Fuzzy Logic Control Design for Induction Motor Speed Control Improvement Through Field Oriented Control

Roslina Mat Ariff, Dirman Hanafi, Whayu Mulyo Utomo, Kok Boon Ching, Nooradzianie Muhd Zin, Sy Yi Sim and Azuwien Aida Bhohari

Abstract This paper focuses on improving induction motor performance by controlling its speed. The induction motor speed is controlled using field oriented control based structure associated with an induction motor. The field oriented control is implemented by combining with fuzzy logic control to reduce the uncertainties factors. The fuzzy logic control is developed based on Mamdani method. The inputs of fuzzy logic control are the error and derivative error between actual and reference speed of induction motor. The output of fuzzy logic control is the reference electric torque. The fuzzy logic control input output variables membership functions are chosen based on the parameters of the motor model. Motor state variables are identified indirect from induction motor model. The controller develops is implemented MATLAB Simulink. The simulation result shows that the fuzzy logic control is a suitable controller for improving induction motor performance with gives less settling time and steady state error than Proportional Integral Derivative control.

Keywords Induction Motor (IM) · Field Oriented Control (FOC) · Fuzzy Logic Control (FLC)

R. M. Ariff (✉) · D. Hanafi
Robotic and Mechatronic Department, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400 Batu Pahat, Johor, Malaysia
e-mail: roslinamatariff@yahoo.com.my

W. M. Utomo · K. B. Ching · N. M. Zin · S. Y. Sim · A. A. Bhohari
Electrical Power Department, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400 Batu Pahat, Johor, Malaysia

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1 Introduction

Fuzzy Logic Control (FLC) as an Intelligent Control has widely applied for solving nonlinear systems problems like an electric motor drives [1]. As an intelligent control FLC does not depend on the system mathematical model [2–5] and has ability to handle nonlinearity of arbitrary complexity system.

Basic concept of an induction motor operates on the basis of interaction between induced rotor current and air gap field. In this condition often exists the motor's dynamic uncertainties like mechanical parameter uncertainty, external load disturbance, and unmodelled dynamics properties that all influenced the induction motor performance [6–8]. To solve this problem need to use the high performance controller.

Field-oriented control (FOC) of induction motor (IM) drives has been used in industrial applications [9]. High performance rotary machine drive required the field-oriented control technique, which is one of the most effective vector controls of IM due to the simplicity of designing and implementation [10]. Advent of high switching frequency PWM inverters has made it possible to apply for sophisticated control strategies to AC motor drives. The concept of the field oriented method is to use a separate controller to make the rotor's flux stabilizes to a desirable reference set point and motor independently control the speed through conventional linear control approaches. This technique makes variable speed drive with independent torque and flux control of induction motor possible implement, which also provides excellent dynamic response [11].

2 Induction Motor Model

The dynamic model of an induction motor is derived by first transformed to two-phase ones is the three-phase variables [12–15].

Voltage induced in a rotor bar of an induction motor depends on the speed of rotor relative to the magnetic field.

The magnetizing inductance of the motor Convenience or compatibility with the presentations of other network components is $d-q$ reference frames are usually selected on the basis form. The currents of the rotor are decomposed into d – q coordinates, thus resulting into i_{dr} and i_{qr}. Since the frame $d-q$ of the rotor aligns with the frame $\alpha-\beta$ of the stator after rotation by an angle (θ) d it holds that:

$$\begin{pmatrix} \frac{i_{\alpha r}}{i_{\beta r}} \end{pmatrix} = \begin{pmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} \frac{i_{dr}}{i_{dr}} \end{pmatrix} \tag{1}$$

Each of voltage variable, current or flux linkage in synchronous frame is stationary and fixed to a constant magnitude in steady state. The relationship is represented by Eq. 2.

$$\begin{pmatrix} Vqs \\ Vds \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} Rs + LsP & \omega_e Ls & LmP & \omega_e Lm \\ -\omega_e Ls & Rs + LsP & -\omega_e Lm & LmP \\ LmP & \omega_r Lm & Rr + LrP & \omega_r Lr \\ -\omega_r Lr & LmP & -\omega_r Lr & Rr + LrP \end{pmatrix} \begin{pmatrix} Iqs \\ Ids \\ Iqr \\ Idr \end{pmatrix} \tag{2}$$

Regardless of reference frame, the instantaneous input power (Pin) is:

$$P_{in} = (3/2)\left(V_{qs} I_{ds} + V_{ds} L_{qs}\right). \tag{3}$$

Electromagnetic torque defined as:

$$\begin{aligned} T_e &= (3/2) P L_m \left(I_{qs} I_{dr} - I_{ds} I_{qs}\right) \\ &= (3/2)(P/2)(L_m/L_x)\lambda_{dr} i_{qs} \end{aligned} \tag{4}$$

Speed of rotor defines as:

$$\omega_r = d\theta_r/dt. \tag{5}$$

where, V_{ds} and V_{qs} are d-q axis stator voltage, i_{ds} and i_{qs} are axis stator currents, i_{dr} and i_{qr} are d–q axis rotor currents. R_s and R_r are stator and rotor resistance per phase. L_s and $L_r$are the self-inductance of the stator and rotor respectively. L_m is the mutual inductance and T_e is electromagnetic torque. $T_L$is load torque and J_m is inertia. ω_e and ω_r are the speed of the rotating magnetic field and the speed of rotor respectively. P is the number of pole and θ_r is the rotor position.

3 Field Oriented Control Model

The electric motor position can be expressed as:

$$\theta_e = \int \omega_w dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl}. \tag{6}$$

where, ω_r is rotor speed and ω_{sl} is slip frequency. Then ω_e is electric motor speed formulated as Eq.7.

$$\omega_e = \omega_r + \omega_{sl}. \tag{7}$$

Slip speed define as:

$$\omega_{sl} = 2LrTe/3PTr\lambda^*_{dr}. \tag{8}$$

For decoupling control, the rotor circuit equations are given as:

$$d\Psi_{dr}/dt + R_r i_{dr} - (\omega_e - \omega_r)\Psi_{qr} = 0. \tag{9}$$

Based on the induction motor model and FOC model, block diagram of induction motor driver can be developed as in Fig. 1.

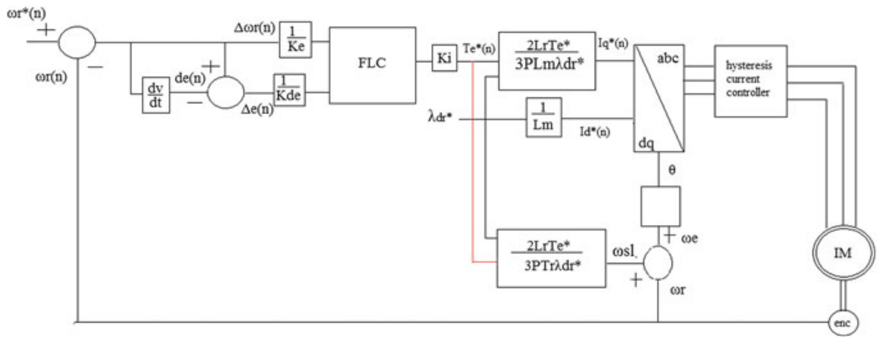

Fig. 1 The IM drive

The rotor time constant τ_r of IM is given by:

$$\tau_r = L_r/R_r. \tag{10}$$

The ω_r and λ_{dr} are determined using Eqs.11 and 12 respectively.

$$\omega_r = (L_m/\tau_r)\left(I_{qs}/\lambda_{dr}\right). \tag{11}$$

$$p\lambda_{dr} = (1/\tau_r)(-\lambda_{dr} + L_m I_{ds}). \tag{12}$$

4 Fuzzy Logic Control Design

In this paper, a Mamdani-type of FLC is developed for controlling the IM speed controller. The FLC input variables consist of the IM speed error and change of speed error and the output variable is the electrical torque. Each input variables have 5 membership functions and 7 membership functions as described in Figs. 2 and 3. Types of membership functions apply are triangular and trapezoidal functions. The functional relation between input and output of FLC are given by:

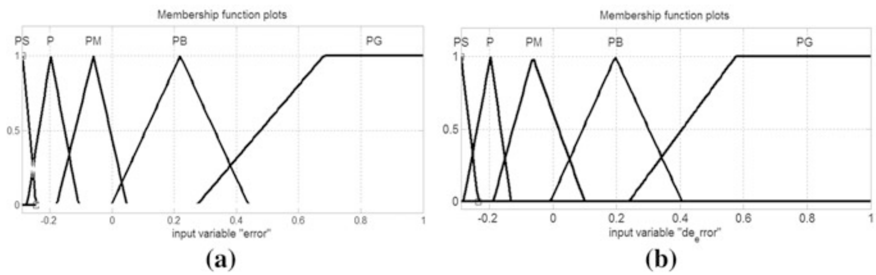

Fig. 2 The membership function for (**a**) error $\Delta\omega_r(n)$, **b** change in error $\Delta e(n)$

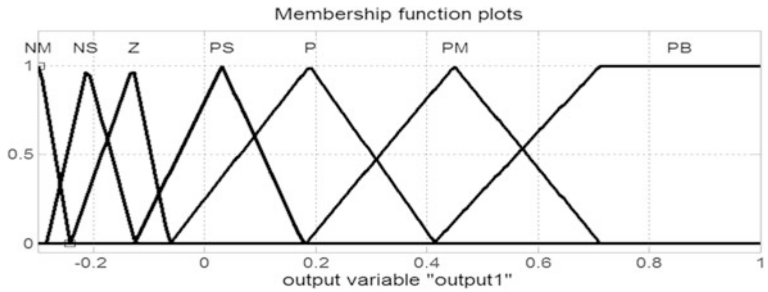

Fig. 3 The membership functions of output $Te^{*}(n)$

$$Te^{*}(n) = \int_{discrete} \Delta Te^{*}(n) = f(\Delta e(n), \Delta\omega_r(n)). \tag{13}$$

where, $\Delta e(n)$ is the change of speed error and $\Delta\omega_r(n)$ is the sample of speed error. $T_e^{*}(n)$ is the electric torque reference and f is denotes the nonlinear function.

The data for rule of fuzzy logic control is show in table 1.

5 Result and Discussion

5.1 Result

The IM use as object of work has Frequency and Poles pairs are 50 Hz and 2, is stator resistance (Rs) is 0.3 Ω, rotor resistance (Rr) is 0.25 Ω, stator inductance (Ls) is 0.0415 mH, rotor inductance (Lr) 0.0412 mH, mutual inductance (Lm) is 0.0403 mH, Inertial moment and friction ceoficient are 0.1 and 0.02, and maxsimum torque (Tmax) is 250.

The test is started for constant speed 150 rad/s. The controllers responses comparison are represented in Fig. 4.

Based on graph responses above, FLC has steady state error and settling time are 0.13 % and 0.14 s respectively, while PID controller produces 0.53 % steady error and 0.5 s settling time.

Table 1 Rule of fuzzy logic control (FLC)

e	de				
	PS	P	PM	PB	PG
PS	NM	NM	NM	NM	NM
P	NM	NM	NM	NS	NS
PM	NM	NS	Z	PM	PB
PB	P	PM	PB	PB	PB
PG	PB	PB	PB	PB	PB

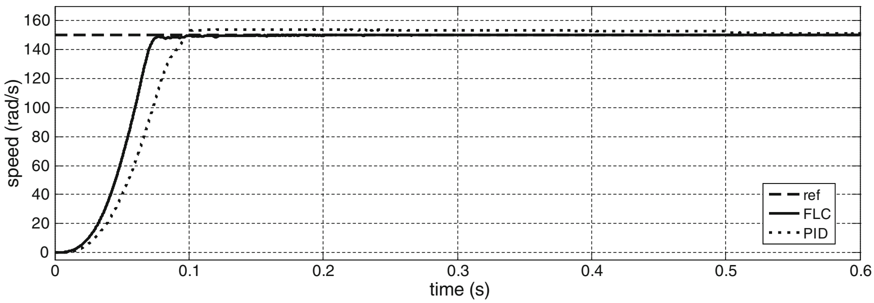

Fig. 4 Controller responses comparison for constant speed

The second test is done by increasing the IM speed from 100 rad/s to 150 rad/s and the result is shown by Fig. 5.

In this test FLC response has steady state error 0.13 % and settling time is 0.52 s. Then, PID controller response has steady state error and settling time are 0.87 % and 0.54 s respectively.

The final test is done by reducing the IM speed from 150 rad/s to 100 rad/s. The response of each controller is illustrated in Fig. 6.

For this kind of input signal, the steady state error of FLC and PID controller are 0.6 % and 0.22 % respectively.

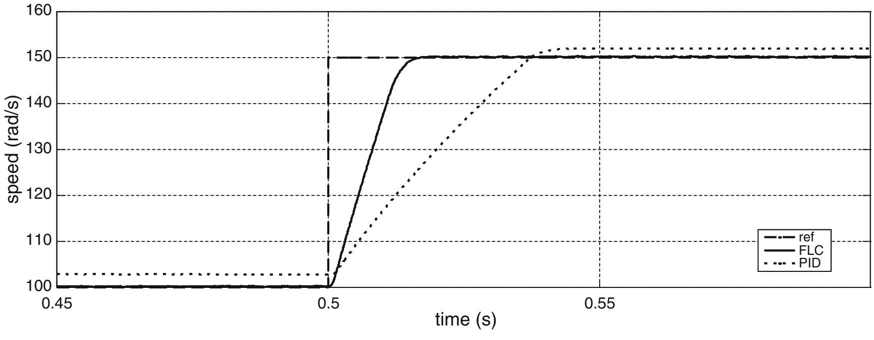

Fig. 5 simulation speed step up response of the drive of the FLC compare with the PID

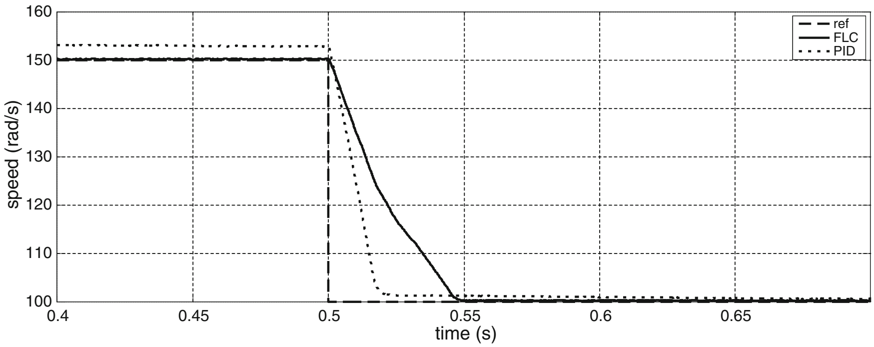

Fig. 6 simulation speed step down response of the drive of the FLC compare with the PID

6 Discussion

The IM speed control improvement has been representing. The improvement is done through control the FOC using FLC. The proposed method has been implemented using the MATLAB Simulink. Three kinds of input have applied to test and analyze the controller response.

7 Conclusion

This paper explains the method to improve the performance of the IM speed as a driver by control the FOC using FLC. Based on the test results for three types of input signals, FLC has better performance than PID controller. FLC has lower steady error and settling time. It means FLC is suitable controller for improve the IM speed performance.

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