AMSE JOURNALS –2014-Series: Advances C; Vol. 69; N° 1; pp 69-84
Submitted Oct. 2013; Revised June 30, 2014; Accepted July 15, 2014

Intelligent Control Systems and Performance Analysis of PMDC Motor Drives

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Abstract

This research paper discuss about the artificial intelligent technique and to derive mathematical analysis to control the speed and error calculation of the Permanent Magnet DC (PMDC) motor. The speed control of PMDC motor found to be difficult with the conventional methods like Proportional Integral (PI) and Proportional Integral Derivative (PID) controllers. So, the proposed control of speed by using intelligent control technique with Fuzzy-PD (F-PD) controller is used to improve the performance of the motor drive by minimizing the overshoot, settling time and peak time of the controller. To overcome these problems fuzzy based intelligent control system is being incorporated with PMDC motor based optimal fuzzy rule. The performance has been investigated based on steady state response. The metrics based on error outcome of IAE (Integral Absolute Error), ITAE (Integral Time Absolute Error) and ITSE (Integral Time Square Error) of the above controllers were calculated. The result of the fuzzy logic-PD (FLPD) controller shows least overshoot, settling time and peak time, with low metrics of IAE, ITAE and ITSE. Thus the intelligent control systems of fuzzy-PD controller used in a more effective and efficient manner to control the motor speed.

Key words

PMDC Motor model, PID controller, PIC30F4011, Performance indices, F-PD controller

1. Introduction

DC motor possess a good speed control with a high response, so the formal system of speed control needs a high control requirements, such as rolling mill, double-hulled tanker, high precision digital tools and most of the areas [10], [3], [4]. DC drives are currently used in many industries because of the torque speed characteristics of DC motor that can be varied over a wide range while retaining high efficiency compared to AC motors [10], [7]. In robotic and actuation applications, a wide variety of speed or position control is required. In many situations, PMDC motors are used to identify the speed of positioning and tracking under variable loads [10], [8]. Thus requirements of control system have increased as the industrial growth rapidly [3], [9]. The analysis of the control systems performance is done effectively and in a very fast manner in the proposed system. There are different methods for controlling the PMDC motor by using the controllers like PI and PID [6], [7]. Conventionally, the speed control of PMDC motor had been done by controlling the speed and system error.

To connect the PMDC motor transfer function, it needs a circuit to transform the low-level motor signal from the controllers to a reference speed signal which is given to the controllers, this in turn run the motor and produce the error and steady state speed[5],[14]. In this research paper, PI, PID and novel Fuzzy-PD are implemented from which it infers and calculate the Speed and system error. The use of Fuzzy Logic controller finds its application in the area of control system design with human expert knowledge rather than the precise mathematical modeling [11], [13], and implementation of the required controller.

2. Mathematical Modeling

DC motor and generator are the examples for electromechanical system, which are used in various control system applications. PMDC machine consist of electrical systems and mechanical systems, the former comprises of field poles, armature windings and later comprises of commutator and load. This inhibits low inertia, high starting torque and starting current [11], [17].

A. PMDC motor schematic diagram

Simulations of the system has been established with an appropriate mathematical model and executed with a schematic diagram representation of a PMDC motor. Fig.1 shows the model for Mathematical calculation of PMDC motor to control the motor speed.

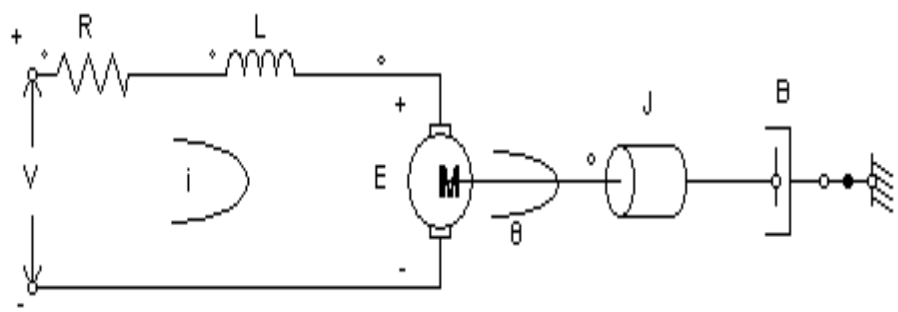


Fig.1. Armature controlled PMDC motor

B. System Equation

Using KVL law, the armature voltage equation in the DC motor, is given by

$$V_a - E_b = iR + L\frac{di}{dt} \tag{1}$$

$$V_a = iR + L\frac{di}{dt} + E_b \tag{2}$$

Where E_b is back emf of the motor, E_b is proportional to speed

$\theta(t)_m = \frac{d\theta}{dt}$ = speed of the motor

$$E_b \alpha \frac{d\theta}{dt}$$

$E_b = K_B \frac{d\theta}{dt}$ (K_B is back emf constant)

$$V_a = iR + L\frac{di}{dt} + K_B\frac{d\theta}{dt} \tag{3}$$

$$V_a(t) = i(t)R + L\frac{di(t)}{dt} + K_B\theta(t)_m \tag{4}$$

C. Transfer function

Taking Laplace transform on both sides in Equation (4)

$$V_a(s) = Ri(s) + sLi(s) + K_b s\theta(s)_m \tag{5}$$

Where 's' denotes the Laplace operator in equation (5). In a PMDC motor the torque is proportional to the product of main flux and armature current (I). The developed torque is given by,

$$T_d = K_{tm} I$$

Where K_{tm} is the motor torque constant, T_J is the inertia torque. By the use of Alembert's principle, the torque is calculated as

$T_d = T_J + T_B$

$$T_d = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} \tag{6}$$

$$K_{tm} I = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} \tag{7}$$

$$T_d = K_{tm} I = J\frac{d\omega}{dt} + B\omega \tag{8}$$

Taking Laplace transform for the Equation (7) and simplified

$$I(s) = \frac{(Js^2 + Bs)}{K_{tm}}\theta(s)_m \tag{9}$$

Substitute Equation (8) in Equation (5), is given by

$$V_a(s)=\frac{(sL+R)(Js^2+Bs)}{K_{tm}}\theta(s)_m+K_B s\theta(s)_m \quad (10)$$

$$V_a(s)=\frac{[(sL+R)(Js^2+Bs)+sK_BK_{tm}]}{K_{tm}}\theta(s)_m \quad (11)$$

Transfer function of the PMDC motor is given by

$$G(s)=\frac{\theta(s)_m}{V_a(s)}=\frac{K_{tm}}{[(sL+R)(Js^2+Bs)+sK_BK_{tm}]} \quad (12)$$

From the block diagram in Fig1, it is easy to see that the transfer function from the input voltage, $V_a(s)$, to the angular velocity, $\omega_m(s)$ is:

$$T.F=\frac{\omega(s)_m}{V_a(s)}=\frac{K_1}{[(sL+R)(Js+Bs)+K_1^2]} \quad (13)$$

3. PID Controller Model

The Proportional (P), Integral (I), Derivative (D) controllers are the most popular type of controller used in different engineering applications. Both PI and PID controllers are used to minimize the system error with the help of reference input and output signals [6].

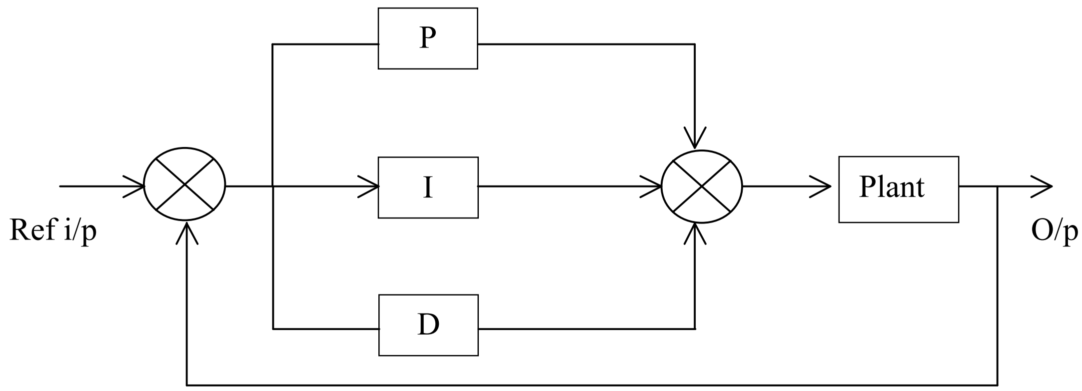


Fig. 2. Model of PID controller

The mathematical representation of the PID controller is given as:

$$U(t)=e(s)+K_d se(s)+K_i\frac{e(s)}{s} \quad (14)$$

Where U(t) is the controller output signal, e(s) is the error signal, K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain. In Equation (14) the PID controller has three parameters like Proportional term, Integral term and Derivative term, each term has a gain value related to input and it makes the control system in a different way from the other controllers. The proportional controller improves the steady state term and reduces the sensitivity error of the system [12], [15]. The pure proportional controller cannot be used to produce constant steady state error. The K_p value is high for the fast change of the system output, which makes the controller output to be highly sensitive keeping the proportional, integral and derivative values has constant. The PI and PID controllers reduce the steady state error, the integral controller depends on summation of the present as well as previous errors and the output signal obtained very smoothly and reached the steady state value. Finally PID controller output signal is depended on the two terms one is proportional and another one is derivative signal. The damping value is increase by reduce the maximum overshoot. These two controllers depend on the rate of change of error. Both the value of the current error and the output error are taken into account, it speeds up the controller response, and produce maximum overshoot in the system [11].

4. Design and Description of Fuzzy Logic Controller

Fuzzy logic controller is easy to understand, very simple, more stable without complexity, flexible and tolerant to imprecise data. Fuzzy logic is used to model non-linear function of arbitrary complex function based on natural system language. The output control is a smooth control function despite a wide range of input variations. Since the FLC processes user-defined rules governing the target control system, it can be modified easily to improve the system performance [1]. It is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters to be implemented. The rule-based operation becomes complex if two inputs and one output is chosen for a single implementation since, rules defining their interrelations must also be defined [1]. It would be better to break the control system and use several smaller Fuzzy logic controllers distributed on the system, each with more number of limited responsibilities to control the mathematical model [2]. The main contributions of these variable gains are improving the control performance and they can change the errors and the rate of change of errors caused by time delay affects the system. Figure.3 shows the fuzzy controller process.

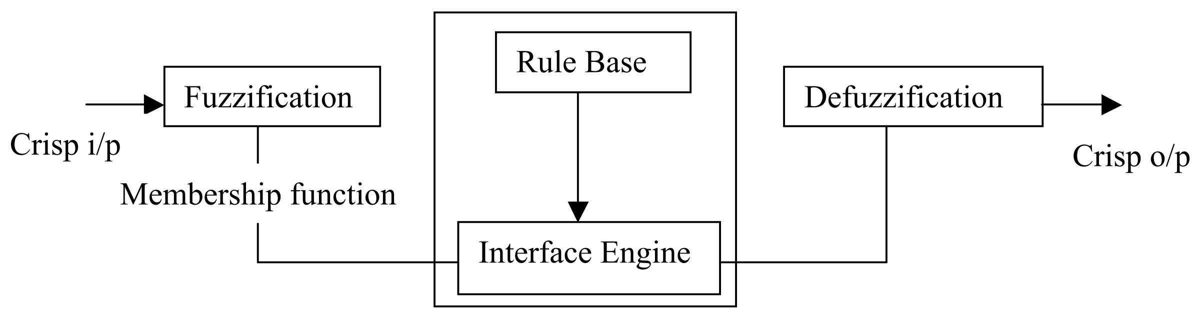


Fig.3. Process Blocks of Fuzzy Controller

The architectural diagrams of fuzzy logic controller along with different linguistic variables are described. This design of fuzzy rule is used to obtain the control performance for the membership function plot operation [12]. Classical analysis and control strategy are incorporated in the rule base. Each rules describes If (e (t) is NVH) and (Δe (t) is NVH) then (output is NVH). The rule base is used for different optimization techniques like GA, PSO and Intelligent controllers. The universe of input and output variables are divided into seven fuzzy sets like: NVH, NH, NS, ZO, PS, PH and PVH. Each variable are member of subsets with degree of -1 and +1. The representation of membership functions of input (E and CE) and output variables are described in Figure 4, 5 and Fig 6.

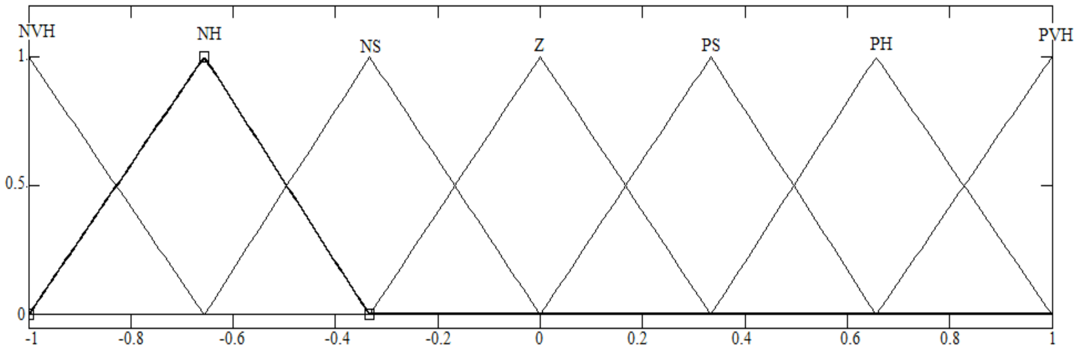


Fig.4. Input Error Membership function

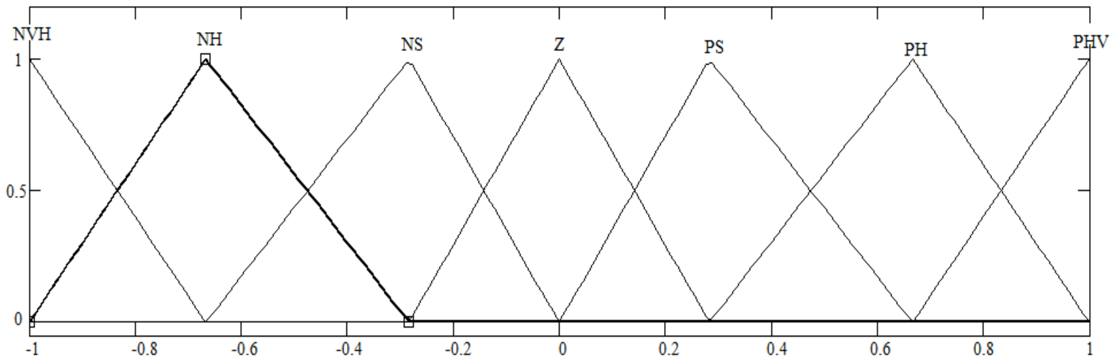


Fig.5. Change in Error Membership function

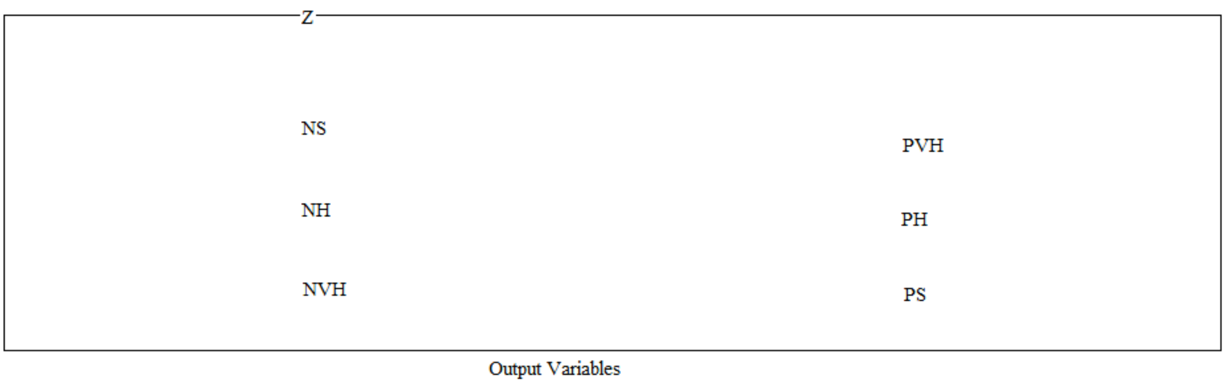


Fig.6. Output variable Membership function

These variables are processed by an inference engine which executes 49 rules [4]. There are two inputs which are used in FLC error *(E)* and change of error *(CE)* for linguistic variables and produce the control rules. Control variable (C) is applied to produce angular value (α) of the system, which determines output cycle [16].

$E(s) = [\ \omega_r(s) - \omega_a(s)\ ] * K_{1e}$ (15)

$CE(s)=[E(s) - e(s-1)\ ] * K_2C_e$ (16)

$C_\alpha(s)=[\ \alpha(s) - \alpha(s-1)\ ] * K_3C_\alpha$ (17)

In the above equations K_1e, K_2Ce and K_3C_α are gain coefficients of FC. Table.1 shows Rule base for Fuzzy logic controller. Even though DC motor consists of a normal condition, the time and speed of error is high, while the proposed fuzzy-PD controller is incorporated in the system the time and speed of error has been reduced. The maximum value of motor speed error gives larger value in range of –1 and +1. Finally, defuzzified output is obtained from the fuzzy inputs with the help of Waver method of de-fuzzification [13].

Table.1. If-Then Rule Base for FLC

U(T)		**e(t)**						
		NVH	**NH**	**NS**	**Z**	**PS**	**PH**	**PVH**
Δe(t)	**NVH**	NVH	NVH	NVH	NVH	NH	NS	Z
	NH	NVH	NVH	NVH	NH	NS	Z	PS
	NS	NVH	NVH	NH	NS	Z	PS	PH
	Z	NVH	NH	NS	Z	PS	PH	PVH
	PS	NH	NS	Z	PS	PH	PVH	PVH
	PH	NS	Z	PS	PH	PVH	PVH	PVH
	PVH	Z	PS	PH	PVH	PVH	PVH	PVH

5. Simulation Model and Results

The analysis of the simulation and testing of output using different controllers, fuzzy-PD controller shown in Fig.11 yields a feasible result when compared with other controllers and the performance graph are plotted in Fig.12.

PI controller:

The designed intelligent control system has been simulated via MATLAB Simulink software rather than conventional method. The anisotropic metrics of conventional and PI controllers in time and errors were found to be reduced in this controller. Simulink setup has been done with the schematic diagram shown in Fig.7.

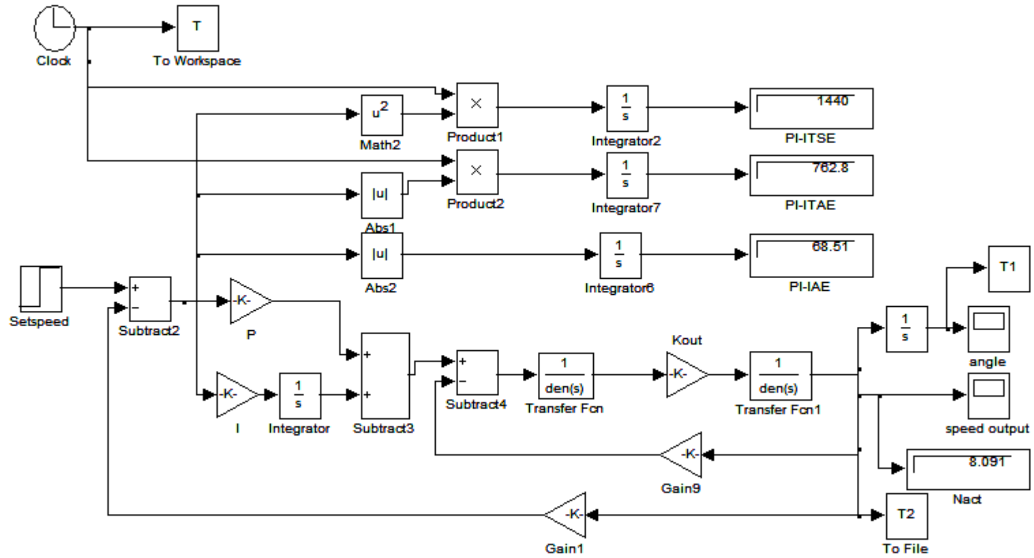
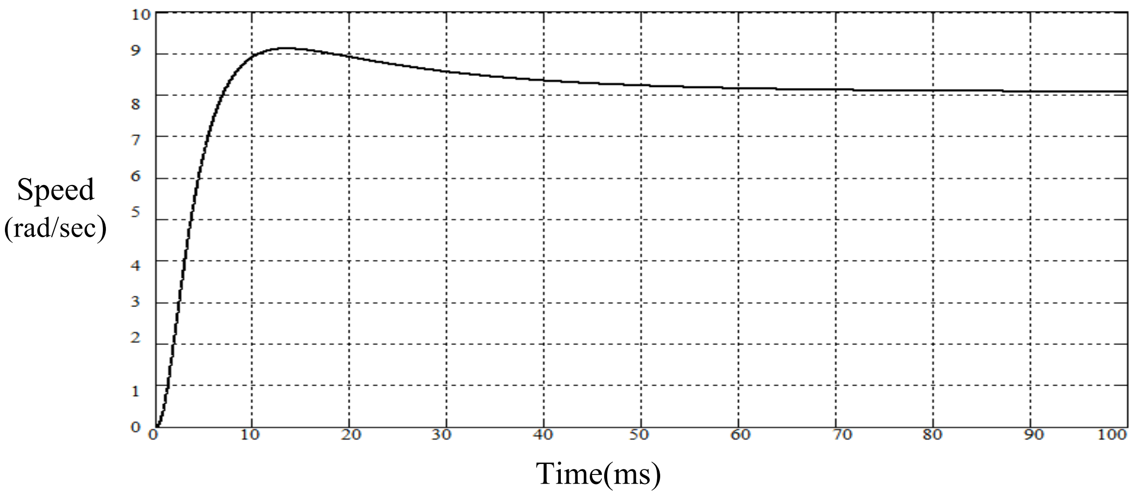


Fig.7. Simulink of PMDC motor with PI controller

The graph plotted in Fig.8 shows the step response of PI controller with time plotted in msec in x-axis and speed in rad/sec in y-axis. Initially the speed starts increasing 7.12msec where there is a rise time, with a peak time of 13.82msec and settling time of 88.59msec measurements are evaluated with the set speed of 8.09rad/secs.



S.No	1	2	3	4	5	6	7	8	9	10
Time	10	20	30	40	50	60	70	80	90	100
Speed	9.2	8.3	8.16	8.11	8.10	8.09	8.09	8.09	8.09	8.09

Fig.8. Step response of PMDC motor using PI controller

PID controller:

The designed intelligent control system has been simulated via MATLAB Simulink software rather than conventional method. The anisotropic metrics of PI and PID controllers, time and errors are found to be reduced in this controller. Simulink setup has been done and the schematic diagram shown in Fig.9.

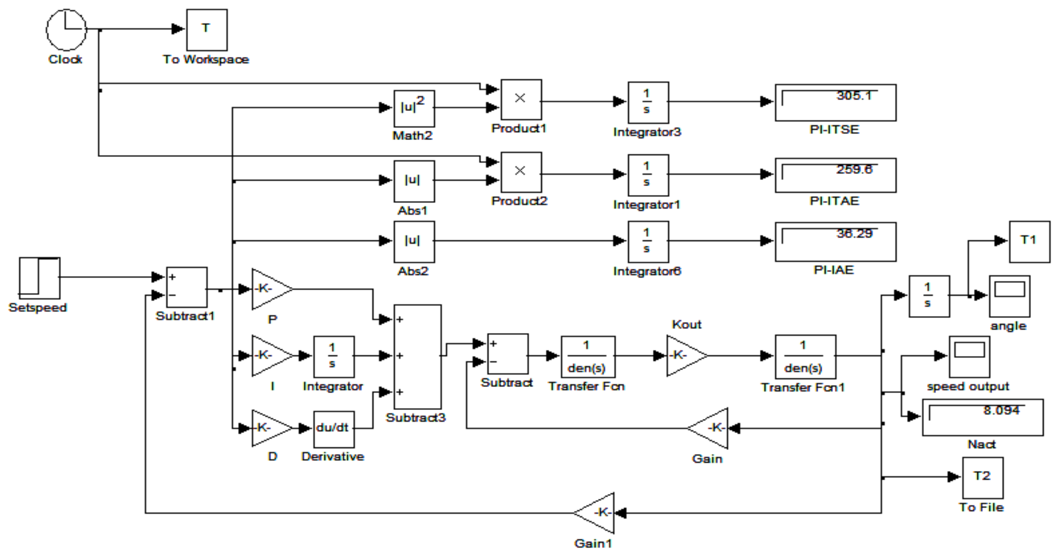
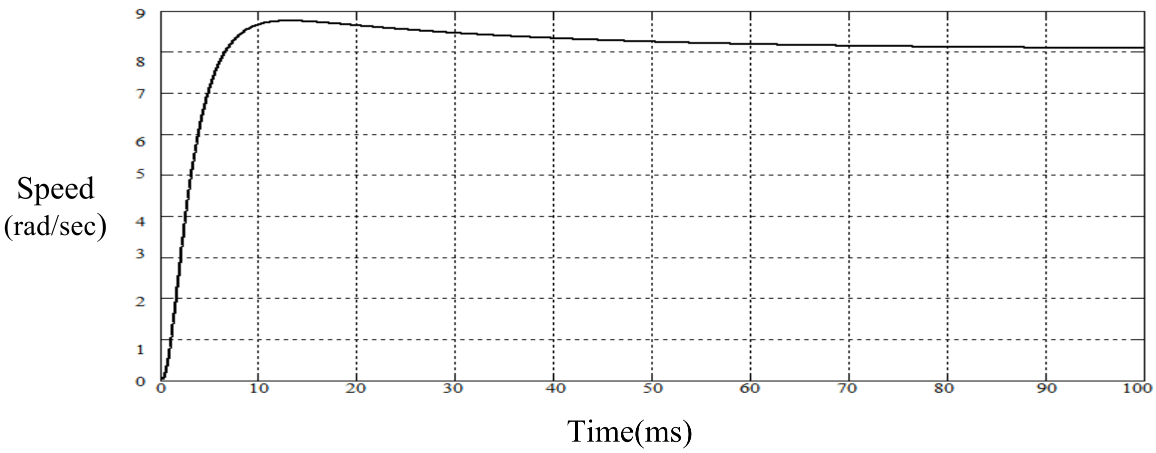


Fig.9. Simulink representation of PMDC motor with PID controller

The graph shown in Fig.10 describes the step response of PID controller with time plotted in msec in x-axis and speed in rad/sec in y-axis. Initially the speed starts increasing from 6.82msec as a rise time, with a peak time of 12.76msec and settling time of 86.4msec measurements are evaluated with the set speed of 8.09rad/sec.



S.No	1	2	3	4	5	6	7	8	9	10
Time	10	20	30	40	50	60	70	80	90	100
Speed	8.92	8.35	8.17	8.11	8.09	8.09	8.09	8.09	8.09	8.09

Fig.10. Step response of PMDC motor using PID controller

Combination of Fuzzy Logic-PD Controller:

Fuzzy-PD controller is the novel controller which is compared with other controllers. The specialty of Fuzzy-PD controller with occurring time and speed error is significantly reduced, although in this research paper where there is less maximum overshoot time, least settling time and peak time. From which the diagram Lit surface plot is obtained, shown in Fig.13.

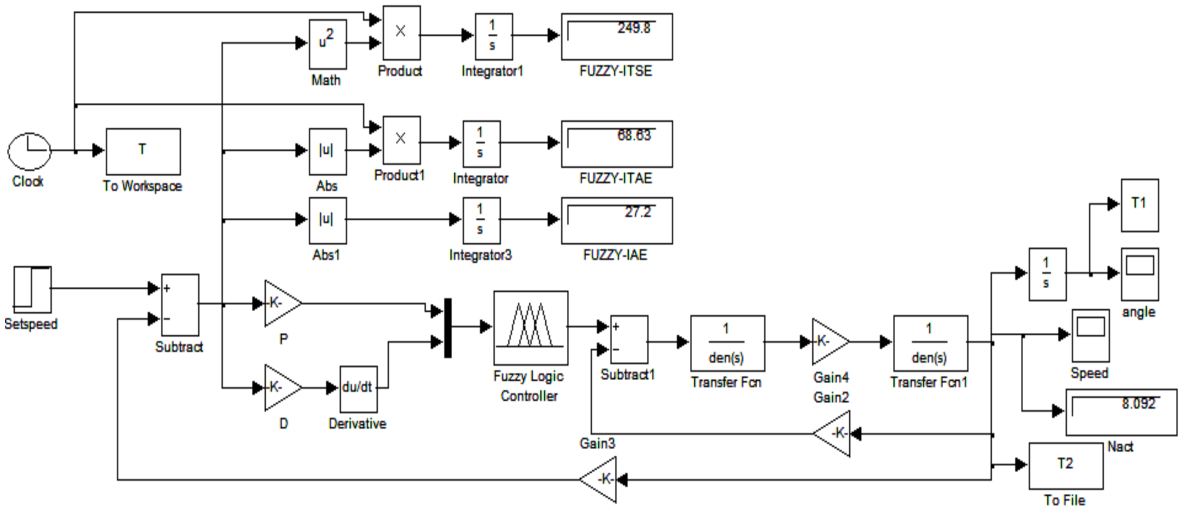
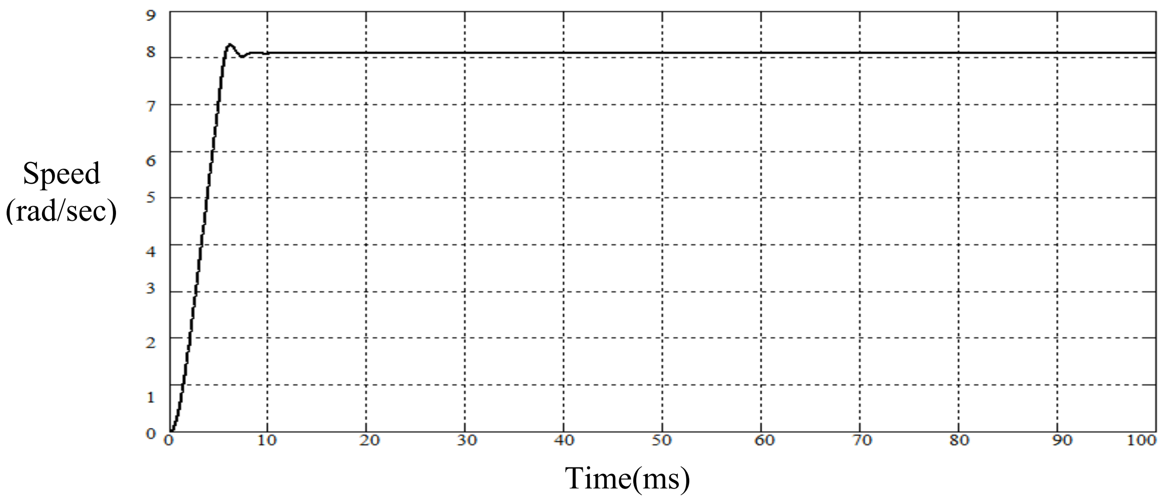


Fig.11. Simulink representation of Fuzzy-PD controller

The graph plotted in Fig.12 illustrates the response of fuzzy-PD controller with time plotted in msec in x-axis and speed in rad/sec in y-axis. Initially the speed starts increasing from 5.765 msec as rise time, with peak time of 6.188msec and settling time of 9.272msec measurements are evaluated with the set speed of 8.09rad/sec.



S.No	1	2	3	4	5	6	7	8	9	10
Time	10	20	30	40	50	60	70	80	90	100
Speed	8.09	8.09	8.09	8.09	8.09	8.09	8.09	8.09	8.09	8.09

Fig.12. Step response of PMDC motor using Fuzzy-PD controller

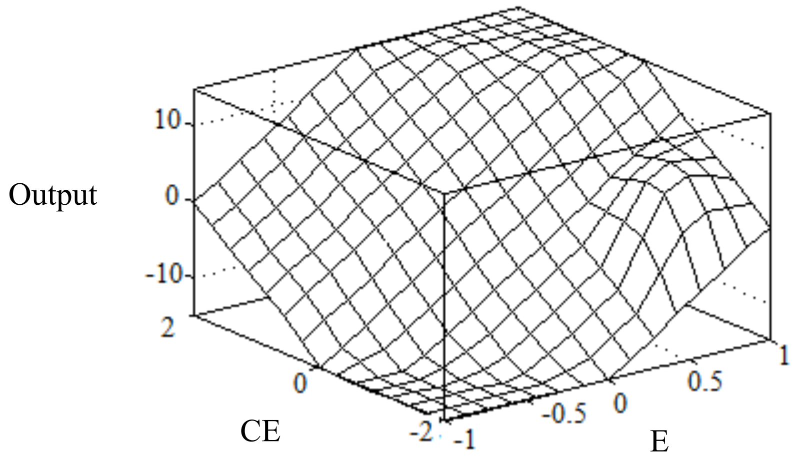


Fig.13. Surface plot

6. Result and Discussion

Thus the fuzzy-PD controller was designed and verified with various parameters like rise time, peak time, settling time, and overshoot of PI, PID controllers are compared with Fuzzy-PD controllers. In Table.2 the comparison of various parameters with different controllers are given which makes clear that conventional controller has high peak time, settling time and overshoot [11]. The Fuzzy-PD controller for PMDC motor is the novel work which gives the overshoot of 2.40%, 5.765ms rise time, 6.188ms peak time and 9.272ms as settling time which has low overshoot and time response than the other two controllers.

TABLE.2 CONTROLLER PARAMETERS

S.no	Controllers	Performance Parameters			
		Rise time	Peak time	Settling time	Overshoot
1.	PI	7.139ms	13.82ms	88.59ms	12%
2.	PID	6.821ms	12.76ms	86.40ms	8.25%
3.	Fuzzy-PD	5.765ms	6.188ms	9.272ms	2.40%

The bar chart shown in Fig.14 also clearly explains the optimal rise time, peak time and settling time which are observed in fuzzy-PD and compared with PI and PID controller.

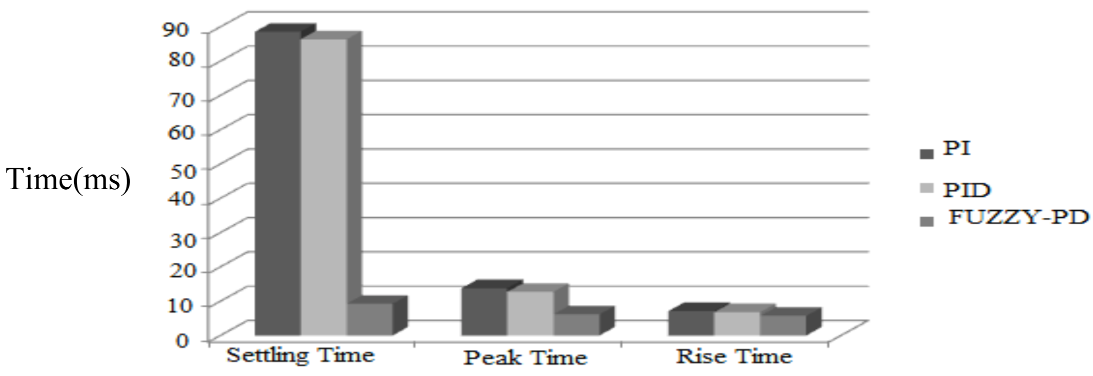


Fig.14. Comparison of Time response for PI, PID and Fuzzy-PD controller

In Table.3, comparison of the performance parameters of Integral Absolute Error (IAE), Integral Time Absolute Error (ITAE) and Integral Time Square Error (ITSE) with different types of controllers are shown. It has been noted that the error in fuzzy-PD controller is minimum when compared to PI and PID methods.

Table.3 Motor Performance

S.No	**Controllers**	**Performance Indices**		
		IAE	**ITAE**	**ITSE**
1.	PI	53.01	760	570.6
2.	PID	45.58	753.7	385
3.	Fuzzy-PD	27.13	65.54	249.5

7. Hardware Implementation

The speed controller for PMDC motor is designed with various intelligent controllers and tested for different speed and duty cycle ratio in open loop and closed loop system. Under closed loop control system it is also tested with load and without loading conditions.

System Overview

The PMDC motor is controlled by DC source through four quadrants chopper circuit. The output voltage of chopper drive is fed to the PMDC motor which rotates in both directions according to the conduction of chopper drives. In a closed loop system the combination of PI controller and PIC30F4011 controller are implemented and motor speed is sensed through proximity sensor in the shaft part.

Circuit Description

The hardware is based on chopper fed PWM technique with PI controller. In open loop condition, drive provides the desired DC supply by adjusting duty cycle as 64%, 70% and 72% and the motor rotates at speed of 809rpm, 1833rpm and 2211rpm. Initially in open loop system upto 50% of duty cycle the output voltage of chopper drive is less and the motor runs at low speed. After increasing the duty cycle to 64%, 70% and 72% the motor speed is proportionately increased. In closed loop system the motor speeds are set by the PI controller to confirm the corresponding duty cycles measured and found accurate. In open and closed loop system, under loading condition the motor actual speed (Nact) is closure to the set speed of 809rpm, 1833rpm, and 2211 rpm and the corresponding changes in armature current are given in Table.4 and Table.5.

C. Experimental Setup

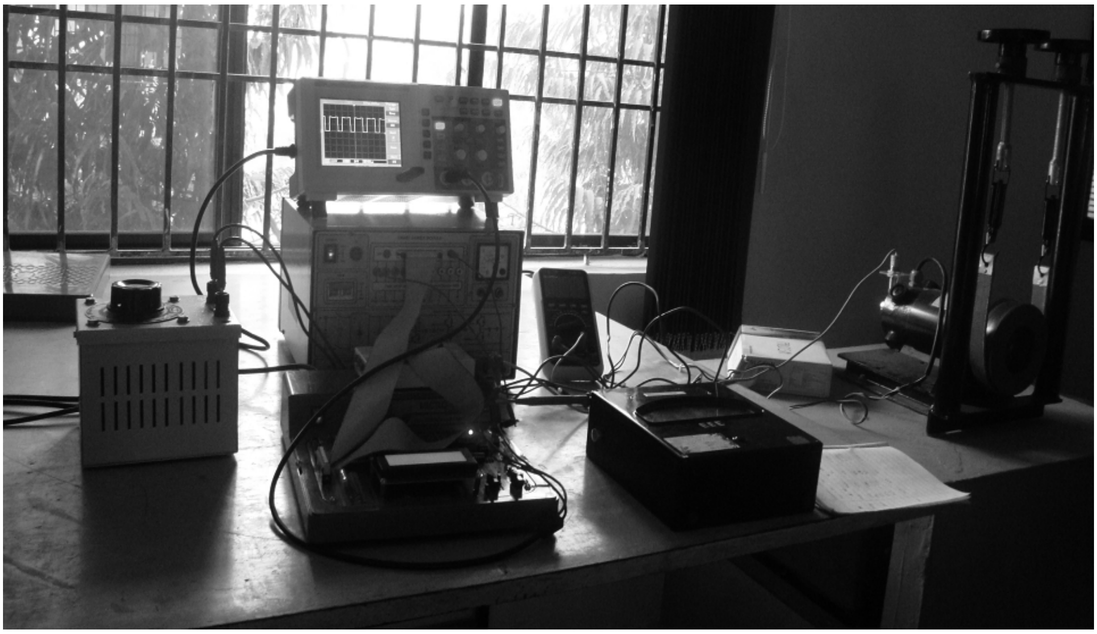


Fig.15. Experimental overview

Hardware Result

Closed loop without load

In a closed loop condition the controller inputs of Kp and Ki values and driver inputs of 220V are given, the motor runs at forward direction in with and without load condition. The performance parameters of fall time, rise time, overshoot, armature voltage (V_a), armature current (I_a) and actual speed (N_{act}) are calculated.

Table.4 System performance without load

S.No	Set Speed (rpm)	Duty Cycle (%)	Performance Parameters					
			Fall time (ms)	Rise time (ms)	Over Shoot (%)	V_a	Ia	N_{act}
1.	809	64	400	16	12.2	45	0.24	820
2.	1833	70	400	16	11.9	100	0.31	1839
3.	2211	72	200	16	11.6	120	0.34	2211

Closed loop with load

Table.5 System performance with load

S.No	Set Speed (rpm)	Duty Cycle (%)	Performance Parameters					
			Fall time (ms)	Rise time (ms)	Over Shoot (%)	Va	Ia	N_{act}
1.	809	64	4	4	13.6	45	0.65	805
2.	1833	70	4	4	12.5	105	0.83	1806
3.	2211	72	600	16	12.3	125	0.91	2197

8. Conclusion

In this research paper the performance analysis of PMDC motor with various intelligent controllers are discussed. The mathematical model of PI, PID and F-PD controllers are developed to control the speed of PMDC motor using intelligence technique. The simulations for different controllers are designed and the performances of systems are tested with hardware, which provides better results. The high settling time, rise time and overshoot time are found better in artificial intelligent technique based on fuzzy-PD, using simulink. Therefore the proposed Fuzzy-PD controller is the best controller compared to PI and PID controllers. For this reason, the implemented artificial intelligence technique in the controller performance was used. This is practically calculated at many instants at which the fuzzy-PD control system plays a vital part in PMDC motor drives.

Acknowledgement

The author acknowledges with thanks all necessary support extended by M.A.M College of Engineering and St.Joseph's college of Engineering and Technology for providing facilities and support for this project and also thank the editor and reviewers for their comments and suggestions to improve the quality of this work.

References:

1. A. Zadeh (1965) ''Fuzzy Sets" Informal Control, 01.8p, pp-338- 353.
2. Yager R. R. and Filer D.P. (1994) "Essentials of Fuzzy Modeling and Control", johnWiley, Vol. 6- 4, pp-22-23.
3. Pierre Guillemin(1996) "Fuzzy logic Applied to Motor control", IEEE Transaction on Industrial application Vol 32-1,pp-51-56.
4. Ahmed, F.I., A.M. El-Tobshy, A.A. Mahfouz and M.M.S. Ibrahim (1997), "P-I and I-Pcontrollers in a closed loop for DC motor drives", Proceedings of the Power Conversion Conference Nagaoka, IEEE Xplore Press, Nagaokam,
5. Y. Tipsuwan, Y. Chow (1999), "Fuzzy Logic Microcontroller Implementation for DC Motor Speed Control",IEEE Power Electronics conference, pp-101-110..
6. Tang, K.S., K.F. Man, G. Chen and S. Kwong(2001), "An optimal fuzzy PID controller", IEEE Transaction on Industrial Electronics,Vol.48-4, pp-757-765.

7. K. B. Mohanty, A. Routray, and N. K. De (2001), "Design of a fuzzy sliding mode controller for a field oriented induction motor drive," Journal of Systems Society of India, Paritantra, vol. 6-1, pp. 8-16.
8. R. Abdessemed, L. Mokrani, (2005) "A fuzzy self-tuning PI controller for speed control of a field oriented induction motor drive", AMSE Journal, Advances C, Vol 60, pp-77-89.
9. M. A. Jabbar, Hla Nu Phyu, Zhejie Liu and Chao Bi(2004), "Modeling and Numerical Simulation of a Brushless Permanent-Magnet DC Motor in Dynamic Conditions by Time-Stepping Technique", IEEE Transactions On Industry Applications, Vol.40-3,pp-763-770.
10. WaiPhyoAung (2007), "Analysis on Modeling and Simulink of DC Motor and its Driving System Used for Wheeled Mobile robot," World Academy of Science, engineering and technology, Vol.32, pp. 299-306.
11. Rahul Malhotra, Narinder Singh (2010), "Design of Embedded Hybrid Fuzzy-GA Control Strategy for Speed Control of DC Motor: A Servo Control" International Journal of Computer Application, Vol-6, pp-37-46.
12. T.v.Mahendiran, P.Thangam, K.Thanushkodi (2011), "A comparative study on non linear drive control for separately excited dc motor using fuzzy logic controller, fuzzy pi controller and pso tuned fuzzy pi controller", International journal of research and reviews in electrical and computer engineering vol. 1-1, pp-1473-1477.
13. Ramkumarkarsh, Dr. G.K.Choudhary, Chitranjan Kumar (2011), "Speed Control of Separately Excited dc Motor using Fuzzy Technique" ACEEE International Journal on Electrical and Power Engineering, Vol. 02,.pp-31-35
14. Atul Kumar Dewangan, SashaiShukla, VinodYadu (2012), "Speed Control of a Separately Excited DC Motor Using Fuzzy Logic Control Based on Matlab Simulation Program", International Journal of Scientific & Technology Research Vol-1,pp-52-54.
15. PayalP.Raval, C.R.Mehta (2012), "Modeling, Simulation and Implementation of Speed control of DC motor using PIC 16F877A", International Journal of Emerging Technology and Advanced Engineering,Vol 2-3,pp-146-151.
16. Nader Jamali Sufi Amlashi(2012),"Design and Implementation of Fuzzy Position control System for Tracking Applications and Performance Comparison with conventional PID", IAES International Journal of Artificial Intelligence (IJ-AI)Vol.1-1,pp-31-44.
17. Dipti K. Shah, Prof. B. T. Deshmukh (2013), "Speed Control of PMDC Motor Using LM3524 PWM IC", International Journal of Computer Technology and Electronics Engineering (IJCTEE) Vol 3, pp-57-59.

18. Mirza Ashab, Hussain Sarfraz (2002),"DC motors speed asynchronization in nonlinear process by selective state feedback and integral control", AMSE journals, Advances in Modelling and Automatic Control (theory and applications), Vol 57, pp-45-58.
19. Anupama.S, Sarita.B, Janakiraman.A,(2007),"PSPICE Modelling and simulation of computation free digital speed control of a DC motor", AMSE journals, Advances C, Vol-62, pp-64-76.