COMPARISON BETWEEN ZIEGLER-NICHOLS AND COHEN-COON METHOD FOR CONTROLLER TUNINGS

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COMPARISON BETWEEN ZIEGLER-NICHOLS AND COHEN-COON METHOD FOR CONTROLLER TUNINGS

MOHD FADZLI BIN MOHD NORIS

A thesis submitted in fulfillment
of the requirements for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
University College of Engineering & Technology Malaysia

November 2006

DECLARATION

I declare that this thesis entitled *"Comparison Between Ziegler-Nichols & Cohen-Coon Methods For Controller Tunings"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	……………………………........................
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Special dedication to my beloved mother, father, brothers and sisters

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My sincere appreciation and grateful also extends to my mother; Madam Fauziah Rozali, my father; Mr. Mohd Noris Mansor, brothers and sisters and finally to others who have provided assistance at various occasions. Besides that, I would like to thank to my entire fellows friends for their support and guidance. Thanks a lot for your contribution.

ABSTRACT

Proportional-Integral-Derivative (PID) controllers are the predominant types of feedback control. PID controller is widely used in industry due to their simplicity and easy to tuning. For controller tuning, the PID parameters are tuned by any conventional method in order to assure a good reference signal to the closed loop system is obtained by filtering appropriately the set-point step signal. This study is conducted to get the optimum PID controller parameters (K_c, τ_I, τ_D) for first order process model. Two well known methods; Ziegler-Nichols (Z-N) method and Cohen-Coon (C-C) are used to tune controller. Both methods are compared to get the optimum condition for the process model with one-quarter decay ratio at minimum settling time and minimum largest error. The responses for both methods are analyzed using Simulink in MATLAB software. Block diagram for the process model with controllers was created for simulation process. *Kc*= 16.667, τ_I =6.283 and τ_D =1.571 are optimum parameters setting for Ziegler-Nichols method and the minimum largest error as 0.582 and minimum settling time equal with 11.8s in sample 11. For Cohen-Coon method, *Kc*= 14.703, τ_I =3.622 and τ_D =0.541 are optimum parameters setting. The minimum largest error and minimum settling time from response in sample 39 are 0.4914 and 12.2s. The results indicated that responses using Cohen-Coon tuning are slightly better than those with the Ziegler-Nichols settings method.

ABSTRAK

Kawalan perkadaran-pengamiran-perkadaran (PID) adalah pengawal “feedback” yang dominan. Kawalan PID digunakan secara meluas didalam industri kerana ianya mudah dan senang untuk diselaraskan. Untuk mengawal penyelarasan, parameter PID akan diselaraskan dengan mengunakan pelbagai peraturan konvensional yang ada bagi memastikan respon yang baik digunakan dalam sistem gelung tertutup dengan mencapai isyarat titik set yang ditentukan. Kajian ini dijalankan untuk mendapatkan parameter-parameter (K_c, τ_I, τ_D) kawalan PID yang optimum bagi proses model arahan pertama. Dua peraturan yang sangat dikenali;peraturan Ziegler-Nichols dan peraturan Cohen-Coon digunakan untuk pelarasan kawalan PID. Kedua-dua peraturan dibandingkan untuk mendapat keadaan yang optimum bagi proses model dengan suku “decay ratio” pada ketetapan masa yang minima dan kesilapan besar yang minima. Respon yang terhasil dari kedua-dua peraturan akan di analisis dengan menggunakan aplikasi “Simulink” didalam perisian “MATLAB”. Gambarajah blok untuk proses model serta kawalan dibina untuk proses simulasi. *Kc*= 16.667, τ_I =6.283 dan τ_D =1.571 ada parameter-parameter yang optimum bagi peraturan Z-N dengan kesilapan besar minima 0.582 dan ketetapan masa minima, 11.8s dalam sampel 11. Bagi peraturan C-C; *Kc*= 14.703, τ_I =3.622 dan τ_D =0.541 adalah parameter-parameter optimum. Ketetapan masa dan kesilapan besar yang minima dalam sampel 39 adalah 0.4914 dan 12.2s. Keputusan menunjukkan, respon yang menggunakan penyelarasan Cohen-Coon adalah lebih baik dari penyelarasan yang dibuat dalam Ziegler-Nichols.

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LIST OF SYMBOLS

MATLAB	-	Matrix Laboratory
Kc	-	Controller Parameter of Proportional
τ_I	-	Controller Parameter of Integral
τ_D	-	Controller Parameter of Derivative
DR	-	Decay Ratio
α	-	The Height of First Peak
γ	-	The Height of Second Peak
P	-	Period of Oscillation
t_r	-	The Time the Process Output Takes To First Reach
t_p	-	Time Required For the Output to Reach First Maximum Value
t_s	-	Settling Time
K	-	The Output Steady State Divided By the Input Step Change
τ	-	Effective Time Constant
t_d	-	Dead Time
M	-	Amplitude Ratio of The System's Response
Kcu	-	1/M
ωco	-	Crossover Frequency
Pu	-	$\frac{2\pi}{\omega_{co}}$

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years the performance requirements for process plants have become increasingly difficult to satisfy. Stronger competition, tougher environmental and safety regulation, and rapidly changing economic condition have been key factors in tightening product quality specifications. A further complication is that modern plants have become more difficult to operate because of trend toward complex integrated processes.

Process control has become increasingly important in the process industries as a consequence of global competition, rapidly changing economic conditions, and more stringent environmental and safety regulations. Process control is also a critical concern in the development of more flexible and more complex processes for manufacturing high value added products. One of the complex and difficult in process control is control tuning. Control tuning is the major key issue to operate the plant. Process tuning is a key role in ensuring that the plant performance satisfies the operating objectives.

Controller tuning inevitably involves a tradeoff between performance and robustness. The performance goals of excellent set-point tracking and disturbance rejection should be balanced against the robustness goal of stable operation over a wide range of conditions.

Before started the tuning, it is general to make various reason and criteria for selecting which controller type will be adequate for which application. In control tuning, feedback control was used. Feedback control is that the controlled variable is measured and the measurement is used to adjust the manipulated variable and the disturbance variable is not measured [1]. This controller is used to make tuning in process control. The selection made on the basis of the general characteristics of the different feedback controllers are the most practical.

It have three major type of feedback controller, the controller are proportional controller (P), proportional-integral controller (PI) and proportional-integral-derivative controller (PID). P controller only can achieve acceptable offset with moderate value and it only used for gas pressure and liquid-level control. For provide sufficiently small steady-state errors PI controller will be used. Consequently, integral control mode make the speed of the closed-loop system remains satisfactory despite the slowdown of flow system response in PI controller. The combination of the process, the feedback controller, and the instrumentation is referred to as a feedback control loop or a closed-loop system [1].

To increase the speed of the closed-loop response and retain robustness, PID controller is used. PID controllers are widely used in industrial practice more than 60 years. The development went from pneumatic through analogue to digital controllers, but the control algorithm is in fact are same. The PID controller is a standard and proved solution for the most of industrial control applications. In spite of this fact, there is not some standard and generally accepted method for PID controller design and tuning based on known process model.

Over the years, there are many formulas derived to tune the PID controller for adjusted parameters and achieved optimum value. There are three parameters must be tuning to achieved optimum value. The table 1.1 shows the parameters are considered in PID controller

Table 1.1: Parameters Of PID Controller

SYMBOL	PARAMETER
Kc	Proportional
τ_I	Integral
τ_D	Derivative

After PID controller has been selected, there are need approaches to use for tuning a controller and get the optimum parameters. It have many approaches for tuning and general approaches are use simple criteria such as the one-quarter decay ratio, minimum settling time, minimum largest error and so on. It provides multiple solutions with simple and easily implement table on actual process rather than use the approach is rather cumbersome and relies heavily on the mathematical model like time integral performance criteria such as integral of the squared error (ISE), integral of the absolute value of the error (IAE) or integral of the time-weighted absolute error (ITAE) and semi empirical rules.

Two controller tuning relations were published by Ziegler and Nichols (1942) and Cohen and Coon (1953) are used were develop to provide closed-loop responses that have one-quarter decay ratio with minimum settling time and minimum largest error [2]

Abnormal process operation can occur for a variety of reason, including equipment problems, instrumentation malfunctions, and unusual disturbances. Severe abnormal situations can have serious consequences such as even forcing a plant shutdown. It have been estimated that improved handling control tuning could result in savings of $10 billion U.S Dollar each year to the U.S petrochemical industry [1]. That mean, controls tuning are important activities.

1.2 Problem Statement

The controller tuning problem gives an effect on closed-loop stability and overall process control. It difficult to find the simple and easy implement table approach for tune the parameters. It also difficult to achieved the optimum parameter in controller tuning with method to minimize the largest error and settling time. To develop a good performance controller tuning method is also hard.

1.3 Objective

The aim of this study is to

- To get the optimum Kc, τ_I , & τ_D to control a given process
- To tune the feedback controller using Cohen-Coon & Ziegler-Nichols method
- To compare the performance criterion between Cohen-Coon & Ziegler-Nichols method for the selection and the tuning of the controller.

1.4 Scope

To achieve the objective of this research, there are four scopes that have been identified:

- Select first order model for process control tuning
- Control the process using proportional-integral-derivative controller (PID controller)
- Determine the beat optimum PID controller parameter.

- Tune PID controller using Cohen-Coon & Ziegler-Nichols method
- Calculate the error.
- Compare the performance of Cohen-Coon & Ziegler-Nichols method

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Proportional-integral-derivative (PID) controllers are the predominant types of feedback control. PID controller is widely used in industry due to their simplicity and easy to tuning. The output of PID controller is a linear combination of the input, the derivative of the input and the integral of the input. It is widely used and enjoys significant popularity because it is simple, effective and robust.

One of the reason why this is so is the existence of tuning rules for finding suitable parameters for PID, rules that do not require any model of the plant to control. All that needed to apply such rules is to have a certain time response of the plant [3]. It will be use some method like Ziegler-Nichol, Cohen-Coon and Kappa-Tau rules or method.

2.2 Closing The Loop Control System

Systems that utilize feedback are called closed-loop control systems. The feedback is used to make decisions about changes to the control signal that drives the plant. An open-loop control system does not use feedback.

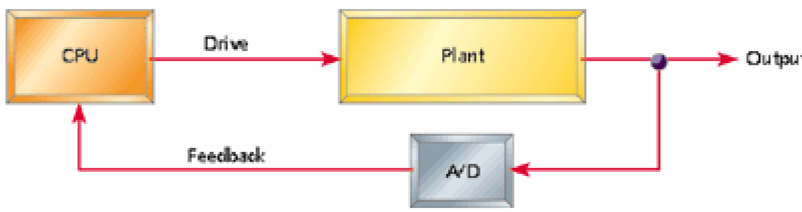

Figure 2.1: A Closed-Loop Control System

A basic closed-loop control system as shown in Figure 2.1 can describe a variety of control systems, including those driving elevators, thermostats, and cruise control.

Closed-loop control systems typically operate at a fixed frequency. The frequency of changes to the drive signal is usually the same as the sampling rate, and certainly not any faster [4]. After reading each new sample from the sensor, the software reacts to the plant's changed state by recalculating and adjusting the drive signal. The plant responds to this change, another sample is taken, and the cycle repeats. Eventually, the plant should reach the desired state and the software will cease making changes.

If feedback indicates that the temperature in plant is below desired set point, the thermostat will turn the heater on until the plant is at least that temperature [4]. The simple example like a car is going too quickly, the cruise control system can temporarily reduce the amount of fuel fed to the engine

An effective feedback control system is expected to be stable and capable of causing the system output ultimately to attain its desired set-point value for example [5]. The approach of this system output to desired set-point should neither be too sluggish, nor too oscillatory. It reveals three types of criteria by which closed loop system performance may be assessed in general.

- Stability Criteria
- Steady state Criteria
- Dynamic Response Criteria

Only first two are very easy to specify.

Figure 2.2 illustrates type of feedback response that raise depend on the process being controlled, choice of controller type and the controller parameters selected [5]. The best control systems are decided with the response for particular problem.

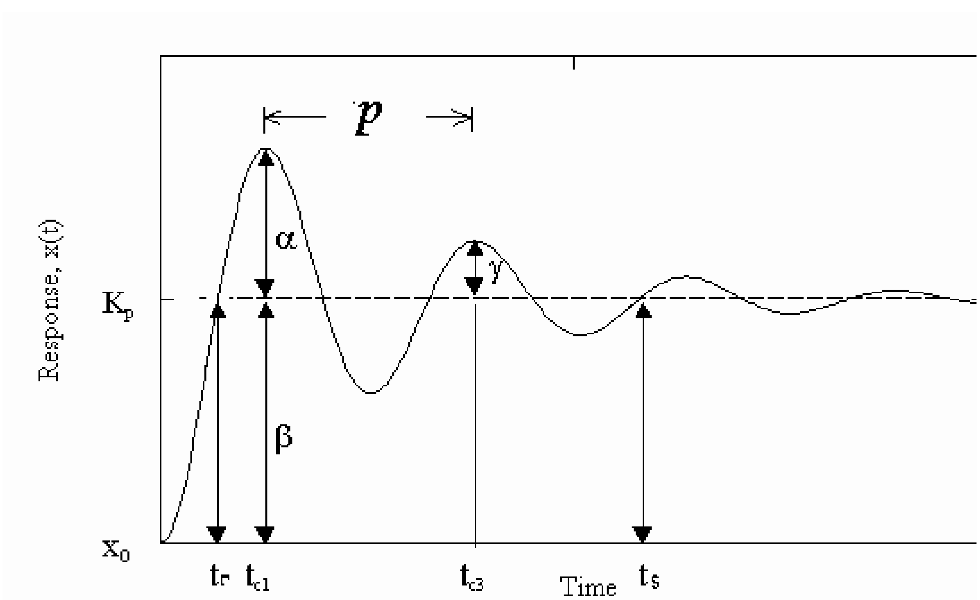

Figure 2.2: Type Of Feedback Response

- $\frac{\gamma}{\alpha} = DR$, a specified maximum decay ratio
- P, Period of oscillation.
- t_r, the time the process output takes to first reach the new steady state value and time to the first peak,
- t_p, the time required for the output to reach its first maximum value.
- t_s, settling time

2.3 PID Controller

PID stands for Proportional, Integral, and Derivative. Controllers are designed to eliminate the need for continuous operator attention. Cruise control in a car and a plant thermostat are common examples of how controllers are used to automatically adjust some variable to hold the measurement at the set-point.

The set-point is where you would like the measurement to be. Error is defined as the difference between set-point and measurement. The variable being adjusted is called the manipulated variable which usually is equal to the output of the controller. The output of PID controllers will change in response to a change in measurement or set-point [6] From figure 2.3, it shows the different of P, PI and PID controllers.

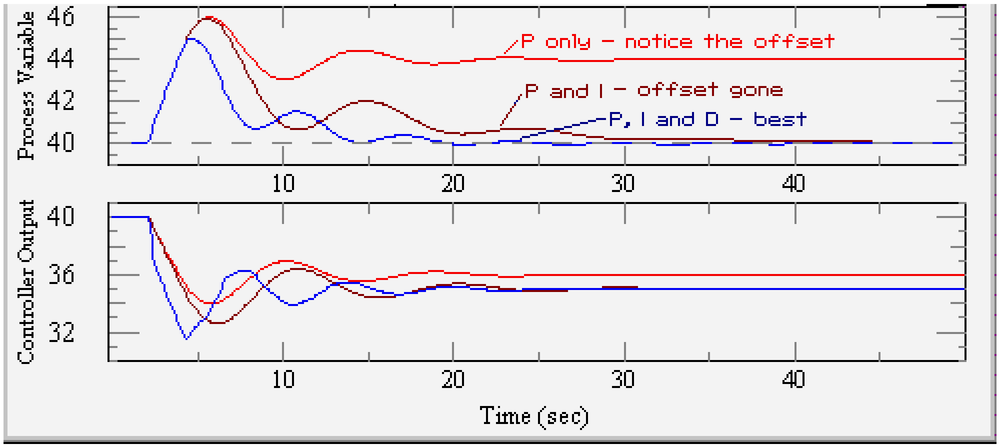

Figure 2.3: Different Of P, PI And PID Controllers

PID controllers are designed to automatically control a process variable like flow, temperature, or pressure. A controller does this by changing process input so that a process output agrees with a desired result. Example like the set point is considered. An example would be changing the heat around a tank so that water coming out of that tank always measures 100° C [7].

2.3.1 Proportional Action

The units of proportional action may be either percent Proportional Band *P* or Proportional Gain K_c, where

$$K_C = 100 / P \tag{2.1}$$

$$P = 100 / K_C \tag{2.2}$$

The proportional action should work on deviation or controlled variable depending on the user selection. The user should also be able to adjust the amount of proportional action applied to the set point.

Proportional Band setting should range from 1 to 10,000. If gain is used, the gain range should be from 0.01 to 100.

2.3.2 Integral Action

The units of integral action should be in minutes per repeat. The integral action must operate on the deviation signal. The Integral time should be adjustable between 0.002 to 1000 minutes.

There should be anti-reset windup logic so that the output of the integral term does not saturate into a limit when the controller output reaches that limit. The method of anti-reset windup should incorporate integral feedback. This allows the secondary measurement signal to be feeedback to the primary controller in cascade, feedforward, and constraint control systems, maximizing their effectiveness, operability, and robustness.

The controller should be capable of operation without integral action, through the application of an adjustable output bias.

2.4 Ziegler-Nichol Method (Z-N)

This pioneer method, also known as the close-loop or on-line tuning method was proposed by Ziegler and Nichols in 1942. Like all the other tuning methods, it consists of two steps:

1. Determination of the dynamic characteristics, or personality, of the control loop
2. Estimation of the controller tuning parameters that produce a desired response for the dynamic characteristic determined in the first step, in other words, matching the personality of the controller to that of the other elements in the loop.

In this method the dynamic characteristic of the process are represented by the ultimate gain of a proportional controller and the ultimate period of oscillation of the loop. It usually determinate the ultimate gain and period from the actual process by the following procedure:

- Switch off the integral and derivative modes of the feedback controller so as to have a proportional controller.
- With the controller in automatic (i.e., the loop closed), increase the proportional gain (or reduce the proportional band) until the loop oscillates with constant amplitude. Record the value of the gain that produces sustained oscillation. To prevent the loop from going unstable, smaller increments in gain are made as the ultimate gain is approached.
- From a time recording of the controlled variable such as the figure below, the period of oscillation is measured and recorded as *T* the ultimate period.

For the desired response of the close loop, Z-N method specified a decay ratio of one-fourth. The decay ratio is the ratio of the amplitudes of two successive oscillations. It should be independent of the input to the system and should depend only on the roots of the characteristic equation for the loop [9].

The tuning relationship are intended to minimize the integral of the error, their use is referred to as minimum error integral tuning. However the integral of the error cannot be minimized directly, because a very large negative error would be the minimum. In Figure 2.4, it shows the error integrals for disturbance and for set point changes.

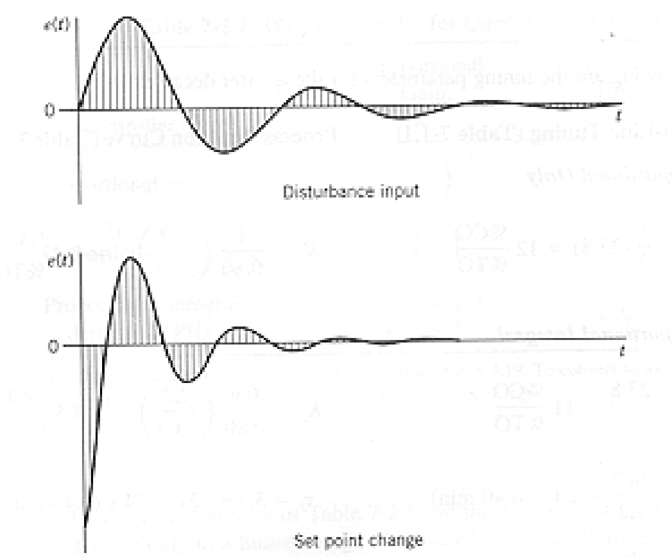

Figure 2.4: Error Integrals For Disturbance And For Set Point Changes

The Z-N method is more robust because it does not require a specific process model. To tune a controller using the Z-N method the integral and derivative elements of the PID controller are ignored. The proportional element is used to find a Kc that will sustain oscillation. This value is considered the Kcu, or the ultimate gain. The period of oscillation is the Pu, or ultimate period. Consequently, Z-N settings are reasonable to applied in controller tuning using table 2.1.

Table 2.1: Controller Settings Based On The Z-N Method.

	P	PI	PID
K_c	$.5K_{cu}$	$.45K_{cu}$	$0.6K_{cu}$
τ_I	-	$P_u/1.2$	$P_u/2$
τ_D	-	-	$P_u/8$

2.5 Cohen-Coon Method (C-C)

There are several ways to determine what values to used for the proportional, integral, and differential parameters in the controller, and used the Cohen-Coon method is one of the method . By looking at the system's response to manual step changes without the controller operating, initial values for the PID parameters and then tune them manually are determine

.

The system's response is modeled to a step change as a first order response plus dead time, using the Cohen-Coon method. From this response, three parameters: *K*, τ, and t_d are founded. *K* is the output steady state divided by the input step change, τ is the effective time constant of the first order response, and t_d is the dead time [9].

$$G_{PRC(S)} = \frac{\overline{y_m}(s)}{\bar{c}(s)} \simeq \frac{Ke^{-td^s}}{\tau s+1} \qquad (2.4)$$

C-C method used the approximated mode of equation 2.4 and estimated the value of the parameters K, τ, and t_d as indicated above. Then it derived expressions for the best controller settings using one-quarter decay ratio. From K, τ, and t_d the PID parameters are calculated from the following formulas [2].

$$Kc = (1/K)\,(\tau/t_d)\,(4/3 + t_d/(4\tau)) \tag{2.5}$$

$$\tau_I = t_d\,(32 + 6t_d/\tau) / (13 + 8t_d/\tau) \tag{2.6}$$

$$\tau_D = 4t_d / (11 + 2\,t_d/\tau) \tag{2.7}$$

CHAPTER 2

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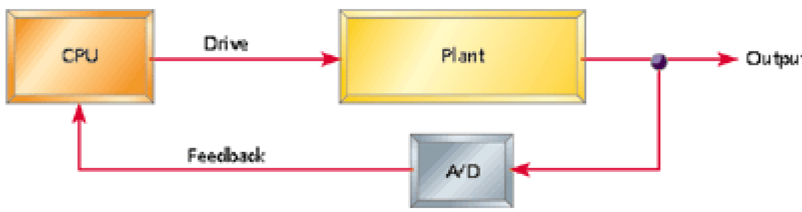

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- Dynamic Response Criteria

Only first two are very easy to specify.

Figure 2.2 illustrates type of feedback response that raise depend on the process being controlled, choice of controller type and the controller parameters selected [5]. The best control systems are decided with the response for particular problem.

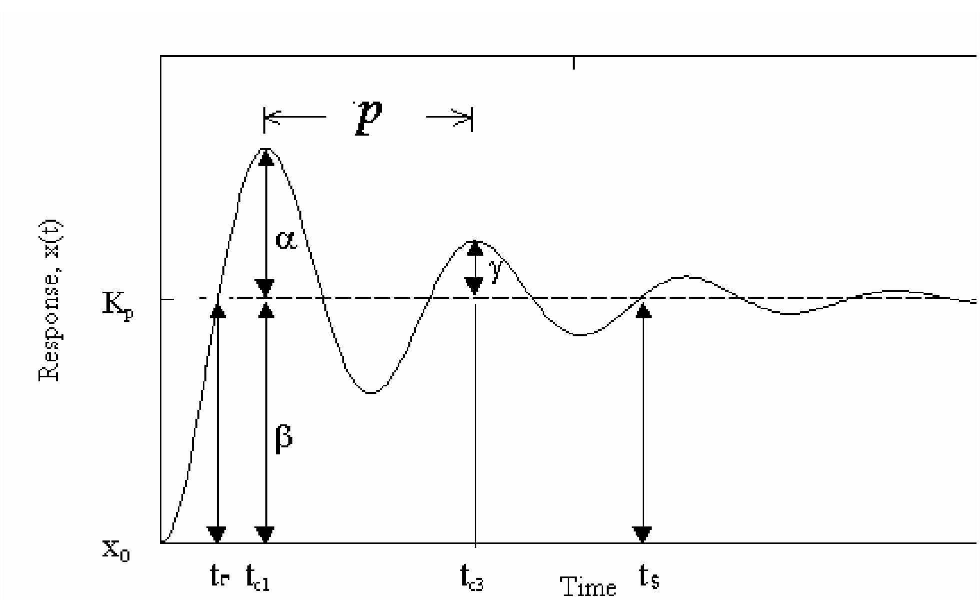

Figure 2.2: Type Of Feedback Response

- $\frac{\gamma}{\alpha} = DR$, a specified maximum decay ratio
- P, Period of oscillation.
- t_r, the time the process output takes to first reach the new steady state value and time to the first peak,
- t_p, the time required for the output to reach its first maximum value.
- t_s, settling time

2.3 PID Controller

PID stands for Proportional, Integral, and Derivative. Controllers are designed to eliminate the need for continuous operator attention. Cruise control in a car and a plant thermostat are common examples of how controllers are used to automatically adjust some variable to hold the measurement at the set-point.

The set-point is where you would like the measurement to be. Error is defined as the difference between set-point and measurement. The variable being adjusted is called the manipulated variable which usually is equal to the output of the controller. The output of PID controllers will change in response to a change in measurement or set-point [6] From figure 2.3, it shows the different of P, PI and PID controllers.

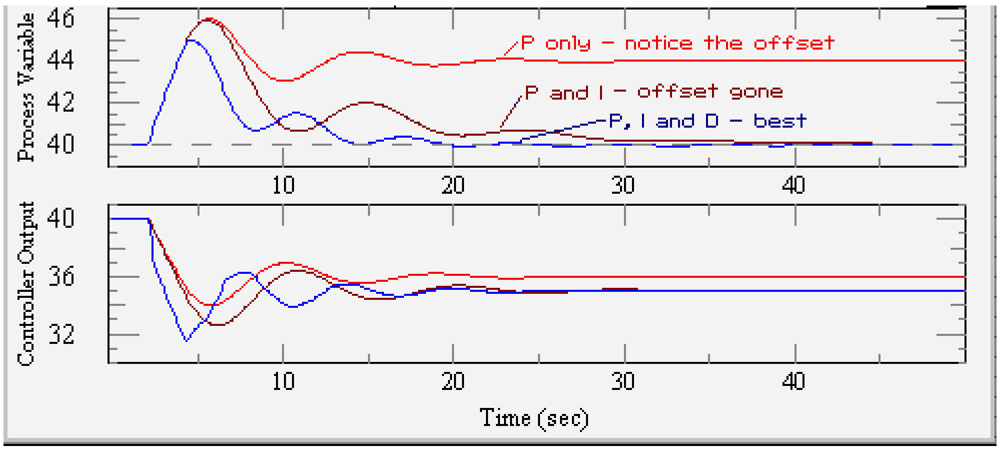

Figure 2.3: Different Of P, PI And PID Controllers

PID controllers are designed to automatically control a process variable like flow, temperature, or pressure. A controller does this by changing process input so that a process output agrees with a desired result. Example like the set point is considered. An example would be changing the heat around a tank so that water coming out of that tank always measures 100° C [7].

2.3.1 Proportional Action

The units of proportional action may be either percent Proportional Band *P* or Proportional Gain K_c, where

$$K_C = 100 / P \tag{2.1}$$

$$P = 100 / K_C \tag{2.2}$$

The proportional action should work on deviation or controlled variable depending on the user selection. The user should also be able to adjust the amount of proportional action applied to the set point.

Proportional Band setting should range from 1 to 10,000. If gain is used, the gain range should be from 0.01 to 100.

2.3.2 Integral Action

The units of integral action should be in minutes per repeat. The integral action must operate on the deviation signal. The Integral time should be adjustable between 0.002 to 1000 minutes.

There should be anti-reset windup logic so that the output of the integral term does not saturate into a limit when the controller output reaches that limit. The method of anti-reset windup should incorporate integral feedback. This allows the secondary measurement signal to be feeedback to the primary controller in cascade, feedforward, and constraint control systems, maximizing their effectiveness, operability, and robustness.

The controller should be capable of operation without integral action, through the application of an adjustable output bias.

2.4 Ziegler-Nichol Method (Z-N)

This pioneer method, also known as the close-loop or on-line tuning method was proposed by Ziegler and Nichols in 1942. Like all the other tuning methods, it consists of two steps:

1. Determination of the dynamic characteristics, or personality, of the control loop
2. Estimation of the controller tuning parameters that produce a desired response for the dynamic characteristic determined in the first step, in other words, matching the personality of the controller to that of the other elements in the loop.

In this method the dynamic characteristic of the process are represented by the ultimate gain of a proportional controller and the ultimate period of oscillation of the loop. It usually determinate the ultimate gain and period from the actual process by the following procedure:

- Switch off the integral and derivative modes of the feedback controller so as to have a proportional controller.
- With the controller in automati*c* (i.e., the loop closed), increase the proportional gain (or reduce the proportional band) until the loop oscillates with constant amplitude. Record the value of the gain that produces sustained oscillation. To prevent the loop from going unstable, smaller increments in gain are made as the ultimate gain is approached.
- From a time recording of the controlled variable such as the figure below, the period of oscillation is measured and recorded as T the ultimate period.

For the desired response of the close loop, Z-N method specified a decay ratio of one-fourth. The decay ratio is the ratio of the amplitudes of two successive oscillations. It should be independent of the input to the system and should depend only on the roots of the characteristic equation for the loop [9].

The tuning relationship are intended to minimize the integral of the error, their use is referred to as minimum error integral tuning. However the integral of the error cannot be minimized directly, because a very large negative error would be the minimum. In Figure 2.4, it shows the error integrals for disturbance and for set point changes.

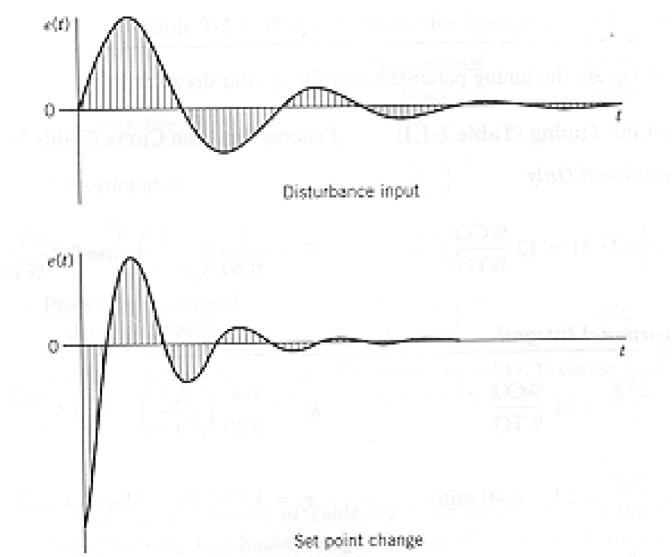

Figure 2.4: Error Integrals For Disturbance And For Set Point Changes

The Z-N method is more robust because it does not require a specific process model. To tune a controller using the Z-N method the integral and derivative elements of the PID controller are ignored. The proportional element is used to find a Kc that will sustain oscillation. This value is considered the Kcu, or the ultimate gain. The period of oscillation is the Pu, or ultimate period. Consequently, Z-N settings are reasonable to applied in controller tuning using table 2.1.

Table 2.1: Controller Settings Based On The Z-N Method.

	P	PI	PID
K_c	$.5K_{cu}$	$.45K_{cu}$	$0.6K_{cu}$
τ_I	-	$P_u/1.2$	$P_u/2$
τ_D	-	-	$P_u/8$

2.5 Cohen-Coon Method (C-C)

There are several ways to determine what values to used for the proportional, integral, and differential parameters in the controller, and used the Cohen-Coon method is one of the method . By looking at the system's response to manual step changes without the controller operating, initial values for the PID parameters and then tune them manually are determine

.

The system's response is modeled to a step change as a first order response plus dead time, using the Cohen-Coon method. From this response, three parameters: *K*, τ, and t_d are founded. *K* is the output steady state divided by the input step change, τ is the effective time constant of the first order response, and t_d is the dead time [9].

$$G_{PRC(S)} = \frac{\overline{y_m}(s)}{\bar{c}(s)} \simeq \frac{Ke^{-td^s}}{\tau s+1} \tag{2.4}$$

C-C method used the approximated mode of equation 2.4 and estimated the value of the parameters K, τ, and t_d as indicated above. Then it derived expressions for the best controller settings using one-quarter decay ratio. From K, τ, and t_d the PID parameters are calculated from the following formulas [2].

$$Kc = (1/K)\,(\tau/t_d)\,(4/3 + t_d/(4\tau)) \tag{2.5}$$

$$\tau_I = t_d\,(32 + 6t_d/\tau)\,/\,(13 + 8t_d/\tau) \tag{2.6}$$

$$\tau_D = 4t_d\,/\,(11 + 2\,t_d/\tau) \tag{2.7}$$

CHAPTER 3

METHODOLOGY

3.1 Introduction

This study is conducted using MATLAB software to develop the process model and generate data. MATLAB is an abbreviation for *MATrix LABoratory*. MATLAB is a high-level programming environment that processes arrays and matrices and provides a powerful graphical environment. A high-level programming environment allows the users to program without worrying about declaring variables, allocating memory, using pointers, and compiling code and other routine tasks.

MATLAB has several toolboxes with functions that facilitate process model identification, system stability assessment, control system design, and process simulation. The toolboxes deal with a wide variety of control areas from conventional control to optimal and model predictive control. Simulink is a part of MATLAB that can be used to simulate dynamic systems. It can used to get the response from controller setting are used.

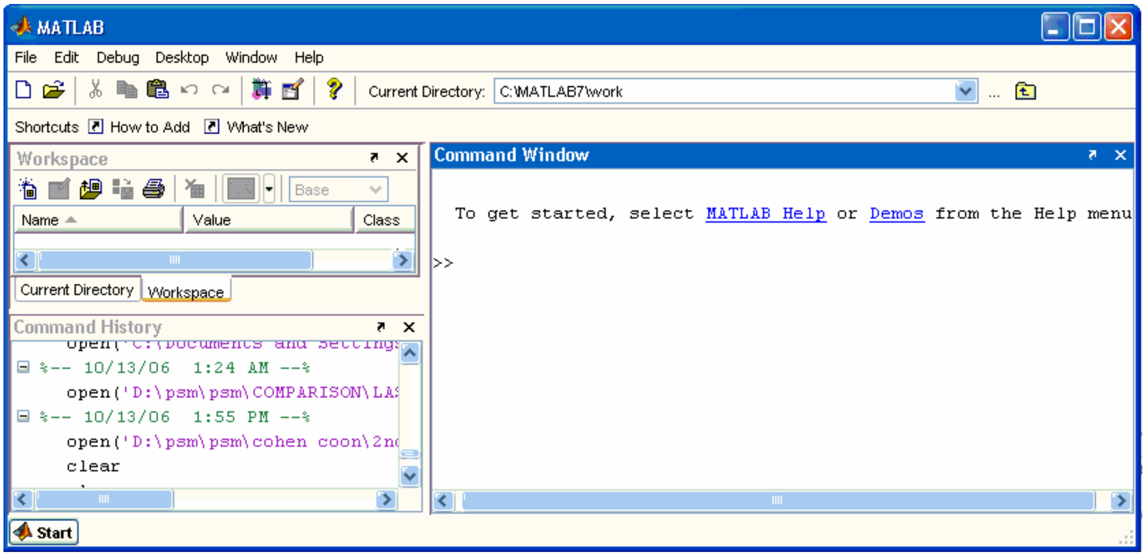

Figure 3.1: MATLAB Overview

Simulink is an interactive tool for modeling, simulating, and analyzing dynamic, multi domain systems. It has accurately described, simulated, evaluated, and refine a system's behavior through standard and custom block libraries. Simulink models have ready access to MATLAB, provided with flexible operation and an extensive range of analysis and design tools.

The block diagram models are creating from the Simulink library browser as shown in Figure 3.2. The models were being developed in new model window; the model can create by copy blocks into the model window from Simulink block libraries. The major library are use to create the block diagram for controller tuning are Sources Library, Sinks Library and Continuous Library.

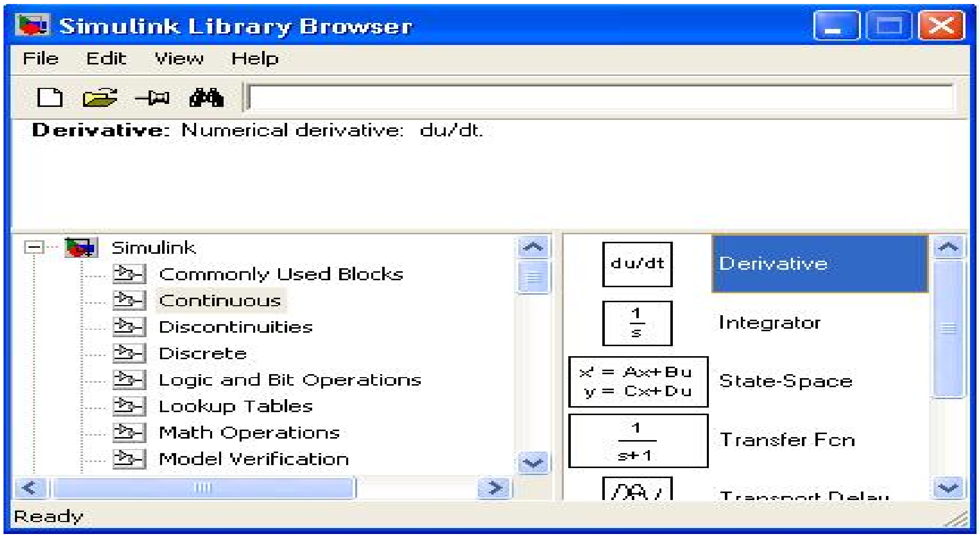

Figure 3.2: Simulink Library Browser

3.2 Development Of Process Model Using Simulink

Draw the general block diagram consist of *Step, Sum, PID Controller, Transfer Function* and *Scope block* from Simulink Library browser. The *Step* block provides a step between two definable levels at a specified time [10]. If the simulation time is less than the step change parameter value, the block's output is the initial value parameter value. For simulation time greater than or equal to the step change, the output is the Final value parameter value. For this study the step change is the output when the simulation time reaches and exceeds the step change parameter. The default is 1.

The PID Controller block is used to enter expressions for proportional, integral, and derivative terms. The controller was tuned using this block. The Transfer Function block implements a transfer function where the input and output can be expressed in transfer function form. The numerator and denominator are displayed on the Transfer Function block depending on how they are specified. If each is specified as an expression, a vector, or a variable enclosed in parentheses, the icon shows the transfer function with the specified coefficients and powers of s [10]. For example, if numerator specified as [1] and denominator as [10 7 1], the block looks like transfer function block in Figure 3.3. From this transfer function, it notifies this is second order process.

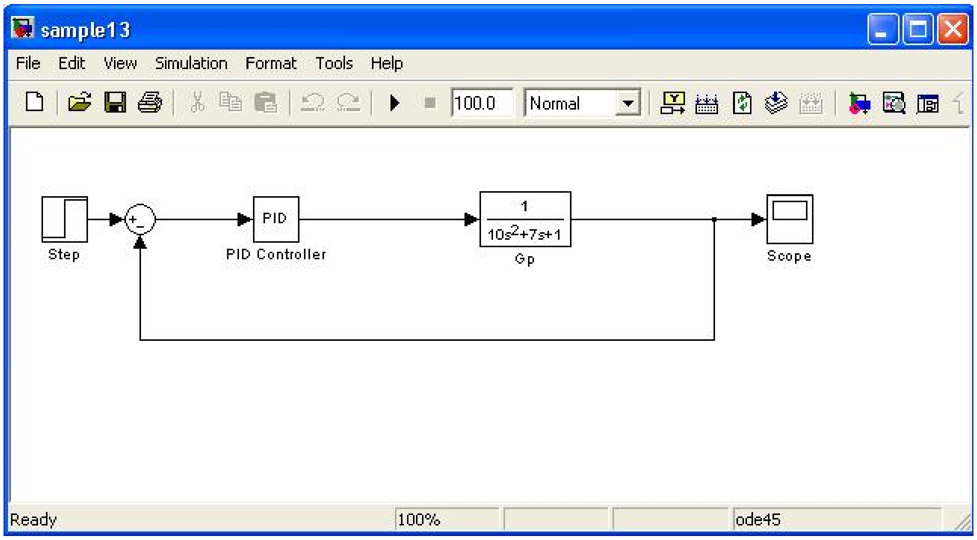

Figure 3.3: Block Diagram For Controller Tuning

The *Scope* block displays its input with respect to simulation time. The *Scope* block can have multiple axes (one per port). However, all axes have a common time range with independent y-axes [10]. The *Scope* can be adjusted the amount of time and the range of input values displayed.

Figure 3.3 shows the block diagram created in new model window which consist of input, PID controller, process model and output. The PID controller parameter was set up as shown in Figure 3.4 before simulation started. Process response can be determined by double click on *Scope* block. Figure 3.5 shows the process response for the particular process.

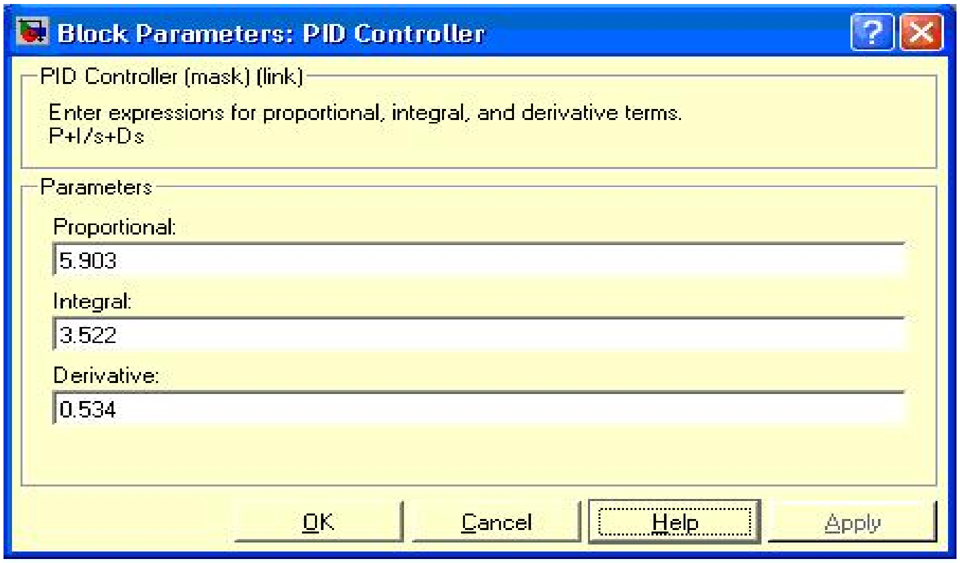

Figure 3.4: PID Controller Block Parameters

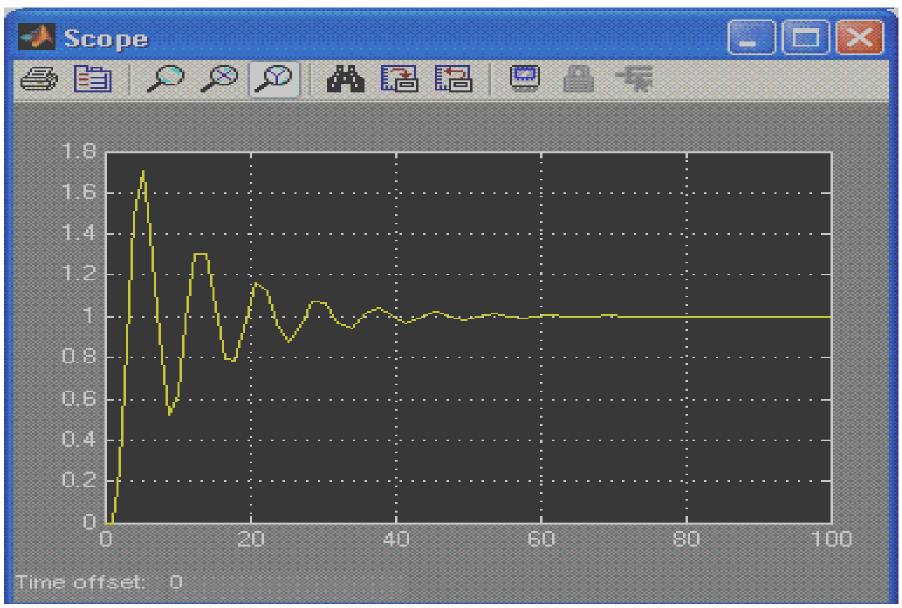

Figure 3.5: Simulation Result In Scope Window

3.3 Controller Tuning

An affective controller tuning strategies is very important to select the optimum parameters value of PID controller. Different process response will get from different selections of PID controller parameters value. The selections of PID controller parameters depend on the optimum value of one-quarter decay ratio with minimum settling time and minimum largest error.

One-quarter decay ratio is the height of second peak error, γ divide with the height of first peak, α as shown in Figure 2.2. One-quarter decay ratio equal with 0.25. Settling time, t_s is the time required for the output to reach and remain inside a band whose width is equal to $\pm 5\%$ of the total change in y for 95% response time. The largest error is the height of first peak.

Ms Excel is used to generate the value for K_c, τ_I and τ_D using Ziegler-Nichols and Cohen-Coon method as shown in Table 3.1. Then, the calculated parameters were used in Simulink process model until the optimum condition is achieved.

Table 3.1: PID Controller Settings

	K_c	τ_I	τ_D
Ziegler-Nichols	$0.6K_{cu}$	$P_u/2$	$P_u/8$
Cohen-Coon	$(1/K)(\tau/t_d)(4/3 + t_d/(4\tau))$	$t_d(32 + 6t_d/\tau)/(13 + 8t_d/\tau)$	$4t_d/(11 + 2t_d/\tau)$

The value of PID parameters in controller tuning is a critical step in conducting this research. The selection should be based on process response, objective and scope of the research.

3.3.1 Ziegler-Nichols Method (Z-N)

Ziegler-Nichols method introduced continuous cycling method for controller tuning. The term continuous cycling refers to a sustained oscillation with constant amplitude. The important parameters; *M, Kcu,* ω_{CO} and P_U are use to get introduce *Kc* with 30, momentary set-point change so that the controlled variable moves away from the set point. The value of *Kc* will decrease to achieve one quarter decay ratio for the the other sample. PID controller parameters were calculated using Z-N method as show in Table 3.2.

Table 3.2: Generate Parameters For Z-N Method

Sample	M	ωco	Kcu	Pu	Kc	τ_I	τ_D	a	c
1	0.020	0.500	50.000	12.566	30.000	6.283	1.571	0.550	0.167
2	0.025	0.500	40.000	12.566	24.000	6.283	1.571	0.560	0.157
3	0.030	0.500	33.333	12.566	20.000	6.283	1.571	0.575	0.155
4	0.035	0.500	28.571	12.566	17.143	6.283	1.571	0.582	0.148
5	0.040	0.500	25.000	12.566	15.000	6.283	1.571	0.590	0.174
6	0.045	0.500	22.222	12.566	13.333	6.283	1.571	0.596	0.211
7	0.050	0.500	20.000	12.566	12.000	6.283	1.571	0.600	0.252
8	0.055	0.500	18.182	12.566	10.909	6.283	1.571	0.650	0.295
9	0.060	0.500	16.667	12.566	10.000	6.283	1.571	0.693	0.340
10	0.065	0.500	15.385	12.566	9.231	6.283	1.571	0.735	0.364

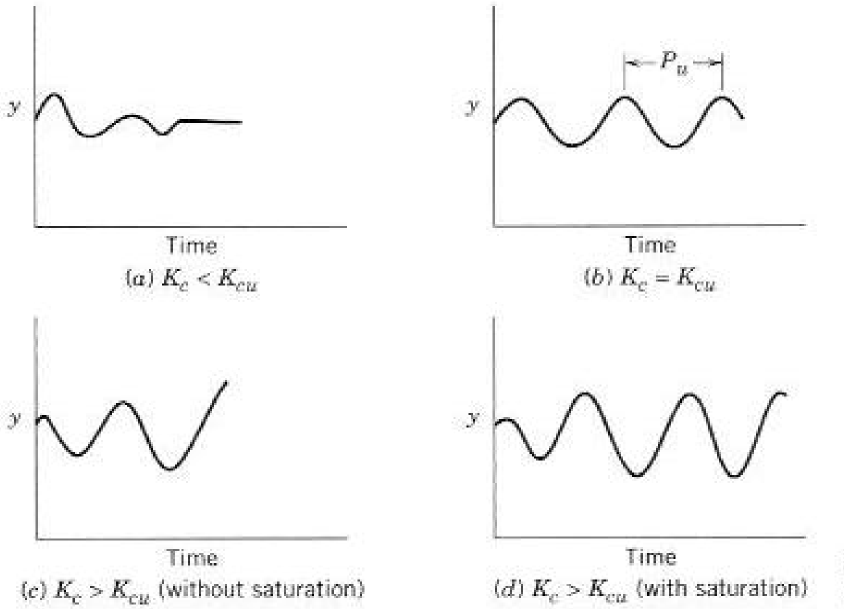

Figure 3.6: Experimental Determination Of Ultimate Gain *Kcu*

Results for the trial-and-error determination of *Kcu* are shown in Figure 3.6. *Kc* < *Kcu*, the close-loop response y(t) as shown in Figure 3.6(a) is usually overdamped or slightly oscillatory. For the ideal case where *Kc* = *Kcu*, continuous cycling occurs in Figure 3.6b. For *Kc* > *Kcu*, the closed-loop system was unstable and theoretically have an unbounded response as in Figure 3.6(c). But in practice, controller saturation prevents the response from becoming unbounded and produces continuous cycling instead. The estimated value of *Kcu* and *Kc* would be too large if controller saturation is used to determine *Kcu.* Therefore the controller saturation must be avoided during the simulation process.

All the parameter calculated using Z-N method was plug in Simulink to simulate dynamic process to get a response. A small set point change was introduced into the process loop response was observed. The Z-N parameters were varied up to 10 samples as shown in Table 3.2 in order to find the optimum condition for the process.

3.3.2 Cohen-Coon Method (C-C)

There are several ways to determine values to use for the proportional, integral, and differential parameters in PID controller, other than Z-N method, Cohen-Coon method can be applied. Cohen-Coon recommended the settings as in Table 3.1 to give responses having ¼ decay ratios,

The process model was responses are modeled to a step change as a first order response plus dead time, using Cohen-Coon method. From this response three parameters are founded K, τ, and t_d. K is the output steady state divided by the input step change, τ is the effective time constant of the first order response, and t_d is the dead time.

The value of K and t_d were keep constant at 2 and 1.5 respectively, τ was set at 1 and gradually increase up to 15s. Based on the K, τ, and t_d value calculated using C-C method, PID parameters is determined as shown in Table 3.3.

For the sample have small error with one quarter decay ratio then it manually adjust the parameters of the sample to get better response from the control system. The values of τ were adjusted to archive the one-quarter decay ratio.

The C-C parameter were varied up to 35 sample part of generate parameters as shown in Table 3.3 in order to get the optimum condition for the process.

Table 3.3: Part Of Generate Parameters For C-C Method

Sample	K	τ	td	Kc	τ_I	τ_D
1	2	1	1.5	0.569	2.460	0.429
2	2	2	1.5	1.014	2.882	0.480
3	2	3	1.5	1.458	3.088	0.500
4	2	4	1.5	1.903	3.211	0.511
5	2	5	1.5	2.347	3.292	0.517
6	2	6	1.5	2.792	3.350	0.522
7	2	7	1.5	3.236	3.393	0.525
8	2	8	1.5	3.681	3.427	0.527
9	2	9	1.5	4.125	3.453	0.529
10	2	10	1.5	4.569	3.475	0.531
11	2	11	1.5	5.014	3.494	0.532
12	2	12	1.5	5.458	3.509	0.533
13	2	13	1.5	5.903	3.522	0.534
14	2	14	1.5	6.347	3.534	0.535
15	2	15	1.5	6.792	3.543	0.536

3.5 Comparison

Sample response from both methods is achieved one-quarter decay ratio will be compared to get the best result. The comparisons are indicating the response of the controller to step changes in the set point and load. It also considers the small minimum settling time and the minimum largest error.

3.6 Conclusion

The methodology for this study is summarized as shown in Figure 3.7 while for comparison between Z-N and C-C method is shown in Figure 3.8

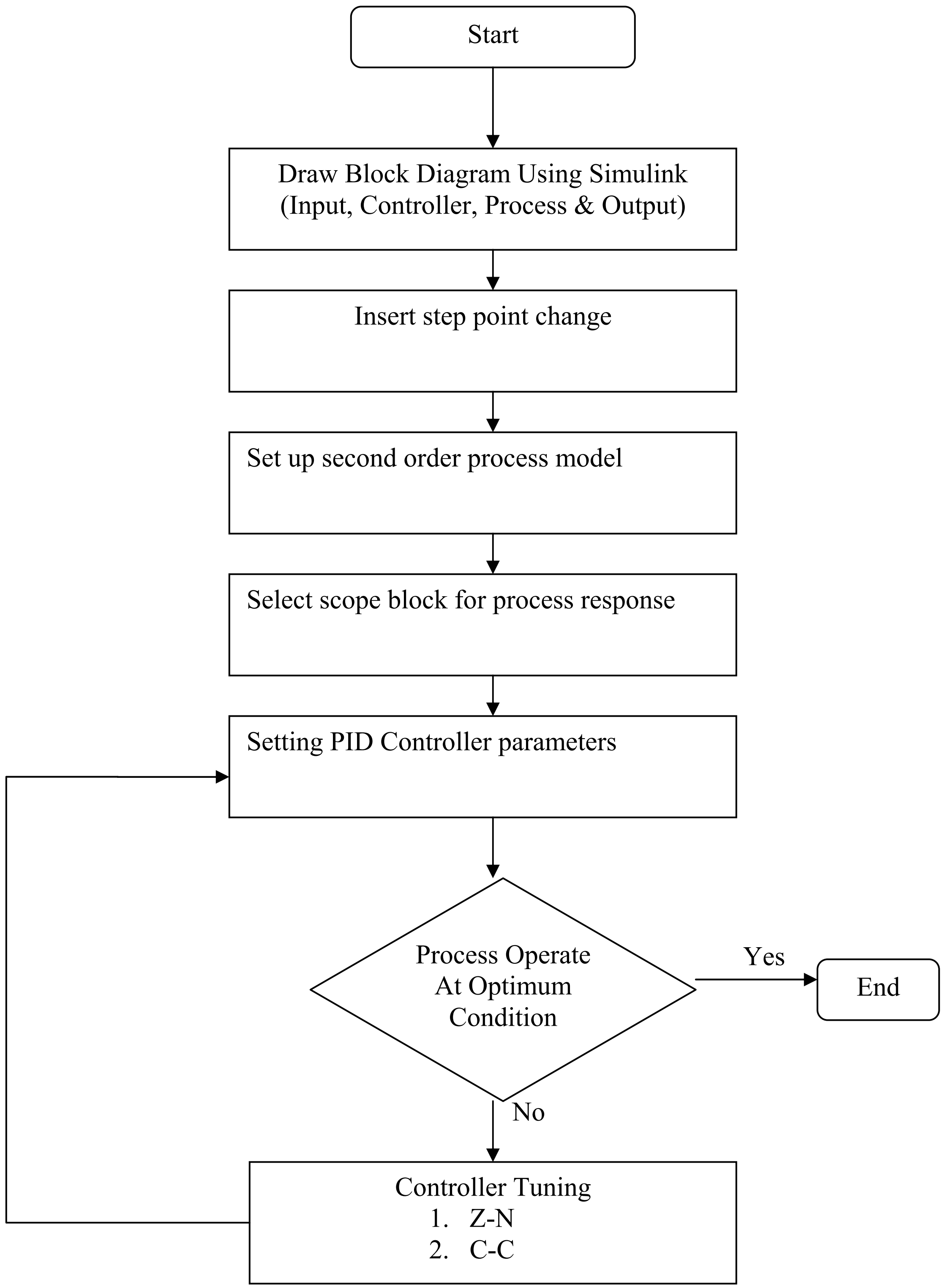

Figure 3.7: Operational Framework For Controller Tuning Process

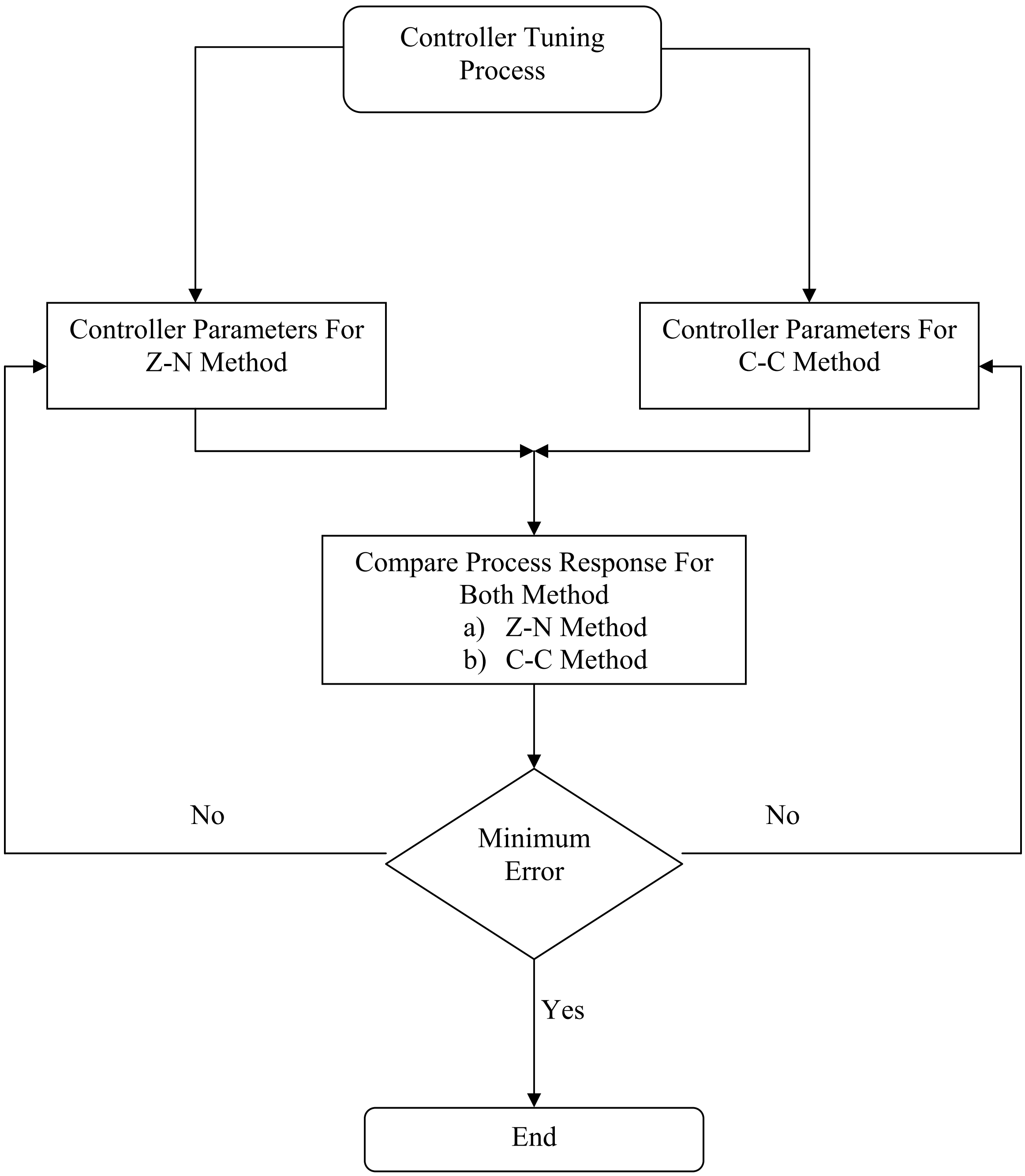

Figure 3.8: Operational Flow For Comparison

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Development Of Process Model

Block diagram in Simulink was draw generally as shown in Figure 4.1, this block diagram was set with *Step* block, *Sum* block, *PID Controller* Block, *Transfer Function* block and *Scope* block.

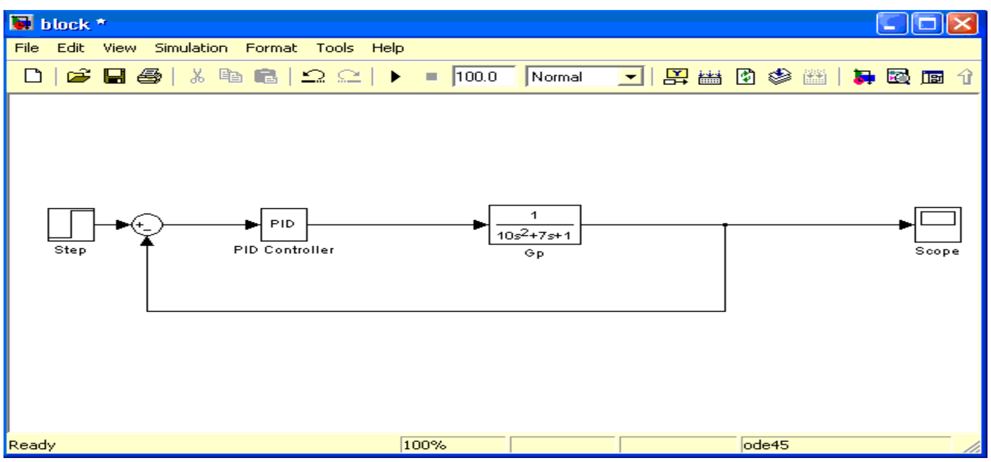

Figure 4.1: General Block Diagram

In Step block there are three parameters to set up; step time, initial value and final value. Step time is the output jumps from the initial value parameter to the final value parameter and the default step time are using as 1 second. Initial value is the block output until the simulation time reaches the step time parameter and setting it as 0. The simulation time reaches and exceeds the step time parameter is a final value block output and was setting as 1s [10]. The Sum block first converts the input data type to the output data type using the specified rounding and overflow modes, and then performs the specified operations.

PID parameters were calculated using MS Excel and Simulink to calculate the error between output and set point. The PID values were shown in Table 4.1 to Table 4.4. Numerator and denominator are the parameters for Transfer Function block. The row vector of numerator coefficients was used default value as [1]. [10 7 1] was entered into the row vector of denominator coefficients. From the value of numerator and denominator, transfer function for this model are develop as

$$Gp = \frac{1}{10s^2 + 7s + 1}$$

The Scope block displays its input with respect to simulation time. The scope provides toolbar buttons that enable to zoom in on displayed data, display all the data input to the scope, preserve axis settings from one simulation to the next, limit data displayed, and save data to the workspace [10]. The toolbar buttons are labeled in this figure, which shows the scope window as it appears when you open a Scope block. After start a simulation, Simulink does not open Scope windows, although it does write data to connected Scopes. As a result, the scope open after a simulation and the scope's input signal or signals will be displayed. The process response was show in scope window as Figure 4.2 to calculate the error between output and set point.

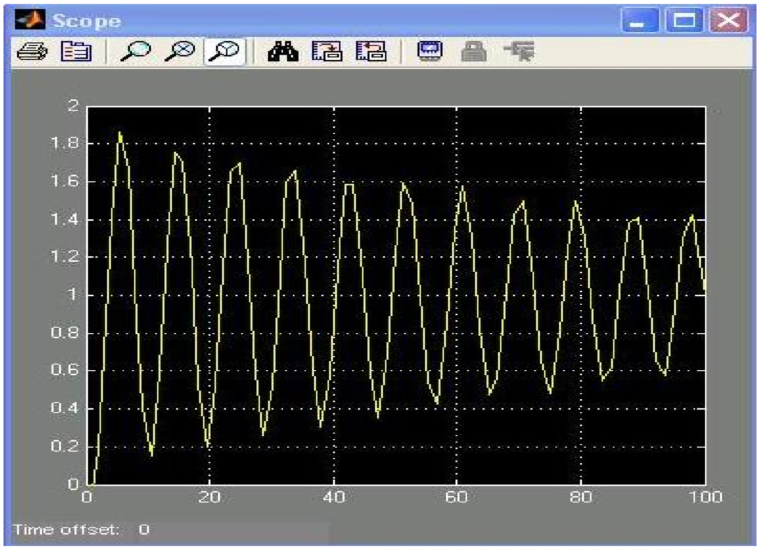

Figure 4.2: Process Response In Scope Block

4.2 Z-N Controller Tuning Analysis

Ten samples at different Z-N method parameter were generated as shown in Table 4.1 The parameters are calculated by using equation in Table 2.1 for controller settings using Ziegler-Nichols method. Fourteen samples using Ziegler-Nichols method method are generated to get the optimum parameters. Using following equations used

$$K_u = \frac{1}{M} \tag{4.1}$$

$$P_u = \frac{2\pi}{\omega_{CO}} \tag{4.2}$$

ω_{CO} and Pu we kept constant at 0.5 and 12.566 respectively. While other parameters are varies.After the PID parameters are generated, the parameters will enter in PID Controller block in Simulink.

Table 4.1: First Analysis For Ziegler-Nichols Method

Sample	M	ω_{co}	Kcu	Pu	Kc	τ_I	τ_D	α	γ	Decay Ratio
1	0.020	0.500	50.000	12.566	30.000	6.283	1.571	0.550	0.167	0.304
2	0.025	0.500	40.000	12.566	24.000	6.283	1.571	0.560	0.157	0.280
3	0.030	0.500	33.333	12.566	20.000	6.283	1.571	0.575	0.155	0.270
4	0.035	0.500	28.571	12.566	17.143	6.283	1.571	0.582	0.148	0.254
5	0.040	0.500	25.000	12.566	15.000	6.283	1.571	0.590	0.174	0.295
6	0.045	0.500	22.222	12.566	13.333	6.283	1.571	0.596	0.211	0.354
7	0.050	0.500	20.000	12.566	12.000	6.283	1.571	0.600	0.252	0.420
8	0.055	0.500	18.182	12.566	10.909	6.283	1.571	0.650	0.295	0.454
9	0.060	0.500	16.667	12.566	10.000	6.283	1.571	0.693	0.340	0.491
10	0.065	0.500	15.385	12.566	9.231	6.283	1.571	0.735	0.364	0.495

The values of α and γ are collected for each sample to calculated value of decay ratio in MS Excel as shown in Table 4.1. From Table 4.1, the parameters calculated from sample 1 achieved the set point after 1s. It show the decay ratio for sample 4 and 5 was closely with 0.25. This samples were be analyzed for second time. As *Kc* was decreased, the responses rise to overlay aggressive control action. Figure 4.3 shows the process response in sample 1 and sample 8

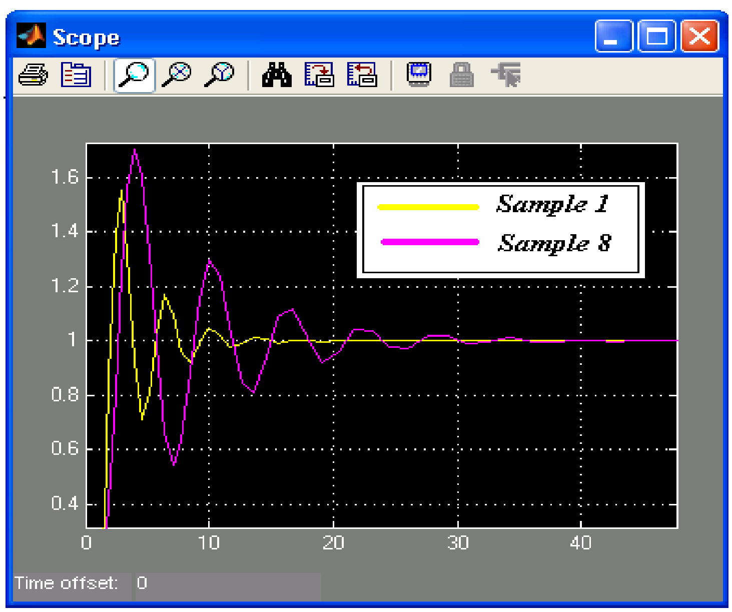

Figure 4.3: Sample 1 and sample 8 responses

The second analysis, Kc was decrease to 17.143 and 15. M, amplitude ratio was increase to 0.01 for each sample and the optimum parameter was choose when the response archive decay ratio equal to 0.25. Sample 11 give the best response with one-quarter decay ratio in the output of process response.

Table 4.2: Second Analysis For Ziegler-Nichols Method

Sample	M	ωco	Kcu	Pu	Kc	τ_I	τ_D	α	γ	Decay Ratio
4	0.035	0.500	28.571	12.566	17.143	6.283	1.571	0.582	0.148	0.254
11	0.036	0.500	27.778	12.566	16.667	6.283	1.571	0.583	0.146	0.250
12	0.037	0.500	27.027	12.566	16.216	6.283	1.571	0.585	0.151	0.258
13	0.038	0.500	26.316	12.566	15.789	6.283	1.571	0.586	0.159	0.271
14	0.039	0.500	25.641	12.566	15.385	6.283	1.571	0.586	0.159	0.271
5	0.040	0.500	25.000	12.566	15.000	6.283	1.571	0.590	0.174	0.295

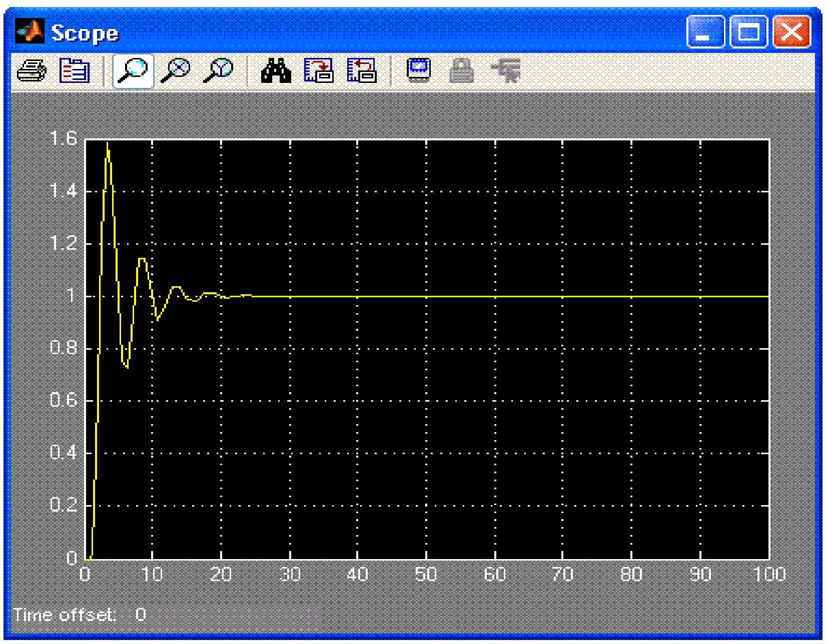

Figure 4.4: Response For Sample 11 Using Z-N Method

4.3 C-C Controller Tuning Analysis

From the Table 4.3, the parameters Kc, τ_I , τ_D are increased from sample 1 to sample 35. It is different with sample from Z-N method, only parameters Kc changes in each sample. The other parameters, τ_I and τ_D are kept constant. It makes C-C method need more sample than Z-N method. In early sample the responses are more complex with highly oscillatory responses. After sample 10 it more stable and closely with one-quarter decay ratio response as in sample 32 and sample 33.

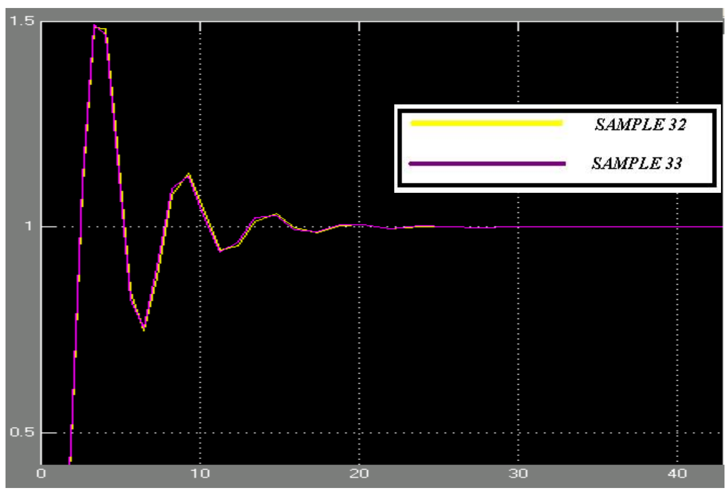

Figure 4.5: Comparison Between Sample 32 And 33

Table 4.3: First Analysis For Cohen-Coon Method

Sample	K	τ	Td	Kc	τ_I	τ_D
1	2	1	1.5	0.569	2.460	0.429
2	2	2	1.5	1.014	2.882	0.480
3	2	3	1.5	1.458	3.088	0.500
4	2	4	1.5	1.903	3.211	0.511
5	2	5	1.5	2.347	3.292	0.517
6	2	6	1.5	2.792	3.350	0.522
7	2	7	1.5	3.236	3.393	0.525
8	2	8	1.5	3.681	3.427	0.527
9	2	9	1.5	4.125	3.453	0.529
10	2	10	1.5	4.569	3.475	0.531
11	2	11	1.5	5.014	3.494	0.532
12	2	12	1.5	5.458	3.509	0.533
13	2	13	1.5	5.903	3.522	0.534
14	2	14	1.5	6.347	3.534	0.535
15	2	15	1.5	6.792	3.543	0.536
16	2	16	1.5	7.236	3.552	0.536
17	2	17	1.5	7.681	3.560	0.537
18	2	18	1.5	8.125	3.567	0.537
19	2	19	1.5	8.569	3.573	0.538
20	2	20	1.5	9.014	3.579	0.538
21	2	21	1.5	9.458	3.584	0.538
22	2	22	1.5	9.903	3.589	0.539
23	2	23	1.5	10.347	3.593	0.539
24	2	24	1.5	10.792	3.597	0.539
25	2	25	1.5	11.236	3.601	0.540
26	2	26	1.5	11.681	3.604	0.540
27	2	27	1.5	12.125	3.607	0.540
28	2	28	1.5	12.569	3.610	0.540
29	2	29	1.5	13.014	3.613	0.540
30	2	30	1.5	13.458	3.616	0.541
31	2	31	1.5	13.903	3.618	0.541
32	2	32	1.5	14.347	3.620	0.541
33	2	33	1.5	14.792	3.622	0.541
34	2	34	1.5	15.236	3.624	0.541
35	2	35	1.5	15.681	3.626	0.541

In second analysis, four new samples are added between sample 32 and sample 33. In this samples, value of τ are increased to 0.2 for each sample. From that we use new parameters to simulate new parameters. Sample 39 be a best response with one-quarter decay ratio before archive set point.

Table 4.4: Second Analysis For Cohen-Coon Method

Sample	K	τ	Td	Kc	τ_I	τ_D	α	γ	Decay Ratio
32	2	32	1.5	14.347	3.620	0.541	0.4885	0.1254	0.2567
36	2	32.2	1.5	14.436	3.621	0.541	0.4900	0.1245	0.2541
37	2	32.4	1.5	14.525	3.621	0.541	0.4911	0.1241	0.2527
38	2	32.6	1.5	14.614	3.622	0.541	0.4910	0.1235	0.2515
39	2	32.8	1.5	14.703	3.622	0.541	0.4914	0.1229	0.2501
33	2	33	1.5	14.792	3.622	0.541	0.4920	0.1224	0.2488

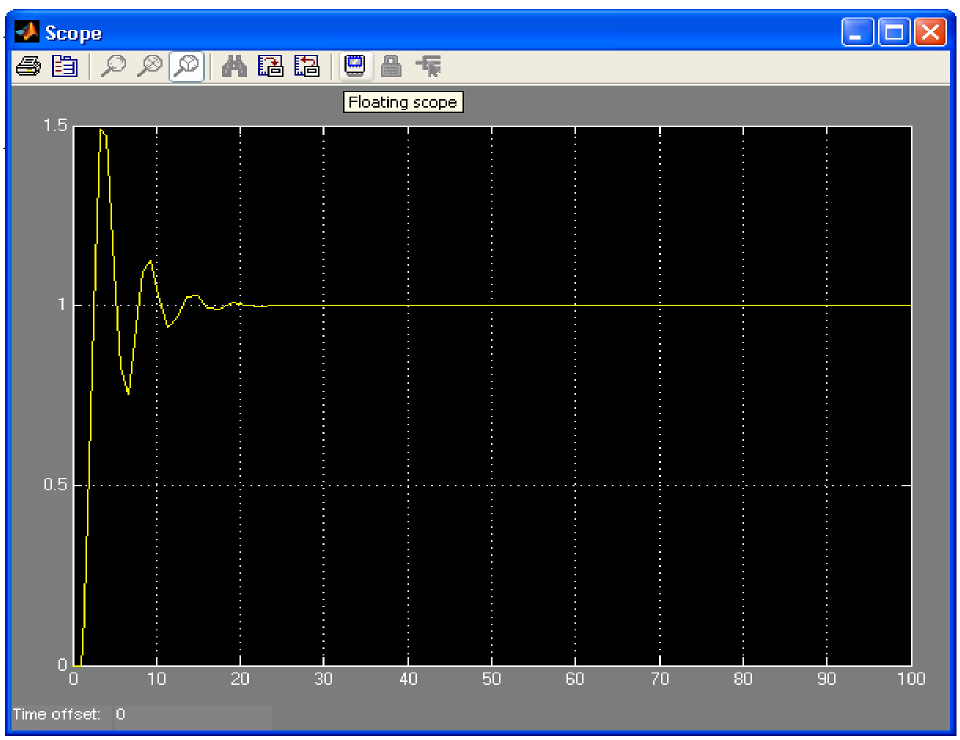

Figure 4.6: Response Sample 39 In C-C Method

4.4 Comparison

New block diagram are develop in Simulink to compare the performance criterion between Cohen-Coon & Ziegler-Nichols method for the selection and the tuning of the controller as shown in Figure 4.7. The comparison of both methods can get from minimum settling time and minimum largest error as shown in Figure 4.8. From Table 4.2 and Table 4.3, The C-C method has minimum largest error with 0.4914 compared to Z-N method, 0.583.

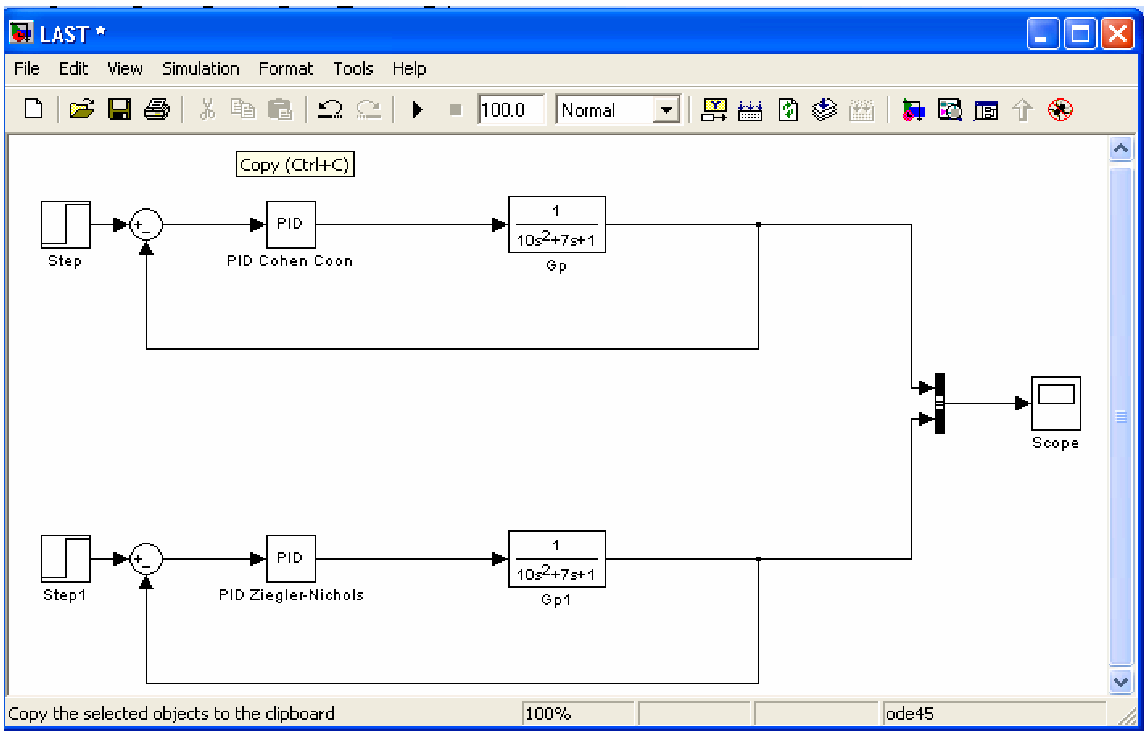

Figure 4.7: New Block Diagram For Comparison

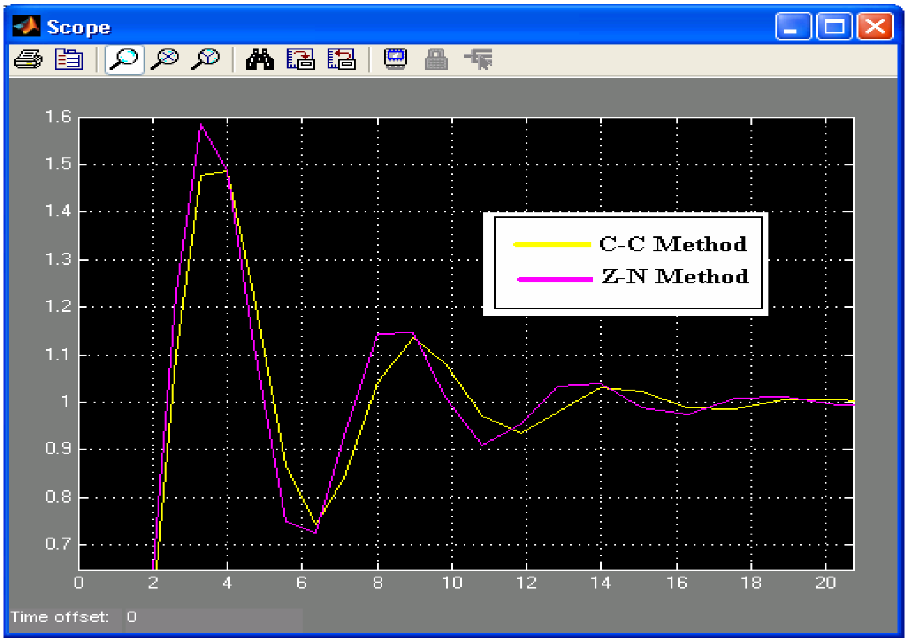

Figure 4.8: New Response For Both Methods

For the minimum settling time, the response from both methods will compare to get the minimum settling time as shown in Figure 4.9. The settling time for Z-N are 11.8s and C-C with 12.2s. From Figure 4.8 indicate the responses of the closed-loop system to step changes in the set point and load, respectively using PID controller with Z-N and C-C settings. The responses notice that C-C tuning is slightly better than those with the Z-N settings.

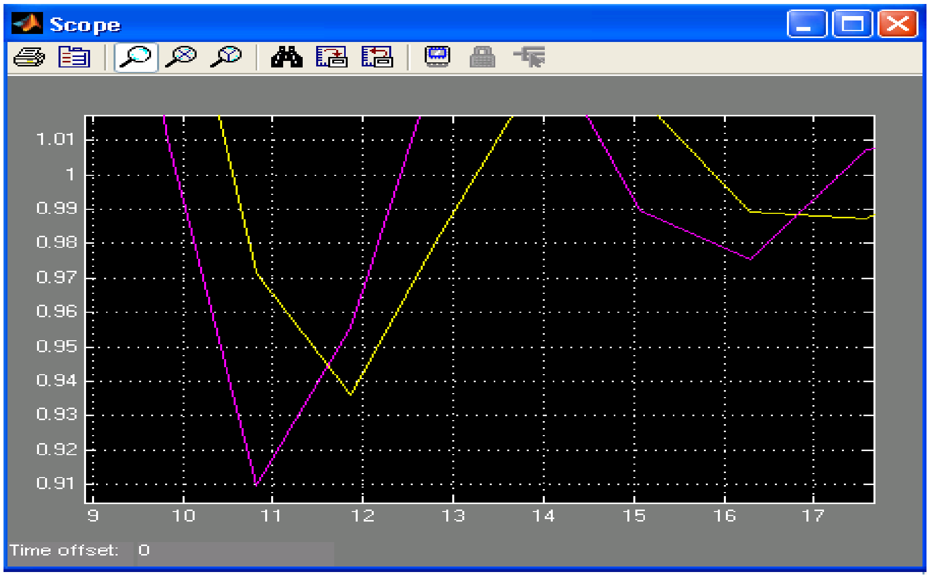

Figure 4.9: Settling Time

CHAPTER 5

CONCLUSION

5.1 Conclusion

From this research, the controller tuning problem give an effect on closed-loop stability and overall process control. To get the optimum parameters, two methods are used to get the stability in overall process control in this research. Ziegler-Nichols and Cohen-Coon methods are widely used in industrial practice as PID settings. This method gives good tuning settings for this research in overall.

Kc= 16.667, τ_I =6.283 and τ_D =1.571 are optimum parameters setting for Ziegler-Nichols method. These researches get the minimum largest error for Z-N method as 0.582 and minimum settling time equal with 11.8s in sample 11. For Cohen-Coon method, Kc= 14.703, τ_I =3.622 and τ_D =0.541 are optimum parameters setting. The minimum largest error and minimum settling time from response in sample 39 are 0.4914 and 12.2s.

This research notices that the responses with C-C tuning are slightly better than those with Z-N settings. It must be emphasized, though, that no general conclusions can be drawn as to the relative superiority of one method over the other [12]. The only conclusion from this research draw is that both methods provide very good first guesses for the value of the controllers' adjustable parameters.

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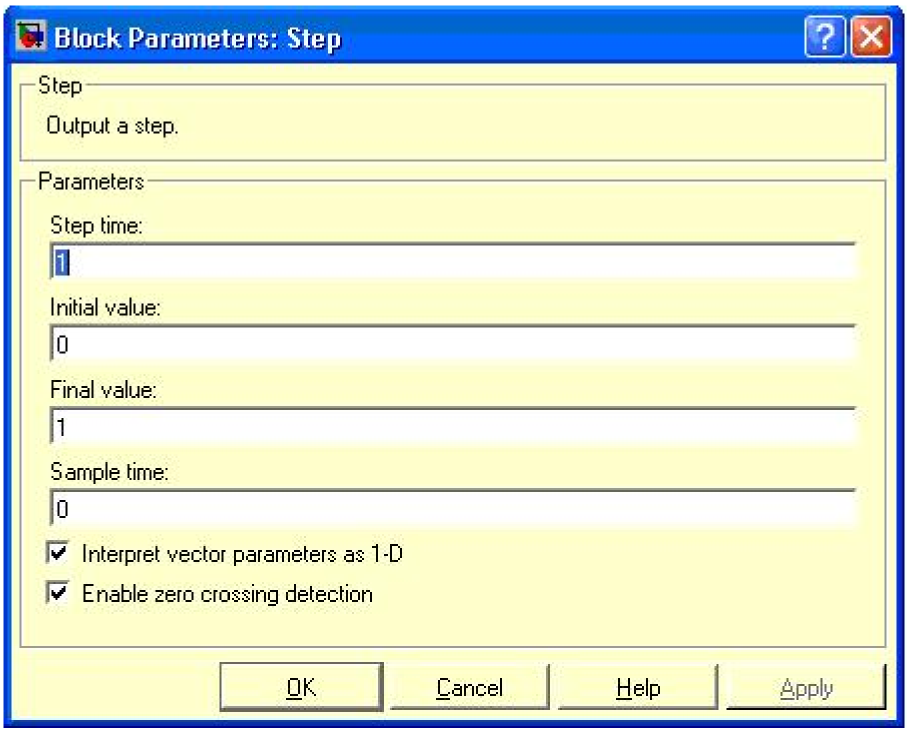
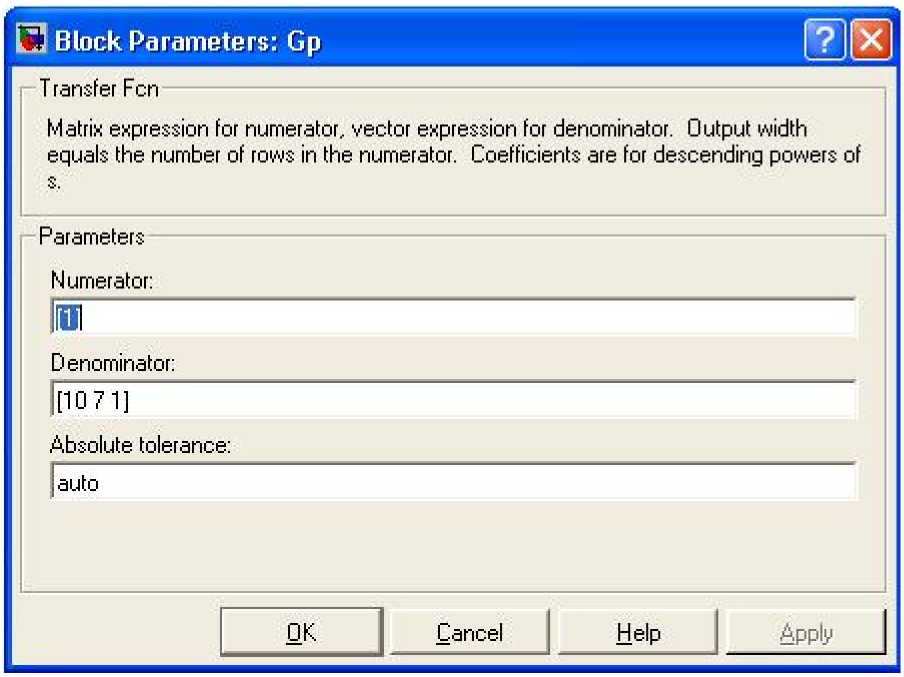
APPENDIX A

PARAMETERS FOR STEP BLOCK


Block Parameters: Step
Step
Output a step.
Parameters
Step time:
1
Initial value:
0
Final value:
1
Sample time:
0
Interpret vector parameters as 1-D
Enable zero crossing detection
OK
Cancel
Help
Apply

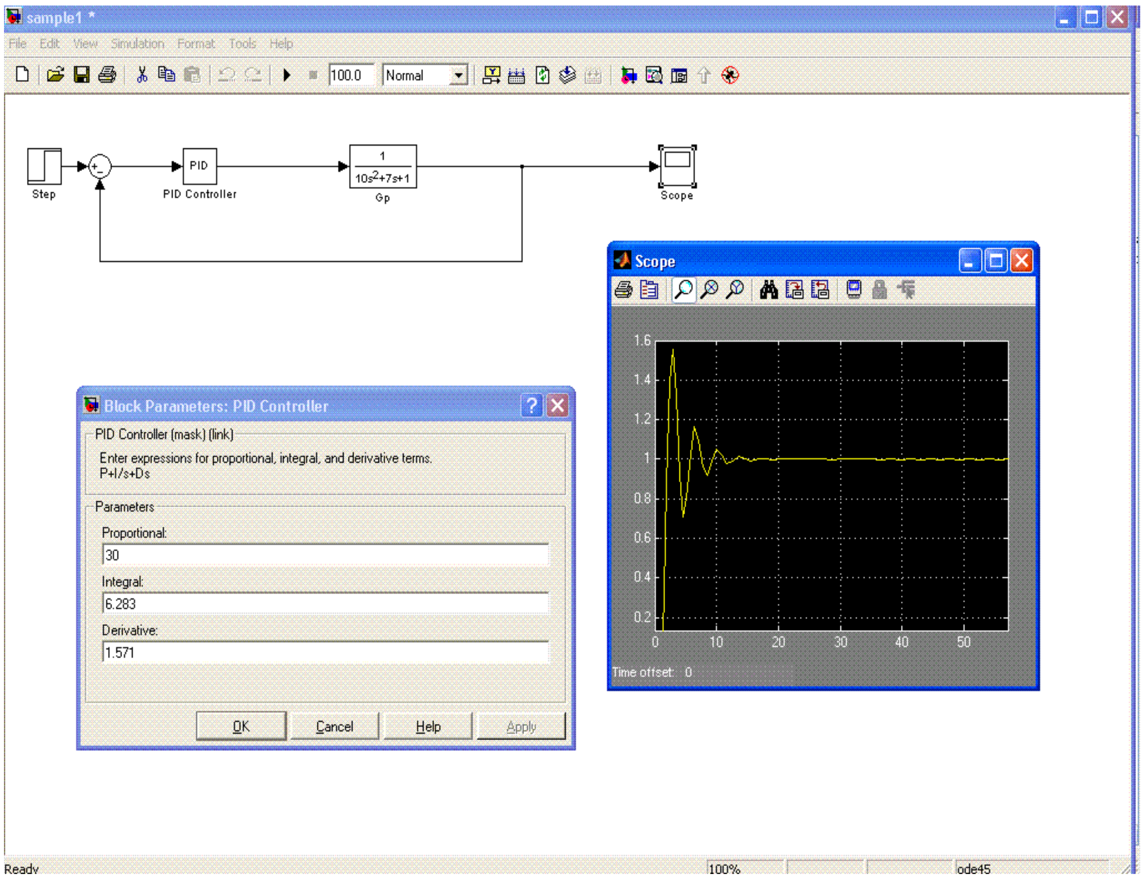
APPENDIX B

PARAMETERS FOR TRANSFER FUNCTION BLOCK


Block Parameters: Gp
Transfer Fcn
Matrix expression for numerator, vector expression for denominator. Output width equals the number of rows in the numerator. Coefficients are for descending powers of s.
Parameters
Numerator:
[1]
Denominator:
[10 7 1]
Absolute tolerance:
auto
OK
Cancel
Help
Apply

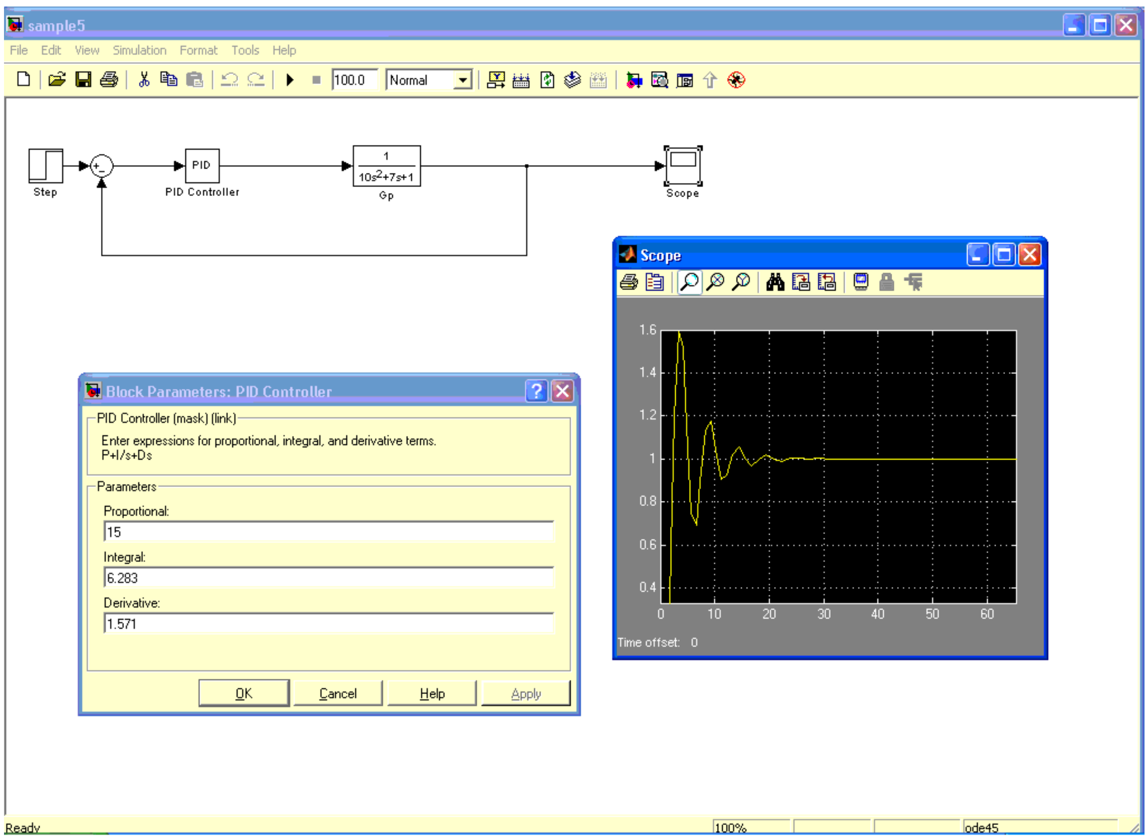
APPENDIX C

SAMPLE 1 OF Z-N METHOD


sample1 *
File Edit View Simulation Format Tools Help
100.0
Normal
Step
PID
PID Controller
1
10s2+7s+1
Gp
Scope
Scope
Time offset: 0
Block Parameters: PID Controller
PID Controller (mask) (link)
Enter expressions for proportional, integral, and derivative terms.
P+I/s+Ds
Parameters
Proportional:
30
Integral:
6.283
Derivative:
1.571
OK
Cancel
Help
Apply
Ready
100%
ode45

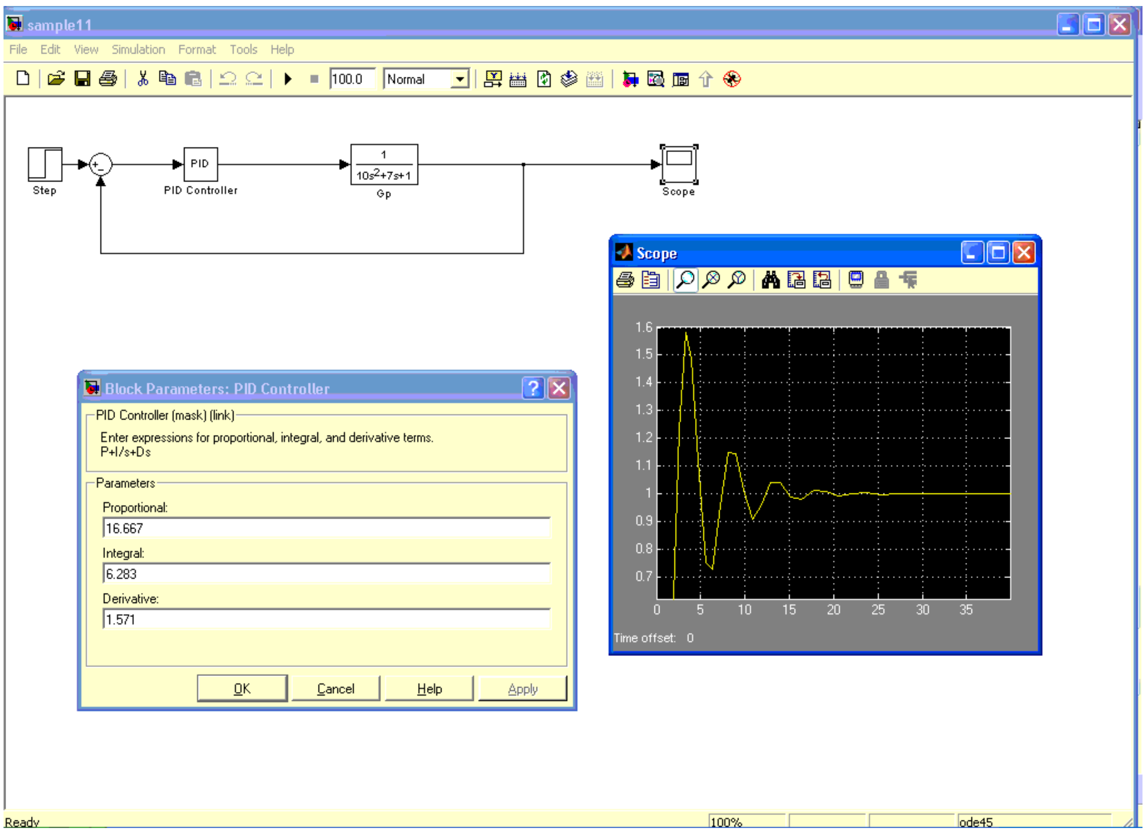
APPENDIX D

SAMPLE 5 OF Z-N METHOD

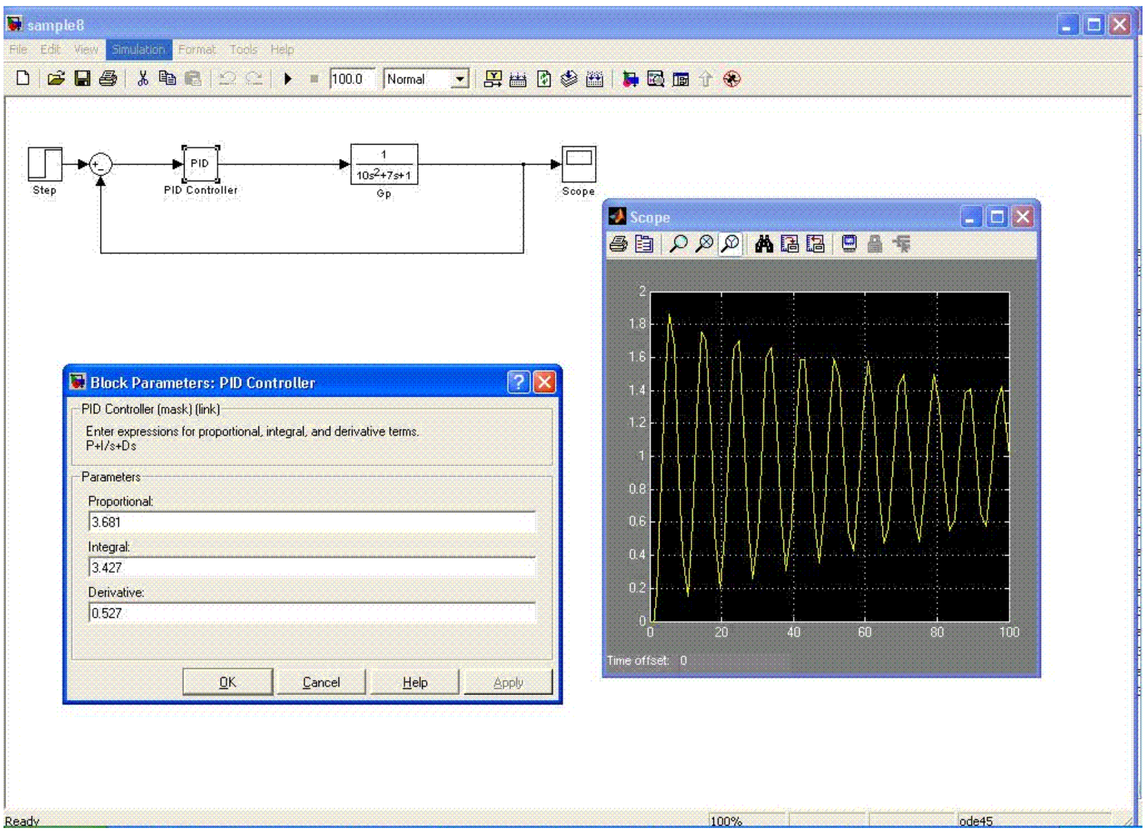

sample5
File Edit View Simulation Format Tools Help
100.0
Normal
Step
PID
PID Controller
1
10s^2+7s+1
Gp
Scope
Scope
Time offset: 0
Block Parameters: PID Controller
PID Controller (mask) (link)
Enter expressions for proportional, integral, and derivative terms.
P+I/s+Ds
Parameters
Proportional:
15
Integral:
6.283
Derivative:
1.571
OK
Cancel
Help
Apply
Ready
100%
ode45

APPENDIX E

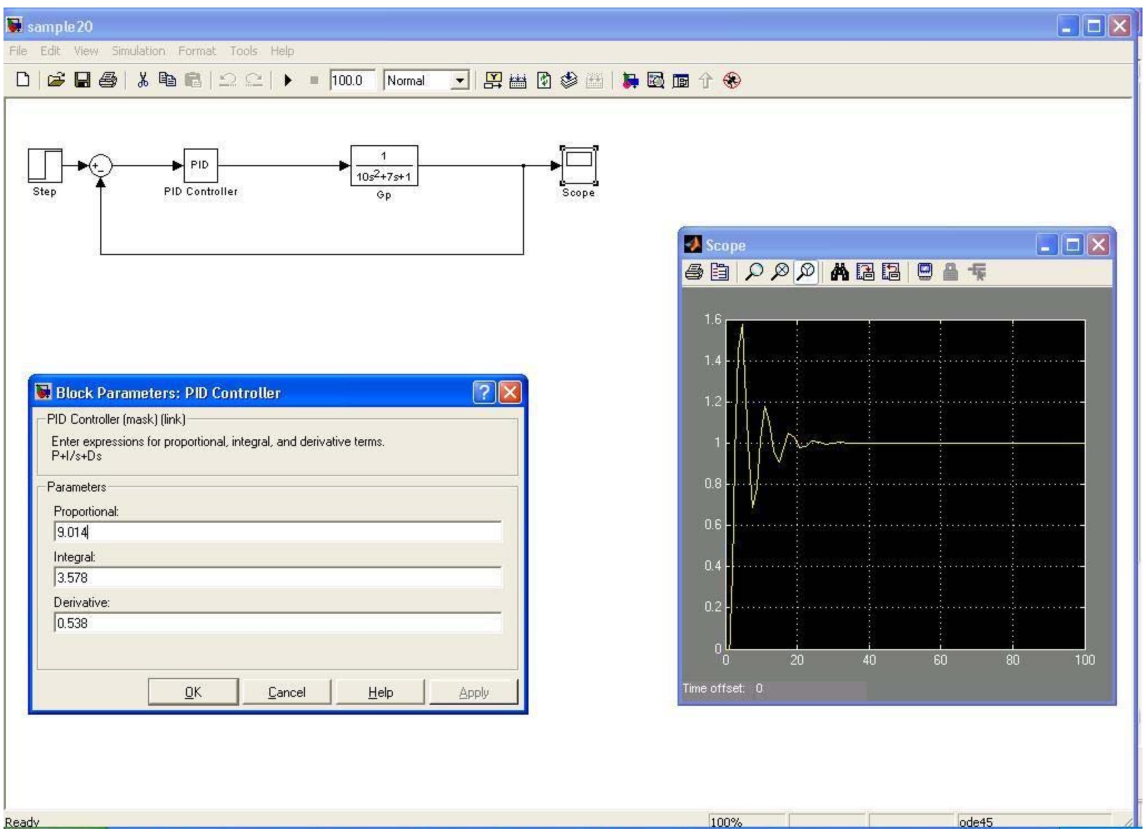
SAMPLE 11 OF Z-N METHOD


sample11
File Edit View Simulation Format Tools Help
100.0
Normal
Step
PID
PID Controller
1
10s2+7s+1
Gp
Scope
Scope
Block Parameters: PID Controller
PID Controller (mask) (link)
Enter expressions for proportional, integral, and derivative terms.
P+I/s+Ds
Parameters
Proportional:
16.667
Integral:
6.283
Derivative:
1.571
OK
Cancel
Help
Apply
Time offset: 0
Ready
100%
ode45

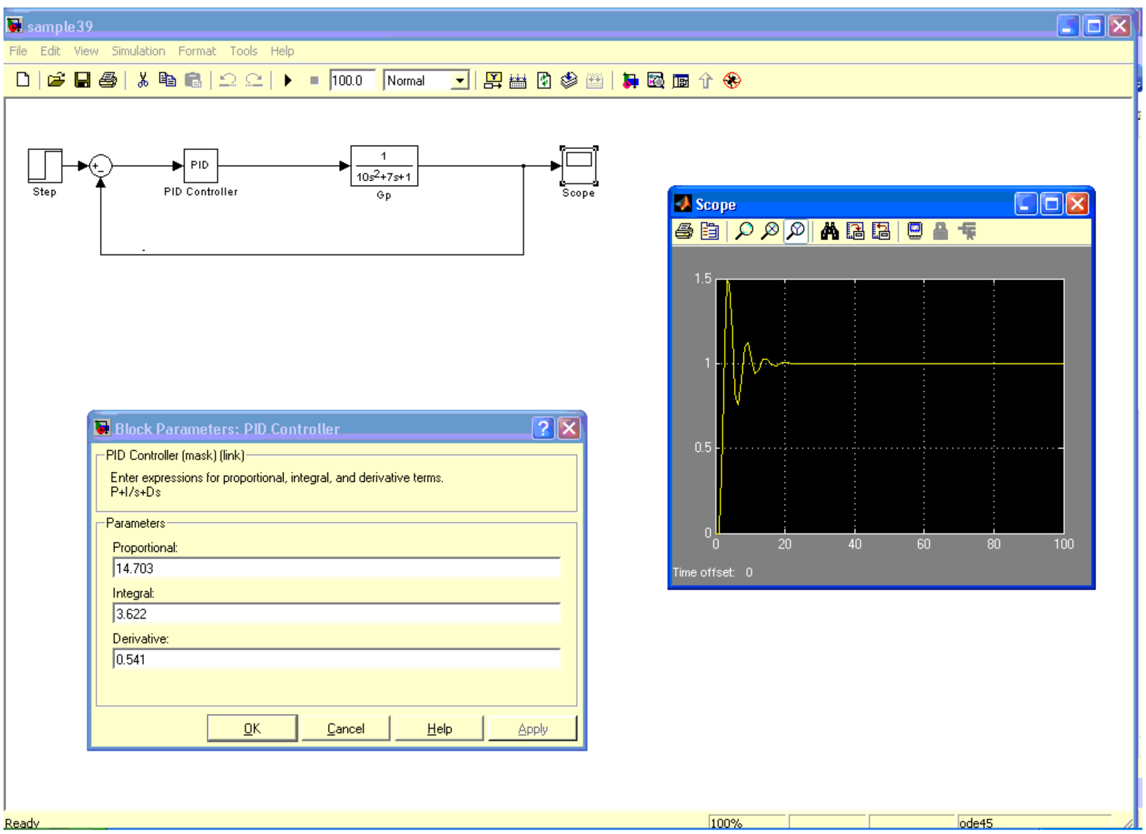
APPENDIX F
SAMPLE 8 OF C-C METHOD


sample8
File Edit View Simulation Format Tools Help
100.0
Normal
Step
PID
PID Controller
1
10s^2+7s+1
Gp
Scope
Scope
Block Parameters: PID Controller
PID Controller (mask) (link)
Enter expressions for proportional, integral, and derivative terms.
P+I/s+Ds
Parameters
Proportional:
3.681
Integral:
3.427
Derivative:
0.527
OK
Cancel
Help
Apply
Time offset: 0
Ready
100%
ode45

APPENDIX G
SAMPLE 20 OF C-C METHOD


sample20
File Edit View Simulation Format Tools Help
100.0
Normal
Step
PID
PID Controller
1
10s2+7s+1
Gp
Scope
Block Parameters: PID Controller
PID Controller (mask) (link)
Enter expressions for proportional, integral, and derivative terms.
P+I/s+Ds
Parameters
Proportional:
9.014
Integral:
3.578
Derivative:
0.538
OK
Cancel
Help
Apply
Scope
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Time offset: 0
Ready
100%
ode45

APPENDIX H
SAMPLE 39 OF Z-N METHOD


sample39
File Edit View Simulation Format Tools Help
100.0
Normal
Step
PID
PID Controller
1
10s2+7s+1
Gp
Scope
Scope
1.5
1
0.5
0
0
20
40
60
80
100
Time offset: 0
Block Parameters: PID Controller
PID Controller (mask) (link)
Enter expressions for proportional, integral, and derivative terms.
P+I/s+Ds
Parameters
Proportional:
14.703
Integral:
3.622
Derivative:
0.541
OK
Cancel
Help
Apply
Ready
100%
ode45