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Comparative analysis of tuning technique of fuzzy logic PID controllers and classical PID controllers over armature control DC motor

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ABSTRACT

This paper give solution of tuning technique of PID (Proportional integral derivative) controller by using Ziegler-Nichols and fuzzy logic technique applied in speed control of DC motor. The proportional, integral and derivate (K_P, K_I, K_D) gains of the PID controller are regulate according to fuzzy logic technique. The Fuzzy logic Proportional integral derivative FLPID controller is designed according to fuzzy rules. Twenty five self tuning rules are programmed for PID controller. Two inputs are applied to PID controller one for speed error actual speed and the second is rate of change in speed error. The Parameter of PID controllers are used to control the speed of the DC Motor. The MATLAB model for speed control of DC motor using fuzzy logic is easy and less calculation required. The results proof that the designed self-tuned PID controller perform optimum speed control of DC motor, and compared the FLPID conventional PID controller.

Keywords: *Fuzzy Logic, PID Controller, DC, Membership Function, FLPIDC*

1. INTRODUCTION

The DC motor posses the High starting torque Speed control over a wide range, both below and above the normal speed Accurate step less speed control with constant torque quick starting stopping, reversing and accelerating high reliability. The speed and torque curve of dc motor are very good as compare to AC motor. A DC motors can give excellent control of speed in accelerating and breaking mode provide excellent control of speed for acceleration and deceleration. To control the speed of DC motor to take different work there are number of technique are used one of the popular technique is PID control the main purpose of is paper is to improve the error in conventional PID controller by using Fuzzy logic technique. Applicability and ease of use offered by the PID controller. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly. Fuzzy logic technique now a day very popular for researcher it was introduced by L.A.Zadeh in year1965 and mamdani (1975) give Since then, FLC has been very helpful tool in research and various industrial application. The error and the change of the error are two inputs for the design of such a fuzzy logic PID Controller (FLPID).

2. DC MOTOR

In figure 2.1 show a separately excited DC motor the applied voltage of the armature varies without changing the field voltage. The dc motor is connected with mechanical load having moment of inertia J and viscous friction coefficient B a variable voltage is applied to armature and following parameter is consider for calculation.

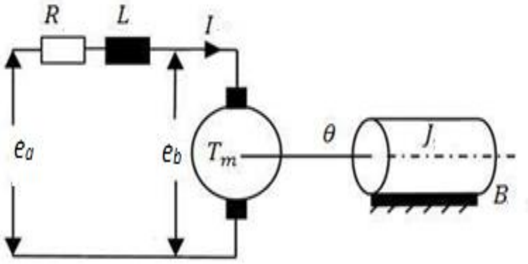

Fig. 1: Diagram of DC motor modal for speed control

Notations
R = Armature Resistance (Ω).
L = Inductance of armature winding (H).
i_a = Armature current (A).
i_f = Field current (A).
e_a = applied armature voltage (V)
e_b = back emf (V)
T_m = torque developed by motor (Nm)
θ = angular displacement of motor shaft (rad). ω = angular speed of motor shaft (rad/sec.)
J = equivalent moment of inertia of motor and load referred to motor shaft (kg-m^2)
B = equivalent friction coefficient of motor and load referred to motor shaft (Nm/rad/sec)

In armature control of separately excited DC motor the voltage is changed by changing the applied voltage. Applying torque equation and KVL in loop of DC motor figure (2.1) we get the following equation.

The Mechanical torque T_m of motor is proportional to the product of armature current and air gap flux, i.e.

$$T_m = K_1 K_f i_f i_a \qquad (2.1)$$

Here K_1 is constant.

In this case dc motor, the field current is constant

$$T_m = K i_a \qquad (2.2)$$

$$e_b = K_b \frac{d\Theta}{dt} \qquad (2.3)$$

KVL in loop of dc motor

$$L\frac{di_a}{dt} + Ri_a + e_b - e_a = 0 \qquad (2.4)$$

$$J\frac{d^2\Theta}{dt^2} + B\frac{d\Theta}{dt} = T_m = K_T i_a \qquad (2.5)$$

Laplace transforms of (2.3) (2.4) and (2.5) assuming zero initial condition

$$E_b(s) = K_b s\, \Theta(s) \qquad (2.6)$$

$$(Ls+R)\, i_a(s) = E_b(s) - E_a(s) \qquad (2.7)$$

$$(Js^2 + Bs)\Theta(s) = T_m = K_T i_a(s) \qquad (2.8)$$

$$\frac{\Theta(s)}{E_a(s)} = \frac{K_T}{s[(R+Ls)(Js+B)+K_T K_b]} \qquad (2.9)$$

$$\Theta(s) = \frac{\omega(s)}{s} \qquad (2.10)$$

Angular velocity ω(t)= (dΘ(t))/dt

$$\frac{\omega(s)}{E_a(s)} = \frac{K_T}{[(R+Ls)(Js+B)+K_T K_b]} \qquad (2.11)$$

DC motor of 3.70KW, 240V 17500rpm DC motor with the below parameter is used

R=0.5Ω,L=0.02 H, V=240 V, J=0.1 Kg.m2, B=0.008Nms/rad , N=1500rpm K_T=1 Nm/A

$K_b = 1.28$Vs/rad

Putting the above value the Transfer function of the DC motor is given by

$$G(s) = \frac{\omega(s)}{E_a(s)} = \frac{1}{0.002s^2+0.05s+1.2} \qquad (2.12)$$

3. RESPONSE OF TRANSFER FUNCTION OF DC MOTOR (WITHOUT USING FLPID CONTROLLER)

The unit step response of equation (2.12) is obtained by using mat lab Programs

```
Command Window
>> num1=[1];
>> den=[0.02 0.05 1.2];
>> G=tf(num1,den)

Transfer function:
          1
-----------------------
0.02 s^2 + 0.05 s + 1.2

>> step(G)
```

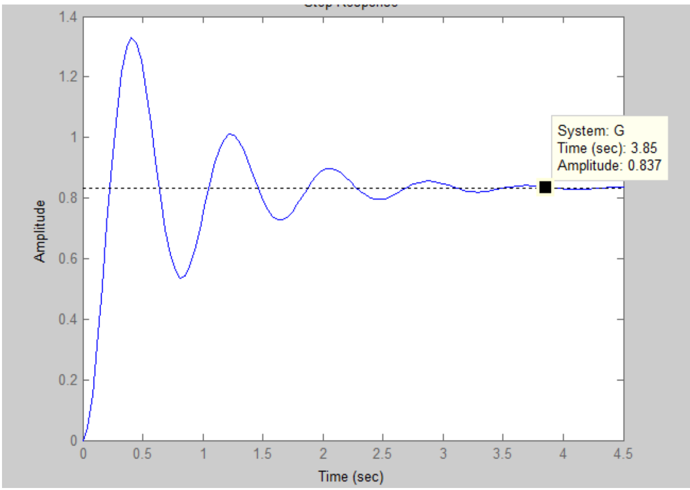

Fig. 3: Response of transfer function of dc motor (without using FLPID controller)

$$\text{Response of } \frac{\omega(s)}{e_a(s)} = \frac{1}{0.002s^2+0.05s+1.2}$$

By using MATLAB Programming the response of the transfer function is shown in Figure 3.1 from the graph the value of Maximum overshoot, Rise Time, Peak time, Settling time is obtained.

Maximum overshoot Mp=33%.
Delay time T_d=0.141sec.
Rise Time Tr=0.228sec.
Peak time T_p=0.423sec.
Settling time T_S=3.08sec.

To improve the performance of these parameter of the system a controller is required the conventional controller are PD, PI,and PID controllers are widely used in industrial use.

4. PID CONTROLLER

PID controls of plants. Figure 4.1 shows a PID control of a plant. If a mathematical model of plant can be derived, then it is possible to apply various design techniques for determining parameters of the controllers that will meet the transient and steady-state specifications of the closed-loop system. However, if the plant is so complicated that its mathematical model cannot be easily obtained, then analytical approach to the design of a PID controller is not possible. Then we must resort to experimental approaches to the tuning of PID controllers. The process of selecting the controller parameters to meet given performance specifications is known as controller tuning. Ziegler and Nicholas suggested rules for tuning PID controllers (meaning a set values Kp , Ti and td) based on experimental steps responses or based on the value Kp that results in marginal stability when only the proportional control action is used. Ziegler and Nicholas rules, which are presented in the following, are very convenient when mathematical models of plants are not known.

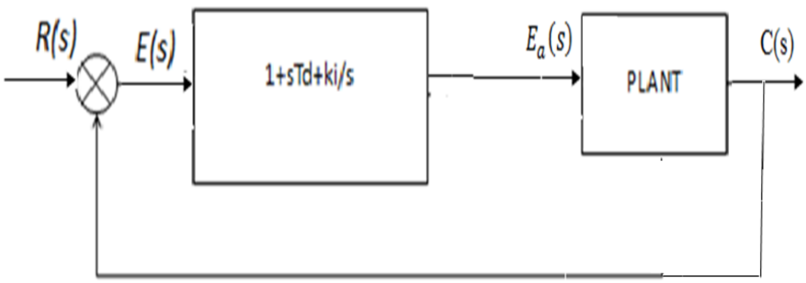

Fig. 4: PID Control

$$e_a\,(t)= K_P\, e(t)+ K_I \int e(t) + K_D \frac{de(t)}{dt} \qquad (4.1)$$

$$e_a\,(t)= [e(t)+\frac{1}{T_I}\int e(t) +T_D \frac{de(t)}{dt}] \qquad (4.2)$$

Where K_P =Proportion gain, K_I =Integral gain , K_D =Derivative gain

$$T_i = Integral\ time = \frac{K_p}{K_i}$$

$$T_d = Derivative\ time = \frac{K_d}{K_i}$$

The Laplace transform of the actuating signal incorporating PID control

$$E_a(s) = E(s)+sT_d E(s) + \frac{K_i}{s} E(s) \qquad (4.3)$$

$$E_a(s) = E(s)[1+sT_d + \frac{K_i}{s}] \qquad (4.4)$$

If the transfer function of system is known then it is possible to apply usual design techniques for tuning PID controller known as Ziegler-Nichols (Z-N) method, for determine parameters of the controller that will meet the transient and steady state specifications of the close loop system by using PID controller. However the plant is so complicated that model cannot be easily tuned i.e. it is difficult to selecting the parameters (KP, KI, KD) , This paper give solution of the tunning problem Fuzzy logic technique give solution of this problem.

5. ZIEGLER NICHOLS TUNING RULE BASED ON CRITICAL GAIN K_cr AND Critical Period P_cr

Second method: To solve the problem with Ziegler Nichols Tuning Rule first set Ti = ∞ and Td = 0. Using the proportional control action only (see figure 4.1B), increase Kp from 0 to a critical Kcr where the output first exhibits sustained oscillations. Ziegler and Nicholas suggested that we set the values of the parameters Kp, Ti and Td according to the formula shown in the table (4.1B)

Table(4.1B) Ziegler Nichols Tuning Rule

Type of controller	Kp	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

G_s (s)=K_p (1+1/(ST_i)+sT_d) (4.1b)

=0.6K_cr (1+1/(0.5sP_cr)+0.125sP_cr) (4.2b)

=0.075K_cr P_cr 〖(s+4/P_cr)〗^2/s (4.3b)

Where
K_cr= critical gain
P_cr = critical period

From equation (9) putting the value of motor parameter

G(s)= 1/((0.002s^3+0.05s^2+1.2s)) (4.4b)

By using Routh Hurwitz stability criterion

K_p=18, T_i=0.12828, T_d=0.0625

The response of the system after tuning is shown in figure (4.1B)

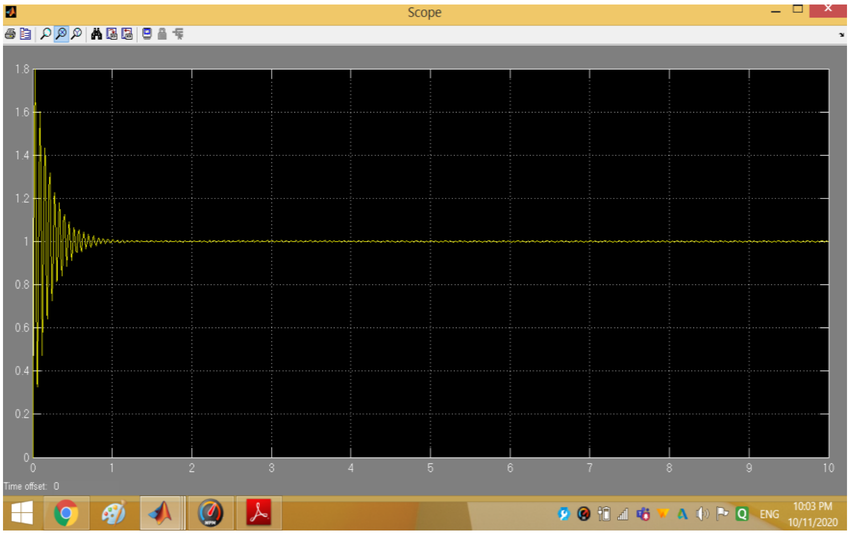

Figure (4.1B) Response of the system after tuning by Ziegler-Nichols method

It is clear that after tuning with Ziegler-Nichols method the response of the system get stable after 1sec but between 0 to 1 sec the graph is not satisfactory so we need some other tuning technique to improve the result. Ziegler-Nicholas tuning rules (and other tuning rules presented in the literature) have been widely used to tune PID controllers in process control system where the plant dynamics are not precisely known. Over many years, such tuning rules proved to be very useful. Ziegler-Nicholas tuning rules can, of course, be applied to plants whose dynamics are known. (If plant dynamics are known, many analytical and graphical approaches to the design of PID controllers are available, in addition to Ziegler-Nicholas tuning rules.

6. FUZZY LOGIC PROPORTIONAL INTEGRAL DERIVATIVE (FLPID) CONTROLLER DESIGN

Designing of FLPID Controller for proposed modal The FLPID controller in a closed loop control system is shown below Figure 5.

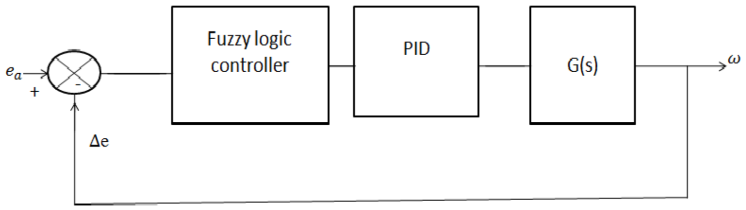

Fig. 5: Block diagram of System with FLPID

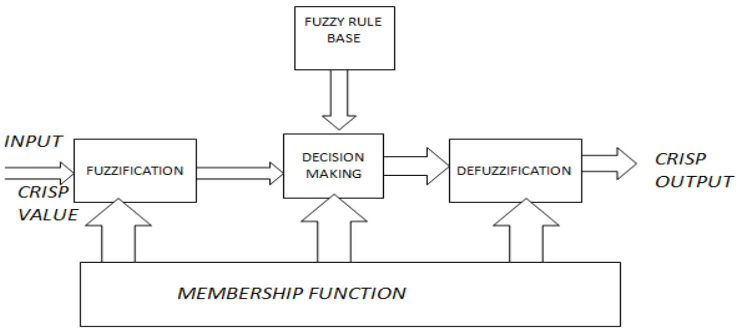

Fig. 6: Block diagram of Fuzzy inference unit(FIU)

Figure 6 show Block diagram of Fuzzy inference Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are described in membership function logical operation and If then rules.

6.1 Fuzzification

The process of fuzzification is to transformation of crisp input to the fuzzy input for example if any one want to convert the height of human being which is a crisp value may varies from 2 feet to 7 feet into a membership function which varies from 0 to 1,so the person below 2 feet and above 7 feet is not consider in this particular membership function. The maximum crisp value of this case is 7 feet so the fuzzy value of this is 1 similarly the person whom height is 3.5 feet the value of fuzzy is 0.5 in this way the membership may be framed so height may defined as very high(VH) ,medium (ME),short(SH), very short(VS) . For the proposed

FLPID controller the membership function is define as fuzzy sets: NM (Negative Medium), NS (Negative Small), ZO (Zero), PS (Positive Small), and PM (Positive Medium). Each fuzzy variable is a member of the subsets with a degree of membership µ varying between 0 (non-member) and 1 (full-member). All the membership functions have asymmetrical shape with more crowding near the origin (steady state). This permits higher precision at Steady state. Fuzzy rule for input voltage and change in voltage (Kp,Kd ,Ki) is given in Table 5.1b ,Table5.1c and Table 5. 1d. Table 5.1a show the fuzzy logic algorithm

6.2 Fuzzy logic algorithm

Table 1: Fuzzy logic algorithm

Fuzzy logic algorithm:	
1	Define linguistic variable and term
2	Build MF (Membership Function)
3	Configure rule base
4	Transform crisp data to fuzzy value with help of MF
5	Judge the rule in rule base
6	Merge the result of each rule
7	Transform output data to non-fuzzy values.

Table 2: Fuzzy Rule defied for Kp

e↓ Δe→	NM	NS	ZO	PS	PM
NM	PM	PM	PS	PS	ZO
NS	PM	PM	PS	ZO	NS
ZO	PM	PS	ZO	NS	NM
PS	PS	ZO	NS	NS	NM
PM	ZO	NS	NM	NM	NM

Table 3: Fuzzy Rule defied for Ki

e↓ Δe→	NM	NS	ZO	PS	PM
NM	NM	NM	NS	NS	ZO
NS	NM	NS	NS	ZO	PS
ZO	NM	NS	ZO	PS	PM
PS	NS	ZO	PS	PS	PM
PM	ZO	PS	PS	PM	PM

Table 4: Fuzzy Rule defied for Kd

e↓ Δe→	NM	NS	ZO	PS	PM
NM	NS	NM	NM	NM	NS
NS	NS	NM	NM	NS	NS
ZO	NS	NS	NS	NS	NS
PS	ZO	ZO	ZO	ZO	ZO
PM	PS	PS	PS	PS	PS

The membership function plots for the input variable of (Kp,Ki,Kd) are taken by using MATLAB as Shown in Figure 7, 8, 9.

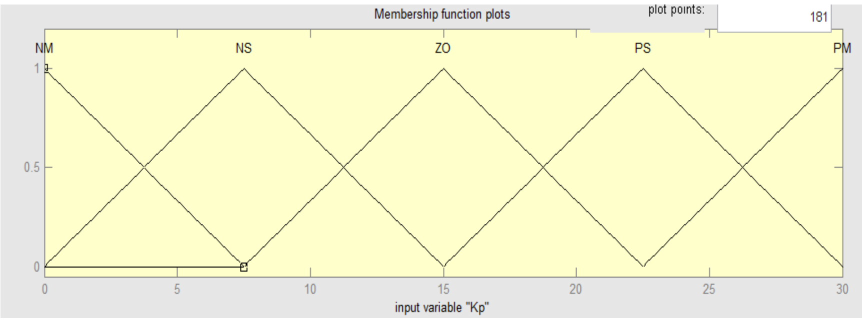

Fig. 7: Membership Function plots for input Kp.

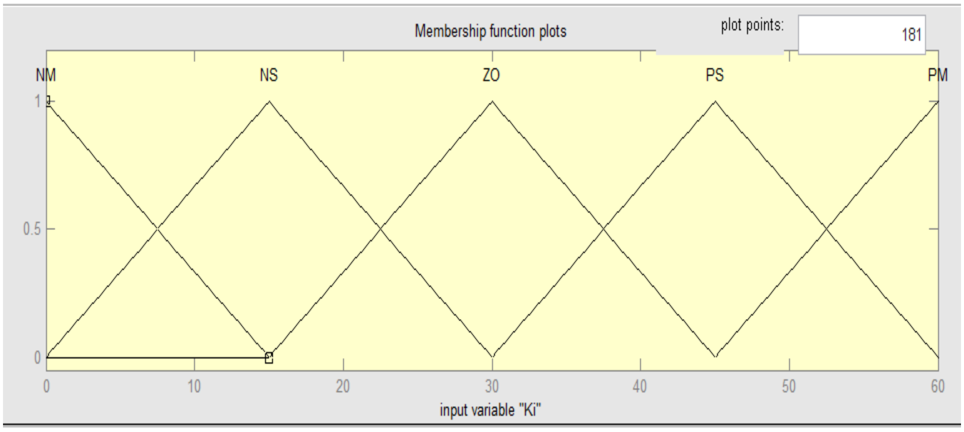

Fig. 8: Membership Function plots for input Ki

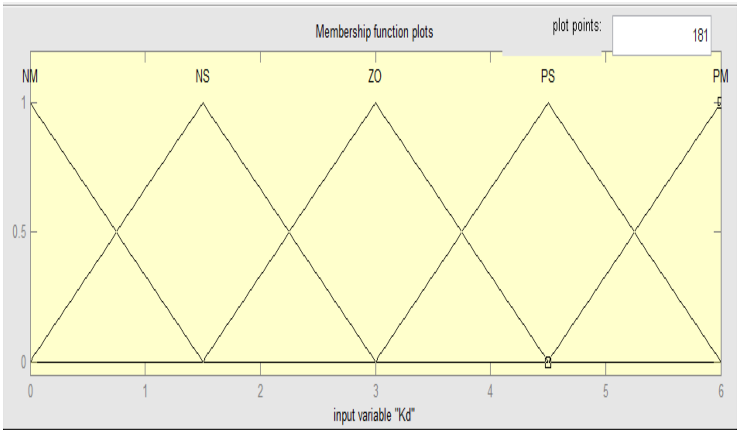

Fig. 9: Membership Function plots for input K_d

6.2 Detemination of Rule for Flpid

The input variable and output variable is governed by certain rule which is defined in FIS editor for FLPID as shown in figure 10 If then rule is fed in Mamdani block shown in white color in FIS editor after defining 20 rules (figure 11) the graph of the rule is observed in figure 12 and figure 13(3D graph) show the K_p K_i and K_d relationship for fuzzy controller and Figure 14 Membership Function plots for output PID controller.

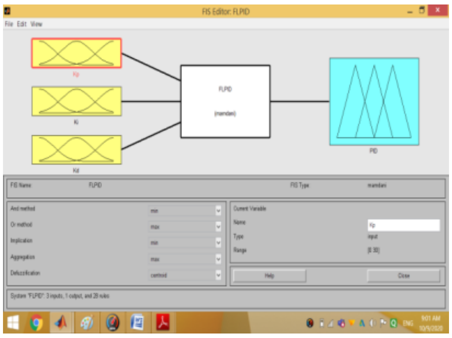

Fig. 11: FIS Editor for FLPID.

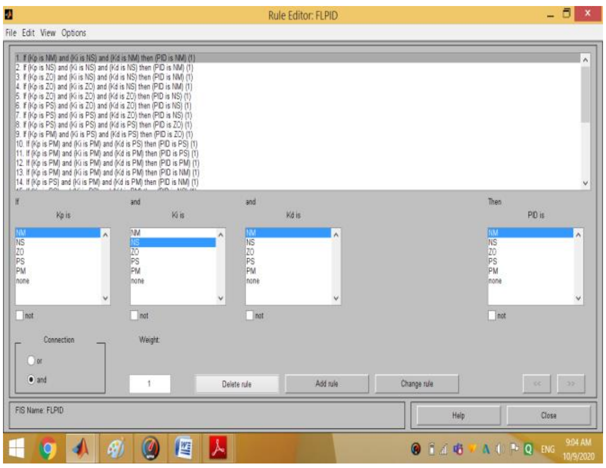

Fig. 12: Rule editor for FLPID

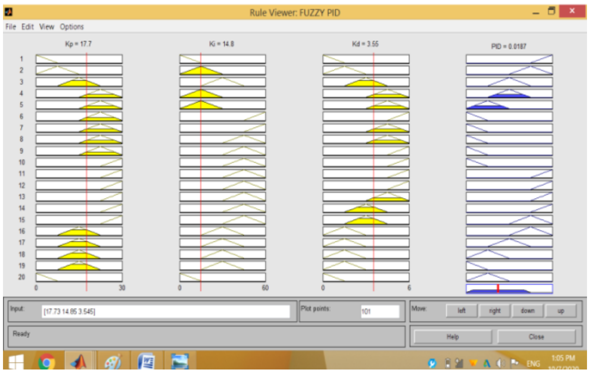

Fig. 13: Rule Viewer for Fuzzy Logic PID controller

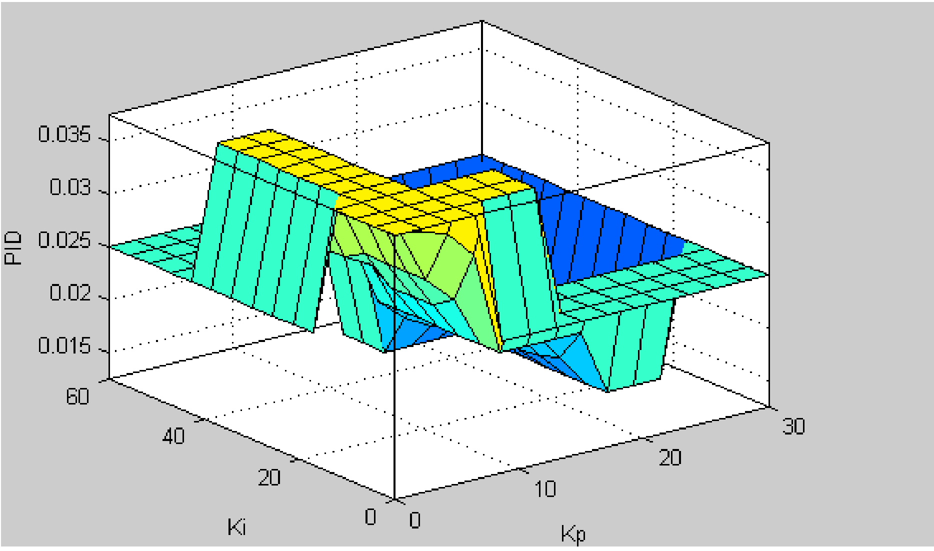

Fig. 14: K_p K_i and K_d relationship for fuzzy controller.

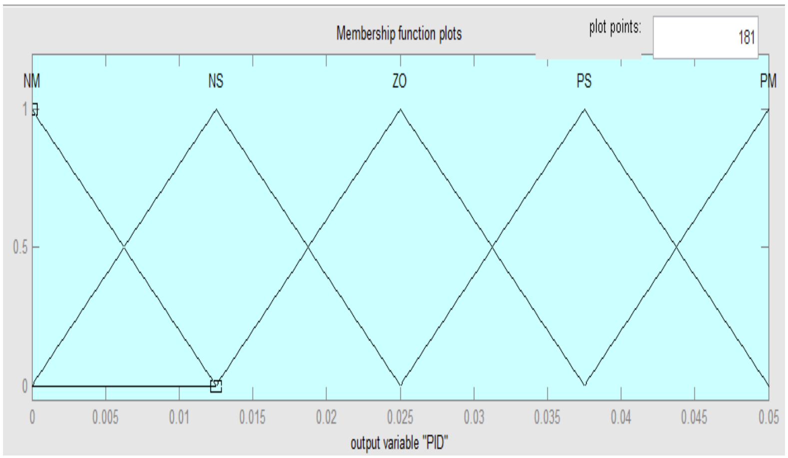

Fig. 15: Membership Function plots for output PID controller

6.3 Defuzzification

There are many defuzzification methods but the most common methods are as follows:

- Mean of maximum (MOM) Technique
- Center of gravity (COG) Technique
- Bisector of area (BOA) Technique
- Smallest of maximum (SOM) Technique

6.4 Advantages

There are many advantages of Fuzzy logic to controlling the devices as compare to other controlling techniques. The Some are:-

- Fuzzy logic is a accurate problem solving Technique
- It is able to handle big numerical data and linguistic knowledge.
- A technique that facilitates control of a complicated system without knowledge of its mathematical description.
- Fuzzy logic differs from classical logic in that statements are no longer black or white, true or false, on or off.

In traditional logic an object takes on a value of either zero or one. In fuzzy logic, a statement can assume any real value between 0 and 1, representing the degree to which an element belongs to a given set.

- A computational paradigm that is based on how humans think
- Fuzzy logic looks at the world in the imprecise terms, in much the same way that our brain takes in information (e.g temperature is hot, speed is slow),then responds with precise actions.
- The human brain can reason with uncertainties, vagueness, and judgments. Computers can only manipulate precise valuation. Fuzzy logic is an attempt to combine the two techniques.

7. SIMULINK IMPLEMENTATION GAIN INTEGRATAR

In this section the **FLPDI** model is design by using MATLAB as shown in figure 16. To design the model the Integrator. derivative ,gain, fuzzy logic controller block is selected from Simulink library browser and drag to workspace and for testing unit step signal is applied and summer is added to give feedback to summer with and output signal is observe in scope transfer function block differentiator gain summer is drag to workspace and model is formed as shown in the figure 6

The input test signal is given by using unit step test signal a summer is add to take feedback signal.

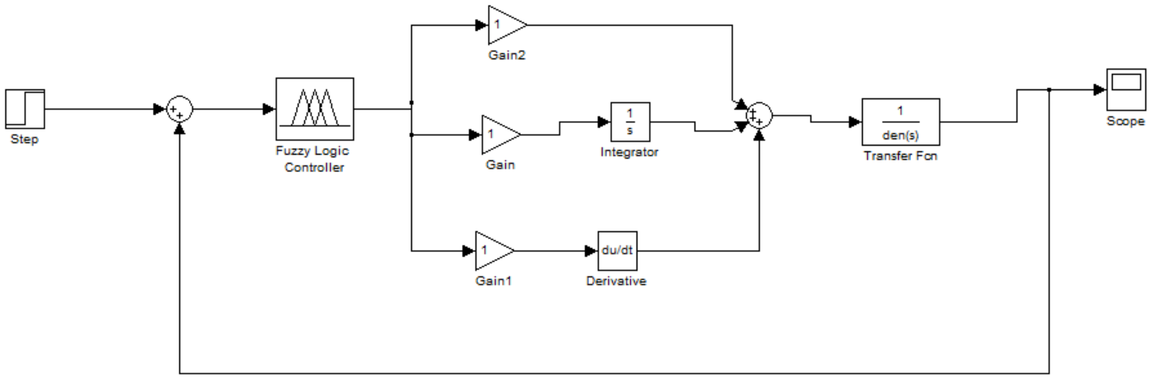

Fig. 16: FLPID control system

Fuzzy logic controller is connected with the system having transfer function G(s) the result is taken in scope.

8. RESULTS AND CONCLUSION

This paper addressed the problem of tuning the gain of FLPID Figure 17. shows the responses of the system and the conclude that the FLPID controller improve rise time, delay time, peak time, Maximum overshoot, setting time, which is shown in Table 7.1a hence the system become fast.

Fig. 17: Output of the scope

Table 7.1a Simulation Result Of The Flpid Controller

	Delay time (sec)	**Rise time (sec)**	**Peak time (sec)**	**Peak over shoot(M_p)**	**Settling time(sec)**
Without using FLPID controller	**0.141**	**0.228**	**0.423**	**33%**	**3.08**
With FLPID	**0.0152**	**0.0224**	**0.0399**	**5%**	**0.341**

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