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Comparison of Speed Control of DC Motor Using PID Controller and Optimization Techniques

Satish Arora [1], Samikshya Tarei[2]

Associate Professor, Dept. of EE ,Baddi University of Emerging Sciences and Technologies, H.P., India[1].

M.Tech, Dept. of EE, Baddi University of Emerging Sciences and Technologies, H.P., India[2].

ABSTRACT : This paper presents a comparative study on speed control of dc motor using different types of controllers, fuzzy logic controller ,optimization techniques. DC motors are widely used in industrial applications ,robotics and domestic appliances because of their high reliabilities, flexibilities and low costs. Dc motor can be varied below or above the rated speed by various techniques. There are basically three types of control methods are used to control the speed of dc motor which are field flux control, armature control and voltage control. The conventional controller proportional integral derivative (PID) is commonly used to control the speed of dc motor in various application because it is simple, robust and highly effective. The controller is modelled in MATLAB environment, the simulation results shows that the proposed controllers(fuzzy based PID controller, GA based PID controller) give better performance and less settling time when compared with the traditional PID controller.

KEYWORDS: DC motor ,PID controller, tuning of PID controller, fuzzy logic controller, genetic algorithm based speed control.

I.INTRODUCTION

The field of electrical energy will be divided into three areas electronics , power and control system. Electronics basically deals with the study of semiconductor device and circuit at low power, power involves generation, transmission and distribution of electrical energy .The electric motor which is high performance motor drives are very much essential for industrial application. These motor require automatic control of their main parameters such as speed, position, acceleration etc. In this paper to control the speed of dc motor separately excited dc drive system is described .So dc motor is used in many applications such as steel rolling mills, electric vehicles, electric trains, electric cranes and robotic manipulators require speed controller to perform its tasks smoothly because of their simplicity, reliability, and low cost dc drive have long been used in industrial application. Compared to ac drive dc drive are less complex.[6]Many types of controllers such as proportional, integral, derivative, proportional integral(PI), proportional derivative(PD), proportiona lintegralderivative(PID),fuzzy logic controller and optimization techniques have been developed for speed control of dc motor.

II.MATHEMATICALLY MODELLING OF SEDC MOTOR

In order to build the dc motor transfer function its simplified mathematical model has been used. This model consists of different equations for the electrical part, mechanical part and interconnection between them. The electrical circuit of armature and free body diagram of the motor are shown in fig.1.

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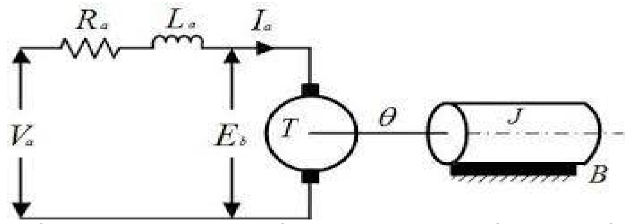

Fig 1:The electric circuit of the armature and the free body diagram of the rotor for a dc motor.

The armature equation is shown below

$$Va(t)=Ra.Ia(t)+La\frac{dIa(t)}{dt}+Eb(t) \qquad (1)$$

Where Va is the armature voltage in volts,Eb is the motor back emf in volts, Ia is the armature current in amperes, Ra is the armature resistance in ohms,La is the armature inductance in Henry.

From fig1,The following equation can be written based on Newton's law combined with Kirchhoff's Laws

$$Tm(t)=JmdW/d+BmW+TL \qquad (2)$$

Where: TL is load torque in Nm,Tm is the torque developed in Nm,Jm is moment of inertia in kg/m²,Bm is friction coefficient of the motor in Nms/rad ,W is angular velocity in rad/sec,θ is angular position of rotor shaft in rad,Kt is torque constant in Nm/A,Kb is back emf constant in Vs/rad.

Equation for back emf of motor can be written as :

$$Eb(t)=KbW(t) \qquad (3)$$

And also, $$Tm(t)=Kt.Ia(t) \qquad (4)$$

Let us combine the upper equations together

$$Va(t)=Ra.Ia(t)+L\frac{dIa(t)}{dt}+Kb.W(t) \qquad (5)$$

$$Kt.Ia(t)=Jm.\frac{dW(t)}{dt}+Bm.W(t) \qquad (6)$$

Taking laplace transfer function for above equations 5 and 6

$$Va(S)=Ra.Ia(s)+La.Ia(s)+Kb.W(s) \qquad (7)$$

$$Kt.Ia(s)=Jm.W(s)+Bm.W(s) \qquad (8)$$

By eliminated Ia(s) , the transfer function can be obtained ,where the rotational speed is the output and the voltage Va(t) input. When the motor is used as a component in a system. It is desired by the approximate transfer function between the motor voltage and its speed.

$$Va(S) =W(S)/Kt[LaJmS2+(RaJm+LaBm)s+(RaBm+KtKb)] \qquad (9)$$

The relation between rotor shaft, speed and applied armature voltage is represented by transfer function

$$\frac{W(S)}{VA(S)} = \frac{kt}{[La.Jm.s2+(Ra.Jm+La.Bm)s+(Ra.Bm+Kb.KT)]} \qquad (10)$$

The relation between position and speed is

$$\theta(s)=\frac{1}{s}W(S) \qquad (11)$$

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Then the transfer function between shaft position and armature current at no load is

$$\frac{\theta(s)}{Va(s)} = \frac{Kt}{[La.Jm.s3+(Ra.Jm+La.Bm)s2+(Ra.Bm+Kb.Kt)\,]} \qquad (12)$$

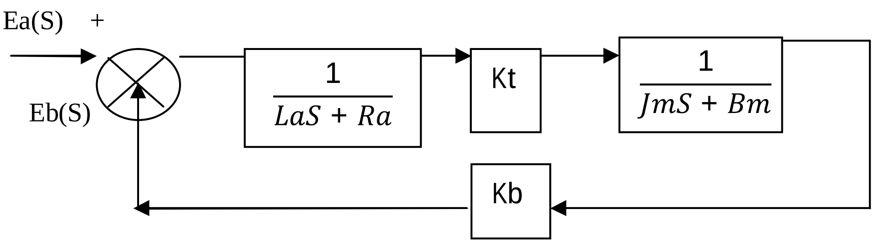

Fig2: Block model of dc motor

III.SPEED CONTROL OF DC MOTOR

The speed control which stands for intentional speed variation, carried out manually or automatically .Natural speed change due to load ,is not included in the term speed control.[11]
The speed of dc motor is

$$Wm=Eb/Ka\phi$$

$$Eb=Va-IaRa$$

$$Wm=(Va-IaRa)/Ka\phi$$

Where Ka=armature constant=PZ/2aπ,Wm=speed of dc motor, ϕ=field flux per pole

IV.PID CONTROLLER

PID controller is most commonly used algorithm for controller design and it is most widely used controller in industry. The controllers used in industry are either PID controller or its improved version. The PID controllers are the most common control methodology to use in real applications and comninesadvantagesofthree proportional,derivative and integral control action.Derivative mode which gives fast reaction on change of the controller input ,integral mode which increases the control signal to lead error towards zero and proportional mode is suitable action inside control error area to eliminate oscillations. Derivative mode improves stability of the system and enables increase in gain Kd and decrease in integral time constant Ti, which increases speed of the controller response.PID controllers are the most often used controllers in the process industry.[6]

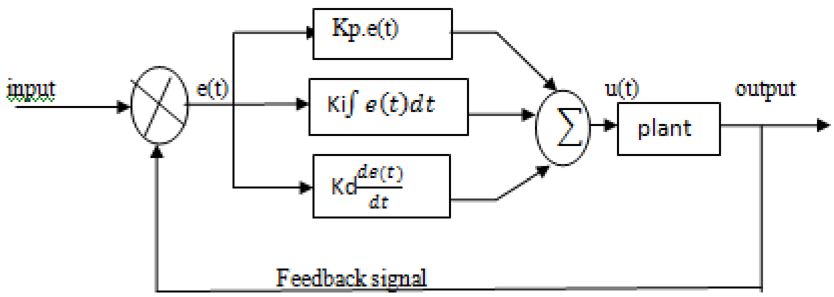

Fig3:Block diagram of PID controller

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$$U(t) = Kp.e(t)+Ki\int e(t).dt+Kd\frac{de(t)}{dt}$$

IV.TUNING OF PID CONTROLLER

Tuning a control loop is the adjustment of its control parameters (proportional gain Kp, integral gain Ki and derivative gain(Kd) to the optimum values for the desired control response. There are several methods for tuning a PID loop.[6] The most effective methods generally involve the development of some form of process model, then choosing P, I, and D based on the dynamic model parameters. The choice of method will depend largely on whether or not the loop can be taken "offline" for tuning, and the response time of the system. If the system can be taken offline, the best tuning method often involves subjecting the system to a step change in input, measuring the output as a function of time, and using this response to determine the control parameters. Different tuning methods are[12]

- Manual tuning
- Ziegler-Nichols tuning
- Software tuning

In this paper Ziegler-Nichols tuning method is presented

Ziegler-Nichols tuning introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s. in the method, the Ki and Kd gains are first set to zero. The proportional gain Kp is increased until it reaches the ultimate gain, Ku, at which the output of the loop starts to oscillate. Ku and the oscillation period Pu are used to set the gains as shown.[8]

Table 1: Ziegler–Nichols rule

Control type	Kp	Ki	Kd
P	0.50Ku	-	-
PI	0.45Ku	1.2Ku/Pu	-
PID	0.60Ku	2Ku/Pu	Ku Pu/8

Simulink Implement:

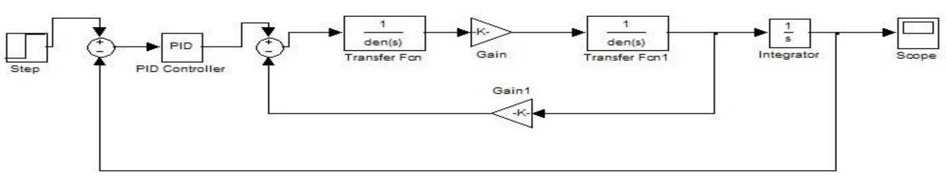

Fig 4:Simulink implementation of PID controller dc motor

Here We first set Ti=∞ (i.e. Ki=0) and Td=0 (i.e. Kd=0) .Using the proportional control action increase Kp from 0 to a critical value Ku(ultimate gain), at which the output first exhibits sustained oscillations The value of Ku so obtained is 2.7 .The parameters thus obtained are: Kp= 2.7, Ki= 0, Kd= 0.

The response obtained is

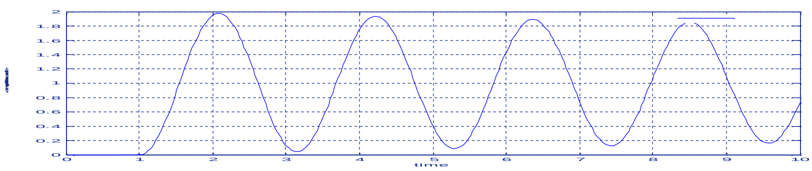

Fig5: Angular position waveform

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The disadvantage of this method is that it should take a long time to find the optimal values. Another method to tune PID parameters is Ziegler-Nichols frequency response method The value of Pu is found to be 1.67. The value of the parameters Kp, Ki and Kd based on Ziegler Nichols tuning method: Kp= 1.62, Ki= 3.23 , Kd= 0.5636.
The response obtained is

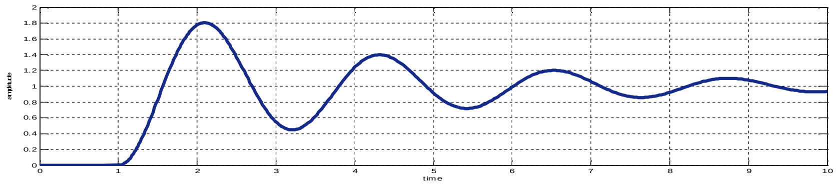

Fig6:Response of model using Ziegler-Nichols tuning

Hand Tuning of the parameters is done to reduce the overshoot to a tolerable range. The values of the parameters which yielded the most suitable results are :Kp= 1.7 , Ki= 1.5,Kd=0.7
The response obtained is

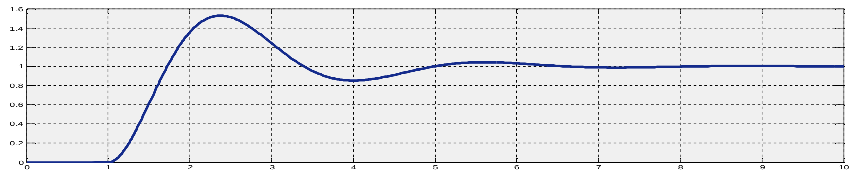

Fig7:response of model using hand tuning.

V.FUZZY LOGIC CONTROLLER

Fuzzy logic is expressed by means of the human language [3].Based on fuzzy logic, a fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. First, set the error (e)and the error change (ec) of the angular velocity to be the input variables of the fuzzy logic controller. The control voltage u(t) is the output variable of the fuzzy logic controller. The linguistic variables are defined as . The Linguistic fuzzy sets are el (error low),em (error medium),eh(error high),ecl (error change low),ecm(error change medium),ech (error change high),cl (control low),cm (control medium),ch(control high).The type of fuzzy inference engine is Mamdani.

Table2:Rule for output variable “control”

e/ec	ecl	ecm	ech
el	cl	cm	cm
em	cl	cm	ch
eh	cm	cm	ch

Membership function

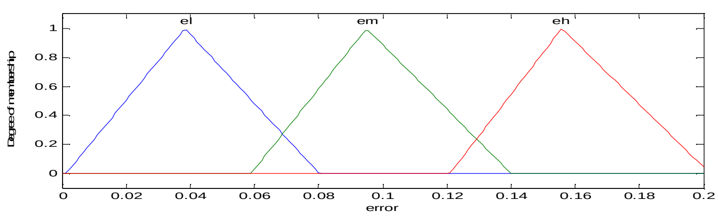

Fig.7: Fuzzy input variables “error”

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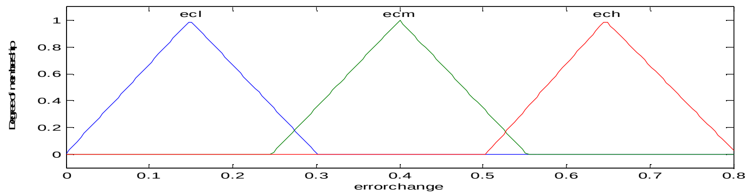

Fig8. : Fuzzy input variables "change in error"

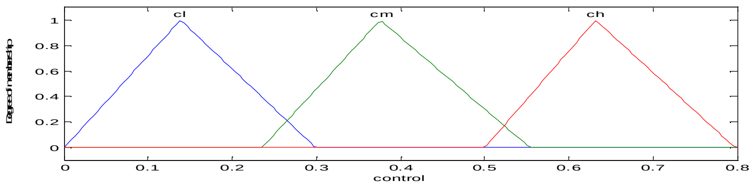

Fig9. : Fuzzy output variable "control"

Simulink implementation:

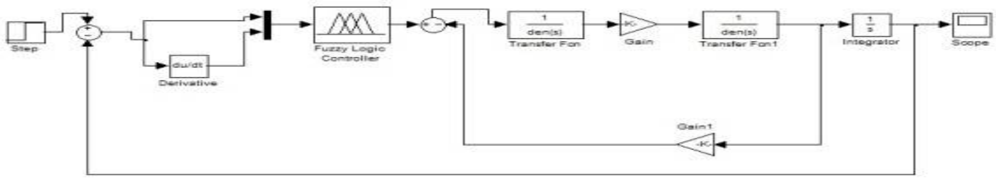

Fig10:simulink model of fuzzy controller

Result:

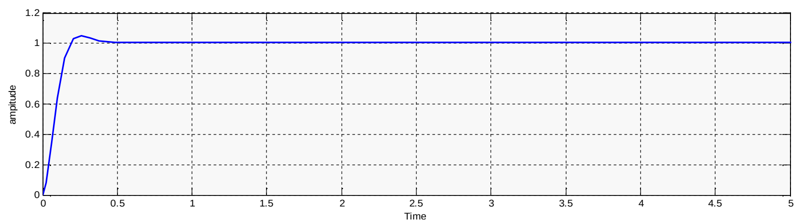

Fig 11:Response of model using fuzzy controller

VI .MPLEMENTATION OF GA BASED PID CONTROLLER

In the proposed work a DC Motor model is called by a program which is coded in Matlab for a fitness function i.e cost function. In order to use GA to tune the PID controller for DC motor. Variables Kp, Ki, & Kd are coded to solve string structures. Binary coded string having 1"s & 0"s are mostly used. The length of string is usually determined according to the desired solution accuracy. Here 10 bits are used to code each variable. We can use 8 bit & 4 bit also. Thereafter select the random strings from the population to form the mating pool.[11] In order to use tournament selection procedure, we calculate the average fitness of the population. Then the mating pool strings are used in the crossover operation. The next step is to perform mutation on strings in the intermediate population . The resulting population becomes the new population. The whole process is coded in matlab & after running the program we get the optimized values of Kp, Ki & Kd .

Objective Function of the Genetic Algorithm :

The most challenging part of creating a genetic algorithm is writing the objective functions. In this paper, the objective function is required to evaluate the best PID controller for the system. An objective function could be created to find a PID controller that gives the smallest overshoot, fastest rise time or quickest settling time.[21] However in order to combine all of these objectives an objective function is designed to minimize the performance indices of the controlled system instead.

Table3 : Setting of GA parameters

Lower bound [Kp Ki Kd]	[0 0 0]
Upper bound [Kp Ki Kd]	[500 500 500]
Populations	25
Generations	100
Population type	Double vector
Crossover fraction	0.8
Mutation rate	0.01
Elite count	5
Selection function	Tournament

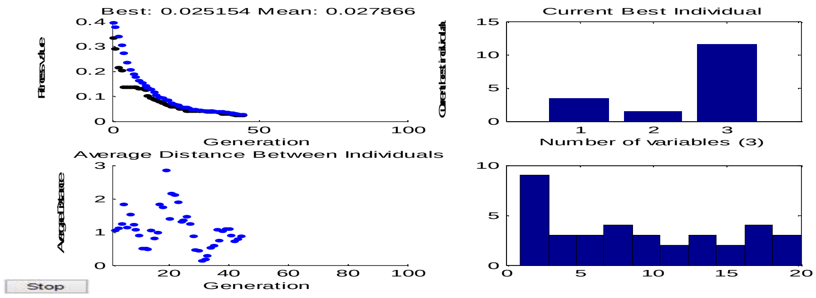

Fig 12 :GA optimization process

It is clear from results that the simple PID controller is not getting the accurate results but the G.A based PID controller getting the proper optimized gain values of KP, Ki and Kd. Below fig. shows the simulation result.

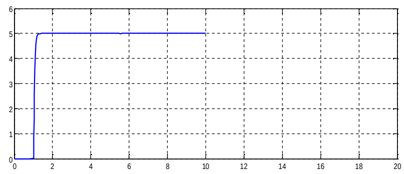

Fig13: Simulink result of GA based dc motor

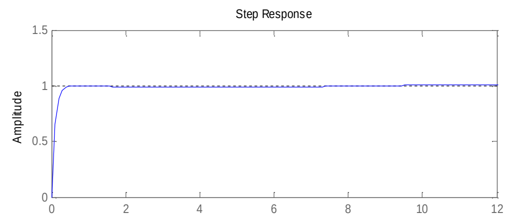

Fig12 :Step response of GA based optimization

VII. RESULTS AND DISCUSSION

The performance of tuning of PID parameters using Z-N tuning, Hand tuning ,fuzzy logic controller and genetic algorithm optimization technique are shown in this paper. The tuning methods efficient in improving the step response characteristics such as, reducing the rise time, settling time and maximum overshoot in speed control of DC motor. In this paper comparison is given for various values like proportional gain, integral gain, derivative gain, rise time, dead time, %maximum overshoot, settling time. The results obtained from different tuning methods, using fuzzy logic controller and GA based optimization technique are shown in the table given below.

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Table 4: Comparison of different performance indices

CONTROLLER	KP	KI	KD	DELAY TIME (TD)	RISE TIME(TR)	% OF MAXIMUM OVERSHOOT	SETTLING TIME
Z-N TUNING	1.62	3.23	0.5636	1.4 SEC	1.7 SEC	80%	15 SEC
HAND TUNING	1.7	1.5	0.7	1.3 SEC	1.5 SEC	50%	6.5 SEC
FLC	-	-	-	1.1 SEC	0.2 SEC	4%	0.3 SEC
GA	6.432	0.007	0.312	0 SEC	0 SEC	0%	0.1 SEC

- In the above table comparative results of Z-N tuning and Hand tuning were provided. The rise time of Z-N tuning PID controller is 1.7 sec and Hand tuning PID controller is 1.5 sec. It is also shown that the rise time response of with PID controller had got better performance than without PID controller. There is significant change of delay time and rise time i.e from 1.4 sec to 1.3 sec and 1.7 sec to 1.5 sec respectively. Coming to percentage of maximum overshoot there is a drastic change from 80% to 50%.Coming to settling time there is drastic change from 15 sec to 6.5 sec. This is not desirable. This drawback can be overcome by fuzzy logic controller.
- Using fuzzy logic controller the rise time slightly is 1.1 sec. There is significant change of delay time from 1.4 sec to 1.1 sec. The rise time of FLC drastic change from 1.5 sec to 0.2 sec Coming to percentage of maximum overshoot there is a drastic change from 50% to 4%.Coming to settling time there is drastic change from 6.5 sec to 0.3 sec. The simulation results so obtained show that the PID controller gives high overshoot and settling time. Hence, fuzzy logic controller design was proposed and implemented using the principles of artificial intelligence. The fuzzy logic control is implemented and the response is compared with conventional PID controller. The fuzzy logic control shows a better control of motor parameters as compared with the conventional PID controller.[9]
- In order to verify the validity of the proposed controller, conventional fuzzy controller is compared with GA based PID controller. In the table, there is no dead time in the system i.e. dead time is 0. Hence we have reached one of our aim .There is a considerable decrease in rise time which is in the order of 0 sec. This shows how firstly the system is responding. system has reached its steady state before 0.1 seconds. The G.A designed PID controller is much better in terms of rise time, settling time, overshoot then simple PID controller, Z-N PID controller and fuzzy logic controller.

VII. CONCLUSION

In this paper Speed response characteristics of separately excited dc motor were obtained by mathematical model using MATLAB coding and SIMULINK model. In this paper speed of D.C. motor is controlled by four methods of PID controlling techniques. The four methods used are: Ziegler-Nichols tuning, hand tuning, Fuzzy logic controller and genetic optimization techniques. The response is found to be not satisfactory i.e. response doesn't satisfy the desired design requirements like rise time, settling time, peak value, steady state error and dead time by conventional method. To overcome the above drawback we employed PID controller design, by proper tuning of Kp, Ki and Kd to improved the characteristics like steady state error. But the above designed system failed to reduce the dead time of the system. Hence in order to reduce the dead time modern technique like FUZZY controller was employed. FUZZY controller is proposed to replace conventional PID controller to improve the system characteristics. Comparison of Z-N tuning PID controller and Hand tuning PID controller of results of the simulations, it is found that the Fuzzy Logic Controller better than other methods. Research work also has been carried out to get an optimal PID tuning by using GA. The G.A designed PID controller is much better in terms of rise time, settling time, overshoot time then simple PID controller and fuzzy logic controller.

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