International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 8, pp: 25-35 www.ijaem.net ISSN: 2395-5252

Speed Control of Field Controlled Dc Servomotor by Using Tuning Technique of Fuzzy Logic Pid Controllers And Classical Pid Controllers And Comparative Analysis

Dr Abhishek Kumar[1, a *], Arpana Kumari [2,b] and Arvind Kumar[3,c]
[1] R.T.C institute of Technology, Ranchi, Jharkhand 835219 India.
[2] Ex faculty IMS Ghaziabad 201001 India
[3] Ex faculty C.I.T Ranchi Jharkhand India

Date of Submission: 01-10-2020 Date of Acceptance: 19-10-2020

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 field controlled DC servomotor. 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

I. 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).

II. DC MOTOR

D.C machines is a highly versatile energy conversion device. It can meet the demand of loads requiring highly starting torques high accelerating and decelerating torques. At the same time, d.c. machine is easily adaptable for drives requiring wide-range speed control and quick reversals. These inherent characteristics can further be modified, if desired, by feedback circuits. In view of these outstanding features, d.c machine possesses a high degree of flexibility. These are therefore widely used in industry, particularly for tough jobs as are encountered in steel-mill drives in spite of their higher initial cost.
In figure 2.1 field controlled DC servomotor the applied voltage of the field varies without changing the armature voltage.

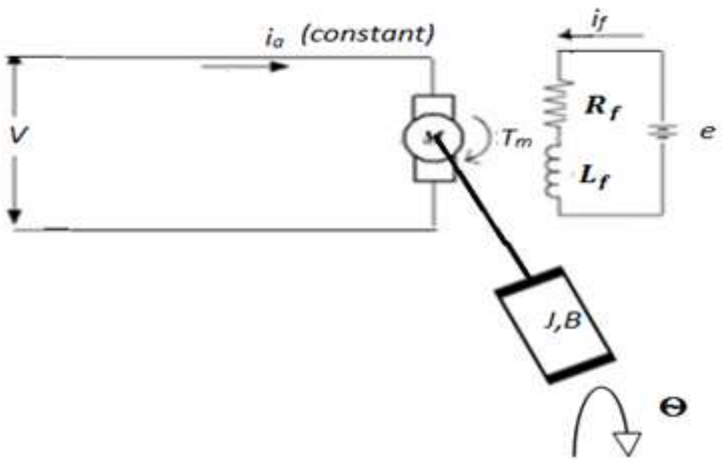

Figure 2.1 Diagram of DC motor modal for speed control

Notations

R_f = Field Resistance (Ω).
L_f = Inductance of field winding (H).
i_a = Armature current (A).
i_f = Field current (A).
e = Field control 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 field control DC motor the armature current is fed from a constant current source.
Since the motor is operating in the linear region the magnetization curve the flux is proportional to the field current

$$\Phi = K_f i_f \quad (1)$$

Where K_f =constant
The torque T_m developed by the motor is proportional to the product of armature current and air gap flux, i.e.

$$T_m = K_1 K_f i_f i_a = K_T i_f \quad (2)$$

Where is constant K_1 and K_T
The equation for the field circuit

$$L_f \frac{di_f}{dt} + R_f i_f = e \quad (3)$$

The torque equation is

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} = T_m = K_T i_a \quad (4)$$

Taking the Laplace transform of (3) and (4) assuming zero initial condition

$$(L_f s + R_f)\, I_f(s) = E(s)$$

$$I_f(s) = \frac{E(s)}{(L_f s + R_f)} \quad (5)$$

$$(Js^2 + Bs)\Theta(s) = T_m(s) = K_T I_f(s) \quad (6)$$

Putting the value of $I_f(s)$ in equation (6)

$$(Js^2 + Bs)\Theta(s) = K_T I_f(s) = \frac{K_T E(s)}{(L_f s + R_f)}$$

$$\frac{\Theta(s)}{E(s)} = \frac{K_T}{s(Js+B)(L_f s+R_f)} \quad (7)$$

Angular velocity $\omega(t) = \frac{d\Theta(t)}{dt}$ (8)

Taking Laplace transform of (8)

$$\Theta(s) = \frac{\omega(s)}{s} \quad (9)$$

$$\frac{\omega(s)}{E(s)} = \frac{K_T}{(Js+B)(L_f s+R_f)} \quad (10)$$

Transfer function of the DC motor is given by taken as

$$\mathbf{G(s)} = \frac{1}{s^3+s^2+5s} \quad (11)$$

III. PID CONTROLLER

PID controls of plants. Figure 3.1 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

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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.

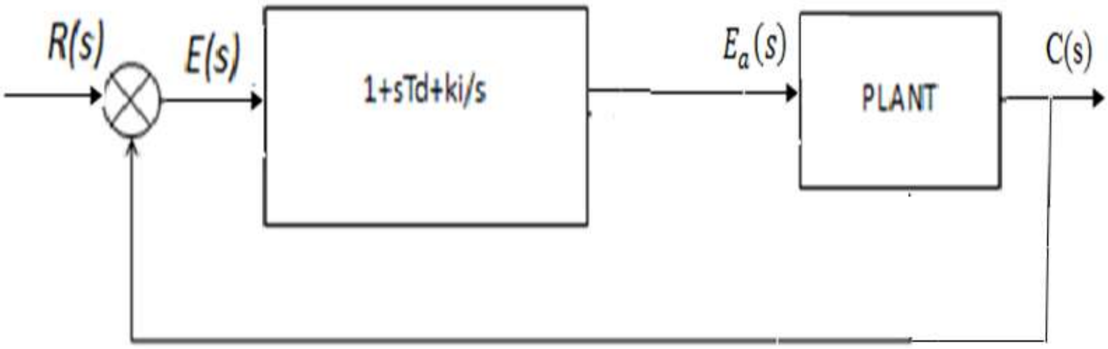

Figure 3.1 PID Control

$e_a(t) = K_P\, e(t) + K_i \int e(t) + K_D \frac{de(t)}{dt}$ (12)

$e_a(t) = [e(t) + \frac{1}{T_I} \int e(t) + T_D \frac{de(t)}{dt}]$ (13)

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

$E_a(s) = E(s) + sT_d E(s) + \frac{K_i}{s} E(s)$ (14)

$E_a(s) = E(s)[1 + sT_d + \frac{K_i}{s}]$ (15)

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 (K_P, K_I, K_D) , This paper give solution of the tunning problem Fuzzy logic technique give solution of this problem.

IV. 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 4.1), 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 (4.1)

Table(4.1) 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	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

$$G_s(s) = K_p\left(1 + \frac{1}{sT_i} + sT_d\right) \quad (16)$$

$$=0.6K_{cr}\left(1 + \frac{1}{0.5sP_{cr}} + 0.125sP_{cr}\right) \quad (17)$$

$$=0.075K_{cr}P_{cr}\frac{\left(s+\frac{4}{P_{cr}}\right)^2}{s} \quad (18)$$

Where
K_{cr} = critical gain
P_{cr} = critical period

By using Routh Hurwitz stability criterion
K_p =39.4198 , T_i =3.069 , T_d=0.7685
MATLAB Program for unit step PID controlled system

```
>> n=[0 0 6.3223 18 12.811];
>> d=[1 6 11.32 18 12.811];
>> G=tf(n,d)
 Transfer function:
      6.322 s^2 + 18 s + 12.81
--------------------------------------
s^4 + 6 s^3 + 11.32 s^2 + 18 s + 12.81

>> step(G)
```

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

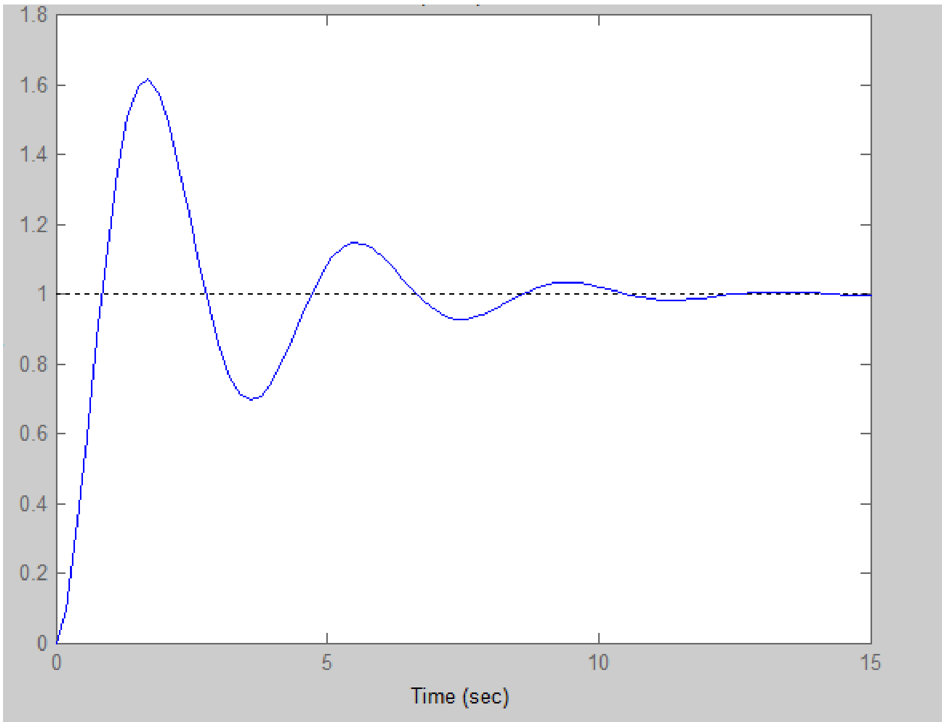

Figure (4.1) Response of the system after tuning by Ziegler-Nichols method

Maximum overshoot Mp=65%.
Delay time T_d=0.51sec.
Rise Time Tr=0.852sec.
Peak time T_p=1.65sec.
Settling time T_S=12.6sec.

From figure(4.1) It is clear that after tuning with Ziegler-Nichols method the response of the system get stable after 12.6 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.

V. 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 5.1

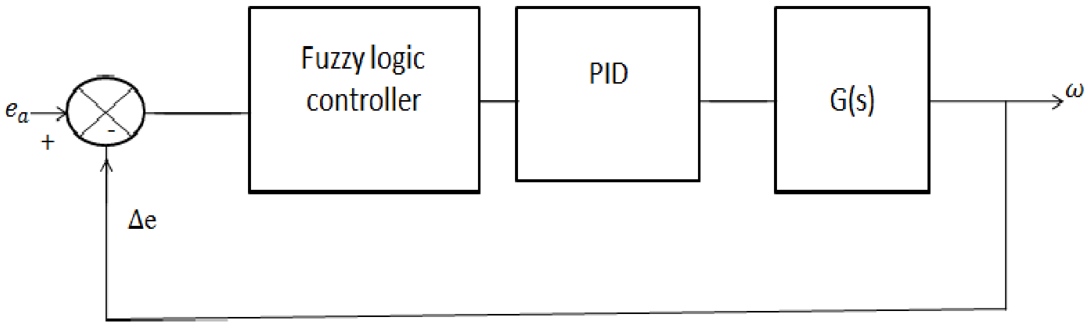

Figure 5.1:Block diagram of System with FLPID

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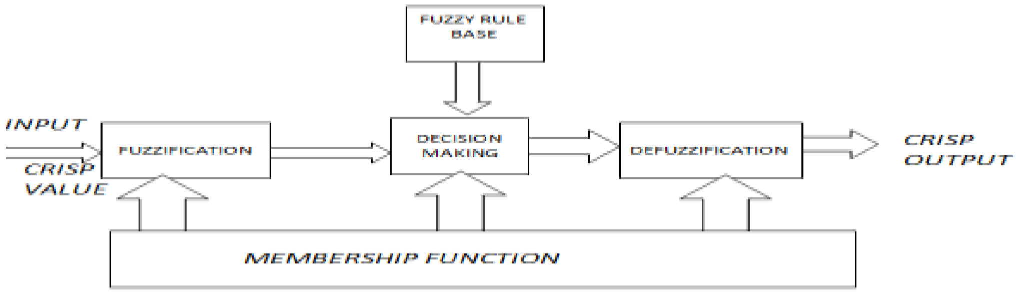

Figure 5.2: Block diagram of Fuzzy inference unit(FIU)

Figure 5.2 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.

5.1 FUZZIFICATION:-

Fuzzification is the first step in the fuzzy inference process. This involves a domain transformation where crisp inputs are transformed into fuzzy inputs. Crisp inputs are exact inputs measured by sensors and passed into the control system for processing, Each crisp input that is to be processed by the FIU has its own group of membership functions or sets to which they are transformed. This group of membership functions exists within a universe of discourse that holds all relevant values that the crisp input can possess. The following shows the structure of membership functions within a universe of discourse for a crisp input. Each universe of discourse is divided into five overlapping 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

Fuzzy logic algorithm:
Table 5.1a

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 5.1b : 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 5.1c: 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 5.1d: 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 5.3, Figure 5.4, and Figure5.5.

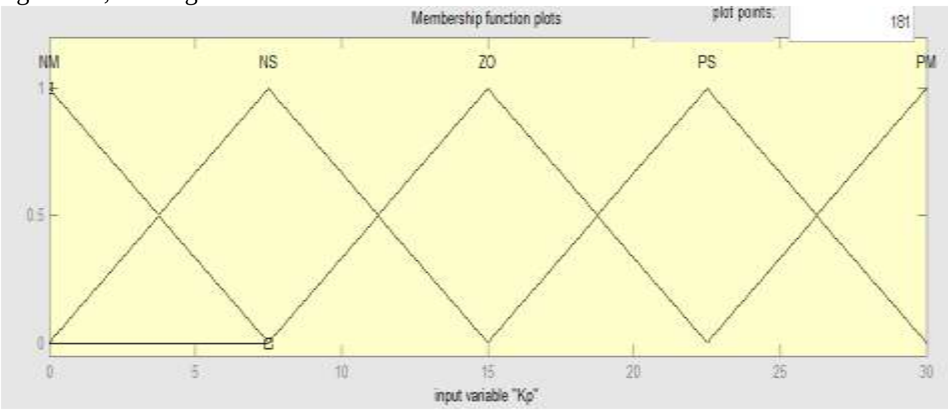

Figure 5.3 Membership Function plots for input Kp.

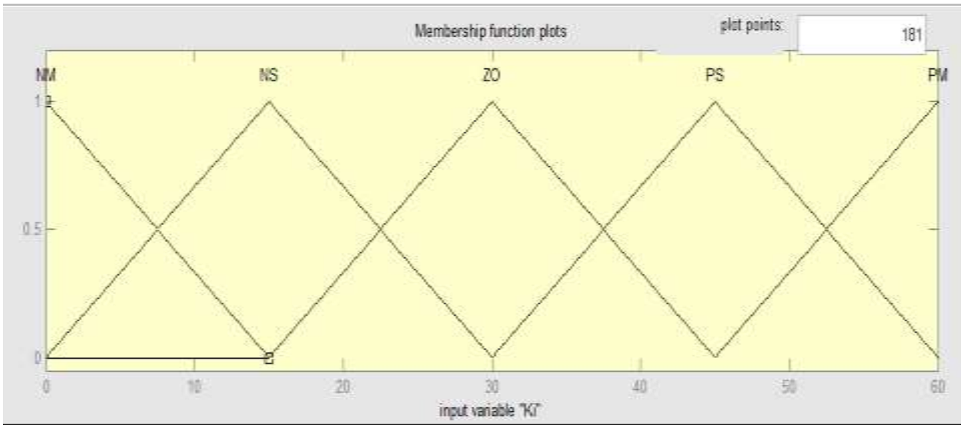

Figure 5.4 Membership Function plots for input Ki

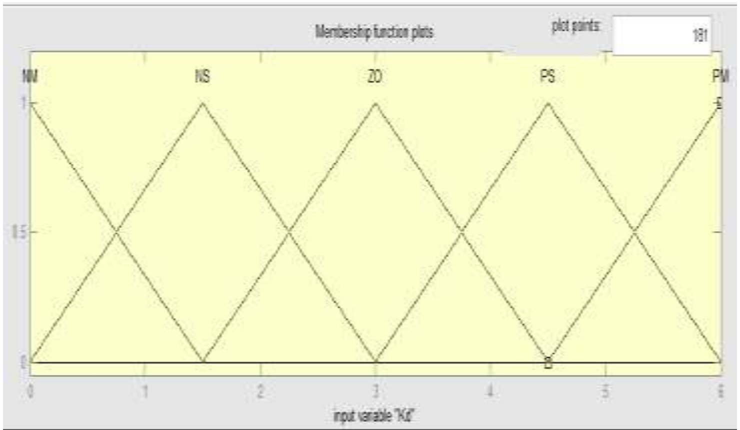

Figure 5.5 Membership Function plots for input K_d

5.2 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 5.6 If then rule is fed in Mamdani block shown in white color in FIS editor after defining 20 rules (figure 5.7) the graph of the rule is observed in figure 5.8 and figure 5.9(3D graph) show the K_p K_i and K_d relationship for fuzzy controller and Figure 5.10 Membership Function plots for output PID controller.

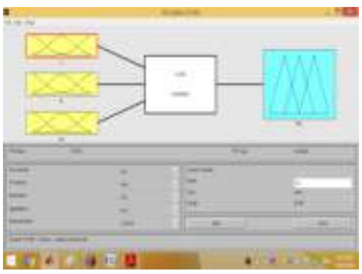

Figure 5.6 FIS Editor for FLPID.

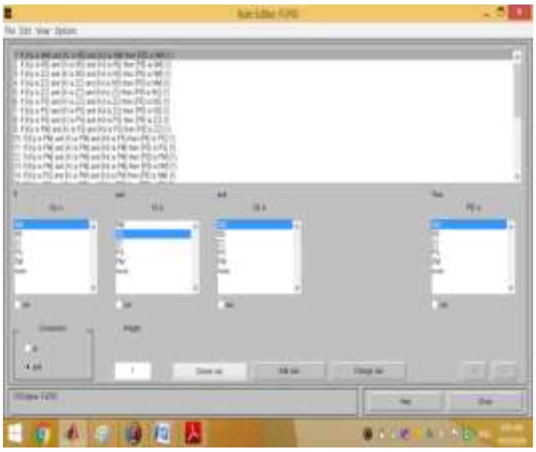

Figure 5.7 Rule editor for FLPID

Figure 5.8 Rule Viewer for Fuzzy Logic PID controller

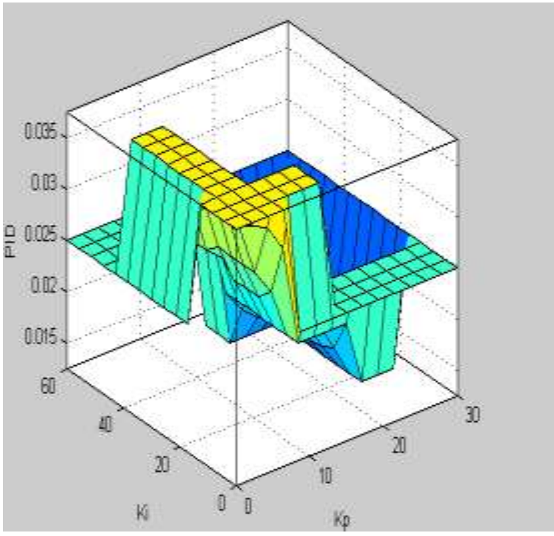

Figure:5.9 K_p K_i and K_d relationship for fuzzy controller.

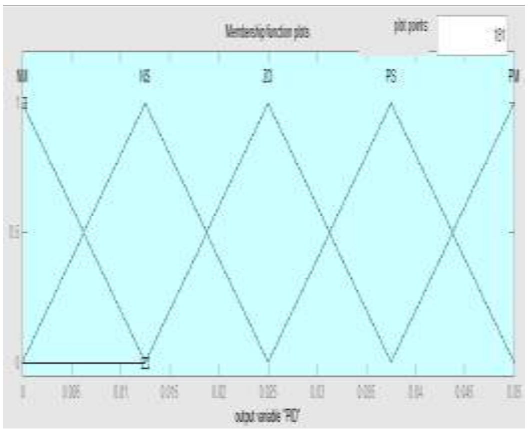

Figure 5.10 Membership Function plots for output PID controller

5.3 DEFUZZIFICATION:-

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

(1)Mean of maximum (MOM) Technique
(2)Center of gravity (COG) Technique
(3) Bisector of area (BOA) Technique
(4)Smallest of maximum (SOM) Technique

5.4 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.

VI. SIMULINK IMPLEMENTATION GAIN INTEGRATAR

In this section the **FLPDI** model is design by using MATLAB as shown in figure 6.1. 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 6.1

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

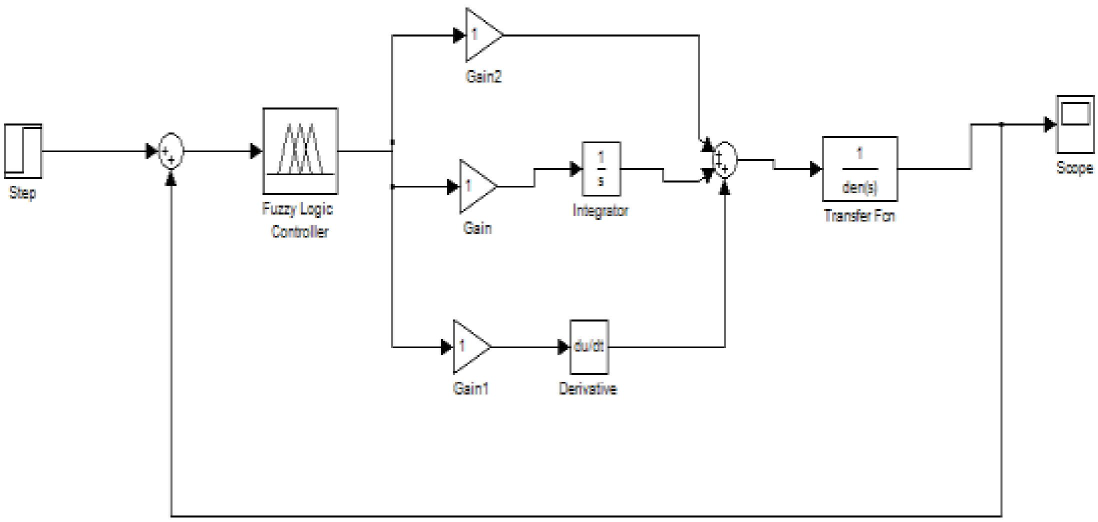

Figure 6.1 FLPID control system

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

VII. CONCLUSION

In this paper Fuzzy logic technique proposed for turning the PID controller to get good performance .The result obtained with Fuzzy logic control is compare with the PID controller tuned with FLPIC and controller has been modeled and stimulated in Matlab/Simulink. The problem of PID controller tuned with Ziegler – Nicholas method was short out. The gain of FLPID Figure 7.1 shows the is better than that of the Figure(4.1) so this technique help in improvement of response.

Figure7.1 output of the scope

Table 7.1a SIMULATION RESULT OF THE FLPID CONTROLLER

Several parameter rise time peak time, delay time, setting time Maximum overshoot are compare with the Ziegler – Nicholas method (classic method) and FLPID The result obtained from simulations demonstrate the improved performance .

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