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Analysis and Performance Evaluation of the Position Control of an AC Motor Using PD-PI-PID Fuzzy Logic Controller

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Authors' Contributions

This work was carried out in collaboration between all authors. Author ZAO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author SAS managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

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Abstract

Aims: This paper presents an analysis and performance evaluation of the position control of an AC motor.
Study Design: Mathematical model which represents the position control of an AC motor is used in this Paper, where is obtained from experimental data of the AC motor.
Place and Duration of Study: Computer and software engineering department, collage of engineering, Diyala University-Iraq between October 2011 and June 2012.
Methodology: Different types of controllers are used to analyze and evaluate the performance of the position control of AC motor. Classical Proportional- Integral-Derivative CPID, Fuzzy-like Proportional-Derivative (FPD), Fuzzy-like Proportional-Integral (FPI) and Fuzzy-like Proportional- Integral-Derivative (FPID) are used for the purpose of this paper.
Results: For classical controllers, the rising time was decreased with most types, classical Ziegler-Nichols is used to tune the CPID parameters. The effective values of Kp are from 4.2 to 14.4, where the overshoot is increased from 0.2 to 0.5 and the steady state error is decreased from 2.5 to 2. The response performance of the system is improved with the fuzzy controllers' types. FPD eliminates the overshoot with small change on the error where the FPD with three Membership Function (3FPD) versions I is 0.005 and with 3FPD version II is zero overshoot, while the steady state error is zero in both versions of 3FPD. Fuzzy PD with 5 MSF (5FPD) has zero overshoot with steady state error equal to 0.005 and faster system response.
Conclusion: Fuzzy PD with 8 MSF (8FPD) provides system response with zero overshoot versus big error bigger than 0.5 and slower system response due to the huge number of rules where was 64 fuzzy rules. Fuzzy PI with 5 MSF (5FPI) eliminates the error but with big

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overshoot equal to 0.2. FPID got the better response performance of the control system but slower than FPD.

Keywords: Fuzzy PD, fuzzy PI, fuzzy PID, classical PID, position control of AC motor.

1 Introduction

Fuzzy logic has rapidly become one of the most successful methods for developing sophisticated control systems. With its aid, complex requirements may be implemented in amazingly simple, easily maintained, and inexpensive controllers [1].

In the case of classical controller, the mathematical model of the system is needed. A common form of the system model is differential equations for continuous-time systems or difference equations for discrete-time systems. Strictly speaking, all physical systems in existence are nonlinear. Unless physical insight and the laws of physics can be applied, establishing an accurate nonlinear model using measurement data and system identification methods is difficult in practice. Even if a relatively accurate model of a dynamic system can be developed, it is often too complex to use in controller development, especially for many conventional control design procedures that require restrictive assumptions for the plant (e.g., linearity) [2,3].

As an alternative, fuzzy control provides a formal methodology for representing, and implementing a human's heuristic knowledge about how to control a system, which may provide a new paradigm for nonlinear systems. Fuzzy controller is unique in its ability to utilize both qualitative and quantitative information. Qualitative information is gathered not only from the expert operator strategy, but also from the common knowledge [2,4,6].

Although much of the opposition to fuzzy logic is based on misconceptions, fuzzy control is not a cure-all. Fuzzy control should not be employed if the system to be controlled is linear, regardless of the availability of its model. In summary, PID control should be tried first whenever possible [2].

2 Methodologies

AC motors are used worldwide in many residential, commercial, industrial, and utility applications. Motors transform electrical energy into mechanical energy. An AC motor may be part of a pump or fan, or connected to some other form of mechanical equipment such as a winder, conveyor, or mixer. AC motors are found on a variety of applications from those that require a single motor to applications requiring several motors. Siemens manufactures a wide variety of motors for various applications. AC motors are relatively constant speed devices. The speed of an AC motor is determined by the frequency of the voltage applied (and the number of magnetic poles). There are two main types of AC motors, depending on the type of rotor used. The first type is the induction motor, which runs slightly slower than the supply frequency. The magnetic field on the rotor of this motor is created by an induced current. The second type is the synchronous motor, which does not rely on induction and as a result, can rotate exactly at the supply frequency or a sub-multiple of the supply frequency. The magnetic field on the rotor is either generated by current delivered through slip rings or by a permanent magnet. Other types of motors include eddy current motors, and also AC/DC mechanically commutated machines in which speed is dependent on voltage and winding connection. It commonly consists of two basic parts, an outside stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and an inside rotor attached to the output shaft that is given a torque by the rotating field as shown in Fig. 1 bellow:

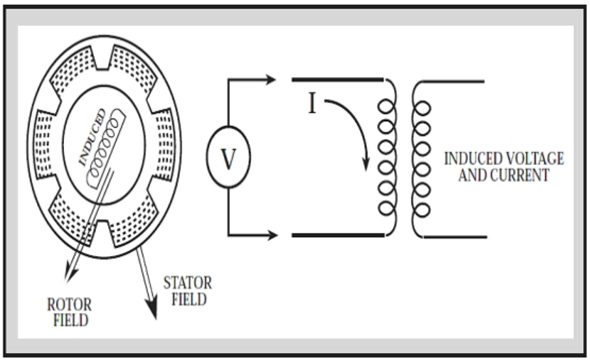


Fig. 1. Structure of AC motor

2.1 Stability Analysis of Position Control of AC Motor

The methods of evaluate the stability of position control of an AC motor for open loop transfer function will be discussed in the following sections, this transfer function was obtained from experimental data of the position control of an AC motor as shown in equation 1 [3,8]. Nyquist is a graphical procedure for determining the absolute and relative stability of closed-loop control systems. Stability information obtained directly from a graph of the open-loop frequency response, It is also useful for obtaining information about transfer functions of systems from the experimental frequency response data. As shown in Fig. 2. The Nyquist can be used for systems with time delays without the need for approximations and gives exact results about both absolute and relative stability of the system.

G= 1\(s^2+2.75s+0.5) (1)

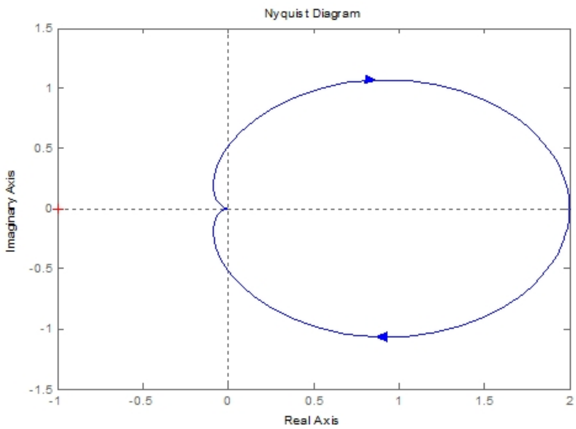
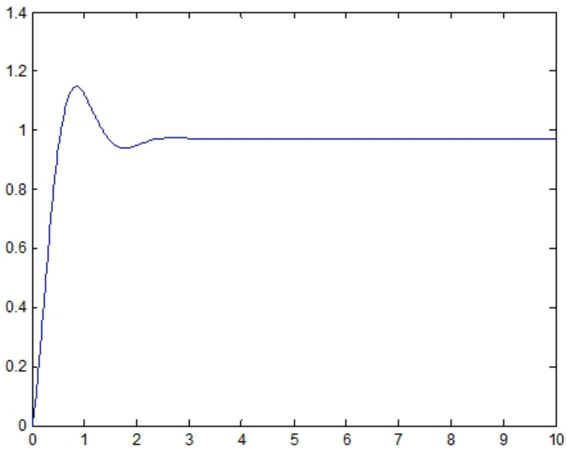


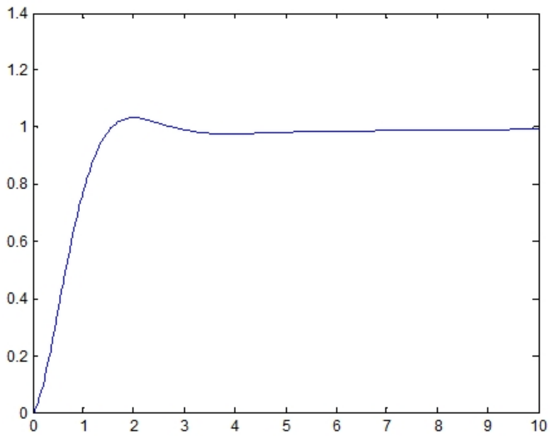
Fig. 2. Nyquist plot to position control of an AC motor

Table 1. Results of applying Ziegler-Nichols (The first method)

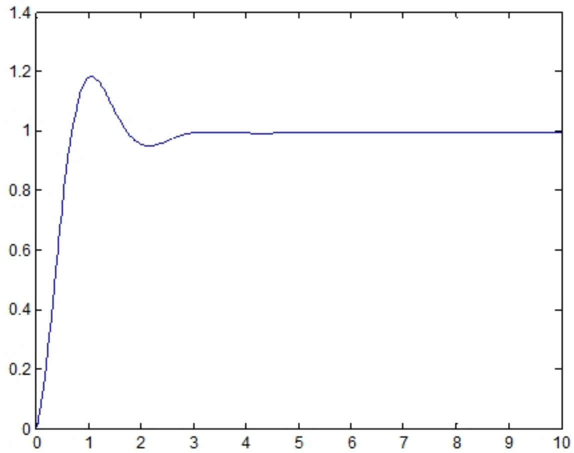
kp	Ti	Td	ts	tr	Mp	e
14.4	1	0.25	0.1	0.7	0.5	2.01
4.2	0.6	0.15	3.24	0.2	0.2	2.56
10.28	1.4	0.35	1.3	0.3	0.4	2.78



(a) When KP=14.4, Ti=1 and Td=0.25



(b) When KP=4.2, Ti=0.6 and Td=0.15



(c) When KP=10.28, Ti=1.4 and Td=0.3.

Fig. 3. The result of applying on position control of an AC motor with different values of KP, Ti and Td

2.3 Fuzzy Logic Controller Design

Fuzzy Logic has been successfully applied to a large number of control applications. The most commonly used controller is the PID controller, which requires a mathematical model of the system. A fuzzy logic controller provides an alternative to the PID controller. It is a good tool for the control of systems that are difficult to model fuzzy logic has rapidly become one of the most successful of today's technologies for developing sophisticated control systems. With its aid, complex requirements may be implemented in amazingly simple, easily maintained, and inexpensive controllers [3, 9-13] where the Structure of the typical fuzzy logic controller shown in Fig. 4.

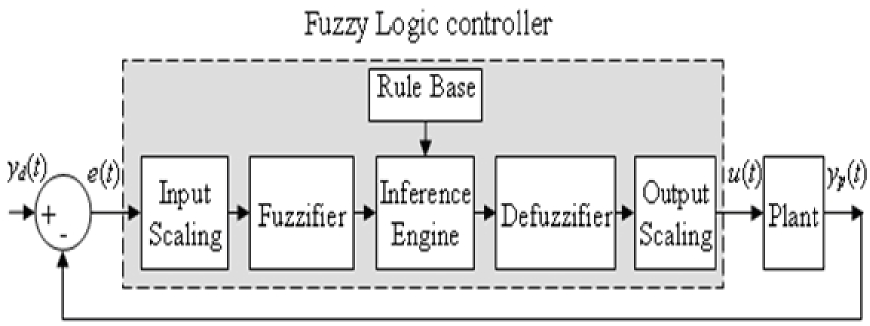


Fig. 4. Structure of fuzzy logic controller with unity feedback control system

In addition to Groups of (three, five and eight) triangular membership functions for inputs/outputs variables, and rule table of (9, 25 and 64) rules were used in this design. The control action in fuzzy logic controllers can be expressed with membership function and simple “if-then”.

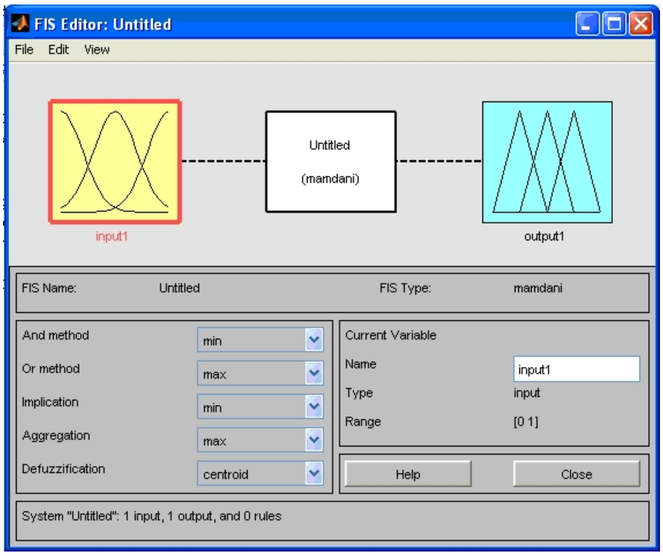


Fig. 5. Typical fuzzy logic toolbox

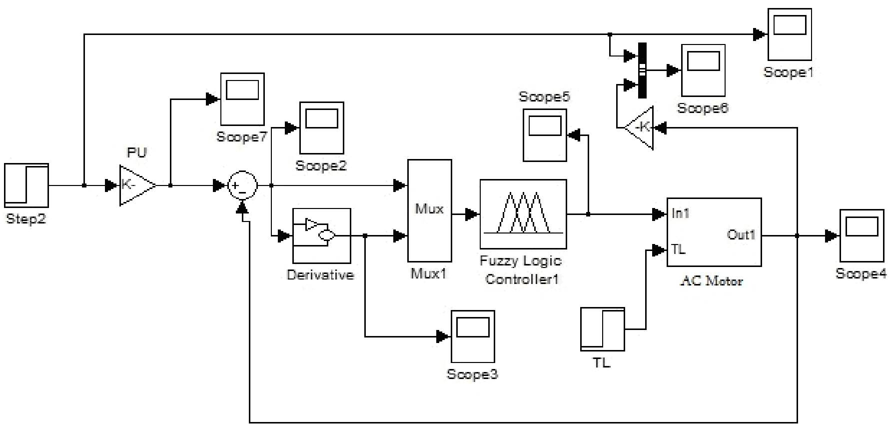


Fig. 6. Matlab Simulink of fuzzy controller with the poison control of an AC motor

3 Results and Discussion

Fuzzy logic toolbox was used to design the fuzzy inference using Matlab simulink as shown in Fig. 5 and Fig. 6 in order to design the fuzzy-like P controller and the fuzzy-like PD controller, while Matlab M-file was used to design the fuzzy-like PI controller and fuzzy-like PID controller with 5 Membership Function (MSF). The assignment of FL rules was done using Control engineer experiences. Mathematical Model of Position control of AC motor was identified from experimental data using Matlab Identification toolbox.

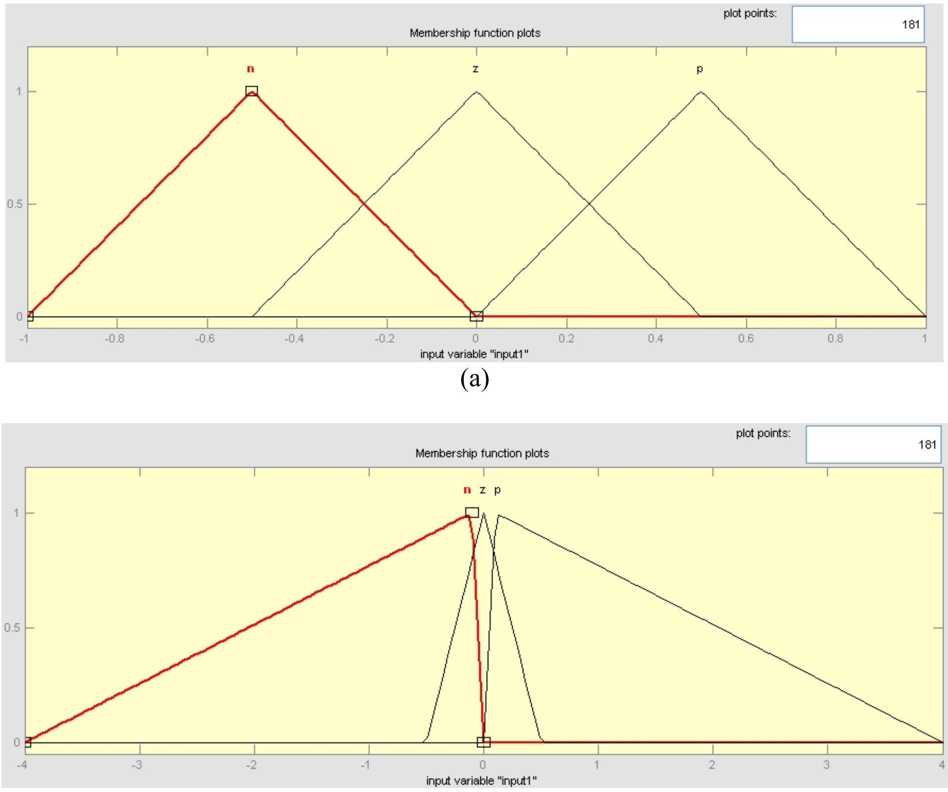
3.1 Membership Function of 3*3 Rule Base

By using group of three triangular membership functions for input/output variables and rule table of 9 rules were used in this design a 3*3 rule base was defined in Table 2 to develop the position control of an AC Motor system. The membership function of inputs /output variables are depicted in Fig. 7-a for Version I and Fig. 7-b for Version II.

Table 2. Fuzzy rule base of 9 rules for 3*3 two inputs fuzzy Pd

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

The membership function of 3*3 is shown in figure bellow for two versions-I&II.



(b)

Fig. 7. (3 Membership function), (a) I/O MSF of version I and O MSF of version II fuzzy PD, (b) Inputs MSF of version II

Fig. 8 shows the Structure of fuzzy-like PD controller using 3*3 MSF. Fig. 9 shows the System response with the fuzzy-like PD controller using 3 MSF of version I and version II as shown in Fig. 9. It is clear that both versions provide good response performance but Version I with small delay and error while Version II with no delay and error, both versions have no overshoot in their responses.

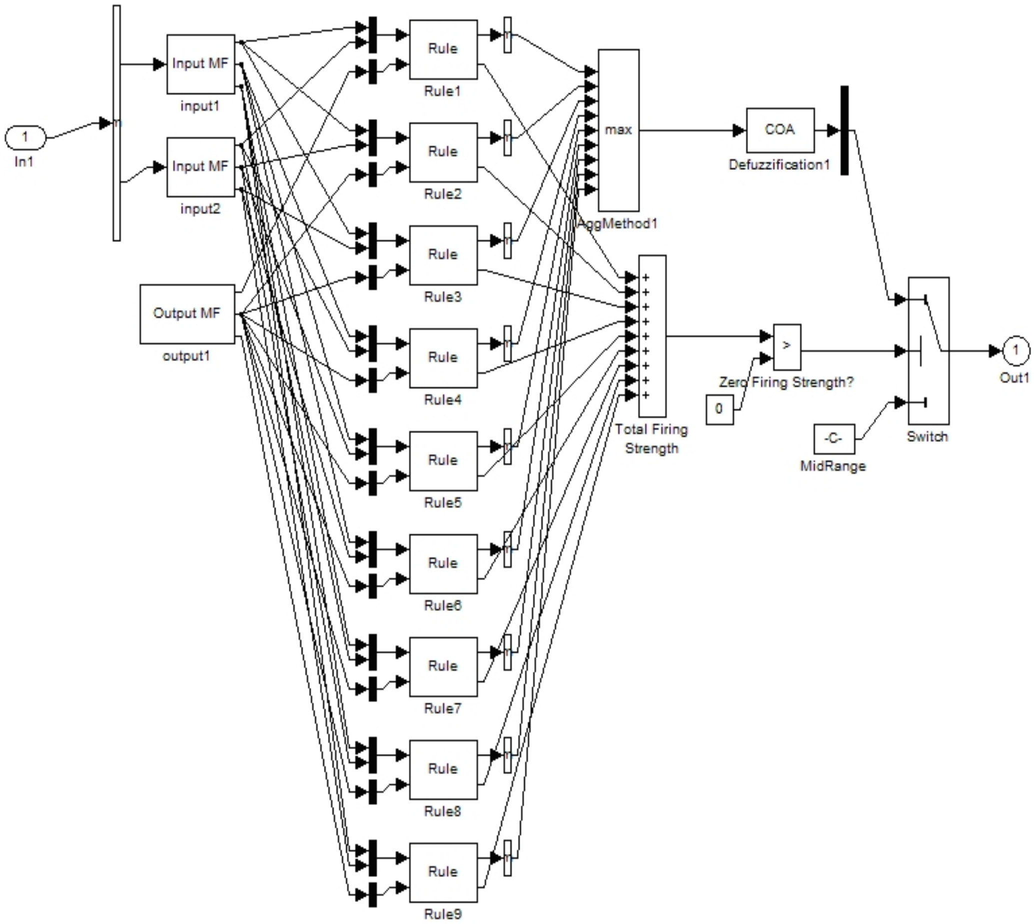
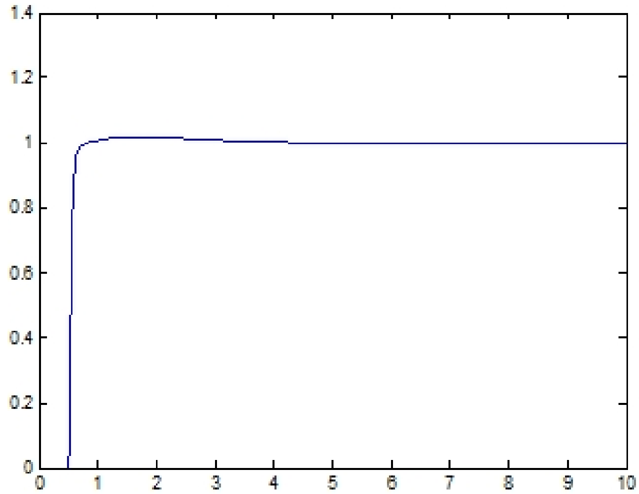
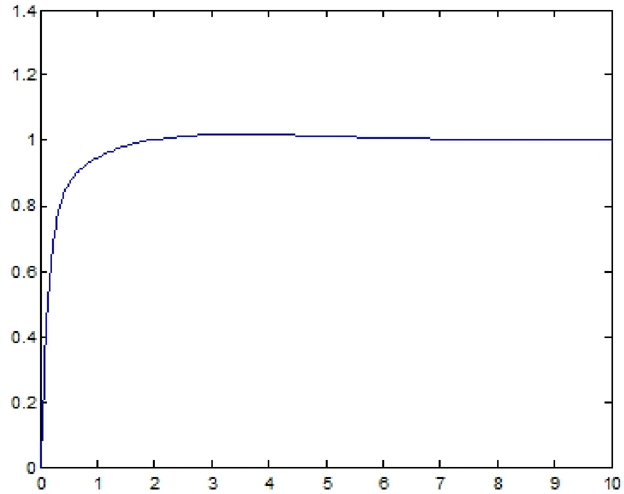


Fig. 8. The Structure of fuzzy-like PD Controller using 3*3 MSF Viewed in Matlab Simulink



(a)



(b)

Fig. 9. The Response obtained by applying fuzzy logic-like PD controller to the position control of an AC motor for the 3*3 rule base (a) Version I and (b) Version II

3.2 Membership Function of 5*5 Rule Base

By using group of five triangular membership functions for input/output variables and rule table of 25 rules were used in this design a 5*5 rule base was defined in Table 3 and Fig.10.

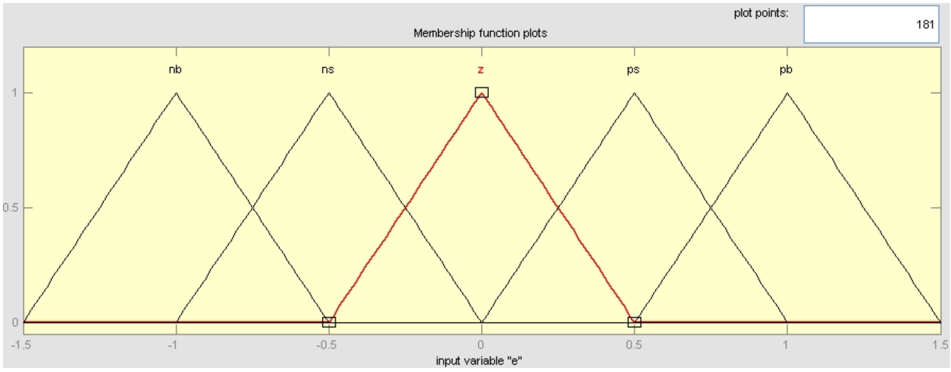


Fig. 10. I/O membership function of 5*5

Table 3. Fuzzy rule base of 25 rules for 5*5 two inputs fuzzy PD.

e/de	NB	NS	Z	PS	PB
NB	PB	PB	PB	PS	Z
NS	NS	PB	PS	Z	NS
Z	PB	PS	Z	NS	NB
PS	PS	Z	NS	NB	NB
PB	Z	NS	NB	NB	NB

The response from applying fuzzy logic controller to the position control of an AC Motor for the 5*5 rule base as shown in Fig. 11.

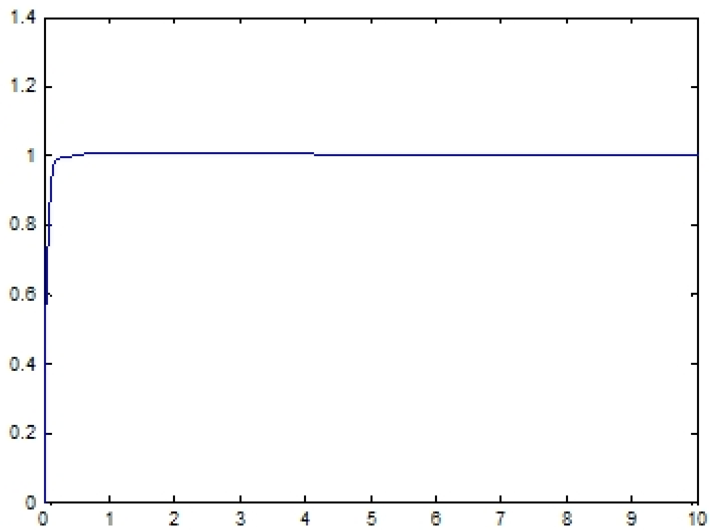


Fig. 11. The response by applying fuzzy logic –like PD controller to the position control of an AC motor for the 5*5 rule base.

3.3 Membership function of 8*8 rule base

By using group of eight triangular membership functions for input/output variables and rule table of 64 rules were used in this design a 8*8 rule base was defined in Table 4. Fig 12 shows the I/O MSF of 8 linguistics variables using Matlab Toolbox, Fig. 13 shows the system response of fuzzy-like PD controller by using the 8 MSF and Rule base of 64 Rule in unity feedback control system where showing that the system response become slower, It important to notice that the response without any tuning method. Fig. 14 shows a response comparison by applying fuzzy PD fuzzy using 5*5, 3*3 and 8*8 fuzzy rules where the controller with 5*5 presents the best control performance with zero error and overshoot and very fast raising time.

Table 4. Fuzzy rule base of 64 rules for 8*8 two inputs fuzzy PD.

e/de	NB	NM	NS	NZ	PZ	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	NZ	PZ
NM	NB	NB	NM	NM	NS	NZ	PZ	PZ
NS	NB	NM	NM	NS	NZ	PZ	PZ	PS
NZ	NM	NM	NS	NZ	PZ	PZ	PS	PM
PZ	NM	NS	NZ	NZ	PZ	PS	PM	PM
PS	NS	NZ	NZ	PZ	PS	PM	PM	PB
PM	NZ	NZ	PZ	PS	PM	PM	PB	PB
PB	NZ	PZ	PS	PM	PM	PB	PB	PB

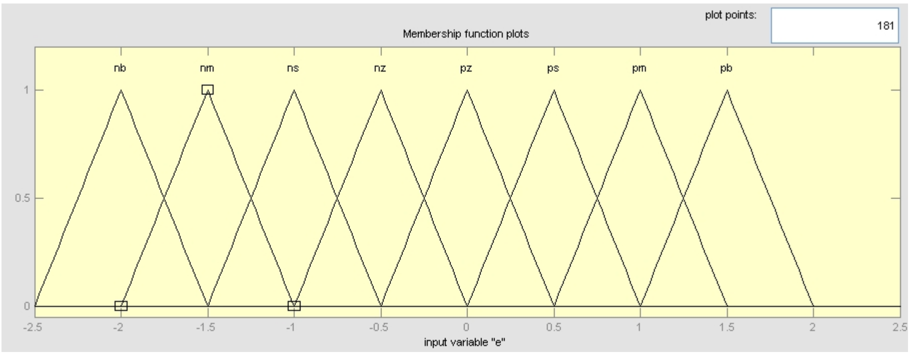


Fig. 12. I/O membership function of 8*8

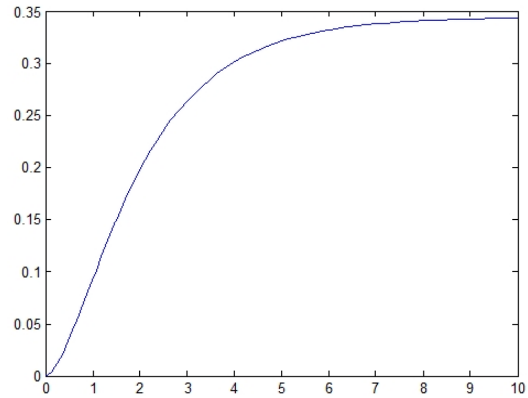


Fig. 13. The response by applying fuzzy logic –like PD controller to the position control of an AC motor for the 8*8 rule base

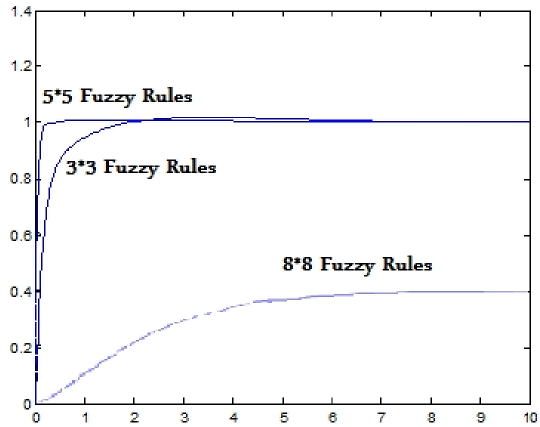


Fig. 14. The Response comparison by applying fuzzy logic –like PD controller to the position control of an AC motor for the 3*3, 5*5 and 8*8 rule base

3.4 Results of PI-PID Fuzzy Logic Controller in Matlab M-File

Due to limitation in Matlab Toolbox and Simulink for obtaining summation of error where used for designing PI fuzzy controller as well as the huge number of rule needed for designing PID fuzzy logic controller where in the case of 5 MSF that mean 5*5*5=125 rule needed. Therefore, M-file was used for designing PI_PID fuzzy controller where PID fuzzy controller designed using parallel structure of classical PID by using two inputs only with two PD fuzzy logic controller and by accumulating the output of the second PD fuzzy logic controller to form as PI fuzzy logic controller as shown in Fig. 15 where is obtained in discrete form x-axis are for the sampling rate (for real time should multiplied by 0.25 where is the value of the sampling rate). Fig. 16 shows the simulation results of fuzzy-like PI controller while Fig. 17 shows the simulation results of fuzzy-like PID controller using 5 MSF and Rule base of 25 rules.

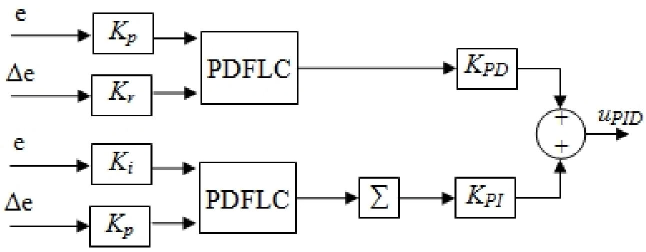


Fig. 15. Two inputs PID fuzzy controller [5]

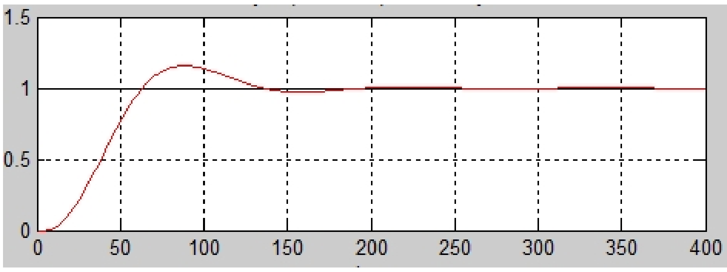


Fig. 16. System response by using fuzzy-like PI controller (for time values should multiply by 0.25)

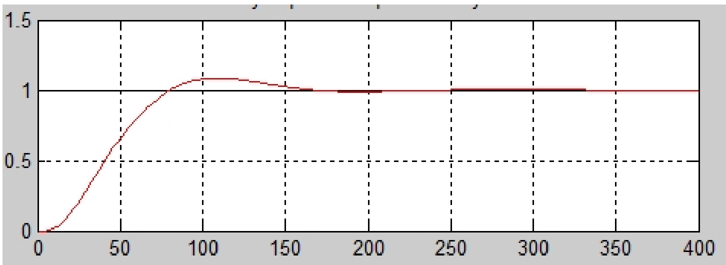


Fig. 17. System response by using fuzzy-like PID controller (for time values should multiply by 0.25)

The effective values of Kp is from 4.2 to 14.4, where the overshoot is increased from 0.2 to 0.5 and the steady state error is decreased from 2.5 to 2. The response performance of the system is improved with the fuzzy controllers' types. FPD eliminates the overshoot with small change on the error where the FPD with three Membership Function (3FPD) versions I is 0.005 and with 3FPD version II is zero overshoot, while the steady state error is zero in both versions of 3FPD. Fuzzy PD with 5 MSF (5FPD) has zero overshoot with steady state error equal to 0.005 and faster system response. Fuzzy PD with 8 MSF (8FPD) provides system response with zero overshoot versus big error bigger than 0.5 and slower system response due to the huge number of rules where was 64 fuzzy rules. Fuzzy PI with 5 MSF (5FPI) eliminates the error but with big overshoot equal to 0.2. FPID got the better response performance of the control system but slower than FPD.

4 Conclusions

This paper presents the analysis and performance evaluation of the position control of an AC motor, Classical PID controller with classical tuning method was used with the system model, as well as 3FPD, 5FPD, 8FPD, 5FPI and 5FPID. From the design and simulation results of the, it can be concluded that:

Higher execution speed versus is achieved by tuning the classical PID controller with the classical tuning methods. The fuzzy logic controller with fuzzy rules base of 5*5 provide the best control performance with respect to other types of controller Fuzzy controller provides good control performance versus faster execution speed. The design of the fuzzy control is based on human observation of a typical step response. Gradual increases in the controller gains, as the system response approaches zero error, provide improved system operation by increasing the speed of system and decrease the time delay with small rate of error.

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Competing Interests

Authors have declared that no competing interests exist.

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