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Tuning of PI Controller and Fuzzy Logic Based PI Controller for Speed Control of DC Motor

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ABSTRACT- *Permanent magnet direct current (PMDC) brushed motor are widely used in various industrial application like small toys, drills, boring mills, lathe machine, spinning and weaving machine. It has constant speed from no load to full load, higher energy density and simplicity in construction which opens a wide range of household uses such as hair drier, vacuum cleaner, fan and sewing machine. The presentation of PI and fuzzy logic based PI controller to control speed of the PMDC motor using MATLAB simulation. The MATLAB/Simulink model is designed and developed for fuzzy logic based speed control of PMDC motor. The fuzzy controller is compared with conventional PI controller for speed response. Results in this paper shows that the proposed fuzzy based control approach produce faster speed reaction with less rise time and settling time as compared to the conventional PI controller.*

Keyword- PMDC; speed control; PI; fuzzy logic based PI controller.

I. INTRODUCTION

PMDC motor systems are frequently used in modern industries. PMDC motors have wide varieties of applications in industrialelectronics and robotics which require accurate placement, precise positioning and wide range of speed control [1]. It usesfeedback controller to measure the speed, or positioning, or else both at the same time. Since, the PI controller was introduced, ithas become very popular controller today and are most frequently used in industry [2,3], but the major drawback of PI controllersare high trial and error manipulations which does not offer satisfying results whenever required as compared with the fuzzyalgorithms [4,5].The fuzzy logic-based PI controller gained popularity by using Sugeno method in the applications of speed control for thePMDC motors [6-10]. The automatic tuning with mean of maxima was used for desirable speed response with an efficientperformance [6]. The main difference between the two methods lies in the resultant fuzzy rules. Mamdani fuzzysystems use fuzzy sets as resultant rule whereas; TS (Takagi-Sugeno-Kang) fuzzy systems employ linear functions of inputvariables as resultant rule.

Also, Sugeno type systems can be used to model any inference systems in which the outputmembership functions are either linear or constant. Thus, in this proposed work, on the basis of simulation results, an investigation iscarried-out by using Mamdani method, regarding speed of the Permanent Magnet Direct Current (PMDC) motor, which is then controlled by Fuzzy Logic Based PIcontroller separately. The speed of the Permanent Magnet Direct current (PMDC) Motor is pragmatic with its corresponding settling time. This shows the behavior ofa traditional PI Controller and Fuzzy Logic-based PI Controller. So, for the accurate or precise operation of the motor it is necessaryto adjust the Fuzzy Logic Controller in order to gainthe desired performance. Therefore, a fuzzy logic-based controller applied tothe PMDC motor is investigated. With the application of assigned or allocated rules, the overshoot is minimum and the settlingtime is within the desired ranges. So, because of Fuzzy Logic Controller, manual tuning is discarded and intelligent tuning takesplace with satisfactory performance. In this work, speed control of Permanent Magnet Direct Current (PMDC) motor is simulated using MATLAB / Simulink environment.

In this proposed work, the speed performance of a PMDC motor is look over by using advanced intelligent controller. A conventional Proportional-Integral (PI) Controller is used for comparative response with intelligent controller. Here, Fuzzy Logic-based PI Controller is used as an advanced intelligent controller. An overshoot in speed is observed with an accompanied settling time thereby confirming the behavior of a PI controller and Fuzzy Logic-based PI Controller. So, a Fuzzy Logic-based PI Controller useful to the PMDC motor is investigate through speed response in various advance applications or else closed loop control applications like rocket launching.With the application of appropriate expert rules, there is an observation of minimum overshoot and the settling time is within the desired value. With the Fuzzy Logic-based PI Controller, manual tuning is eliminated and advanced intelligent tuning takes the center stage with satisfactory performance.

II. MATHEMATICAL MODELLING OF DC MOTOR

A.

lectrical characteristics

The equivalent electrical circuit of a permanent magnet dc motor is shown. The electrical equivalent of voltagesource (V_a) across the coil of the armature, inductance (L_a) in series with a resistance (R_s), in series with an induced voltage (V_c)which opposes the voltage source. The induced voltage is generated by the rotation of the electrical coil through the fixed flux lines of the permanent magnets. This voltage is often referred to as the back electromotive force. The differential equation for the equivalent circuit can be consequent by using Kirchhoff's voltage law around the electrical loop.Kirchhoff's voltage law states that the sum of all voltages around a loop must be equal to zero.

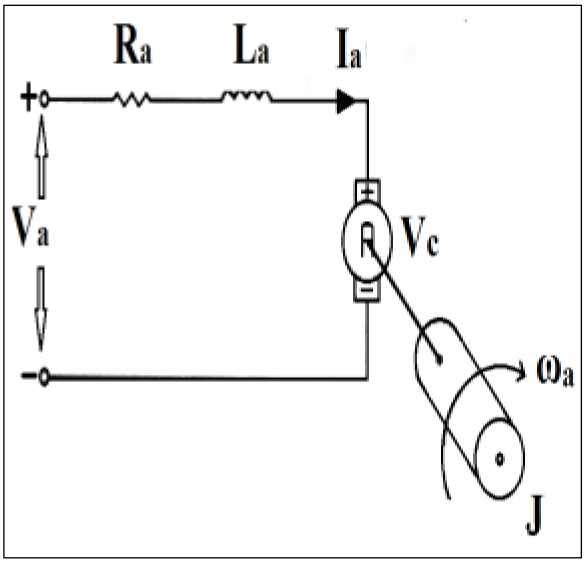


Fig 1.Electrical Representation ofDC Motor

$V_a - V_{Ra} - V_{La} - V_c$=0……….(1)

Where,

V_a – Voltage source of electrical equivalent across armature coil.

La– Inductance

Ra– Resistance

V_c– Inductive voltage

The voltage across the resistor,

V_{Ra}=$I_a R_a$………(2)

Where,

I_a– Armature current.

The voltage across the inductor is proportional to the change in current through the coil with respect to time, which can be

Written as,

$V_{La} = V_a\, d\frac{Ia}{dt}$………(3)

Where, La– inductance of armature coil

$V_c = K_v \omega_a$………(4)

Where, K_v – Velocity constant

ω_a- Rotational angular velocity of

Armature

E

The reluctance of the iron core of the armature and the number of turns of the armature winding is the rotational angular Velocity of the armature.

$V_a - I_a R_a - L_a \frac{d}{dt} I_a - K_v \omega_a = 0$……(5)

B. Mechanical Characteristics

Execution an energy balance on the system, the sum of the torque of the motor must equal to zero.

$T_e - T_{\omega'} - T_{\omega} - T_L = 0$……….(6)

Where,

T_e – is the electromagnetic torque

$T_{\omega'}$ – is the torque due to rotational Acceleration of the rotor

T_{ω} –is the torque produced from the Velocity of the rotor

T_L– is the torque of the mechanical Load

The electromagnetic torque is related to the current through the armature winding and can be written as

$T_e = k_t i_a$…………..(7)

Where, k_t- is Torque constant and like the velocity constant is dependent on the flux density of the fixed magnet, the reluctance of the iron core, and the number of turns in the armature winding.

$T_{\omega'} = J\frac{d}{dx}\omega_a$………..(8)

Where, J – is the Inertia of rotor and the corresponding mechanical load. The torque associated with the velocity,

$T_{\omega} = B\omega_a$……..(9)

Where, B is the Damping coefficient associated with the mechanical rotational system of the DC machine.

Substituting equation (7)(8) and (9) into equation (6)

$k_t i_a - J\frac{dy}{dx}\omega_a - T_L = 0$……….(10)

III. FUZZY LOGIC-BASED PI CONTROLLER

The block diagram of Fuzzy Interference System (FIS) is shown in fig 2. It consists of a fuzzification interference database, a decision-making unit, and finally a defuzzification interface. The function of each block is as follows.

a. A rule base containing a number of fuzzy IF-THEN rules;

b. Databases which define the membership function of the fuzzy sets used in the fuzzy rules.

c. A decision-making unit which

performs the inference operation on the rules;

d. A fuzzification interference which transforms the crisp inputs into degrees of match with linguistic values; and

e. A defuzzification interface which transforms the fuzzy results of the interference into a crisp output.

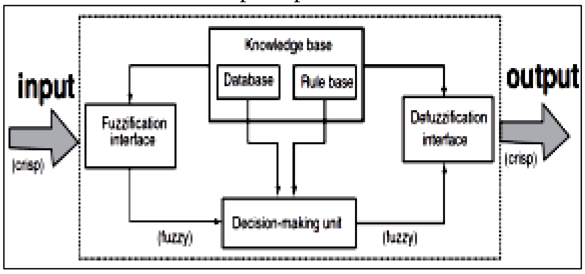


Fig 2. Block diagram of Fuzzy Inference system

The working of FIS is as follows. The crisp input is converted into fuzzy by using fuzzification method. After rule base is formed. The rule base and the database are jointly referred to as the knowledge base. Defuzzification converts fuzzy value to the real-world value which is the output.

The steps of fuzzy reasoning (inference operation upon fuzzy IF-THEN rules) performed by FIS are:

a. Compare the input variables with the membership function on the antecedent part to obtain the membership values of each linguistic label. (This step is often called fuzzification.)

b. Combine (through a specific t-norm operator, usually multiplication or min) the membership values on the premise part to get firing strength (weight) of each rule.

c. Generate the qualified consequents (either fuzzy or crisp) or each rule depending on the firing strength.

d. Aggregate the qualified consequents to produce a crisp output. (This step is called defuzzification.) The controller requires error and change in error as inputs. Here, our objective is regulates some processed output around a prescribed set-point or reference.

TABLE 1

A LINEAR TWO DIMENTIONAL RULE BASE

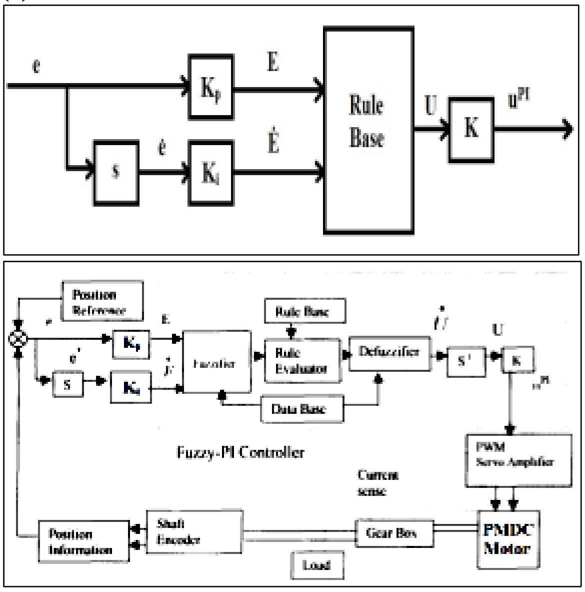
dE/E	NG	NM	EZ	PM	PG
PG	EZ	PM	PM	PG	PG
PM	NG	EZ	PM	PM	PG
EZ	NM	NG	EZ	PM	PM
NM	NM	NM	NG	EZ	PM
NG	NG	NM	NM	NG	EZ

Where, NL=negative grate, NM=negative medium, EZ=zero, PS=positive small and PM=positive grate.

As linear rule base is shown in Table 1. The relationship between two input scaling gains can be approximated as a constant. The fuzzy gains (KP and Ki) should have qualitatively similar to the gains (KP and Ki) of linear PI controller.

Fuzzy-PD like, conventional-PD has steady state error. Fuzzy PID needs acceleration error; measuring or estimating acceleration terms are difficult and inaccurate. Due to these disadvantage associated with PD and PID based controller, fuzzy-based PI controller is chosen here.

(a)



(b)

Fig3. (a) Digital structure of fuzzy based controller and (b) block diagram of a fuzzy based PI compensated PMDC motor drive.

The digital structure of fuzzy based controller and block diagram of a fuzzy –based PI compensated Permanent Magnet Direct Current (PMDC) motor drive is shown in fig 3(a,b). The task of the control algorithm is to rotate the shaft of the motor to set point without overshoot. UPI is the fuzzy output given to generate PWM pulse and then to PMDC motor. It is necessary to write a set of fuzzy control statements based on the error signal between the preset and the measured shaft position and the change of the error is also applied so as to adjust the output of the drive unit. The controller is designed after studying the various response obtained from the traditional controller.

IV. SIMULATION AND RESULTS

A. Speed Control of PMDC Motor using traditional PI controller

The MATLAB/Simulink model for speed control of PMDC motor using traditional PI controller is shown in fig 4.

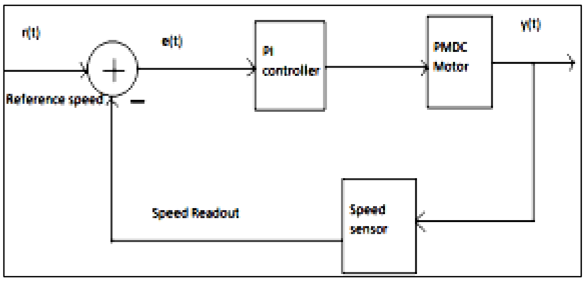


Fig 4.Block diagram ofMATLAB model for Speed Control of PMDC motor using traditional PI Controller

The main block used to develop the MATLAB model using traditional PI controller as shown in fig 4. are, speed reference (generally a constant block), PI controller subsystem, gain block, a masked PMDC motor block and speed feedback loop along with scope and workspace blocks for measurement purpose. From Fig 4. The values of KP and Ki are assigned after the traditional trial-and-error method. Initially, the values of KP and Ki are kept to minimum values starting from 0.1 and 1, respectively, and the response is observed. Hence, depending upon the variation in values of P and I the tuning is carried out and the approximate final value which coincides reference response is selected. The representation of PI controller in MATLAB Simulink model is shown in fig.5.

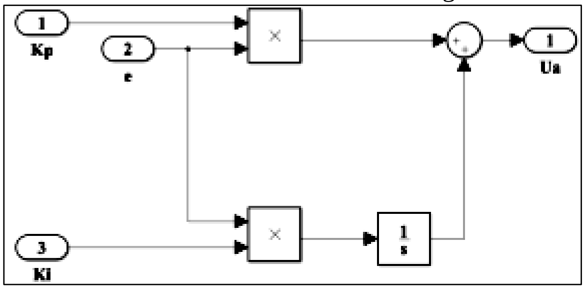
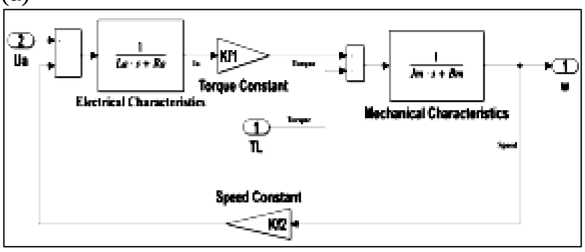


Fig.5. PI controller representation in Simulink model

The final calculated transfer function required for DC motor is derived from the electrical and mechanical
Characteristics. This is as shown in Fig. 6(a) and 6(b) respectively.

(a)



(b)

Fig.6. MATLAB implementation of PMDC motor

The speed response using traditional PI controller is shown in fig.7. As shown figure below, the rise time and settling time is calculated and shown in the response of speed graph. The model is tuned so that no overshoot occurs in this response using PI controller. Load torque is applied at various intervals for all the speed shown with PI controller at 200rpm, 800rpm and 1500rpm, which oscillating variations in load torque response coincides with reference speed

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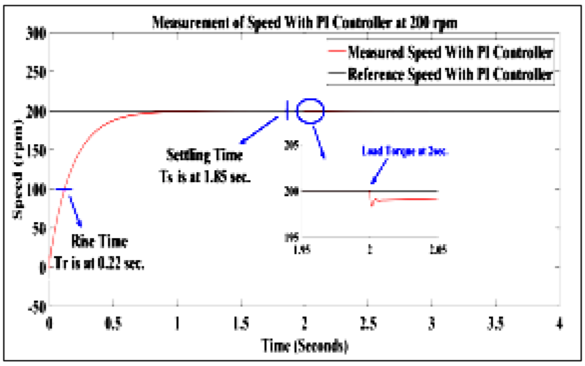
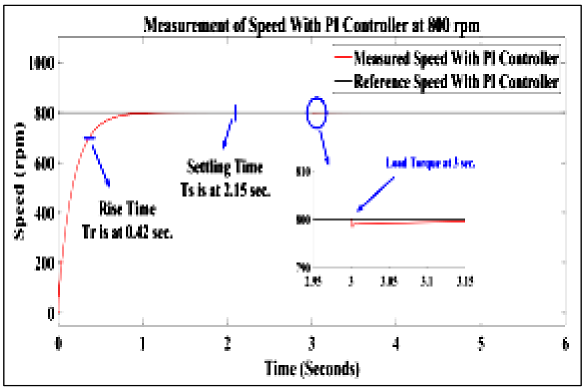


(a)



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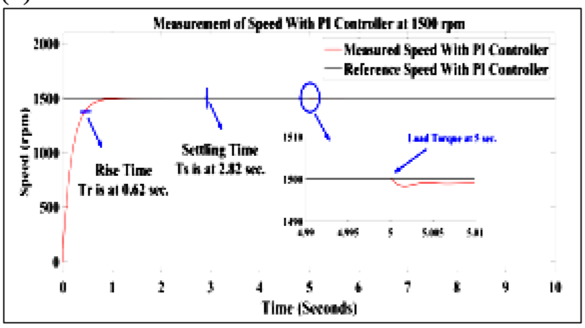


(c)

Fig.7. Various Speed Response of PMDC Motor using traditional PI controller

B. Speed Control of PMDC Motor using Fuzzy Based PI controller

The simulation of the Fuzzy
Logic Based PI Controller is done using fuzzy toolbox of the MATLAB/SIMULINK application software
Package. Using fuzzy toolbox, the membership function definition of the inputs and outputs of Fuzzy-PI controller, fuzzification, rule base

evaluation and defuzzification are defined offline. Then fuzzy-PI controller block is integrated with the system (fig.8.) and system simulation is carried out using the fifth-order-Runga-Kuttamethod (ode5).

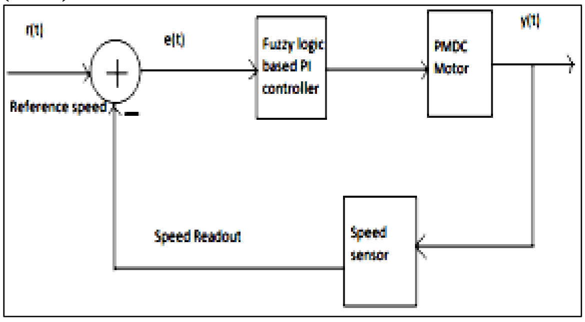


Fig.8. Block diagram of MATLAB model of Speed Control of PMDC motor using Fuzzy based PI Controller

As seen in the fig.8. The only adding to the model is the fuzzy-logic based controller block and the change of error $\frac{du}{dt}$ block as compared to traditional PI controller model. The implementation of Fuzzy Logic-Based controller block is shown in fig.9. The values ofG_e,G_{de} G_{kp} and G_{ki} are kept on the basis of trial-and –error method of tuning. Once these values are tuned, fuzzy logic controller will adjust all the rest possible uncertainties.

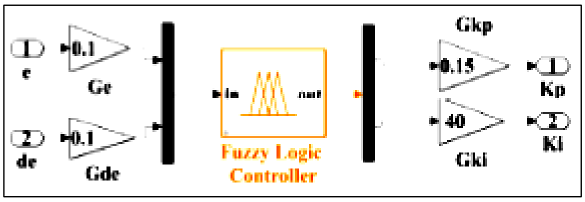


Fig.9. MATLAB implementation of fuzzy-based PI controller

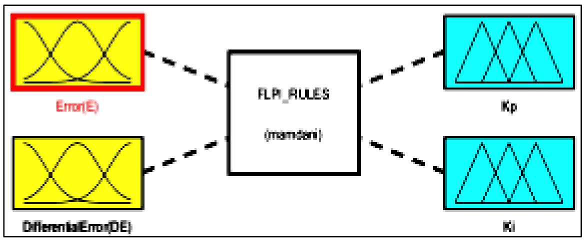


Fig.10. Fuzzy Logic Based Designer in MATLAB

As seen in fig.10, two input membership function Error (E) and change of error (DE) are designed and two output membership functions KP and Ki are derived. The Mamdani based fuzzy interface system (FIS) is used for setting rules for these functions. Two inputs and two output variables are added with its input ranges. The centroid method is used as defuzzification method. This tool is widely used in Simulink models. The membership functions based on previous chapter is designed and shown in figs.11, 12, 13, and 14 for error (E), change in error (DE), KP and Ki, respectively.

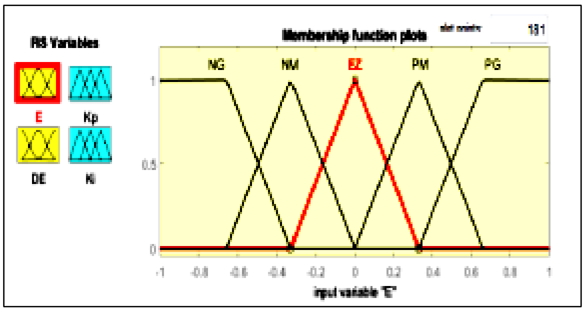


Fig.11. Membership Function for Error (E)

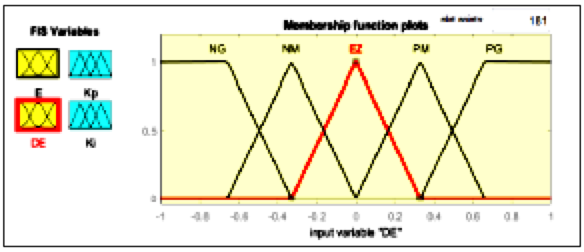


Fig.12. Membership Function for Change of Error (DE)

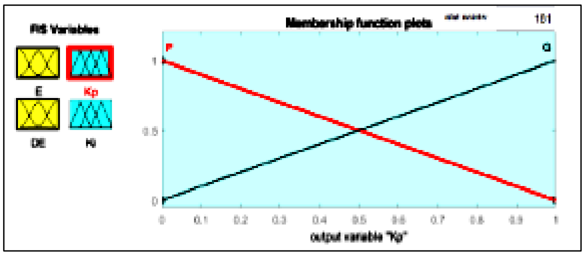


Fig. 13 Membership Function for KP

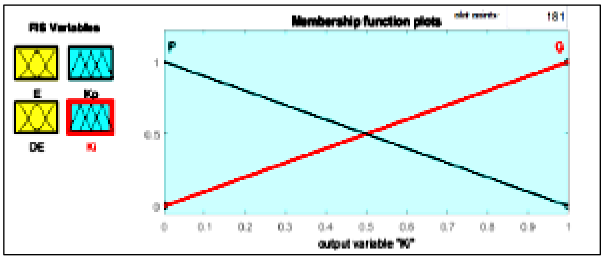


Fig. 14 Membership Function for Ki

The behavior of fuzzy logic-based controller rules shows control surface plot in fig. 15. This behavior indicates the application working of 25-rule sets and their effect on individual membership functions. Also, it shows the relationship between the changes in input variables affecting the output of the fuzzy logic block set.

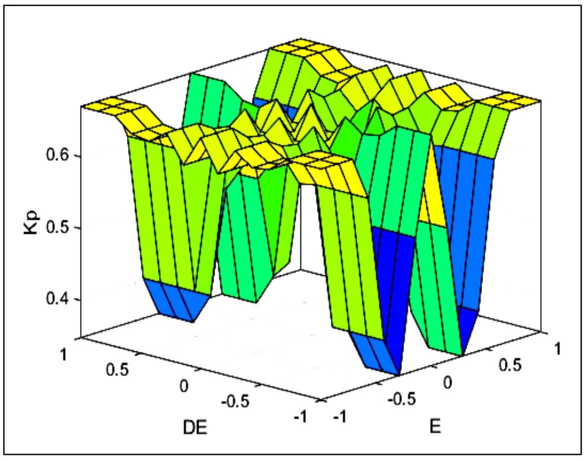
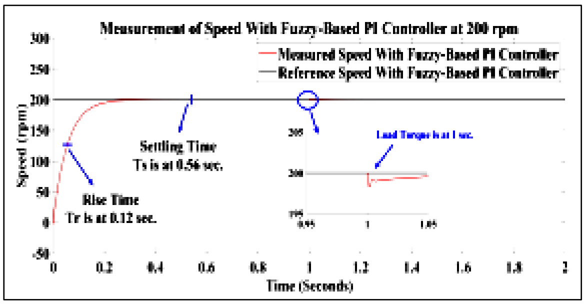
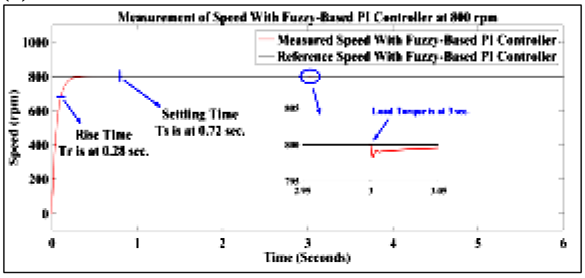


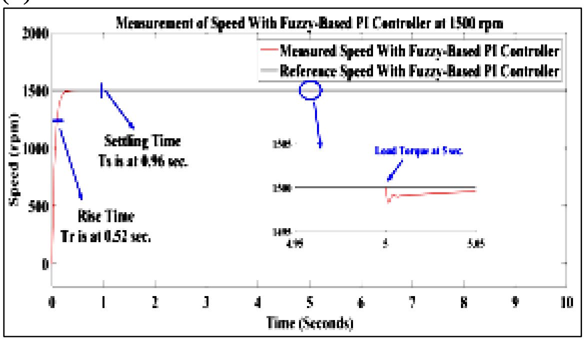
Fig.15. Fuzzy logic-based controller behavior control surface



(a)



(b)



(c)

Fig.16. Speed Response of DC Motor using traditional PI controller using proposed Fuzzy Logic-based PI controller

The speed response using proposed fuzzy logic-based PI controller is shown in fig.16. The initial performance of Fuzzy Logic-based PI Controller is shown in Table 2 and compared with traditional PI Controller. The rise time and settling time is measured and shown in response of speed graph. In comparison with the traditional PI controller, the response of fuzzy logic-based PI controller is faster by 0.5 sec (26.35%) (For rise time) and 4.16 sec (194.72%) (For settling time).

TABLE 2

RESULT OF TIME RESPONSE OF SIMULATION STUDY

Controller type	T_r(sec)			T_s (sec)		
Results from Fig.7. And Fig.16.	(a)	(b)	(c)	(a)	(b)	(c)
PI controller	0.22	0.42	0.62	1.85	2.15	2.82
Fuzzy logic-based PI controller	0.12	0.28	0.52	0.56	0.72	0.96

Where,

T_r- Rise Time and

T_s- Settling Time

V CONCLUSION

From the simulation results it is observed that fuzzy logic-based PI controller with FIS is more reliable to check the speed response and speed control of the PMDC drive. The Fuzzy Logic-based PI Controller settles earlier as compared with traditional PI Controller. Hence, it can be concluded that Fuzzy Logic-based PI Controller is more suitable for the speed control application of PMDC motor.

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