Tuning PID Controllers for Processes with Difficult Dynamics

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

MAY 2013

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

_____

Dr Lemma Dendena Tufa

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May, 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NURUL SAFIKA BINTI ABDUL FATAH

ABSTRACT

PID controllers provide satisfactory performance and widely used in many of control processes due to their simplicity. An appropriate controller tuning provide a good performance of the controller to perform well. Some processes are difficult to control especially processes with difficult dynamic. In this report, the author will discuss mostly on two types of dynamic processes which are time delay process and inverse response process. A model of each dynamic process is obtained to studies their behaviour using various type of tuning method such as internal model control (IMC), SIMC, Ziegler-Nichols (Z-N) and Tyreus-Luyben (T-L). Matlab Simulink is used to observe their behaviour and simulation result on each process. This is because difference tuning methods perform difference controller response. The project is successfully done and achieved the objectives.

ACKNOWLEDGEMENT

First and foremost, my deepest gratitude to God, for given me strength and guidance to overcome the challenges and problems in completing the whole 28 weeks of my final year project. I also would like to greet my family for giving me great support from the beginning of my journey until the end.

My sincerest appreciation goes to my Supervisor, Dr Lemma Dendena Tufa for his patience in guiding me and his determination to make me learn as much as I can throughout my final year project period. He has motivated me to become a better person and ready to face challenges in future instead of technical aspects that I learned during this period.

Also not to forgot to the Final Year Project Committee that arranging and managing my final year project in order to successfully complete the course. It has been such a superb and knowledgeable experience being exposed to this project.

To all my friends, thank you for all your support, and motivation to me. I truly appreciate the knowledge and experience shared that made me strives to be a better somebody. Hope we continue the friendship and cooperation in the future.

Nurul Safika Bt Abdul Fatah

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CHAPTER 1

INTRODUCTION

1.1   Background of Study

Time delay and inverse response are examples of dynamic processes that affect the stability of a closed-loop system. Nowadays, numerous of PID controllers are used in control processes because its simplicity and provide a good controller performance in the closed-loop system. The desired closed-loop system performance can be achieved with an appropriate adjustment of controller setting. This procedure is known as controller tuning.

Tuning a PID controller involves setting the proportional (P), integral (I), and derivative (D) modes to obtain the best possible control for a particular process. These modes are capable of exceptional control stability when properly tuned [1, 2]. Controller tuning also allows for optimization of a process and minimizes the absolute error between the process response and its set point. Following equation shows the PID algorithm [3].

$$u(t) = K_c \left(e(t) + \frac{1}{\tau_I} \int_0^t e(t)dt + \tau_D \frac{d\,e(t)}{dt} \right)$$

where

u is the control signal

e is the difference between the current value and the set point.

K_c is the gain for a proportional controller.

τ_I is the parameter that scales the integral controller.

τ_D is the parameter that scales the derivative controller.

t is the time taken for error measurement.

Ideally, the closed-loop system is a system which uses feedback control to satisfy the following performance criteria [4]:

- The closed-loop system must be stable
- Disturbance is minimized and proving good disturbance rejection
- Faster and smooth responses to set point changes (good set point tracking).
- Offset eliminated.
- Avoid excessive control action.

PID controller settings can be determined by several of alternative techniques or methods:

- Internal model control (IMC)
- SIMC
- Ziegler-Nichols (Z-N)
- Tyreus-Luyben (T-L)

1.2   Problem Statement

Dynamic processes such as time delay and inverse response are commonly present in process industries and difficult to control. Time delay is a delay when a controller output signal is issued until the measured process variable first begins to response. Whereas, the inverse response initial cause an opposite effect from the expected one. This control problem can be overcome with different types of tuning method.

1.3   Objectives

Some case studies of time delay and inverse response process are used to obtain the objectives of this project. The objectives are

- To test the PID controller performance using several tuning method for improved closed loop performance of these processes.
- To segregate and analyses tuning methods for each processes.

1.4   Scope of Study

In this FYP II, the scopes of study based on the case study model in literature review are:

- Test the PID controller performance using several tuning method such as internal model control (IMC), SIMC, Zigler-Nichols (Z-N) and Tyreus-Luyben (T-L).
- To analyses the controller performance based on graph obtained.
- Choose an appropriate controller tuning for the time delay and inverse response process.

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1.5　Relevancy and Feasibility of Project

The project will be based on performing the appropriate tuning of PID controller using different method approaches mainly IMC, SIMC, Z-N and T-L. All this tuning approaches is carrying out base on two different case studies in MATLAB Simulink. This enable author to learn a new knowledge and also strongly enhance the Process Control and Analysis understanding.

The time given to complete final year project, FYP is two semesters (28 weeks). At the end of the period given, a detail presentation will be conducted, and submission of final report to the coordinator. In order to meet the objectives in time, the project will be focused the objectives and scope of studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Methods of Tuning PID Controller

PID controller settings can be determined by a number of alternative methods:

- Internal Model Control (IMC) Method
- SIMC
- Ziegler-Nichols (Z-N) Method
- Tyreus-Luyben (T-L) Method

2.1.1 IMC Method

Internal Model Control (IMC) was developed by Morari and coworkers that based on assumed process model and leads to analytical expressions for the controller setting. This method is to produce identical controller if the design parameter are specified in a consistent manner [4].

The IMC method can be used to derive PID controller setting for a variety of transfer function models. Table 1 presents the PID controller tuning relations for the parallel form that were derived by Chien and Fruehauf (1990) for common type of process [4].

Table 1: PID controller setting based on IMC Method.

Case	Model	KK_c	τ_I	τ_D
Time Delay	$\dfrac{K(\tau_3+1)e^{-\theta s}}{(\tau_1 s+1)(\tau_2 s+1)}$	$\dfrac{\tau_1+\tau_2-\tau_3}{\tau_c+\theta}$	$\tau_1+\tau_2-\tau_3$	$\dfrac{\tau_1\tau_2-(\tau_1+\tau_2-\tau_3)\tau_3}{\tau_1+\tau_2-\tau_3}$
Inverse Response	$\dfrac{K(-\beta s+1)}{\tau^2 s^2+2\zeta\tau s+1}$	$\dfrac{2\zeta\tau}{\tau_c+\beta}$	$2\zeta\tau$	$\dfrac{\tau}{2\zeta}$

The choice of design parameter, τ_c is a key decision in IMC method. Generally, increase in τ_c produces a more conservative controller because K_c decrease while τ_I increase. Thus τ_c is obtained by manipulate its value from $\tau_c = \theta$.

2.1.2 SIMC Method

SIMC Method is one of a best and easy method for controlling processes with time delay and inverse response. Table 2 below shows that summary of controller setting for SIMC method for PI and PID controller [5]

Table 2: SIMC-PI and SIMC-PID controller setting

Controller	K_c	τ_I	τ_D
SIMC-PI	$\dfrac{1}{K}\dfrac{\tau_1}{\tau_c+\theta}$	8θ	-
SIMC-PID	$\dfrac{1}{K}\dfrac{\tau_1}{\tau_c+\theta}$	$min\{\tau_I, 4(\tau_c+\theta)\}$	τ_2

$-\theta < \tau_C < \infty$ is the value of tuning parameter. For robust tunings it is recommended to use $\tau_C \geq \theta$.

- Fast speed of response and good disturbance rejection
- Stability, robustness and small input usage

2.1.3 Z-N Method

Ziegler and Nichols (1942) introduced the continuous cycling method for controller tuning. It is based on the following procedure:

Step1. Use Skogested half rule to approximate the high order model by reducing the degree of the order.

Step2. Derive the amplitude ratio, A by substitute the value of s with ω_j and rearrange the model in term of phase angle, $\emptyset$.

Step3. Obtained the value of critical frequency, ω_c using Matlab at $-180° \, (-\pi \, rad)$

Step4. The value of ultimate frequency, P_{cu} can be obtained using

$$P_{cu} = \frac{2\pi}{\omega_c}$$

Step5. The value of ultimate gain K_{cu} can be finding at marginal stability, $AR(G_{OL}) = 1$

$$AR = 1 = \frac{K_{cu}}{A}$$

Table 3 shows the controller setting based on continuous cycling method [4].

Table 3: Controller setting using Ziegler-Nichols method

Controller	K_c	τ_I	τ_D
P	0.50K_{cu}	-	-
PI	0.45K_{cu}	P_u/1.2	-
PID	0.60K_{cu}	P_u/2	P_u/8

2.1.4   T-L Method

Tyreus-Luyben (1997) is also a continuous cycling method of controller setting. The value of K_{cu} and P_u can be calculating same as previous in Ziegler-Nichols procedure.

Table 4 below shows the value of parameters K_c, τ_I and τ_D for controller setting of PI and PID [4]

Table 4: Controller setting using Tyreus-Luyben method

Controller	K_c	τ_I	τ_D
PI	$0.31K_{cu}$	$2.2P_u$	-
PID	$0.45K_{cu}$	$2.2P_u$	$P_u/6.3$

2.2   Case study 1 - Time delay processes

According to Seborg & Edgar from Process Dynamic and Control book, there is a time delay associated with a movement of material or energy in a process or plant [4]. Several of chemical process and plant do exhibit time delay behavior. This process does not response immediately to input change before they respond to corrective action. Controller tends to overreact and cause instability to occur [6]. The transfer function of a time delay of magnitude, θ is given by

$$\frac{Y(s)}{X(s)} = G(s) = e^{-\theta s}$$

Equation shows a general approach of first-order-plus-time-delay, FOPTD and second-order-plus-time delay, SOPTD transfer function respectively with time constant, τ.

$$G'_1(s) = \frac{Ke^{-\theta s}}{\tau s + 1}$$

$$G'_2(s) = \frac{Ke^{-\theta s}}{(\tau_1 s + 1)(\tau_2 + 1)}$$

Based on the tickle-bed catalytic reactor shown in Figure 1 utilizes product recycle to obtain satisfactory operating condition for temperature and conversion. Concentration of the single reactant and the product are measured at a point in the recycle line where the product stream is removed. A liquid phase first order reaction is involved.
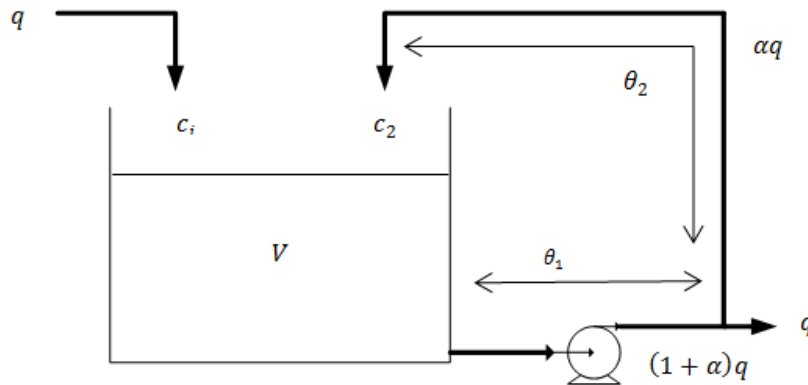
Figure 1: Tickle-bed catalytic reactor

Assumption is made under normal operating condition:

- The reactor operates isothermally with a reaction rate given by $r = kC$, where r denotes the rate of reaction, C is the concentration of reactant and k is the rate constant.
- All flow rates and liquid volume V are constant
- No reaction occurs in the piping. The dynamics of the exit and recycle lines can be approximated as constant time delays θ_1 and θ_2 as indicate in the figure. Let C_1 denote the concentration at the measurement point.

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Parameter Values	
$V = 500m^3$	$\alpha = 12$
$q = 5\ m^3/min$	$\theta_1 = 9\ min$
$k = 0.04\ min^{-1}$	$\theta_2 = 11.1\ min$

The component balance around the reactor is,

$$V\frac{dc}{dt} = qc_i + \alpha qc_2 - (1+\alpha)qc - Vkc$$

where the concentration of the reactant is denoted by c, this equation is linear with constant coefficients yield

$$V\frac{dc'}{dt} = qc'_i + \alpha qc'_2 - (1+\alpha)qc' - Vkc'$$

Additional relation are needed for c'_1 and c'_2 due to the exit and recycle lines can be modeled as time delays,

$$c'_1 = c'(t - \theta_1)$$

$$c'_2 = c'(t - \theta_2)$$

Taking the Laplace transform of each equation yields

$$sVC' = qC'_i(s) + \alpha qC'_2(s) - (1+\alpha)qC'(s) - VkC'(s)$$

$$C'_1(s) = e^{-\theta_1 s}C'(s)$$

$$C'_2(s) = e^{-\theta_2 s}C'_1(s)$$

$$= e^{-(\theta_1+\theta_2)s}C'(s)$$

$$= e^{-\theta_3 s}C'(s)$$

Where $\theta_3 = \theta_1 + \theta_2$ thus

$$C'(s) = \frac{q}{sV - \alpha q e^{-\theta_3 s} + (1 + \alpha)q + Vk} C'_i(s)$$

Rearranged to the following form

$$C'(s) = \frac{K}{\tau s + 1 + \alpha K(1 - e^{-\theta_3 s})} C'_i(s)$$

where

$$K = \frac{q}{q + Vk} = \frac{5}{5 + (500)(0.04)} = 0.2$$

$$\tau = \frac{V}{q + Vk} = 20 \ min$$

Note that, in the limit as $\theta_3 = 0, e^{-\theta_3 s} \to 1$ and

$$C'(s) = \frac{K}{\tau s + 1} C'_i(s)$$

So K and τ can be interpreted as the process gain and time constant respectively of a recycle reactor with no time delay in recycle line. The desired transfer function $C'_1(s)/C'_i(s)$ is obtained

$$\frac{C'_1(s)}{C'_i(s)} = \frac{Ke^{-\theta_1 s}}{\tau s + 1 + \alpha K(1 - e^{-\theta_3 s})}$$

With $c'_i(t) = 2000 \ kg/m^3$

$$C'_1(s) = \frac{2000 K e^{-\theta_1 s}}{s[\tau s + 1 + \alpha K(1 - e^{-\theta_3 s})]}$$

To eliminate the time delay term, a 1/1 Pade approximation is introduce and rearrange to yield

$$C'_1(s) = \frac{2000 K \left(\frac{\theta_3}{2} s + 1\right)}{s\left[\tau \frac{\theta_3}{2} s^2 + \left(\tau + \frac{\theta_3}{2} + \alpha K \theta_3\right) s + 1\right]}$$

This expression can be written in the form

$$C'_1(s) = \frac{2000(\tau_a s + 1)e^{-\theta_1 s}}{s(\tau_1 s + 1)(\tau_2 s + 1)}$$

Where $\tau_a = \theta_3/2$ and τ_1 and τ_2 are obtained by factoring the expression in the brackets. By substitute the value of K and τ, the equation will yields

$$C'_1(s) = \frac{0.2(s + 1)e^{-0.9s}}{s(25s + 1)(0.8s + 1)}$$

2.3   Case study 2 - inverse response.

A process with inverse response where step change is applied in input, the process will output the opposite direction initially to steady state. This type of process will move in the wrong direction as they response to desired action [7]. Thus, an appropriate controller setting is needed to unsure the process behaves in a stable condition throughout the process reaction. Figure 2 and 3 show the inverse response and block diagram of inverse process respectively.
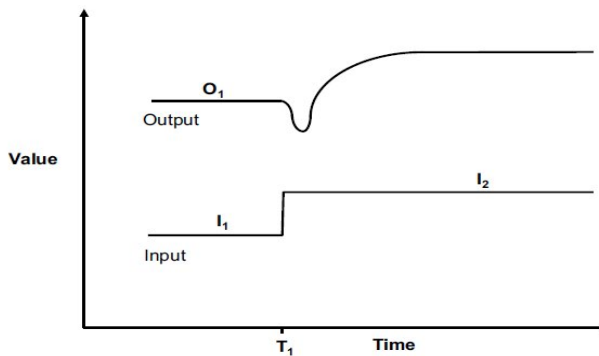
Figure 2: The output signal of inverse response when a step change in input is applied
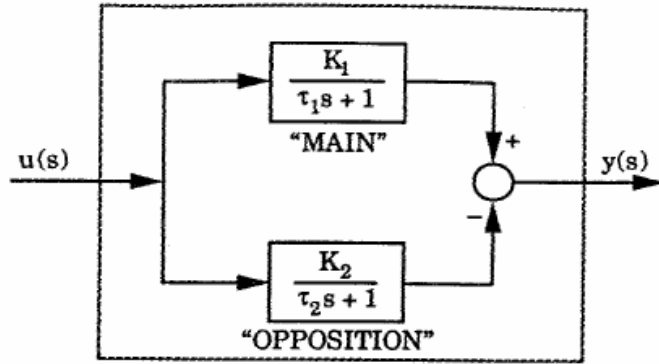
Figure 3: The inverse response block diagram

The transfer function for *inverse response* process is given in equation (1-3) and (1-2) with K_1 and K_2 are the gains for the main process and opposite process respectively.

$$G(s) = \frac{K_1}{\tau_1 s + 1} - \frac{K_2}{\tau_2 s + 1}$$

$$G(s) = \frac{K(\xi s + 1)}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

Where

$$\xi = \frac{K_1 \tau_2 - K_2 \tau_1}{K_1 - K_2}$$

$$K = K_1 - K_2$$

According to Victor M. Alfaro, control industrial processes that illustrate an inverse response are one of challenge task to perform by engineer in order to achieve better performance and robustness level [8].

CSTR has been considered in which concentration of two chemicals is controlled for a better results, the chemical ethylene oxide (X) and water (Y) and by product of ethylene glycol (Z).

Assumption is made as follow

- The temperature is at constant
- The stoichiometric equation $X + Y = Z$

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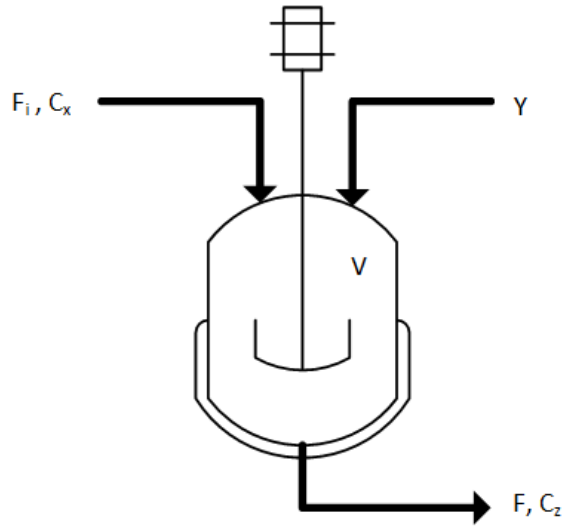
Figure 4: Continuous Stirred tank reactor (CSTR)

The component balances around CSTR are

$$\frac{dVC_x}{dt} = F_i C_{xi} - FC_x + Vr_x$$

$$\frac{dVC_z}{dt} = -FC_z + Vr_z$$

Where rx and rz represent rate of generation of species X and Z per unit volume and C_{xi} represents the inlet concentration of species X. The rates of reaction equation are yield

$$r_x = -k_1 C_x - k_3 C_x^2$$

$$r_z = k_1 C_x - k_2 C_z$$

Expending the equation

$$\frac{dVC_x}{dt} = V\frac{dC_x}{dt} + C_x\frac{dV}{dt}$$

$$\frac{dC_x}{dt} = \frac{F_i}{V}(C_{xi} - C_x) - k_1 C_x - k_3 C_x^2$$

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$$\frac{dC_z}{dt} = -\frac{F}{V}C_z + k_1 C_x + k_2 C_z$$

Table 6: The parameter values for the CSTR

Parameter Values	
$k_1 = 5/6 \, min^{-1}$	$C_{xs} = 3 \, gmol/liter$
$k_2 = 5/3 \, min^{-1}$	$C_{zs} = 1.117 \, gmol/liter$
$k_3 = 1/6 \, mol/liter.min$	$F_s/V = 0.5714 \, min^{-1}$

From [9] the manipulated input output process transfer function is

$$G_p = \frac{-1.117s + 3.1472}{s^2 + 4.6429s + 5.3821} = \frac{-0.355s + 1}{(0.416s + 1)(0.447s + 1)}$$

CHAPTER 3

RESEARCH METHODOLOGY

3.1   Project Activities

Final year project (FYP) II is the continuing of work progress form FYP I. In FYP II, author has to evaluate two case studies which are time delay and inverse response. Firstly, the process dynamic model or transfer functions of each dynamic process are obtained. There controller parameter are calculated using difference tuning methods which is IMC, SIMC, T-L and Z-N. The controller settings are adjusted using two controllers PI and PID.

The set point change is introduced in the first evaluation. Then, after the responses achieve their steady state, the disturbance is applied to observe the disturbance rejection. All the responses are observed and analyzed.
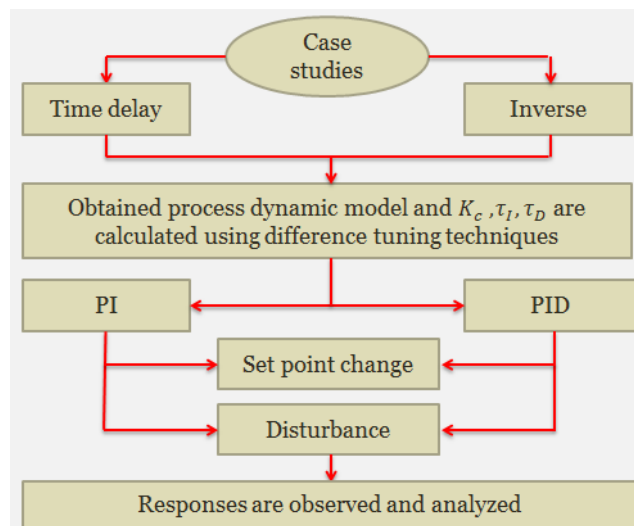
Figure 5: procedures in handling the project

3.2 Key Milestone

Week 1-5 — **Performance Test**	**Week 6-8** — **Integral Error Criteria**	**Week 9-10** — **Pre-SEDEX**	**Week 10-12** — **Dissertation and technical paper**

- The tests is done using difference technique:
  - ✓ IMC
  - ✓ SIMC
  - ✓ Z-N
  - ✓ T-L

- Matlab Simulation is used to observe the performance

- The error is calculated using matlab m-file. There are three integral error criteria:
  - ✓ IAE

- Poster preparation

- Soft bound report and technical paper preparation.
- Viva

Figure 6: Project Key milestone

3.3   Gantt Chart

Table 7: Project Gantt Chart[10]

No	Detail/week	01	02	03	04	05	06	07		08	09	10	11	12	13	14	15
1	Project Work Continue	■	■	■	■	■	■	■									
2	Submission Progress Report							√									
3	Project Work Continue									■	■	■	■	■			
4	Pre-SEDEX											√					
5	Submission of Draft Report												√				
6	Submission of Dissertation (soft bound)													√			
7	Submission of Technical Paper													√			
8	Oral Presentation														√		
9	Submission of Project Dissertation (hard bound)																√

√ Suggested milestone   ■ Mid-semester break   ■ Work progress

3.4 Tool

Throughout the project, author use Matlab Simulink and Microsoft office in performing the following tasks:

Table 8: Project tools

Task	Tool
Test performance of various tuning technique.	Matlab Simulation
Calculation for Integral Error Criteria	Matlab m-file
τ_c iteration for IMC method	Microsoft Excel
Writing report	Microsoft Word
Poster	Microsoft Publisher

Author manage to perform the task using above tool successfully with supervise by supervisor.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Case Study I – Time Delay Process

From the literature review, the transfer function of the time delay system is used to observe and analyses the response performance of difference tuning method.

$$C'_1(s) = \frac{0.2(s + 1)e^{-0.9s}}{s(25s + 1)(0.8s + 1)}$$

For PI controller, the tuning methods that will be used in the simulation are

- SIMC Method
- Z-N Method
- T-L Method

For PID controller, the tuning methods that will be used in the simulation are

- IMC Method
- SIMC Method
- Z-N Method
- T-L Method

4.1.1 IMC Method

Table 9: PID controller setting based on IMC Method for time delay process

Case	Model	KK_c	τ_I	τ_D
Time Delay	$\dfrac{K(\tau_3+1)e^{-\theta s}}{(\tau_1 s+1)(\tau_2 s+1)}$	$\dfrac{\tau_1+\tau_2-\tau_3}{\tau_c+\theta}$	$\tau_1+\tau_2-\tau_3$	$\dfrac{\tau_1\tau_2-(\tau_1+\tau_2-\tau_3)\tau_3}{\tau_1+\tau_2-\tau_3}$

For time delay process, the value of τ_c is obtained using trial and error, starting from $\tau_c = \theta = 0.9$ to 10.0

$$K = 0.2, \tau_1 = 25, \tau_2 = 0.8, \tau_3 = 1 \; and \; \theta = 0.9$$

Table 10: τ_c values iteration from 0.9 to 10

τ_c	$K_c K$	τ_I	τ_D	
0.9	13.7778	24.8	-0.1935	The best controller setting
1	13.0526	24.8	-0.1935	
2	8.5517	24.8	-0.1935	
3	6.3590	24.8	-0.1935	
4	5.0612	24.8	-0.1935	
5	4.2034	24.8	-0.1935	
6	3.5942	24.8	-0.1935	
7	3.1392	24.8	-0.1935	
8	2.7865	24.8	-0.1935	
9	2.5051	24.8	-0.1935	
10	2.2752	24.8	-0.1935	

4.1.2 SIMC Method

From the literature review, the value of K_c, τ_I and τ_D can be calculated using following values for time delay

$$K = 0.2, \tau_1 = 25, \tau_2 = 0.8 \; and \; \theta = 0.9$$

Controller	K_c	τ_I	τ_D
SIMC-PI	$\dfrac{1}{K}\dfrac{\tau_1}{\tau_c + \theta}$	8θ	-
SIMC-PID	$\dfrac{1}{K}\dfrac{\tau_1}{\tau_c + \theta}$	$min\{\tau_I, 4(\tau_c + \theta)\}$	τ_2

4.1.3   Z-N and T-L Method

Time delay process

Derive the amplitude ratio, A by substitute the value of s with ω_j and rearrange the model in term of phase angle, $\emptyset$.

$$G(s) = \frac{0.2(s + 1)e^{-0.9s}}{(25s + 1)(0.8s + 1)}$$

$$G(\omega j) = \frac{0.2(\omega j + 1)e^{-0.9\omega j}}{(25\omega j + 1)(0.8\omega j + 1)}$$

$$G(\omega j) = \frac{0.2\sqrt{\omega^2 + 1}e^{\emptyset_1 j}e^{-0.9\omega j}}{\sqrt{(25\omega)^2 + 1}\sqrt{(0.8\omega)^2 + 1}e^{\emptyset_2 j}e^{\emptyset_3 j}}$$

$$Magnitude = \frac{0.2\sqrt{\omega^2 + 1}}{\sqrt{(25\omega)^2 + 1}\sqrt{(0.8\omega)^2 + 1}}$$

$$\emptyset = tan^{-1}(-\omega) - 0.9\omega - tan^{-1}(25\omega) - tan^{-1}(0.8\omega)$$

$$f = \pi + tan^{-1}(-\omega_c) - 0.9\omega_c - tan^{-1}(25\omega_c) - tan^{-1}(0.8\omega_c)$$

ω_c, P_u and K_{cu} can be calculated using Matlab

$$\omega_c = 0.6463$$

$$P_u = \frac{2\pi}{\omega_c} = 9.7219$$

$$K_{cu} = \frac{\sqrt{(25\omega)^2 + 1}\sqrt{(0.8\omega)^2 + 1}}{0.2\sqrt{\omega^2 + 1}} = 58.6619$$

Table 12: Controller setting based on Z-N method

Controller	K_c	τ_I	τ_D
PI	$0.45K_{cu}$	$P_u/1.2$	-
PID	$0.60K_{cu}$	$P_u/2$	$P_u/8$

Table 13: Controller setting based on T-L method

Controller	K_c	τ_I	τ_D
PI	$0.31K_{cu}$	$2.2P_u$	-
PID	$0.45K_{cu}$	$2.2P_u$	$P_u/6.3$

Table 14: Summary parameter value of various tuning method

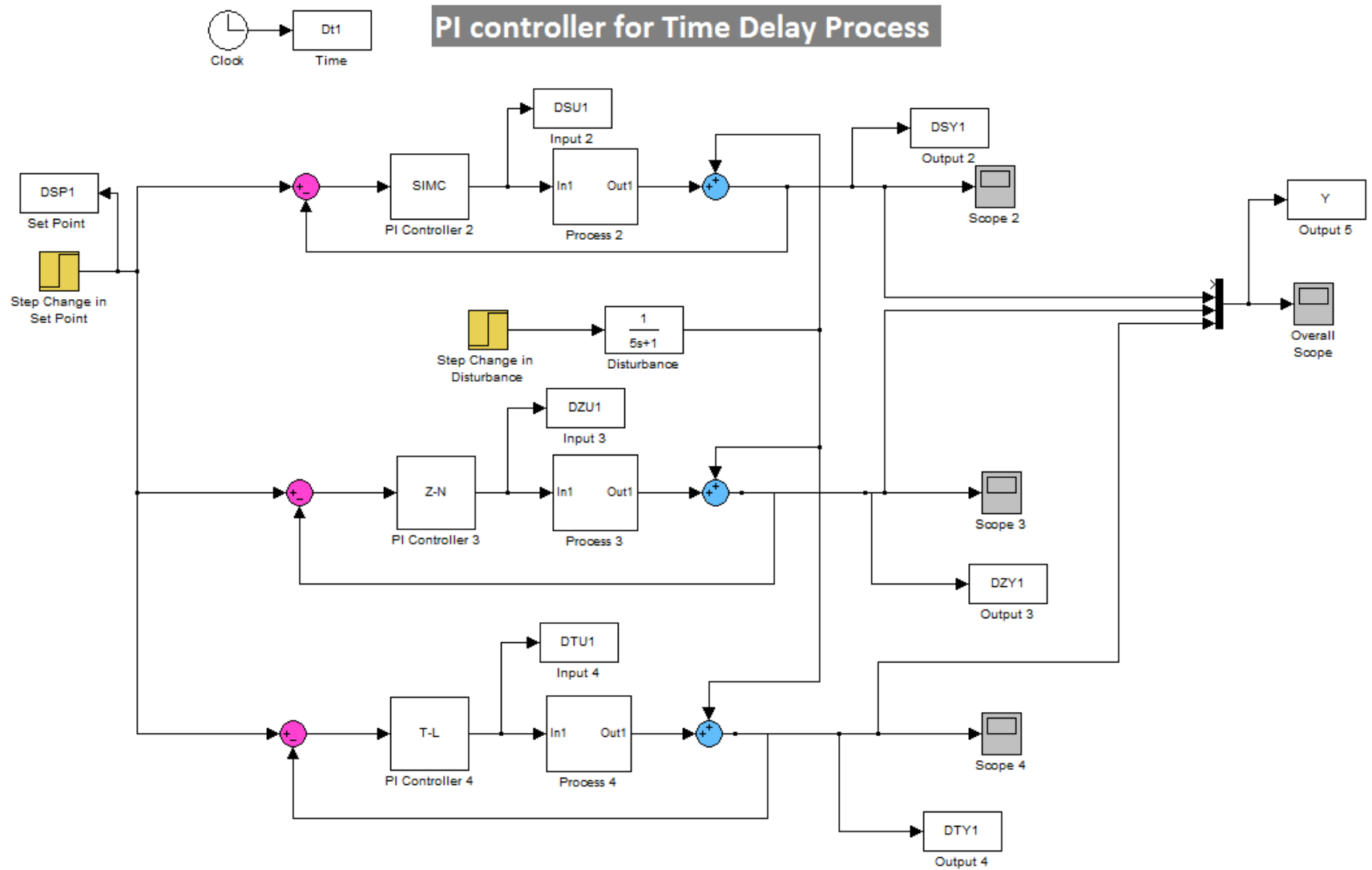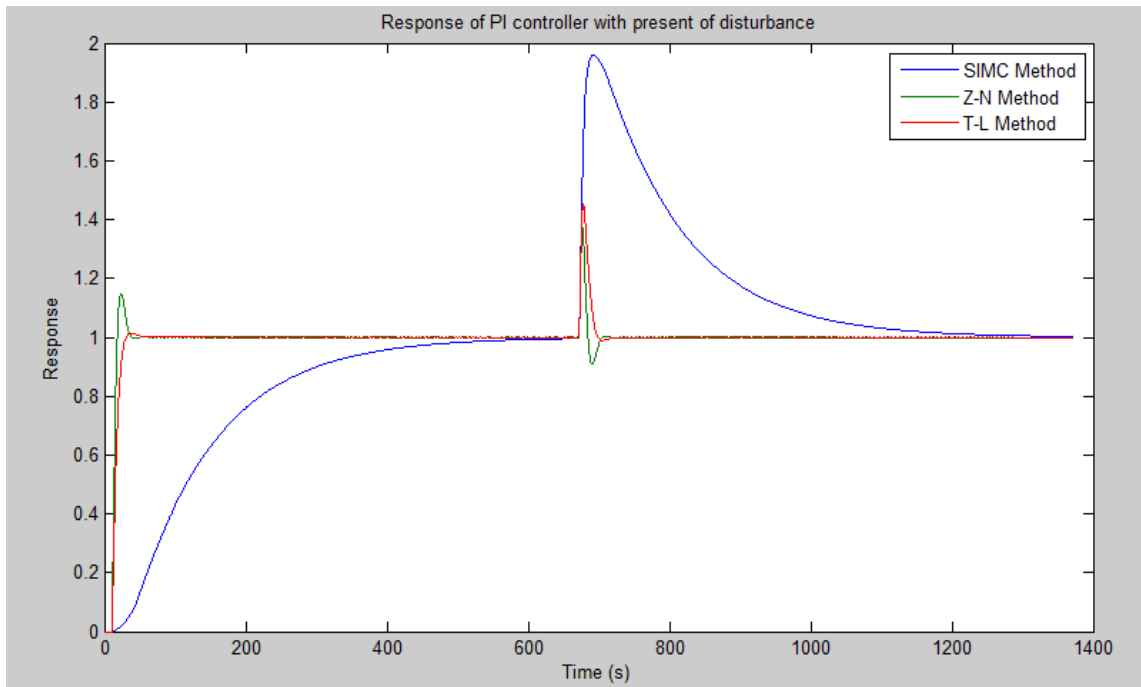| Method	Controller	K_c	τ_I	τ_D
IMC	PID	13.778	24.800	-0.194
SIMC	PI	69.44	7.200	-
	PID	69.44	7.2	0.8
Z-N	PI	26.398	8.102	-
	PID	35.197	4.861	1.215
T-L	PI	18.185	21.388	-
	PID	26.398	21.388	1.543

Figure 7: Simulation block diagram for PI controller of time delay process

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Figure 8: Response of PI controllers with set point change and disturbance rejection using SIMC, Z-N and T-L methods for time delay process.

The simulation result in Figure 8 indicate a graph of PI controller responses with change in set point at beginning and present in disturbance at 700s using SIMC, Z-N and T-L tuning methods. From the graph, SIMC method shows the slowest response toward set point change and produces the highest overshoot in disturbance. Whereas Z-N shows small overshoot at beginning of set point change and provide much better disturbance rejection. In other hand, T-L controller provides an excellent set point response by compared to the others that have significant overshoot and longer settling times.
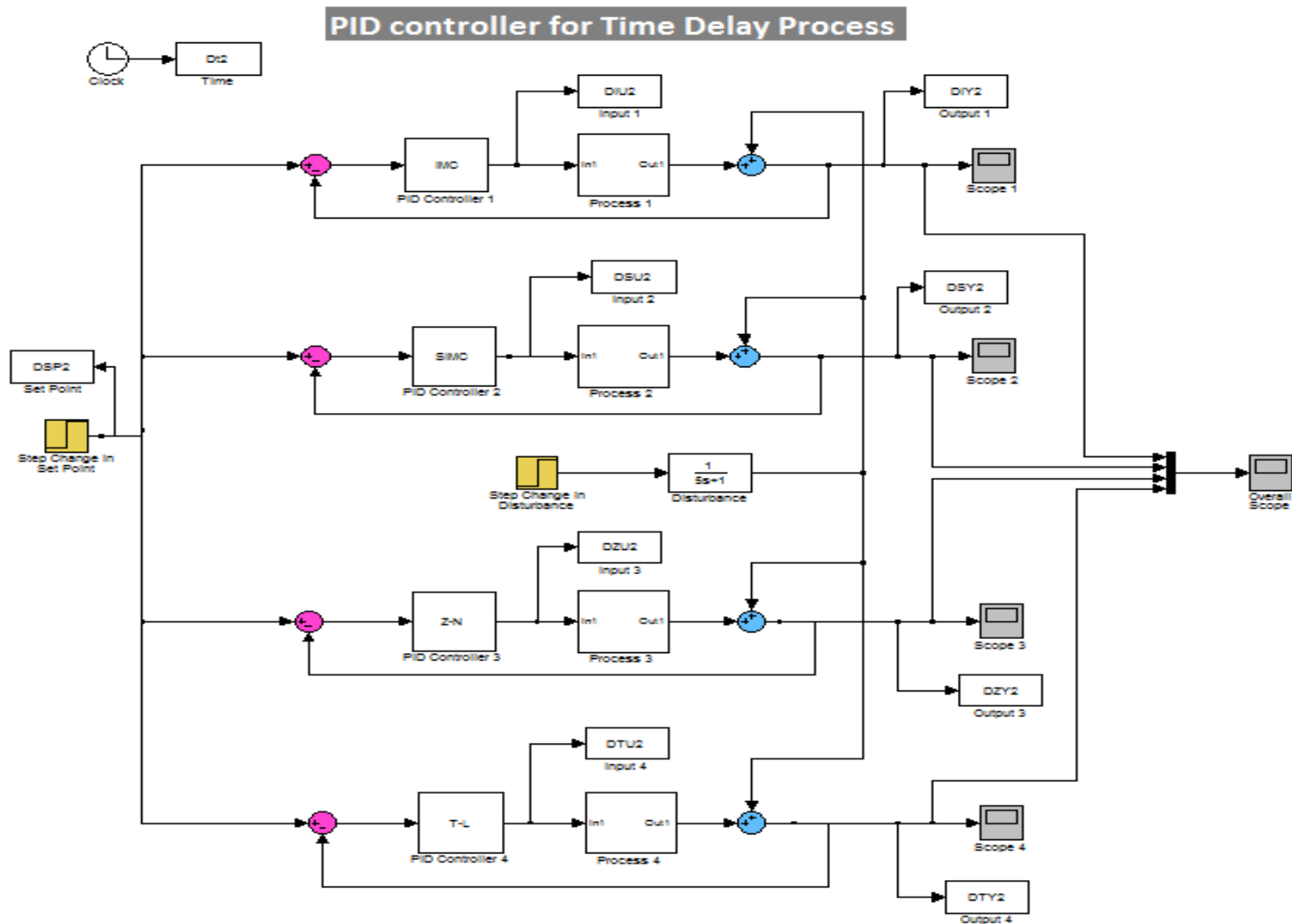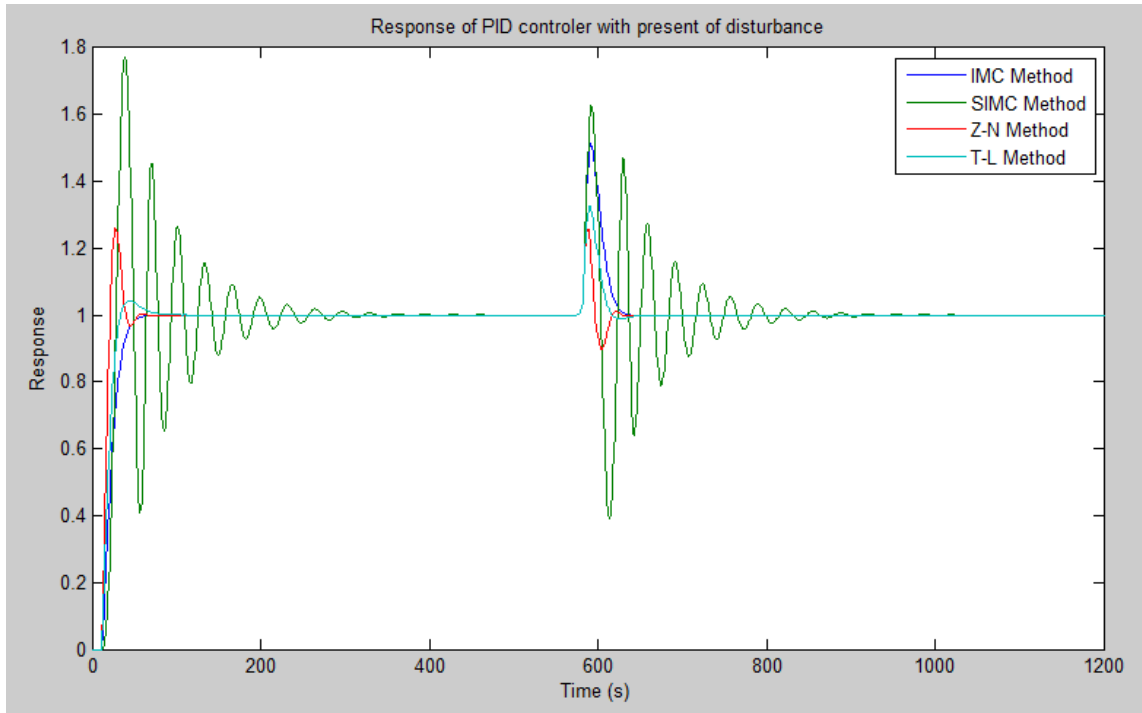
Figure 9: Simulation block diagram for PID controller of time delay process

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Figure 10: Response of PID controllers with set point change and disturbance rejection using IMC, SIMC, Z-N and T-L methods for time delay process.

A graph of PID controller response with set point change at beginning and disturbance rejection at 550s is shown in Figure 10 using IMC, SIMC, Z-N and T-L methods. The best PID controller responses is T-L method as its show the faster response (small settling time) and also less overshoot compared to other tuning methods. However, SIMC shows the slowest response with huge oscillation in set point change and disturbance rejection. Z-N and IMC methods show a slow response and overshoot when disturbance is introduced.

4.2 Case Study II – Inverse Response

Same procedure is done for case study II, the transfer function of the inverse response system is used from literature review to observe and analyses the response performance of difference tuning method.

$$G_p = \frac{-1.117s + 3.1472}{s^2 + 4.6429s + 5.3821}$$

$$G_p = \frac{-0.355s + 1}{(0.416s + 1)(0.447s + 1)}$$

For PI controller, the tuning methods that will be used in the simulation are

- SIMC Method
- Z-N Method
- T-L Method

For PID controller, the tuning methods that will be used in the simulation are

- IMC Method
- SIMC Method
- Z-N Method
- T-L Method

4.2.1   IMC Method

Table 15: PID controller setting based on IMC Method for inverse response process

Case	Model	KK_c	τ_I	τ_D
Inverse Response	$\dfrac{K(-\beta s + 1)}{\tau^2 s^2 + 2\zeta\tau s + 1}$	$\dfrac{2\zeta\tau}{\tau_c + \beta}$	$2\zeta\tau$	$\dfrac{\tau}{2\zeta}$

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For inverse response, the value of τ_c is obtained using trial and error, starting from $\tau_c = \theta = 0$ to 10.0

$$K = 1, \tau_1 = 0.416, \tau_2 = 0.447, \tau_3 = 0.355 \; and \; \theta = 0$$

Table 16: τ_c values iteration from 0.9 to 10

τ_c	K_cK	τ_I	τ_D
0	2.4289	0.8620	0.2155
1	0.6362	0.8620	0.2155
2	0.3660	0.8620	0.2155
3	0.2569	0.8620	0.2155
4	0.1979	0.8620	0.2155
5	0.1610	0.8620	0.2155
6	0.1356	0.8620	0.2155
7	0.1172	0.8620	0.2155
8	0.1032	0.8620	0.2155
9	0.0921	0.8620	0.2155
10	0.0832	0.8620	0.2155

The best controller setting

4.2.2   SIMC Method

From the literature review, the value of K_c, τ_I and τ_D can be calculated using following values for time delay and inverse response

$$K = 1, \tau_1 = 0.416, \tau_2 = 0.447 \; and \; \theta = 1$$

Table 17: SIMC-PI and SIMC-PID controller setting

Controller	K_c	τ_I	τ_D
SIMC-PI	$\dfrac{1}{K}\dfrac{\tau_1}{\tau_c + \theta}$	8θ	-
SIMC-PID	$\dfrac{1}{K}\dfrac{\tau_1}{\tau_c + \theta}$	$min\{\tau_I, 4(\tau_c + \theta)\}$	τ_2

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4.2.3   Z-N and T-L Method

Inverse Response

Derive the amplitude ratio, A by substitute the value of s with ω_j and rearrange the model in term of phase angle, $\emptyset$.

$$G(s) = \frac{-0.355s + 1}{(0.416s + 1)(0.447s + 1)}$$

$$G(\omega j) = \frac{-0.355\omega j + 1}{(0.416\omega j + 1)(0.447\omega j + 1)}$$

$$G(\omega j) = \frac{\sqrt{(-0.355\omega)^2 + 1}e^{\emptyset_1 j}}{\sqrt{(0.416\omega)^2 + 1}\sqrt{(0.447\omega)^2 + 1}e^{\emptyset_2 j}e^{\emptyset_3 j}}$$

$$Magnitude = \frac{\sqrt{(-0.355\omega)^2 + 1}}{\sqrt{(0.416\omega)^2 + 1}\sqrt{(0.447\omega)^2 + 1}}$$

$$\emptyset = tan^{-1}(-0.355\omega) - tan^{-1}(0.416\omega) - tan^{-1}(0.447\omega)$$

$$f = \pi + tan^{-1}(-0.355\omega_c) - tan^{-1}(0.416\omega_c) - tan^{-1}(0.447\omega_c)$$

ω_c, P_u and K_{cu} can be calculated using Matlab

$$\omega_c = 4.2955$$

$$P_u = \frac{2\pi}{\omega_c} = 1.4628$$

$$K_{cu} = \frac{\sqrt{(25\omega)^2 + 1}\sqrt{(0.8\omega)^2 + 1}}{0.2\sqrt{\omega^2 + 1}} = 2.431$$

The table below shows the controller setting for Z-N method

Table 18: Controller setting based on Z-N method

Controller	Controller	K_c	τ_I
P	$0.50K_{cu}$	-	-
PI	$0.45K_{cu}$	$P_u/1.2$	-
PID	$0.60K_{cu}$	$P_u/2$	$P_u/8$

The table below shows the controller setting for T-L method

Table 19: Controller setting based on T-L method

Controller	K_c	τ_I	τ_D
PI	$0.31K_{cu}$	$2.2P_u$	-
PID	$0.45K_{cu}$	$2.2P_u$	$P_u/6.3$

Table 20: Summary parameter values of various tuning method

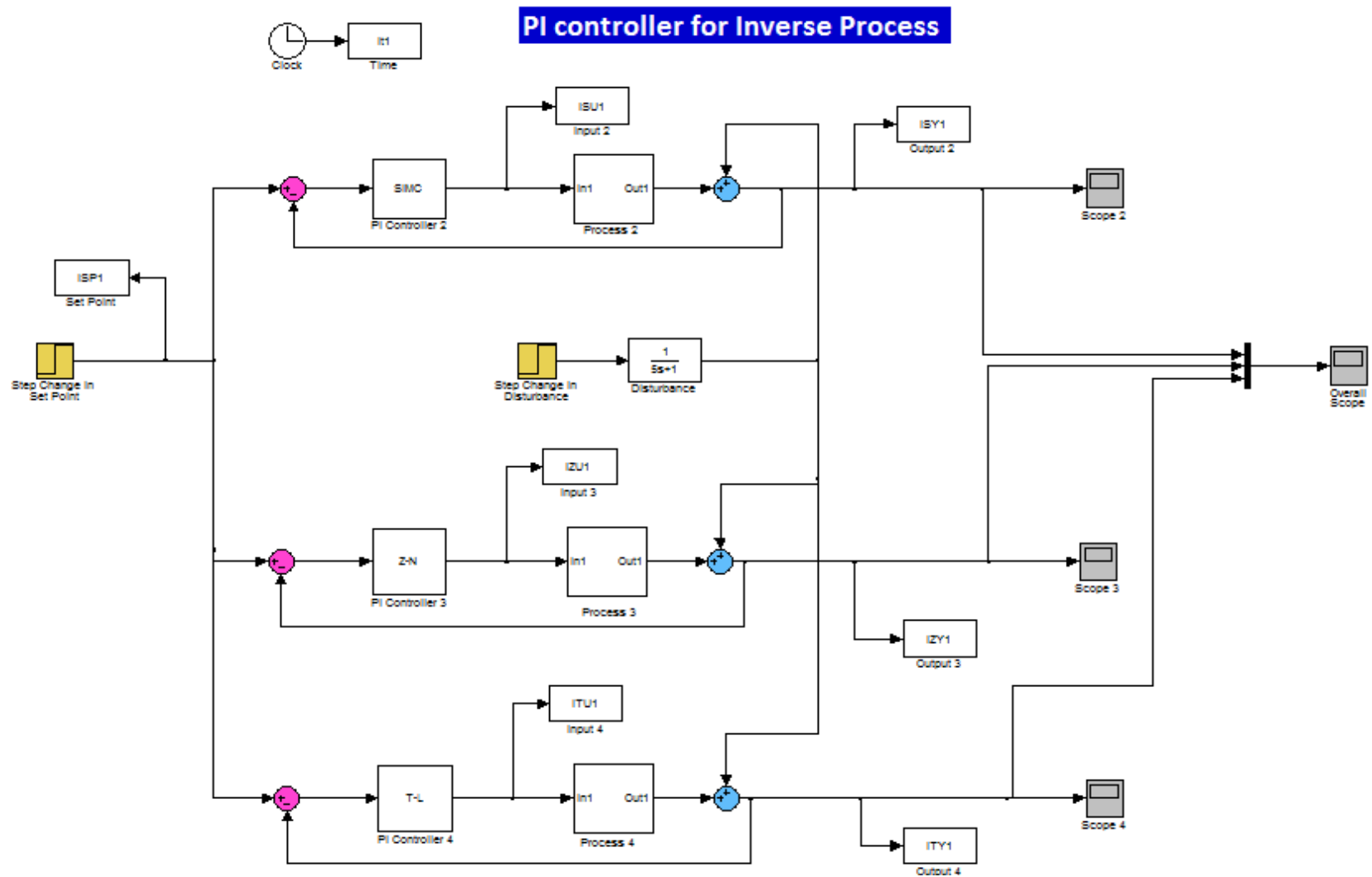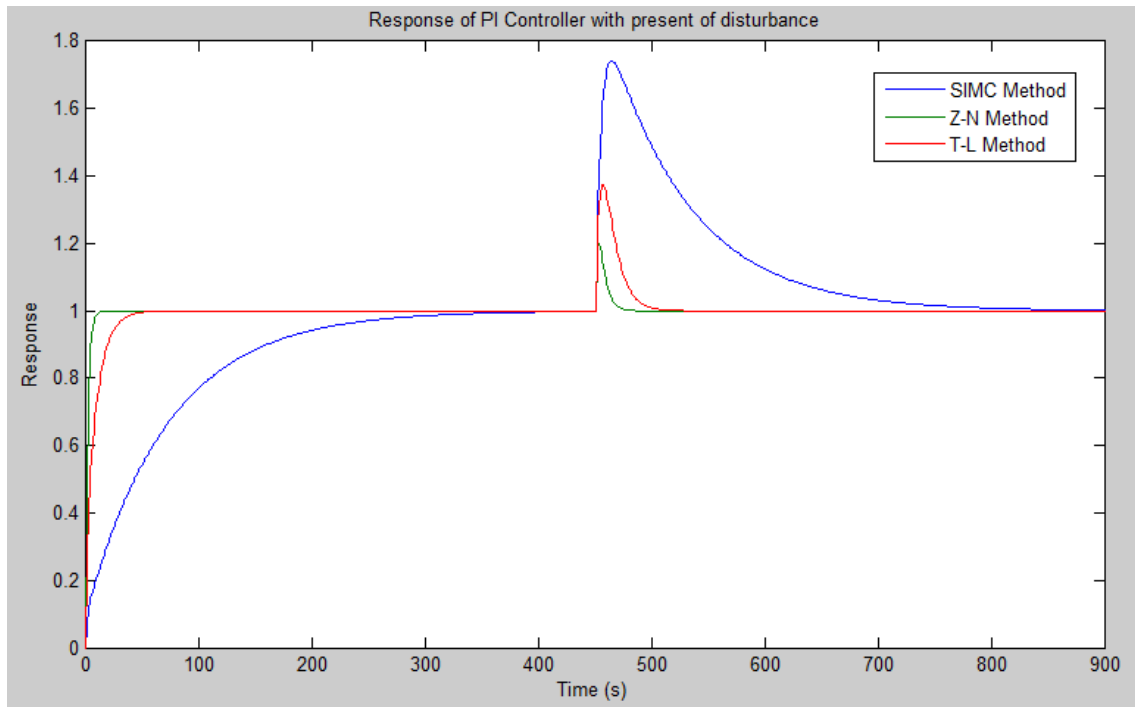| Method	Controller	K_c	τ_I	τ_D
IMC	PID	2.431	0.863	0.2155
SIMC	PI	0.208	8.000	-
	PID	0.208	0.416	0.447
Z-N	PI	1.094	1.219	-
	PID	1.459	0.731	0.183
T-L	PI	0.754	3.218	-
	PID	1.094	3.218	0.232

Figure 11: Simulation block diagram for inverse response of PI controller

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Figure 12: Response of PI controllers with set point change and disturbance rejection using SIMC, Z-N and T-L methods for inverse response process.

Figure 12 shows a graph of PI controller response with set point change and disturbance rejection using SIMC, Z-N and T-L tuning method in inverse process. Z-N method indicates small settling time and less overshoot when set point change and disturbance are introduce respectively. SIMC method shows slowest response when the set point change is introduced and give a huge overshoot when disturbance is present. In the other hand, T-L shows the intermediate response between Z-N and SIMC methods.
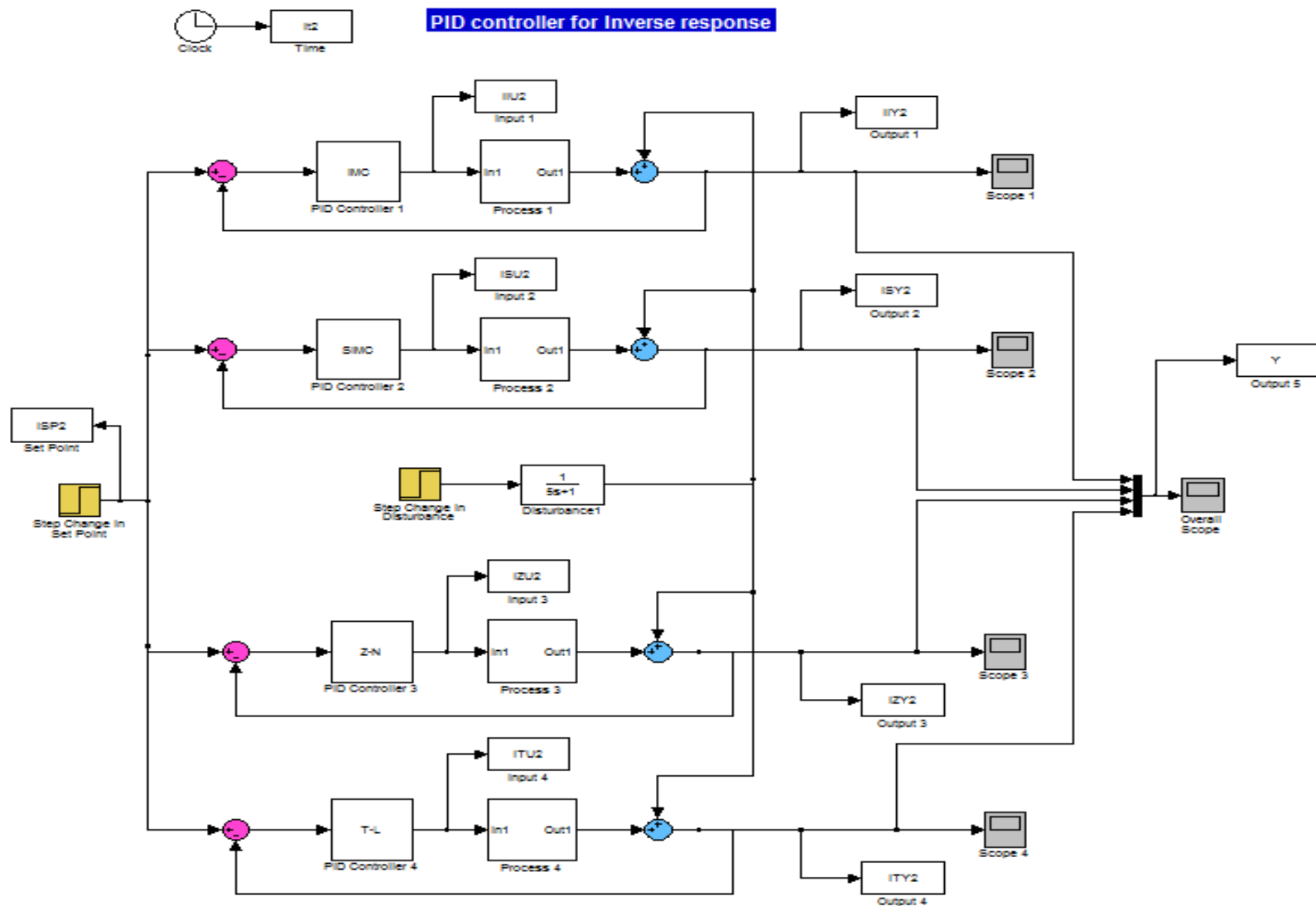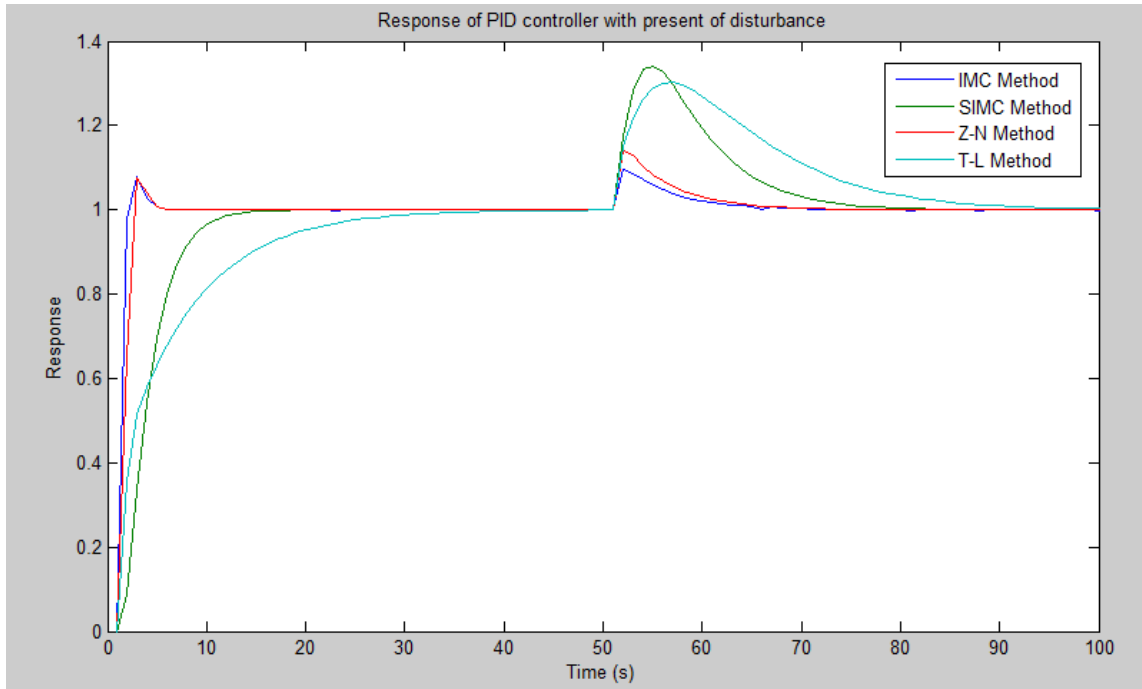
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Figure 13: Simulation block diagram for inverse response of PID controller

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Figure 14: Response of PID controllers with set point change and disturbance rejection using IMC, SIMC, Z-N and T-L methods for inverse response process.

Figure 14 shows the response of PID controller with set point change and disturbance rejection using IMC, SIMC, Z-N and T-L method for inverse response process. IMC method shows the faster response compared to the other method. IMC also shows good disturbance rejection as its show smallest overshoot compared to other method. Z-N method is the second faster response after IMC method. T-L and SIMC show slow response in set point change and produce higher overshoot when disturbance is introduced.

4.3   Summary of data analysis

Table 21: Graph observation

Case Studies	Method	Controller	Observation Without disturbance	Observation With disturbance
I	IMC	PID	• Fast response	• High overshoot
	SIMC	PI	• Slowest response	• Highest overshoot
		PID	• Huge oscillation • Slow response	• Huge oscillation • Slow response
	Z-N	PI	• Overshoot present • Fast response	• Less overshoot • Fast response
		PID	• High overshoot • Fast response	• High overshoot • Fast response
	T-L	PI	• Less overshoot • Fast response	• Overshoot present • Fast response
		PID	• Less overshoot • Fast response	• High overshoot • Fast response
II	IMC	PID	• Less overshoot • Fast response	• Less overshoot • Fast response
	SIMC	PI	• Slowest response	• Highest overshoot • Slow response
		PID	• Slow response	• Highest overshoot • Slow response
	Z-N	PI	• Faster response	• Less overshoot • Fast response
		PID	• Less overshoot • Fast response	• Overshoot present • Fast response
	T-L	PI	• Moderate response	• Overshoot present • Moderate response
		PID	• Slowest response	• High overshoot • Slowest response

CHAPTER 5

CONCLUSION

Two process dynamic models are obtained from the literature review. The process dynamics are time delay process and inverse response. The transfer functions of the model are applied in the MATLAB Simulink to observe their behaviour with difference method of controller tuning. The controller tuning methods that are used in this project are internal model control (IMC), SIMC, Ziegler-Nichols (Z-N) and Tyrues-Luyben (T-L). The simulation results show the difference performance of the response with varies method of tuning.

The control of time delay process, PID controller with T-L tuning is the suitable because T-L-PID controller small settling time to stable even with the set point change and after disturbance present. Whereas, for controlling the inverse response, the appropriate controller used is IMC-PID controller. This is because IMC-PID controller shows the faster and small overshoot compared to the other technique. Therefore, the smallest the settling time will provide a faster response for a system to reach its desired target.

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APPENDIX

Controller	PI (1)		PID (2)	
Process	**Inverse (I)**	**Time delay (D)**	**Inverse (I)**	**Time delay (D)**
Set point (SP)	ISP1	DSP1	ISP2	DSP2
IMC Input (IU)	IIU1	DIU1	IIU2	DIU2
SIMC Input (SU)	ISU1	DSU1	ISU2	DSU2
Z-N Input (ZU)	IZU1	DZU1	IZU2	DZU2
T-L Input (TU)	ITU1	DTU1	ITU2	DTU2
IMC Output (IY)	IIY1	DIY1	IIY2	DIY2
SIMC Output (SY)	ISY1	DSY1	ISY2	DSY2
Z-N Output (ZY)	IZY1	DZY1	IZY2	DZY2
T-L Output (TY)	ITY1	DTY1	ITY2	DTY2
Time(t)	It1	Dt1	It2	Dt2