Comparitive Analysis of P-I, I-P, PID and Fuzzy Controllers for Speed Control of DC Motor

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Abstract – *In this paper, speed of DC motor is controlled by using Proportional Integral(P-I), Integral Proportional(I-P), Proportional Integral derivative(PID) controllers and fuzzy logic controller(FLC). Ziegler-Nichols method is used to design P-I, I-P and PID controllers. Fuzzy logic controller is designed by 49 fuzzy rules set with two inputs speed error and change in speed error and one output. These controllers are developed with the help of MATLAB/SIMULINK.*

Key Words: P-I controller, I-P controller, PID controller, Fuzzy logic controller, Ziegler-Nichols method, DC motor.

1.INTRODUCTION

DC motors are highly used in industries over AC motors because of it's excellent speed characteristics. Many techniques are there for speed control of DC motor. Some of them are,

1. Armature voltage control
2. Field control

Controllers are designed for closed loop systems for better results. Here P-I, I-P, PID controllers are designed by using Ziegler-Nichols tuning method. The main difference between P-I and I-P controllers is that in P-I controller proportional gain is in feed forward path where as in I-P controller the proportional gain is in feedback path.

PID controllers are highly used controllers in industries because of their high performance over P-I and I-P controllers. There are many techniques to design PID controllers. Ziegler-Nichols method is a basic and simple method.

Fuzzy logic controller mainly consists of rule base, fuzzification, defuzzification processes. FLC contains two inputs error, derivative error and one output. We can set the number of rules and membership functions according to our requirements. The main disadvantage of the P-I controller is that it has high overshoot. Which is undesirable in speed control of DC motor? This is somewhat reduced in I-P controller. But it doesn't eliminate the overshoot completely. Hence we go to PID controller, which eliminates the overshoot, but settling time for this controller is a little high.

The fuzzy controller eliminates the overshoot completely and the settling time is very much less when compare with PID controller.

2. MATHEMATICAL MODELLING

We consider a seperately excited DC motor as shown in the below figure.

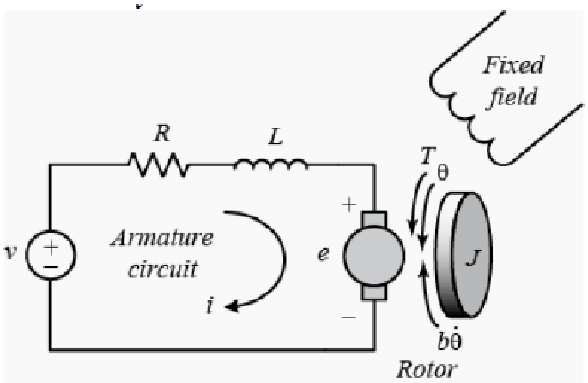

fig-1: separately excited DC motor

From fig-(1) by applying KVL we can get the armature loop equation as

$$V(t) = IR + L\frac{dI}{dt} + E \qquad (1)$$

Here V = applied voltage
I = armature current
E = back emf
L = armature inductance
R = armature resistance

We have,

$$E = K_b w(t) = K_b \frac{d\theta}{dt} \qquad (2)$$

Here K_b = emf constant
θ = angular displacement
w = angular speed

From equ.(1) and (2), we get

$$V(t) = IR + L\frac{dI}{dt} + K_b w(t) \quad (3)$$

For normal operation, the torque equation is given by

$$T = J\frac{dw}{dt} + Bw(t) + T_L \quad (4)$$

Here

T = motor torque
T_L =load torque
J = rotor inertia
B = friction coefficient

We have, $T = K_t I$ and substitute T_L =0 in equ(4)

$$J\frac{dw}{dt} + Bw(t) = K_t I \quad (5)$$

Laplace transforms for equ.(3) and (5) gives,

$$V(s) = R.I(s) + L.S.I(s) + K_b.W(s) \quad (6)$$

$$K_t.I(s) = J.S.W(s) + B.W(s) \quad (7)$$

From equ.(6) and (7) we can get the transfer function of DC motor as,

$$\frac{W(s)}{V(s)} = \frac{K_t}{(SL+R)(JS+B)+K_t.K_b} \quad (8)$$

And we have,

$$\theta(s) = \frac{1}{S}.W(s) \quad (9)$$

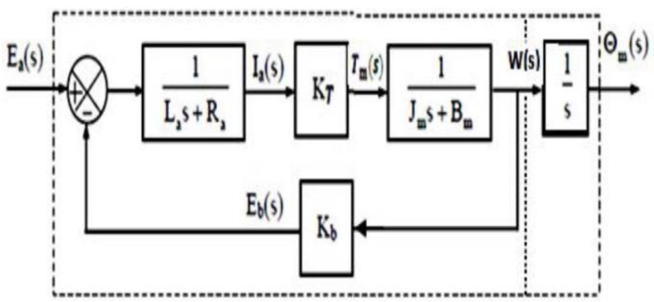

Fig -2: Block diagram of DC motor

Table-(1): parameters of DC motor

Parameter	Value
Armature resistance(R)	0.6Ω
Armature inductance(L)	0.012H
Emf constant(K_b)	0.55(volt/(rad/sec))
Torque constant(K_t)	0.55(N-m/ampere)
Moment of inertia(J)	0.0465 (kg-m^2/rad)
Friction coefficient(B)	0.004 (N-m/(rad/sec))

3. DESIGN OF CONTROLLERS

A) P-I CONTROLLER:

Proportional integral controller contains two componants of proportional gain and integral gain parts. This controller put in feedforward path of closed loop of the system. Proportional gain is to establish the system stability and to improve transient response. Integral part is to reduce the steady state error. By applying Ziegler-Nichols method we can calculate the values of proportional and integral gains.

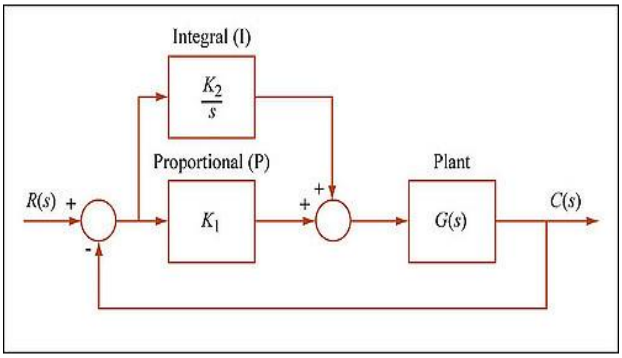

Fig-3: Block diagram of P-I controller

Controller is defined as,

$$G_c(s) = K_p + \frac{K_I}{S}$$

Here

K_p = proportional gain

K_I = integral gain

B) I-P CONTROLLER:

Integral proportional controller is advance form of proportional integral controller. In this controller the integral part is in feedforward path and proportional part is in feedback path. The disadvantage in P-I controller is that high peak overshoot. To reduce that peak overshoot considerably we can use this I-P controller.

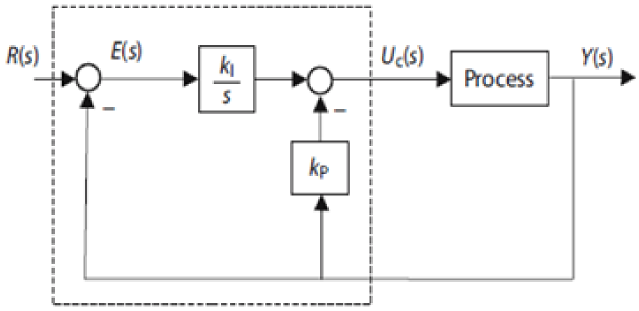

Fig-4: Block diagram of I-P controller

C) PID CONTROLLER:

PID controller is mostly used controller in real time applications. Because of this controller advantages over P-I and I-P controllers. This controller put in feed forward path of the closed loop system as shown in below figure.

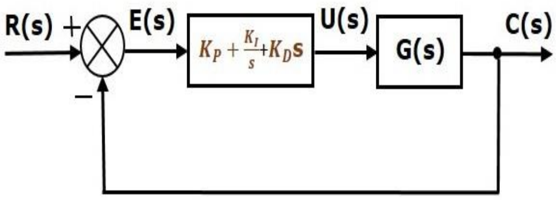

Fig-(5): block diagram of PID controller

PID controller is defined as,

$$G_c(s) = K_p + \frac{K_I}{S} + K_d S$$

$$G_c(s) = K_p(1 + \frac{1}{T_i S} + T_d S)$$

Here

T_i = integral action time

T_d = derivative action time

D) ZIEGLER-NICHOLS TUNING METHOD:

The proper tuning of a controller is necessary to improve the performance of any system. There are many methods for designing these controllers. This method is a simple and best method for design of controllers.

By setting $T_i = \infty$ and $T_d = 0$ and using proportional control gain only, the value of gain is increased from 0 to a critical value(K_{cr})at which the output is exhibiting oscillations(undammed system). At this value of gain, note down the value of period of oscillations(P_{cr}).

Table-(2): controller gain values

Controller type	K_p	T_i	T_d
P	$0.5\ K_{cr}$	∞	0
PI	$0.45\ K_{cr}$	$\frac{P_{cr}}{1.2}$	0
PID	$0.6\ K_{cr}$	$\frac{P_{cr}}{2}$	$\frac{P_{cr}}{8}$

E) FUZZY CONTROLLER:

Fuzzy logic control is a control algorithm based on a linguistic control strstegy, which is derived from expert knowledge into an automatic control strategy. A block diagram for a fuzzy control system is given in below figure.

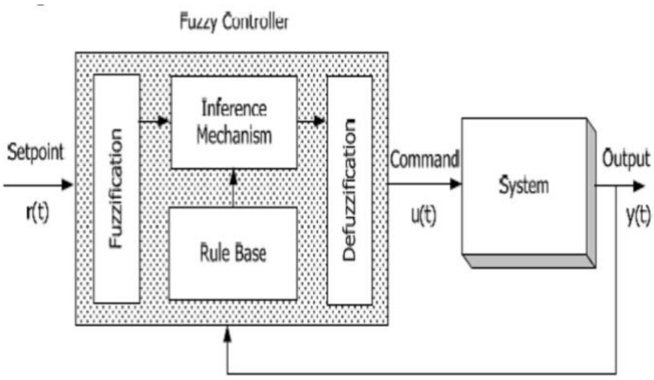

Fig-(6): block diagram of fuzzy controller

This has two inputs speed error and change in speed error and one output. Inputs has seven membership functions each and output also has seven membership functions.

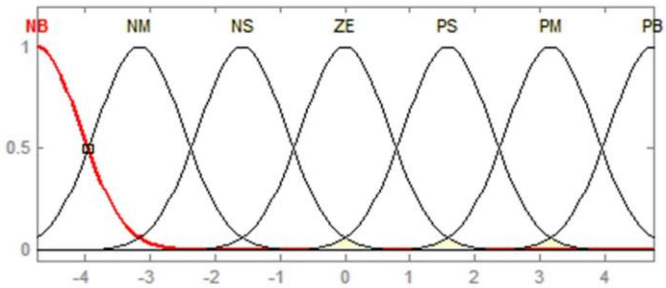

Fig-(7): speed error variable

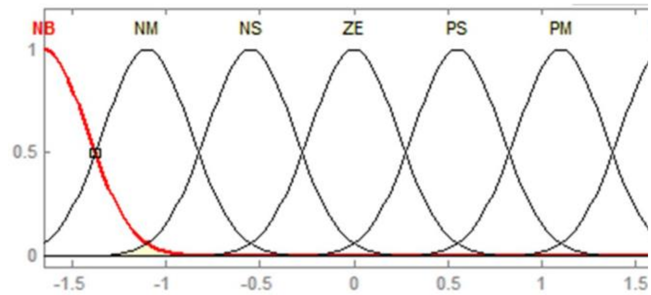

Fig-(8): change in speed error variable

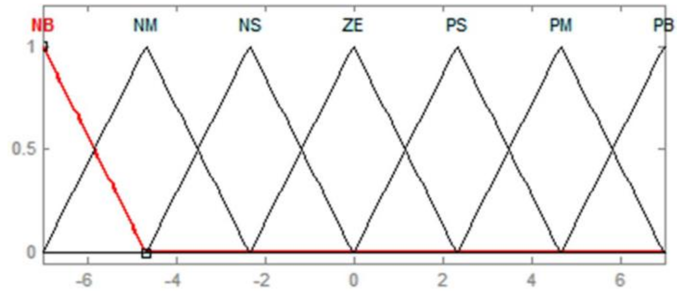

FIG-(9): output variable

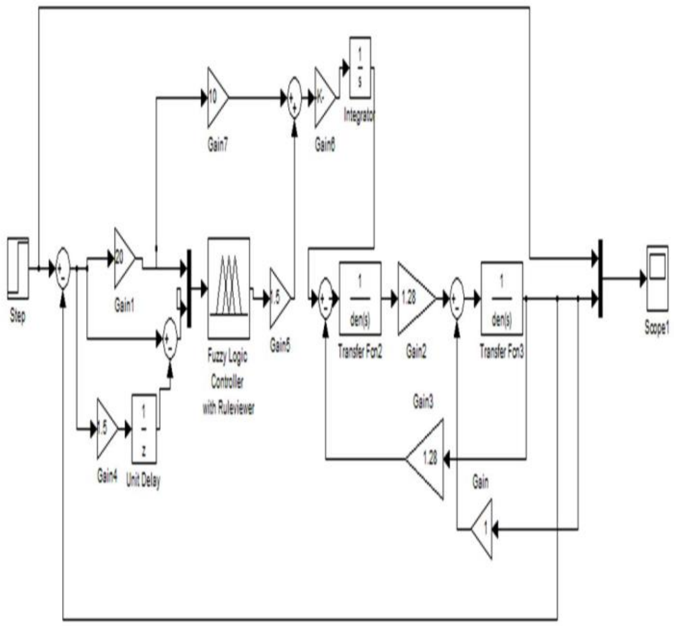

Fig-(10): Simulink model of fuzzy logic controller

There are 49 fuzzy rules in this system. They are defined as,

Table-(3): fuzzy rules

CE E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	MS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Here

NB = negative big
NM = negative medium
NS = negative small
ZE = zero
PS = positive small
PM = positive medium
PB = positive big

4.SIMULATION RESULTS

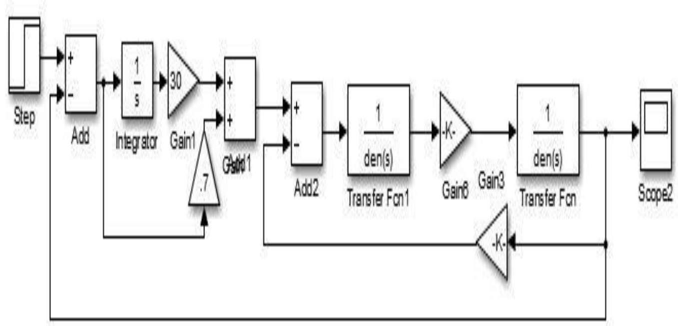

Fig-(11): simulation model for P-I controller

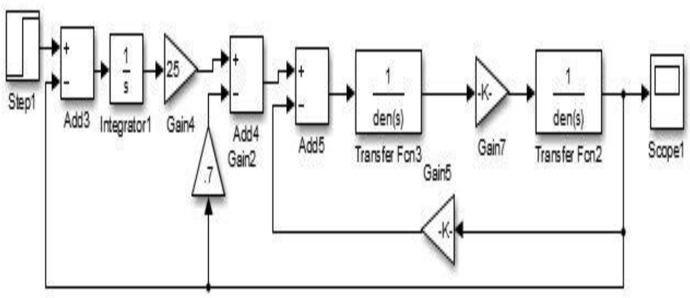

Fig-(12): simulation model for I-P controller

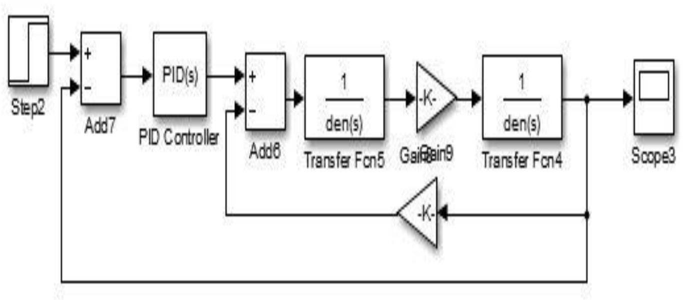

Fig-(13): simulation model for PID controller

The below figure shows the response of the system for different controllers of P-I, I-P, PID and fuzzy.

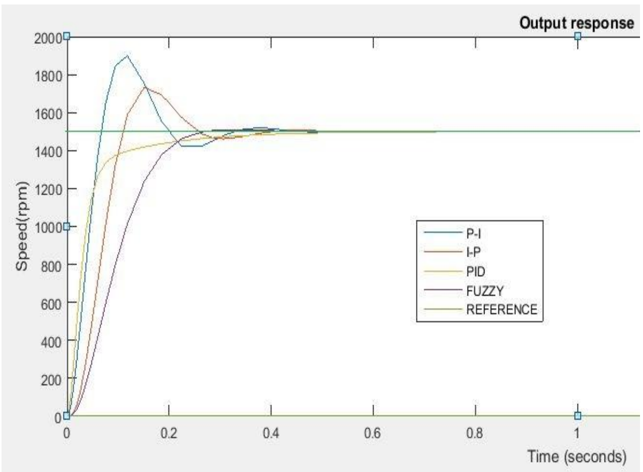

Fig-(14): Speed vs time

Table-(4): comparision of controllers

Controller type	% Overshoot	Settling time(sec)
P-I	26.6	0.6
I-P	16.6	0.55
PID	0	0.45
FUZZY	0	0.25

5. CONCLUSION

P-I controller has high overshoot and high settling time. In I-P controller overshoot is reduced. But still settling time is high. PID controller eliminates overshoot completely, but settling time not considerably reduced. Fuzzy controller completely eliminates overshoot and settling time is also reduced. Hence fuzzy controller performs better among all the controllers.

6. REFERENCES

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