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Analyze and Evaluate the Performance Velocity Control in DC Motor

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Abstract: **A mathematical model of controlling the DC motor has been applied in this paper. There are many and different types of controllers have been used with purpose of analyzing and evaluating the performance of the of DC motor which are, Fuzzy Logic Controller (FLC), Linear Quadratic Regulator (LQR), Fuzzy Proportional Derivative (FPD) ,Proportional Integral Derivative (PID), Fuzzy Proportional Derivative with integral (FPD plus I) , and Fuzzy Proportional Integral (FPI) with membership functions of 3*3, 5*5, and 7*7 rule bases. The results show that the (FLC) controller with 5*5 rule base provides the best results among all the other controllers to design the DC motor controller.**

Keywords: **PID controller, LQR controller, Fuzzy controller, DC Motor**

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1. INTRODUCTION

Last decades, due to system instability, many controllers have been explored, such as PID controller, which refers to the family of controllers with various configurations of the Proportional, Integral and Derivative terms. The most common controller that has been used in industry is Conventional PID controllers due to its simplicity in tuning and effectiveness and design for general linear systems with convenient low cost and implementation. The Linear Quadratic Regulator (LQR) is a method that runs optimally controlled response in order to enable the high-performance design and the closed-loop systems [1,2]. Recently, fuzzy logic is becoming one of the most important for producing and developing a control system. Fuzzy logic has solved many complex problems as it is simple, easily maintained, and inexpensive. The mathematical model in this case is very important to build a good controller for controlling any complex system. The differential equations are the most common system that is used for discrete time systems or continuous time systems. As it's known that the nonlinear physical system could be designed based on the collected data and system identification methods but practically is difficult and challenging due to complexity particularly for conventional control design [3,4]. Furthermore. The quantitative and qualitative information could be used by the Fuzzy controller. Qualitative information has been collected from common knowledge and the expert operator strategy [5,6]. The fuzzy logic control has not been used for linear systems as most of the them based on misconceptions as mentioned above. However, the linear controllers such as PID have been able to solve any kind of control problem with less cost, effort and time. Therefore, the PID has to be tried first [2]. The main characteristics of fuzzy controllers is:

1) a fuzzy controller is cheaper to be developed rather than developing the other controllers such as model-based;

2) the fuzzy controllers are covering a wider range of operating conditions rather than LQR and PID;

3) the fuzzy controller is easy to be designed as it is not complicated and easy to understand [7].

1.1. Statement of problem and methodology of solution

The DC motor speed may change due to disturbance present surrounding it. This will make the desired speed sometimes change and will be not maintain. By using classical Proportional Integral and Derivative (PID), Linear Quadratic Control (LQR), and soft computing methods, such Fuzzy Logic Controller (FLC), PI-Fuzzy, PID-Fuzzy and PD-Fuzzy controllers, the speed could be minimized. The main aim of this paper is analyzing and evaluating the speed control performance of DC motor with various controllers. These controllers are Fuzzy-PID, PID controller, LQR controller, Fuzzy Logic controller, Fuzzy-PI, Fuzzy-PD controllers. A comparison is made among these controllers in order to see which one among them give best performance [8].

2. CONTROLLERS DESIGN

2.1. Classical PID

The classical PID controller could have different configurations which are integral, proportional and others. The most common controller that is used in the industries is conventional PID controller because it is very simple in tuning and design and effectiveness. As is known that the using of P-controller is to reduce input and output phase shift signal, and detection of tracking error [1,2,4].

2.1.1. Proportional Controller (P-controller)

It is one of the linear feedback control system. this system is not for an on/off system which is simpler than the PID control system. The signal of this controller is proportional to the error signal as it is the difference between the process set point and variable (the proportional controller is the multiplication of the proportional and the error signal. The following formula is how the P-controller calculated mathematically [5,6]:

$$P_{out} = K_p e(t), \quad (1)$$

$$e(t) = SP - PV, \quad (2)$$

where P_{out} – the proportional controller output, K_p – the gain of the proportional, $e(t)$ – immediate process error at time 't', SP – Set point, PV – the variable of the process.

2.1.2. Proportional plus Derivative Controller (PD-controller)

The PD-regulator can lessen the greatest overshoot yet may hold a consistent state following blunder. The utilization of subsidiary control is constrained

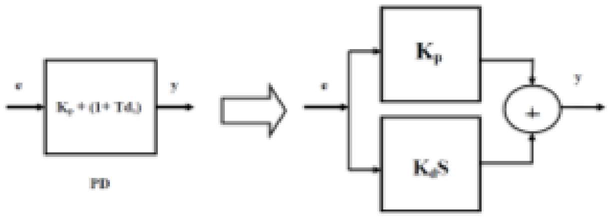


Fig. 1. *PD controller* [1].

from the start, subordinate control looks appealing as appeared in **Fig. 1**. It assists with lessening the time required to balance out a blunder. In any case, it won't expel counterbalance. The control signal from subsidiary activity stops when the blunder quits changing, which won't really be at the set point. Essentially it is likewise constrained to slow acting procedures When its utilizing for quick acting procedure, for example, stream. Control flags because of subsidiary activity will frequently drive the control valve to limits following very little however steep (enormous de dt changes in input). Mathematically proportional plus derivative (PD) control is expressed as [1,2,4]:

$$m = K_p \left(e + TD \frac{d_e}{d_t} \right) + b, \tag{3}$$

where m – controller signal, K_p – controller gain, TD – derivative time, e – error, b – constant.

2.1.3. Proportional plus Integral Controller (PI-controller)

A proportional plus integral (PI) controller contains the transfer function: $Gc(s) = K_p + K_I/s$ as shown in **Fig. 2**. The task of this controller is to tune the control parameters K_p and K_I to achieve better control. By combining the P and I controllers, the system performance will be better since there are two parameters to tune [5,6].

2.1.4. Proportional plus Integral Plus Derivative Controller (PID Controller):

This controller is fast and settling in time, and no steady state error as shown in **Fig. 3** below. Despite the fact that PID controller could be logically designed and pre-tuned for provided lower-order

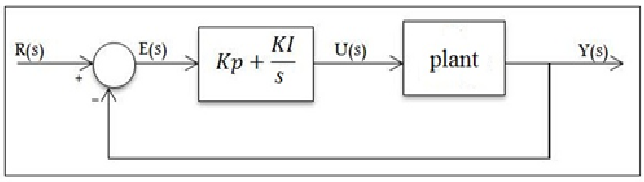


Fig. 2. *PI Controller in unity Feedback* [1].

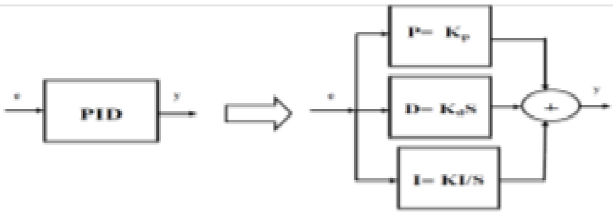


Fig. 3. *PID Controller Structure* [1].

linear system. Also, it could be physically worked for most systems that include higher-order system, for example, Nonlinearity and vulnerabilities., Ziegler-Nichols and Cohen-Coon of the Taylor Instrument Company started, well-known heuristic guidelines for experimental design and tuning strategies, have been utilized so as to have powerful controllers. However, the tuning of the system is consistently a test in the best in class of PID controller structure. This issue turns out to be more significant and basic, especially, when issues including stability, specifications and performance that are considered [1,2].

2.1.4.1. Tuning of PID-Controller

In order to take advantage of this feature, this console systematically introduces the design process based on Ziegler and Nichols' approach. In the Ziegler-Nichols method, parameter setting is based on the stability limits of the system. The derivative and complementary terms are initially taken out of the system and the relative gain is increased to the critical oscillation point. A desirable function of industrial automation is to modify PID control parameters, which mainly includes control gain and possibly also some measurement parameters used in the controller, depending on changes to the systems (installations, process) and their working environments [1,2].

- **Tuning with Ziegler-Nichols methods (The First Method)**

This method of tuning PID controller by obtaining experimentally the step response of the position control of a DC Motor as shown in **Fig. 4**. The curve is characterized by two constants, the time constant

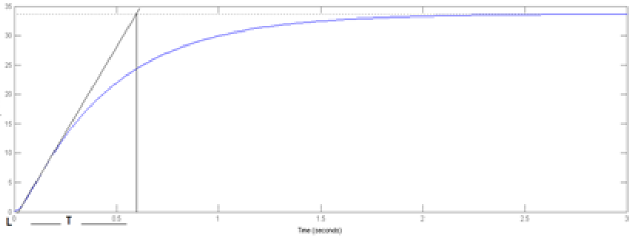


Fig. 4. *The step response by using Ziegler-Nichols methods.*

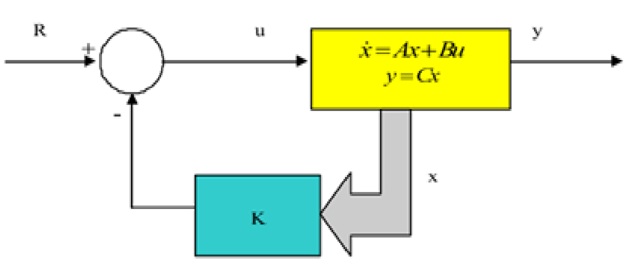


Fig. 5. *LQR system design* [1].

T and the delay time *L*. the time constant and the delay time are determined by drawing a tangent line to the point of incidence of the curve and determining the intersection of the tangent line with the time axis and the line $c(t)$ = k as shown in **Fig. 5**. The transfer function $c(s)/u(s)$ can be approximated by a first-order system with the transfer shift as follows: $C(s)/u(s) = ke$^ – $Ls/Ts + 1$, Ziegler-Nichols suggested assigning values Kp, Ti and Td according to the formula given in the **Table 1** bellow [9]:

2.2. Linear Quadratic Regulator (LQR) controller:

LQR controller is classified as an ideal control system. **Fig. 6** below shows the configuration of the designed LQR. LQR is the best theory of pole placement; In theory, pole placement method involves determining the desired location of the electrodes and relocating the system poles position to the desired location of the electrodes to achieve the desired response of the system. The LQR algorithm determines the optimal location of columns based on two cost functions. To find the optimum gain, we must first determine the optimum performance index, and then solve the Ricati algebraic equation. LQR has no specific solution for defining the cost function to achieve the optimum gain and the cost function must be determined iteratively. The state space representation of a linear system is [1]:

$$\dot{X} = Ax + Bu, \quad y = Cx, \tag{4}$$

where x – sate vector, y – output vector, u – input vector, A – state matrix, B – input matrix, and C – output matrix.

Table 1

Ziegler-Nichols values of Kp, Ti and Td

The controller type	Kp	TI	Td
PI	0.9T/	L/	0
P	T/L	∞	0
PID	1.2T/L	2L	0.5L

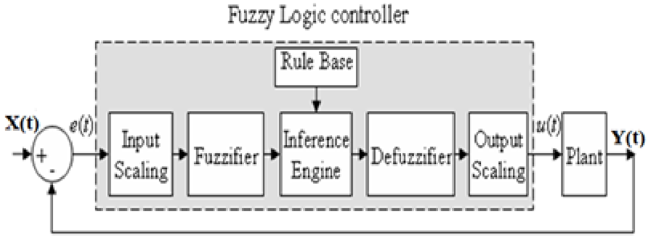


Fig. 6. *Fuzzy logic controller structure (feedback control system)* [10].

The feedback control equation, that is minimizes the cost value [1]:

$$u = -k\,x(t). \tag{5}$$

To find the gain values, $K = K1$ and $K2$ only because the system is a second order, it must solve the Riccati equation below:

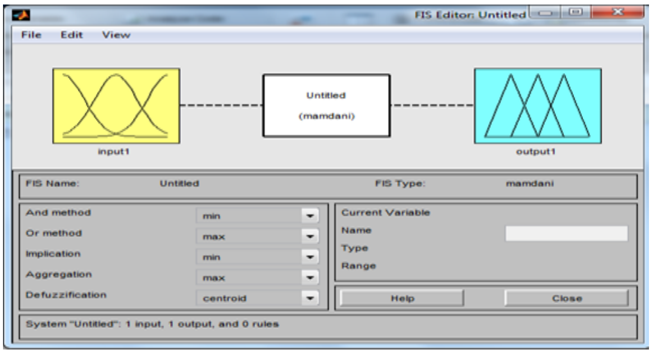
$$A^TX + XA - XBR^{-1}B^TX + Q = 0. \tag{6}$$

The design procedures can be found from [2]. The matrices *Q and* R *has been selected by* trial and error. Some text books and literatures use $Q = C'*C$ and R = 0.1 or 0.2.

2.3. Fuzzy logic controller design

Fluffy Logic has been effectively applied to many applications. The most normally utilized controller is the PID controller. The PID controller has been provided by the fuzzy logic system in order to have better controlling [10,11,12]. This is better for control systems because it is not easy to model the fuzzy logic. Recently, the fuzzy logic and PID controller becomes one of the most efficient systems for developing advanced control systems. Furthermore, any other requirements can be executed in controllers that are simple, inexpensive and easy to maintain [13,14,15]. The fuzzy control uses only a small portion of the available fuzzy mathematics. This part is fairly simple mathematically and conceptually easy to understand. This article introduces some basic concepts, terminology, arithmetic for ambiguous combinations, and fuzzy logic. The fuzzy controller as shown in Fig. 6 consists of four main mechanisms: *a* – Rule Base, *b* – Inference Mechanisms, *c* – Fuzzification Interface, *D* – Defuzzification Interface [16,17,18,19].

In general, two signals should be considered as input signals, which are change of error ($\Delta e(s)$) and error ($e(s)$) signals. These signals represent the PD gain. The change of error signal could be obtained by multiplying the error signal with the delay signal and then subtracting it from the original error signal



FIS Name: Untitled
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
System "Untitled": 1 input, 1 output, and 0 rules

Fig. 7. *Input/output Fuzzy Sets* [10].

[20,21]. While, the error signal could be obtained by subtract the plant (*Y*) output from the output (*Y*(*t*)). **Fig. 7** shows the simulation of symmetric triangular and the singleton fuzzy sets [22,23]. Additionally, in this article the table of 9, 25 and 29 rules have been used with the group of 3, 5, 7, as discussed later in the next section.

The fuzzy logic controller action be expressed with membership function and simple "if-then" rules to the position control of an DC Motor with a 3*3, 5* 5 and 7*7 rule base in chapter three.

2.3.1.MEMBERSHIP FUNCTION OF 7*7 RULE BASE

In this design 49 rules have been used based on the seven triangular membership, **Table 2** shows a 7*7 rules base for the purpose of developing the DC motor speed system.

The membership function of 7*7 rules is shown in **Fig. 8** below

The response from applying fuzzy logic controller to the speed control of a DC motor for the 7*7 rule base will be shown in chapter three.

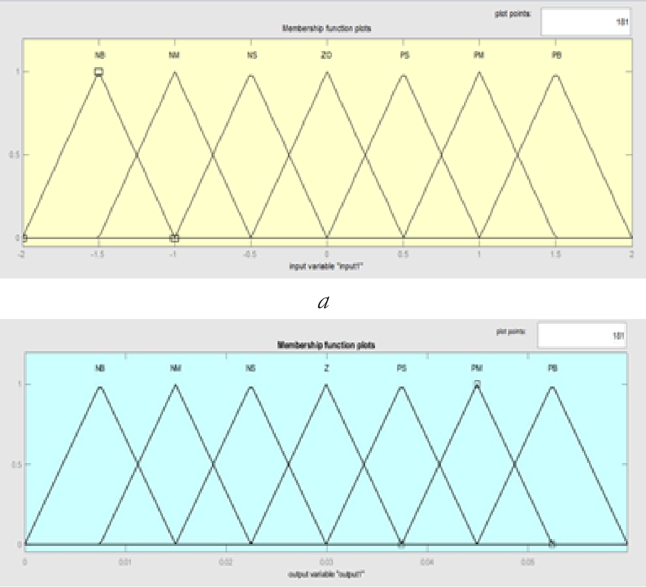
2.4. DC MOTOR

Generally, the motors have been used to convert the electrical energy into mechanical energy. This conversion has been done by two very interactive magnetic fields, which are stator and rotor. The DC motor has the ability of providing very high torque, and easy to miniaturize. The electromagnetic induction machines have been discovered by Faraday, Gauss, and Oersted in early 1800's [24]. Moreover, two kind of converting machine have been used recently, the machine that converts the mechanical to electrical called generator, and the machine that converts the electrical to mechanical called motor. **Fig. 9** shows the DC motor with its equivalent circuit [25].

Table 2

Fuzzy Rule Base [10].

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



a

b

Fig. 8. *The Membership function of 7*7 (a) Inputs variables, (b) Output Variable.*

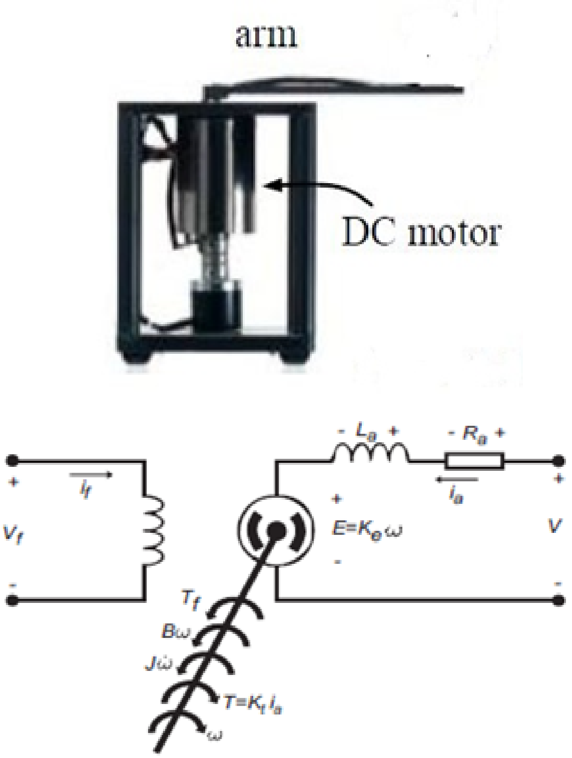


Fig. 9. *DC motor with its equivalent circuit* [25].

According to the Kirchhoff's voltage law, consequently the dynamic of DC motor are expressed by the following equations [8]:

$$V = Ra\, La + La\, dia/dt + ke\, w, \quad (7)$$

$$Kt\, ia = J\, dw/dt + B\, w + Tf. \quad (8)$$

The actual parameters of a DC motor from [8] are: *Ke* – the back emf constant = 14.7*e* 3*N.m/A*, *Tf* – the load torque = 0, *Ra* – the armature resistance = 4.67 Ω, *La* – the armature inductance = 170 e-3 *H*, *w* – the rotor angular speed, *Kt* = the torque constant = 14.7*e* 3*V*.sec/rad, *B* – the viscous (damping) friction = 47.3*e* 6 *N.m/rad/sec*.

And by substituting equation (8) into equation (7) and taking Laplace transformation, the transfer function of speed to voltage is

$$\frac{W(s)}{V(s)} = \frac{2030}{S^2} + 28.58S + 60.34, \quad (9)$$

where *W*(*s*) and *V*(*s*) are the output and the input of the system respectively. simply it has obvious that the denominator roots are equal to -26.2843 and -2.2957, that means the system is stable but it will be shown in section 3.2 the system suffers from oscillation with overshoot and steady state error.

3. RESULTS AND DISCUSSION

This chapter contains all the result of the graduation project which can be obtained by using Mat lab toolbox to design fuzzy logic system like (PI- Fuzzy, Fuzzy, PD-Fuzzy and PID-Fuzzy) controllers and applying these controllers for a DC motor speed control and compares the results with the classical PID and LQR controllers.

3.1. Response of DC motor

By taking the DC motor closed-loop transfer function as in equation (9) with unity feedback and step input the results are show in **Fig. 10**.

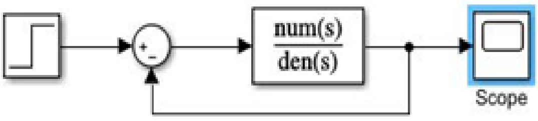


Fig. 10*a. DC motor in unity feedback.*

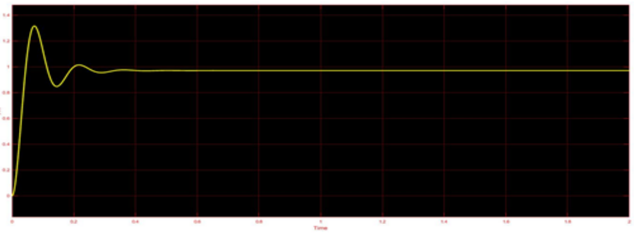


Fig. 10*b. DC motor in unity feedback.*

Table 3

Result of applying the Ziegler-Nichols (The First Method)

Kp	Ti	Ki = Kp/Ti	Td	Kd = Kp*Td
17.38	0.077	225.714	0.019	0.33

The system suffers from oscillation with maximum overshoot, Mp = 31.7%., Rising Time = 0.028 sec., Settling Time = 0.245 sec., Steady State Error (es.s) after oscillation = 0.04.

3.2. Tuning using PID controller results

In this section the tuning of classical PID controller include with Ziegler-Nichols (The first method). The result in table (3) was obtained by applying the Ziegler-Nichols (The first Method) to tuning DC motor speed based on classical PID controller.

The system information are Tr = 0.027 sec., Ts = 0.24 sec., Mp = 14.3 %, es.s = 0.01.

3.3. LQR controller results

It has been shown that from section 2.4 to achieve LQR controller it must solve the Riccati equation (6). Riccati equation can be easily programmed for a computer, or solved using MATLAB function lqr, that is:

$$[k,s,e] = \mathrm{lqr}\,(A,B,Q,R). \quad (10)$$

The matrices *A, B,* and *C* in Riccati equation must be written in a Jacobian matrices [2], from equation (10) as follows:

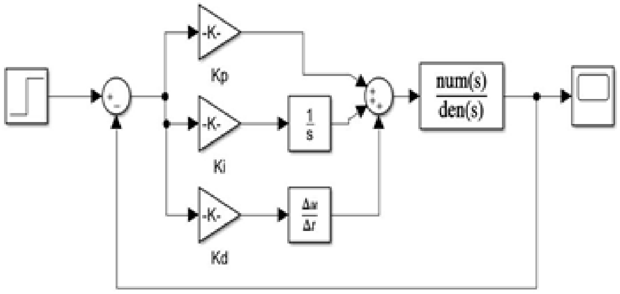


Fig. 11*a. PID controller.*

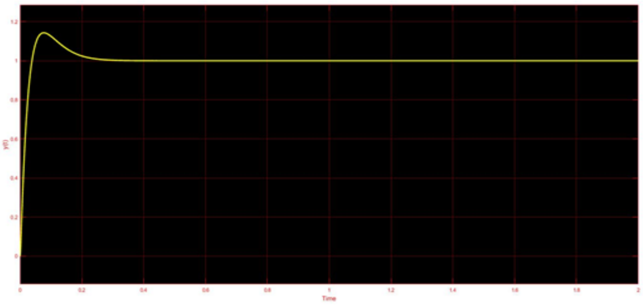


Fig. 11*b. The response of PID controller.*

$$A=\begin{bmatrix}0 & 1\\ -60.34 & -28.58\end{bmatrix},\ B=\begin{bmatrix}0\\ 2030\end{bmatrix},\ C=[1\ \ 0].$$

The state-feedback gain is *K*, LQR returns the solution *S* of the associated Riccati equation and e is the eigen values. This type of controller needs prefilter to remove the offset between input and output. By simulating the Matlab program for the DC motor system with LQR controller, the optimal values of gains by adding the pre-filter are: k_1 = 0.9707 and k_2 = 0.3616. The response will be as follows:

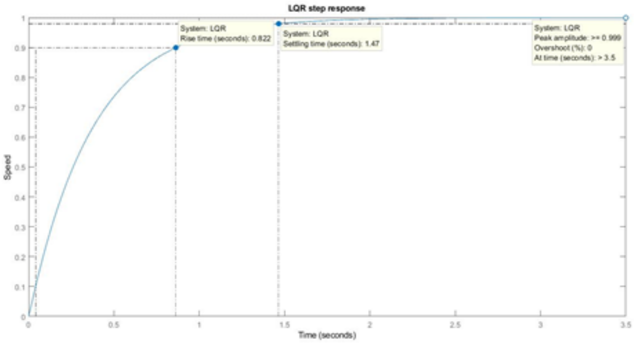


Fig. 12. *The response of LQR controller.*

The system information are Tr = 0.822 sec., Ts = 1.47 sec., Mp = 0 %, es.s = 0.01.

3.4. Fuzzy logic controller results

The fuzzy logic controller action can be expressed with membership function and simple "if-then" rules to the speed control of DC motor which will implemented with a 3*3, 5*5 and 7*7 rule base as shown in **Fig. 12.2** below:

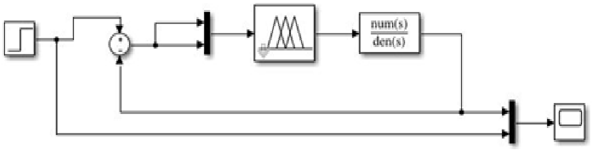


Fig. 12.2. *Fuzzy logic controller.*

3.4.1. Membership function of 7*7 rule base results:

By using group of seven triangular membership functions input/output rule an variables table of 49 rules that are used in this design a 7*7 rule base as shown in **Table 2** in section two to develop the speed control of DC motor system we obtained this response.

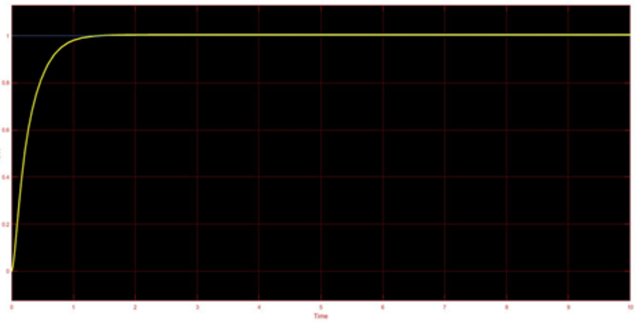


Fig. 13. *The response of Fuzzy Logic Controller 7*7 rule base.*

The system information are Tr = 0.58 sec., Ts = 1.32 sec., Mp = 0 %, es.s = 0.

3.5. PI-Fuzzy logic controller results

In this section applying PI controller with fuzzy logic controller to the speed control of DC motor which will implemented with a 3*3, 5*5 and 7*7 rule base as shown in **Fig. 14** below, where the values of Kp and KI were obtained from optimal PID controller, section 3.3:

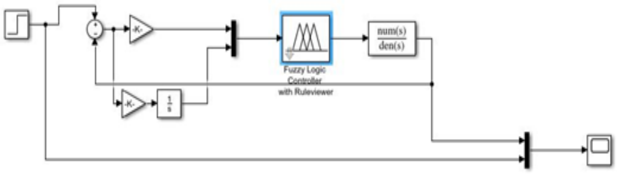


Fig. 14. *PI-Fuzzy logic controller.*

3.6. PD fuzzy logic controller results

The fuzzy logic controllers action can be expressed with membership function and simple "if-then" rules to the speed control of DC motor which will implemented with a 3*3, 5*5 and 7*7 rule base as shown in **Fig. 15** below, where the values of Kp and Kd were obtained from optimal PID controller, section 3.3:

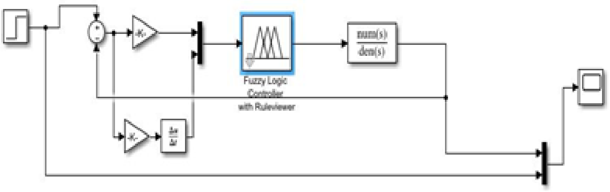


Fig. 15. *PD-Fuzzy logic controller.*

3.6.1. Membership function of 7*7 rule base results:

By using group of seven triangular membership functions input /output variables and rule table of 49 rules were used in this design a 7*7 rule base was defined in table (2) in chapter two to develop the speed control of DC motor system we obtained this response:

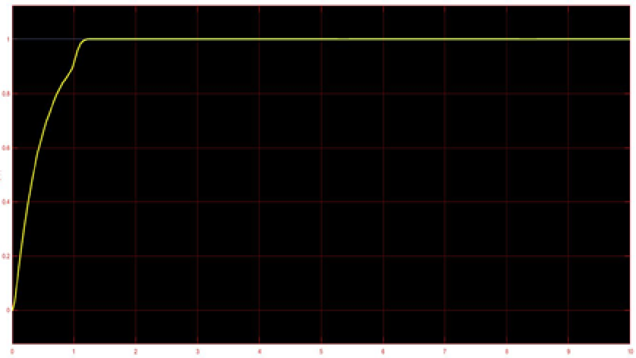


Fig. 16. *The Response of PD-Fuzzy Logic Controller 7*7 rule base.*

The system information are Tr = 0.899 sec., Ts = 1.8 sec., Mp = 0 %, es.s = 0.

3.7. PID FUZZY LOGIC CONTROLLER RESULTS

In this section applying I controller as assistant to PD controller with fuzzy logic controller to the DC motor speed control which will implemented with a, 5*5 and 7*7 rule base as shown in **Fig. 17** below, where the values of Kp, Kd, and KI were obtained from optimal PID controller, section 3.3:

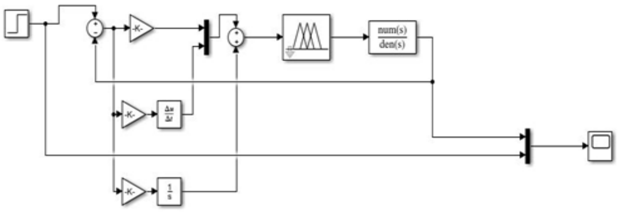


Fig. 17. *PID-Fuzzy controller.*

3.7.1. MEMBERSHIP FUNCTIONS OZ. 5*5, AND 7*7 RULES BASE RESULTS

The response from applying PID-Fuzzy Logic controller to the speed control of DC motor for the 3*3, 5*5, and 7*7 rules base were defined in table (2, 3 and 4) in the previous sections to develop the speed control of a DC motor system we obtained the same response for all rules, that as shown in **Fig. 18** below:

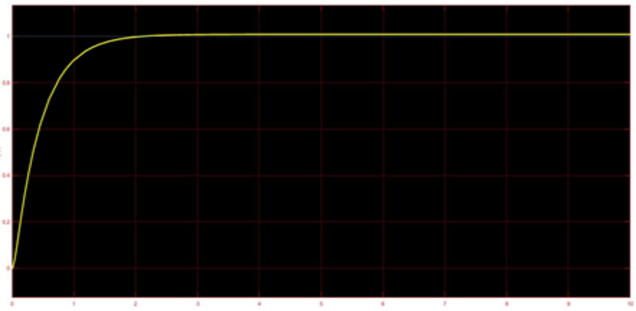


Fig. 18. *The response of PID-Fuzzy Logic controller 5*5, 7*7 rules base.*

The system information for all rules are the same and are as follows Tr = 0.948 sec., Ts = 2 sec., Mp = 0 %, es.s = 0.

4. DISCUSSION

To discuss the results which are obtained by using MATLAB toolbox to design fuzzy logic system controllers by applying these controllers for speed control of a DC motor, it is necessary to compare the results of the PID and LQR controllers with fuzzy logic controllers. The response of the DC motor system has approximately the same rise time (Tr) and settling time (Ts) and equal to 0.028 sec. and 0.24 sec. respectively before and after applying PID controller, but the maximum overshoot (Mp) decrease from 31.7% to 14.3% with minimum steady sate error (es.s) with PID controller. LQR controller has larger Tr = 0.822 sec. and Ts = 1.47 sec. compared with the PID controller but it removed the maximum overshoot (Mp).

For the Fuzzy Logic Controller (FLC), it has been shown that from the table below both of PI-Fuzzy, PD-Fuzzy, and PID-Fuzzy controllers have the same Tr = 0.9 sec., Ts = between 1.5 to 2 sec., Mp = 0, and es.s = 0, but the Fuzzy Logic Controller (FLC) with

Table 4

Discussion of result

	Rise Time (sec.)	Settling Time (sec.)	Overshoo (%)	Steady State Error
DC motor	0.028	0.24	31.7	0.01
PID Tuning With Ziegler-Nichols	0.027	0.24	14.3	0.01
LQR	0.822	1.47	0	0
Fuzzy logic controller 3*3	0.46	0.9	0	0
Fuzzy logic controller 5*5	0.38	0.7	0	0
Fuzzy logic controller 7*7	0.58	1.32	0	0
PI-Fuzzy logic Controller 3*3, 5*5, and 7*7	0.94	2	0	0
PD-Fuzzy logic Controller 3*3, 5*5, and 7*7	0.93	1.5 to 1.8	0	0
PID-Fuzzy logic Controller 3*3, 5*5, and 7*7	0.94	2	0	0

5*5 rule base is better than others, which has Tr = 0.3 sec., Ts = 0.7 sec., Mp = 0 %, and es.s = 0, so the later controller is better than LQR controller.

5. CONCLUSION

This paper presents the analysis and performance evaluation of speed control of a DC motor as follows:

1. Classical PID controller provides a higher execution for DC motor, but the PID controller does not remove the maximum overshoot compared with other controllers.
2. PI-Fuzzy, PD-Fuzzy, and PID-Fuzzy controllers provide a better control performance by removing maximum overshoot and steady state error, but with larger rise time and settling time compared with PID controller.
3. Fuzzy Logic Controller with 5*5 rule base improved the system much more than PID, PI-Fuzzy, PD-Fuzzy, and PID-Fuzzy controllers by increasing the speed of system and decrease time delay.

REFERENCES

1. Westphalia L. *Handbook of Control Systems Engineering*. John-Wiley Inc.,1995.
2. D.K.Anand, R.B.Zmood. *Introduction to Control Systems*. 3rd Edition, Butterworth Heinemann Ltd, 1995.
3. Fakhrulddin H. Ali and Hussein Mohammed Mahmood. LABVIEW FPGA Implementation of PID Controller for DC Motor Speed Control. *1st International Conference on Energy, Power and Control (EPC-IQ)*, pp.1-6. IEEE, 2010.
4. Guishan S. Chen. Particle Swarm Optimization for PID Controllers with Robust Testing. *International Conference on Machine Learning and Cybernetics,* Hong Kong, 2007, pp. 956-961. IEEE, 2007.
5. Sujit Kumar and V. Kumar. Speed Control DC Motor using Fractional Fuzzy based PID Controller. *2012 IEEE International Conference on Engineering and Technology (ICETECH)*, Coimbatore, pp. 1-6, IEEE, 2012.
6. P. vas and M.J.E. Bulale. Design and Implementation of Fuzzy based PID Controller. *Industrial Technology, IEEE ICIT '02. 2007 IEEE International Conference on*, vol. 1, pp. 220-225, IEEE, 2007.
7. Wang Xiao kan and Sun Zhong liang. Design and Research based Fuzzy-PID Parameters Self-Tuning Controller with MATLAB. *International Conference on Advanced Computer Theory and Engineering, ICACTE '08*, pp.996-999, IEEE, 2008.
8. Munaz Cesar and A. Abdelrahman. Speed Control of DC Motor using Fuzzy Logic Controller. *2008 International Conference on Communication, Control, Computing and Electronics Engineering (ICCCCEE)*, Khartoum, pp.1-8, IEEE, 2008.
9. RG Kanojiya and PM Meshram. Tuning of PID Controller using Ziegler-Nichols Method for Speed Control of DC Motor. I*EEE-International Conference On Advances In Engineering, Science And Management (ICAESM-2012),* Nagapattinam, Tamil Nadu, 2012, pp. 117-122, IEEE, 2012.
10. E. Cox. Fuzzy Fundamentals. *IEEE spectrum,* 29(10), October 1992.
11. H. Ying. *Fuzzy Control and Modeling, Analytical Foundations and Applications*. Institute of Electrical and Electronic Engineers Inc., USA, 2000.
12. KM Passino and Stephen Yurkovich. *Fuzzy Control*. Addison-Wesley Longman Inc., USA, 1998.
13. *Math works. Fuzzy Logic Toolbox User's Guide*. Math works, Inc., 1999.
14. Y Huang and S Yasunobu. Design of Neuro-Fuzzy Controller. *9th International Symposium on Communications and Information Technology,* Icheon, pp. 808-813, IEEE, 2009.
15. MM Kamal, L Mathew and S Chatterji. Speed Control of Brushless DC Motor using Genetic Algorithm. *2014 Students Conference on Engineering and Systems*, Allahabad, pp. 1-5, IEEE, 2014.
16. Zhang Xiao Ming and Long Shi Liu. Simulation Study of Fuzzy-PID Controller for DC Motor based on DSP. *2012 International Conference on Industrial Control and Electronics Engineering*. pp.3401-3405, IEEE, 2012.
17. SG Kadwane and S Gupta. Real Time Based PI-Fuzzy Controller for DC Servomotor. *2006 International Conference on Power Electronic, Drives and Energy Systems,* New Delhi, 2006, pp.1-4.
18. Zhao Yongjuan and Pan Yutitan. The Design and Simulation of Hybrid Fuzzy-PID Controller. *International Forum on Information Technology and Applications (IFITA)*, 2010, vol. 3, pp. 95-98, IEEE, 2010.

19. JP Rey and MM Dalvi. A Numerical-based Fuzzy-PID Controller applied to a DC Drive. *IEEE International Symposium on Industrial Electronics, Symposium Proceedings, ISIE'*, pp. 429-434, IEEE, 2009.
20. M Surya Kalawati and Mitra R. Comparative Analysis of Robustness of Optimally Offline Tuned PID Controller and Fuzzy Supervised PID Controller. *2014 Recent Advances in Engineering and Computational Sciences (RAECS)*, pp.1-6, 2014.
21. Salim Jyoti Ohri and Naveen. Speed Control of DC Motor using Fuzzy Controller in LABVIEW WSEAS. *IEEE Conference on Transactions on Systems and Control,* Vol. 10, pp. 2224-2856.IEEE, 2015.
22. Vishal Mehra and V Kala. Design and Simulation of FOPID Composite Parameters Controller with MATLAB. *2010 International Conference on Computer Design and Applications (ICCDA)*, vol. 4, pp. V4-308-V4-311, IEEE, 2010.
23. Ahamadraza Ahmadi and Kumari SU. Optimal Fuzzy-PID Controller. *International Conference on Power Signals Control and Computations (EPSCICON)*, pp. 1-6, IEEE, 2012.
24. Austin Hughes. *Electric Motors and Drives Fundamentals, Types and Applications*. 3rd Edition, Linacre House, Jordan Hill, Oxford OX2 8DP, 2006.
25. Mohammed Salah, Mohammed Abdelati. Parameters Identification of a Permanent Magnet DC Motor. *International Conference on Modelling Identification and Control* (MIC 2010) At: Aust.