Journal of Engineering and Applied Sciences 14 (23): 8594-8599, 2019
ISSN: 1816-949X

Speed Control of Induction Motor using Fuzzy Logic Control

Wafaa A. Humadi and Naseer M. Yasin
Department of Electrical Power Engineering Techniques, Electrical Engineering Technical College,
Middle Technical University, Baghdad, Iraq
wafaaabdullah1993@gmail.com

Abstract: This study is aimed to show the dynamic response of an induction motor to speed changes at start up and load changes during normal steady state operation. A classical PI control was first applied, a fuzzy logic and a fuzzified PI were then implemented. Simulations were carried out by using MATLAB in order to determine the most effective controller. A comparison between the three different controllers under various load conditions demonstrated the robustness of Fuzzy Logic (FL).

Key words: Fuzzy logic control, PI controller, induction motor, MATLAB/Simulink, robustness, dynamic response

INTRODUCTION

Induction motors, especially, the Squirrel Cage Induction Motors (SCIM) are widely used for industry and several applications such as hybrid cars, textile and paper mills, wind power generation systems and robotics because of their many advantages like their reliability, simple construction, low cost, low maintenance needs and robustness (Kusagur *et al*., 2012). However, their controllability by conventional control methods is still a difficult task. High nonlinearity of the motors behavior, complexity of its model and presence of interactive multi-variable structures are the main reasons for their control difficulty. Therefore, the design of a classical controller takes a lot of time and effort. Recent advances in computing and power electronics fields have made it possible to incorporate three phase induction machines in applications of high performance (Karanayil *et al*., 2001). Also, more intelligent and robust controllers have been applied for induction motor control. A fuzzy controller is one of these intelligent controllers. The fuzzy controller allows the incorporation of a human experience to be employed in the control process (Toufouti *et al*., 2007). A technique called field oriented control or vector control could be used to change the speed of an induction motor. This technique was initially developed by Blaschke (1972). With this method of vector control, an induction machine can be controlled just like a Direct Current (DC) motor that is separately excited. The control of torque and field of an induction motor is done independently or by decoupling, through the manipulation of field quantities (Bose, 2002; Blaschke, 1972).

MATERIALS AND METHODS

Mathematical model of induction motor: A fourth-order state space model is used to represent the electrical part of the induction motor while the mechanical part is represented with a system of second order (Bose, 2002). The electrical parameters are usually referred to a stator as shown in Fig. 1. In the generalized two axes frame of reference, the electrical Eq. 1-8 of an induction machine are:

$$\nu_{qs} = R_s i_{qs} + \omega_e \psi_{ds} + p\psi_{qs} \tag{1}$$

$$\nu_{ds} = R_s i_{ds} + \omega_e \psi_{qs} + p\psi_{ds} \tag{2}$$

$$\nu_{qr} = R_r i_{qr} + (\omega_e - \omega_r)\psi_{dr} + p\psi_{qr} \tag{3}$$

$$\nu_{dr} = R_r i_{dr} - (\omega_e - \omega_r)\psi_{qr} + p\psi_{dr} \tag{4}$$

$$\psi_{qs} = L_{ls} i_{qs} + L_m (i_{qs} + i_{qr}) \tag{5}$$

$$\psi_{ds} = L_{ls} i_{ds} + L_m (i_{ds} + i_{dr}) \tag{6}$$

Corresponding Author: Wafaa A. Humadi, Department of Electrical Power Engineering Techniques,
Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq,
wafaaabdullah1993@gmail.com

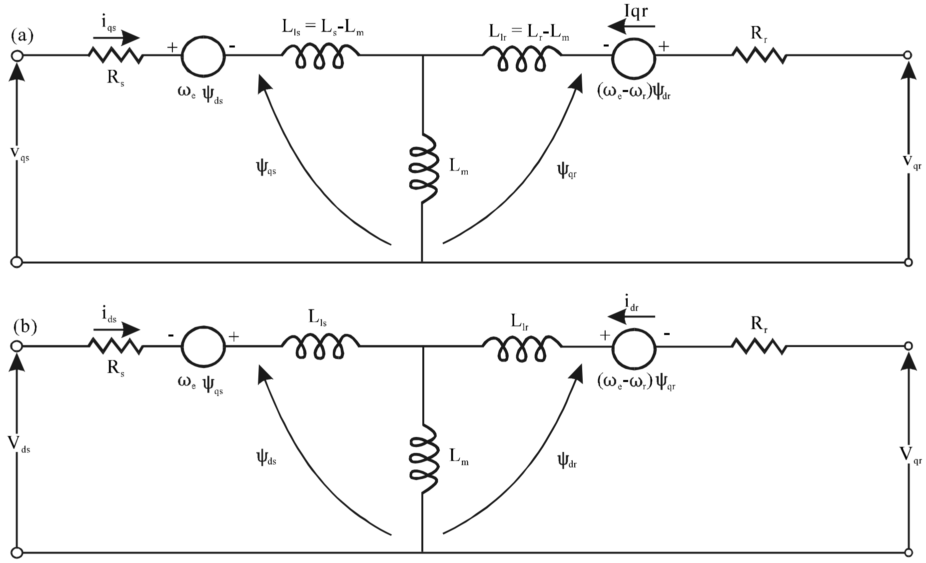

Fig. 1: Two axis frame of reference of stator and rotor: a) q-axis and b) d-axis

$$\psi_{qr} = L_{lr}i_{qr} + L_m\left(i_{qr} + i_{qs}\right) \tag{7}$$

$$\psi_{dr} = L_{lr}i_{dr} + L_m\left(i_{dr} + i_{ds}\right) \tag{8}$$

The electro-magnetic torque is:

$$T_e = \frac{3}{2}\frac{P}{2}\left(i_{qs}\psi_{ds} - i_{ds}\psi_{qs}\right) \tag{9}$$

Electrical angular velocity equation is given by:

$$p\omega_r = \frac{P}{2}\frac{\left(T_e - T_l\right)}{J} \tag{10}$$

Where:

p = The operator d/dt
ψ_{qs}, ψ_{ds} = The q and d-axis component for stator flux
ψ_{qr}, ψ_{dr} = The q and d-axis component for rotor flux
L_{ls}, R_s = The Leakage inductance and stator resistance
L_{lr}, R_r = The Leakage inductance and rotor resistance
L_m = The magnetizing inductance
ω_e = The electrical angular velocity
ω_{sl} = The slip frequency (ω_e-ω_r)
J = The inertia of the rotor
T_l = The load torque

Indirect vector control: This method is just the same as that of direct vector control with the exception that the unit vector will be generated by feed forward manner by using the measured values of speed (ω_r) and the slip speed (ω_{sl}). The following equations will be taken into consideration for the implementation of the strategy of indirect vector control (Bose, 2002):

$$\theta_e = \int\omega_e\, dt = \int\left(\omega_r + \omega_{sl}\right) = \theta_r + \theta_{sl} \tag{11}$$

The rotor circuit equation. From Eq. 3 and 7, we get:

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\psi_{dr} = 0 \tag{12}$$

From Eq. 4 and 8, we get:

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} + \omega_{sl}\psi_{qr} = 0 \tag{13}$$

For a decoupling control it desirable that $\psi_{qr} = 0$, $d\psi_{qr}/dt = 0$. Then, the total rotor flux ψ_r will be directed on the d-axis. Substituting of the above two conditions in Eq. 12 and 13, we get:

$$\omega_{sl} = \frac{L_m R_r i_{qs}}{\psi_r L_r} \tag{14}$$

$$\frac{L_r}{R_r}\frac{d\psi_r}{dt} + \psi_r = L_m i_{ds} \tag{15}$$

For constant rotor flux ψ_r and $\psi_r/dt = 0$. Substituting in Eq. 15, we get:

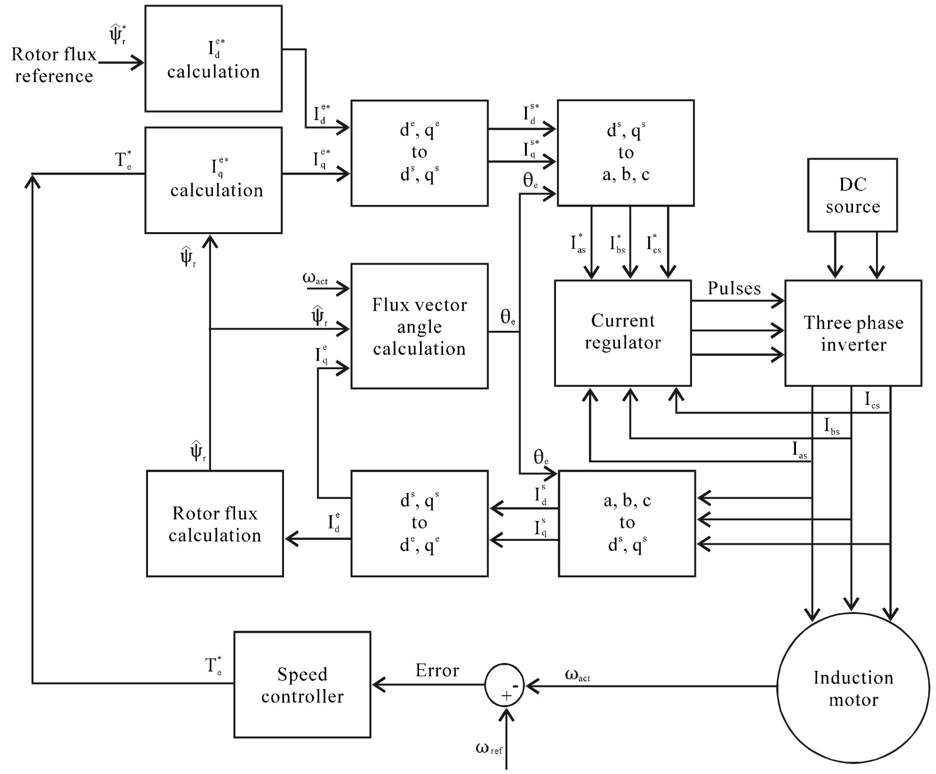

Fig. 2: Block diagram of indirect vector control technique

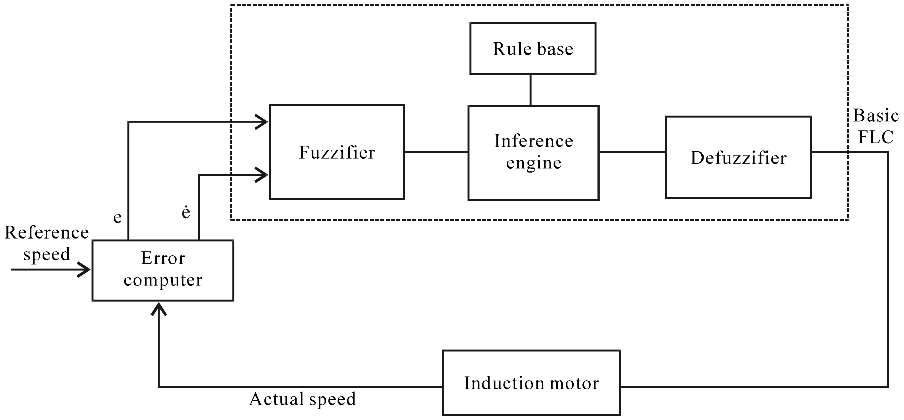

Fig. 3: Block diagram for a fuzzy logic controller

$$\psi_r = L_m i_{ds} \tag{16}$$

The electro-mechanical torque developed is given by:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\psi_r i_{qs} \tag{17}$$

The block diagram in Fig. 2 shows an indirect vector control. Two control loops are being used for the control of induction motors drive namely the external speed control loop and the internal pulse width modulation current control loop (Kalhoodashti and Shahbazian, 2011).

Fuzzy Logic Controller (FLC): FLC is an algorithm which is based on control strategy that is linguistic and is derived from an expert knowledge to form an automatic strategy for the control process (Fig. 3). Unlike, other control systems which use rather difficult mathematical calculations in order to provide a model for the controlled

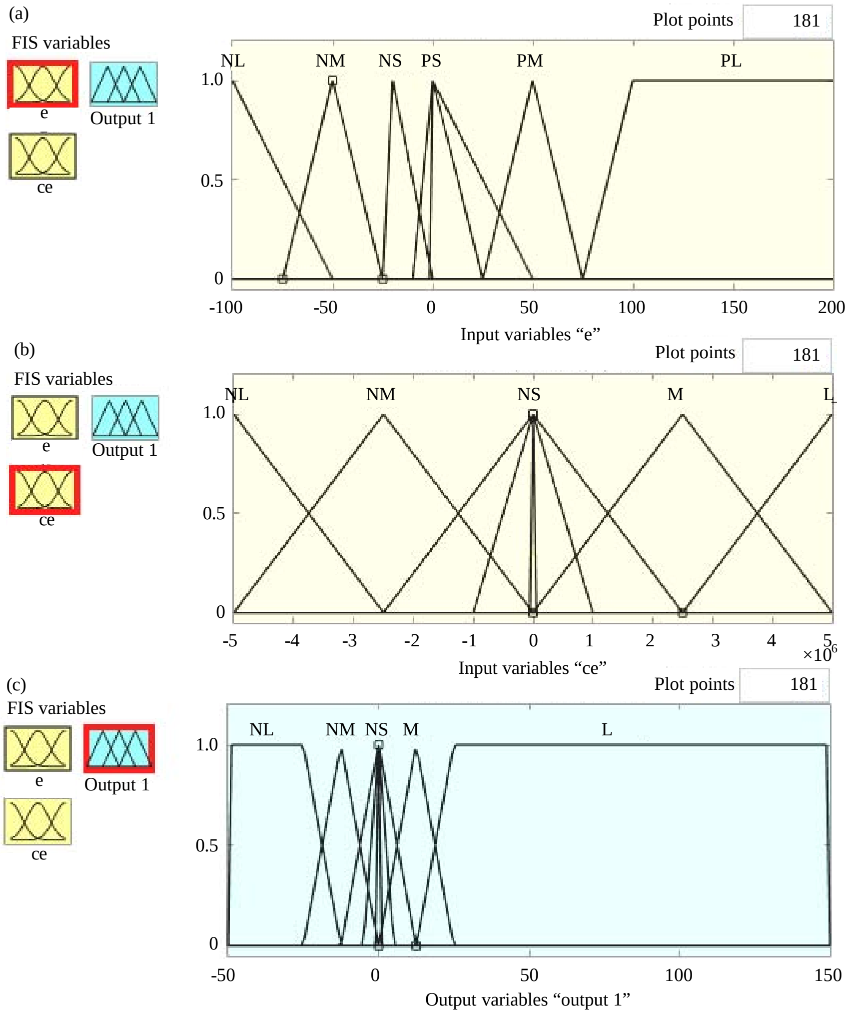

Fig. 4: Membership functions for: a) Error "e"; b) Change of error "ce" and c) Output

unit, FLC uses simple calculations only to simulate the expert's knowledge and an inference engine to determine an accurate crisp output, resulting in a good performance as far as system control is concerned. That is why FLC is considered as one of the best available techniques today for many challenging control systems (Ogata, 2010; Zimmermann, 2001; Ziegler *et al*., 1942). Figure 3 shows the main features of a FLC for the control of a plant.

The mapping and scaling of input variables into fuzzy sets is done by the fuzzifier. The approximate reasoning and deduction of the control action is made by the inference engine with the help of the rule base. Then the defuzzifier converts the fuzzy output to control actions (Jang *et al*., 1997). The signal of speed error and its time derivative are considered as the input variables and the electromagnetic torque as the output variable in this proposed model (Table 1). The speed error is determined by comparing the feedback of the speed signal and a preset reference speed. The membership function that were defined for both the input and the output parameters are shown in Fig. 4a-c.

Table 1: Fuzzy logic control rule

ce/e	PL	PM	PS	Z	NS	NM	NL
PL	PS	PS	PM	PL	PL	PL	PM
PM	PM	PM	PL	PM	PL	PM	PS
PS	PM	PL	PL	PS	PL	PM	PS
Z	PM	PS	PS	Z	NS	NS	NM
NS	NS	NM	NL	NS	NL	NM	NS
NM	NS	NM	NL	NM	NL	NM	NS
NL	NM	NL	NL	NL	NM	NL	NL

RESULTS AND DISCUSSION

A simulation was performed under no load for the three control strategies and the results are shown in

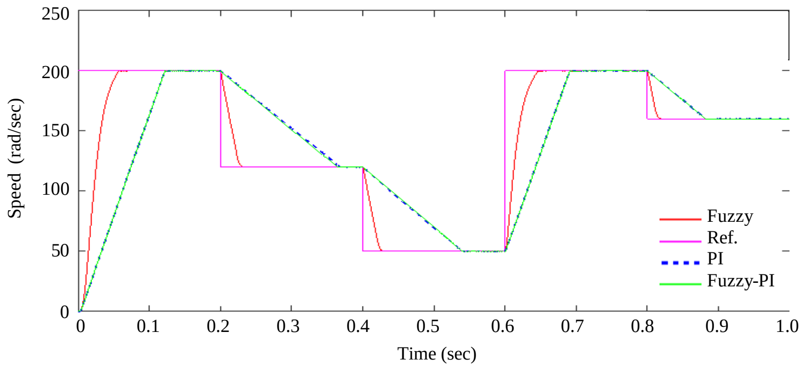

Fig. 5: Speed response with PI, Fuzzy, PI-Fuzzy controller

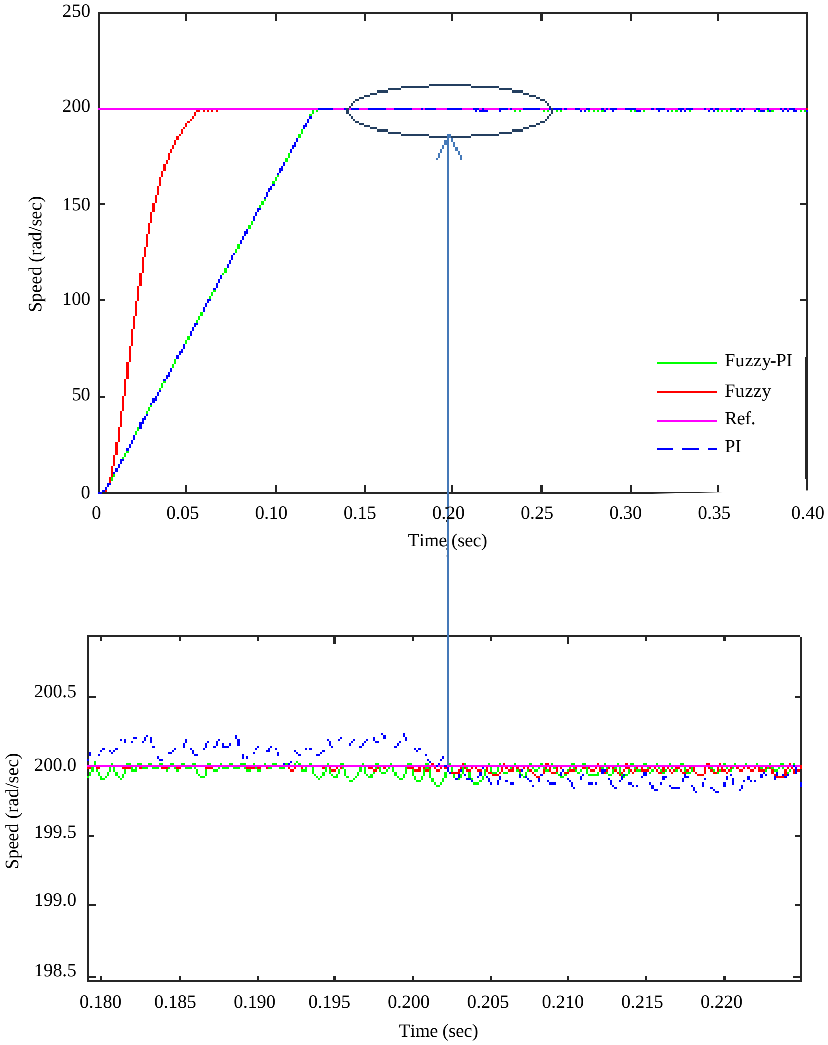

Fig. 6: Speed response for changes of load torque

Fig. 5 and 6. Initially, the motor was at halt and a step change of 200 rad/sec is applied at time zero, then at time 0.2 sec the reference speed was reduced to 120 rad/sec, this condition was maintained for 0.2 sec, the speed

Table 2: Parameters of the induction motor used for the simulation

Parameters	Values
HP	3
Voltage	220 (V)
Frequency	60 (Hz)
Rotor type	Squirrel cage
Stator resistances (Rs)	0.435
Rotor resistances (Rr)	0.816
Stator inductances (Ls)	0.0713
Rotor inductances (Lr)	0.0713
Mutual inductances (Lm)	0.0693
No. of poles	4
Moment of inertia (J)	0.089

reference was reduced again to a value of 50 rad/sec for another 0.2 sec to be raised back to 200 rad/sec at time 0.6 sec for a period of 0.2 sec, finally, the speed reference was reduced to 160 rad/sec at 0.8 sec.

It is seen that the FLC has managed to reach the reference speed in 0.0570 sec while Fuzzy-PI took 0.1218 sec and PI controller took 0.1241 sec. It is obvious that the FLC has reached the reference speed to nearly half the time taken by the other two controllers.

Another simulation was performed to realize the effectiveness of the proposed controller, during which no load was applied for 0.2 sec to allow the three different controllers to reach the reference speed and establish steady state condition (Table 2). The load was then modified to a value of 12 NM to examine the system robustness in holding on to a predefined value of a speed. It could be seen in Fig. 6, the fuzzy controller is more capable in maintaining the reference speed than the Fuzzy-PI and PI controller.

CONCLUSION

In this study three control schemes were investigated and applied to the control of an induction motor, namely conventional PI, fuzzy controller, fuzzified PI. Simulation results verified the superiority of this proposed FLC over the other two controllers in arriving at a reference speed in a much faster response time and a satisfactory overall performance for both changes in speed reference and load torque.

REFERENCES

Blaschke, F., 1972. The principle of field-orientation as applied to the transvector closed-loop control system for rotating-field machines. Siemens Rev., 34: 217-220.

Bose, B.K., 2002. Modern Power Electronics and AC Drives. Prentice Hall PTR, India, ISBN: 9780130167439, Pages: 711.

Jang, J.S.R., C.T. Sun and E. Mizutani, 1997. Neuro-Fuzzy and Soft Computing: A Computational Approach to Learning and Machine Intelligence. Prentice-Hall Inc., New York, USA., ISBN-13: 9780132874670, Pages: 614.

Kalhoodashti, H.E. and M. Shahbazian, 2011. Hybrid speed control of induction motor using PI and fuzzy controller. Intl. J. Comput. Appl., 30: 44-50.

Karanayil, B., M.F. Rahman and C. Grantham, 2001. A complete dynamic model for a PWM VSI fed rotor flux oriented vector controlled induction motor drives using simulink. Master Thesis, Universry of New South Wales, UNSW Sydney, Kensington, Australia.

Kusagur, A., S.F. Kodad and S. Ram, 2012. Modelling and Simulation of an ANFIS controller for an AC drive. World J. Modell. Simul., 8: 36-49.

Ogata, K., 2010. Modern Control Engineering. Vol. 4, Prentice-Hall, Upper Saddle River, New Jersey, USA., ISBN:9780136156734, Pages: 894.

Toufouti, R., S. Meziane and H. Benalla, 2007. Direct torque control for induction motor using intelligent techniques. J. Theor. Appl. Inf. Technol., 3: 35-44.

Ziegler, J.G., N.B. Nichols and N.Y. Rochester, 1942. Optimum settings for automatic controllers. Trans. Am. Soc. Mech. Eng., 64: 759-765.

Zimmermann, H.J., 2001. Fuzzy Set Theory and Its Applications. 4th Edn., Kluwer Academic Publishers, Boston Dordrecht London.