A Comparative Study of Various Controllers for Azimuth Position Control of Reduced Order Antenna System

A Dissertation submitted in partial fulfilment of the
Requirements for the award of degree of

Master of Engineering
In
Electronic Instrumentation and Control

Submitted By
Ramandeep Saini
Roll No: 801251017

Under the Guidance of
Mr. Vikram Chopra
Lecturer, EIED
Thapar University, Patiala

Department of Electrical and Instrumentation Engineering
Thapar University
(Established under the section 3 of UGC act, 1956)
Patiala, 147004, Punjab, India
July 2014

DECLARATION

I hereby certify that the work is being presented in this thesis work entitled **"A Comparative Study of Various Controllers for Azimuth Position Control of Reduced Order Antenna System"** in partial fulfillment of award of degree of Master of Engineering in Electronics Instrumentation & Control submitted in Electrical & Instrumentation Engineering Department, Thapar University, Patiala is an authentic record of my own work carried under the supervision of Mr.Vikram Chopra (lecturer) , Department Of Electrical & Instrumentation Engineering, Thapar University, Patiala, Punjab.

Date: 17-7-14

Ramandeep Saini
801251017

I certify that the above statement made by the student is correct to the best of my knowledge and belief.

Date: 17/07/14

(Mr. Vikram Chopra)
Lecturer, EIED
Thapar University, Patiala
Punjab

Countersigned By:

(Dr.Ravinder Agarwal)
Professor & Head of
Electrical & Instrumentation
Engineering Department
Thapar University, Patiala.
Punjab

(Dr. S.K. Mohapatra)
Dean of Academic Affair
Thapar University, Patiala
Punjab

ACKNOWLEDGEMENT

I would have never succeeded in completing my task without the cooperation, encouragement and help provided to me by various personalities.

I am very thankful to **Prof. Prakash Gopalan,** Director of Thapar University, Patiala for providing the facilities for the completion of M.E. I express my deep sense of gratitude towards **Dr.Ravinder Agarwal**, Head of the Department of Electrical & Instrumentation Engineering, Thapar University, Patiala who has been a constant source of inspiration for me throughout this work.

With deep sense of gratitude I express my sincere thanks to my esteemed and worthy supervisor **Mr. Vikram Chopra,** Department of Electrical & Instrumentation Engineering, Thapar University, Patiala for his valuable guidance in carrying out this work under his effective supervision, encouragement, enlightenment and cooperation. Most of the novel ideas and solutions found in this thesis are the result of our numerous stimulating discussions. His feedback and editorial comments were also invaluable for writing of this thesis.

.

I am also thankful to all the staff members of the Department for their full cooperation and help. This acknowledgement would be incomplete if I do not mention the emotional support and blessings provided by my friends. I had a pleasant enjoyable and fruitful company with them.

Thapar University, Patiala Ramandeep Saini
Date 801251017

ABSTRACT

In this thesis, Antenna azimuth position is controlled by three controllers PID, Fuzzy and Fuzzy-PID .The transfer function of antenna system is a third order system which has been reduced to a first order system using two different model order reduction techniques ie. Half rule approximation and balanced truncation. The comparative analysis of different model order reduction techniques has been done using matlab/simulink .Various controllers ie. PID, fuzzy and fuzzy-PID are implemented on reduced order model to obtain the desired output

The performance of different controllers in the terms of various performance specifications such as rise time, settling time, peak overshoot, integral square error (ISE), integral absolute error(IAE) and integral time absolute error(ITAE) has been compared. simulation results reveals that fuzzy controller outperforms PID controller in the terms of rise time, settling time and peak overshoot while fuzzy-PID controller outperforms fuzzy controller in the terms of settling time and rise time.

Table of Contents

CHAPTER 1

CHAPTER-2

CHAPTER-3

CHAPTER-5

List of figures

List of tables

LIST OF SYMBOLS AND ABBREVIATIONS

PID	Proportional integral derivative
PI	Proportional Integral
PV	Process Variable
K_c	Controller Gain
K_p	Proportional Gain
K_i	Integral Gain
K_d	Derivative Gain
T_i	Integral Time
T_d	Derivative Time
PB	Proportional Band
K_{cr}	Ultimate Gain
P_{cr}	Ultimate Period Of Sustaining Oscillations
GA	Genetic Algorithm
FIS	Fuzzy Inference System
MIMO	Multiple Input and Multiple Output
MISO	Multiple Input and Single Output
TSK	Takagi-Sugeno-Kang
Ts	Settling Time
Mp	Peak Overshoot
ISE	Integral Square Error
ITAE	Integral time absolute error
IMC	Internal model control
SIMC	Simple internal model control

BLOCK DIAGRAM PARAMETERS

K	Amplifier Gain
KI	Power Amplifier Gain
a	Power Amplifier pole
K_m	Motor and Load gain
A_m	Motor and Load pole
K_g	Gear Ratio

CHAPTER-1

INTRODUCTION

1.1 Introduction of antenna azimuth position control system

Automatic control system is essential in any field of engineering and science. Automatic control is integral part of space-vehicle system, robotic system and modern manufacturing system and any industrial system involving control of temperature pressure, humidity [1]. The familiar example is steering of an automobile. The driver observes the location of the car relative to the preferred location and makes improvements by turning the steering wheel. The car reacts by changing direction and the driver try to decrease the error between the desired and actual route of travel and in this case the controlled output is the automobile's path of travel and the control system consist of driver, the automobile and the road plane. The control system has a number of examples, but our main focus is its application in electromechanical systems.

The control system design for an antenna was discussed by Norman S. Nise [1]. The key purpose is the movement of a large antenna by adjusting the potentiometer manually from a control tower.

Okumus, H.I. [2] proposed that the PI controller, fuzzy logic controller and a self-tuning fuzzy logic controller for azimuth position control of the antenna .the input of the fuzzy logic controller is error and change in error and the output is desired azimuth angle .The performance of proposed controller is better than the other controllers in terms of the settling time and overshoot.

Boban Temelkovskia[3] describes the management system of the antenna position in the frequency range and in the state space representation also known as time–domain approach. The results of systematic calculations and programming in Matlab/Simulink will give the clear explanation of the response of the system.

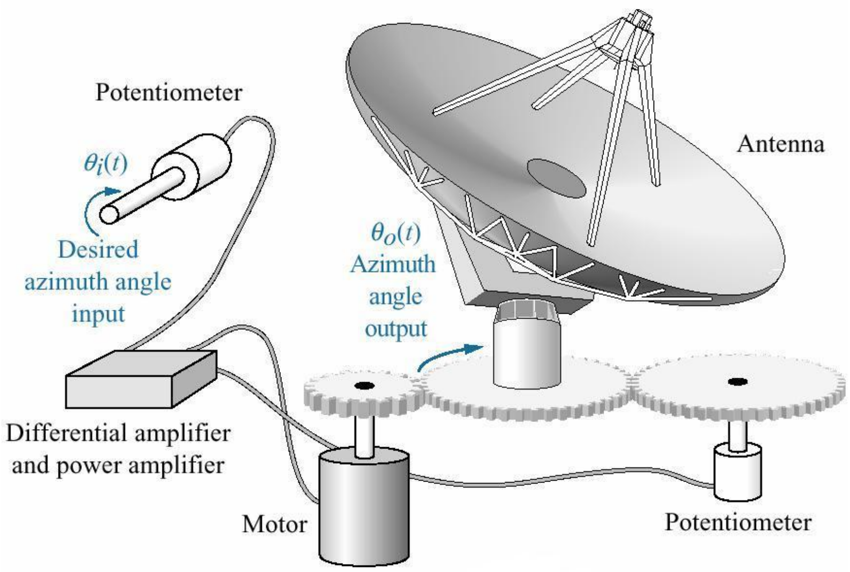


Figure1.1 pictorial view of antenna azimuth control system [1]

1.2 System description

Above figure shows the pictorial view of the antenna azimuth position control system.

The basic operation of the system is explained as follow

When power is applied to a potentiometer and the knob of the potentiometer is rotated to a certain position. There is some voltage difference from the source and the new position which is then measured. The new measured voltage is sent to a preamplifier as a voltage signal. The result of the preamplifier which is the amplified signal by a gain “K” will be sent to a power amplifier.

The power amplifier input is a weak electrical signal which is amplified that is, it is made stronger so as to have a significant gain. Therefore, the signal received from the preamplifier will be amplified by the power amplifier and the resultant will be sent to a motor. The motor will be connected to different mechanical devices like gears, shafts etc.. Firstly, the motor is connected to a shaft and gear #1. Gear #1 is connected to a larger gear #2. Gear #2 is connected to gear #3. Gear #2 is also directly connected to the shaft of the antenna.

Once the motor powers gear #1 then gear #2 will start to rotate the antenna. Gear #3 and gear #2 have the same ratio. Another potentiometer is connected to Gear #3. That potentiometer is connected to the same voltage source as the first one. The feedback is given to the original preamplifier which is the difference between that potentiometer and the voltage source. Then the preamplifier will take the difference between the two voltage signals and output that result into the power amplifier. The antenna will be moved by the motor which would be derived by the power amplifier. The procedure will continue to until there is a voltage difference present between the two potentiometers in the system. The textbook has already provided the graphical.

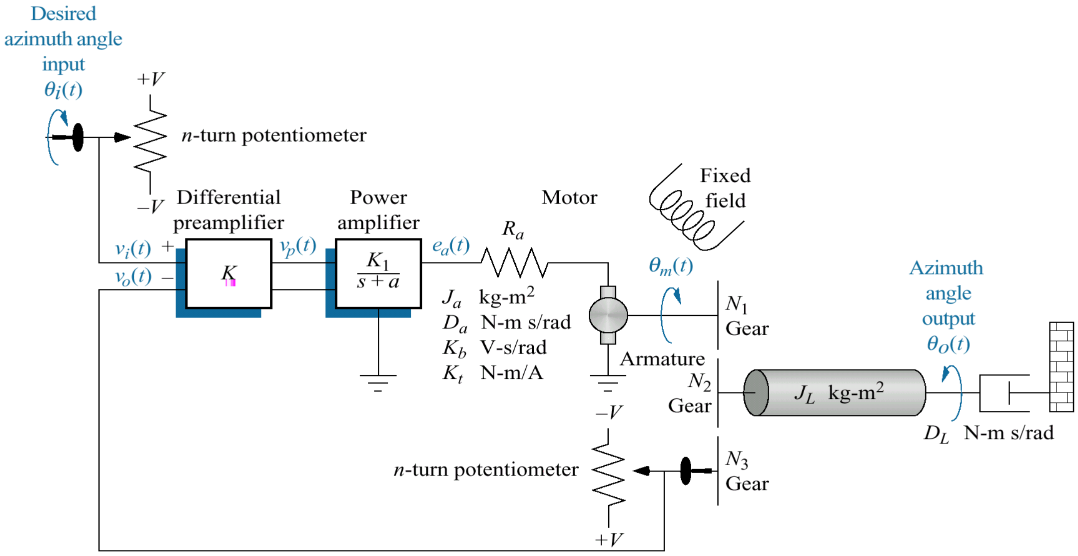


Figure 1.2 components used in antenna azimuth position control [1]

In the above block diagram, we can briefly see all parts of our physical system. At the top most position, there is the potentiometer which is controlled by the operator. The preamplifier receives the signal followed by the power amplifier. The result is forwarded to a motor (gyrator) then to a gear, which is connected to another gear for the movement of the antenna. Finally the antenna's signal is connected to another gear and a potentiometer. As shown above,[1] the feedback going back from the potentiometer into the differential pre amplifier. The most important factor is the feedback in determining whether our antenna is in the correct position or not.

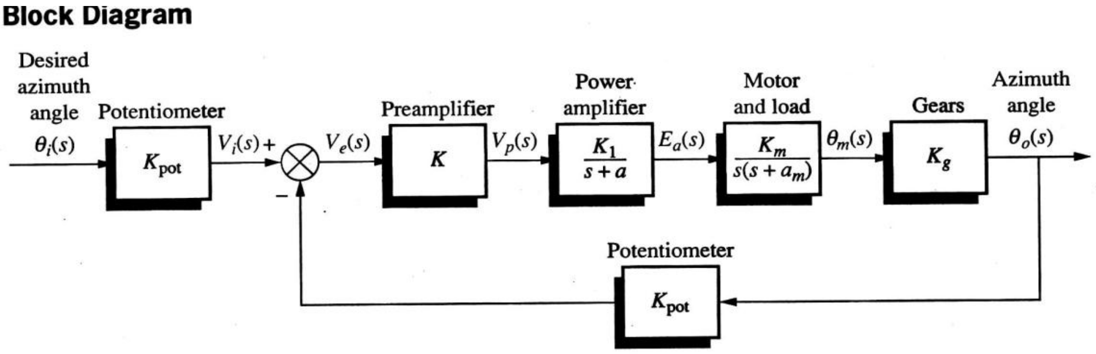


Fig1.3 Block diagram of antenna azimuth position control [1]

Table 1.1 shows all the parameters of block diagram

Parameters	**Values**
K_{pot_i}	3.18
K	1*
K_1	100
a	100
K_m	.8
a_m	1.32
K_g	.2

1.2.1Subsystem 1 and 5

The input and feedback potentiometer each have an associated transfer function, in the form of a gain. The potentiometer changes the input angle $\theta_i(s)$ to a voltage, Vi(s). This ratio is described by the value K_{pot_i}. This value is computed by Equation 1. The number of turns the potentiometer is built for, both of these values which are given in Table 1.

$$\frac{V(s)}{\theta_i(s)} = K_{pot\_i} = \frac{v}{n\pi} = \frac{10}{1*\pi} \qquad (1.1)$$

1.2.2 Subsystem 2

The principle of the preamplifier is to take the input signal voltage and output a voltage that the power amplifier which is used. The Preamplifier is modeled by a gain that can be précised by the design engineer to achieve a preferred output. The

Preamplifier is a system in which the input voltage is amplified by some gain K and act output as a voltage. The equation therefore is quite simple as shown in Equation 2.

$$\frac{Vp(s)}{Ve(s)} = K \qquad (1.2)$$

1.2.3 Subsystem 3

The second last subsystem is a Power Amplifier. It takes output voltage from the Preamplifier and converts it to a Voltage which is used by motor. This requires the Power Amp. to output a major amount of power, in which Preamplifier is not capable . The power amplifier type is given in the design diagram and the given block diagram and the value of k_1 and a in the transfer function are given in the design data.

$$\frac{Ea(s)}{Vp(s)} = \frac{k_1}{S+a} \qquad (1.3)$$

1.2.4 Subsystem 4

After the Power Amplifier is the motor which is attached to the gears and load which in this case is an antenna. All of these items must be considered when computing the transfer function of the resulting mechanical system. It is understood that the motor is an armature controlled DC servo motor. This is determined by the note that the motor has a fixed field, which also makes simple control of the motor

$$\frac{\theta_o(s)}{Ea(s)} = \frac{k_m}{s(S+a)} \qquad (1.4)$$

1.3 Transfer function of antenna azimuth position control system

$$\frac{\theta_o(s)}{\theta_i(s)} = G(S) = \frac{50.88}{s^3+101.32\,s^2+132s} \qquad (1.5)$$

1.4 Model order reduction

There are several methods of model order reduction, and it depends on the context which one is preferred [4]. Originally, model order reduction was developed in the area of systems and control theory for reducing their complexity, while preserving their i/p-o/p performance as much as possible. The field has also been taken up by numerical mathematicians. Nowadays model order reduction is a successful field of study, both in systems and control theory and in numerical analysis. This has a very strong effect on model order reduction as a whole, bringing together different techniques and different points of view, pushing the field forward quickly.

In order to deal with the simplification of dynamical models that may contain many equations and/or variables (10^3 – 10^9). Such simplification is needed in order to perform simulations within an acceptable amount of time and limited storage capacity, but with reliable outcome. In some cases, we would even like to have on-line predictions of the behavior with acceptable computational speed, in order to be able to perform optimizations of processes and products. Model Order Reduction tries to speedily capture the essential features of a structure.

This means that in an early stage of the process, the most basic properties of the original model must already be present in the smaller approximation. At a certain time the process of reduction is stopped. At that point all essential properties of the original model must be captured with sufficient precision. All of this has to be done automatically. In this paper all the simulation is done with the help of matlab software and selection of coefficients through the use of time response. we use model reduction to reduce model order we want to preserve model characteristics that are important for our application.

1.4.1 Model order reduction techniques

In this work two model order reduction techniques are used

1. Balance truncation reduction technique
2. Half rule approximation

1.4.1.1 Balance truncation model order reduction

Given a state space (A,B,C,D) of a system and k, the desired reduced order the following steps will produce a similarity transformation to truncate the original state space system to the k_{th} order reduced model [5].

Find the SVD of the controllability and observability grammians

$$P = U_P \Sigma_P V_P^T \qquad (1.7)$$

$$Q = U_q \Sigma_q V_q^T \qquad (1.8)$$

Find the square root of the grammians (left/right eigenvectors)

$$L_p = U_p \Sigma_p^{1/2} \qquad (1.9)$$

$$Lo = U_q \Sigma_q^{1/2} \qquad (1.10)$$

Find the SVD of $(L_O^T L_p)$

$$L_o L_p = U \Sigma V^T \qquad (1.11)$$

Then the left and right conversion for the final k_{th} order reduced model is

$$S_{L,BIG} = L_O U(:,1:k) \Sigma(1;k,1:k))^{-1/2} \qquad (1.12)$$

$$S_{R,BIG} = L_P V(:,1:k) \Sigma(1;k,1:k))^{-1/2} \qquad (1.13)$$

Finally

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} S_{L,BIG}^T A\, S_{R,BIG} & S_{L,BIG}^T B \\ C S_{R,BIG}^T & D \end{bmatrix}$$

1.4.1.2 Half rule to approximate the transfer function

The largest ignored (denominator) time constant (lag) is circulated evenly to the effective delay and the smallest retained time constant. let the original model be in the form

$$\prod_{j}(-t_{jo}^{INV} + 1) / \prod_{i}(-\tau_{io} + 1) * e^{-\theta_o s} \qquad (1.14)$$

Where the lags τ_{io} are ordered according to their magnitude and $T_{INV} > 0$ denote the inverse response (negative numerator) time constants [6]. Then, according to the halfrule, to obtain a first-order mode

$\frac{e^{-\theta s}}{\tau s+1}$, we use$\tau_{io}$

$$\tau_1 = \tau_{10} + \frac{\tau_{20}}{2} \qquad (1.15)$$

$$\theta = \theta_o + \frac{\tau_{20}}{2} + \sum_{i>3}(\tau_{io}) + \sum_{i>3} \tau_{j}{}_{JO}^{INV} + \frac{h}{2} \qquad (1.16)$$

1.5 Organization of thesis

Chapter 1- In this chapter introduction and modeling of antenna azimuth position control system is done and introduction of model order reduction technique. Literature survey on antenna azimuth position control system

Chapter 2- In this chapter introduction of PID controller and various tuning methods Ziegler Nichols, IMC, SIMC and their methodology

Chapter 3- In this chapter the introduction of fuzzy logic controller is described

Chapter 4- This chapter gives results and discussions

Chapter 5- The conclusion of entire thesis and future scope

CHAPTER-2

PID CONTROLLER AND VARIOUS TUNING METHODS

2.1 Introduction

Control Theory is that branch of Engineering and Mathematics which deals with the analysis design, and identification of systems with a vision of controlling them that is to make them perform discrete tasks. For example, when the pilot pushes the throttle, the translated action is in the form of control signal that makes the engine increase its power output by a specified amount. Thus, even though the controller of a system is used for a small period of time occasionally but its role is crucial [7].

Control theory has different definitions in different fields like psychology, sociology and criminology. Control theory is a theory that deals with affecting the working of dynamic systems. A controller directs the inputs of a system to obtain desired effect on output when one or more output variables of a system need to follow a certain reference over time. Control Theory is at the heart of communication and information technologies of multiplex systems. It can help in meeting the energy and environmental challenges which are being faced by the world.

Controllers are of two types mainly that is the open loop controller and the closed loop controller. In open loop controller, there is no connection present between the output of the system and the actual conditions are encountered; therefore, the system does not and cannot compensate for unexpected forces.

In a closed-loop controller system, the output is monitored by a sensor and the data goes to a computer which constantly adjusts the control input as required to keep the control error to a minimum. The main component of closed loop system is the feedback. This will allows the controller to dynamically compensate for disturbances to the system such as changes in slope of the ground .A feedback control system which cancels out all errors successfully mitigating the effects of any forces that might or not arise during operation and producing a response in the system that perfectly matches the user's wishes is known as ideal feedback control system, which is in reality cannot be achieved due to measurement errors in the sensors, imperfections in the control input and delays in the controller.

sigurad skogestad proposed analytic rules for PID controller tuning that are simple and still result in good closed-loop behaviour. He start with IMC-PID tuning rules that have achieved extensive industrial approval. There is a just a single tuning rule for a first-order or second-order time delay model. A Simple analytic rules for model reduction are presented to obtain a model in this form, including the ‘‘half rule’’ for obtaining the efficient time delay.

Hang, C.C proposed that the accuracy of Ziegler Nichols tuning method is reviewed for PID and PI automatic tuning and it will be shown that for excessive set point undershoot the Ziegler Nichols formula will have to modified

2.2 Historical view

There is a history of each and every thing that we study. The analysis of this field began with analysis of a dynamics of the centrifugal governor conduct by the physicist James Maxwell in 1868 entitled on Governors [7]. The phenomenon of "hunting", which lags in the system, can lead to overcompensation and unstable response was described and analyzed. Routh Hurwitz theorem was a result of study of Adolf Hurwitz of system stability using differential equations. Similarly different people studied the behaviors of a number of systems and gave different views and theorems.

2.3 Classical control theory

For eliminating the errors in the open loop control system, feedback was introduced. A Feedback controls the states and output of a dynamical system in a closed loop system [7].

It is called so as it is the information path between the inputs, example voltage given to a motor and the output, motor rotation, torque etc., which is being measured by the sensors and organized by the controller and from the controller, the control signal goes to the input closing the circuit. The closed loop controllers have a number of advantages over open loop controllers which are as follows.

- Stabilizes the instability.
- Variations in the parameters are reduced.
- Performance will be finer when the model parameters are not exact.
- Reference tracking performance is enhanced.
- Sometime, the closed loop control systems and the open loop control systems are used together for better performance of the system

2.4 Control loop basics

To understand the how a closed loop system works, an example is a must to be explained which is as follows; the temperature of the faucet water is maintained at desired temperature by adjusting the hot and cold faucet valves. Mainly it involves mixing of hot and cold stream. The temperature of water is sensed by a person by touching. So, they conduct the required action to adjust the hot and cold water valve till the desired temperature value is achieved. Sensing the temperature of water is homologous to process variable. Set point is the desired temperature. The input values are called the manipulated variable. Error is the difference between the set point and the temperature sensed and that tells whether the water is too hot or too cold. When the controller turns the valve on, it may be turned on slightly or may be fully turned on according to the amount of hot water is required, it is known as simple proportional control .In case, if the hot water doesn’t come out as per the demand, the controller may speed up the process by opening the hot water valve more and more as the time passes. This is an example of integral control [7]. When the error is small and if the change made is too high then it is equivalent to high gain controller and leads to overshoot and if the controller were to repeatedly make changes which is too large and repeatedly overshoot the target and output will oscillate around the set point in either a constant, growing or decaying sinusoidal. If the oscillations increase with time then the system is unstable and if they decrease the system is stable .If the oscillations remain at a constant magnitude the system is marginally stable.PID controllers are the controllers of choice for many of these applications, due to their well-grounded theory established history and simple setup and repairs necessities.

2.5 Close Loop Transfer Function

The reference is r and the output is y which is given back to the input r through a sensor measurement F. The difference between the reference and the output that is the error is taken by the controller P to change the inputs to the system control C [7].

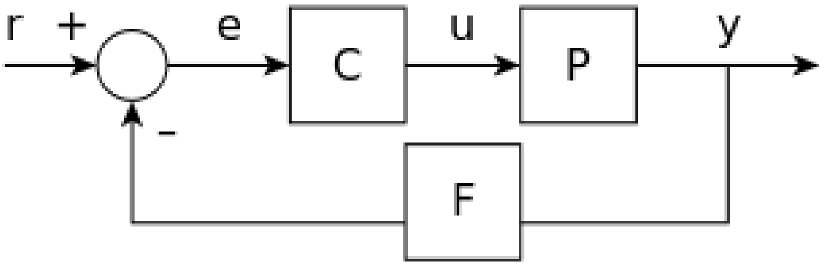


Figure 2.1 Close loop system [7]

- $Y(S) = P(S).U(S)$ (2.1)
- $U(S) = C(S).E(S)$ (2.2)
- $E(S)=R(S)-F(S).Y(S)$ (2.3)

Solving Y(S) in the terms of R(S) gives us

- $Y(S)=\left(\frac{P(S).C(S)}{1+F(S)P(S)C(S)}\right).R(S)=H(S).R(S)$ (2.4)

- $H(S)= \left(\frac{P(S).C(S)}{1+F(S)P(S)C(S)}\right)$ (2.5)

The above expression is referred to as the closed-loop transfer function of the system. The numerator is forward open loop gain from r to y and the denominator is one plus the gain in feedback loop so this is called loop gain.

2.6 PID Controller

The Proportional-Integral-Derivative (PID) controllers [8] are used regularly from the last 60 years in the process industry even though remarkable growth has been done in advanced control system. An investigation was conducted by Japan Electric Measuring Instrument Manufacturers Association in 1989 according to them 90 % of the control loops in companies are of the PID based. Power of the PID controller is that it also deals with main practical issues such as actuator dispersion and integrator windup. The integral action eliminates the steady state error and the proportional action tunes the controller output according to the vastness of the offset and the future is anticipated via derivative action. For the users these useful features are teeming for a large number of process control applications and the precision of the features lead to wide recognition. PID controllers perform well for a broad range of processes and they will give resilient presentation for a wide range of working conditions and are easy to execute using analog or digital hardware.

PID controller in a huge number is used in a single industrial process. The most essential thing is to tune the controllers perfectly to get the preferred response characteristics. Individual tuning is necessary to equalize the process dynamics to provide superior and robust control performance. By automatic tuning we mean methods which enable the controller to tune without human intervention on demand from an operator or an outer signal. If the tuning is done manually it is very irritating and time wastage so if the engineer has excellent process knowledge and experience then the resulting system performance will be good. It is approved that I practice many industrial control loops are poorly tuned. Auto tuning has overcome this trouble Therefore, researchers and engineers gave more and more concentration to Auto tuning. Normally the user will either push a button or send a command to the controller and Industrial practice has clearly indicated that this is highly attractive and useful aspect. The mathematical representation of PID controller is given by:

$$u(t) = k_p\, e(t) + k_d \left(\frac{de(t)}{dt}\right) + k_i \int_0^t e(t)\, dt$$

PID Controller Architecture in Time Domain and Laplace Domain [8]

PID controller involves three separate constant parameters and therefore is said to be three-term control. They are P stands for the proportional term I for the integral term and D for the derivative in the controller. PID controllers are apparently the most widely and commonly used industrial controller. Today, the most complex processes in the industry comprises of the PID control module as a main building block. The three-term PID controller is used from a long period and has sustained the changes of technology from the analog era into the digital computer control system age reasonably. This controller was the first and the only controller to be mass produced for the high volume market that existed in the process industries. A trial made for better understanding and performance study, an introduction of the Laplace transform was made which supported its technological success in the engineering community. The theoretical basis for studying the performance of PID control is considerably abetted by the simple representation of an Integrator by the Laplace transform of 1/s and a Differentiator using s. theoretically the PID controller is quite revolutionary and three different representations can be given. Firstly, it is represented symbolically and each of the three terms can be selected to achieve various control actions. Then there is a time domain operative form and finally there is a Laplace transform sort of the PID controller

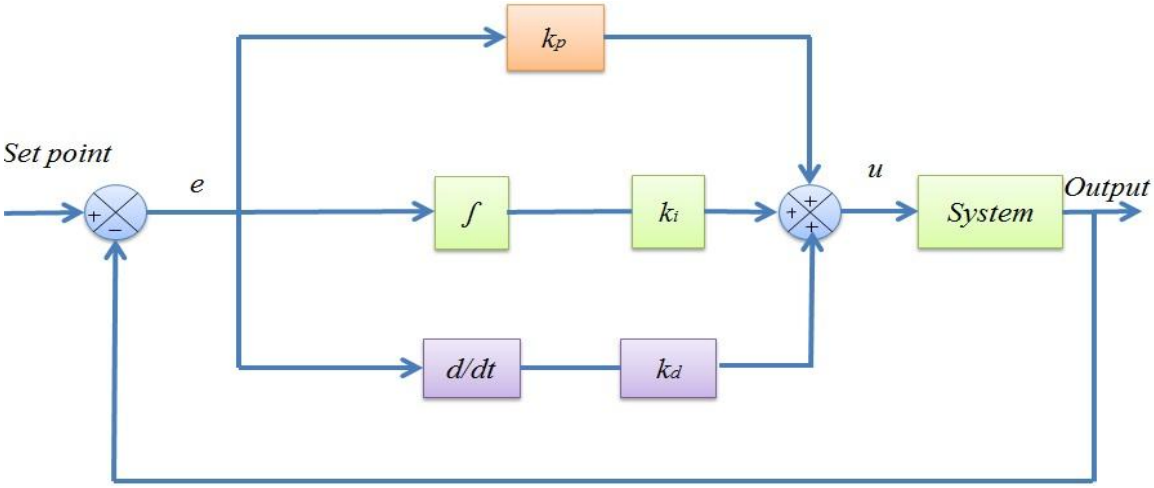


Figure 2.2 Block diagram of PID controller [8]

Table 2.1 Effect of parameters(k_p,k_i,k_d)on system

Parameters	**Rise time** **(t_r)**	**Overshoot** **(μ_r)**	**Settling time** **(t_s)**	**Steady state** **e_{ss}**
K_p	Decrese	Increase	Small change	Decrese
K_i	Decrese	Increase	Increase	Eliminates
K_d	Small decrese	Decrese	Decrese	None

2.7 Ziegler-Nichols tuning method

Ziegler Nichols derived simple mathematical method in the form of the first and second methods for PID controller tuning [9]. These methods are now standards in control system measurements. These techniques make deductive assumptions on the system model but this is not necessary that these models are specifically known. This formulae is based on plant model according to the plant model the parameters are calculated [9]. There are two methods of Ziegler-Nichols tuning

1. First method
2. Second method

2.7.1 First method

The first method is applied to plants with step responses of the form displayed in figure -. This type of response is typical of a first order system with time delay to apply this method we have to reduce the plant model into foptd (first order plus time delay). It is also typical of a plant made up of a series of first order systems. This reaction is characterized by two values L is the delay time and T the time constant [9]. These are created by drawing a tangent to the step response at its point of inflection and noting its intersections with the time axis and the steady value. The plant model is

- $G_1(s)=\frac{k}{Ts+1}e^{-Ls}$ (2.6)

Where G(s)= transfer function of the process

θ = time delay

τ_1 = Time constant

K= gain of the process

Table 2.1 Ziegler Nichols first method [9]

PID type	K_p	$T_i = \frac{K_P}{K_I}$	$T_d = \frac{K_d}{K_p}$
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	2L	0.5L

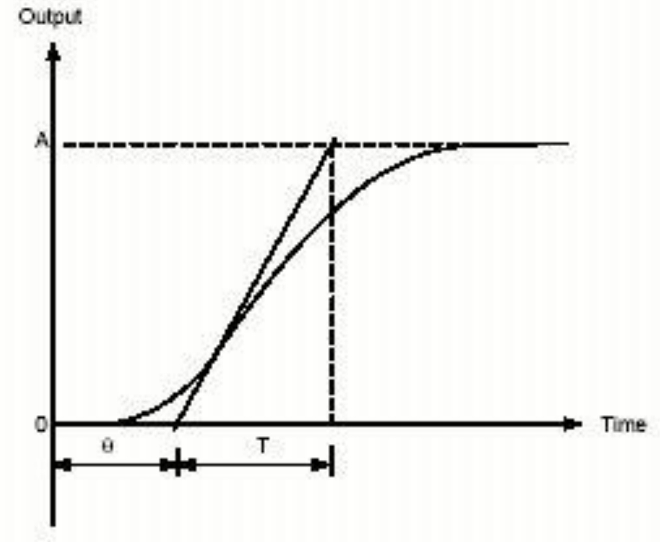


Figure 2.4 Response curve for Ziegler Nichols 1st method [9]

2.7.2 Second method

The second method is useful in plants which give unstable system under proportional control. The technique is intended to result in a closed loop system with 25% overshoot. This is rarely achieved as Ziegler and Nichols determined the adjustments based on a specific plant model [9].

The steps for tuning a PID controller by second method are as follows:

It uses only proportional feedback control:

- First decrease the integrator and derivative gains to 0.
- Increase K_p from 0 to some crucial value $K_p=K_{cr}$ at which sustained oscillations occur. If this condition i does not occur then another method is applied

Note the value K_{cr} and the equivalent period of sustained oscillation, P_{cr}.

Table 2.2 Ziegler Nichols second method [9]

PID type	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$.45K_{cr}$	$\frac{P_{cr}}{1.2}$	0
PID	$.6K_{cr}$	$\frac{P_{cr}}{2}$	$\frac{P_{cr}}{8}$

2.8 IMC-internal model control based feedback design for processes with time delay

In order to fine equivalent form for time delay processes, we have to approximate the dead time as we know that IMC strategy does not approximate dead time so we use pade approximation. We are only doing this for the IMC-Based PID procedure. We will use either a zero or a first-order Padé approximation for dead time. Example IMC-Based PID Design for a First-Order + Dead time Process. Find the PID controller which approximates IMC for a first-order + time-delay process [10].

$$G_p(s) = \frac{kp\, e^{-\theta s}}{\tau s+1} \qquad (2.7)$$

Step1. Use a first-order Pade approximation for dead time

$$e^{-\theta s} = \frac{-0.5\theta s+1}{0.5\theta s+1} \qquad (2.8)$$

$$G_p(s) = \frac{kp\ e^{-\theta s}}{\tau s+1} = \frac{kp(-0.5\theta s+1)}{(\tau s+1)(0.5\theta s+1)} \qquad (2.9)$$

Step2. Factor out the non-invertible elements

$$G_{p-}(s) = \frac{kp}{(\tau s+1)(0.5\theta s+1)} \qquad (2.10)$$

$$G_{p+}(s) = (-0.5\theta s + 1) \qquad (2.11)$$

Step3. Form the idealized controller

$$Q_1(s) = \frac{(\tau s+1)(0.5\theta s+1)}{kp} \qquad (2.12)$$

Step4. Add the filter - in this we will not make Q(s) proper, because a PID controller will not result. We use the “derivative” option, where we allow the numerator of Q(s) to be one order higher than the denominator

$$Q(s) = Q_1(s)\ f(s) = G_{p-}(s)\ f(s) = \frac{(\tau s+1)(0.5\theta s+1)}{kp} * \frac{1}{\lambda s+1} \qquad (2.13)$$

Now we have to find the PID equivalent:-

$$G_c(s) = \frac{Q(s)}{1-G(s)Q(s)} = \frac{Q(s)f(s)}{1-G(s)Q(s)f(s)} \qquad (2.14)$$

$$G_c(s) = \frac{Q(s)f(s)}{1-Gp+(s)Gp-\ Q(s)f(s)} = \frac{Q(s)f(s)}{1-Gp+(s)f(s)} = \frac{(\tau s+1)(0.5\theta s+1)}{kp(0.5\theta s+\lambda)s} \qquad (2.15)$$

$$G_c(s) = \frac{.5\tau\theta s2+(\tau+.5\theta)s+1}{kp(0.5\theta s+\lambda)s} \qquad (2.16)$$

So finally we obtained the PID parameters

$$K_c = \frac{(\tau + .5\theta)}{kp(0.5\theta s + \lambda)} \tag{2.17}$$

$$\tau_i = (\tau + .5\theta) \tag{2.18}$$

$$\tau_d = \frac{\tau\theta}{2\tau + \theta} \tag{2.19}$$

2.9 SIMC rule- Simple internal model control

The SIMC rules are derived using the method of direct synthesis for set points (Smith and Corripio 1985) or equivalently the IMC approach for Set point [6]. For the system in figure 1 the closed-loop set point response is

$$\frac{\mathrm{y}}{\mathrm{y(s)}} = \frac{\mathrm{G(s)C(s)}}{\mathrm{G(s)C(s)}+1} \tag{2.20}$$

The idea of direct synthesis is to identify the desired closed-loop response and solve for the corresponding controller [6].

$$\mathrm{C(s)} = \frac{1}{\mathrm{G(s)}\ \frac{1}{\frac{\mathrm{y}}{\mathrm{y(s)}}-1}} \tag{2.21}$$

$$\frac{\mathrm{y}}{\mathrm{y(s)}} = \frac{1}{\tau_c s+1} e^{-\theta s} \tag{2.22}$$

$$\mathrm{C(s)} = \frac{(\tau_1 s+1)(\tau_2 s+1)}{k} \cdot \frac{1}{\tau_c s+1-e^{-\theta s}} \tag{2.23}$$

tc is the desired closed-loop time constant, and is the sole tuning parameter for the controller.

To derive PID settings, we introduce in a first-order Taylor series Approximation of the delay, $e^{-\theta s} = 1 - \theta s$ This gives

$$\mathrm{C(s)} = \frac{(\tau_1 s+1)(\tau_2 s+1)}{k} \cdot \frac{1}{(\tau_c s+\theta)s} \tag{2.24}$$

This is series form PID controller

$$K_c = \frac{1}{k}\frac{\tau_1}{(\tau_c s+\theta)} \qquad (2.25)$$

$$\tau_i = \tau_1 \qquad (2.26)$$

$$\tau_d = \tau_2 \qquad (2.27)$$

For first order model

- $G_1(s) = \frac{k}{\tau_1 s+1} e^{-\theta s}$ (2.28)

The SIMC result in PI controller setting is

$$K_c = \frac{1}{k}\frac{\tau_1}{(\tau_c s+\theta)} \qquad (2.29)$$

$$\tau_i = \min\{\tau_1, 4(\tau_c+\theta) \qquad (2.30)$$

For second order model

- $G_2(s) = \frac{k}{(\tau_1 s+1)(\tau_2 s+1)} e^{-\theta s}$ (2.31)

SIMC method result in PID controller

$$K_c = \frac{1}{k}\frac{\tau_1}{(\tau_c s+\theta)} \qquad (2.32)$$

$$\tau_i = \min\{\tau_1, 4(\tau_c+\theta) \qquad (2.33)$$

$$\tau_d = \tau_2 \qquad (2.24)$$

CHAPTER-3

FUZZY LOGIC CONTROLLER

3.1 Fuzzy Logic: Introduction

Fuzzy Logic is an extension of Boolean logic. It assimilates the partial values of truth. Fuzzy logic doesn’t show a totally true or false statement rather it assigns a value which represents their extent of truth. In fuzzy systems, truth values are indication of values by a number. It lies in the range from 0 to 1. 0.0 represents absolute falseness and 1.0 represents absolute truth. Fuzzy logic uses expert knowledge to make decisions [11]. Fuzzification is generalization of theory from discrete to continuous. Fuzzy logic is crucial to artificial perception. Boolean logic solves either one extreme or the other whereas the Fuzzy logic allows computers to answer to a certain degree. Computers are permitted to think more like humans. Nothing in our perception is extreme. However, it is correct only to a faint degree. In fuzzy logic, machines are positioned to think in degrees. It solves complex problems where there is no simple mathematical model. Fuzzy logic helps to solve highly nonlinear processes. Fuzzy logic was first originated as a presentation scheme. It acts as calculus for unknown or vague opinions. Fuzzy logic has given basis for machines by resolving intermediate categories between syllabifies like true/false, hot/cold etc. Fuzzy logic is a trouble-solving control system technique. It has range of applications in systems from small, simple, embedded micro-controllers to large, multi-channel, networked PC or workstation-based data acquisition control systems etc. It can be enacted in software, hardware, or a amalgamation of mutually. Fuzzy logic provides a simple approach to enter at a definite conclusion. Cessation is based upon ambiguous or vague, noisy, imprecise, or missing input information.

Professor L.A. Zadeh [11] of the University of California in 1965, Berkely presented his paper delineation of fuzzy theory in which he initiated the basis of fuzzy set proposition and working, fuzzy logic based controller etc. In about 1970, fuzzy logic theory started producing results in Japan, Europe and China. In the year 1987, fuzzy logic logic-based automatic train operation control system was used in building 16 stations subway railway systems in sendai, Japan. The ride was very smooth as the riders do not require gripping straps, and the controller made seventy percent fewer judgmental errors in acceleration and braking that human operators do.

Chanchal Dey[25] proposed a self-tuning fuzzy PID controller is designed through constant updating of its output scaling factor. Instead of using a difficult three dimensional rule base for getting PID action in this paper one and two dimensional base used in parallel. self-tuning method offers improved performance of the proposed fuzzy PID controllers

Georg F. Mauer[14] explores the design of a fuzzy PID controller for a positional control system with totally uncertainty parameters. The controller adopts linear structures as a conventional one, but is improved with better presentation and performance Two types of fuzzy PD and fuzzy PI controllers with two inputs are used to achieve the varying gains develops their properties through connecting them in parallel to build the required fuzzy PID controller. This is achieved using two dimensional rule bases. PD and PI gain changes automatically with the output of the system under control.

Fuzzy logic is a methodology with a myriad of applications in embedded control and information processing. Fuzzy logic allows expressing this knowledge with subjective concepts such as very scorching, light red, and a extended time, which are mapped into exact numeric ranges.

In a sense, fuzzy logic is similar to human decision making with its potential to perform from approximate data and find simplified solutions.

Fuzzy logic is a pattern for an alternative design methodology, which can be utilized in evolving both linear and non-linear systems for embedded control. Fuzzy logic provides replacement solution to non-linear control because it is near to the real world. By using fuzzy logic, designers can observe that there are lower progress costs, better features, and enhanced end product results

3.2 Fuzzy Logic: A Choice to All Control Problems

Fuzzy logic offers several unique features that make it best option for many control problems. Fuzzy logic can operate nonlinear systems that would be difficult or impossible to model mathematically. As it is a rule-based action, any number of inputs can be functional and numerous outputs can be generated, although defining the rule base quickly make it complex if too many inputs and outputs are chosen for a single execution since rules defining their interrelations must also be clear. It would be superior to rupture the control system into smaller parts and utilize several smaller fuzzy logic controllers distributed on the system. Since the fuzzy logic controller processes user-defined rules governing the target control system, it can be improved and twitched easily to improve or drastically alter system performance. New sensors can easily be used into the system simply by generating appropriate governing rules [11].

Fuzzy logic is not restricted to a few feedback inputs and one or two control outputs, nor is it obligatory to measure or compute rate-of-change parameters in order for it to be utilized .It is immanently robust since it does not need accurate, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a level control function regardless of a wide range of input variations

3.3 Fuzzy Logic: Can Implement in All Control Problems

Establish the control objectives and criteria: What is to be controlled? What steps should be taken to control the system? What type of response do I require? What are the possible system failure modes?

Calculate the input and output correlation and get a minimum number of variables for input to the fuzzy logic engine, typically that are error and rate of change of error. Using the rule-based structure of fuzzy logic, make series of the control problem in IF X AND Y THEN Z rules that define the desired system output response for given system input setting. The amount and complication of rules depends on the number of input parameters that are to be processed and the number fuzzy variables related with each parameter. If possible, utilize at least one variable and its time derivative. Explain the meaning input and output terms employed in the rules by constructing fuzzy logic membership functions. Check the system, assess the results, tune the rules and association functions, and retest in anticipation of pleasing results are obtained.

3.4 Fuzzy Logic: Operations

The Fuzzy logic operation requires numerical parameters such as what is considered Important error and significant rate of change of error, but accurate values of these numbers are generally not critical unless very responsive performance is needed in which case empirical tuning would determine them.

3.4.1Fuzzy Logic: Types

- Type I Fuzzy Set
- Type II Fuzzy Set

The above two types of fuzzy sets are described follows:

3.4.1.1Type I Fuzzy Set

Universe of discourse is a collection of objects which is represented by X [12]. Degree of membership maps each element between 0 and 1. A fuzzy set A € X is characterized by membership function μ_A(x) which represents the degree of affiliation. It is:

$$A = \{\left(x, \mu_A\,(x)\right); x€X\}$$

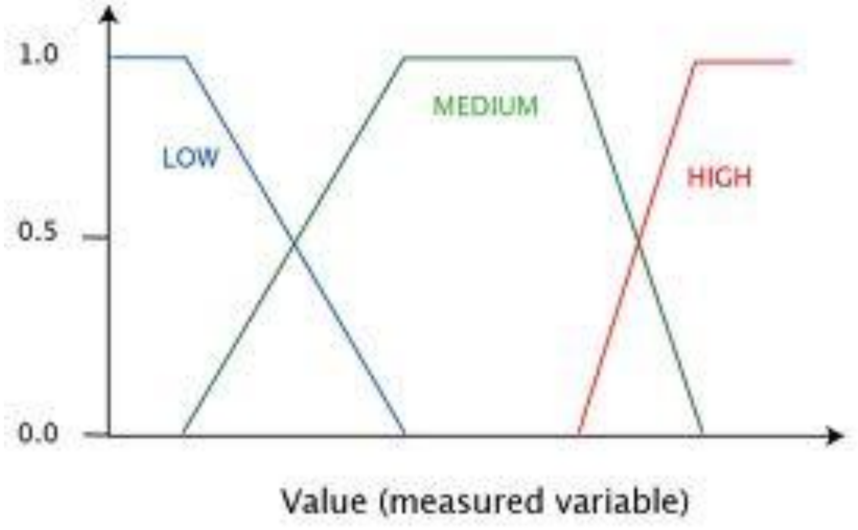


Figure 3.1Three semantic variables as low, medium and high are shown in above figure with the trapezoidal membership function [12]

3.4.1.2Type II Fuzzy Set

Extra third dimensions are utilized in the type-2 fuzzy set model. These sets are typically administered as points stored in an array. Type-2 fuzzy logic is divided in two different levels for the primary and secondary membership functions. In the case of generalized type-2 membership functions, where the secondary is a type-1 fuzzy number, the computational complexity is very large.

3.5 Fuzzy Inference System

Fuzzy inference systems (FIS) are directions-based systems. It is build on fuzzy set theory and fuzzy logic [12]. An output space mapping is done. FIS allows developing structures which are used to generate responses or outputs for certain stimulations or inputs. Response of FIS is based on stored knowledge or relationships between responses and restoratives. Acquaintance is stored in the form of a decree base. Decree base is a set of rules. Decree base expresses relations between inputs of system and its expected outputs.

Knowledge is obtained by extracting data from specialists and is called fuzzy expert systems. Another name for FIS is fuzzy knowledge-based system and also called as data-driven fuzzy systems. FIS are divided in two categories viz. multiple input and multiple output (MIMO) systems and multiple input and single output (MISO) systems, the system gives numerous outputs based on the inputs which it receives. Multiple input and single output systems are those in which from multiple inputs only one output is returned. MIMO systems are disintegrated into a set of MISO systems which works in parallel.

FIS has two general classes in terms of inference process:

1. Mamdani-type FIS
2. Takagi-Sugeno- Kang (TSK) type FIS

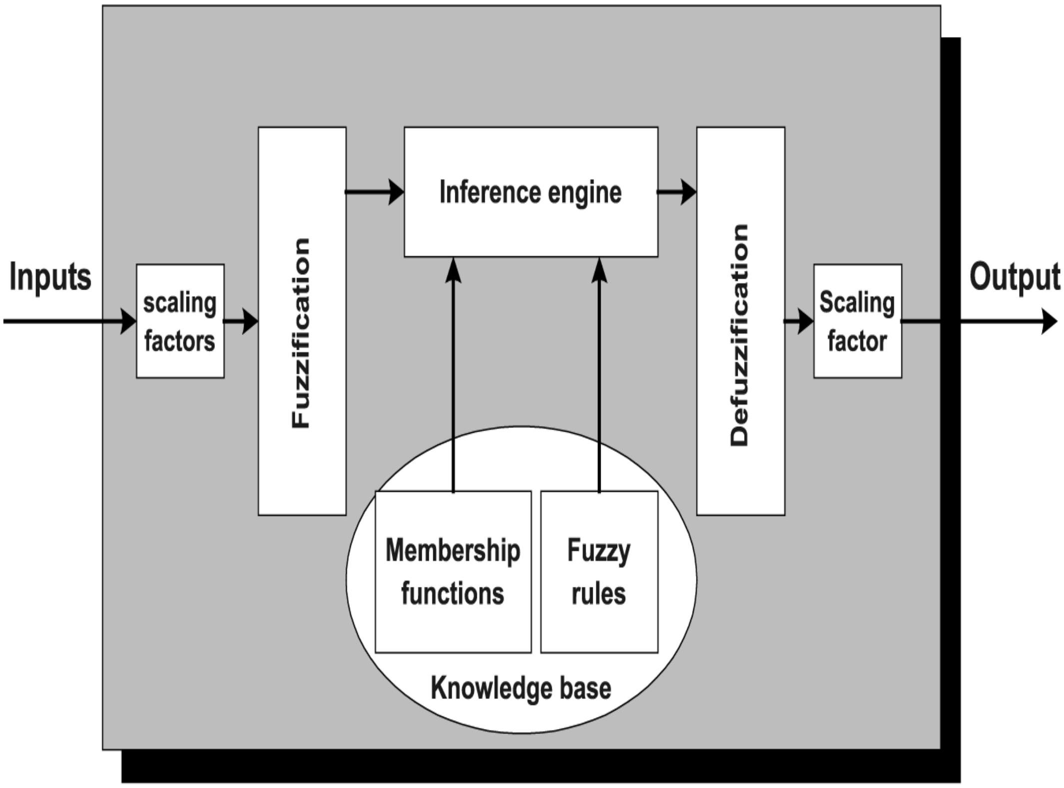


Figure 3.2 The above figure shows the block diagram of fuzzy logic system. It has various blocks: fuzzifier, knowledge base, inference unit and defuzzifier.[12]

3.5.1 Mamdani Based FIS

Inputs and outputs have If-Then rules in mamdani based fuzzy inference system. A typical rule in a sugeno fuzzy model is: IF X is Negative Big AND Y is Negative Small THEN Z is Zero[12].

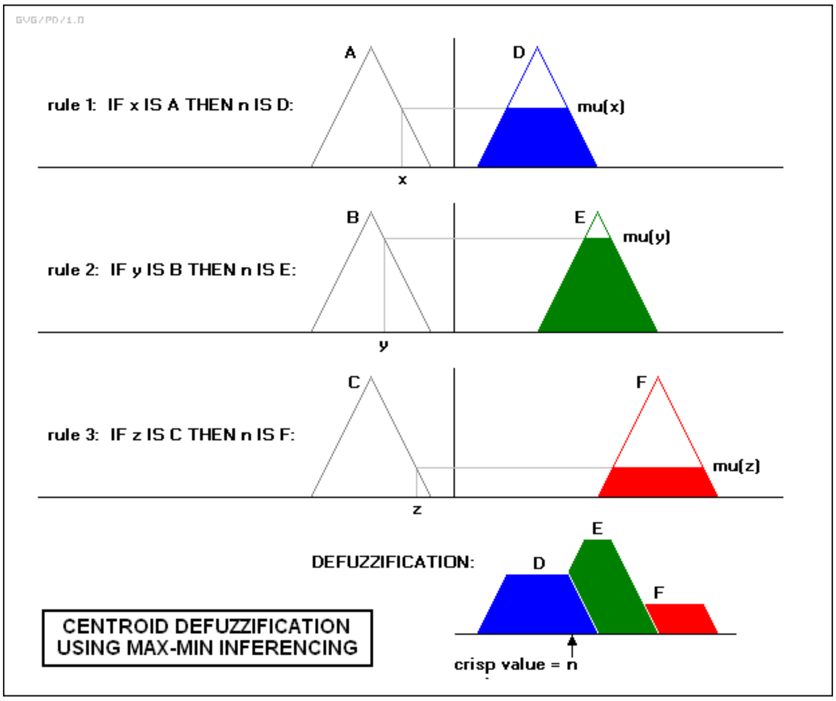
3.5.2 Sugeno Based FIS

When output membership functions are either linear or constant in any inference system which is to be modeled then Sugeno-type systems are used. It is known as Takagi-Sugeno-Kang and was founded in 1985. Sugeno output membership functions (z) are either linear or constant. A common rule in a Sugeno fuzzy model is:

If Input 1 = x and Input 2 = y, then Output is $z = ax + by + c$.
For a zero-order Sugeno model, the output level z is a constant ($a=b=0$).

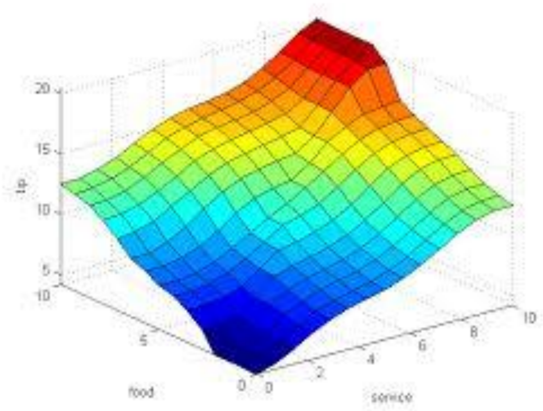
Both sugeno and mamdani FIS can be employed to complete the similar assignments. Defuzzifiers can be chosen for a mamdani FIS and defuzzifiers also originate similar results in a sugeno FIS. There is a definite overlap between both systems. Mamdani FIS is mostly used. It is intuitive and interpretable nature therefore it is used for decision support applications. Consequences of the rules in a sugeno FIS are not direct semantic mean. Consequently, sugeno FIS gets renewed into more degrees of freedom in its model as compared to mamdani FIS. More flexibility is provided. A zero order sugeno FIS can approximate a mamdani FIS. In evaluated terms, a sugeno FIS is more productive than a mamdani FIS because, sugeno FIS does not include computationally expensive defuzzification process. Also, a sugeno FIS always initiates continuous surfaces. If there is any existence of discontinuities, it will result in similar inputs initiating substantially different outputs. It will be a situation which is undesirable from the control monitoring perspective. A sugeno FIS is better and adequate for functional analysis than a mamdani FIS as it is of continuous structure of output functions.

.



The above figure3.3 shows the case of mamdani inference system

Rule viewer of the fuzzy logic system is shownin above figure. The rule viewer shows one calculation at a time detail [12]



The above figure 3.4 shows the surface view of the fuzzy logic system

It is very helpful in case of two or more inputs and one output. [12]

3.6 Defuzzification

In defuzzification, the fuzzy outputs are converted back to crisp values. There are various defuzzification methods are given below[11]:

Max Membership for all $\mu_c\,(z^*) \geq \mu_c\,(z)$ for all z € Z

- Centroid $z^* = \frac{\int \mu_c\,(z).zdz}{\int (\mu)_c(z)dz}$ (3.1)

- Weighted $z^* = \frac{\sum \mu_c\,(z).z}{\sum \mu_c\,(z)}$ (3.2)
- Mean-Max $z^* = \frac{a+b}{2}$ (3.3)

- Centre of sum $z^* = \frac{\int z * \sum \mu_c\,(z).z}{\sum \mu_c\,(z).z}$ (3.4)
- Centre of largest area $z^* = \frac{\int \mu_c\,(z).zdz}{\int (\mu)_c(z)dz}$ (3.5)

3.7 Fuzzy Control: Scheme

The classical control scheme and fuzzy control scheme is described in this portion. In classical control scheme, we have open loop and closed loop control architecture. Figure 3.5 gives the classical feedback control structure of a plant. Fuzzy logic controller replaces the conventional controller in fuzzy control scheme [11]. The fuzzy control scheme is given. Many of fuzzy logic control systems are comprehension-based systems in that either their fuzzy logic controllers or their fuzzy models are described by fuzzy IF-THEN rules, which have to be prearranged depending upon experts' knowledge about the systems, controllers, performance, etc. The basis of designing and application of fuzzy logic control systems is to tackle those vague, ill-described, and complex plants and processes that can hardly be handled by classical systems hypothesis, usual control techniques, and typical two-valued logic. The fuzzy logic controller is involved in a conventional control system and thus becomes part of the mixed control algorithm, so far as to improve the performance of the overall control system. The expert knowledge is converted into automatic control strategy by algorithm provided by fuzzy logic controller. Fuzzy logic has the ability to handle is approximate data in a systematic way and therefore it is best for controlling non linear systems and is used for modeling multifarious systems, where an estimated model exists or systems where ambiguity is common. The fuzzy control systems can replace an expert human operator. The rule base reflects the human skilled knowledge, expressed as semantic variables, while the membership functions present expert explanation of those variables. Classical analysis and control strategy are applied in the rule base. The control prose has operated declining the size of the rule base and optimizing the rule base using various optimization techniques like GA, PSO for intelligent controller. In final stage, defuzzified output is acquired from the fuzzy inputs.

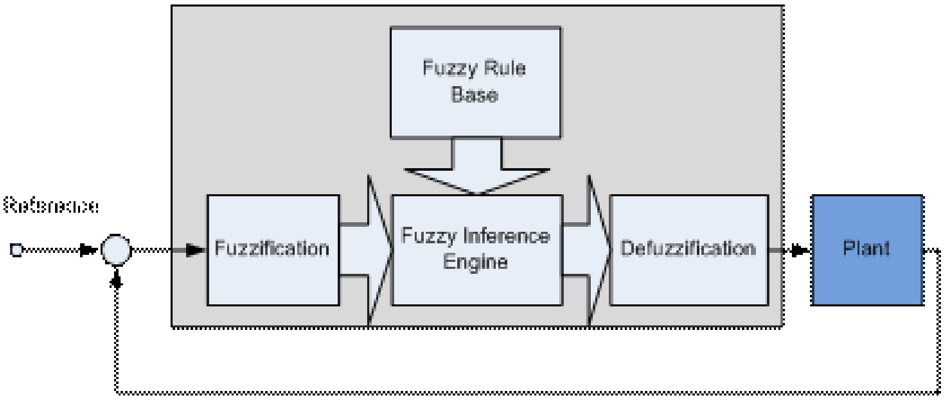


Figure 3.5 block diagram of fuzzy control system [11]

CHAPTER-4

RESULT AND DISCUSSIONS

4.1 Model order reduction

Two model order reduction techniques are used to reduce third order model to first order model ie. half rule and balance truncation method.

4.1.1 Half rule

The main basis for the half-rule is to maintain the robustness of the proposed PI- and PID-tuning rules. Third order model is reduced to first order model.Figure 4.1 gives the step response of the original system and the reduced system

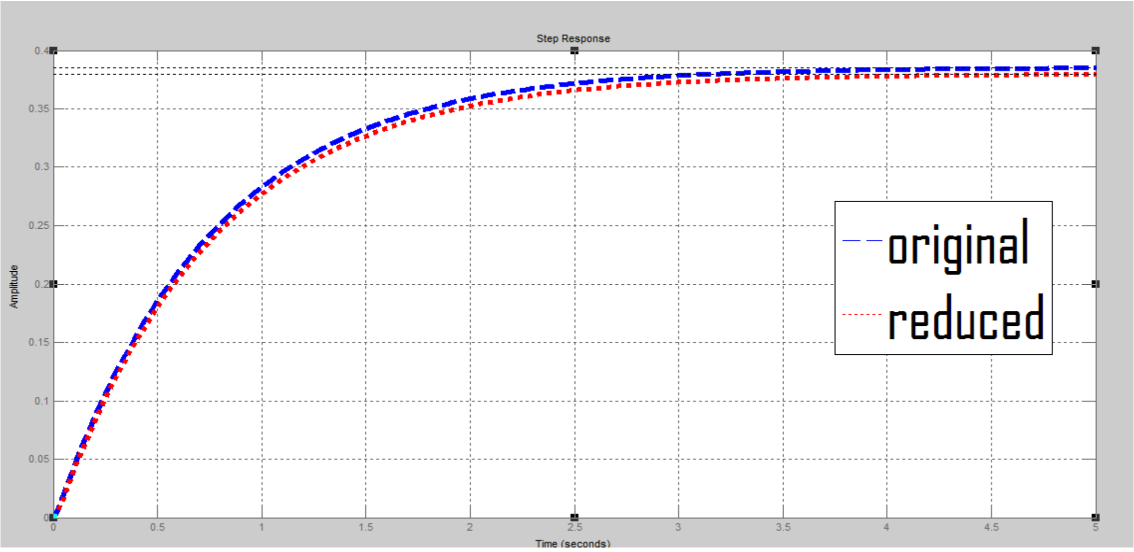


Figure 4.1 Comparison of step response of half rule and original system

Table 4.1 parameters obtained by half rule model order reduction

	Original system	**Half rule**
Peak Amplitude	.385 at >5 sec	.379
Rise time	1.64 sec	1.66 sec
Settling time	2.93 sec	2.79 sec
Steady state	.385	.38

The transfer function of original system is given as

$$G_{(s)} = \frac{50.88}{s^3 + 101.32\, s^2 + 132s}$$

The transfer function obtained by half rule method is given by

$$G_{(pr)} = \frac{.38e^{-.015\,s}}{0.755s + 1}$$

Table 4.1 gives the comparison of original system and reduced order system in the terms of rise time settling time, steady state and peak amplitude.

4.1.2 Balance truncation method

Balanced Truncation is an important projection method which delivers high quality reduced models by making an extra effort in choosing the projection subspaces. Figure 4.1 gives the step response of the original system and the reduced system

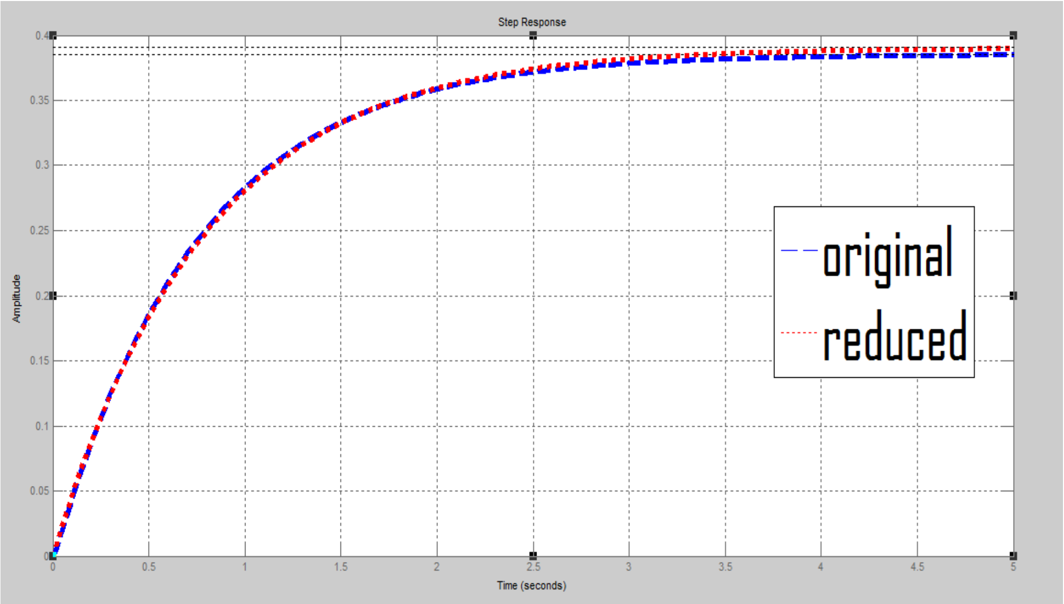


Figure 4.2 Comparison of step response of balance truncation and original system

Table 4.2 parameters obtained by balance truncation model order reduction

	Original system	**Balance truncation**
Peak Amplitude	.385 at >5 sec	.39
Rise time	1.64 sec	1.73 sec
Settling time	2.93 sec	3.08 sec
Steady state	.385	.39

The transfer function obtained by balance truncation method is given by

$$G_{(pr)} = \frac{.4959}{s+1.27}$$

Table 4.2 gives the comparison of original system and reduced order system in the terms of rise time settling time, steady state and peak amplitude.

4.2 PID controller Tuning

PID controller in a huge number is used in a single industrial process. The most essential thing is to tune the controllers perfectly to get the preferred response characteristics [7].

Three PID tuning methods are used ie. Ziegler Nichols, IMC, SIMC

4.2.1 Ziegler nichols first method

$G_1(s)=\frac{k}{Ts+1}e^{-Ls}$

$L = .015$

$T = .755$

$\mathbf{K_p = 1.2\frac{T}{L} = 60.40}$

$\boldsymbol{\tau_i = 2L = .03}$ $\mathbf{k_i = 2013.2}$

$\boldsymbol{\tau_d = .5L = .0075}$ $\mathbf{k_d = 0.42}$

PID gains obtained by Ziegler Nichols first method

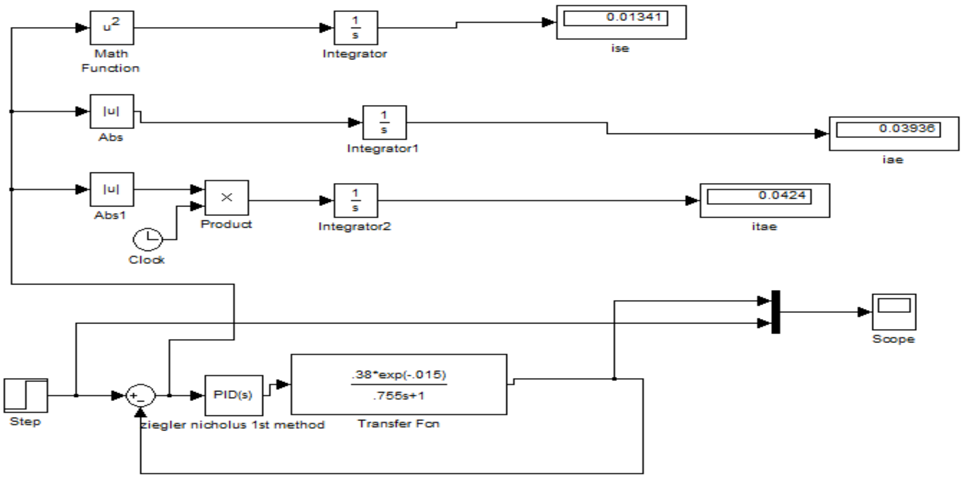


Figure 4.3 Simulink model of Ziegler Nichols first method

In above simulink diagram various parameters are obtained using Ziegler Nichols first method which is applicable only on first order plus dead time processes .The value of K_i is very large which is not feasible in practical system

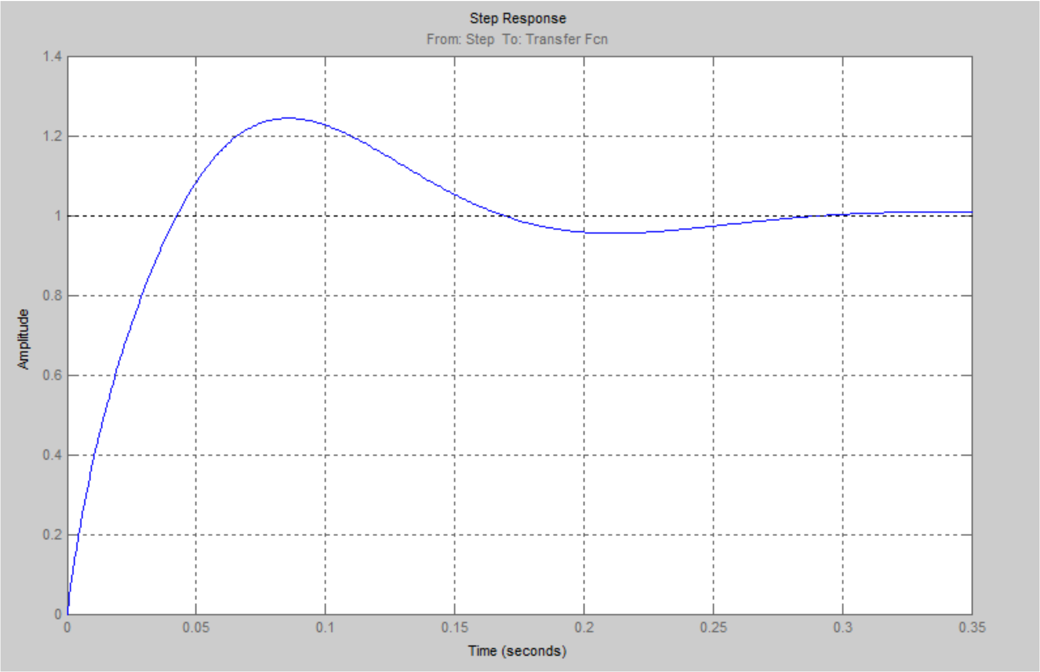


Figure 4.4 Step response of Ziegler nichols first method

4.2.2 Ziegler nichols second method

$K_{cr} = 262.85$

$P_{c\,r} = .54$

$K_p = .6K_{cr} = 157.71$

$\tau_i = \frac{P_{cr}}{2} = .27$ $k_i = 581$

$\tau_d = \frac{P_{cr}}{8} = .017$ $k_{d==}36.8$

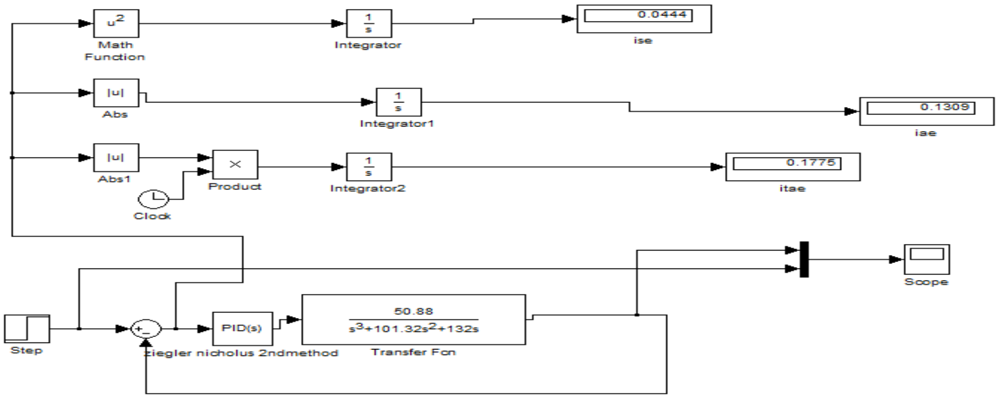


Figure 4.5 Simulink model for Ziegler nichols second method

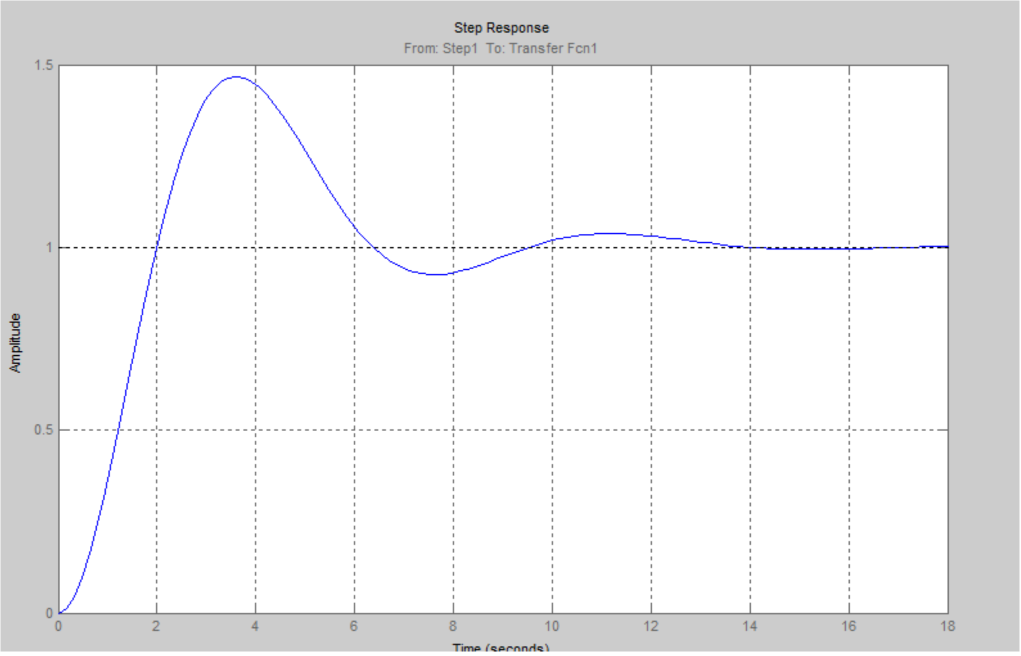


Figure 4.6 Step response of system with Ziegler Nichols second method

Table 4.4 various control parameters obtain bye Ziegler Nichols tuning method

Tuning methods	**ISE**	**IAE**	**ITAE**	**Peak amplitude**	**Rise time**	**Settling time**
Ziegler Nichols first method	.01341	.03936	.0424	24% at.085 sec	.0331 sec	.26 sec
Ziegler Nichols second method	.0444	.1309	.1775	46% at 3.6 sec	1.33sec	12.7 sec

In Ziegler Nichols first and second method first method is more effective. The errors is less compare to second method overshoot decrease to 24% .and improvement in all other parameters.

4.2.3 IMC tuning method (when λ =1)

- K_p=2
- K_i=4
- K_d=0.003

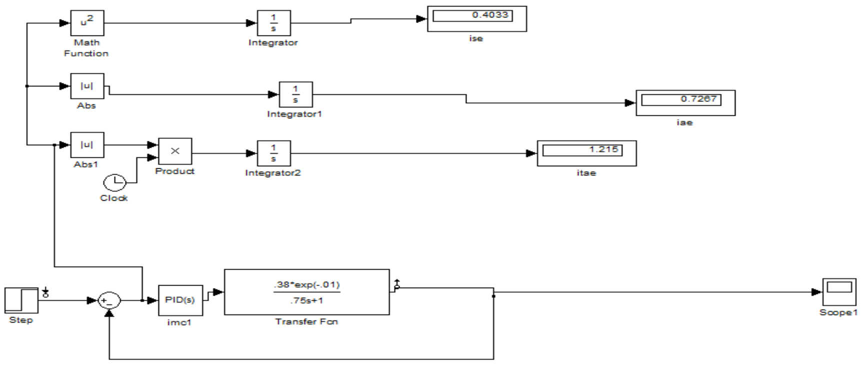


Figure 4.7 Simulink diagram of IMC 1

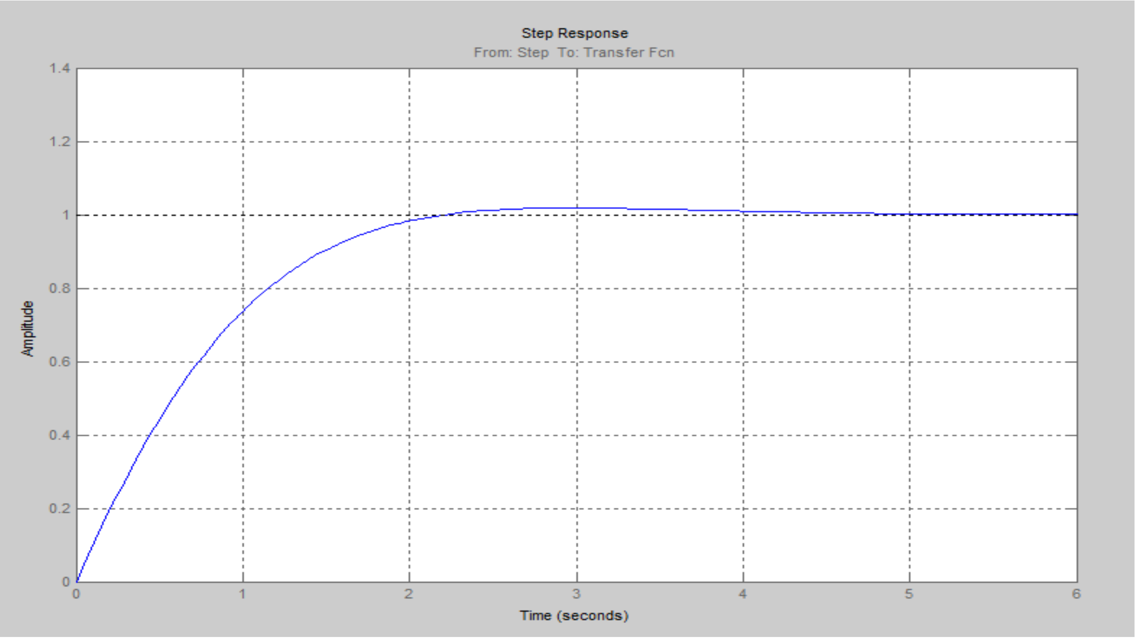


Figure 4.8 Step response of the system with IMC tuning method

4.2.4 IMC tuning method (when $\lambda = 2$)

- K_p=1
- K_i=4
- K_d=0.003

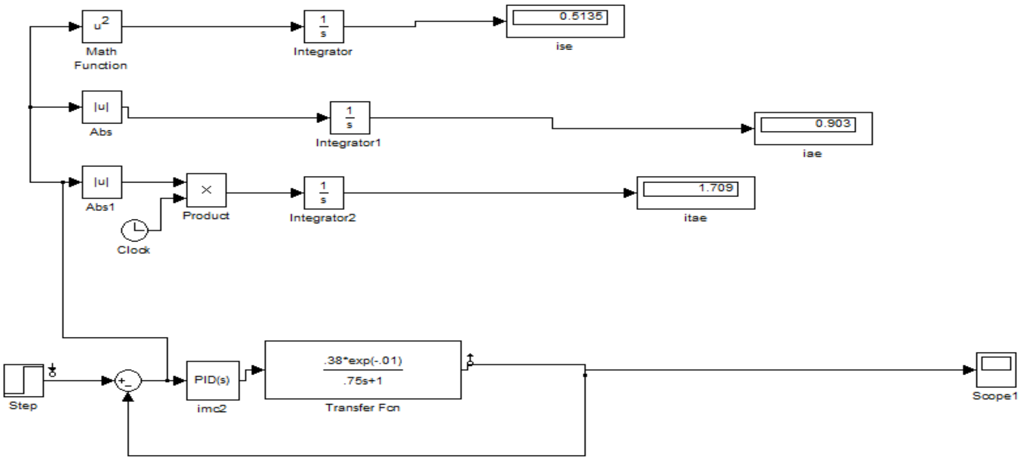


Figure 4.9Simulink diagram of IMC (when λ =2)

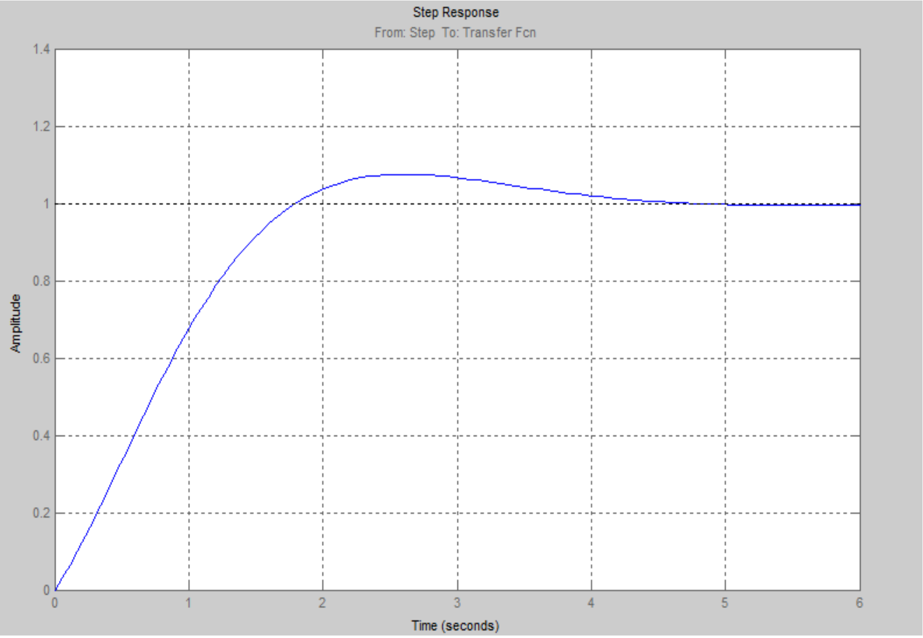


Figure 4.10 step response of the system when λ=2 in IMC tuning method**.**

In above IMC method (internal model control) $\lambda = 1$ and 2 is obtained in first method when λ=1 overshoot error decreases.

Table 4.5 various control parameters obtained by IMC tuning methods

Tuning methods	**ISE**	**IAE**	**ITAE**	**Peak amplitude**	**Rise time**	**Settling time**
IMC first	.4033	.7267	1.215	1.81%	1.38	1.97
IMC Second	.5135	.903	1.79	7.33%	1.2	3.97

4.2.5 SIMC tuning method (when T_c=1)

- K_p=.74
- K_i=1.97
- K_d=0.007

PID Parameters obtained by SIMC METHOD when T_c=1

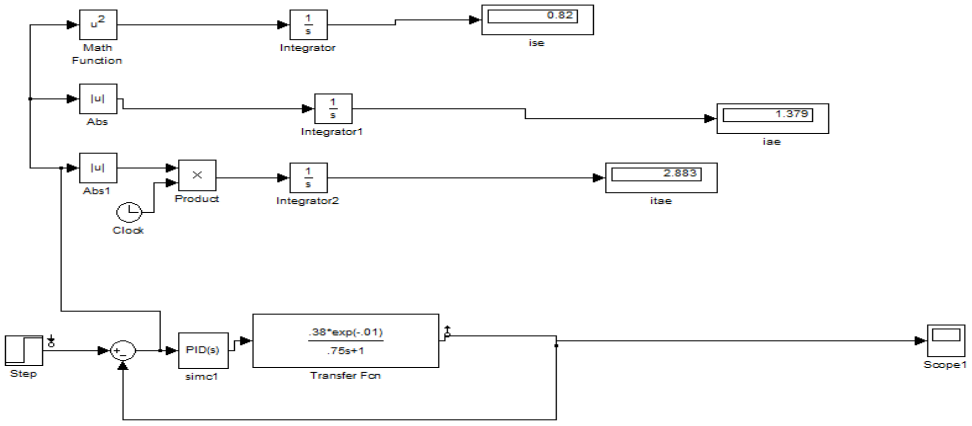


Figure 4.11 Simulink model for SIMC tuning

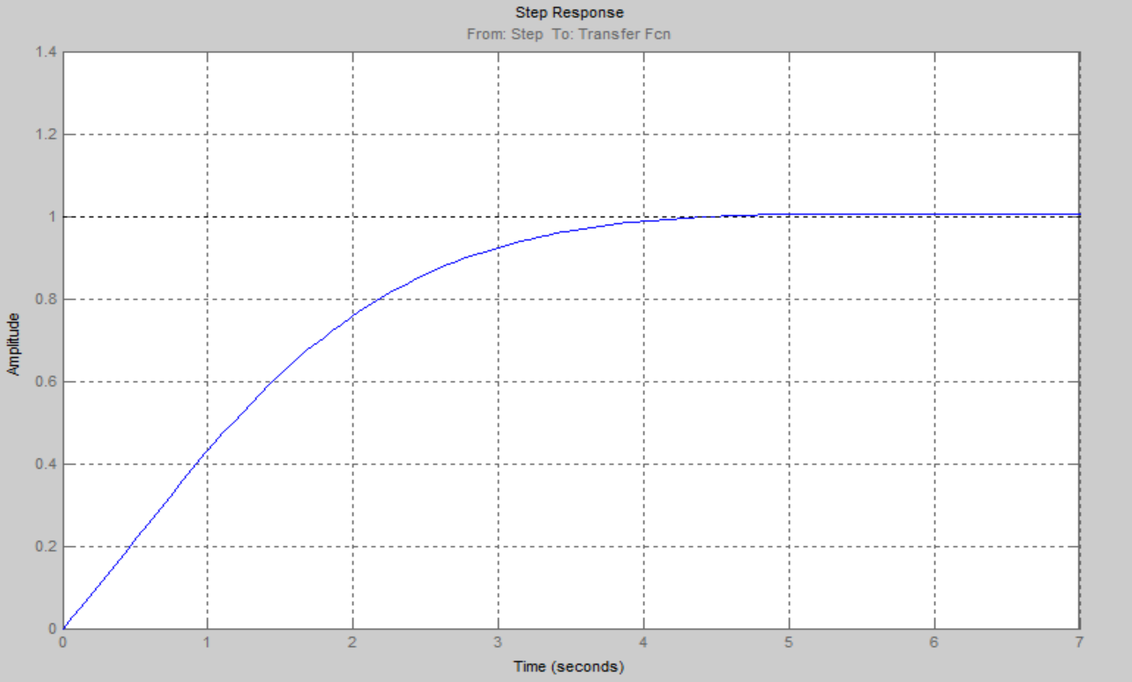


Figure 4.12 Step response of the system with SIMC (when T_c=1)

4.2.6 Simc tuning rule (whenTc=2)

- K_p=.38
- K_i=1.97
- K_d=0.007

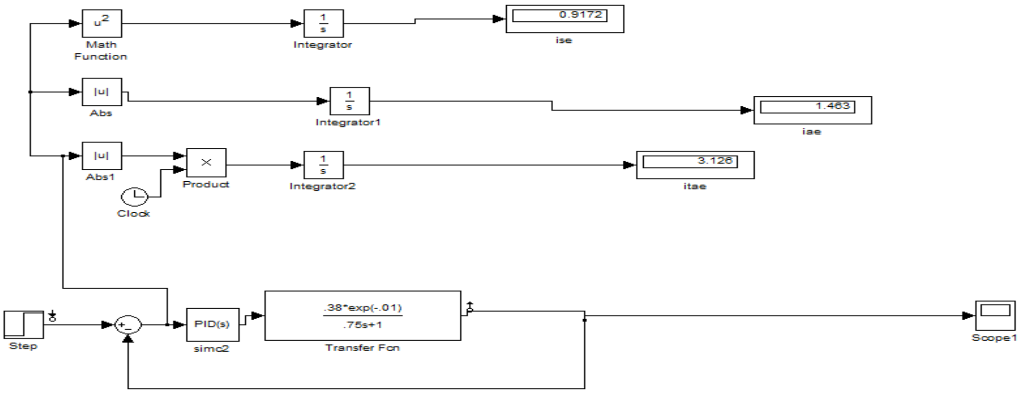


Figure 4.13 Simulink diagram of PID-SIMC tuning rule (whenTc=2)

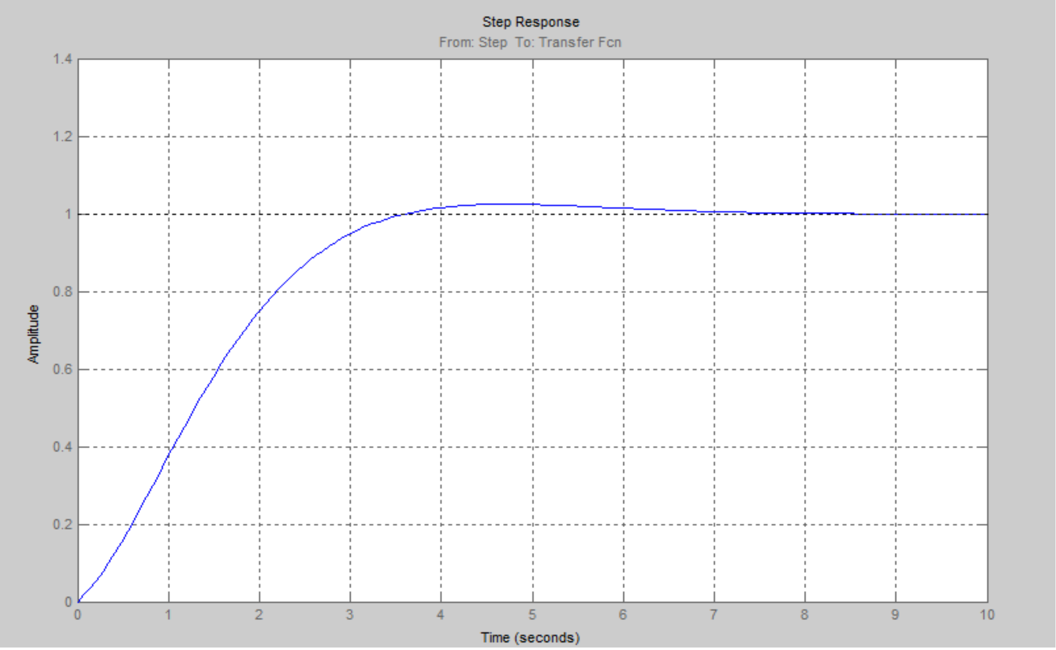


Figure 4.14 Step response of the system with SIMC tuning rule (when Tc=2)

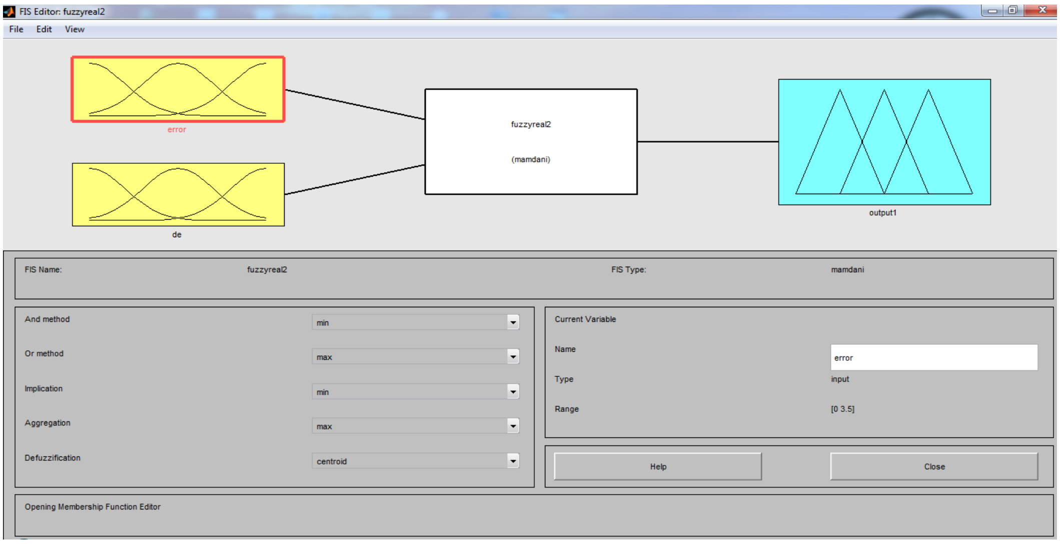
Table 4.6 various control parameters obtained by SIMC tuning methods

Tuning methods	**ISE**	**IAE**	**ITAE**	**Peak amplitude**	**Rise time**	**Settling time**
SIMC first	.82	1.379	2.883	.613%	2.55sec	3.8 sec
SIMC 2nd	.91	1.46	3.126	2.43%	2.32sec	5.42 sec

In SIMC tuning method the overshoot decreased to .613% but the error increases. This method is useful to decrease the overshoot in above table al the parameters of control system obtained.

4.3 Fuzzy logic controller

Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.The input of fuzzy logic controller is error and change in error and the output is desired azimuth angle



FIS Name: fuzzyreal2

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

Name: error

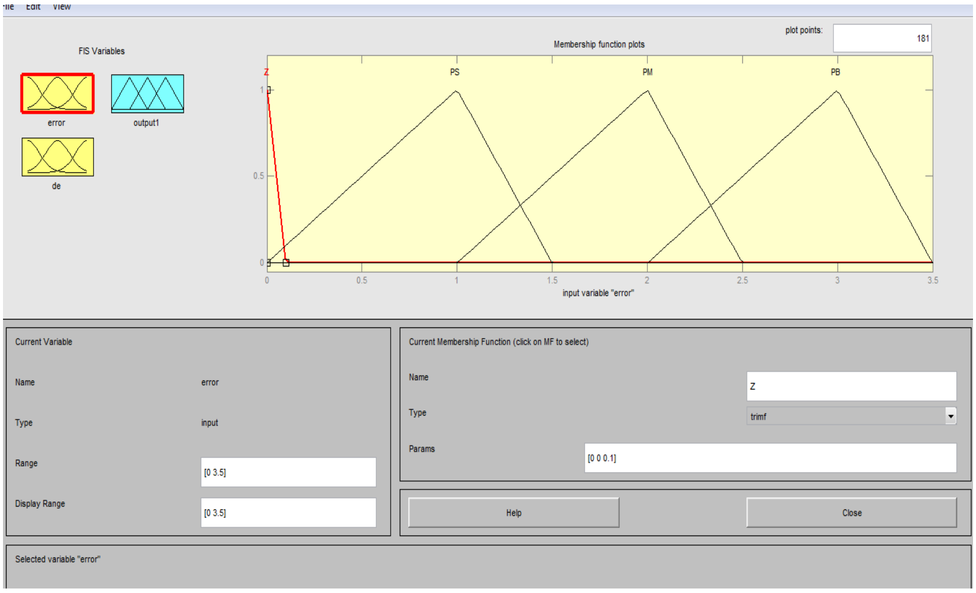
Type: input

Range: [0 3.5]

Opening Membership Function Editor

Figure 4.15: Mamdani Fuzzy Inference System Developed for Fuzzy Controller

The above figure 4.15 shows the fuzzy inference system, in which there are two inputs as error and change in error and one output.



Name error

Type input

Range [0 3.5]

Display Range [0 3.5]

Name Z

Type trimf

Params [0 0 0.1]

Selected variable "error"

Figure 4.16 Membership function for input 1

The above figure 6.12 shows the membership function plots for the first input variable. Triangular membership function is taken for both inputs and outputs. Specify the range then assign the variable name. Then take the second input variable. Again member ship functions are assigned with range. Range is taken from 0-3.5.

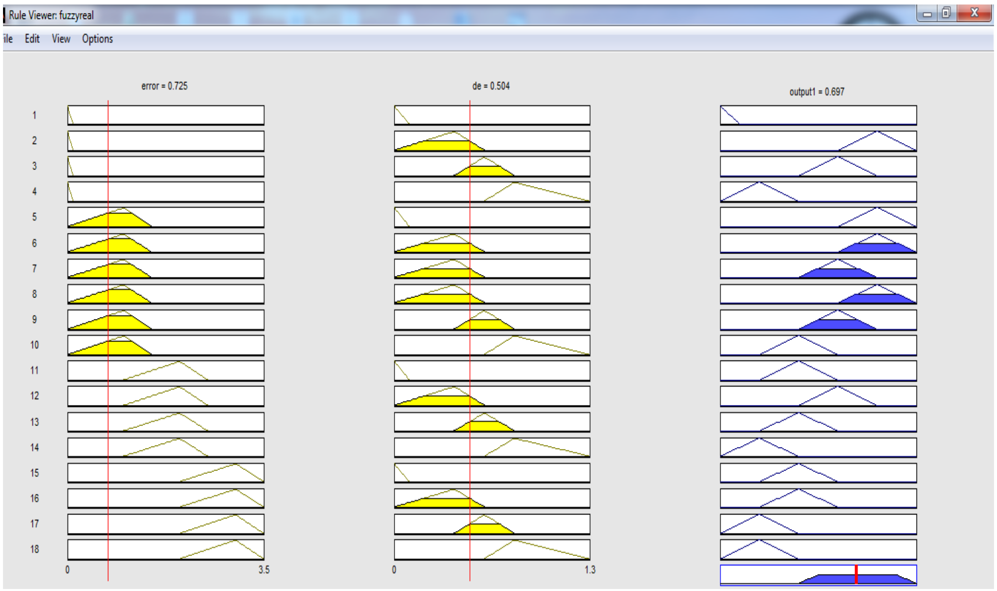
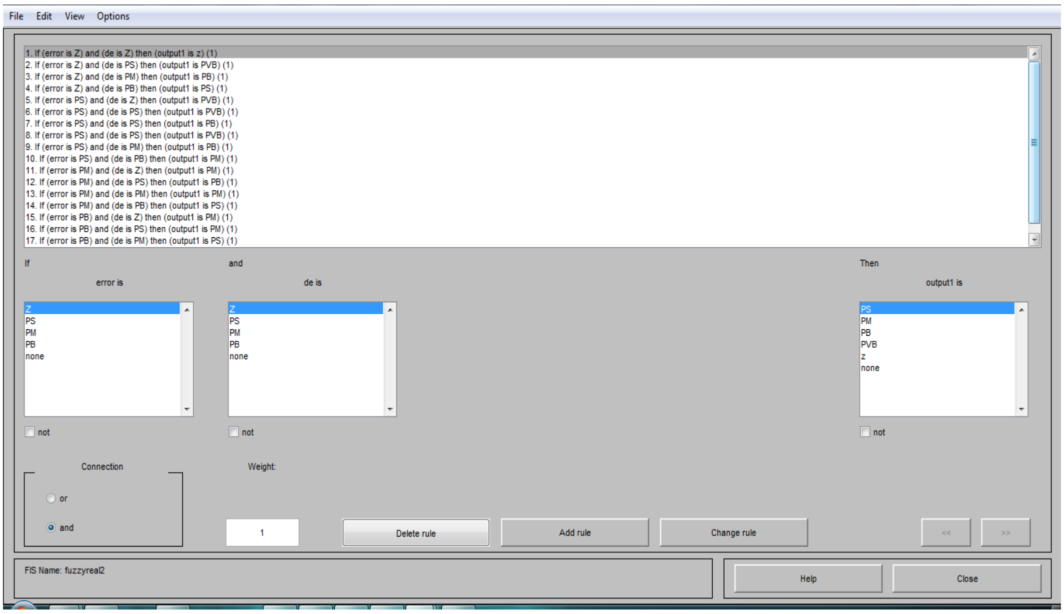


Figure 4.17 Rule viewer of fuzzy inference system

The above figure 6.13 shows the rule base of the fuzzy logic controller for the three element control system. It consists of 25 rule based using If-and-then rules condition.



```
1. If (error is Z) and (de is Z) then (output1 is z) (1)
2. If (error is Z) and (de is PS) then (output1 is PVB) (1)
3. If (error is Z) and (de is PM) then (output1 is PB) (1)
4. If (error is Z) and (de is PB) then (output1 is PS) (1)
5. If (error is PS) and (de is Z) then (output1 is PVB) (1)
6. If (error is PS) and (de is PS) then (output1 is PVB) (1)
7. If (error is PS) and (de is PS) then (output1 is PB) (1)
8. If (error is PS) and (de is PS) then (output1 is PVB) (1)
9. If (error is PS) and (de is PM) then (output1 is PB) (1)
10. If (error is PS) and (de is PB) then (output1 is PM) (1)
11. If (error is PM) and (de is Z) then (output1 is PM) (1)
12. If (error is PM) and (de is PS) then (output1 is PB) (1)
13. If (error is PM) and (de is PM) then (output1 is PM) (1)
14. If (error is PM) and (de is PB) then (output1 is PS) (1)
15. If (error is PB) and (de is Z) then (output1 is PM) (1)
16. If (error is PB) and (de is PS) then (output1 is PM) (1)
17. If (error is PB) and (de is PM) then (output1 is PS) (1)
```

Weight: 1

FIS Name: fuzzyreal2

Figure 4.18 rule base

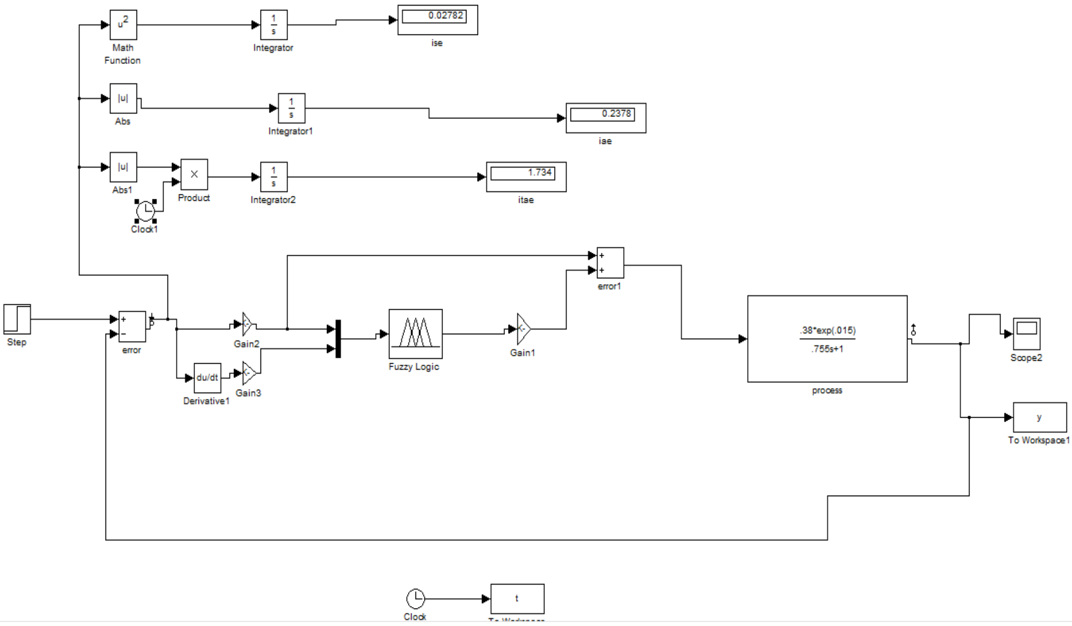


Figure 4.19 Antenna azimuth position control with fuzzy logic as primary controller

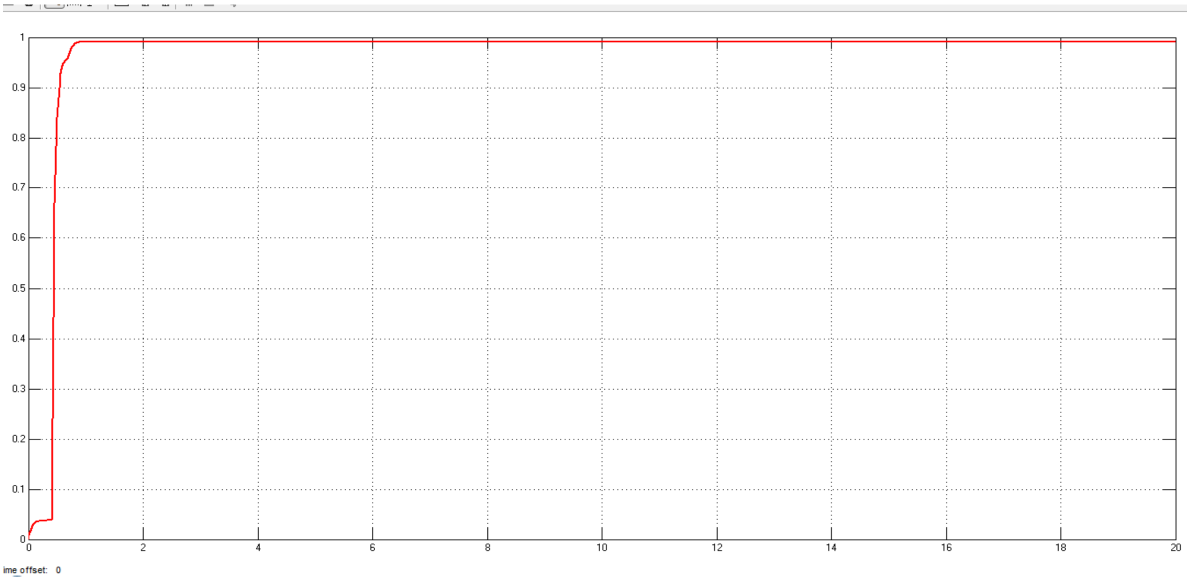
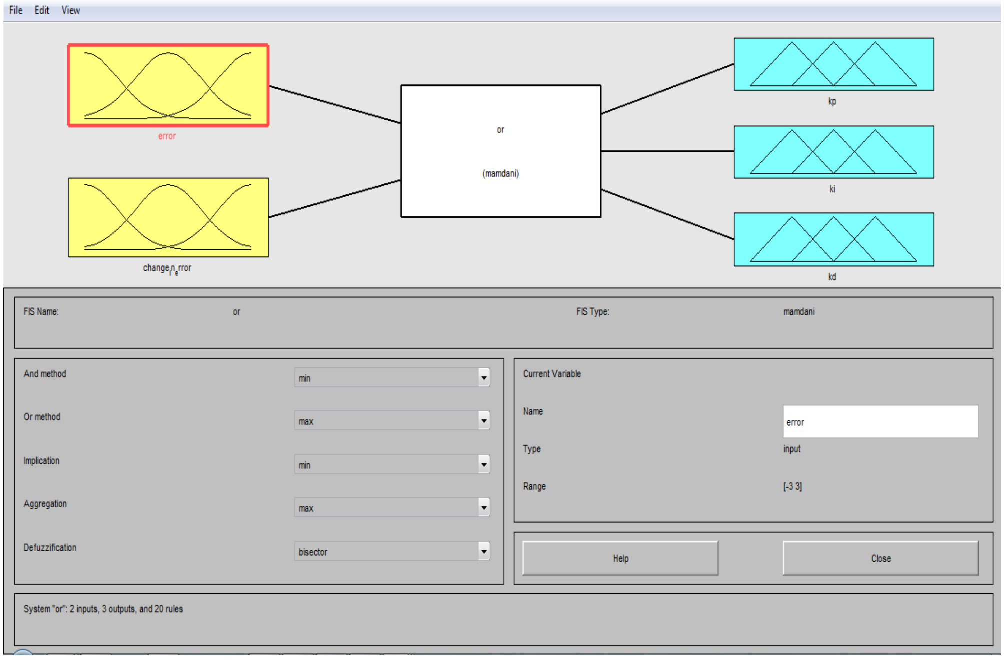


Figure 4.20 Step response of system with fuzzy logic

In above figure the step response of the system is obtained with the help of fuzzy logic

4.4 Fuzzy-PID controller

Fuzzy PID controller is used as primary controller. Fuzzy controller is used to find the optimum values of Kp, Ki and Kd. These parameters are given to PID controller that produces the control signal which is used a set point for the secondary controller



FIS Name: or
FIS Type: mamdani

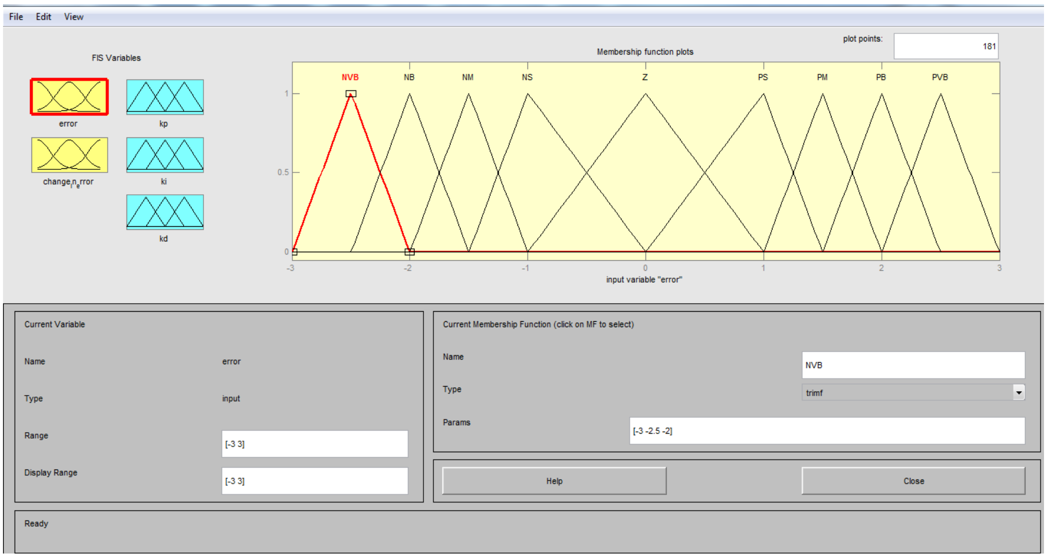
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: bisector

Current Variable
Name: error
Type: input
Range: [-3 3]

System "or": 2 inputs, 3 outputs, and 20 rules

Figure 4.21 Mamdani Fuzzy Inference System Developed for Fuzzy Controller

The above figure 6.11 shows the fuzzy inference system, in which there are two inputs as error and change in error and three outputs as proportional gain, integral gain and derivative



plot points: 181

Current Variable

Name: error

Type: input

Range: [-3 3]

Display Range: [-3 3]

Current Membership Function (click on MF to select)

Name: NVB

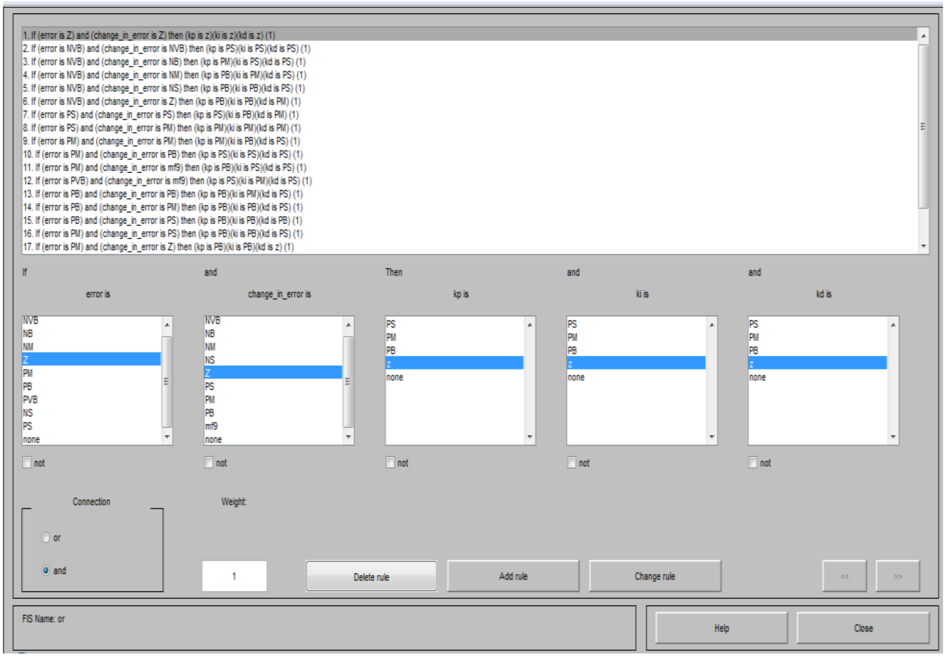
Type: trimf

Params: [-3 -2.5 -2]

Ready

Figure 4.22 Membership function for input 1

The above figure 6.12 shows the membership function plots for the first input variable. Triangular membership function is taken for both inputs and outputs. Specify the range then assign the variable name. Then take the second input variable. Again member ship functions are assigned with range. Range is taken from -3 to 3.



```
1. If (error is Z) and (change_in_error is Z) then (kp is z)(ki is z)(kd is z) (1)
2. If (error is NVB) and (change_in_error is NVB) then (kp is PS)(ki is PS)(kd is PS) (1)
3. If (error is NVB) and (change_in_error is NB) then (kp is PM)(ki is PS)(kd is PS) (1)
4. If (error is NVB) and (change_in_error is NM) then (kp is PB)(ki is PM)(kd is PS) (1)
5. If (error is NVB) and (change_in_error is NS) then (kp is PB)(ki is PB)(kd is PS) (1)
6. If (error is NVB) and (change_in_error is Z) then (kp is PB)(ki is PB)(kd is PM) (1)
7. If (error is PS) and (change_in_error is PS) then (kp is PS)(ki is PB)(kd is PM) (1)
8. If (error is PS) and (change_in_error is PM) then (kp is PM)(ki is PM)(kd is PM) (1)
9. If (error is PM) and (change_in_error is PM) then (kp is PM)(ki is PB)(kd is PS) (1)
10. If (error is PM) and (change_in_error is PB) then (kp is PS)(ki is PS)(kd is PS) (1)
11. If (error is PM) and (change_in_error is mf9) then (kp is PB)(ki is PS)(kd is PS) (1)
12. If (error is PVB) and (change_in_error is mf9) then (kp is PS)(ki is PM)(kd is PS) (1)
13. If (error is PB) and (change_in_error is PB) then (kp is PB)(ki is PM)(kd is PS) (1)
14. If (error is PB) and (change_in_error is PM) then (kp is PB)(ki is PB)(kd is PS) (1)
15. If (error is PB) and (change_in_error is PS) then (kp is PB)(ki is PB)(kd is PB) (1)
16. If (error is PM) and (change_in_error is PS) then (kp is PB)(ki is PB)(kd is PS) (1)
17. If (error is PM) and (change_in_error is Z) then (kp is PB)(ki is PB)(kd is z) (1)
```

error is: Z

change_in_error is: Z

kp is: z

ki is: z

kd is: z

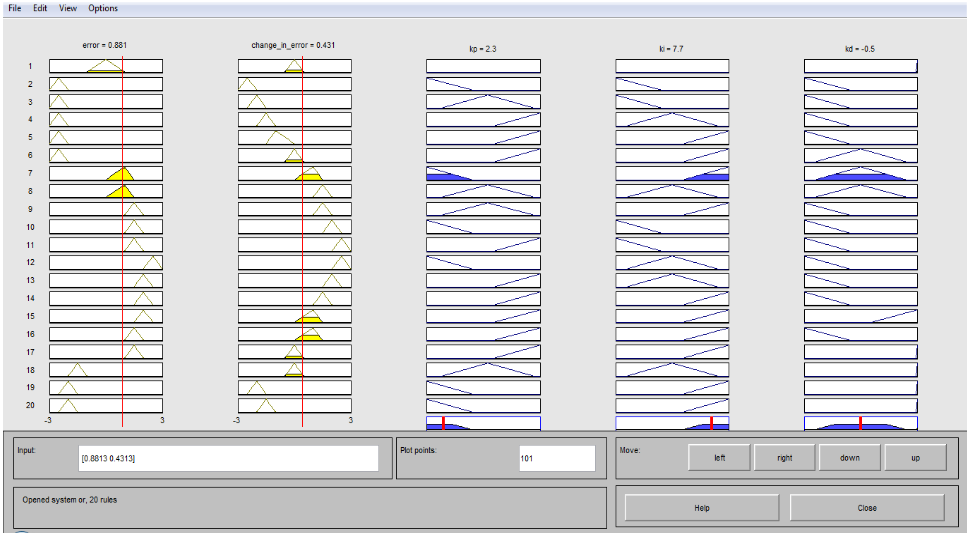
Connection: and

Weight: 1

FIS Name: or

Figure 4.23 rule base

The above figure 4.23 shows the rule base of the fuzzy logic controller for the three element control system. It consists of 81 rule based using If-and-then rules condition.



Input: [0.8813 0.4313]

Plot points: 101

Opened system or, 20 rules

Figure 4.24 shows the rule viewer for the fuzzy inference system. The rule viewer shows one calculation at a time and in great detail.

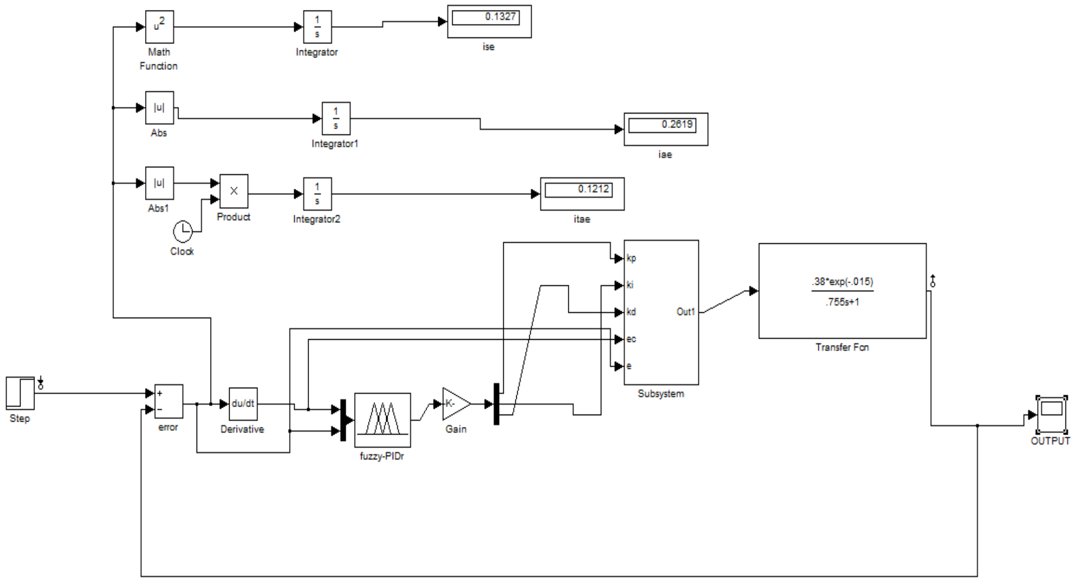


Figure 4.25 Simulink diagram of fuzzy as primary and PID is secondary controller

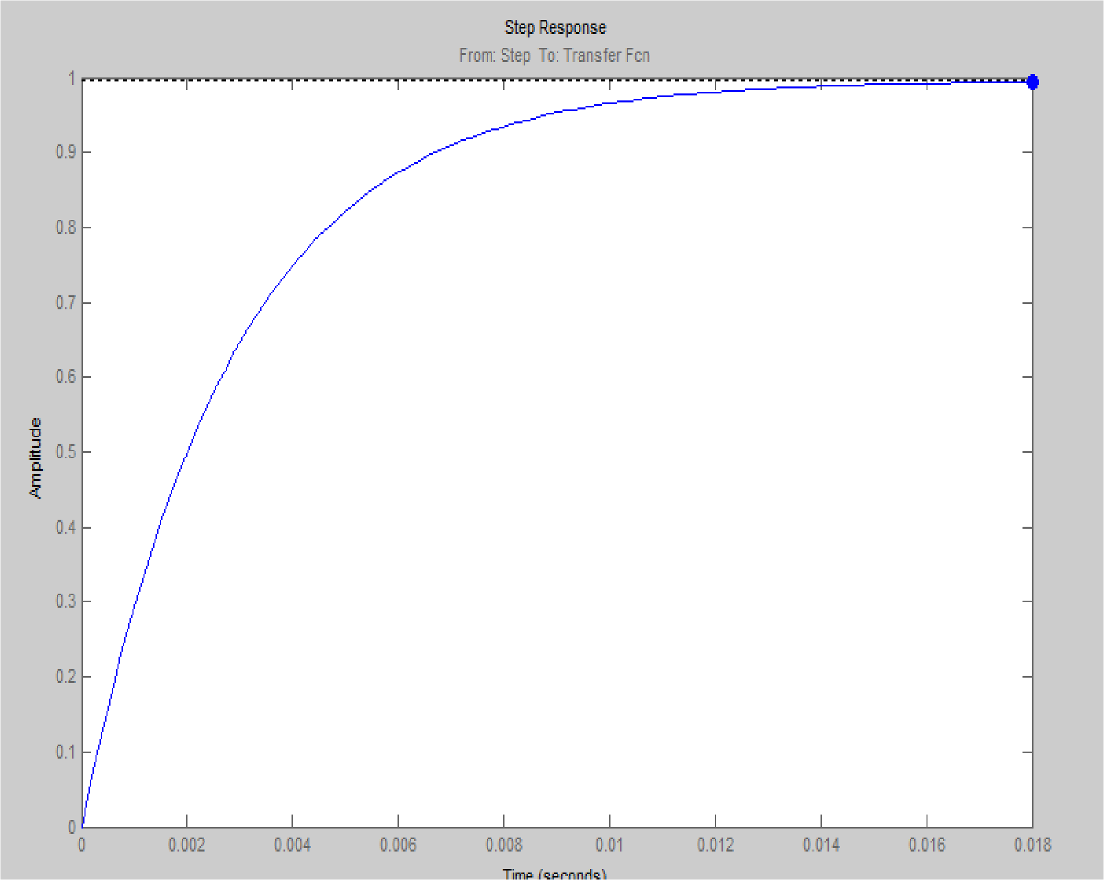


Figure 4.26 Step response of fuzzy-PID controller

Table 4.7 Parameters obtained by fuzzy and fuzzy-PID controllers

CONTROLLERS	**ISE**	**IAE**	**ITAE**	**Peak amplitude**	**Rise time**	**Settling time**
FUZZY	.027	.2378	1.734	.93	.114	.204sec
FUZZY-PID	.1327	.2619	.1212	.994	.006sec	.012sec

Thus in fuzzy PID controller the error increases as compare to fuzzy controller but the system is settled in .012 sec which shows good response of the controller.

4.5 Fuzzy logic rules

Table 4.8 fuzzy logic rules

		E(t)				
		NB	**NS**	**Z**	**PS**	**PB**
$\boldsymbol{\nabla e(t)}$	**NB**	NVB	NB	NM	NS	Z
	NS	NB	NM	NS	Z	PS
	Z	NM	NS	Z	PS	PM
	PS	NS	Z	PS	PM	PB
	PB	Z	PS	PM	PB	PVB

Table 4.9 fuzzy PID rules for k_p,$k_{i,}$ k_d

		E(t)								
		NVB	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**	**PVG**
$\boldsymbol{\nabla e(t)}$	**NVB**	NVB	NVB	NB	NM	NS	Z	PS	PM	Z
	NB	NVB	NB	NM	NS	NS	PS	PS	Z	PS
	NM	NB	NM	NS	Z	NM	NB	Z	PS	PS
	NS	NM	NS	Z	PS	NB	Z	PS	PS	PM
	Z	NS	Z	PS	PS	Z	PS	PS	PS	PB
	PS	Z	PS	PM	PM	PM	PS	PS	PM	PB
	PM	PS	PM	PB	PM	PM	PS	PM	PB	PVB
	PB	PM	PB	PB	PB	PS	PM	PB	PVB	PVB
	PVB	PB	PVB	PVB	PVB	PM	PB	PVB	PVB	PVB

Table 5.6 and 5.7 shows the rule base of the fuzzy logic controller. Mamdani inference system is used for developing rule base of the fuzzy logic controller. NVB means negative very big,NB means negative big, NM means negative medium, NS means negative small,,Z means zero, PS means positive small, PM means positive medium and PB means positive big. PVB means positive very big.

Table 4.10 Comparison of all controllers

CONTROLLERS	**ISE**	**IAE**	**ITAE**	**Peak overshoot**	**Rise time**	**Settling time**
Ziegler Nichols 1st method	.01341	.0396	.0424	24%	.0331 sec	.26 sec
Ziegler Nichols 2nd method	.0444	.1309	.1775	46%	1.33 sec	12.7 sec
IMC 1st	.4033	.7267	1.215	1.81%	1.38 sec	1.97 sec
IMC 2nd	.5135	.903	1.79	7.33%	1.2 sec	3.97 sec
SIMC 1st	.82	1.379	2.883	.613%	2.55 sec	3.8 sec
SIMC 2nd	.91	1.46	3.216	2.43%	2.32 sec	5.42 sec
Fuzzy logic controller	.027	.2378	1.734	.93%	.114 sec	.204 sec
Fuzzy-PID controller	.1327	.2619	.1212	.99%	.006 sec	.012 sec

CHAPTER-5

CONCLUSION AND FUTURE SCOPE

This thesis work discusses a control system case study taking antenna azimuth position control system. First of all modelling of antenna azimuth position control is done. The transfer function of antenna system is a third order system which has been reduced to first order system using two different model order reduction techniques ie. Half rule approximation and balanced truncation.A conventional PID controller with three tuning methods is applied on the reduced model ie. Ziegler Nichols, IMC, SIMC. With Ziegler Nichols method the overshoot of the system is high to reduce the overshoot we use IMC and SIMC tuning methods. Thus with IMC and SIMC methods, the overshoot and the errors decreases but small overshoot is there. So after that we use fuzzy logic controller, the error and the overshoot decreases to a great extent .Then fuzzy PID controller is implemented and it gives a better response than the conventional PID controller and fuzzy logic, the settling time with fuzzy-PID is reduced to .012 sec.

In the future scope, neural network based controller and genetic algorithm or PSO based online optimization techniques can be implemented to improve the control performance. For online tuning of PID controller better tuning method can be used.

References

---

[1] J. Wiley &Sons, Inc. Nise, " Control System Engineering ", 2000.

[2] H.I. Okumus, E. Sahin, O. Akyazi, ‘Antenna Azimuth Position Control with Classical PID and Fuzzy Logic Controllers’, Innovations in Intelligent Systems and Applications (INISTA) 2012.

[3] Boban Temelkovskia and Jugoslav Achkoskia “Modeling and Simulation of Antenna Azimuth Position Control System” International Journal of Multidisciplinary and Current Research 4, Vol.2 (March/April 2014 issue)

[4] Wil Schilders “Introduction to Model Order Reduction” 3rd edition

[5] m. g. safonov and r. y. chiang “a schur method for balanced-truncation
model reduction” ieee transactions on automatic control, vol. 34, no. 7, july 1989

[6] sigurad skogestad “simple analytical rules for model reduction and PID controller tuning” modeling,identification and control”,2004 vol. 25 no.2 85-120

[7] Katsuhiko Ogata “ modern control enginerring” 5th edition

[8] carl j astrom and tore haggland “ PID controllers” 2nd edition

[9] Hang, C.C. “Refinements of the Ziegler-Nichols tuning formula” Control Theory and Applications, IEE Proceedings D (Volume:138 , Issue: 2) Mar 1991

[10] Lee, W.S “Modified IMC-PID controllers and generalised PID controllers for first-order plus dead-time processes” Control, Automation, Robotics and Vision, 2002. ICARCV 2002. 7th International Conference on (Volume:2)

[11] Ronald R. Yager, Lotfi A. Zadeh “An Introduction to Fuzzy Logic Applications in Intelligent Systems” The Springer International Series in Engineering and Computer Science

[12] Paul P. Wang, S. K. Chang “ Fuzzy Sets” Theory and Applications to Policy Analysis and Information Systems

[13] Jin Zheng, Ping Guo, Jack D. Wang, ‘STFC - Self-Tuning Fuzzy’, 0- 803-0720-8/92 -1992 IEEE .

[14] Georg F. Mauer “A Fuzzy Logic Controller for an ABS Braking” System IEEE transaction on fuzzy system, VOL. 3, NO. 4, NOVEMBER 1995

[15] T. H. Lee “Position Control for Wheeled Mobile Robots Using a Fuzzy Logic Controller”

[16] C. Elmas, M.A. Akcayol, T. Yigit, " Fuzzy PI Controller For Speed Control of Switched Reluctance Motor " J.Fac.Eng. Arch. Gazi Univercity, Vol 22, No 1, 65-72, 2007

[17] Sukhbir Hundal, Bee Thao, Tyrone Tracy: Antenna Azimuth Position Control System Verification, 2007

[18] E. Ozkop, H. I. Okumus, I. H. Altas, "A Fuzzy Logic Controlled Electronic Differential for a Direct Wheel Drive Electric Vehicle", ICEM'08, XVIII, International Conference On Electrical Machines, 6th-9th of September 2008, Vilamoura – Algarve, Portugal. 481

[19] Xuan L., Estrada J. and Digiacomandrea J.,"Antenna Azimuth Position Control SystemAnalysis and Controller Implementation", term project, 2009.

[20] R. Chibani and M. Chtourou "IMC based automatic tuning method of PID controllers using neural networks" 2009 6th International Multi-Conference on Systems, Signals and Devices

[21] Mustafa E. Sahin, Ismail H. Altas, H. Ibrahim Okumus, "Design and Analysis of Fuzzy Controller for a Single Holding Tank", International Symposium on INnovations in
Intelligent SysTems and Applications (INISTA 2010), 21-24 June, Kayseri/Turkey, Sayfa 250-254.

[22] Ramli Adnan#1, Mazidah Tajjudin#2, "Self-tuning Fuzzy PID Controller for Electro-
Hydraulic Cylinder" 2011 IEEE 7th International Colloquium on Signal Processing and its Applications

[23] S. Ramesh, A. Krishnan, "A Self –Tuning Fuzzy Logic Controller for a Frequency Stabilization in a Parallel AC – DC Two Area Interconnected Power System", European
Journal of Scientific Research, ISSN 1450-216X Vol.51 No.1 (2011), pp.6-17, c Euro Journals Publishing, Inc. 2011.

[24] M. A. Usta, O.Akyazı, İ. H. Altaş, "Design and Performance of Solar Tracking System with Fuzzy Logic Controller", 6th International Advanced Technologies Symposium\ (IATS'11)", 16-18 Mayıs 2011, Elazığ/Turkey, Sayfa 331- 336.

[25] Chanchal Dey "A Self-Tuning Fuzzy PID Controller with Real-Time
Implementation on A Position Control System" 2012 Third International Conference on Emerging Applications of Information Technology (EAIT)

[26] H. Ibrahim Okumus "Antenna Azimuth Position Control with Classical PID and Fuzzy Logic Controllers" 2012 IEEE

[27] I. H. Altas and A. M. Sharaf, "A Generalized Direct Approach for Designing Fuzzy Logic Controllers in Matlab/Simulink GUI Environment", Accepted for publication in International Journal of Information Technology and Intelligent Computing, Int. J. IT&IC no.4 vol.1.2013

[28] Okumus, H.I. Antenna azimuth position control with fuzzy logic and self-tuning fuzzy logic controllers