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Performance comparison of conventional controller with Fuzzy logic controller using chopper circuit and Fuzzy tuned PID controller

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Abstract

It is often difficult to develop an accurate mathematical model of DC motor due to unknown load variation, unknown and unavoidable parameter variations or nonlinearities due to saturation temperature variations and system disturbances. Fuzzy logic application can handle such nonlinearities so that the controller design is fundamentally robust which is not possible in conventional controllers. The knowledge base of a fuzzy logic controller (FLC) encapsulates expert knowledge and consists of the Data base (membership functions) and Rule-Base of the controller. Optimization of both these knowledge base components is critical to the performance of the controller and has traditionally been achieved through a process of trial and error. Such an approach is convenient for FLCs having low numbers of input variables however for greater numbers of inputs, more formal methods of knowledge base optimization are required. In this work, we study the challenging task of controlling the speed of DC motor. The feasibility of such controller design is evaluated by simulation in the MATLAB/Simulink environment. In this study Conventional Proportional Integral Derivative controller, Fuzzy logic controller using a chopper circuit and Fuzzy tuned PID controller are analyzed and compared. Simulation software like MATLAB with Simulink has been used for modeling and simulation purpose. The performance comparison of conventional controller with Fuzzy logic controller using chopper circuit and Fuzzy tuned PID controller has been done in terms of several performance measures Such as Settling time, Rise time and Overshoot.

***Keywords**: DC motor: Fuzzy tuned PID: Speed control*

1. Introduction

As the applications of direct current (DC) machines have remained vital in industrial processes. The development of high performance motor drives is very important in industrial as well as other purpose applications such as steel rolling mills, electric trains and robotics. Generally, a high performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task. DC drives, because of their simplicity, ease of application, high reliabilities, flexibilities and favourable cost have long been a backbone of industrial applications, robot manipulators and home appliances where speed and position control of motor are required. DC drives are less complex with a single power conversion from AC to DC. Again the speed torque characteristics of DC motors are much more superior to that of AC motors. A DC motors provide excellent control of speed for acceleration and deceleration. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types, the controllers can be: proportional integral (PI), proportional integral derivative (PID), Fuzzy Logic Controller (FLC) or the combination between them [17]. 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.

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2. 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.

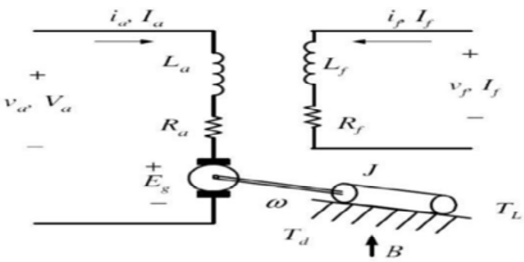

Figure 2.1. Separately excited DC motor

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) (1)

Now the torque balance equation will be given by:

Tm = Jmdω/dt +Bmω+TL (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 = Jmdω/dt + TL (3)

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

Eb = K Φ ω (4)

Also, Tm = K Φ Ia (5)

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

Ia(s) = (Va – KΦω)/ Ra (1+ LaS/Ra) (7)

and

ω(s) = (Tm - TL) /JS = (KΦIa - TL) /JmS (8)

(Armature Time Constant) Ta= La/Ra

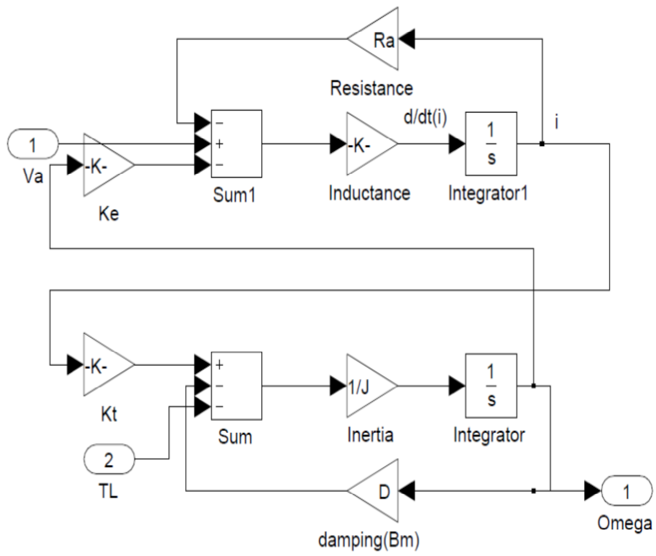

Figure 2.2. Block Model of Separately Excited DC Motor

Table 2.1. Motor parameters

Parameters	Description	Value
R_a	Armature Resistance(Ω)	1
L_a	Armature Inductance(H)	0.5
Jm	Motor of Inertia($Kg.m^2/s^2$)	0.01
K	Motor Constant(Nm/Amp)	0.8
B	Damping ratio of mechanical system(Nms)	0.1

3. 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. Figure 3 shows a basic FLC structure.

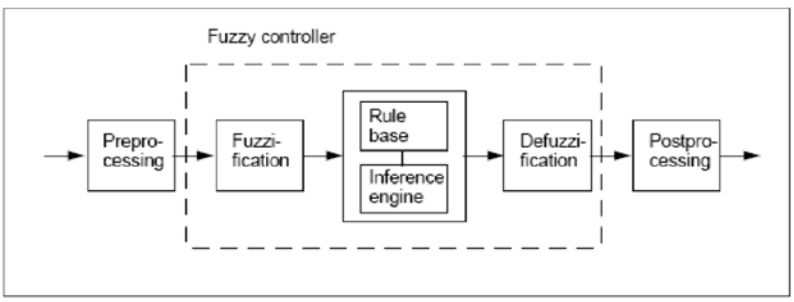

Figure 3.1. Structure of fuzzy logic controller

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 Figure 4.

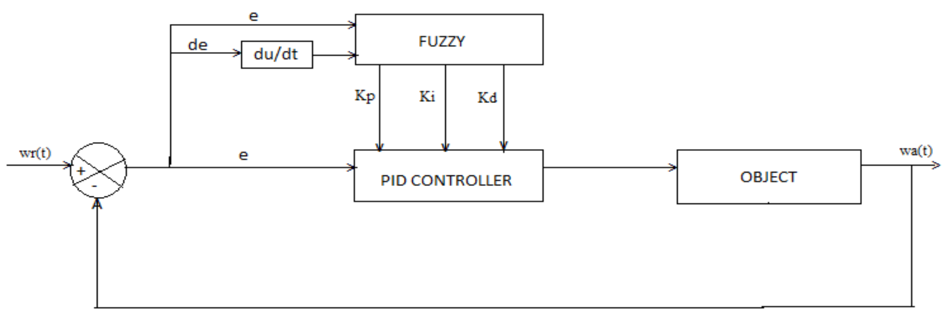

Figure 3.2. The structure of self-tuning fuzzy PID controller

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 3.1. 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

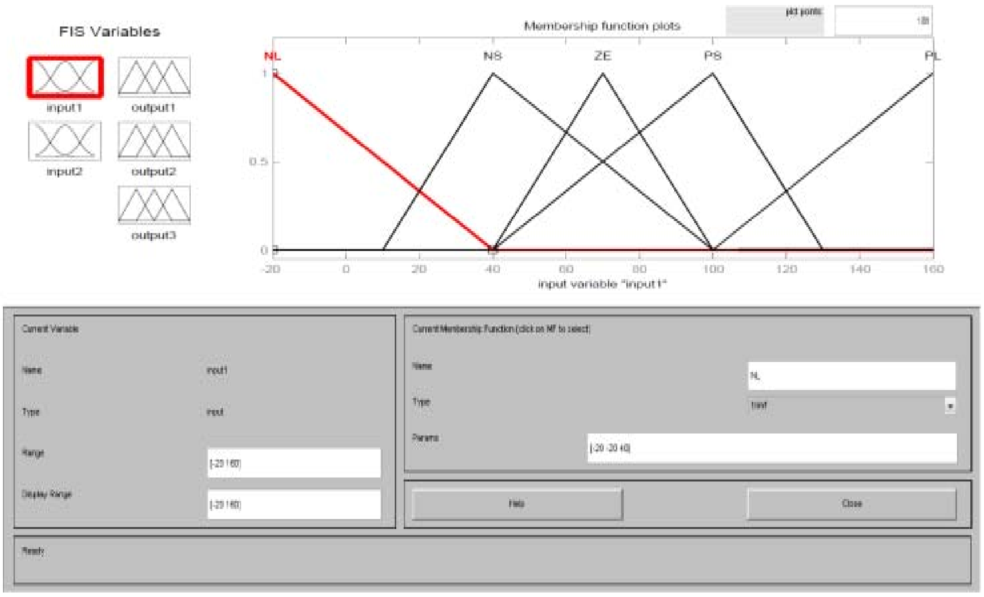

Figure 3.3. Membership function for input variable “e”

Table 3.2. 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

Figure 3.4. Membership function for input variable “de”

Output variable:

Table 3.3. 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

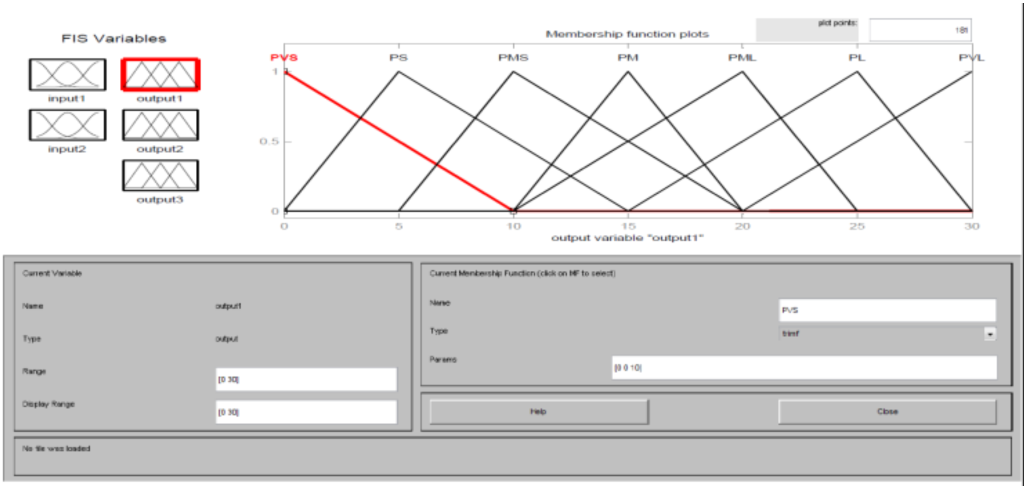

Figure 3.5. Membership function for output variable “KP”

Table 3.4. 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

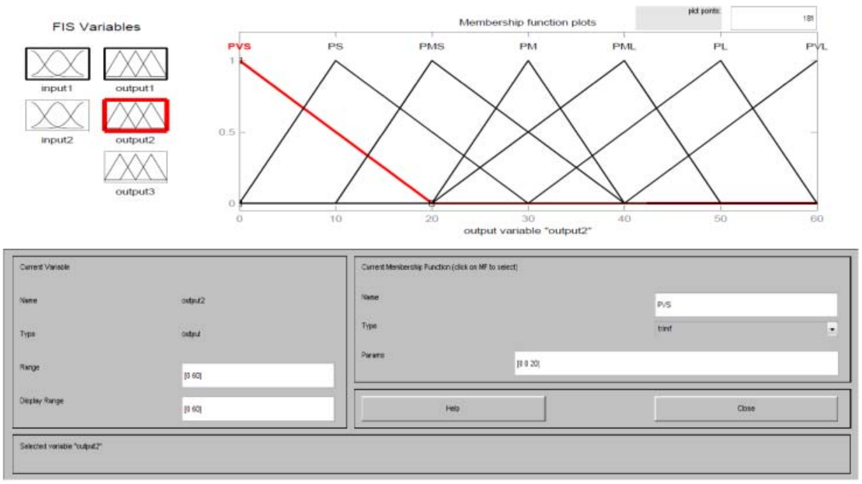

Figure 3.6. Membership function for output variable “KI”

Table 3.5. 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

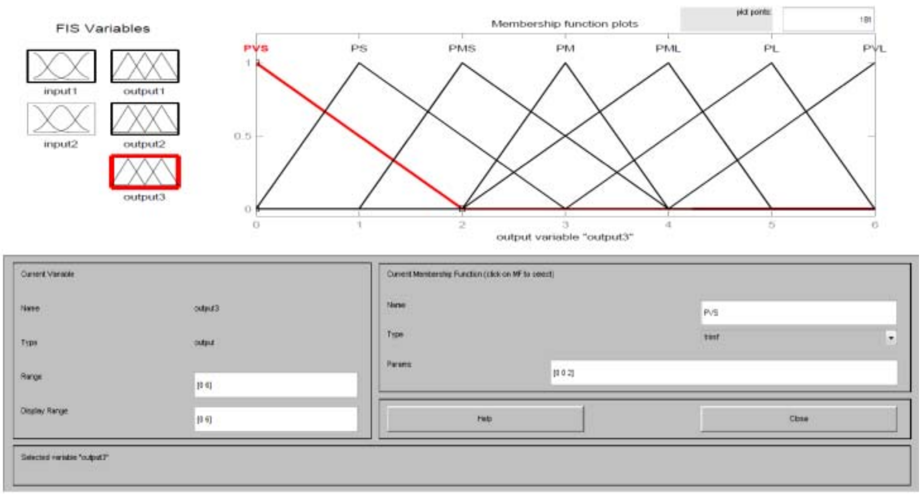

Figure 3.7. Membership function for output variable “KD”

3.2. Fuzzy Logic Controller Using Chopper Circuit

Table 3.6. Fuzzy rules for fuzzy logic controller

e \ Ce	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	NM	Z	Z
NM	PL	PL	PL	PM	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

3.3. Driver Circuit

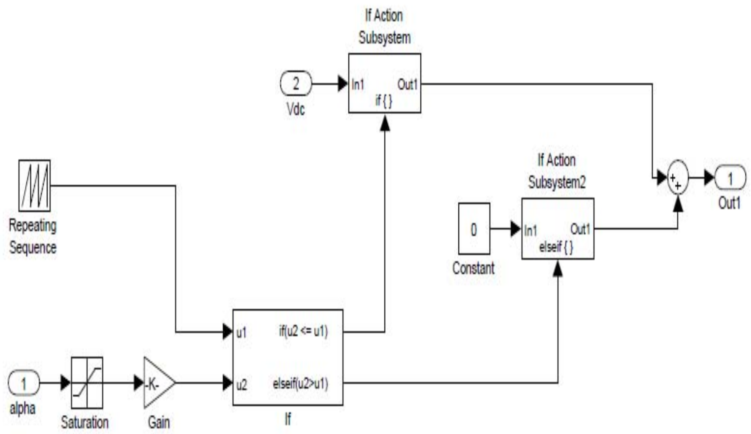

Figure 3.8. Simulink model of DC chopper circuit

3.4. Design of Fuzzy Rules

Table 3.7. 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 3.8. 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 3.9. 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

4. Matlab Simulation

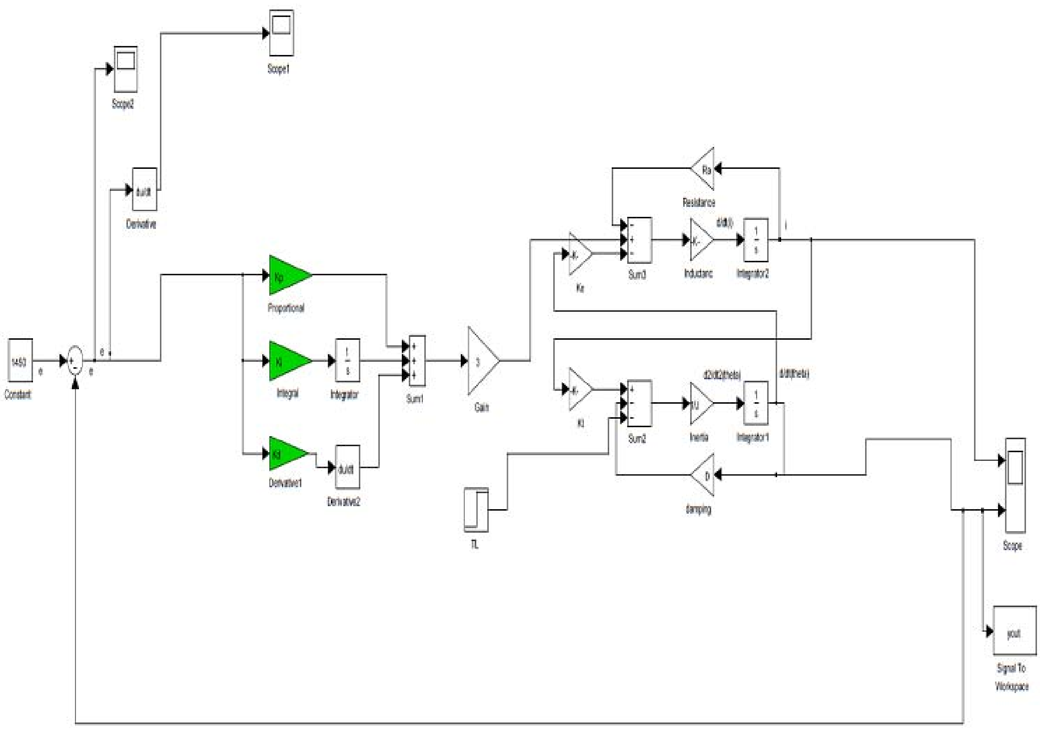

Figure 4.1. Simulink model for speed control of DC motor with PID controller

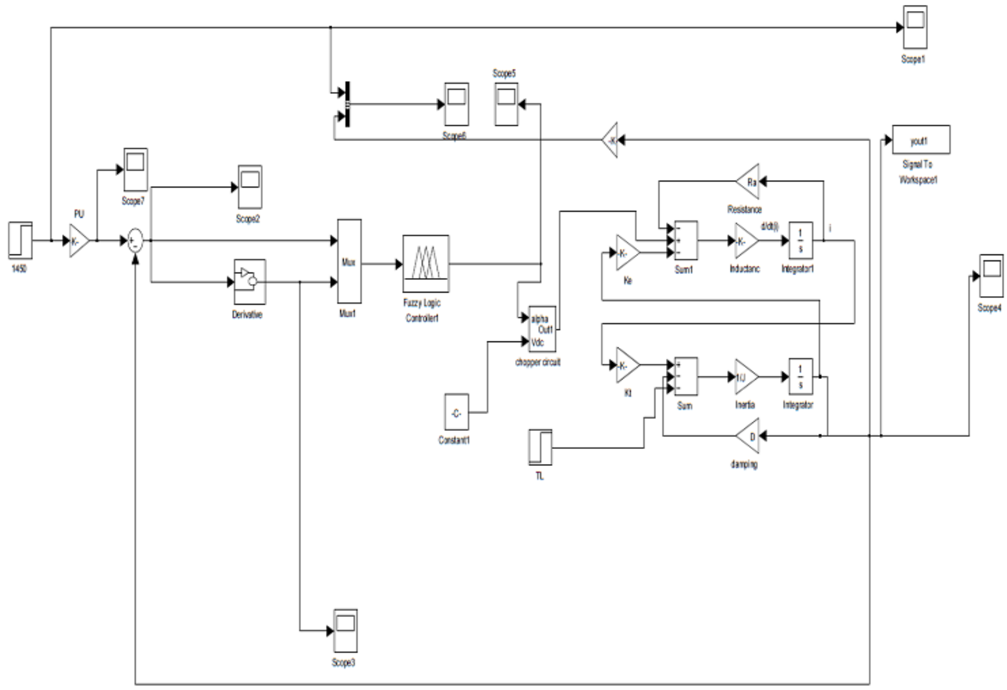

Figure 4.2. Simulink model block diagram for speed control of DC motor with Fuzzy logic controller

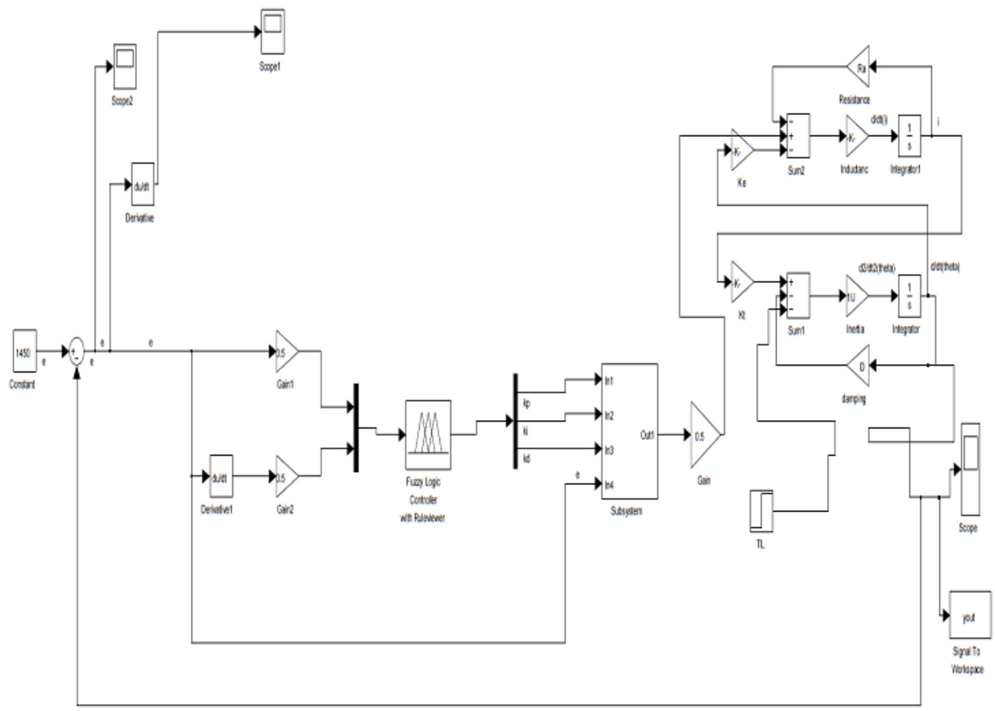

Figure 4.3. Simulink model block diagram for speed control of DC motor with Fuzzy tuned PID controller.

5. Results

The separately excited DC motor has been mathematically modeled in MATLAB environment along with simulink toolbox. The drive response has been simulated using developed model. A comparative study of different speed controllers has been carried out for the drive system. The comprehensive study of different speed controllers for speed control of separately excited DC motor has shown that the individual speed controllers have their own merits and demerits. Depending upon the operation, a choice of a particular speed controller may be made.

Table 0.1. Performance comparison of different controllers

Type of Controllers	%Overshoot	Rise time t_r (sec)	Settling time t_s(sec)
PID	23.0342	2.8702	21.5203
Fuzzy logic controller using chopper circuit	0.3258	2.7739	4.3950
Fuzzy tuned PID controller	6.9363	2.6675	32.1928

When the requirement is that of simplicity and ease of application, the PID speed controller is to be a good choice. When intelligence and fast dynamic response are important, then the Fuzzy logic technique may be selected.

Fuzzy logic controller using chopper circuit has a better performance in terms of %Mp (percent overshoot) when compared to conventional PID controller and Fuzzy tuned PID controller.

6. Conclusion

The main objective of the project has been aimed towards modelling of various controllers for the speed control of a separately excited DC motor. Modelling and simulation of performance of DC motor has been carried out using different speed controllers in MATLAB environment using Simulink. This chapter is an overall summary of the investigations in the various chapters

A comprehensive mathematical model of a separately excited DC motor, various controllers- Proportional Integral Derivative (PID) controller, Fuzzy logic controller using chopper circuit, Fuzzy tuned PID controller has been developed in terms of parameters and physical variables (current and voltages) of the motor. The speed response of the DC motor with various controllers has been compared and analyzed. The response of the drive system has been simulated in MATLAB environment using Simulink.

The comparative study of different speed controllers has shown that the individual speed controllers have their own merits and demerits. The choice of a particular speed controller can be made depending upon the type of response they have provided.

The Fuzzy logic controller using a chopper and Fuzzy tuned PID controller are better controller when compared to conventional PID controller has a better performance in terms of T_r(rise time), %Mp (percent overshoot),steady state error. And Fuzzy logic controller using chopper circuit has a better performance in terms of %Mp (percent overshoot) when compared with Fuzzy tuned PID controller.

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