PID CONTROLLER DESIGN FOR VARIOUS PLANT MODEL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology in

Electronics and Instrumentation Engineering

By

RAJESH KUMAR (110EI0504)

Department of Electronics & Communication Engineering

National Institute of Technology, Rourkela

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Under the Guidance of

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CERTIFICATE

This is to certify that the thesis titled “**PID CONTROLLER DESIGN FOR VARIOUS PLANT MODEL**”, submitted by Mr RAJESH KUMAR (107EI008) in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in ‘ELECTRONICS & INSTRUMENTATION’ Engineering during session of 2010-2014 at the National Institute of Technology (NIT), Rourkela is an authentic work carried out by him under my supervision.

Date:

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Rajesh kumar (110EI0504)

CONTENTS

ABSTRACT

In this thesis I have discussed how to get a process model from response characteristics of a plant. Then I have discussed about various tuning formula used for finding controllers parameters. On the basis of the tuning formula P, PI, PD and PID controllers are designed and simulation is taken using Matlab and Simulink for different value of ‘N’ (filter coefficient) .

Chapter 1

INTRODUCTION

There are various types of industrial process. About process transfer function we know that finding a real value of it is very difficult. So whatever we get the transfer function of plants that can be approximately modelled by some definite transfer function. Some of those are FOPDT (first order plus delay time), IPDT (integral plus delay time) and FOIPDT (first order plus lag and integral delay time).

In thesis modeling of plant is done by using MATLAB. By Matlab we trace step response of plant. And using some basic calculation find out parameters of the model.

After finding model equation, next step is to find out controllers (P, PI,PD and PID) parameters. For this step we use various controller tuning method. For FOPDT model **Ziegler-Nichols tuning formula, Chine-Hrones-Reswick PID tuning algorithm, Cohen-Coon Tuning algorithm, Wang-Juang-Chan tuning formula** and **optimal PID controller design** are used for controller tuning. But controller used for IPDT and FOIPDT can’t be tuned using these tuning formula, so we use different tuning formula for these model. For IPDT and FOIPDT only PD and PID controller is used.

After finding controller parameter response is taken in Simulink. For different value of filter coefficient.

Lastly observation is taken. For different controller rise time and selling time of response is noticed.

Chapter 2

PROCESS MODELING FROM RESPONSE CHARACTERISTICS OF PLANT

FOPDT (first order plus dead time), IPDT (integral plus dead time) and FOIPDT (first order lag and integrator plus dead time) are some basic plant model. In real time process control system a large variety of plant can be approximately model by FOPDT.

Equation of these model are:

FOPDT:

$G(s) = K*e^{-Ls}/(Ts+1)$

IPDT:

$G(s) = Ke^{-Ls}/s$

FOIPDT MODELS

$G(s) = Ke^{-Ls}/s*(Ts+1)$

Where

K=gain;

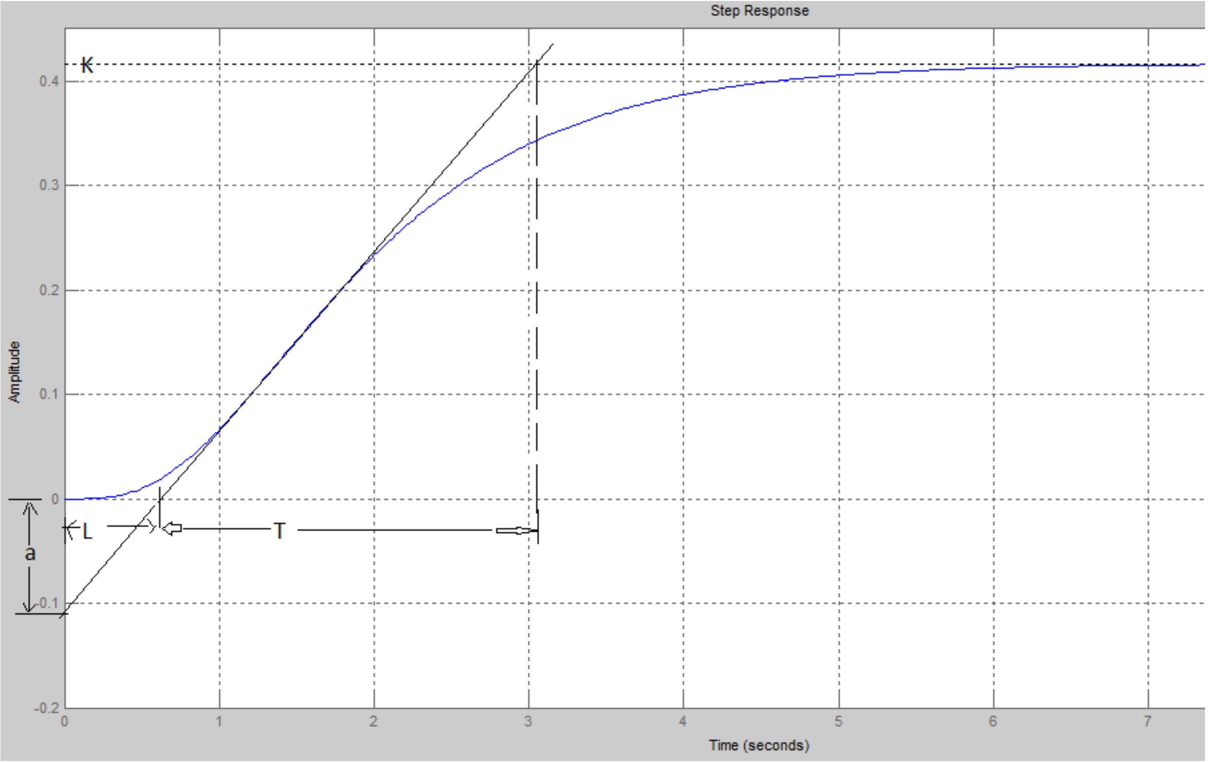
L= time delay;

T= time constant;

We can’t derive the model physically and we need to perform the experiment to get the values of the parameters. Hare Matlab is used to trace the response of plant versus time. For finding plant model parameter some basic calculation have to done.

2.1 FOPDT (first order plus dead time)

For instance, if the step response of the plant model can be measured through an experiment, the output signal can be recorded as sketched below and from which the parameters of k, L, and T (or a, where a = kL/T) can be extracted by the simple approach shown.

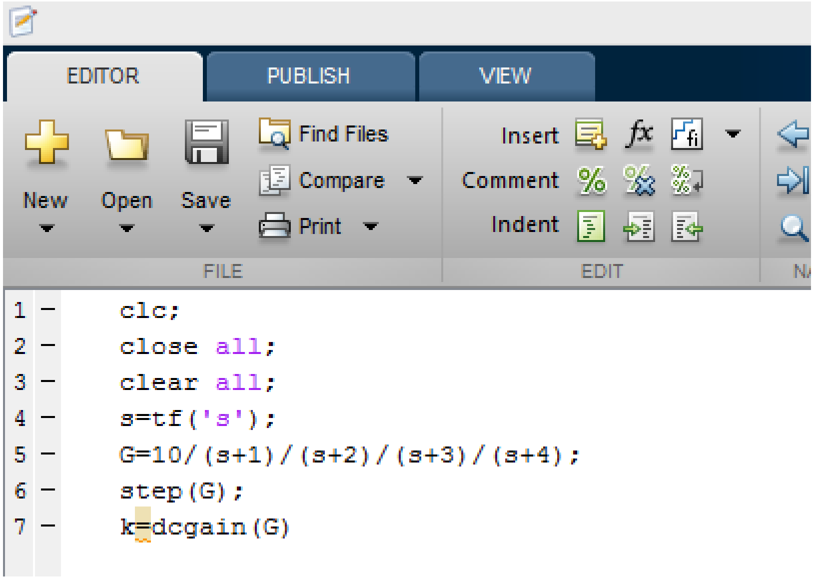


2.1.1 Finding parameter of FOPDT

Let process transfer function of a plant is

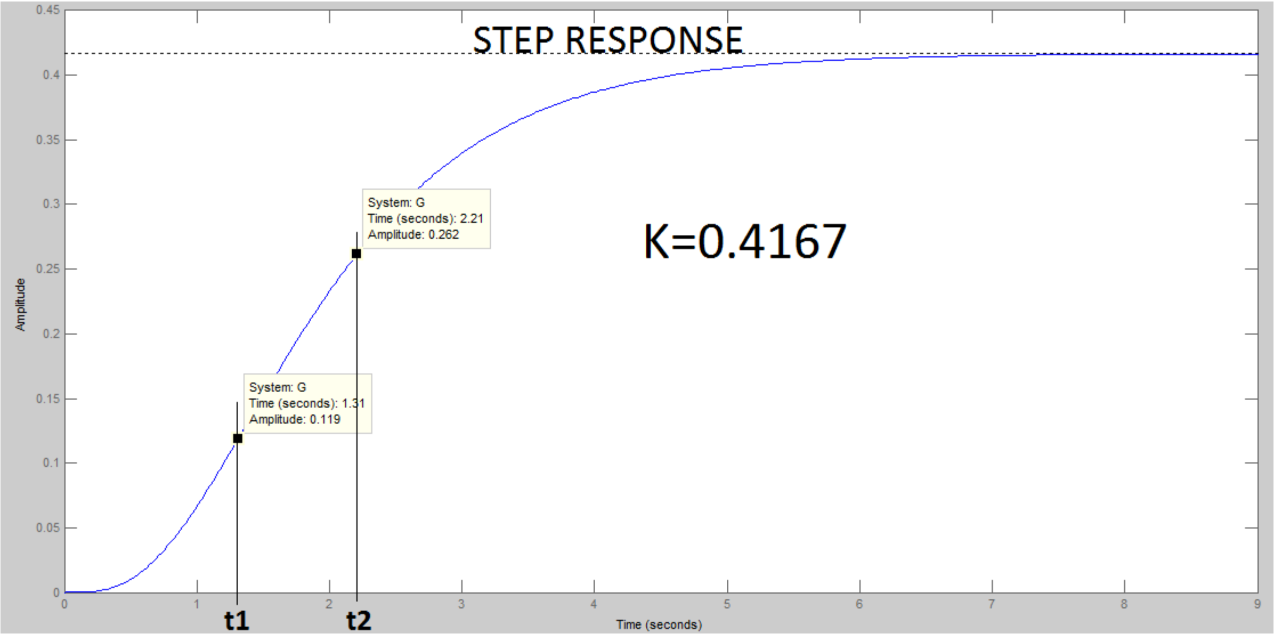
$$G(s) = 10/\ ((s+1)(s+2)(s+3)(s+4))$$

For gating step response of system a small matlab program is written:



```
clc;
close all;
clear all;
s=tf('s');
G=10/(s+1)/(s+2)/(s+3)/(s+4);
step(G);
k=dcgain(G)
```

2.1.2 Step Response of plant is



t_1=time at which, gain(c) =0.283 *steady state gain (K)

t_2=time at which, gain(c) = 0.632 *steady state gain (K)

We have two equation for finding T and L

T=3(t2-t1)/2

L= (t2-t1)

a=KL/T

So from step response;

K=0.4167

t_1= 1.31 sec

t_2=2.21 sec

and

L=.855 sec

T=1.365 sec

Now we have FOPDT equation as:

G(s)= $.4167 * e^{-.855s}/(1.365s+1)$

2.2 IPDT

Parameter of this plant model can be calculated by same procedure as FOPDT.

For this model let

K=.417

L=.855

So plant model equation is:

G(s) = $0.417 * e^{-.855s}/s$

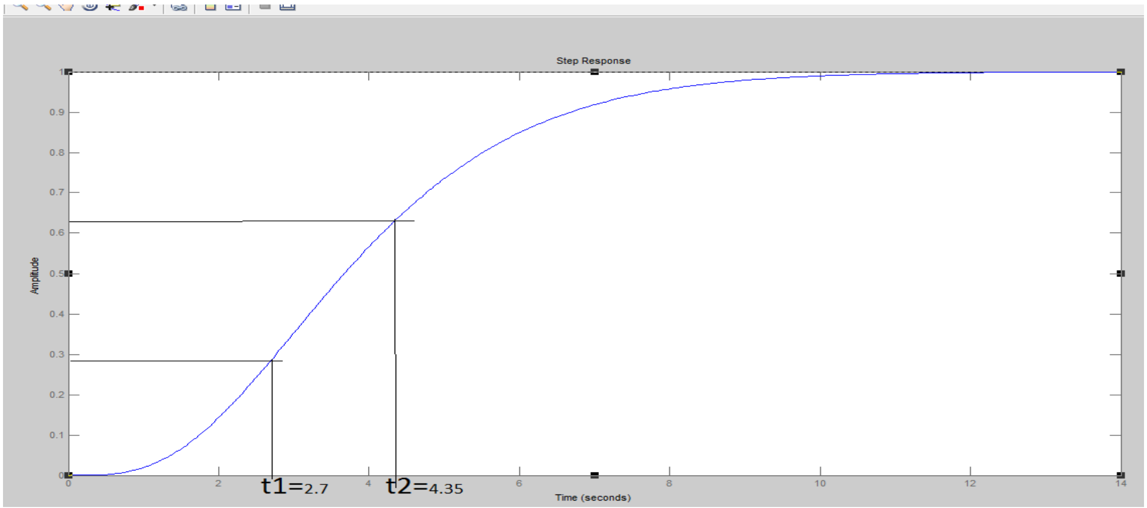
We don’t need any extra integrator to remove the steady state error because there is already an integrator planted and error caused due to disturbances we use integrator for that process. Large overshoot can be ignored by PD controller.

2.3 FOIPDT

Parameters of FOIPDT is calculated using the procedure used in FOPDT model.

Let a process is G(s) = 1/s(s+1)^4

Its step response is



So we may calculate k, T & L with some simple calculation as above done

K=1

T=2.475

L=1.875

Now we have FOIPDT model equation as:

G(s) = K$e^{-1.875s}$/s*(2.475s+1)

Since an integrator is contained in the model, an extra integrator is not necessary in the controller to remove the steady-state error due to set point change. So a PD controller may be used if there is no steady state disturbance at the plant. If steady state error due to disturbance is present then PID controller will be use

Chapter 3

DIFFERENT TUNING PROCEDURE

For finding controller parameters same tuning procedure can't be used for all types of plant model. For each plant model different tuning formula is used.

3.1 Tuning formula used for FOPDT

>Ziegler-Nichols tuning formula

> Chine-Hrones-Reswick PID tuning algorithm

>Cohen-Coon Tuning algorithm

>Wang-Juang-Chan tuning formula

3.1.1 Ziegler- Nichols tuning formula

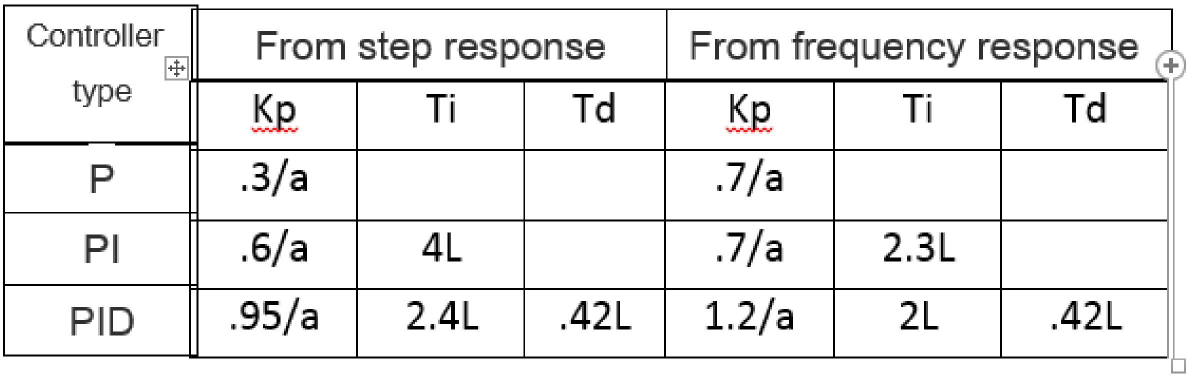
Ziegler and Nichols proposed this formula in 1942.

From the given formula one can find PID controller parameter either tracing step response of process transfer function or Nyquist plot of the transfer function.

From step response we find out 'L' and 'a' value and using this value in the formula we get PID parameter.

From Nyquist plot we get crossover frequency (**ω_c**) and the ultimate gain **Kc** can be obtained. Then using these in formula controller parameter is found out.

The tuning formula is



Controller type	From step response			From frequency response		
	Kp	Ti	Td	Kp	Ti	Td
P	.3/a			.7/a		
PI	.6/a	4L		.7/a	2.3L	
PID	.95/a	2.4L	.42L	1.2/a	2L	.42L

Hare only using step response; controller parameters are found out. Then using Simulink output step response the model plant is taken.

We have FOPDT equation as:

G(s)= .4167$* e^{-.855s}/(1.365s+1)$

So

a=KL/T=.19121

Controller….

P=5.229

PI= 4.7069(1+/s2.565)

PID=6.2758 +3.67006/s+2.6829N/(1+N/s)

3.1.2 Chine-Hrones-Reswick PID tuning algorithm

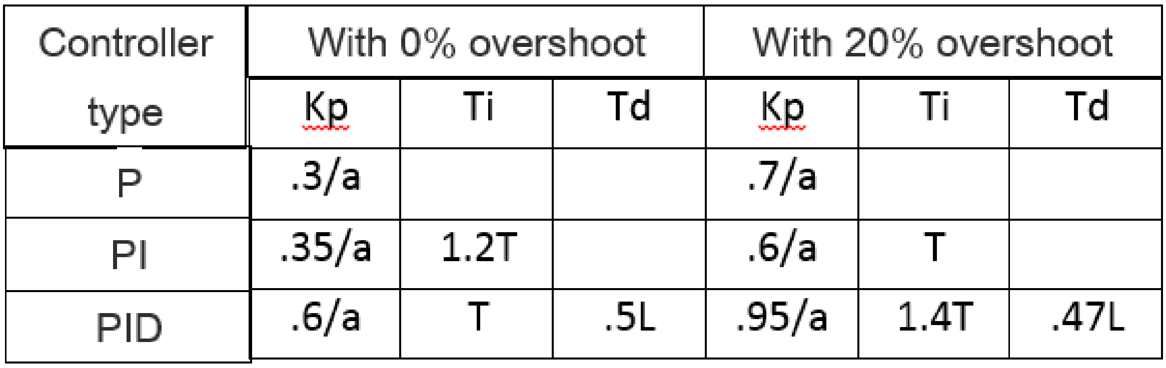
The Chien–Hrones–Reswick (CHR) method focus on the set-point regulation or disturbance rejection. Also regarding response speed and overshoot an additional comment can be that Compared with the traditional Ziegler–Nichols tuning formula, the CHR method uses the time constant T of the plant explicitly.

The more heavily damped closed-loop response, which ensures, for the ideal plant model, the “quickest response without overshoot” is labeled “with 0% overshoot,” and the “quickest response with 20% overshoot” is labeled “with 20% overshoot”.

The CHR PID controller tuning formulas are given hare for set point tracking and disturbance rejection.

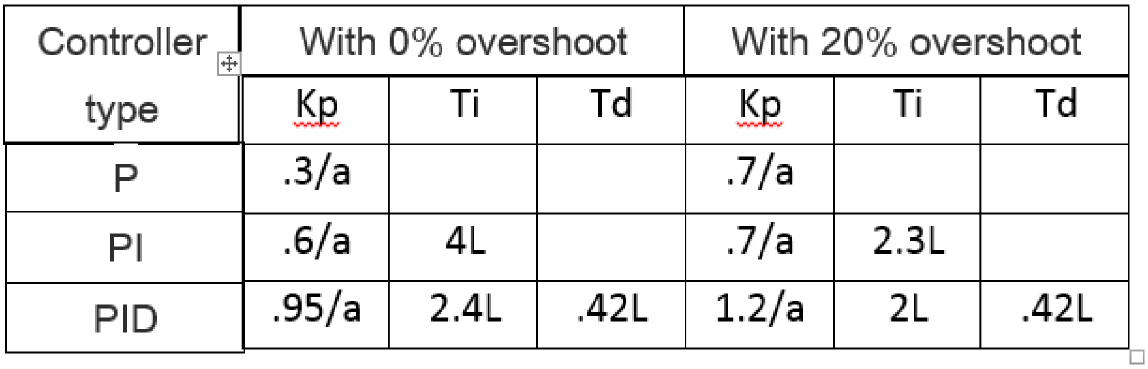
CHR tuning formulae

For set point regulation



Controller type	With 0% overshoot			With 20% overshoot		
	Kp	Ti	Td	Kp	Ti	Td
P	.3/a			.7/a		
PI	.35/a	1.2T		.6/a	T	
PID	.6/a	T	.5L	.95/a	1.4T	.47L

For disturbance rejection



Controller type	With 0% overshoot			With 20% overshoot		
	Kp	Ti	Td	Kp	Ti	Td
P	.3/a			.7/a		
PI	.6/a	4L		.7/a	2.3L	
PID	.95/a	2.4L	.42L	1.2/a	2L	.42L

1

Now on the basis of mentioned table I have found out the controller parameter.

For set point regulation:

For Zero % overshoot

P controller: Kp =1.5687

PI controller: Kp = 1.8305 Ti=1.638

PID controller: Kp = 3.1374 Ti= 1.368 Td=.4275

For 20 % overshoot

P controller: Kp =3.66

PI controller: Kp = 3.137 Ti=1.365

PID controller: Kp = 4.9675 Ti=1.91 Td=.402

For disturbance rejection:

For Zero % overshoot

P controller: Kp =1.5687

PI controller: Kp = 3.137 Ti=3.42

PID controller: Kp = 4.9675 Ti= 2.052 Td=.3591

For 20 % overshoot

P controller: Kp =3.6603

PI controller: Kp = 3.6603   Ti=1.9665

PID controller: Kp = 6.2748   Ti= 1.71   Td=.3591

1.1.3 Cohen-Coon Tuning algorithm

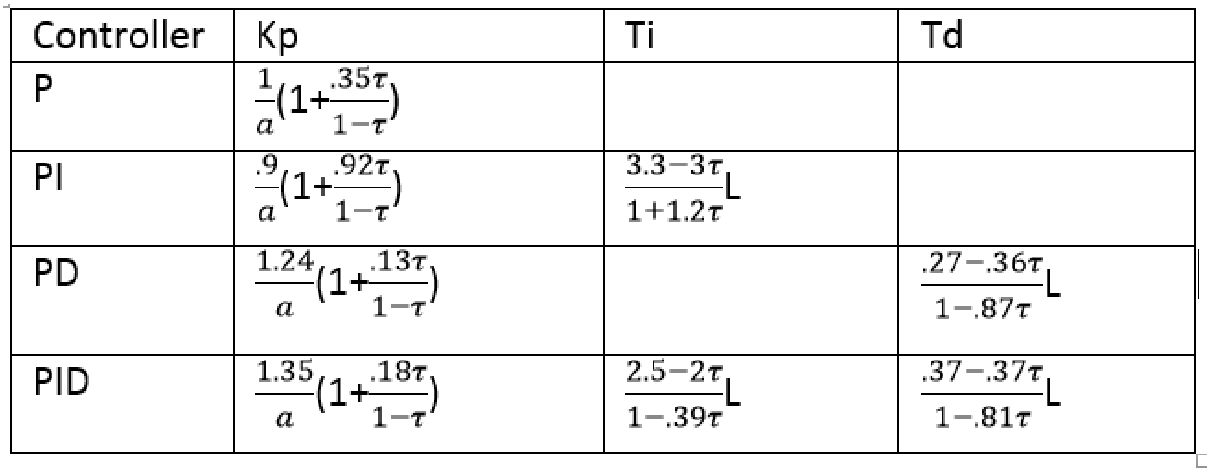
It is another type of Ziegler-nichols tuning formula.

The different controllers can be designed by the direct use of below table.

In this table ‘a’ and τ experimentally calculated.

a= KL/T;

τ=L/(L+T);



Controller	Kp	Ti	Td
P	$\frac{1}{a}(1+\frac{.35\tau}{1-\tau})$		
PI	$\frac{.9}{a}(1+\frac{.92\tau}{1-\tau})$	$\frac{3.3-3\tau}{1+1.2\tau}L$	
PD	$\frac{1.24}{a}(1+\frac{.13\tau}{1-\tau})$		$\frac{.27-.36\tau}{1-.87\tau}L$
PID	$\frac{1.35}{a}(1+\frac{.18\tau}{1-\tau})$	$\frac{2.5-2\tau}{1-.39\tau}L$	$\frac{.37-.37\tau}{1-.81\tau}L$

Controller parameters

P controller: Kp = 6.37536

PI controller: Kp =7.418, Ti=1.254

PD controller: Kp = 7.019, Td= .1688

PID controller: Kp= 7.855, Ti= 1.74, Td= 0.2827

1.1.4 Wang-Juang-Chan tuning formula

This tuning algorithm is proposed by Wang, Juang, and Chan. For selecting the PID parameters it is a simple and efficient method which is based on the optimum ITAE criterion. The controller parameters can given by, if the parameters K, L, T of the plant model are known,

Kp = (.7303+.5307T/L)(T+.5L)/K(T+L)

Ti=T+.5L;

Td=.5LT/(T+.5L)

Parameters value are

- KP= 3.0568
- Ti=1.7925
- Td=.3255

1.1.5 Optimal PID Controller Design

Optimum setting algorithms for a PID controller were proposed by Zhuang and Atherton for various criteria. Consider the general form of the optimum criterion

$$\mathrm{Jn}(\theta) = \int_0^\infty [t^n E(\theta, t)]^2 \, dt$$

Where $e(\theta, t)$ is the error signal which enters the PID controller, with θ the PID controller parameters. Two setting strategies for PID controller are proposed:

One for the set-point input and the other for the disturbance signal $d(t)$. In particular, three values of n are discussed, i.e., for $n = 0, 1, 2$. These three cases correspond, respectively, to three different optimum criteria: the integral squared error (ISE) criterion, integral squared time weighted error (ISTE) criterion, and the integral squared time-squared weighted error

(IST2E) criterion. The expressions given were obtained by fitting curves to the optimum theoretical results.

Set-Point optimum PID tuning

For PI controller

$Kp=(a1/K)(L/T)^{b1}$

$Ti=T/(a2+b2(L/T))$

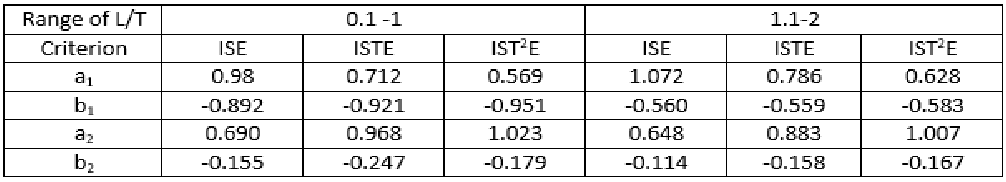
For PID controller

$Kp=(a1/K)(L/T)^{b1}$

$Ti=T/(a2+b2(L/T))$

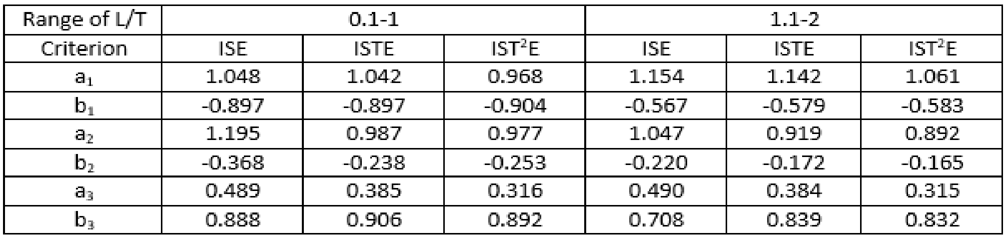
$Td=a3T(L/T)^{b3}$

Set point PI controller parameter



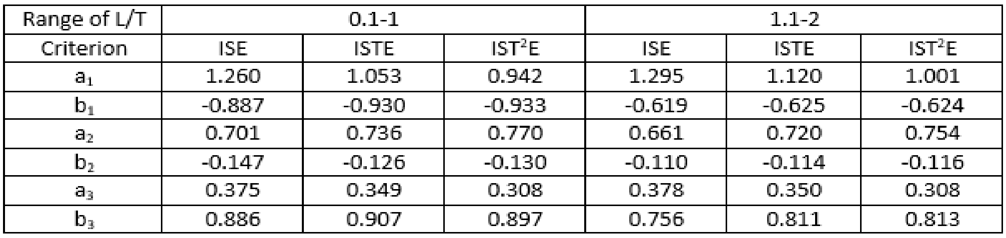
Range of L/T	0.1 -1			1.1-2		
Criterion	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
a_1	0.98	0.712	0.569	1.072	0.786	0.628
b_1	-0.892	-0.921	-0.951	-0.560	-0.559	-0.583
a_2	0.690	0.968	1.023	0.648	0.883	1.007
b_2	-0.155	-0.247	-0.179	-0.114	-0.158	-0.167

Set-point PID controller parameters



Range of L/T	0.1-1			1.1-2		
Criterion	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
a_1	1.048	1.042	0.968	1.154	1.142	1.061
b_1	-0.897	-0.897	-0.904	-0.567	-0.579	-0.583
a_2	1.195	0.987	0.977	1.047	0.919	0.892
b_2	-0.368	-0.238	-0.253	-0.220	-0.172	-0.165
a_3	0.489	0.385	0.316	0.490	0.384	0.315
b_3	0.888	0.906	0.892	0.708	0.839	0.832

Set-point PID controller parameters with D in feedback path



Range of L/T	0.1-1			1.1-2		
Criterion	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
a_1	1.260	1.053	0.942	1.295	1.120	1.001
b_1	-0.887	-0.930	-0.933	-0.619	-0.625	-0.624
a_2	0.701	0.736	0.770	0.661	0.720	0.754
b_2	-0.147	-0.126	-0.130	-0.110	-0.114	-0.116
a_3	0.375	0.349	0.308	0.378	0.350	0.308
b_3	0.886	0.907	0.897	0.756	0.811	0.813

Disturbance rejection PID controller

PI controller

Kp= (a1/T)(L/T)^b1

Ti= (T/a2)*(L/T)^b2

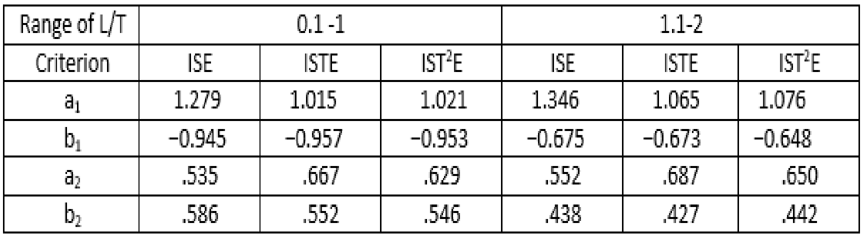
PID controller

Kp= (a1/T)*(L/T)^b1

Ti= (T/a2)(L/T)^b2

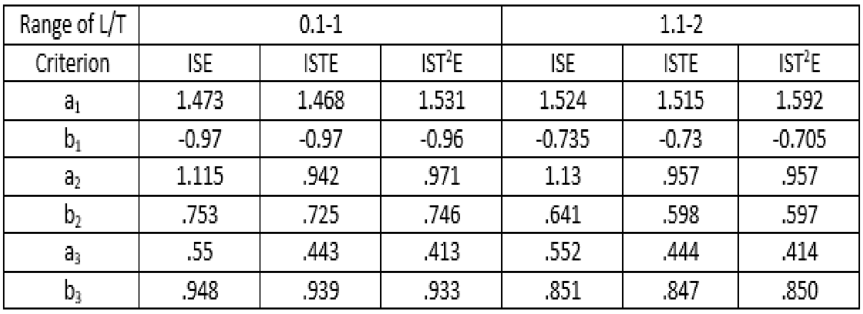
Td=a3T(L/T)^b3

Disturbance rejection PI controller parameter



Range of L/T	0.1 -1			1.1-2		
Criterion	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
a_1	1.279	1.015	1.021	1.346	1.065	1.076
b_1	−0.945	−0.957	−0.953	−0.675	−0.673	−0.648
a_2	.535	.667	.629	.552	.687	.650
b_2	.586	.552	.546	.438	.427	.442

Disturbance rejection PID controller parameters

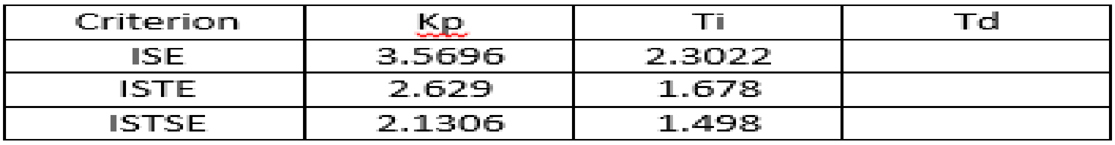


Range of L/T	0.1-1			1.1-2		
Criterion	ISE	ISTE	IST^{2}E	ISE	ISTE	IST^{2}E
a_1	1.473	1.468	1.531	1.524	1.515	1.592
b_1	-0.97	-0.97	-0.96	-0.735	-0.73	-0.705
a_2	1.115	.942	.971	1.13	.957	.957
b_2	.753	.725	.746	.641	.598	.597
a_3	.55	.443	.413	.552	.444	.414
b_3	.948	.939	.933	.851	.847	.850

Calculated controller parameter on the basis of this tuning:

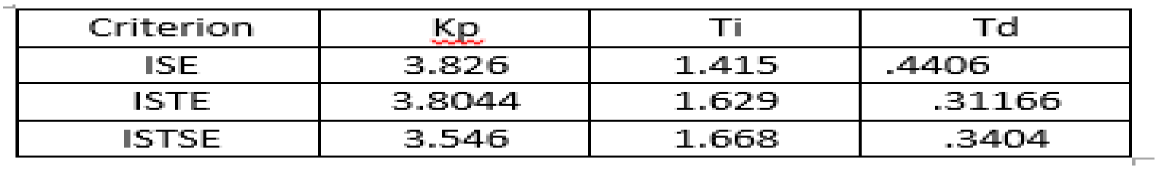
For set point tracking:

Pi controller



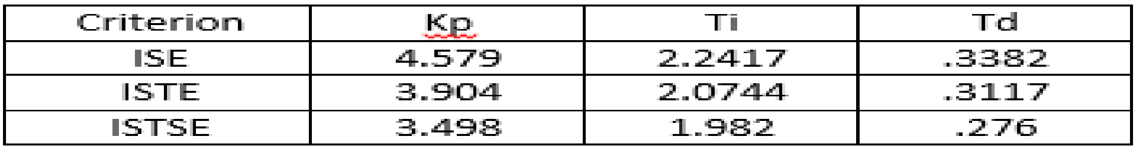
Criterion	Kp	Ti	Td
ISE	3.5696	2.3022	
ISTE	2.629	1.678	
ISTSE	2.1306	1.498	

PID controller



Criterion	Kp	Ti	Td
ISE	3.826	1.415	.4406
ISTE	3.8044	1.629	.31166
ISTSE	3.546	1.668	.3404

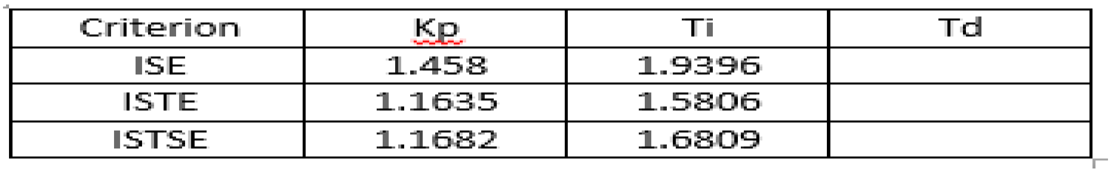
PID controller with D in feedback path



Criterion	Kp	Ti	Td
ISE	4.579	2.2417	.3382
ISTE	3.904	2.0744	.3117
ISTSE	3.498	1.982	.276

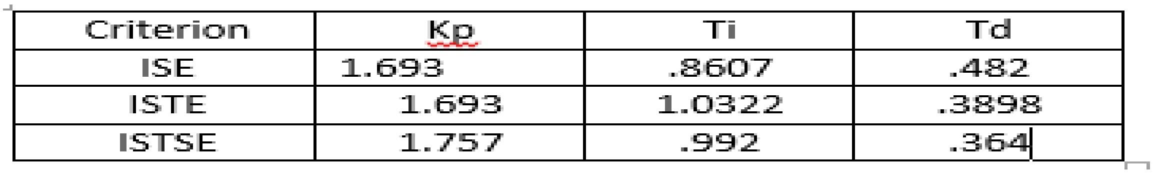
For disturbance rejection

Pi controller



Criterion	Kp	Ti	Td
ISE	1.458	1.9396	
ISTE	1.1635	1.5806	
ISTSE	1.1682	1.6809	

PID controller



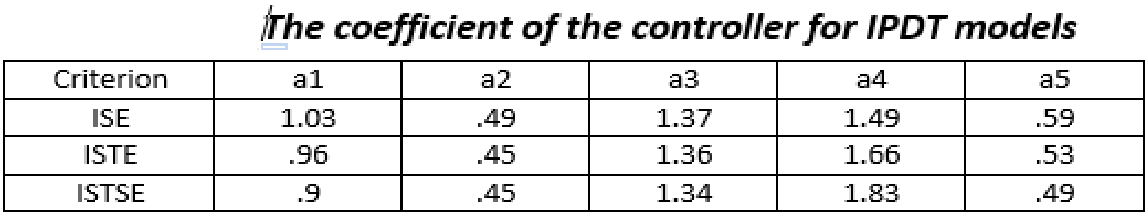
Criterion	Kp	Ti	Td
ISE	1.693	.8607	.482
ISTE	1.693	1.0322	.3898
ISTSE	1.757	.992	.364

3.2 Tuning formula for IPDT

we have IPDT equation as:

G(s) = $0.417 * e^{-.855s}/s$

As above discussed for IPDT we use PD and PID controller



The coefficient of the controller for IPDT models

Criterion	a1	a2	a3	a4	a5
ISE	1.03	.49	1.37	1.49	.59
ISTE	.96	.45	1.36	1.66	.53
ISTSE	.9	.45	1.34	1.83	.49

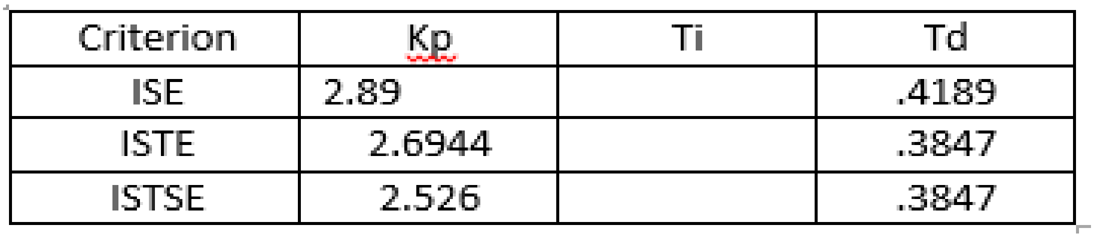
Controller parameters calculated as:

PD controller Kp = a1/KL; Td=aL

PID controller Kp=a3/KL; Ti= a4L ; Td=a5L

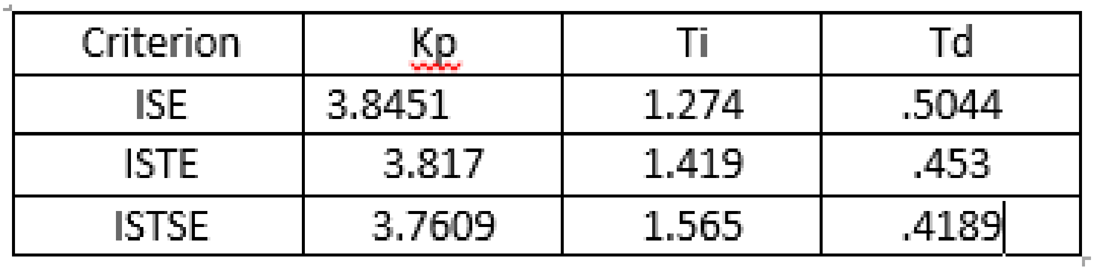
Controller parameter:

PD controller



Criterion	Kp	Ti	Td
ISE	2.89		.4189
ISTE	2.6944		.3847
ISTSE	2.526		.3847

PID controller



Criterion	Kp	Ti	Td
ISE	3.8451	1.274	.5044
ISTE	3.817	1.419	.453
ISTSE	3.7609	1.565	.4189

3.3 Tuning formula for FOIPDT

we have FOIPDT equation as:

$G(s) = Ke^{-1.875s}/s*(2.475s+1)$

A PD controller setting algorithm is

Kp = 2/3KL

Td = T

And PID setting algorithm

Kp=1.111T/(KL^2(1+(T/L)^.65)^2); Ti=2L(1 +(T/L)^.65)

Td=Ti/4

Calculated Controller parameters are:

PD CONTROLLER: Kp= .356, Kd=2.475

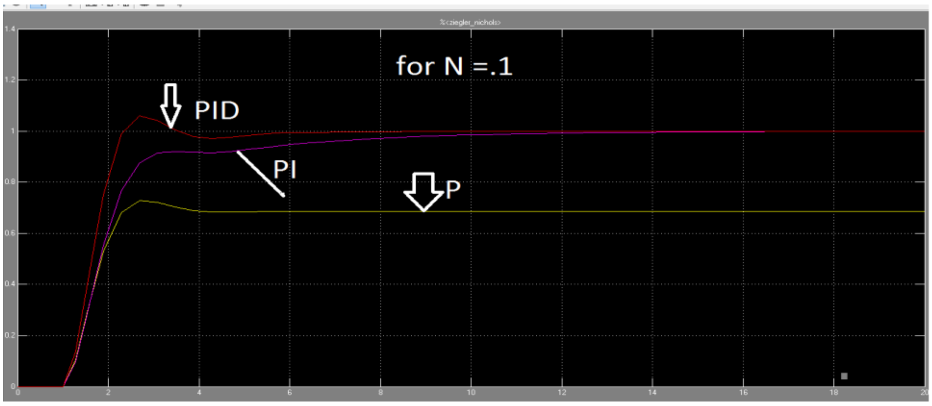
PID CONTROLLER: Kp=1617, Ti=8.2416, Td=2.04

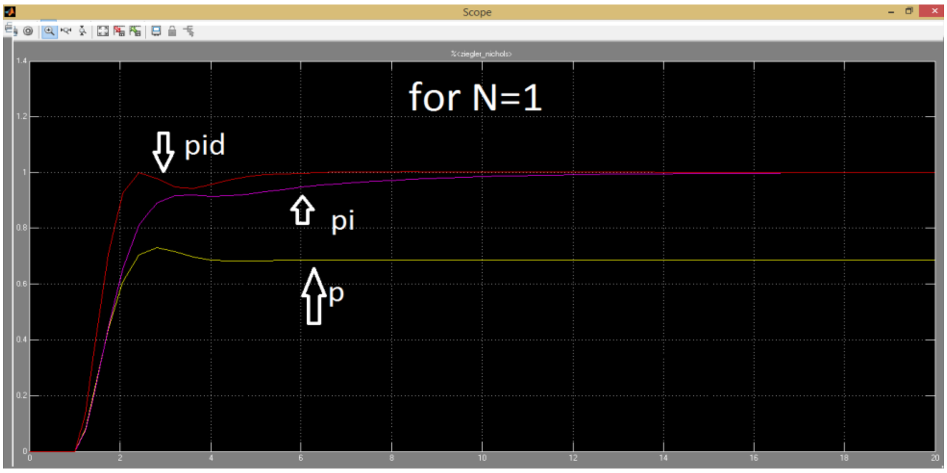
Chapter 4

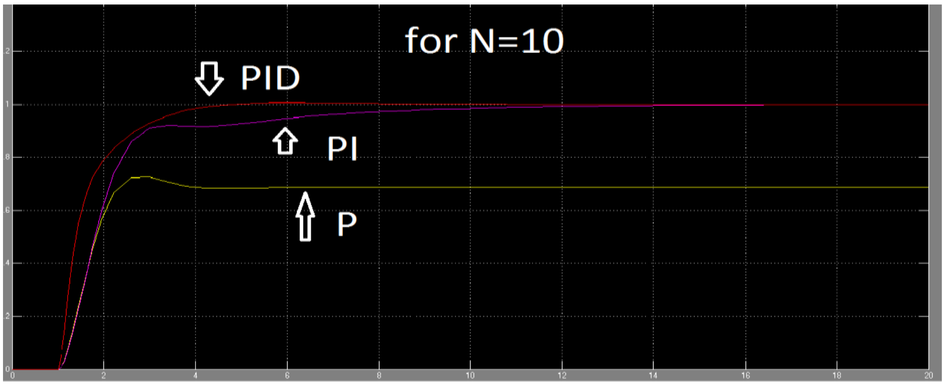
Simulation of FOPDT

Simulation is done using Simulink. Using tuning formula we have found out P, PI, PD and PID controller parameters. Response for FOIPDT plant modal is observed for different value of filter coefficient 'N'.

4.1 **simulation for Ziegler-Nichols tuning formula**







Note

y axis : amplitude

x axis : time(s)

Observation:

For N=10

Controller type	**Rise time**	**Settling time**
P	**1.5**	**3**
PI	**2**	**11**
PID	**2.5**	**3.5**

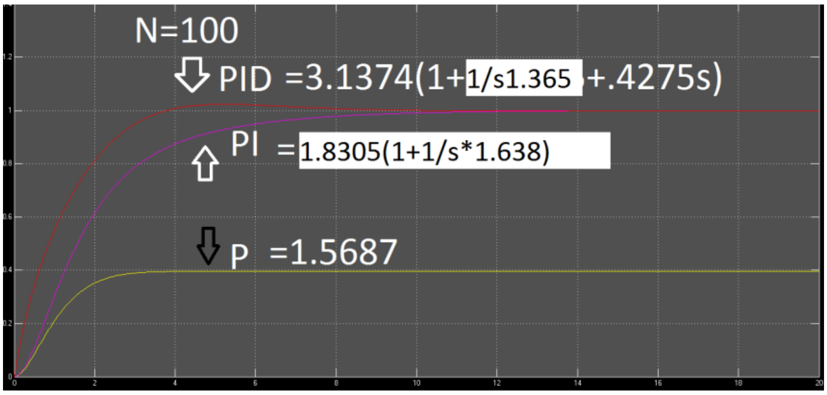
Result:

- So one can see that small value of '**N**' increase overshoot, settling time and oscillation but reduce the rise time for PID controller.
- PI controller is eliminating the error but P controller is giving offset.

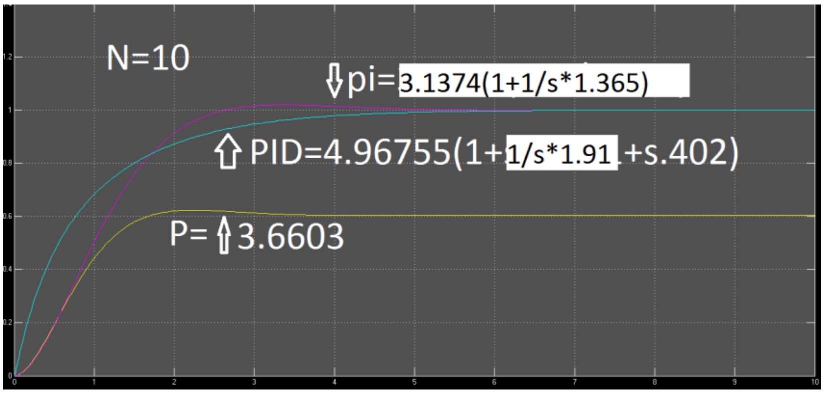
4.2 Simulation for Chine –Hrones-Reswick PID tuning algorithm

N=100

Set point regulation for Zero overshoot

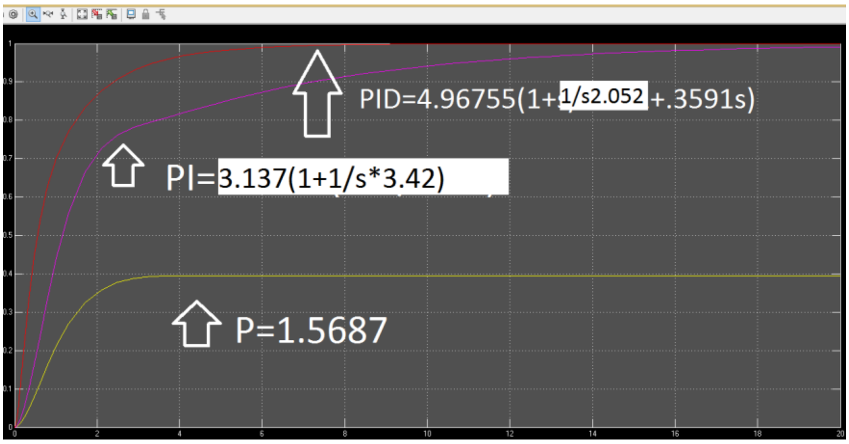


For 20% overshoot

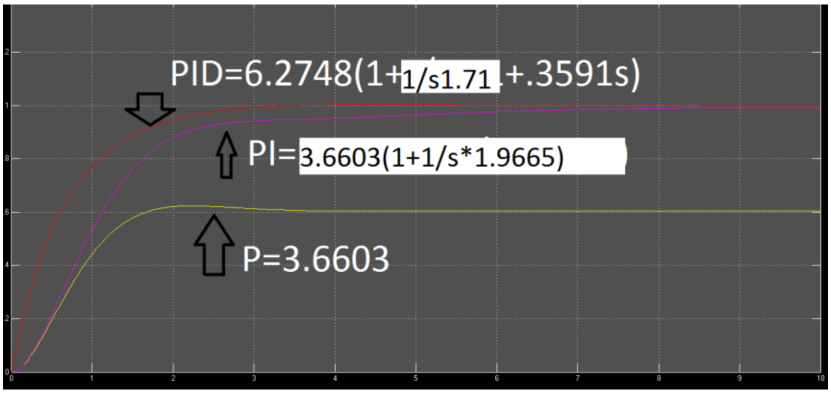


Disturbance rejection for

zero overshoot



20% overshoot



Note:

Y axis: amplitude

X axis: time

Observation:

For set point regulation:

Zero % overshoot

Controller type	R.T	S.T
P	2	3
PI	3.5	9
PID	2.5	8

20% overshoot

Controller type	R.T	S.T
P	1.5	3.5
PI	1.7	5
PID	2.4	6

For disturbance rejection

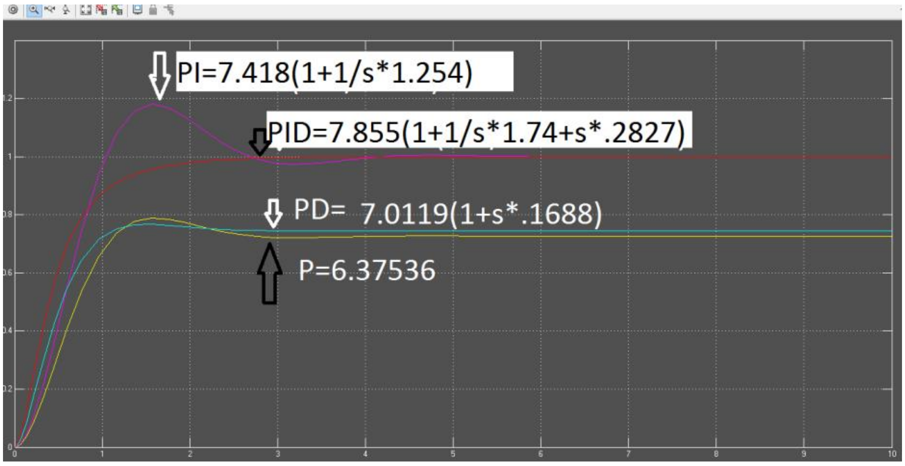
Zero% overshoot

Controller type	R.T	S.T
P	2	3
PI	7.75	20
PID	2	7

20% overshoot

Controller type	R.T	S.T
P	1.5	3
PI	2	8
PID	1.8	3

4.3 Simulation of Cohen-Coon Tuning algorithm



Note:

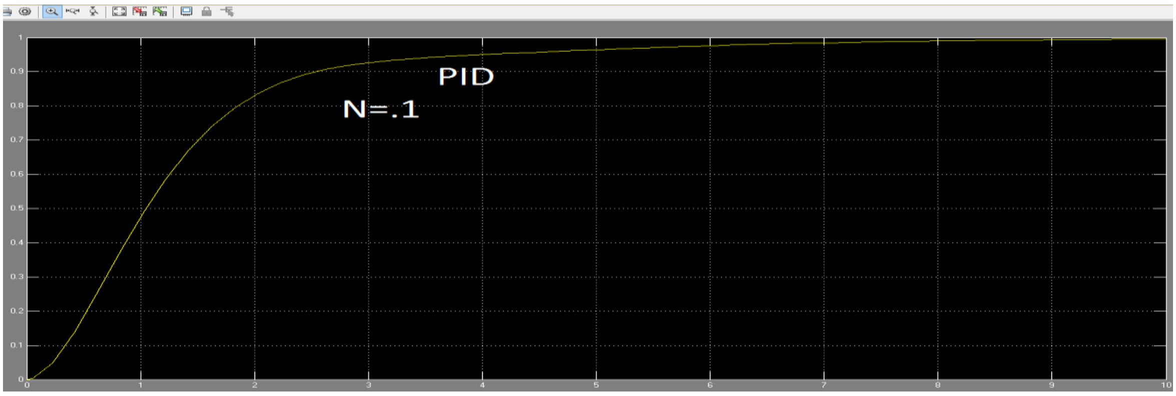
Y axis : amplitude

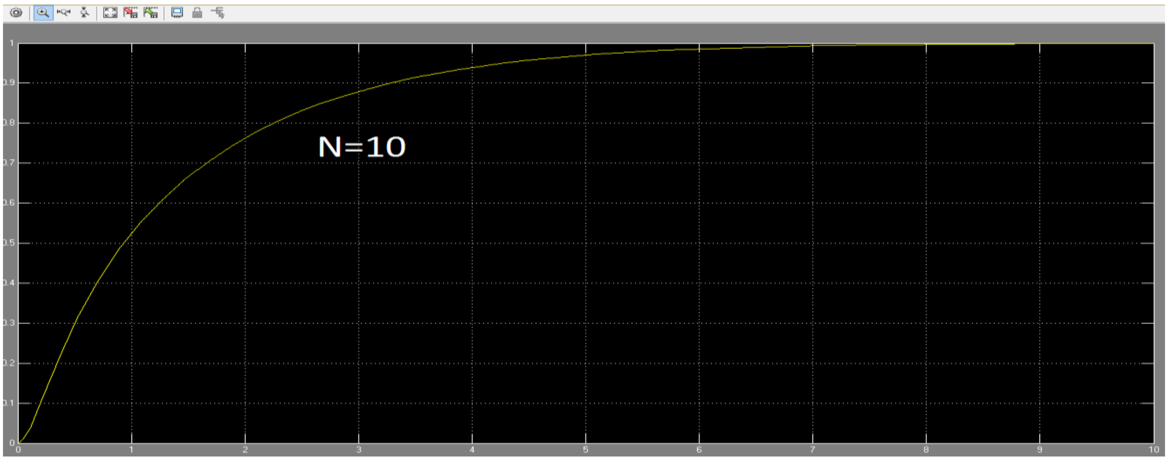
X axis: time(s)

Observation:

Controller type	R.T	S.T
P	.9	2.75
PI	1.2	4
PD	.7	2
PID	1	2.5

4.4 Simulation of Wang-Juang-Chan tuning formula





Note: Y axis: amplitude

X axis: time(s)

Observation: FOR N= 10;

Controller type	R.T	S.T
PID	3	7

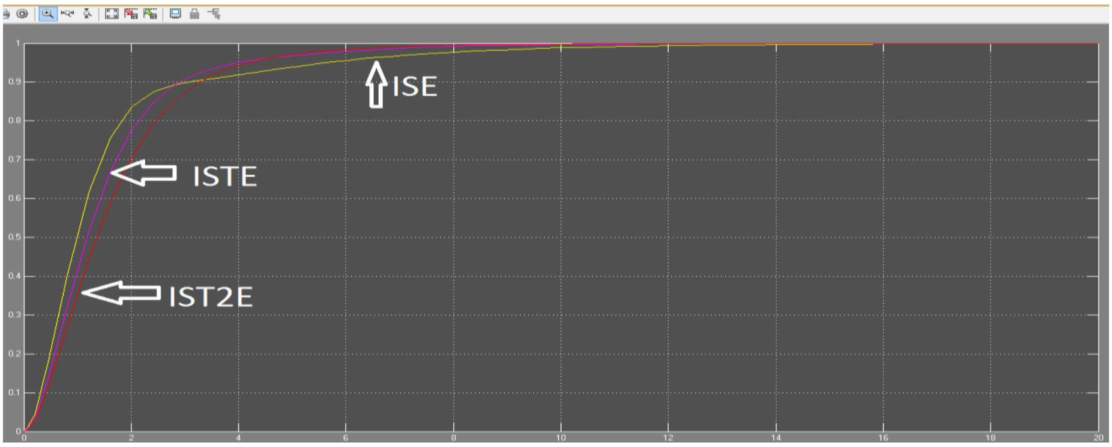
Result:

- small value of **N** reduced the rise time but increased the settling time.

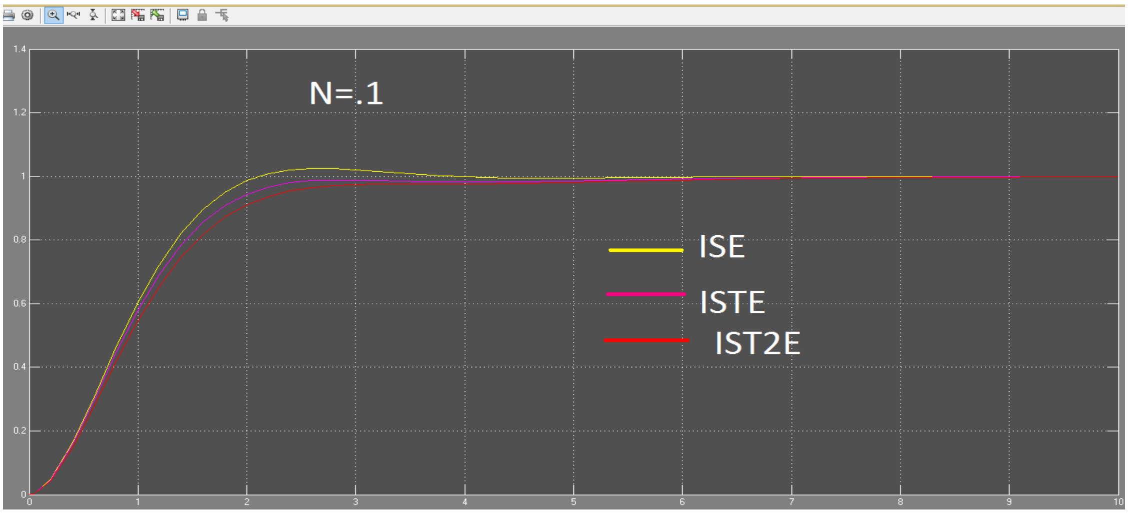
4.5 Simulation of Optimal PID Controller Design

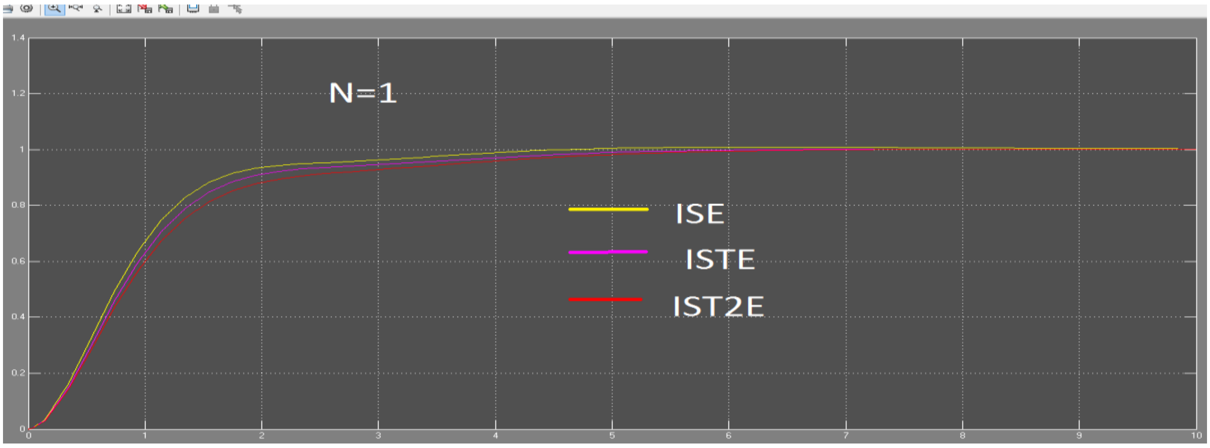
For Set point tracking:

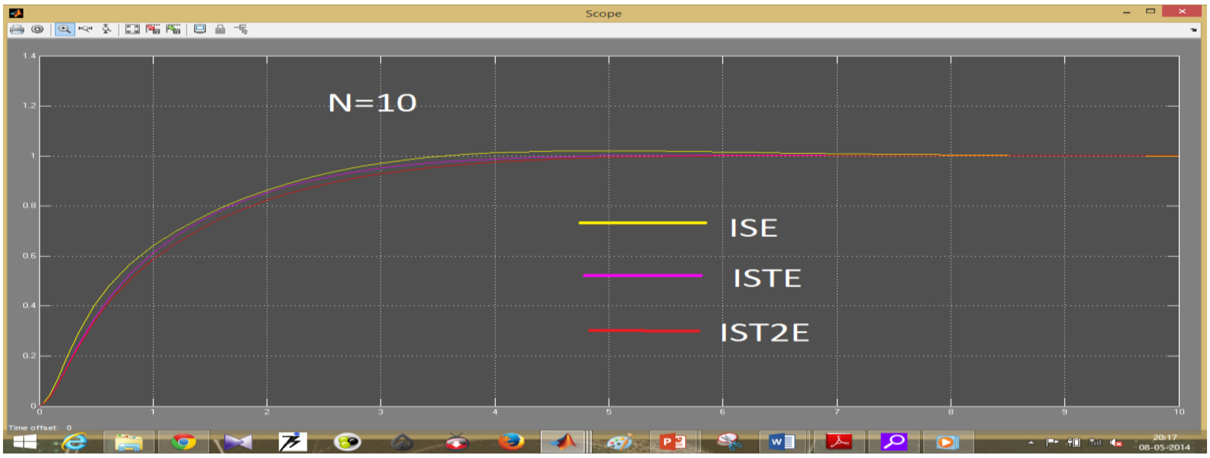
PI controller



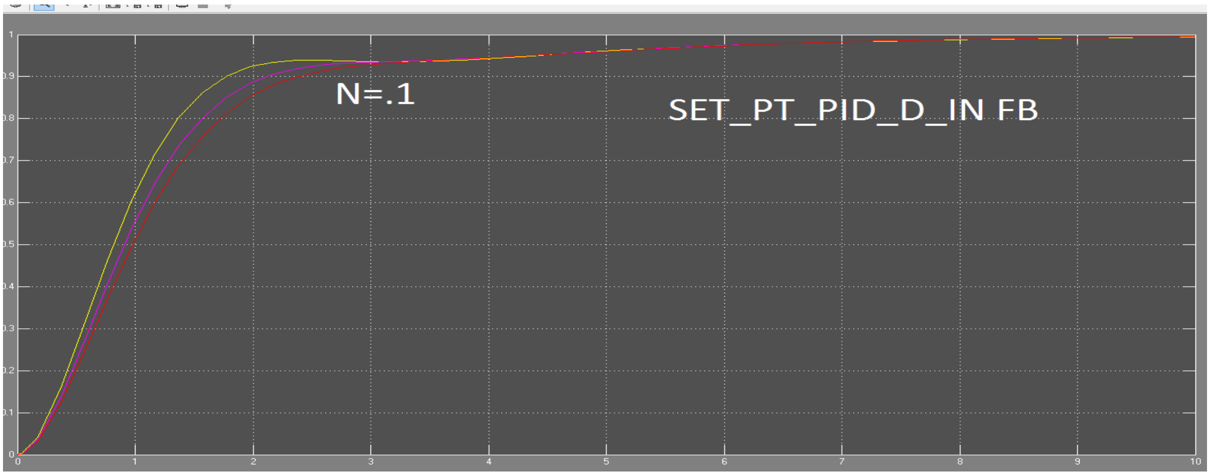
PID controller

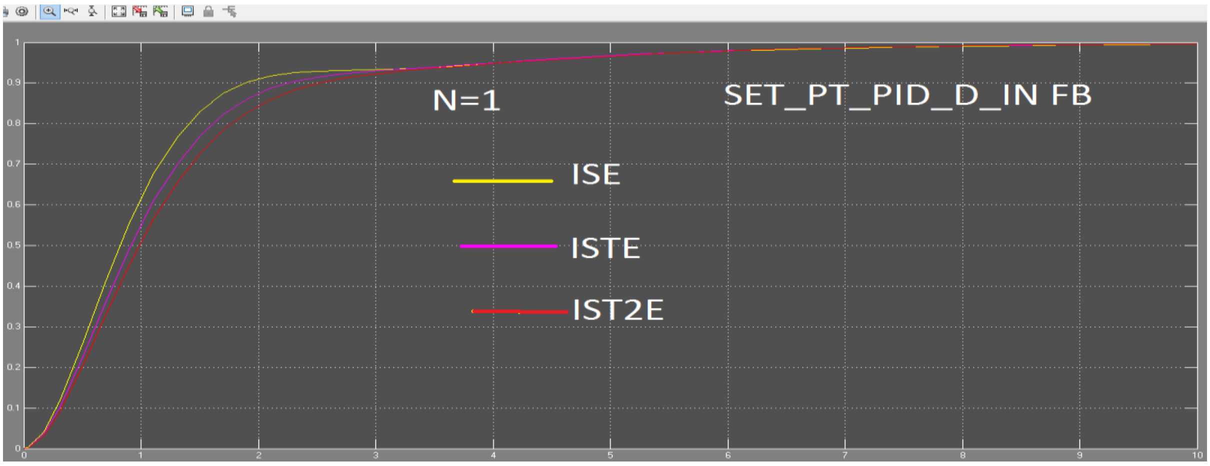


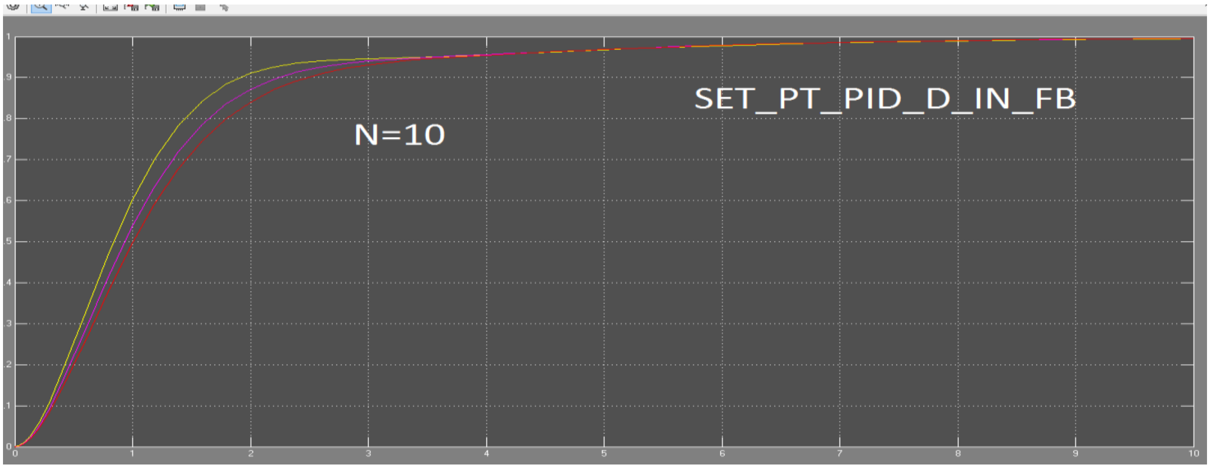




PID controller with D in feedback

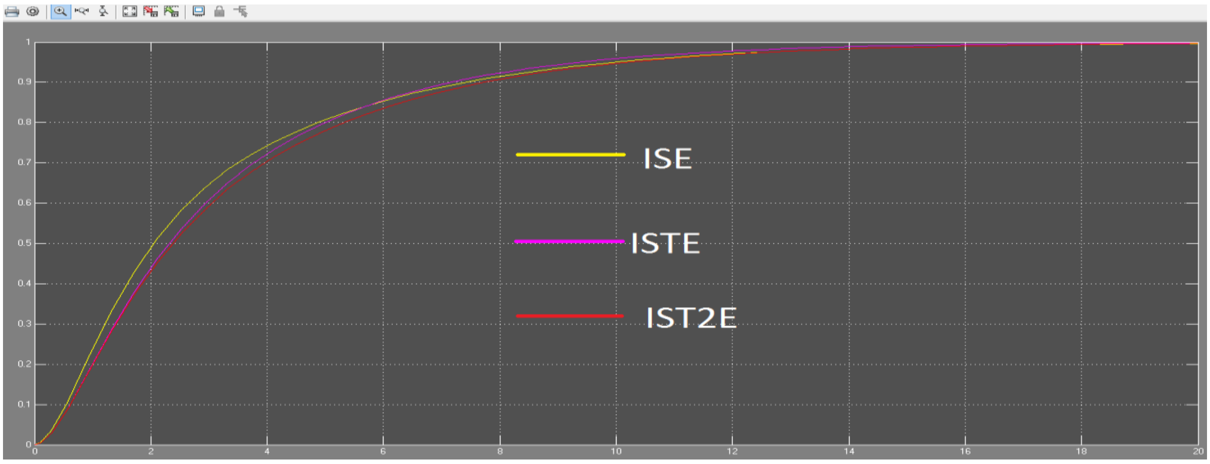




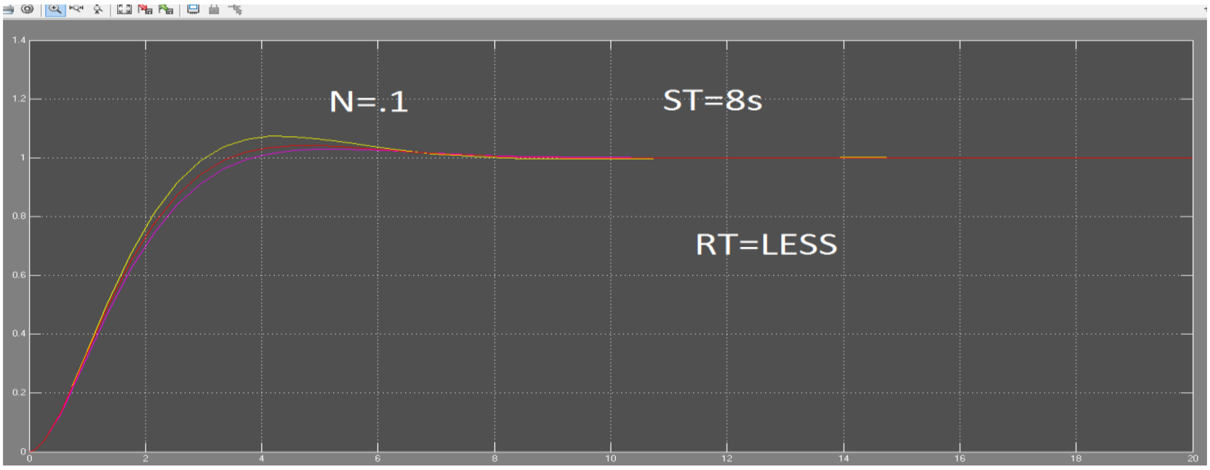


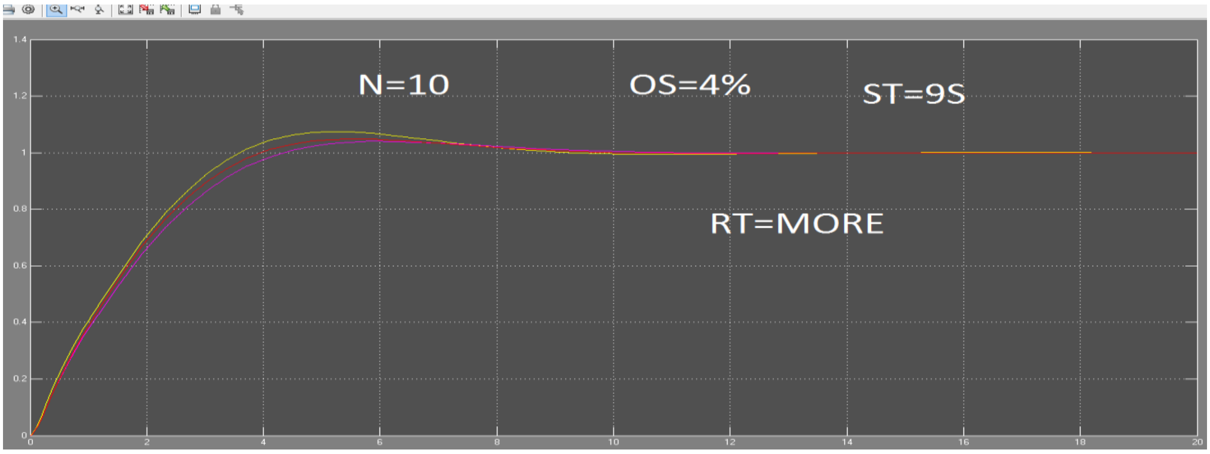
Disturbance rejection:

PI controller



PID controller





Observation:

For set point tracking:

PI controller:

Criterion type	R.T	S.T
ISE	2.8	12
ISTE	2.6	10
IST2E	3	8

PID controller: FOR N = 10

Criterion type	R.T	S.T
ISE	2.1	6.5
ISTE	2.3	4.5
IST2E	3	5

PID controller with D in feedback:

Criterion type	R.T	S.T
ISE	1.6	10
ISTE	2	10
IST2E	2.2	10

For disturbance rejection:

PI controller:

Criterion type	R.T	S.T
ISE	7	15.8
ISTE	6.4	16
IST2E	7.1	16.2

PID controller: N=10

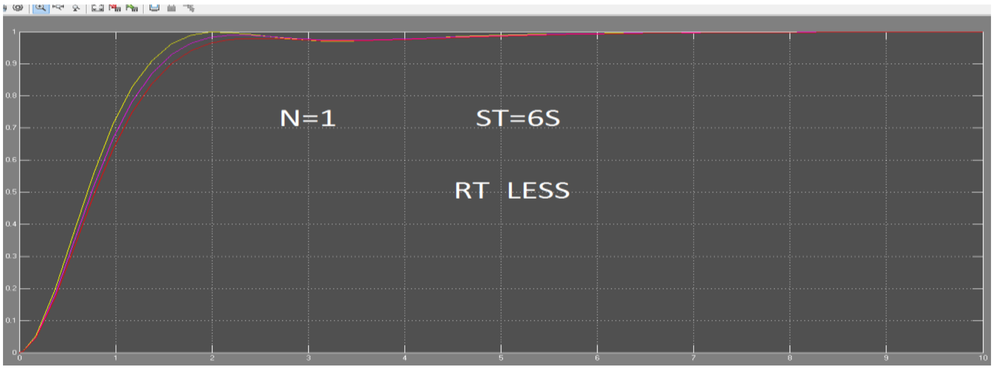
Criterion type	R.T	S.T
ISE	3	7
ISTE	3.4	7.2
IST2E	3.2	7.4

Chapter 5

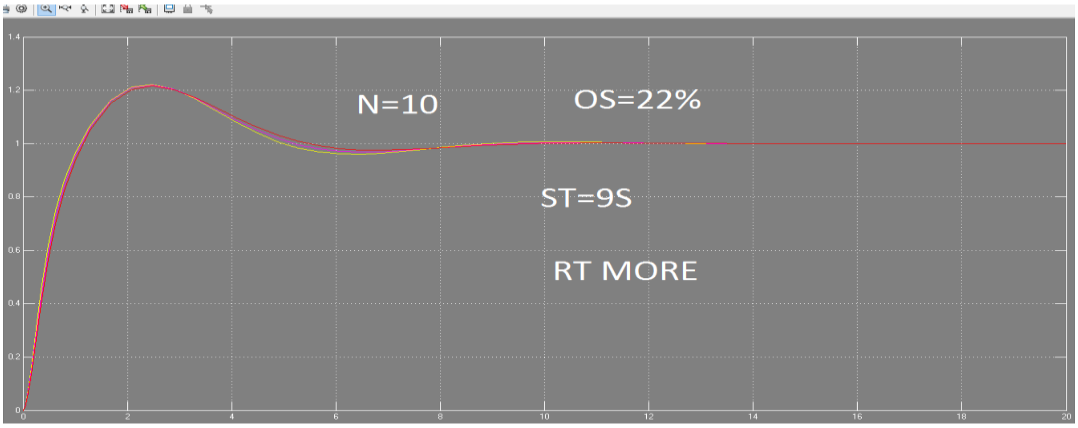
Simulation of IPDT model

As above discussed for IPDT we use PD and PID controllers. Simulation taken corresponding these controller are given below.

PD controller



PID controller



Note:

Y axis: amplitude

X axis :time()

Observation:

For PD controller

Criterion type	R.T	S.T
ISE	1.8	4.9
ISTE	1.9	5
IST2E	2	5.1

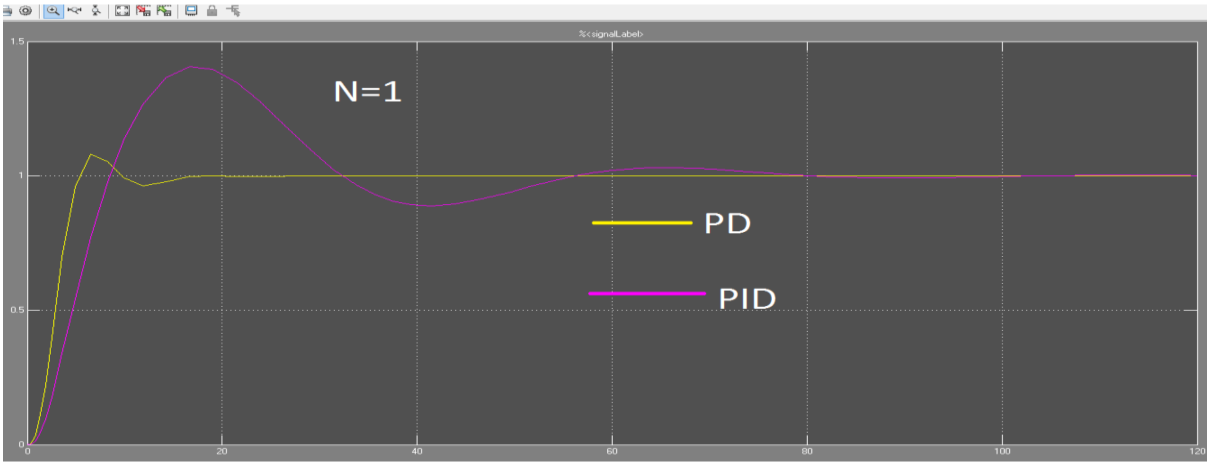
For PID controller:

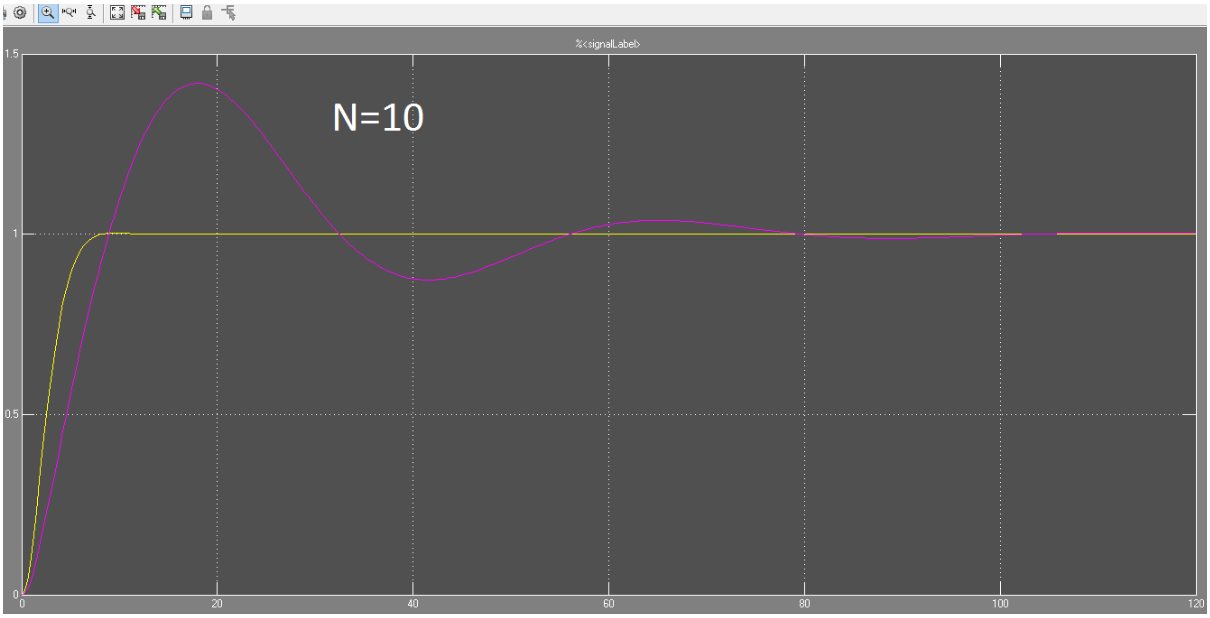
Criterion type	R.T	S.T
ISE	1.6	8.8
ISTE	1.6	9
IST2E	1.6	9.2

Chapter 6

Simulation of FOIPDT MODELS

For FOIPDT PD and PID type of controller are used. Simulation regarding these controller shown below for different value of N.





Note:

Y axis: amplitude

X axis: time(s)

Observation: for N=10

Controller type	R.T	S.T
PD	4	8
PID	12	100

Chapter 7

Conclusion and Future work

Project study on PID controller design for various plant model provide a brief idea of plant modeling, type of plant model and controllers (P, PI, PD and PID) tuning method used for the of the model plant.

Plant model FOPDT, IPDT and FOIPDT are discussed in details. For each model different tuning methods are used. They help in finding controllers parameters. For tuning of controllers of FOPDT **Ziegler-Nichols tuning formula, Chine-Hrones-Reswick PID tuning algorithm, Cohen-Coon Tuning algorithm, Wang-Juang-Chan tuning formula** and **optimal PID controller design** are used. Controllers used for IPDT and FOIPDT can't be tuned by algorithm used for FOPDT.

Discussed Plant modeling will help in modeling of many industrial plant. And tuning method used for that plant will help to find out of controllers parameters. Response will suggest which tuning method is better for the plant. And also it will play great roll in selecting of controller.

Reference

- **Control system engineering - Norman S Nice**
- **Principal of measurement system – John P. Bentlay**
- **Process Control Modeling, Design and Simulation - B. Wayne Bequette**

References from internet

- http://www.siam.org/books/dc14/DC14Sample.pdf
- http://en.wikipedia.org/wiki/PID_controller