Islamic University of Technology

A Thesis

On

FUZZY LOGIC BASED SPEED CONTROL OF DC MOTOR

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A Dissertation on

Fuzzy logic based speed control of DC Motor

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Abstract

This Thesis is based on the speed control of DC motors. In the industrial area, rolling mills, chemical process, electric trains, robotic manipulators and the home electric appliances, the necessity of speed control of DC motor is high. At first, we used the convention PID controller to control the speed of a DC motor using DC-4 model. Later on, we used Fuzzy Logic based controller to match the speed with a reference one more efficiently.

Preface

The undergraduate thesis, "*Fuzzy logic based speed control of DC Motor*" has been written for the completion of Bachelor of Science degree at Islamic University of Technology, Bangladesh. This thesis work and writing has been done during the year 2014 under the supervision of Professor Dr. Md. Ashraful Hoque of the department of Electrical and Electronic Engineering.

We would like to express sincere gratitude to our thesis supervisor Professor Dr. Md. Ashraful Hoque.

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We would like to dedicate this thesis to our supervisor Professor Dr. Md. Ashraful Hoque.

Without the dedicated help of him we won't be able to complete this work. We are also grateful to all of our will-wishers, who provided their perpetual support towards accomplishing this task successfully.

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Chapter -1

Introduction

1.1. General

The speed of DC motors can be adjusted within wide boundaries so that this provides easy controllability and high performance. The development of high performance motor drives is very important in industrial as well as other purposes such as electric train, robotics, steel rolling mills, electric vehicles, and electric cranes. So the improvement of the speed control of electric motors need to be enhanced. So in our thesis we have chosen DC motor and we have tried different controlling methods to enhance the performance of the speed control of the DC motors

1.2. Why we chose DC motor

Generally a high performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task. We have chosen DC drives. There are several reasons behind our choice. These include its-

1. Simplicity
2. Ease of application
3. High reliability
4. Flexibilities
5. Favourable cost

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 motor provides very good control of speed for acceleration and deceleration. The most important aspect of DC motor is it is less expensive for most horse power 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 this application the motor should be precisely controlled to give the desired performance.

1.3. Speed Control of DC drive

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: Fuzzy_Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Swarm. 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 . 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].

1.4. Advanced controlling system

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[2].

Since then, FLC has been an extremely active and fruitful research area with many industrial applications reported .In the last three decades, FLC has evolved as an alternative or complementary to the conventional control strategies in various engineering areas. Fuzzy control theory usually provides non-linear controllers that are capable of performing different complex non-linear control action, even for uncertain nonlinear systems. Unlike conventional control, designing a FLC does not require precise knowledge of the system model such as the poles and zeroes of the system transfer functions. Imitating the way of human learning, the tracking error and the rate change of the error are two crucial inputs for the design of such a fuzzy control system. Lastly we used FUZZY_PID controller which is a self-tuned controller .There are several reason why we chose fuzzy_pid controller. The reasons are-

1. Simplicity of control and Smooth operation
2. high degree of tolerance
3. low cost
4. reduce the effect of Non-linearity
5. inherent approximation capability

6. Possibility to design without knowing the exact mathematical model of the process.

Using fuzzy control rules PID parameters $K_{p,}$ $K_{i,}$ K_d are adjusted automatically by self-tuned FUZZY_PID Controller[3].

1.5. Scope of the thesis

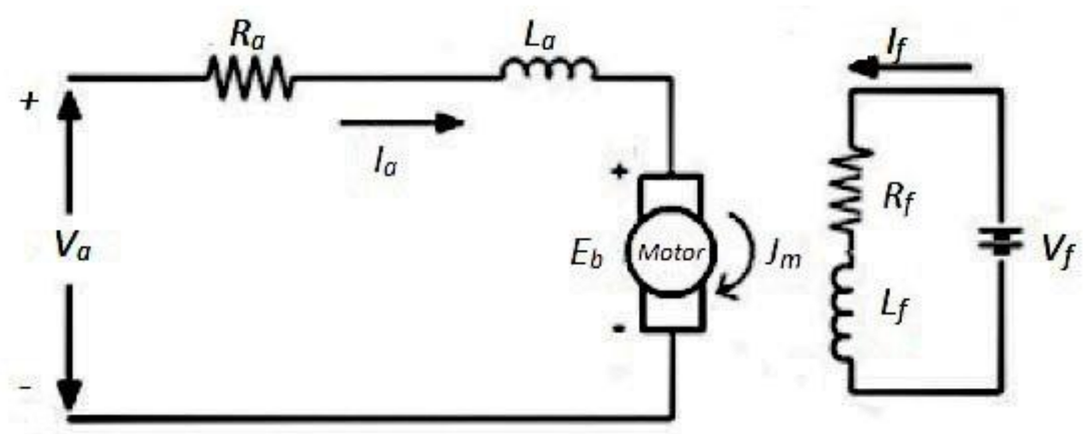
We can apply the results of our simulations to control the speed of a DC motor and use the suitable one for industrial applications.

Chapter -2

Speed Control of DC drive

2.1 Speed control of separately excited DC motor:

Dc motors are most suitable for wide range speed control and are there for many adjustable speed drives. Intentional speed variation carried out manually or automatically to control the speed of DC motors.



$A(V_a - I_aR_a)/\phi$

$=(V_a - I_aR_a)/K_a\,\phi$

Where ϕ = Field Flux per pole

K_a=Armature Constant=$PZ/2\pi a$

Where P= NO. of poles

Z= Total no. of armature conductor,

A= No. of parallel path

From the previous equation it is clear that for DC motor there are basically 3 methods of speed control.

They are-

1. Variation of resistance in armature circuit
2. Variation of field flux
3. Variation of armature terminal voltage.

4. DC motors have variable characteristics and are used extensively in variable speed drives.

Motor speed can be varied by controlling-

1. Armature voltage
2. Field current &
3. Torque demand.

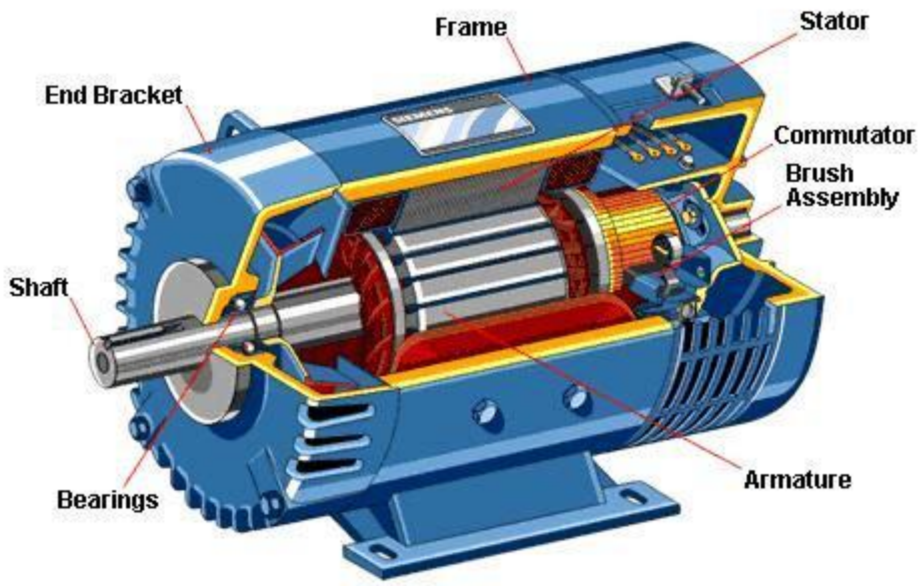


Figure: DC MOTOR

DC Machines are of three kinds as well-

1. Separately excited ,
2. Shunt excited &
3. Series excited

2.2 Modelling of DC motor

From figure 1:

The armature voltage equation is given by:

$V_a = E_b + I_a R_a + L_a (dI_a/dt)$

Now the torque balance equation will be given by:

$T_m = J_m d\omega/dt + B_m \omega + T_L$

Where:

T_l is load torque in Nm.

Friction in rotor of motor is very small (can be neglected), so $B_m = 0$

Therefore, new torque balance equation will be given by:

$T_m = J_m d\omega/dt + T_L$ --------- (i)

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

$E_b = K \Phi \omega$ --------- (ii)

Also, $T_m = K \Phi I_a$--------- (iii)

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

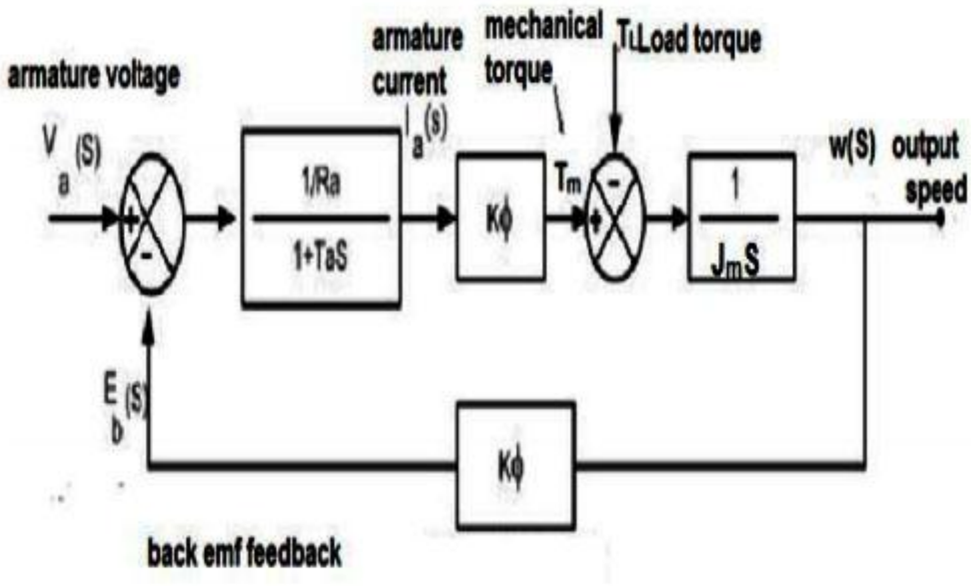
$I_a(S) = (V_a – E_b)/ (R_a + L_a S)$

Now, taking equation (ii) into consideration, we have:

$I_a(s) = (V_a – K\Phi\omega)/ R_a (1+ L_a S/R_a)$

And $\omega(s) = (T_m – T_L) /JS = (K\Phi I_a – T_L) /J_m S$

(Armature Time Constant) $T_a= L_a/R_a$



After simplifying the above motor model,the overall transfer function will be

$\omega(s) / V_a(s) = [K\Phi / R_a] / J_m S(1+T_a S) / [1 + (K^2\Phi^2 / R_a) / J_m S(1+T_a S)]$

Further simplifying the above transfer function:

$\omega(s) / V_a(s) = (1 / k\Phi) / \{1 + (k^2\Phi^2 / R_a) / J_m S(1+T_a S)\}$ ---------------- (iv)

Assuming, $T_{em} = J_m R_a / (k\Phi)^2$ as electromechanical time constant.

Then the above transfer function can be written as:

$\omega(s) / V_a(s) = (1/k\Phi) / [S T_{em} (1+S T_a)+1]$ --------(v)

Let us assume that during starting of motor, load torque TL = 0 and applying full voltage Va

Also assuming negligible armature inductance, the basic armature voltage equation can be written as:

$V_a = K\Phi\omega(t) + I_a R_a$

At the same time Torque equation will be:

$T_m = J_m d\omega/dt = K\Phi I_a$ ----- (vi)

Putting the value of Ia in above armature equation:

$V_a = K\Phi\omega(t) + (J_m\, d\omega/dt)R_a / K\Phi$

Dividing on both sides by KΦ,

$V_a/K\Phi = \omega(t) + J_m R_a (d\omega/dt)/(K\Phi)^2$ ------------------------(vii)

$V_a/K\Phi$ is the value of motor speed under no load condition.

Therefore,

$\omega(\text{no load}) = \omega(t) + J_m R_a (d\omega/dt)/(K\Phi)^2 = \omega(t) + T_{em}(d\omega/dt)$

Where, $K\Phi = K_m$ (say)

And $T_{em} = J_m R_a/(K\Phi)^2 = JR_a/(K_m)^2$

Therefore, $J_m = T_{em}(K_m)^2/R_a$ --------- (viii)

From motor torque equation, we have:

$\omega(s) = K_m I_a(s)/JS – T_L/J_m S$ -------- (ix)

From equation (viii) and (ix), we have:

$\omega(s) = [(R_a / K_m) I_a(s) - T_L R_a / (K_m)^2] (1/T_{em}(s))$

Now, Replacing KΦ by Km in equation (v), we will get:

$\omega(s)/V_a(s) = (1/K_m) / (1 + ST_{em} + S^2 T_a T_{em})$ ------------ (x)

The armature time constant T_a is very much less than the electromechanical time constant T_{em},

$(T_a << T_{em})$

Simplifying, we get ,

$1 + ST_{em} + S^2T_a\, T_{em} \approx 1 + S\,(T_a+T_{em}) + S^2T_a\, T_{em} = (1 + ST_{em})\,(1 + ST_a)$

And again simplifying the equation we get finally:

$\omega(s)\,/V_a(s) = (1/K_m)/((1 + ST_{em})(1 + ST_a))$ -----(xi)

T_{em} and T_a are the time constants of the above system transfer function which will determine the response of the system. Hence the DC motor can be replaced by the transfer function obtained in equation (xi) in the DC drive model.

We are presenting the specification of the DC motor along with the DC motor governing equations in the next chapter where we will show how we took measures to control the speed of the DC motor by different controllers.

Chapter -3

Controllers

3.1 Different Controllers

Over the years works in electric motor control systems have been expanded into a wide range. Various systems have been designed to control the motor parameters such as speed, torque, etc. In this part we took different controllers as techniques of changing the armature voltage to control the speed of a DC motor drive. In this thesis we have used

1. PID Controller
2. 3 PHASE THYRISTOR RECTIFIER FED FOUR QUADRANT DC DRIVE(MODEL-DC4)
3. Lastly Fuzzy_PID controller

3.2. PID Controller

We have tried different methods of speed control. We used PID controller and different parameters. We observed the open loop and close loop system of motor and their output wave shapes Throughout our thesis we have used the same parameters to check the best method . In the PID controller what values we have chosen , the same has been chosen for DC4 model to compare the output to justify which one is the best. Here we have chosen the reference speed 1184 RPM . We will observe to what extent we get the value of speed same to the reference voltage

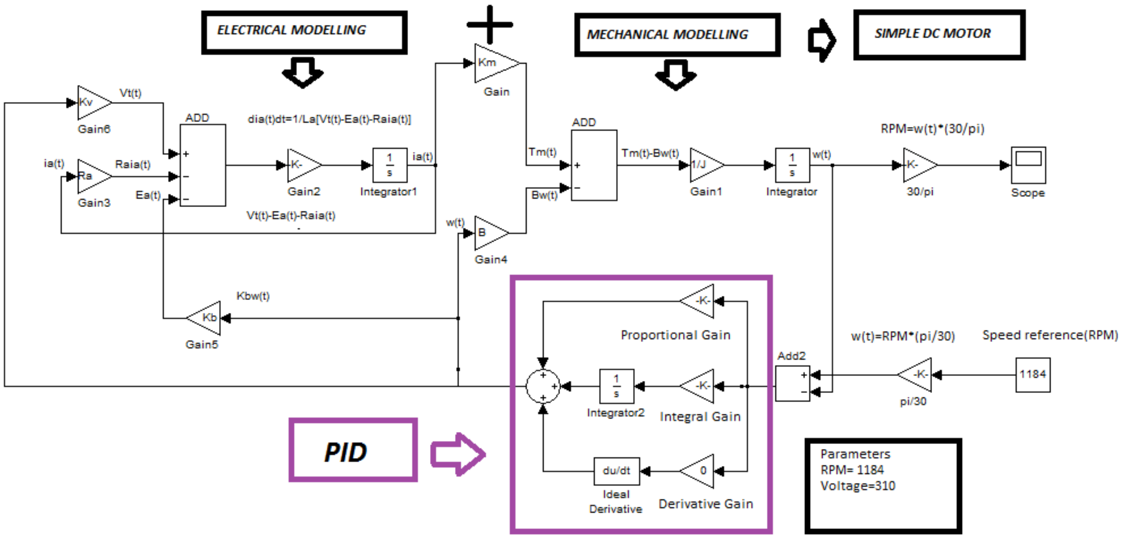


FIGURE: DC Motor model with conventional PID

DC Motor control using PID:

- We will now observe the PID controller operation and the output wave shapes
- The basic equation for PID is: $c(s) = K_p + \frac{K_i}{s} + K_d s$
- We will observe the out put shaped obtained from the controlling the dc motor using PID controller
- We will change the value of the Proportional gain, Integral gain, derivative gain
- By changing the values we will observe the difference in the outputs[4].

  DC Motor model with PID Controller:

There are some specifications of this DC motor.

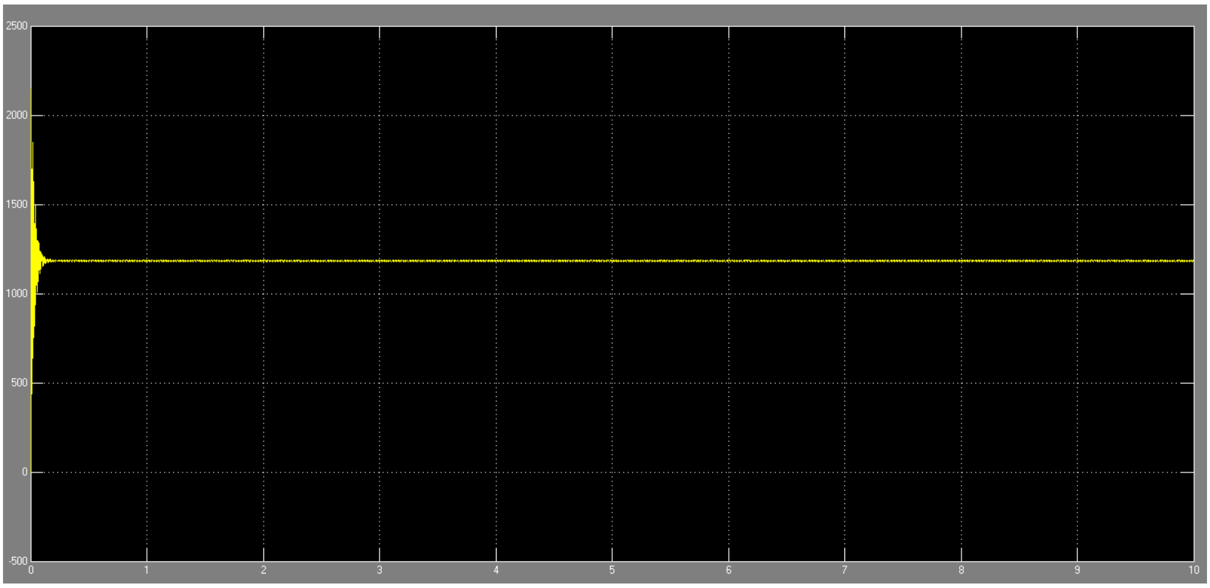
The specifications are stated below:

- Armature resistance(Ra)- 0.5Ω
- Armature induction(La)- 0.02H
- Armature voltage(Va)- 200V
- Mechanical inertia(jm)- 0.1kg.m.m
- Friction co-efficient(Bm)- 0.008N.m/rad/sec
- Back EMF constant(k)- 1.25V/rad/sec
- Rated Speed- 1184 rpm
- Motor torque constant- 1 N.m/A

OUTPUTS:

Speed Time characteristics of different values of Proportional and Integral gain (Derivative gain=0)

Here we have assumed the derivative gain as 0.



The proportional gain , Kp is 10

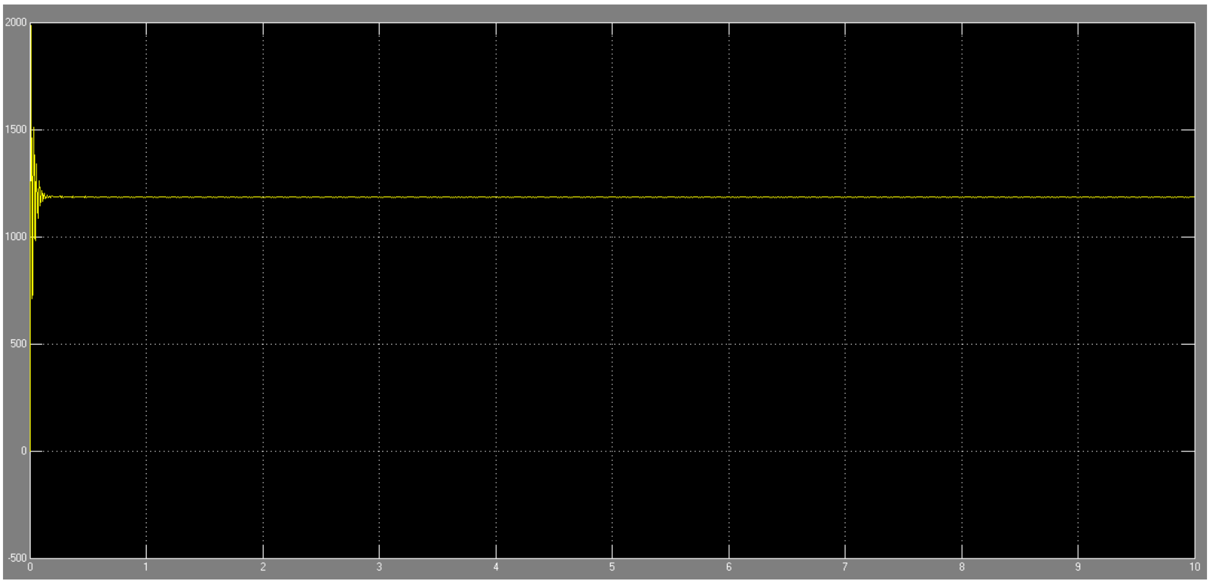
And the integral gain, Ki is 30

Assuming this proportional and derivative gain to be 10 and 30 respectively we have not got the desired out put.

So we have to change the proportional and integral gain to 5 and 10 respectively.

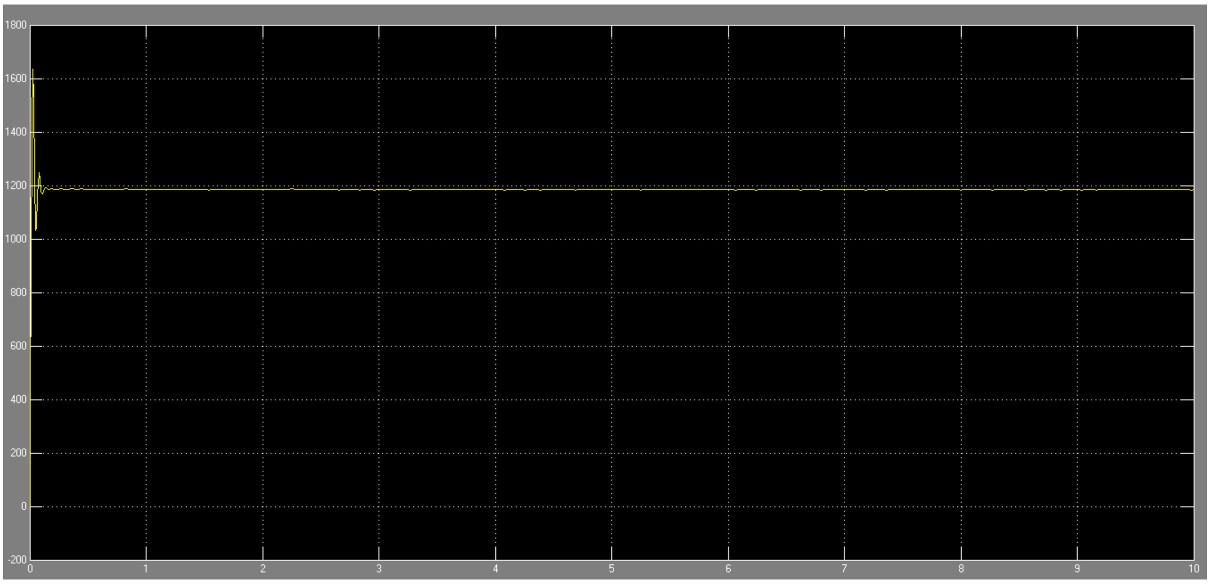
Changed output:

If we set Kp=5 and Ki =10 then the output will be:



Still we didn’t get the desired output. Now we changed the gains again.

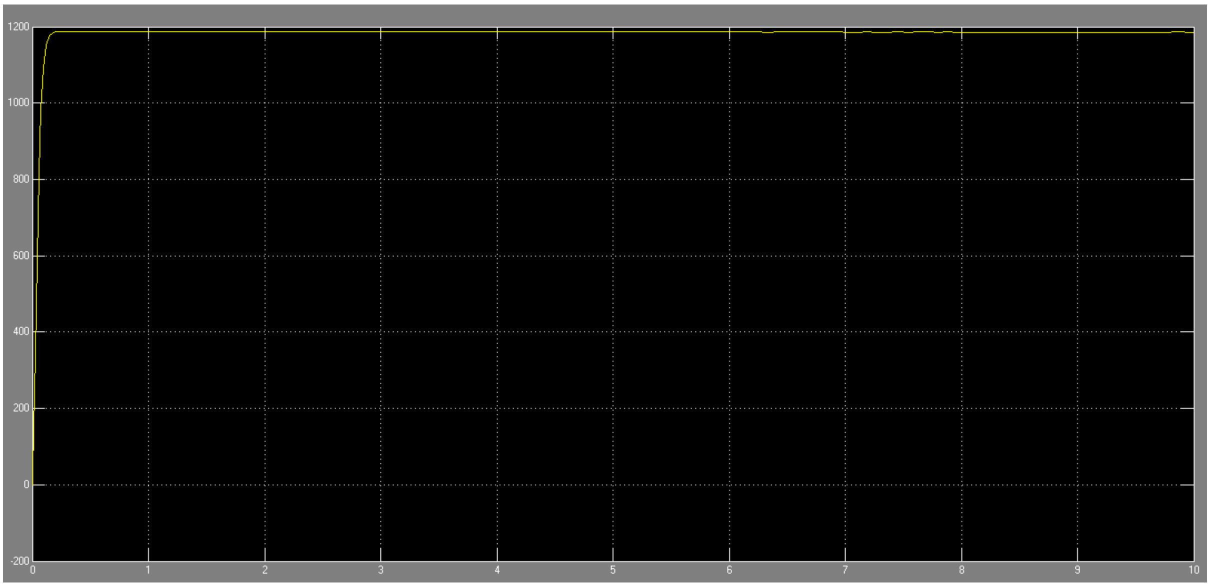
Now if we assume the Kp=1 and Ki= 0.5 then the output will be:



Still the result is not better

But when we assumed the Kp=0.1 and Ki=0.001

Then the output becomes:



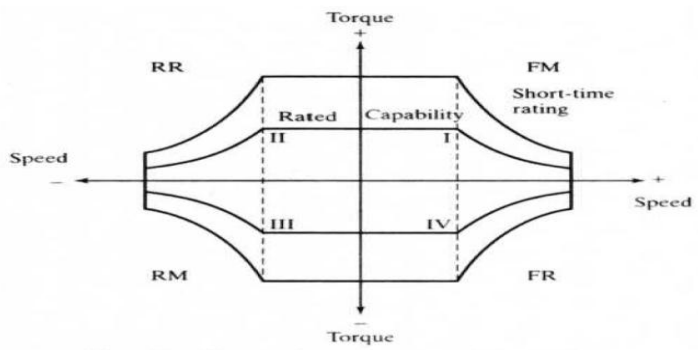
Now the output result matches the rated speed and mostly similar to 1184 rpm.

Now we will go for the **four quadrant operation**

Four quadrant operation:

- There are four distinct areas of operation (quadrants), which are based on the directions of operation as well as the mode of operation.
- The modes are the acceleration and deceleration of the motor.
- Two of the quadrants represent the torque application in the direction of motion.
- The other two quadrants represent the torque being applied in an opposite direction from the motor’s motion.
- So the motor has two quadrants in which the energy flow is from an electrical flow to a mechanical flow.
- With the other two, however, the motor acts as a generator. As the motor is in motion, this motion is being converted into electrical power. The motor drive absorbs this power.

Four quadrant torque –speed characteristic:



Function	Quadrant	Speed	Torque	Power Output
Forward Motoring (FM)	I	+	+	+
Forward Regeneration (FR)	IV	+	−	−
Reverse Motoring (RM)	III	−	−	+
Reverse Regeneration (RR)	II	−	+	−

Figure: Four quadrant torque –speed characteristic

Armature voltage and current requirements for a four quadrant DC motor drive:

Operation	Speed	Torque	Voltage	Current	Power Output
FM	+	+	+	+	+
FR	+	−	+	−	−
RM	−	−	−	−	+
RR	−	+	−	+	−

PHASE THYRISTOR RECTIFIER FED FOUR QUADRANT DC DRIVE(MODEL-DC4):

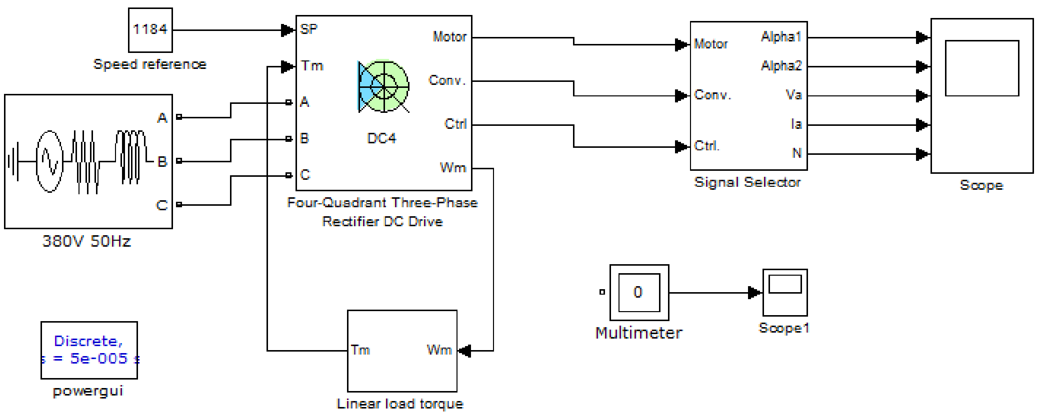


Figure:PHASE THYRISTOR RECTIFIER FED FOUR QUADRANT DC DRIVE(MODEL-DC4)

- Here we have used PHASE THYRISTOR RECTIFIER FED FOUR QUADRANT DC DRIVE(MODEL-DC4) to control the speed of DC Motor.
- The DC Motor can be easily controlled by this MODEL-DC4

The specifications of the DC4 MODEL:

- **DRIVE INPUT VOLTAGE**

1. Frequency – 50 HZ
2. Amplitude – 380 V

- **MOTOR NOMINAL VLAUES**

1. Power- 200 Hp
2. Speed- 1184 rpm
3. Voltage- 310V

Signal Selector:

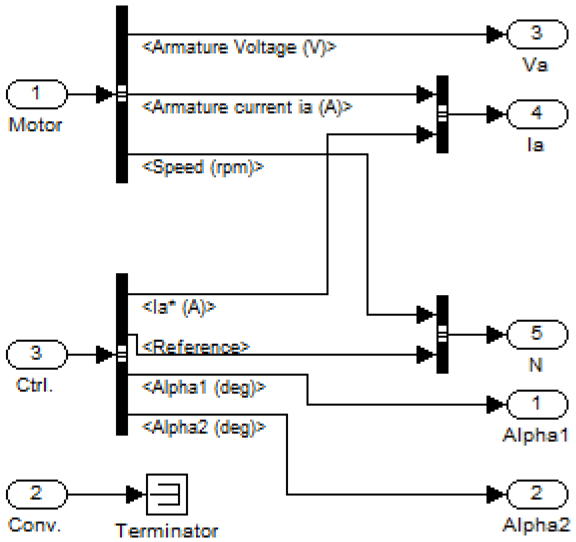
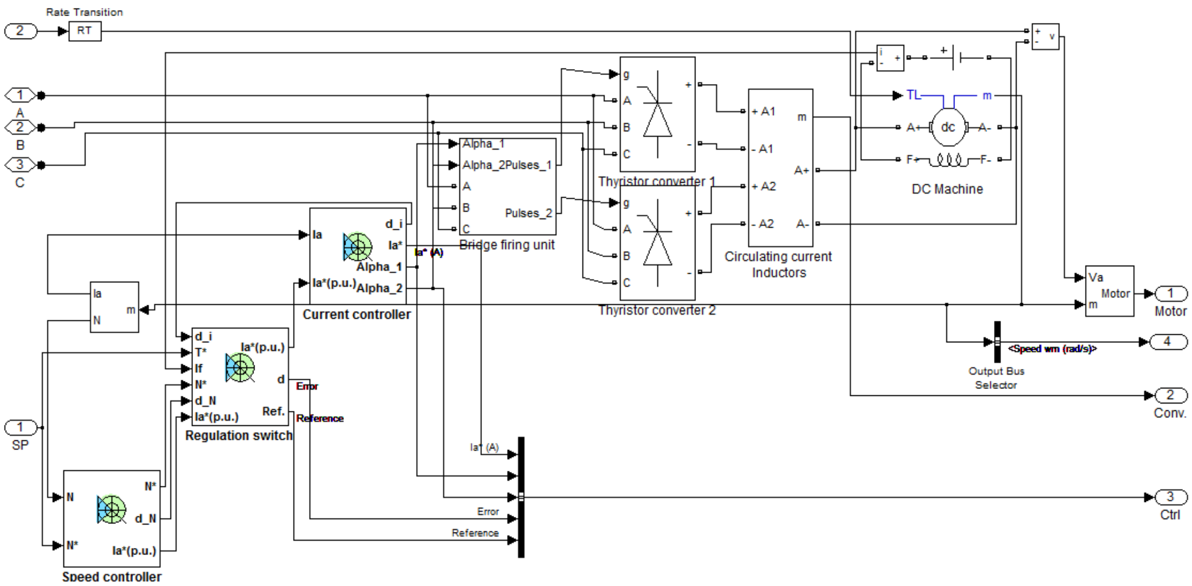
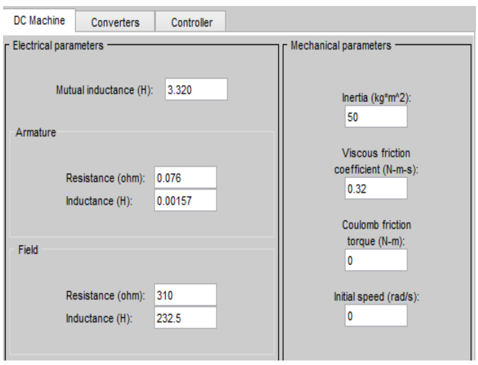


Figure: Signal Selector

Under the mask of Four-Quadrant Three-Phase Rectifier DC Drive



Different parameters of DC Machine and Controller (P, I controller) of DC4:



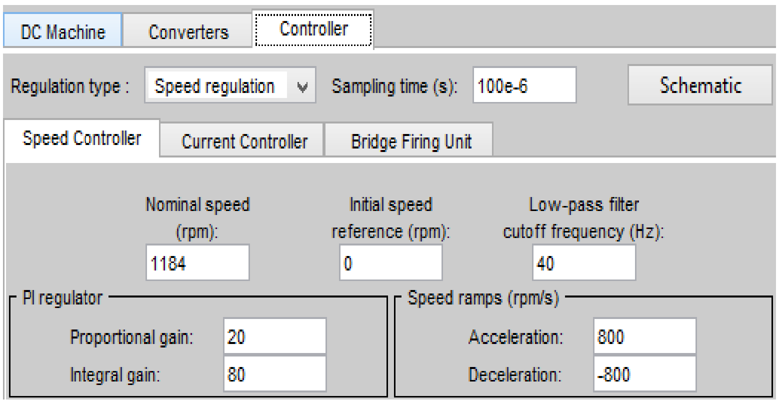
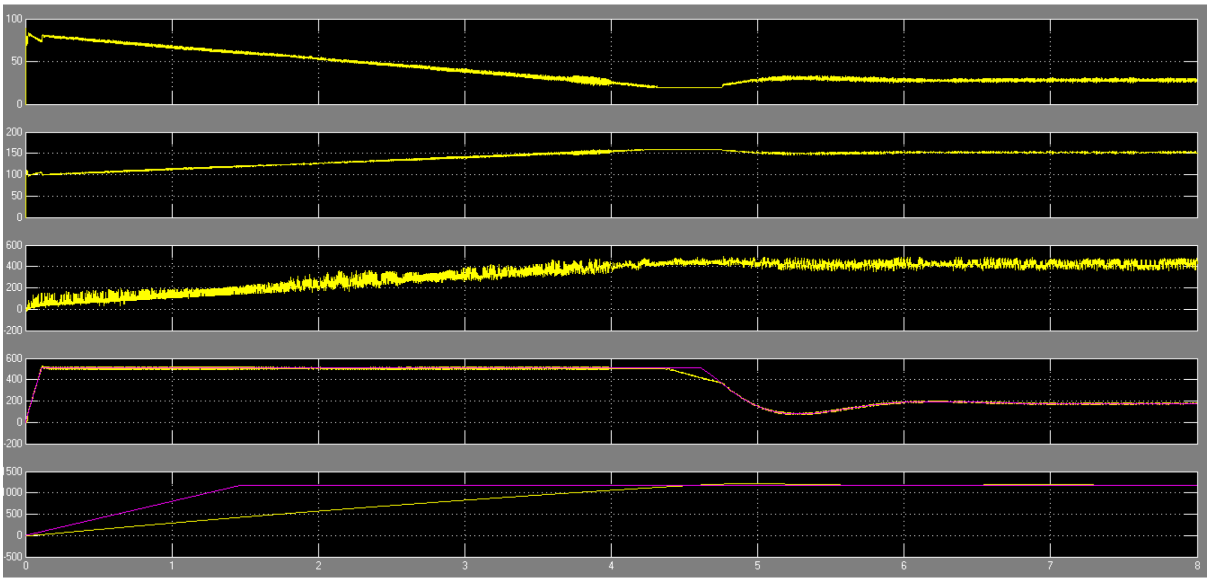


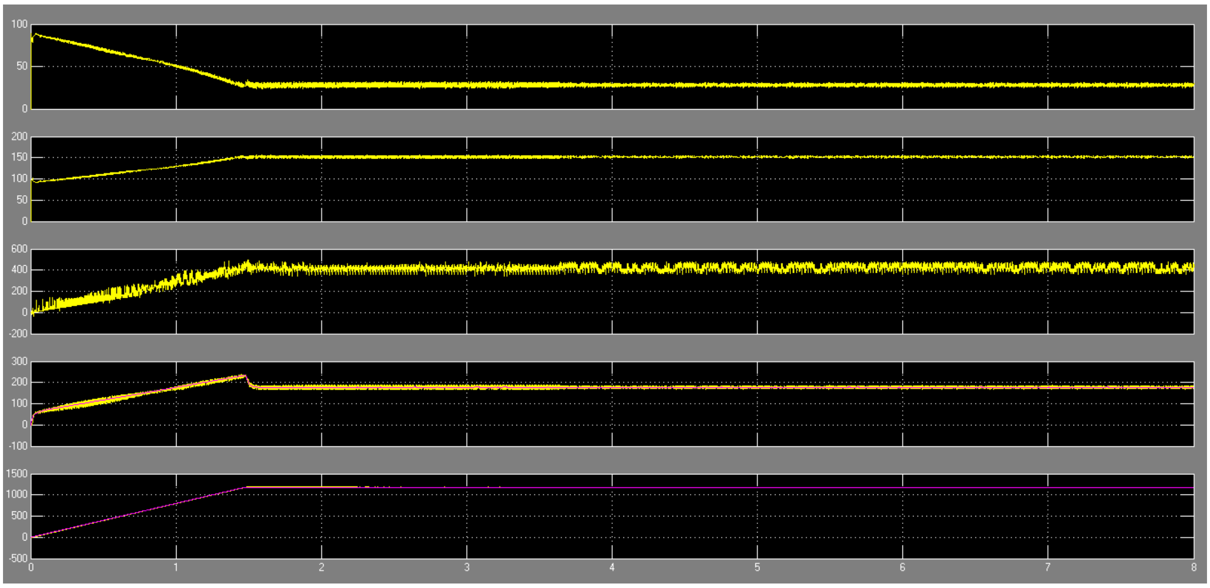
Figure: Different parameters for the DC4 Model

OUTPUT:



Changed parameters of DC Machine and Controller (P, I controller) of DC4

if we change the parameters then the out put we get is:



Chapter 4

Fuzzy logic

4.1. Fuzzy logic controller (FLC)

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. The operation of a FLC is based on qualitative knowledge about the system being controlled .It doesn't need any difficult mathematical calculation like the others control system. While the others control system use difficult mathematical calculation to provide a model of the controlled plant, it only uses simple mathematical calculation to simulate the expert knowledge

The requirement for the application of a FLC arises mainly in situations where:

- The description of the technological process is available only in word form, not in analytical form.
- It is not possible to identify the parameters of the process with precision.
- The description of the process is too complex and it is more reasonable to express its description in plain language words.
- The controlled technological process has a “fuzzy” character.
- It is not possible to precisely define these conditions[5].

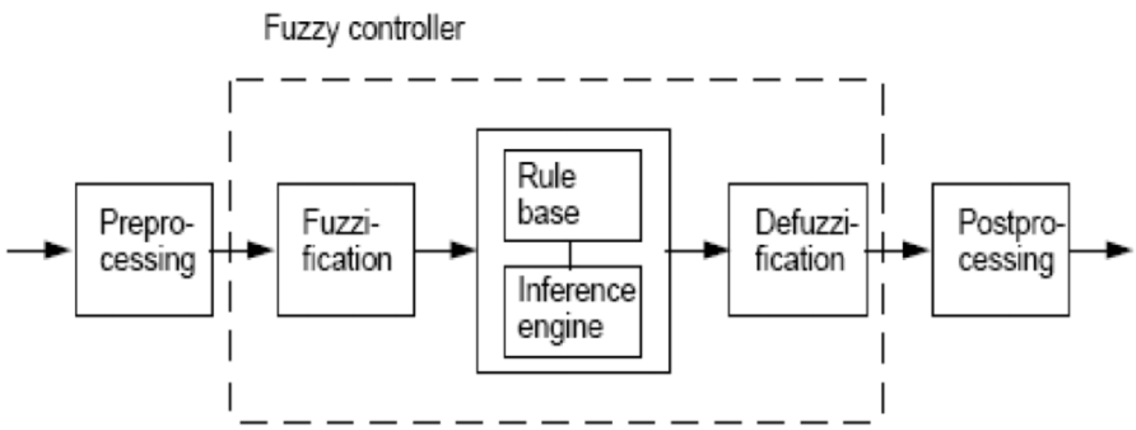
A fuzzy logic controller has four main components as shown in Figure:

a) Fuzzification

b) Inference engine

c) Rule base

d) Defuzzification



4.2: Fuzzification

The first step in designing a fuzzy controller is to decide which state variables represent the

system dynamic performance must be taken as the input signal to the controller. Fuzzy logic

uses linguistic variables instead of numerical variables. The process of converting a numerical

variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called fuzzification. This is achieved with the different types of fuzzifiers[6].

There are generally three types of fuzzifiers, which are used for the fuzzification process.

they are

1. Singleton fuzzifier

2. Gaussian fuzzifier

3. Trapezoidal or triangular fuzzifier

4.3: Rule base

A decision making logic which is, simulating a human decision process, inters fuzzy control

action from the knowledge of the control rules and linguistic variable definitions [7]. The rules are in "If Then" format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error (e) and change in error (de). In a rule based controller the control strategy is stored in a more or less natural language. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller

could be implemented using conventional techniques.

4.4: Inference engine

Inference engine is defined as the Software code which processes the rules, cases, objects or other type of knowledge and expertise based on the facts of a given situation. When there is a problem to be solved that involves logic rather than fencing skills, we take a series of inference steps that may include deduction, association, recognition, and decision making. An inference engine is an information processing system (such as a computer program) that s ystematically employs inference steps similar to that of a human brain[8].

4.5: Defuzzification

The reverse of Fuzzification is called Defuzzification. The use of Fuzzy Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number). According to real world requirements, the linguistic variables have to be transformed to crisp output[9]. There are many defuzzification methods but the most common methods are as follows :

1) Center of gravity (COG)
2) Bisector of area (BOA)
3) Mean of maximum (MOM)

4.5.1: Center of gravity (COG)

For discrete sets COG is called center of gravity for singletons (COGS) where the crisp control value is the abscissa of the center of gravity of the fuzzy set is calculated as follows:

$$u_{COGS} = \sum \frac{i\mu_c(x_i)xi}{i\mu_c(x_i)}$$

Where xi is a point in the universe of the conclusion (i=1, 2, 3…) and μc (xi) is the membership value of the resulting conclusion set. For continuous sets summations are replaced by integrals.

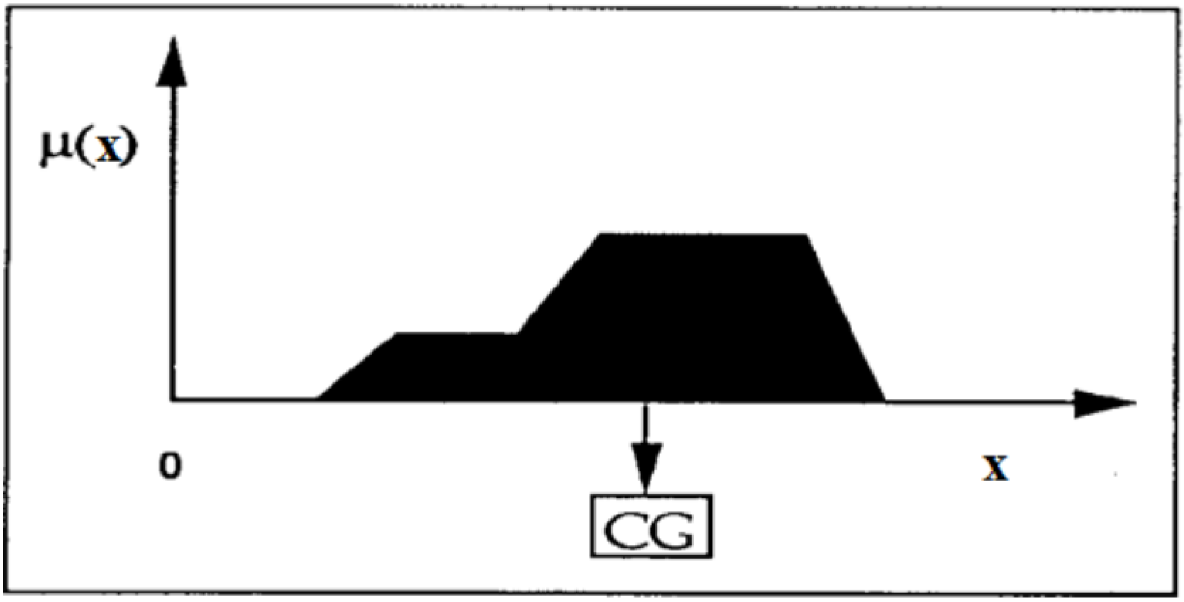


Figure 13: Illustration of centre of gravity method

4.5.2: Bisector of area (BOA)

The bisector of area (BOA) defuzzification[10] method calculates the abscissa of the vertical line that divides the area of the resulting membership function into two equal areas. For discrete sets, u BOA is the abscissa x j that minimizes

$$\left|\sum_{i=1}^{j} \mu_c(x_i) - \sum_{i=j+1}^{i_{max}} \mu_c(x_i)\right|$$

Where, i<j<i_{max}

Here imax is the index of the largest abscissa x imax. BOA is a computationally complex method.

4.5.3: Mean of maximum (MOM)

In this method the crisp value is to choose the point with the highest membership. There may be several points in the overall implied fuzzy set which have maximum membership value. Therefore it's a common practice to calculate the mean value of these points[11]. This method is called mean of maximum (MOM) and the crisp value is calculated as follows:

$$u_{MOM} = \frac{\sum i \in i x_i}{|I|}, \text{ I=\{i I } \mu_c(x_i) = \mu_{max}\}$$

Here I is the (crisp) set of indices i where µc(xi) reaches its maximum µmax, and | I | is its cardinality (the number of members).

Implementation of an FLC requires the choice of four key factors

1. Number of fuzzy sets that constitute linguistic variables.
2. Mapping of the measurements onto the support sets.
3. Control protocol that determines the controller behaviour.
4. Shape of membership functions.

Chapter 5

Fuzzy controller design

5.1: 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 below.

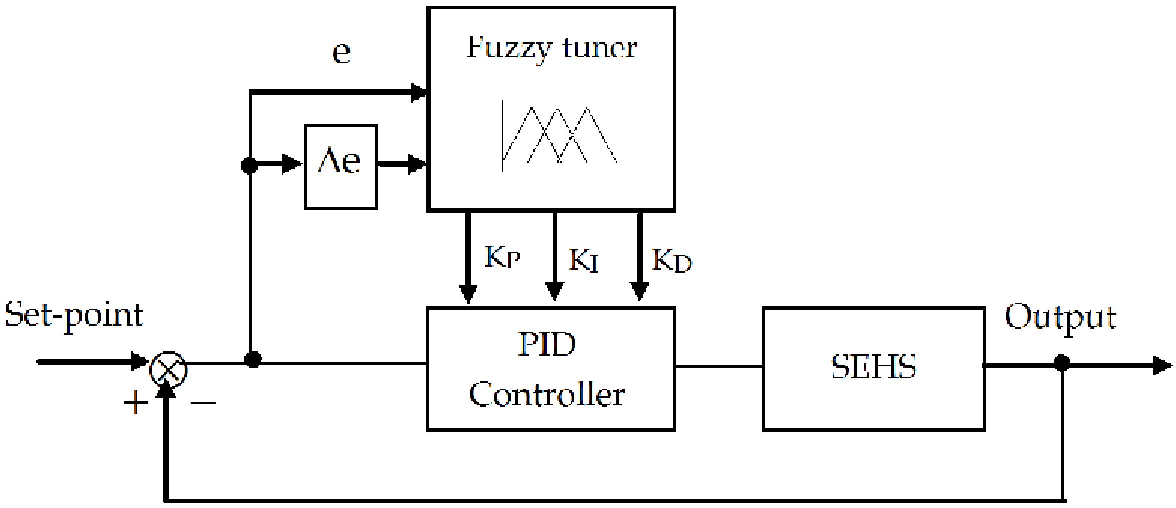


Figure : The structure of self-tuning fuzzy PID controller

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[12].

5.1.1: Adjusting fuzzy membership functions and rules

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 [15]. 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[13]

5.2: Design of Membership Function (MF)

Input Variables

Fuzzy sets of speed error (e) variable

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

Fuzzy sets of change in speed error (de) variable

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

Table : Membership function of change in speed error.

Output Variables

Fuzzy sets for KP

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

Table : Membership function proportional gain KP.

Fuzzy sets for KI

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

Table : Membership function integral gain KI.

Fuzzy sets for Kd

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

5.3: Design of Fuzzy Rules

Rule bases for tuning KP

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

Table : Fuzzy rule table for KP

Rule bases for tuning 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 : Fuzzy rule table for KI

Rule bases for tuning KD

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 : Fuzzy rule table for KD

Rule bases for tuning kp, ki, kd in short

de/e	NL			NS			ZE			PS			PL		
	Kp	*Ki*	*Kd*	*Kp*	*Ki*	*Kd*	*Kp*	*Ki*	*Kd*	*Kp*	*Ki*	*Kd*	*Kp*	*Ki*	*Kd*
NL	PVL	PM	PVS	PVL	PM	PMS	PVL	PM	PM	PVL	PM	PL	PVL	PL	PVL
NS	PML	PMS	PMS	PML	PMS	PML	PML	PMS	PL	PL	PMS	PVL	PVL	PMS	PVL
ZE	PVS	PS	PM	PVS	PS	PL	PS	PVS	PL	PMS	PS	PVL	PMS	PS	PVL
PS	PML	PMS	PML	PML	PMS	PVL	PML	PMS	PVL	PL	PMS	PVL	PVL	PMS	PVL
PL	PVL	PM	PVL	PVL	PM	PVL	PVL	PM	PVL	PVL	PM	PVL	PVL	PM	PVL

Chapter 6

MATLAB Simulation

6.1. Simulink Model

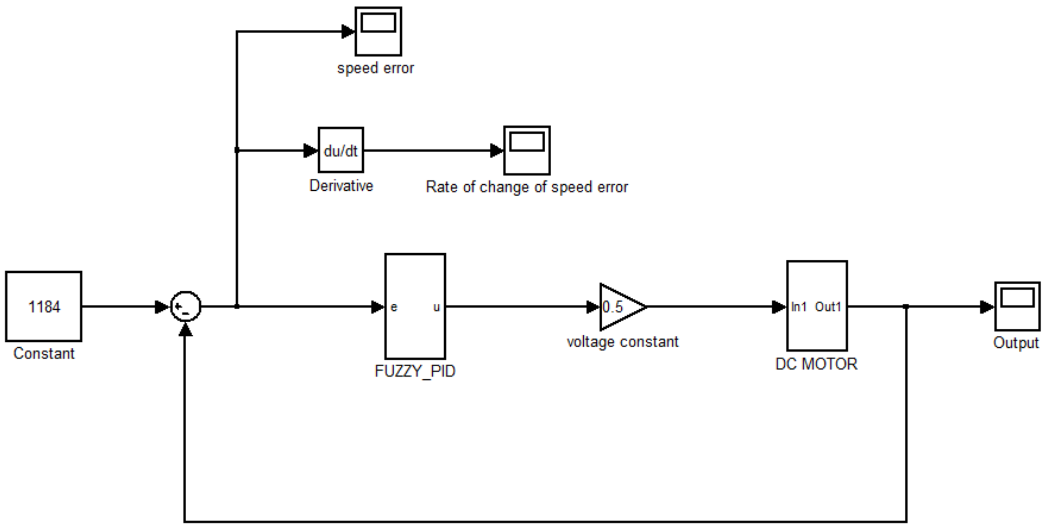


Figure : Simulink Model for Speed Control of Separately Excited DC motor using self-tunedfuzzy PID controller

- In the Simulink model we have used Fuzzy-PID as a controller of the speed of separately excited DC motor.
- The dc motor has some specifications.
- We have used an oscilloscope to observe the output wave shapes.
- We have used three separate oscilloscope in this model to observe the outputs of individual wave shape[14].

6.2. FUZZY-PID Controller Model

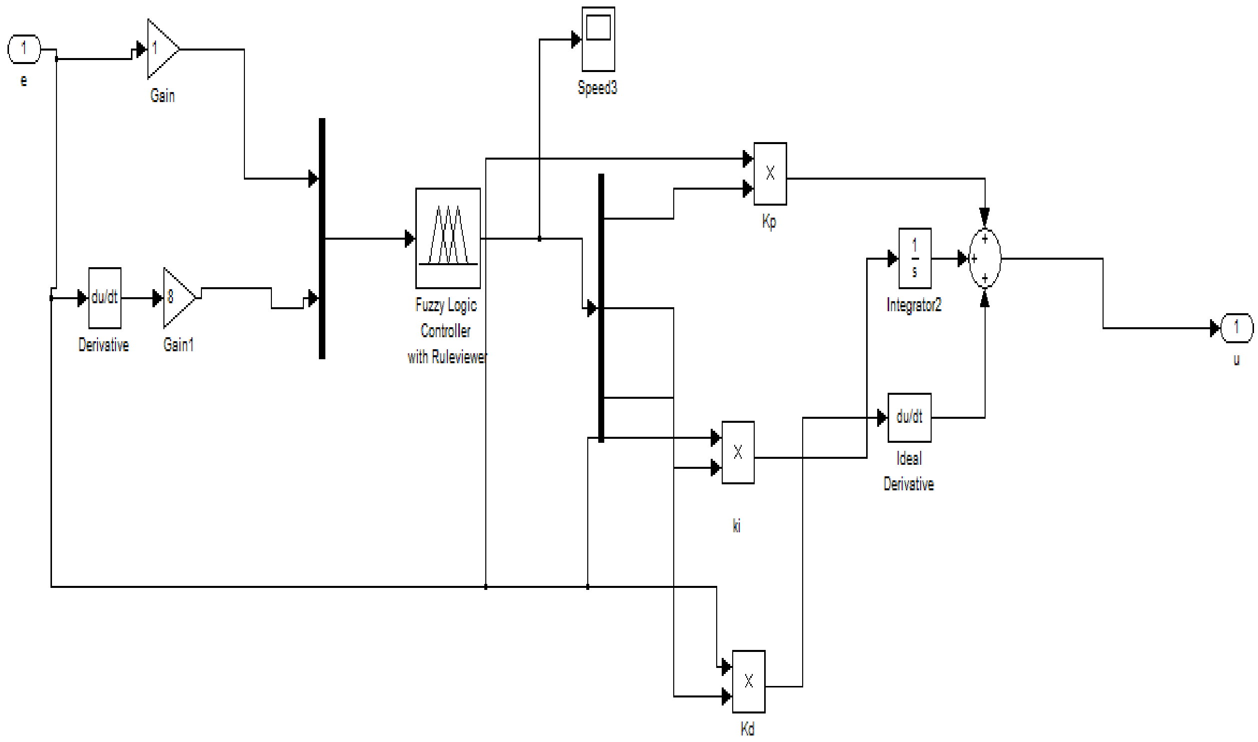


Figure : Simulink model of fuzzy-PID controller

- This is the overall Fuzzy-PID controller. PID is attached with the FUZZY logic controller.
- This fuzzy-PID is connected as the main controller with the main Simulink model before.
- The purpose of the usage of this kind of Fuzzy-PID is to control the speed of the separately excited DC motor[15].

6.3. DC MOTOR MODEL

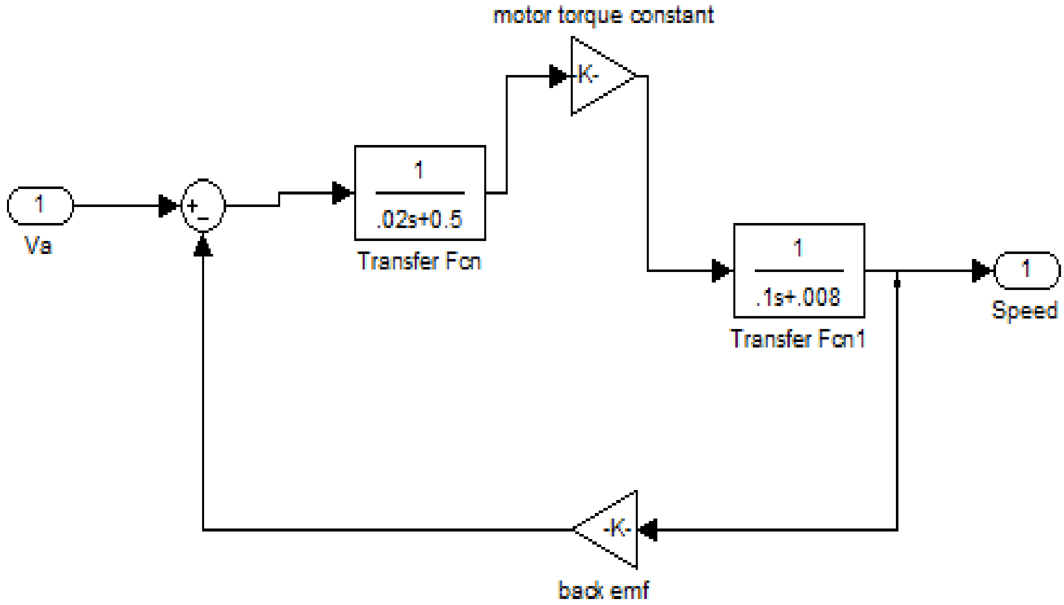
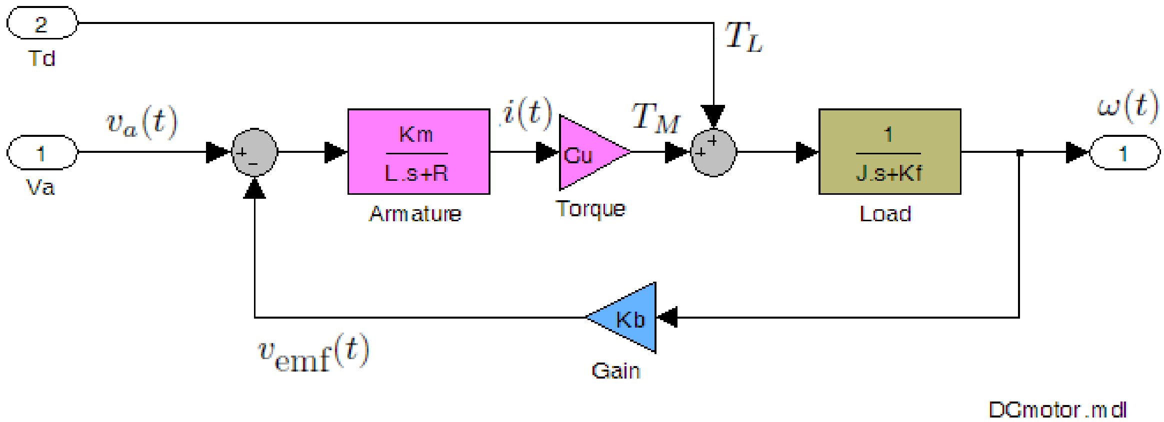


Figure : Model of separately excited dc motor

The meaning of the model:



- There is some specifications of this dc motor.
- This DC motor is a separately excited DC motor[16].

The specification of the DC MOTOR:

Description of the parameter	Parameter Value
Armature resistance(Ra)	0.5Ω
Armature induction(La)	0.02H
Armature voltage(Va)	200V
Mechanical inertia(jm)	0.1kg.m.m
Friction co-efficient(Bm)	0.008N.m/rad/sec
Back EMF constant(k)	1.25V/rad/sec
Rated Speed	1184 rpm
Motor torque constant	1 N.m/A

- The rated speed is 1184 rpm
- With this specification we have observed the out puts of the wave shapes
- And finally we got the desired result

6.4. FIS MODEL

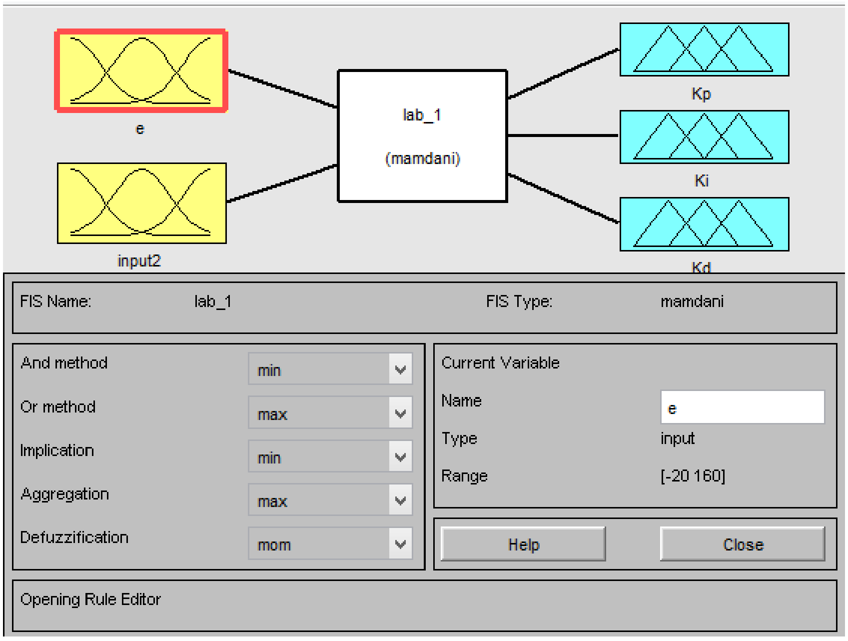


Figure : FIS editor

6.5. Ruler Viewer

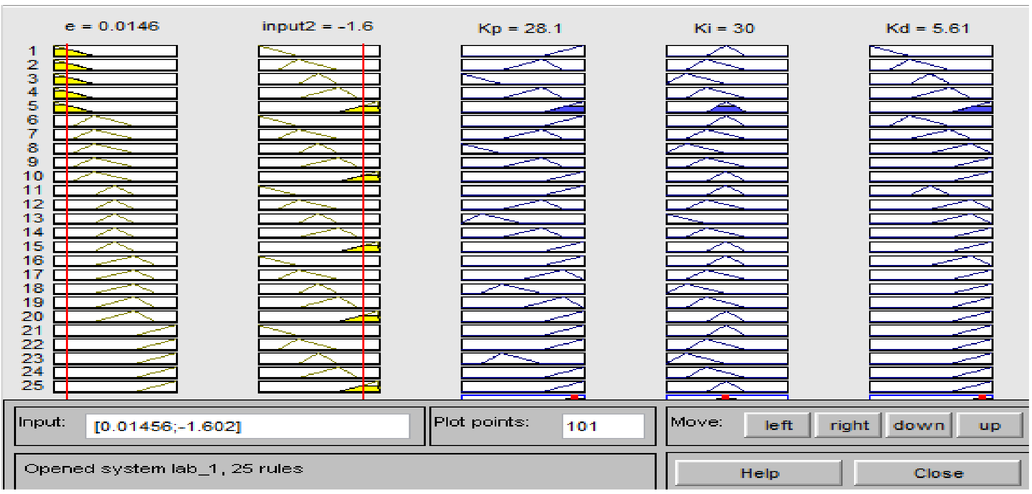


Figure : Rule viewer

6.6. Speed vs time OUTPUT

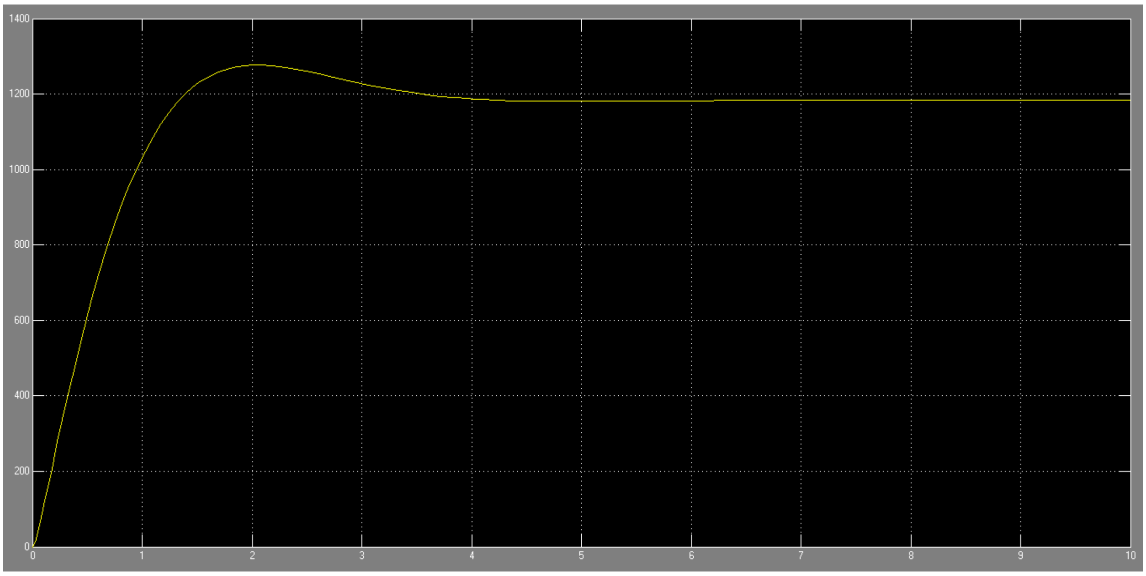


Figure: Speed Vs time response of fuzzy tuned PID controlled DC motor

6.7. Error vs time output

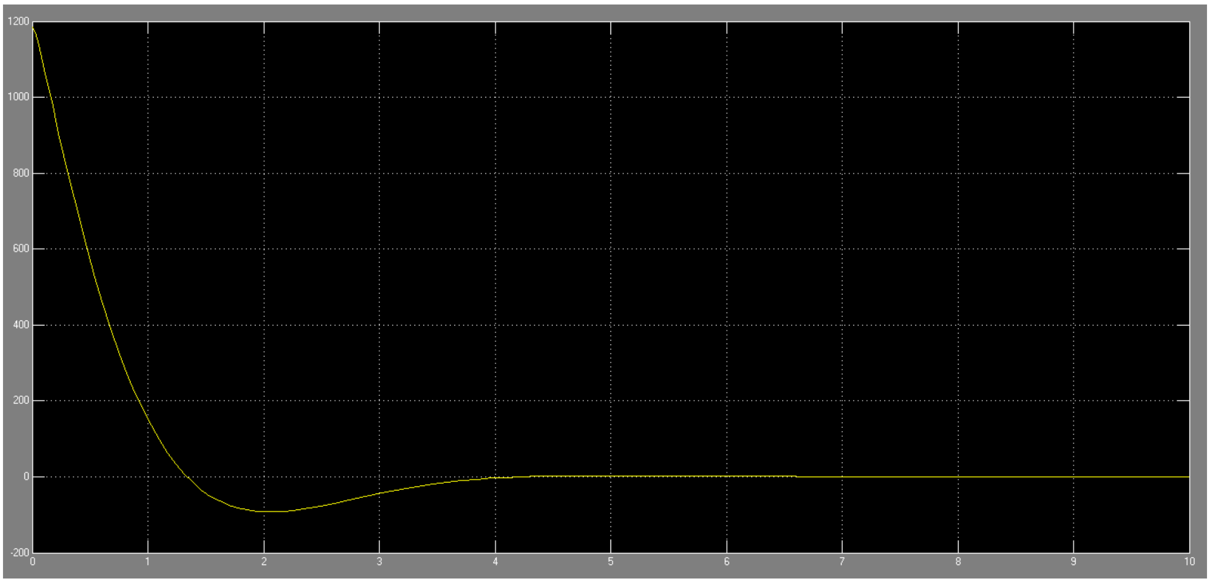


Figure: Error Vs time response of fuzzy tuned PID controlled DC motor

6.8. Change of speed Vs time

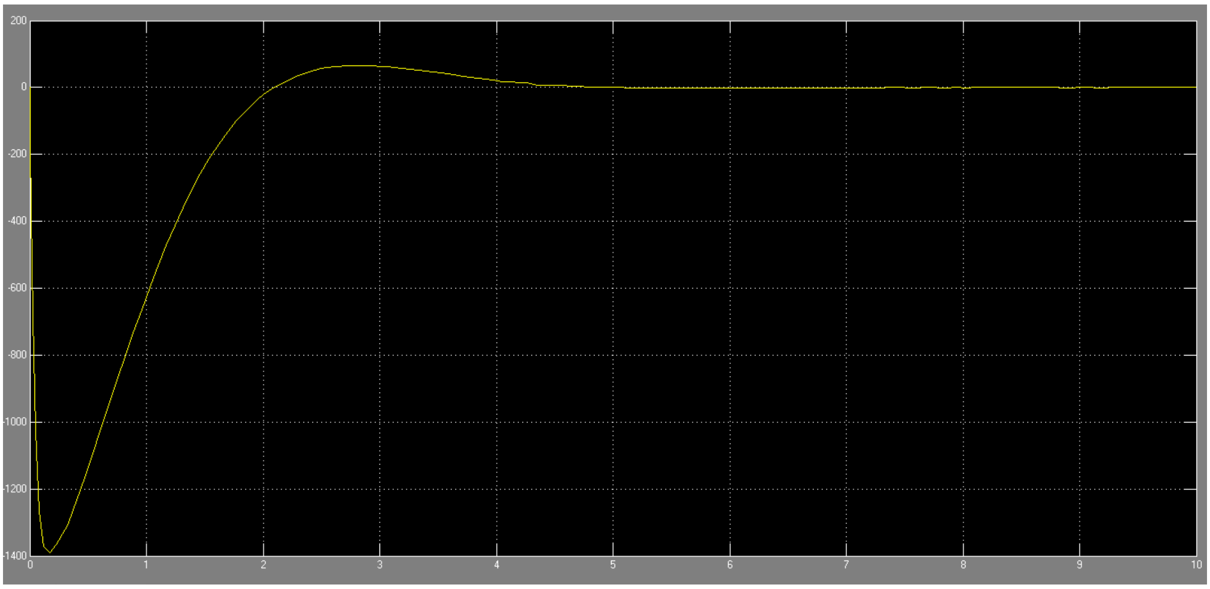
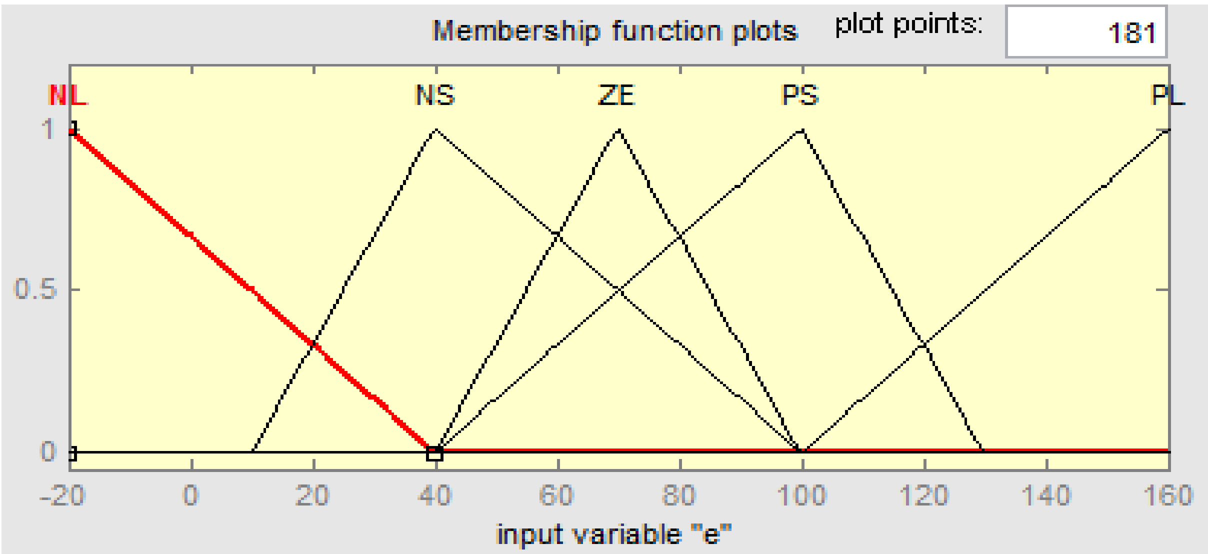


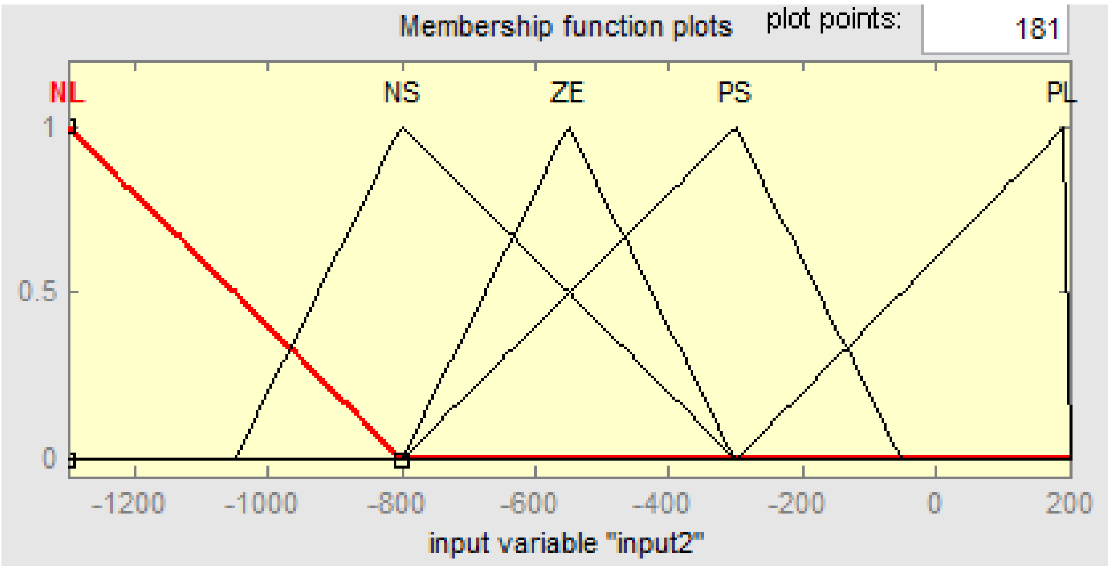
Figure: Change of speed Vs time response of fuzzy tuned PID controlled DC motor

6.9. Membership Functions

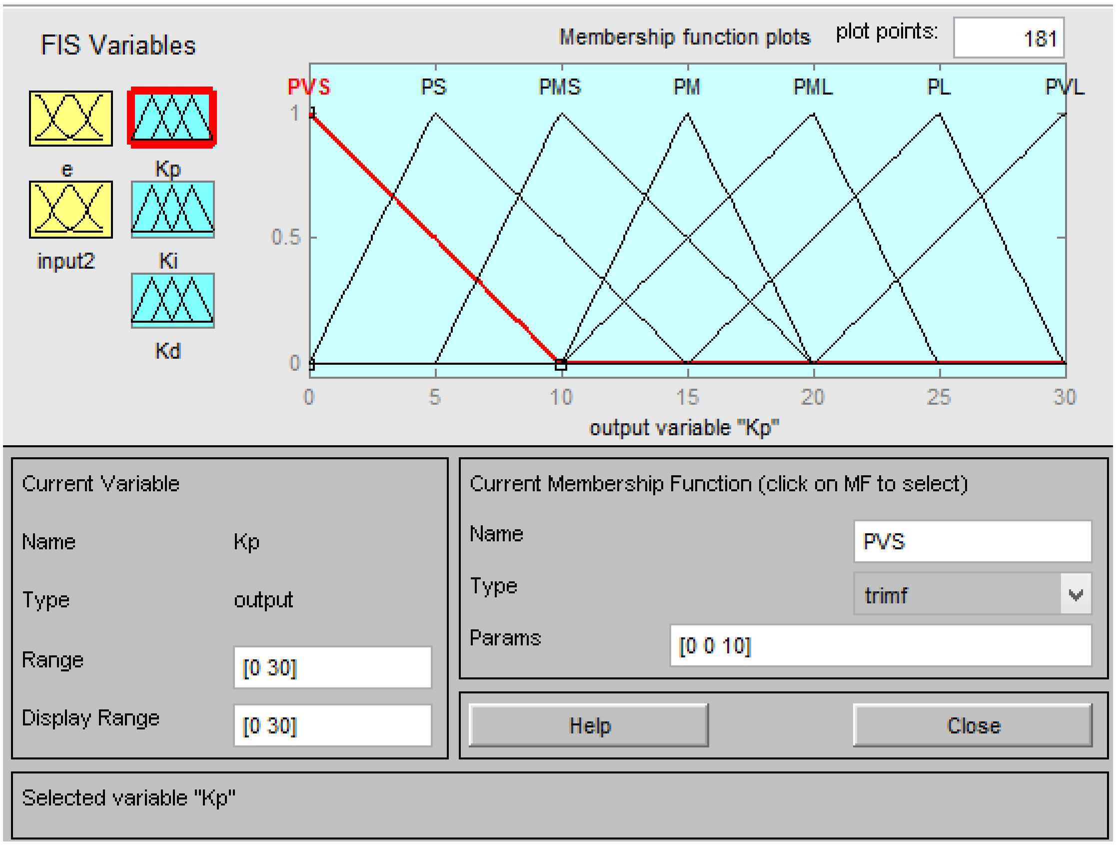
a. Membership function for input variable ‘e’



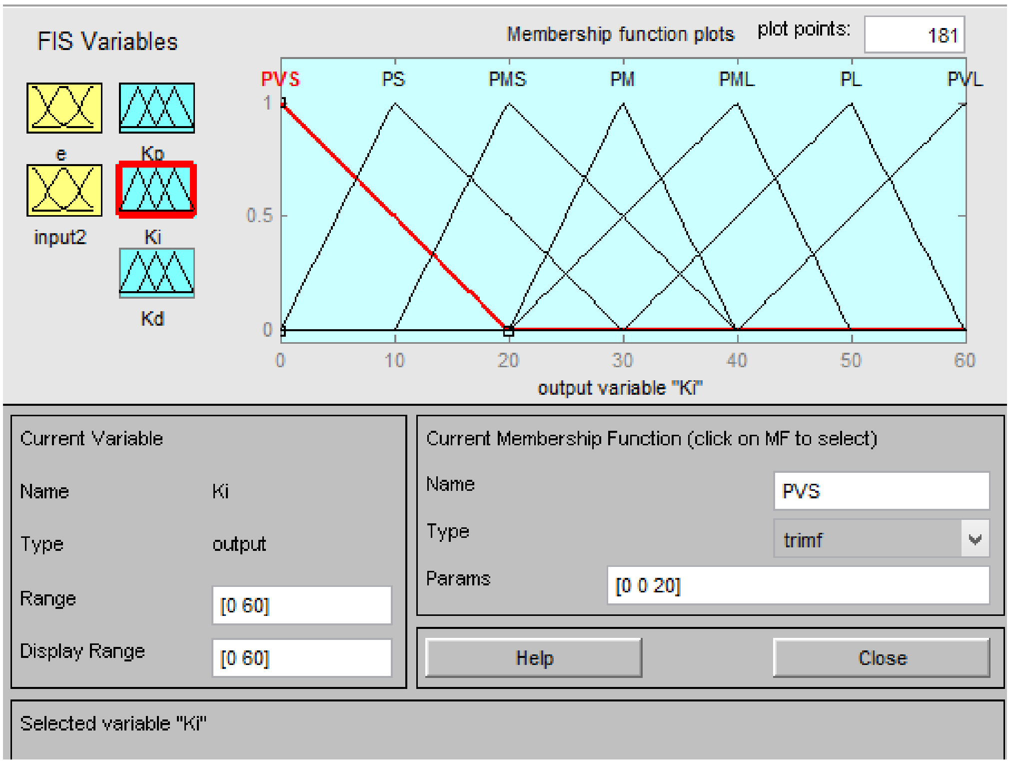
b. Membership function for input variable ‘De’



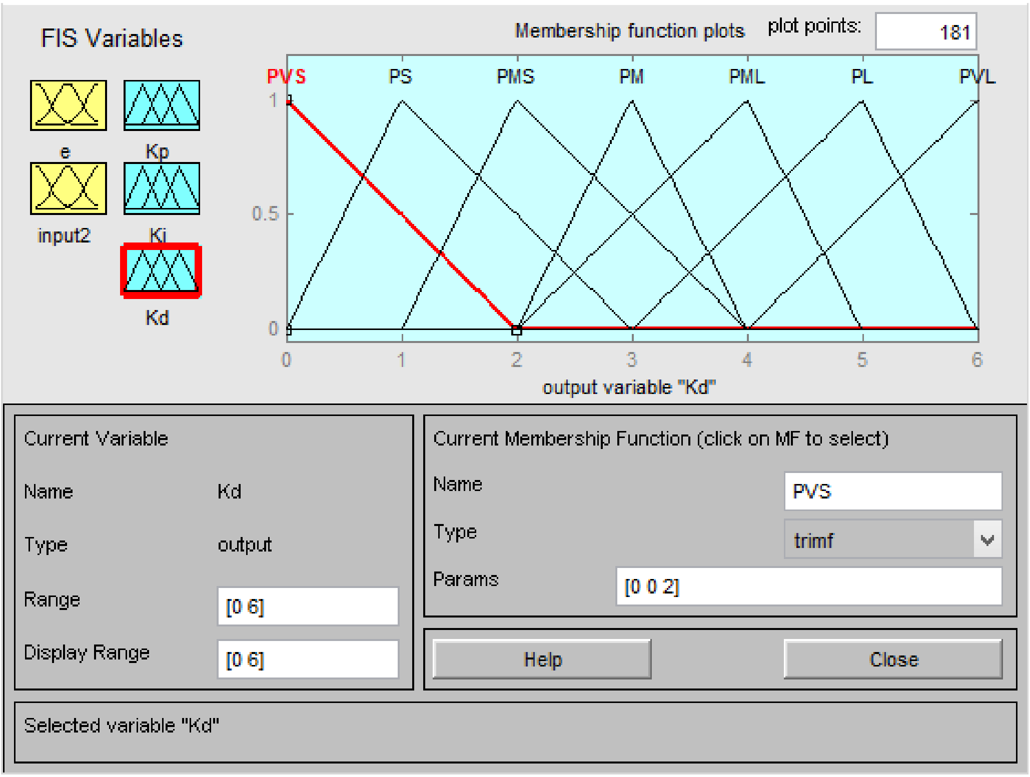
c. Membership function for input variable 'Kp'



d. Membership function for input variable ‘Ki’



e. Membership function for input variable ‘Kd’



Chapter 7

Conclusion

7.1. Summary:

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

In this project we have studied about different method for speed control of DC motor. The steady state operation and its various torque-speeds, torque-current characteristics of DC motor are studied. We also studied different methods like DC4 MODEL. We have also studied basic definition and terminology of fuzzy logic and fuzzy set. This project introduces a design method of two inputs and three outputs self-tuning fuzzy PID controller and make use of MATLAB fuzzy toolbox to design fuzzy 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.

7.2. Future research:

- So we should look forward to higher technologies for better result
- We should emphasize on some points,

  1. Mathematical modelling of motor response
  2. Hardware Improvement and
  3. Software improvement for the better performance.

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