic controller. The robustness of the fuzzy logic control during sudden changes in load has been seen for both the fuzzy logic controller and the self-tuning fuzzy logic controller.

VI. APPENDIX

Table V. Motor Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Power</td>
<td>5 HP</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>1445 rpm</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>415 V</td>
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<tr>
<td>Frequency</td>
<td>50 Hz</td>
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<tr>
<td>Poles</td>
<td>4</td>
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<tr>
<td>Stator Resistance</td>
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<tr>
<td>Stator Inductance</td>
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</tr>
<tr>
<td>Rotor Inductance</td>
<td>0.521 H</td>
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<tr>
<td>Magnetizing Inductance</td>
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<tr>
<td>Inertia Constant</td>
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<tr>
<td>Viscous Constant</td>
<td>0.035 kgm/s</td>
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REFERENCES


