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Performance Comparison of Conventional and Fuzzy Logic Controller on DC Motor

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Abstract: Fuzzy logic systems have recently been utilized in many control processes due to their ability to model uncertainty. This paper presents the design of a fuzzy control system to control the position of a DC motor. The motor was modeled and converted to a subsystem in Simulink. The entire system has been modeled using MATLAB R2014a Simulink toolbox. The fuzzy control was also designed using the Fuzzy Control Toolbox provided within MATLAB, with each rule consisting of fuzzy sets conditioned to provide appropriate response times with regards to the limitations of the desired motor. First, Proportional-integral-derivative (PID) controller was designed and tuned using a Simulink block instead of conventional tuning methods such as hand-tuning or Ziegler-Nichols frequency response method. Then, the Fuzzy Logic Controller (FLC) was designed. The performance of the proposed system is compared with that of its corresponding conventional Proportional-integral-derivative (PID) controller in terms of several performance measures such as rise time (r_p), peak overshoot(M_p) , settling time(t_s) and steady state error(e_{ss}) and in each case , the proposed scheme shows improved performance over its conventional counterpart.

Keywords: DC Motor, Fuzzy logic, PID, speed control.

I. INTRODUCTION

The use of DC shunt motors has increased tremendously since the day of its invention. They are being used in various industrial processes, robotics, house appliances and other similar applications. The reason for its day by day increasing popularity can be primarily attributed to its robust construction, simplicity in design and cost effectiveness. These have also proved to be more reliable. Apart from these advantages, they have some unfavourable features like their time varying and non-linear dynamics. Speed control is one of the various application imposed constraints for the choice of a motor. Hence, in the last few years it has been studied by many, and various methods for the same have been developed.

The controller types that are regularly used are: Proportional Integral (PI), Proportional Derivative (PD), Proportional Integral Derivative (PID), Fuzzy Logic Controller (FLC) or a blend between them. The PID controller offers a very efficient solution to numerous control problems in the real world. If PID controllers are tuned properly, they can provide a robust and reliable control. This very feature has made PID controllers exceedingly popular in industrial applications. The only problem associated with use of conventional PI, PD and PID controllers in speed control of DC shunt motor is the complexity in design arising due to the non-linearity of DC Shunt Motor dynamics.

1.1 Advantages Of Fuzzy Logic Controller

- The advantages provided by a FLC are listed below:
- It is simple to design.
- It provides a hint of human intelligence to the controller.
- It is cost effective.
- No mathematical modeling of the system is required.
- Non-linearity of the system can be handled easily.
- System response is fast.
- Reliability of the system is increased.
- High degree of precision is achieved.
- These advantages allow fuzzy controllers can be used in systems where description of the process and identification of the process parameters with precision is highly difficult. Hence, it provides a fuzzy characteristic to the control mechanism.

II. SYSTEM DESIGN

A.DC Motor

The electric motor is a motor that convert electrical energy into mechanical energy. There are two types of motor which are AC motor, and DC motor.

A simple DC motor use electricity and magnetic field for producing torque which rotate the motor.

Permanent magnet DC motor (PMDC) outperforms to AC motor because it provides better speed control on high torque loads and use in wide industrial application.

B. DC Shunt Motor

In shunt machine, the field circuit is connected in parallel with the armature circuit.

So current is independent of one another between armature and field coils. This motor provides excellent speed control.

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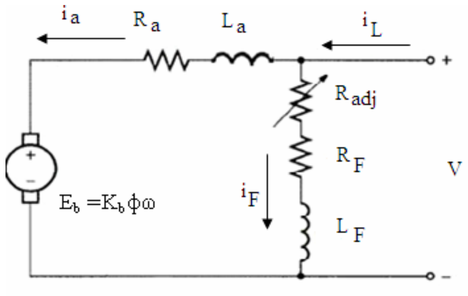

Figure 1: Equivalent Circuit of DC Shunt Motor

C. Speed Control Method of DC Motor. The speed of the DC motor is given by

$$N = \frac{V - I_a R_a}{z\varphi} . \left(\frac{A}{P}\right) = k.\left(\frac{V - I_a R_a}{\varphi}\right)$$

The speed of DC motor can be varied by controlling the field flux, the armature resistance or the terminal voltage that applied to the armature circuit (armature voltage). The three most common speed control methods are field resistance control, armature voltage control, and armature resistance control.

1. Field Resistance Control Method
In the field resistance control method, a series resistance is inserted in the shunt-field circuit of the motor in order to change the flux by controlling the field current. It is theoretically expected that an increase in the field resistance will result in an increase in the load speed of the motor and in the slope of torque speed curve.

2. Armature Voltage Control Method
In the armature voltage control method, the voltage applied to the armature circuit, is varied without changing the voltage applied to the field circuit of the motor. Therefore, the motor must be separately excited to use armature voltage control. When the armature voltage is increased, the no-load speed of the motor increases while the slope of torque speed curve remains unchanged since the flux is kept constant.

3. Armature Resistance Control Method
The armature resistance control is the less commonly used method for speed control in which an external resistance is inserted in series with the armature circuit. An increase in the armature resistance results in a significant increase in the slope of the torque speed characteristic of the motor while the no-load speed remains constant.

D.Speed Regulations As A Means Of Controlling A Process.
Let us consider the process of driving to work. Driving at the highest possible speed would probably cause an accident. And driving at a single speed that will be safe for every portion of the route will take long to reach to the destination. Hence adjusting the speed which goes well with the route minimizes the time to accomplish the objective of the process within limits of reliable operation. The process control benefits that may be provided by an adjustable speed drive are as follows:

- Smoother operation.
- Acceleration control as an added incentive.
- Varying operating speed for each process.

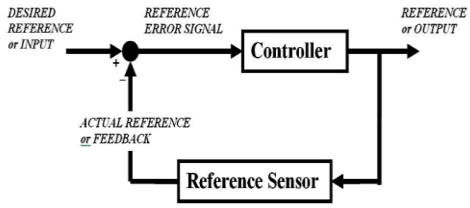

Figure 2: Concept of the Feedback Loop to Control the Dynamic Behaviour of the Reference

- Compensates for fluctuating process parameters.
- Permits slow operation for setup purpose.
- Allows accurate positioning.
- Provides torque control.

E.PID Controller
Although the modern control technique has taken considerable attention during the last several years, PID controllers are still one of the best known controllers used in many industrial processes. Their important and impressive properties such as fast and efficient control action, simple but functional structure, ease of application and robust performance are among the reasons for their preferences.

- During the design phase of PID controllers, there is a crucial and challenging task, in that, three controller parameter Kp, Ki and Kd which have a significant controller.

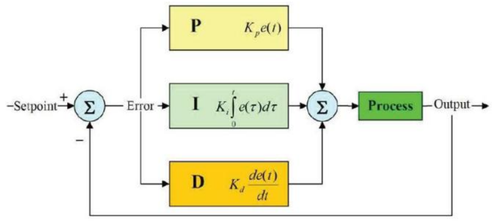

Figure 3: PID Controller

The PID controller calculation involves three separate parameters; the proportional, the integral and the derivative values. The proportional, success, should be determined properly. Practically, this determination or say 'tuning process' is performed by an experienced operator based on trial and error method through the some practical rules. It is apparent that this method is time consuming and accordingly needs for relatively more time. Besides, once tuned, the controller performance may later deteriorate because of nonlinear or time varying characteristics of the process under control. In others word, a PID controller with fixed parameter set cannot provide a moderate performance over wide a range of operating condition. A proportional- integral- derivative controller (PID Controller) widely used in industrial control system. A PID controller attempts to correct the error between a measured process variable and a desired set point.

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Integral and derivative term is given by:

$$P = K_p.\ e(t)$$
$$I = K_i \int_0^t e(\tau)\, d\tau$$
$$D = K_d \frac{de(t)}{dt}$$

Therefore,

$$PID = K_p.\ e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de(t)}{dt}$$

1. Proportional Gain (K_p)
Larger values typically mean faster response since the larger the error, the larger the Proportional term compensation. An excessively large Proportional gain will lead to process instability and oscillation.

2. Integral Gain (K_i)
Larger values imply steady state errors are eliminated more quickly. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before we reach steady state.

3. Derivative Gain (K_d)
Larger values decrease overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

F.Fuzzy Logic Controller
Fuzzy logic is a type of multi valued logic. It deals with approximate reasoning rather than precise. Fuzzy logic derived from fuzzy set theory. Fuzzy logic was first proposed by Lotfi Zadeh in 1965. Fuzzy controller is an innovative technology that modifies the design of systems with engineering expertise. Fuzzy logic use human knowledge to implement a system. It is mostly use in system where there are no mathematical equations for handling system. Common sense, human thinking and judgment are fuzzy rules. It helps engineers to solve non linear control problems. It mathematically emulates human knowledge for intelligent control system and complex application. Today, fuzzy logic are found in a variety of control applications like chemical process control, manufacturing and in such consumer products as washing machines, video cameras and automobiles.

The conventional Boolean logic has been extended to deal with the concept of partial truth – truth values which exist between "completely true" and "completely false", and what we shall be referring to as fuzzy logic. This is achieved through the concept of degree of membership. The essence of fuzzy logic rests on a set of linguistic if-then rules, like a human operator. It has met a growing interest in many motor control applications due to its non-linearity handling features and independence of plant modelling. Moreover, the fuzzy logic concepts play a vital role in developing controllers for the plant since it isn't needy of the much complicated hardware and all it necessitates are only some set of rules.

There are two famous type of system currently used in fuzzy logic which are Mamdani fuzzy inference, and Sugeno fuzzy inference. Mamdani model is preferred here because it follows the Compositional Rule of Inference strictly in its fuzzy reasoning mechanism.

G.Mamdani Fuzzy Inference
The mamdani system usually done in four steps. The steps are fuzzification of the inputs, rule evaluation, aggregation of the rules, and defuzzification. Fuzzifications convert input data to degree of membership functions. In this process data is matched with condition of the rule and determined how well data is matched with rule at particular instance. Thus a degree of membership function is developed.

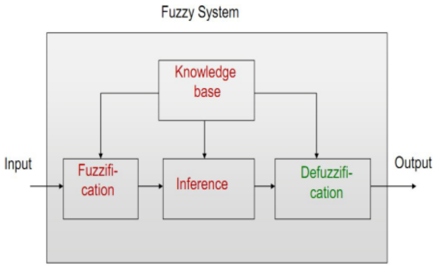

Figure 4: Fuzzy Mamdani inference system

Fuzzifications convert input data to degree of membership functions. In this process data is matched with condition of the rule and determined how well data is matched with rule at particular instance. Thus a degree of membership function is developed.

H. Methodologies
1. DC Motor Modelling

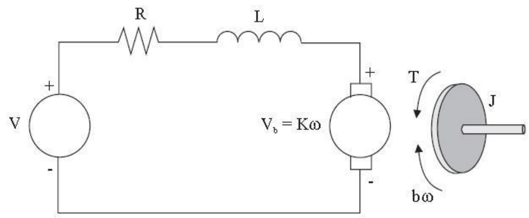

Figure 5: Schematic representation of the considered DC motor

The rotor and the shaft are assumed to be rigid. The following values for the physical parameters of DC motor have been used in this project:

Armature resistance (Ra) = 1.33 Ω
Armature inductance (La) = 0.2218 H
Damping friction of the mechanical system (Kb) = 1.5 Nms
Back electromotive force constant (Ke) = 1.25 Nm/A
Moment of inertia of the rotor (J) = 0.123 $kg.m^2$

2.DC Motor System Equation
The motor torque, T, is related to the armature current, i, by a constant factor K:

$$T = Ki \qquad (4.1)$$

The back electromotive force (emf), Vb, is related to the angular velocity by:

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$$Vb = K\omega = K\frac{d\theta}{dt} \quad (4.2)$$

From Figure 4.1, the following equations based on the Newton's Law combined with the Kirchhoff's Law can be written as:

$$J\frac{d2\theta}{dt2} + b\frac{d\theta}{dt} = Ki \quad (4.3)$$

$$L\frac{di}{dt} + Ri = V - K\frac{d\theta}{dt} \quad (4.4)$$

Using the Laplace transform, equations (4.3) and (4.4) can be written as:

$$JS^2\theta(S) + bS\theta(s) = K\, I(s) \quad (4.5)$$

$$LS\, I(S) + R\, I(S) = V(S) - KS\theta(S) \quad (4.6)$$

Where (s) denotes the Laplace operator. From (4.6) we can express I(s):

$$I(S) = \frac{V(S) - KS\theta(S)}{R+LS} \quad (4.7)$$

And substitute it in (4.5) to obtain:

$$JS^2\theta(S) + bS\theta(s) = K\frac{V(S) - KS\theta(S)}{R+LS} \quad (4.8)$$

This equation for the DC motor is shown in the block diagram in Figure 4.2.

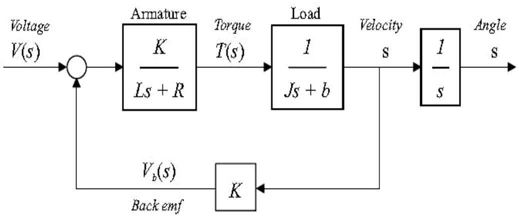

Figure 6: DC motor block diagram

From equation (4.8), the transfer function from the input voltage, V (s), to the output angle, θ, directly follows:

$$Ga(S) = \frac{\theta(S)}{V(S)} = \frac{K}{S(R+LS)(JS+b)+K2} \quad (4.9)$$

From the block diagram in Figure 3-3, it is easy to see that the transfer function from the input voltage, V (s), to the angular velocity, , is:

$$Gv(S) = \frac{\omega(S)}{V(S)} = \frac{K}{(R+LS)(JS+b)+K2} \quad (4.10)$$

Figure 4.3 below show the DC motor modelling system have been used in this project.

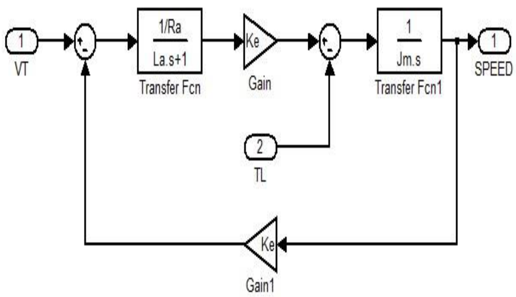

Figure 7: DC motor modelling

III. EXPERIMENTAL APPROACH

The present experimentations have been carried out using an experimental set-up which includes number of apparatus such as DC shunt motor, two variable resistors, one DC ammeter, one DC voltmeter, tachometer etc. Table 1 shows the list of instruments used with their detailed specifications. In Figure 4.4, the schematic representation of the detailed connections of the instruments is shown. The photographic view of the set-up with various instruments connected with the DC shunt motor is shown in Figure 4.5. It is evident that the rotating speed of a DC shunt motor depends on armature voltage and field current applied to the shunt motor. Therefore, in the present experiments, these two process parameters were varied keeping other parameter as constant.

Name of instrument	Specifications
DC shunt motor	Type: DC 112.178.302 Volt: 220 V, Amp.: 12 A HP: 3.0, RPM: 1500
Variable Rheostat (Vh) Vh 1 Vh 2	360 Ω, 1.1 Amp 50 Ω, 3.3 Amp
Ammeter	0 – 1 Amp
Voltmeter	0 – 300 V
Tachometer	Range: 0-2000 RPM

Table -1 Details of instruments used during experiments

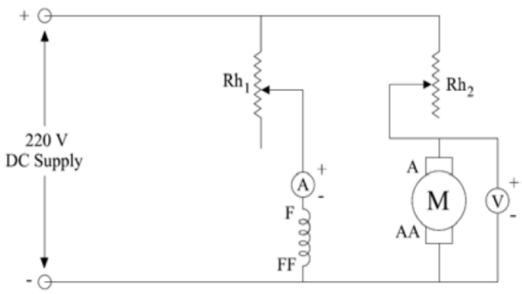

Figure 8: schematic diagrams of connections for the instruments used during experiment

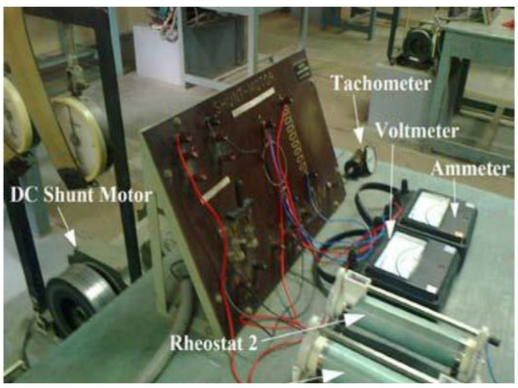

Figure 9: Photographic view of the experimental set-up with various instruments connected

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Two methods of experiment were performed in the laboratory and the values so obtained were noted down.

METHOD-1: Armature control method

I_a (Amp)	V_a (volt)	N (rpm)	$\Omega = \frac{2\pi n}{60}$ (rad/sec)	$E_b = V_a - I_aR_a$
1.5	220	1500	157	218
1.4	210	1432	149.88	208.14
1.4	200	1356	141.9	198.14
1.35	190	1300	136.06	188.21
1.35	180	1230	128.74	178.21
1.3	170	1155	120.89	168.27
1.3	160	1086	113.67	158.27

Table -2 Determination of Back EMF

V_a (volt)	I_a (Amp)	R_a (Ω)
2.6	2.0	1.300
5.2	3.9	1.330
10	7.4	1.350
11	8.3	1.325
12.2	9.1	1.340
	R_a =	**1.33 Ω**

Table-3 Determination of R_a

V_a (volt)	I_a (Amp)	Z_a (Ω)
15	2	7.5
26	3	8.67
34	4	8.5
44	5	8.8
52	6	8.67
60	7	8.57
	Z_a =	**8.45 Ω**

Table-4 Determination of Z_a

1. Modelling of Armature control DC Shunt Motor According to KVL,

$$V_a = I_a R_a + L_a\frac{dIa}{dt} + e_b \qquad (4.11)$$

On taking Laplace transform,

$$I_a(S)\,[R_a + SL_a] + E_b(S) = V_a(S) \qquad (4.12)$$

The differential equation,

$$J\frac{d2\theta}{dt2} + B\frac{d\theta}{dt} = T(S) \qquad (4.13)$$

On taking Laplace transform,

$$E_b(t) = K_b\, S\theta(S) \qquad (4.14)$$

$$I_a(S) = \frac{(JS2+BS)\theta(S)}{Kt} \qquad (4.15)$$

$$\frac{\theta(S)}{Va(S)} = \frac{Kt}{(JS2+BS)(Ra+SLa)+KtKbS} \qquad (4.16)$$

On substituting the values, the transfer function of Armature control DC shunt motor is given by,

$$\frac{\theta(S)}{Va(S)} = \frac{1.5}{S[S2+14.25+132.6]} \qquad (4.17)$$

METHOD-2 Field control method

I_F (Amp)	N (rpm)	$\omega = \frac{2\pi n}{60}$ rad/sec
0.68	1500	157
0.7	1484	155.3
0.8	1386	145.07
0.85	1338	140.04
0.9	1308	136.9
0.95	1278	133.76
1	1246	130.41
1.1	1208	126.44

Table-5 Current-speed relation

V_F(volt)	I_F (Amp)	R_F (Ω)
96	0.56	171.4
134	0.78	171.8
154	0.88	175
168	0.96	175
182	1.04	175
	R_F =	**173.6 Ω**

Table-6 Determination of R_F

V_F(volt)	I_F (Milli Amp)	Z_F (Ω)
50	10	5
90	20	4.5
120	25	4.8
155	30	5.17
185	35	5.29
200	40	5.5
	Z_F =	**5.04KΩ**

Table-7 Determination of Z_F

2. Modeling of Field control DC Shunt Motor According to KVL,

$$R_F\, I_F(t) + L_F\frac{dIF}{dt} = V_F(t) \qquad (4.18)$$

On taking Laplace transform,

$$I_F(S)\,[R_F + SL_F] = V_F(S) \qquad (4.19)$$

$$T(t) = K_F\, I_F(t) \qquad (4.20)$$

Differential equation governing mechanical system of motor is given by,

$$J\frac{d2\theta}{dt2} + B\frac{d\theta}{dt} = T(t) \qquad (4.21)$$

On taking Laplace transform,

$$(JS^2 + BS)\,\theta(S) = T(S) \qquad (4.22)$$

$$\frac{\theta(S)}{VF(S)} = \frac{Km}{S(1+S\tau m)(1+S\tau f)} \qquad (4.23)$$

On substituting the values, the transfer function of Field control DC shunt motor is given by,

$$\frac{\theta(S)}{VF(S)} = \frac{0.96}{S(S2+11.96S+9.35)} \quad (4.24)$$

J PID Controller Design

PID (proportional integral derivative) control is one of the earlier control strategies. Its early implementation was in pneumatic devices, followed by vacuum and solid state analog electronics, before arriving at today's digital implementation of microprocessors. It has a simple control structure which was understood by plant operators and which they found relatively easy to tune. It is a generic control loop feedback mechanism and used as feedback controller. PID working principal is that it calculates an error value from the processed measured value and the desired reference point. The work of controller is to minimize the error by changing in the inputs of the system. If the system or plant is not clearly known then applying PID controller provide the best results if it is tuned properly by keeping parameters of the system according to the nature of system.

The PID measurement depends upon three parameters which are called proportional (P), the integral (I) and derivative (D) part. For the P part, it determines the reaction to current error. I part determines reaction to the sum of recently appeared errors. Then D determines the reaction according to the rate of error changing. As derivative action is sensitive to noise so mostly the controller are PI controller rather than PID as it is not possible a system without the disturbances. Integral part helps the system to reach onto its target value while P part is increase overshoot.

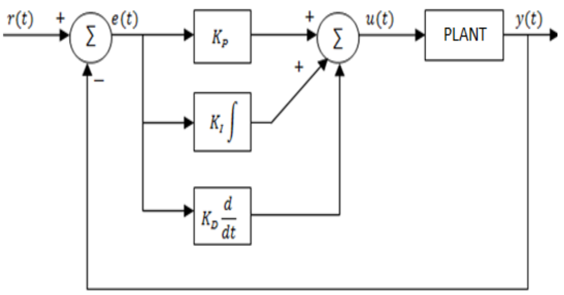

Figure 10: PID Controller Design

K.PID Tuning Method

A PID may have to be tuned when

- Consideration should not be given to the units of gains and other parameters.
- The process dynamics were not Well-understood when the gains or the dynamics have changed.
- Some characteristics of the control system are direction-dependent
- The operator should think the controllers can perform better.
- The aim of the controller tuning is to obtain
- Fast responses
- Good stability
- The two most commonly used tuning methods are,
- Trial and Error method
- Ziegler Nichols method

1. Trial and Error Method

This process is time consuming process. Though much iteration is performed the final result will not be satisfactory. A balance is not obtained between the rise time and % overshoot even though a lot of possible combinations of the gains are incorporated. Continuous cycling may be objectionable because the process may reach to the stability limit.

2. Ziegler Nichols method

Ziegler Nichols formula gives good load disturbance attenuation, but it generally provides a poor phase margin and therefore it produces a large overshoot and settling time in the step-response. The Ziegler-Nichols rule is a heuristic PID tuning rule that attempts to produce good values for the three PID gain parameters:

- Kp - the controller path gain
- Ti - the controller's integrator time constant
- Td - the controller's derivative time constant

Ziegler Nichols Stability Margin			
Controller	**K_p**	**K_i**	**K_d**
P	0.5 K	0	0
PI	0.45 K	1.2 f_o	0
PID	0.6 K	2 f_o	0.125/f_o

Table-8 Calculation of PID Parameters based on Ziegler Nichols Stability Margin

Tuning Method

L. Simulation And Results

1. PI Block

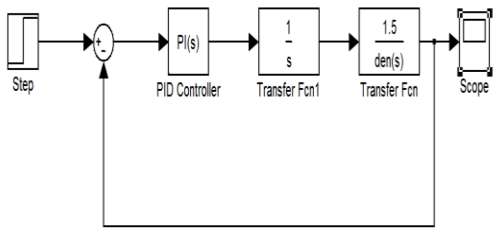

Figure 11: PI Block Diagram

2.Block and Tuned Response

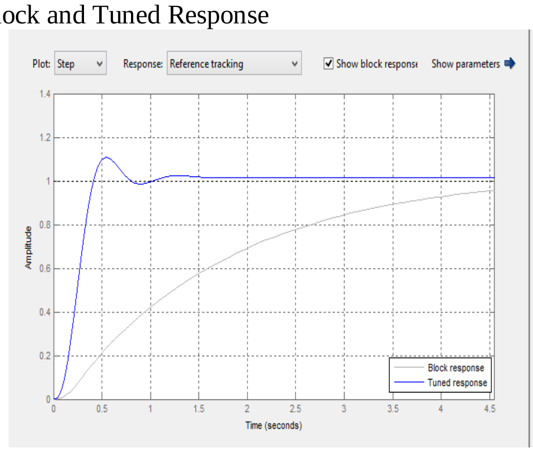

Figure 12: PI Block and Tuned Response

M.PD Block

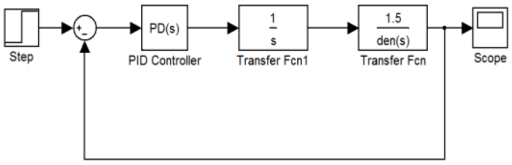

Figure13: PD block diagram

1.Block and Tuned Response

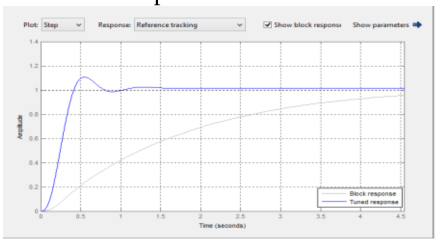

Figure 14: PD block and tuned response

N.PID Block

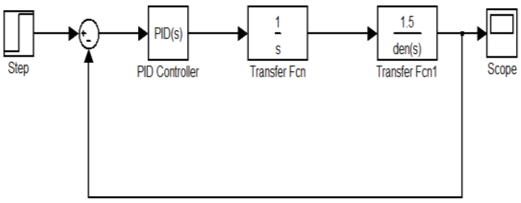

Figure 15: PID block diagram

1. Block and Tuned Response

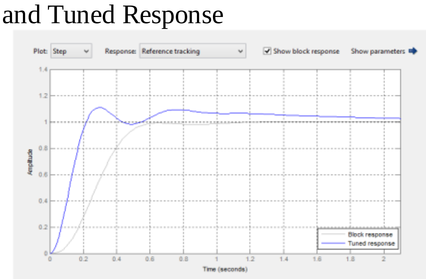

Figure 16: PID block and tuned response

0. Fuzzy Logic Controller

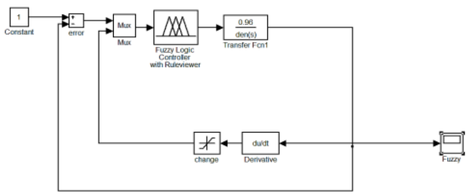

Figure 17: Block diagram of FLC

1. BLOCK RESPONSE

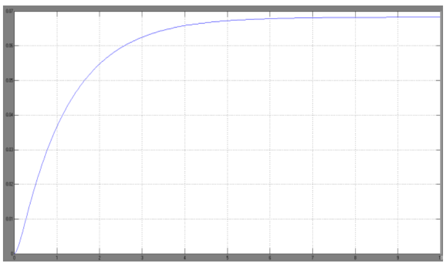

Figure 18: FLC block response

P.COMPARISON

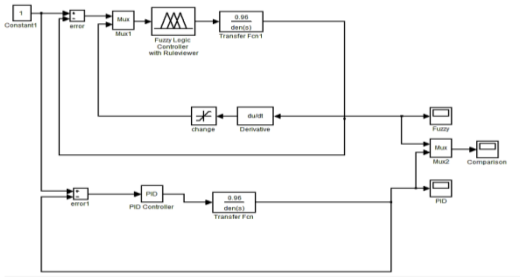

Figure 19: FLC and PID block diagram

1. RESPONSE CURVE

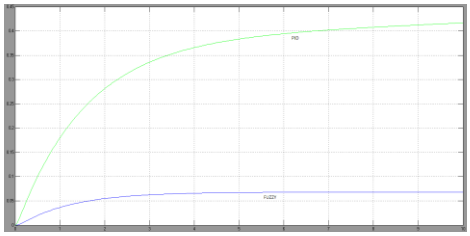

Figure 20: Comparison of responses between Fuzzy and PID

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