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Performance analysis of Fuzzy logic based speed control of DC motor.

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Abstract: *In this paper we have designed a separately excited DC motor whose speed can be controlled using PID and fuzzy tuned PID controller first, the fuzzy logic controller is designed according to fuzzy rules so that the systems are fundamentally robust. There are 25 fuzzy rules for self-tuning of each parameter of PID controller. The FLC has two inputs. One is the motor speed error second is change in speed error and the output of the FLC i.e. the parameters of PID controller are used to control the speed of the separately excited DC Motor. The fuzzy self-tuning approach implemented on a conventional PID structure was able to improve the dynamic as well as the static response of the system. Comparison between the conventional output and the fuzzy self-tuning output was done on the basis of the simulation result obtained by MATLAB. The simulation results demonstrate that the designed self-tuned PID controller realize a good dynamic behavior of the DC motor, a perfect speed tracking with less rise and settling time, minimum overshoot, minimum steady state error and give better performance compared to conventional PID controller.*
Keywords: *DC motor: Fuzzy tuned PID: Speed control*

I. INTRODUCTION

The speed of DC motors can be adjusted within wide boundaries so that this provides easy controllability and high performance. DC motors used in many applications such as still rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators require speed controllers to perform their tasks. Speed controller of DC motors is carried out by means of voltage control in 1981 firstly by Ward Leonard

The proportional – integral – derivative (PID) controller operates the majority of the control system in the world. It has been reported that more than 95% of the controllers in the industrial process control applications are of PID type as no other controller match the simplicity, clear functionality, applicability and ease of use offered by the PID controller [3], [4]. PID controllers provide robust and reliable performance for most systems if the PID parameters are tuned properly.

The major problems in applying a conventional control algorithm (PI, PD, PID) in a speed controller are the effects of non-linearity in a DC motor. The nonlinear characteristics of a DC motor such as saturation and fiction could degrade the performance of conventional controllers [1], [2].Generally, an accurate nonlinear model of an actual DC motor is difficult to find and parameter obtained from systems identification may be only approximated values. The field of Fuzzy control has been making rapid progress in recent years. Fuzzy logic control (FLC) is one of the most successful applications of fuzzy set theory, introduced by L.A Zadeh in 1973 and applied (Mamdani 1974) in an attempt to control system that are structurally difficult to model.

II. Proposed Algorithm

a. Motor model –

When a separately excited motor is excited by a field current of i_f and an armature current of i_a flows in the circuit, the motor develops a back emf and a torque to balance the load torque at a particular speed.

The i_f is independent of the i_a .Each windings are supplied separately. Any change in the armature current has no effect on the field current. The i_f is normally much less than the i_a.

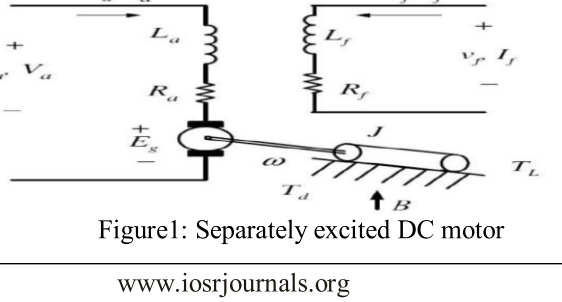

Figure1: Separately excited DC motor

Where
Va is the armature voltage. (In volt)
Eb is back emf the motor (In volt)
Ia is the armature current (In ampere)
Ra is the armature resistance (In ohm)
La is the armature inductance (In Henry)
Tm is the mechanical torque developed (In Nm)
Jm is moment of inertia (In kg/m²)
Bm is friction coefficient of the motor (In Nm/ (rad/sec))
ω is angular velocity (In rad/sec)
The armature voltage equation is given by:

$$Va = Eb + IaRa + La\,(dIa/dt) \text{ -------------------(1)}$$

Now the torque balance equation will be given by:

$$Tm = Jm d\omega/dt + Bm\omega + TL \text{ --------------------(2)}$$

Where: TL is load torque in Nm.
Friction in rotor of motor is very small (can be neglected),so Bm=0
Therefore, new torque balance equation will be given by:

$$Tm = Jm d\omega/dt + TL \text{ ------------------------(3)}$$

Taking field flux as Φ and Back EMF Constant as K. Equation for back emf of motor will be:

$$Eb = K\,\Phi\,\omega \text{ -------------------(4)}$$

Also, $Tm = K\,\Phi\,Ia$-------------------------------------(5)

Taking Laplace transform of the motor's armature voltage equation we get

$$Ia(s) = (Va - K\Phi\omega)/\,Ra\,(1 + LaS/Ra) \text{ ---------------(6)}$$ and

$$\omega(s) = (Tm - TL)\,/JS = (K\Phi Ia - TL)\,/JmS \text{ ------------(7)}$$

(Armature Time Constant) Ta= La/Ra

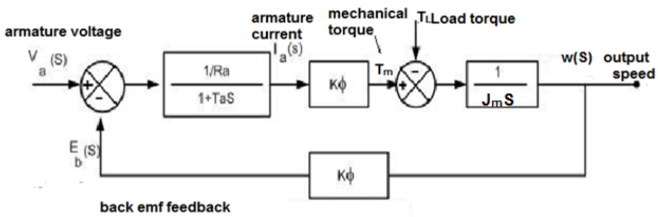

Figure 2: Block Model of Separately Excited DC Motor

TABLE I. DC MOTOR PARAMETERS	
Parameters	**Value**
Armature resistance (Ra)	0.5Ω
Armature inductance (La)	0.02 H
Armature voltage (Va)	200 V
Mechanical inertia (jm)	0.1 Kg.m2
Friction coefficient (Bm)	0.008 N.m/rad/sec
Back emf constant (k)	1.25 V/rad/sec
Rated speed	1500r.p.m

III. FUZZY LOGIC CONTROLLER

The fuzzy logic foundation is based on the simulation of people's opinions and perceptions to control any system. One of the methods to simplify complex systems is to tolerate to imprecision, vagueness and uncertainty up to some extent [10]. An expert operator develops flexible control mechanism using words like "suitable, not very suitable, high, little high, much and far too much that are frequently used words in people's life. Fuzzy logic control is constructed on these logical relationships. Fuzzy sets are used to show linguistic variables. Fuzzy Sets Theory is first introduced in 1965 by Zadeh to express and process fuzzy knowledge [11, 12]. There is a strong relationship between fuzzy logic and fuzzy set theory that is similar relationship between Boolean logic and classic set theory. Fig.3 shows a basic FLC structure.

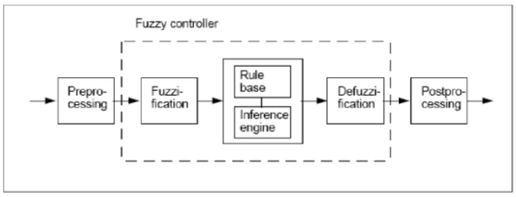

Figure 3: Structure of fuzzy logic controller

The input to the Self-tuning Fuzzy PID Controller are speed error "e(t)" and Change-in-speed error "de(t)". The input shown in figure are described by

e (t)=wr(t)-wa(t)

de (t)=e(t)-e(t-1)

Using fuzzy control rules on-line, PID parameters "KP"," KI"," KD" are adjusted, which constitute a self-tuning fuzzy PID controller as shown in Figure4.

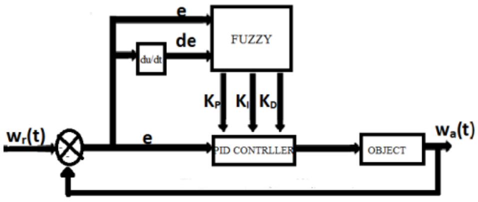

Figure 4: The structure of self-tuning fuzzy PID controller

PID parameters fuzzy self-tuning is to find the fuzzy relationship between the three parameters of PID and "e" and "de", and according to the principle of fuzzy control, to modify the three parameters in order to meet different requirements for control parameters when "e" and "de" are different, and to make the control object a good dynamic and static performance

In order to improve the performance of FLC, the rules and membership functions are adjusted. The membership functions are adjusted by making the area of membership functions near ZE region narrower to produce finer control resolution. On the other hand, making the area far from ZE region wider gives faster control response. Also the performance can be improved by changing the severity of rules [14]. An experiment to study the effect of rise time (Tr), maximum overshoot (Mp) and steady-state error (SSE) when varying KP**,** KI and KD was conducted. The results of the experiment were used to develop 25-rules for the FLC of KP, KI and KD.

3.1 DESIGN OF MEMBERSHIP FUNCTION (MF)

Input variables: Fuzzy sets of speed error (e) variable

Table 2: Membership function of speed error

Fuzzy set (Label)	Description	Numerical Range	Shape of Membership Function
Negative large (NL)	Large Speed difference in negative direction	-20 to -20 -20 to 40	Triangular
Negative small (NS)	Small Speed difference in negative direction	10 to 40 40 to 100	Triangular
Zero (ZE)	Speed difference is zero	40 to 70 70 to 100	Triangular
Positive Small (PS)	Small Speed difference in positive direction	40 to 100 100 to 130	Triangular
Positive large (PL)	Large Speed difference in positive direction	100 to 160 160 to 160	Triangular

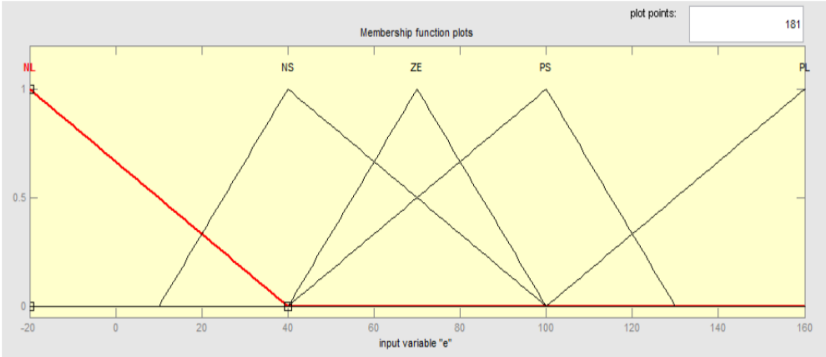

Figure 5: Membership function for input variable “e”

Table 3: Membership function of change in speed error.

Fuzzy set (Label)	Description	Numerical Range	Membership Function
Negative large (NL)	Large error difference in negative direction	-1300 to -1300 -1300 to -800	Triangular
Negative small (NS)	Small error difference in negative direction	-1050 to -800 -800 to -300	Triangular
Zero (ZE)	Error difference is zero	-800 to -550 -550 to -300	Triangular
Positive Small (PS)	Small error difference in positive direction	-800 to -300 -300 to -50	Triangular
Positive large (PL)	Large error difference in positive direction	-300 to -300 -300 to 200	Triangular

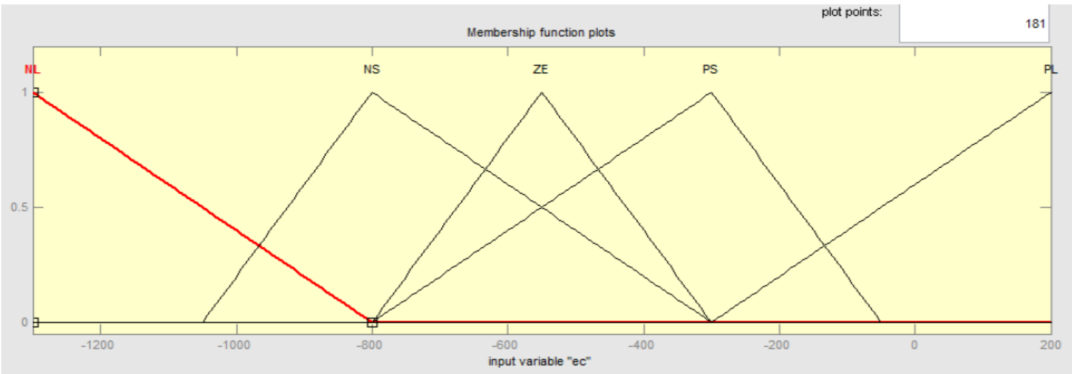

Figure6: Membership function for input variable “de” Output variable:

Table 4: Membership function proportional gain KP.

Fuzzy set (Label)	Numerical Range	Membership function
Positive very small (PVS)	0 to 0 0 to 10	Triangular
Positive Small (PS)	0 to 5 5 to 15	Triangular
Positive Medium small (PMS)	5 to 10 10 to 20	Triangular
Positive Medium (PM)	10 to 15 15 to 20	Triangular
Positive Medium Large (PML)	10 to 20 20 to 25	Triangular
Positive Large (PL)	15 to 25 25 to 30	Triangular
Positive very Large (PVL)	20 to 30 30 to 30	Triangular

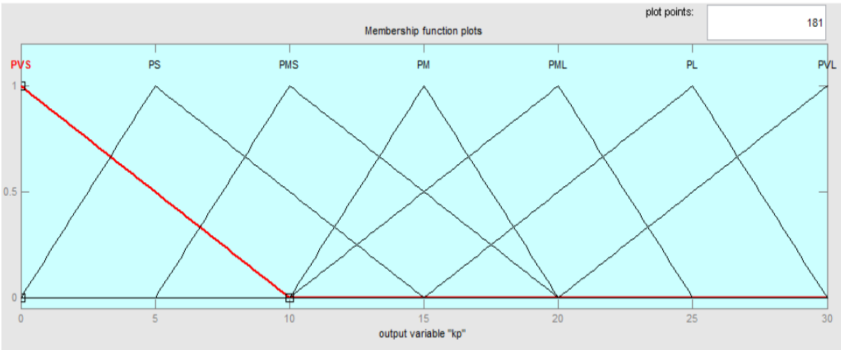

Figure 7: Membership function for output variable "KP"

Table 5: Membership function integral gain KI.

Fuzzy set (Label)	Numerical Range	Membership function
Positive very small (PVS)	0 to 0 0 to 20	Triangular
Positive Small (PS)	0 to 10 10 to 30	Triangular
Positive Medium small (PMS)	10 to 20 20 to 40	Triangular
Positive Medium (PM)	20 to 30 30 to 40	Triangular
Positive Medium Large (PML)	20 to 40 40 to 50	Triangular
Positive Large (PL)	30 to 50 50 to 60	Triangular
Positive very Large (PVL)	40to 60 60 to 60	Triangular

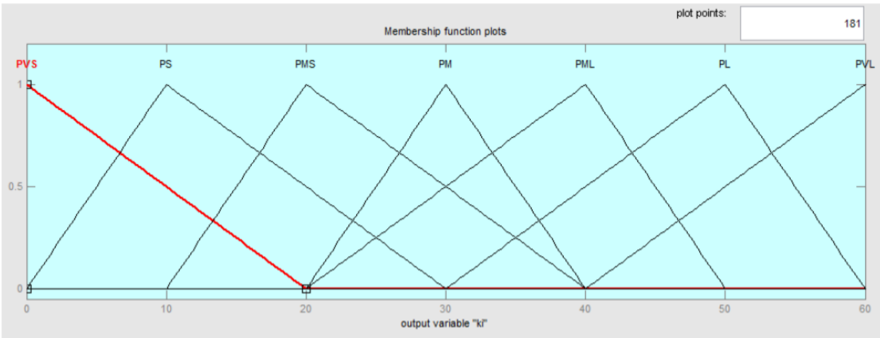

Figure 8: Membership function for output variable "KI"

Table 6: Membership function derivative gain KD.

Fuzzy set (Label)	Numerical Range	Shape of Membership function
Positive very small (PVS)	0 to 0 0 to 2	Triangular
Positive Small (PS)	0 to 1 1 to 3	Triangular
Positive Medium small (PMS)	1 to 2 2 to 4	Triangular
Positive Medium (PM)	2 to 3 3 to 4	Triangular
Positive Medium Large (PML)	2 to 4 4 to 5	Triangular
Positive Large (PL)	3 to 5 5 to 6	Triangular
Positive very Large (PVL)	4 to 6 6 to 6	Triangular

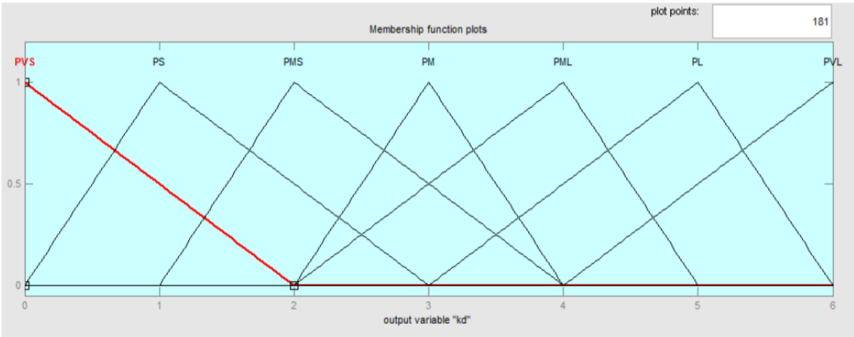

Figure 9: Membership function for output variable "KD

3.2. Design Of Fuzzy Rules

Table 7: Fuzzy rule table for KP

de/e	NL	NS	ZE	PS	PL
NL	PVL	PVL	PVL	PVL	PVL
NS	PML	PML	PML	PL	PVL
ZE	PVS	PVS	PS	PMS	PMS
PS	PML	PML	PML	PL	PVL
PL	PVL	PVL	PVL	PVL	PVL

Table 8: Fuzzy rule table for KI

de/e	NL	NS	ZE	PS	PL
NL	PM	PM	PM	PM	PM
NS	PMS	PMS	PMS	PMS	PMS
ZE	PS	PS	PVS	PS	PS
PS	PMS	PMS	PMS	PMS	PMS
PL	PM	PM	PM	PM	PM

Table 9: Fuzzy rule table for KD

de/e	NL	NS	ZE	PS	PL
NL	PVS	PMS	PM	PL	PVL
NS	PMS	PML	PL	PVL	PVL
ZE	PM	PL	PL	PVL	PVL
PS	PML	PVL	PVL	PVL	PVL
PL	PVL	PVL	PVL	PVL	PVL

IV. Matlab Simulation

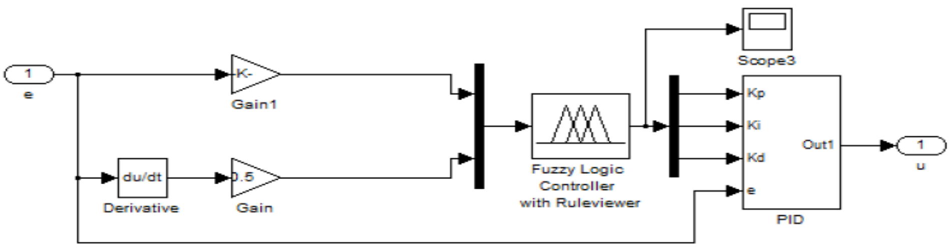

FIGURE 11: SIMULINK MODEL OF FUZZY-PID CONTROLLER

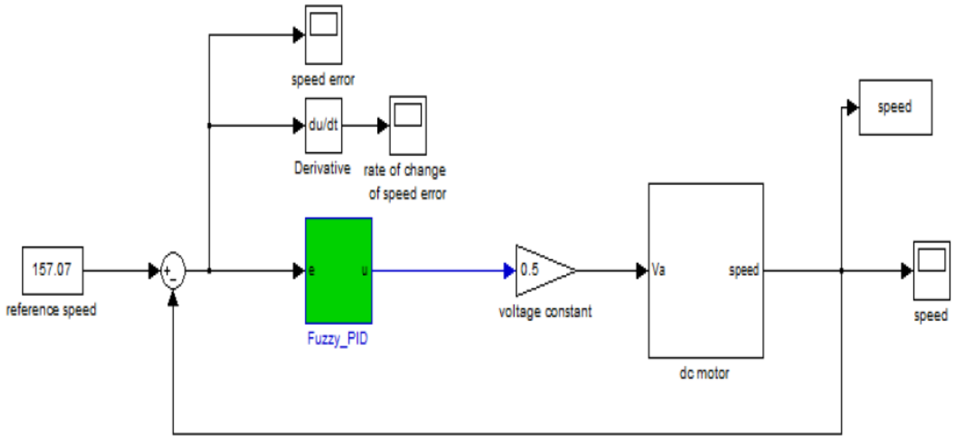

Figure 10: Simulink Model for Speed Control of Separately Excited DC motor using self tuned fuzzy PID controller

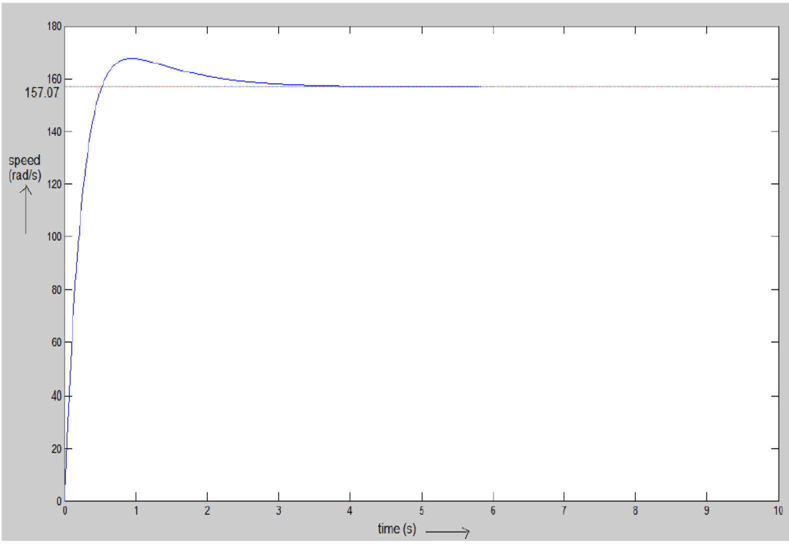

FIGURE 12: SPEED VS TIME RESPONSE OF FUZZY TUNED PID CONTROLLED DC MOTOR

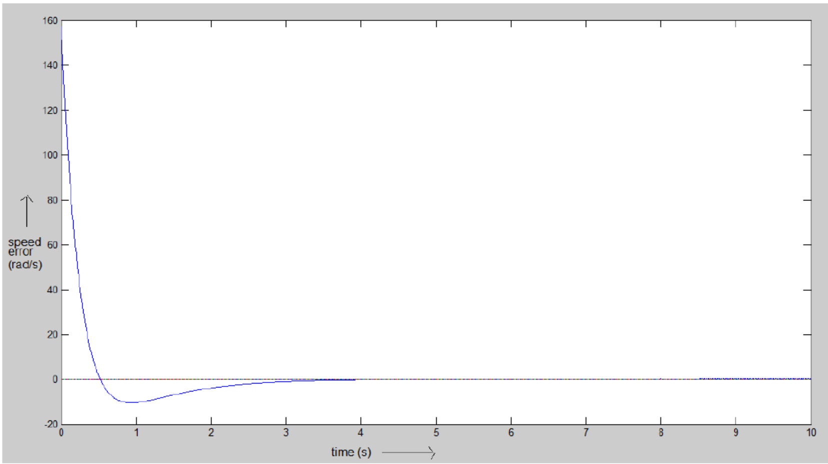

Figure13: Error Vs time response of fuzzy tuned PID controlled DC motor

V. Conclusion

Comparison between self tuned fuzzy PID and conventional PID controller Self-tuned tuning PID controller is less compared to conventional PID controller.

The three parameters "KP", "KI", "KD" of conventional PID control need to be constantly adjust adjusted online in order to achieve better control performance. Fuzzy self-tuning PID parameters controller can automatically adjust PID parameters in accordance with the speed error and the rate of speed error-change, so it has better self-adaptive capacity fuzzy PID parameter controller has smaller overshoot and less rising and settling time than conventional PID controller and has better dynamic response properties and steady-state properties. Steady state error in case of self tuned fuzzy PID is less compared to conventional PID controller.

The fuzzy controller adjusted the proportional, integral and derivate (KP, KI, KD) gains of the PID controller according to speed error and change in speed error .From the simulation results it is concluded that ,compared with the conventional PID controller, self-tuning PID controller has a better performance in both transient and steady state response. The self tuning FLC has better dynamic response curve, shorter response time, small overshoot, small steady state error (SSE), high steady precision compared to the conventional PID controller.

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