Advanced pH Control by Using Fuzzy Logic

by

Muhammad Isa bin Zakaria

16795

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

JAN 2015

Universiti Teknologi PETRONAS
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CERFITICATION OF APPROVAL

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Approved by,

____

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JAN 2015

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.

MUHAMMAD ISA BIN ZAKARIA

ABSTRACT

Upon completion of this manuscript, the goal is to develop an advanced pH control by using fuzzy logic system. This is possible by achieving the objectives set for the specific study. These includes using one model system developed for application of process control and to use steady state model to generate data for synthesizing the basic process control strategy. The next objective will be to develop feedback, feedforward, cascade, smith predictor and IMC control strategy in simulated environments. In this analysis, it is required to study the basic control principles, tuning methods, and the pH reaction characteristics. The main engineering software that is used in achieving the aim of the project is MATLAB in Simulink simulation environment. All the objectives of the study are met, complying with the aim of the control intentions.

ACKNOWLEDGEMENT

Gratitude expression is to all involved in developing this manuscript. First and foremost, this page is to acknowledge my supervisor Dr. Nasser bin Mohamed Ramli in consulting and assisting me in this project. Under his supervision, this study was completed and carefully written into this manuscript.

This goes to all my friends, who gave enduring support and significant assistances over all the doubt and troubles. As for my beloved parents, Zakaria bin Mohd Noor and Norma binti Shukor, it is crystal clear that the love they yield is enough for me to sense their presences.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1-INTRODUCTION

1.0 Background

Nowadays, the advanced control techniques of industrial application for process industries have become more demanding. This is due to the increasing complexity of the process themselves and to produce better requirements in terms of product quality and environmental factors. Thus, a stable, efficient and flexible control system is required in continuing the operation of process plant. There is also a need, for a variety of purposes including control system design, for improved process models to represent the types of plant commonly used in industry.

Advanced technology has had a major impact on industrial control engineering. There is a new method of advanced control technology that is increasing towards the use of a control approach known as “intelligent” control strategy. Intelligent control act as a control approach or solution that tries to imitate important characteristics of the human way of thinking, basically more on decision making processes and uncertainty. It is also a term that is commonly used to describe most forms of control systems that are based on artificial neural networks or fuzzy logic.

1.1 Problem Statement

Usually a control theory can be successfully applied only when the system under control can be sufficiently analyzed and a useful mathematical model has been found. When the process characteristics are known in advance, and are either constant or change predictably, a non-adaptive controller can be used to control it.

Difficulties arise in the control of the pH process due to the severe process non-linearity and frequent load changes. For example, changes in the influent composition or flow rate. The non-linearity can be understood from the s-shaped titration curve. Frequent and rapid load changes are common for most waste water treatment facilities since the influents come from the waste of a number of sources. Therefore, it is difficult to analyze and derive the system model of a pH control process.

The theory of fuzzy sets and algorithms developed by Zadeh, (1965) can be used to evaluate these imprecise linguistic statements directly. Fuzzy logic provides an effective means of capturing the approximate nature of the physical world. Therefore, it can be used to provide an algorithm which can convert a linguistic control strategy based on expert knowledge, into an automatic control strategy.

1.2 Objective

Upon completion of the project, some things are taken into consideration. The objectives are to be referred as a guideline to achieve the specific goal in the project. The general objectives are:

I. To understand the skills and knowledge about the project.

II. To apply the knowledge gain during internship with the project.

III. To adapt with individual independent throughout the project with minimal supervision.

As for the projects, the specific objectives are:

I. To test different control strategies on the pH changes and give the best result.

II. To develop fuzzy logic with the best control strategies in order to gain new best result.

1.3 Scope of Studies

The study will be of two main parts; the first one is to develop five different control strategies with the pH changes and get the best result from the above alternatives method. The control strategies involved are feedforward control, feedback control, cascade control, smith predictor control and integral model control (IMC). Second, choose the best control strategies and try to develop with the fuzzy logic and gain the new best result on the pH control. The scope of study will be mostly of studying and analyzing the types of advanced control strategies available. This will include advantages and disadvantages for the specific control strategies on the pH control.

CHAPTER 2-LITERATURE REVIEW

PH is a measurement of the concentration of hydrogen ions in a solution. Low pH values are associated with solutions with high concentrations of hydrogen ions, while high pH values occur for solutions with low concentrations of hydrogen ions. Pure water has a pH of 7.0, while bases are those solutions that have a pH greater than 7, and acids are those solutions that have a pH less than 7.

2.1 Significance of pH Control

Wide range of industries such as wastewater treatment, biotechnology, pharmaceuticals and chemical processing involve in controlling the pH arises. The general aim is to maintain the pH value within a liquid at a specific level. It is important to satisfy certain environmental requirements or quality standards.

2.2 Overview of pH Control

In general pH control methods can be divided into three main categories. The first category is an open loop type of control scheme in which the control valve opening is kept at certain positions for specific time durations. A specific pH value in the reactor tank is not really the main concern. Normally this type of control approach is used for start-up and shutdown of a process or at an initial stage within a neutralization process in which at the later stages of the process involve a feedback controller to control the pH value to a specific value or within a range of values.

The second category is the most popular and commonly used approach and is based on feedback control principles. It involves a direct relationship between the control valve opening and the pH value in the process. The general idea is that when the pH value is higher than the desired value control valve opening is decreased. Conversely, if it is lower than the set point then the control valve opening is increased. The most widely used type of controller for this feedback control approach is the Proportional, Integral and Derivative (PID) type of controller together with the closely associated variations on this control algorithm involving Proportional control (P) or Proportional plus Integral control (PI).

The third control method is feedforward control. The controller will compensate for any measured disturbance before it affects the process. In order to implement this control approach it will normally be necessary to make more measurements on the process. In the case of pH process the disturbances could arise from unexpected changes in the concentrations of both solutions as well as changes in the flow rates for the two streams. Thus, with a properly designed feedforward scheme, if a disturbance occurs the controller will react before the pH value in the reactor tank is significantly affected.

2.2.1 Terminology

Neutralization, a chemical reaction, according to Arrhenius theory of acids and bases, in which a water solution of acid is mixed with a water solution of base to form a salt and water; this reaction is complete if only the resulting solution has neither acidic nor basic properties. Such a solution is called a neutral solution. In a neutralization reaction in which either a weak acid or a weak base is used, only partial neutralization occurs. In a neutralization reaction in which both a weak acid and a weak base are used, complete neutralization can occur if the acid and the base are equally weak. The heat produced in the reaction between an acid and a base is called the heat of neutralization.

When a acid or base dissolves in water, a certain percentage of the acid or base particles will break up, or dissociate into oppositely charged ions. ***The Arrhenius Theory*** defines an acid as a compound that can dissociates in water to yield hydrogen ions, H^+, and a base as a compound that can dissociate in water to yield hydroxide ions, OH^-, and also chloride ions, Cl^-. The base sodium hydroxide, NaOH, dissociates in water to yield the required hydroxide ions, OH^-, and also sodium ions, Na^+.

Dissociation, in chemistry, is a separation of a substance into atoms or ions. Dissociation is generally reversible; when the atoms or ions of the dissociated substance are returned to the original conditions, they recombine in the original form of the substance. The dissociation is a measure of the extent of dissociation. It is represented by the symbol K. In the simplest case, a substance AB dissociates into two parts A and B and the concentrations of AB, A, and B are represented by [AB], [A], and [B], then it is represented as

$$K = \frac{[A][B]}{[AB]}$$

The dissociation constant is measured at equilibrium, and its value is usually affected by changes in temperature.

2.2.2 The Conventional Approach

The most widely used simple feedback control strategy applied to pH control involves the PID algorithm. Equation 2.1 describes the most basic form of continuous PID algorithm in the time domain. As shown in the equation, the PID algorithm is actually a simple single equation with three control terms; proportional gain, (K_p), integral gain, (K_t), and derivative gain, (K_D). The variable mv(t) represents the controller output while the variable e(t) is the error, which is the difference between the system output which is the measured pH and the set point.

$$mv(t) = K_p e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \qquad \text{Equation 2.1}$$

2.3 Control Strategies

2.3.1 Advanced Regulatory Control

Feedback Control

A classic feedback control is illustrated below in Figure 1. The actual response of a process is directed back to the process. The measurement is taken to comparison with the desired response and corrective action is performed by the controller.

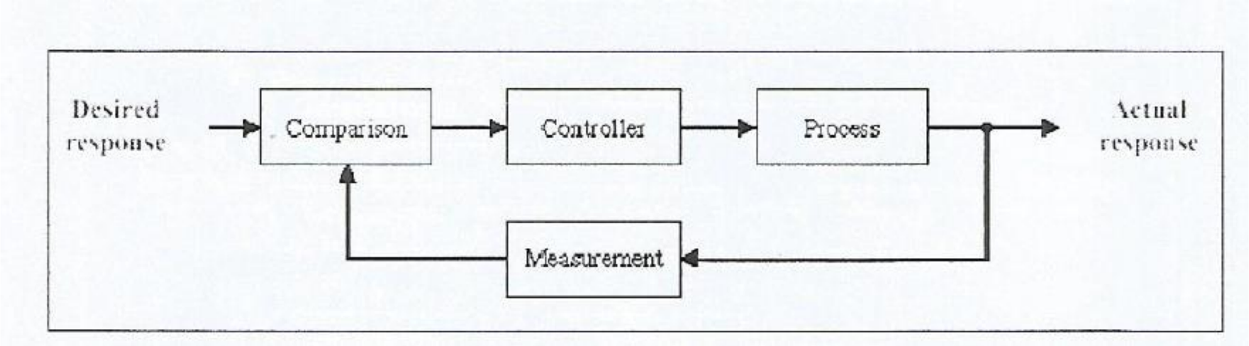


Figure 1- A basic diagram of a feedback control system

Feedforward Control

This is a control strategy where corrective action is performed before result is obtained. This type of control design is most likely to be implemented when disturbances are introduced into the system. The overview of a feedforward control is a Figure 2.

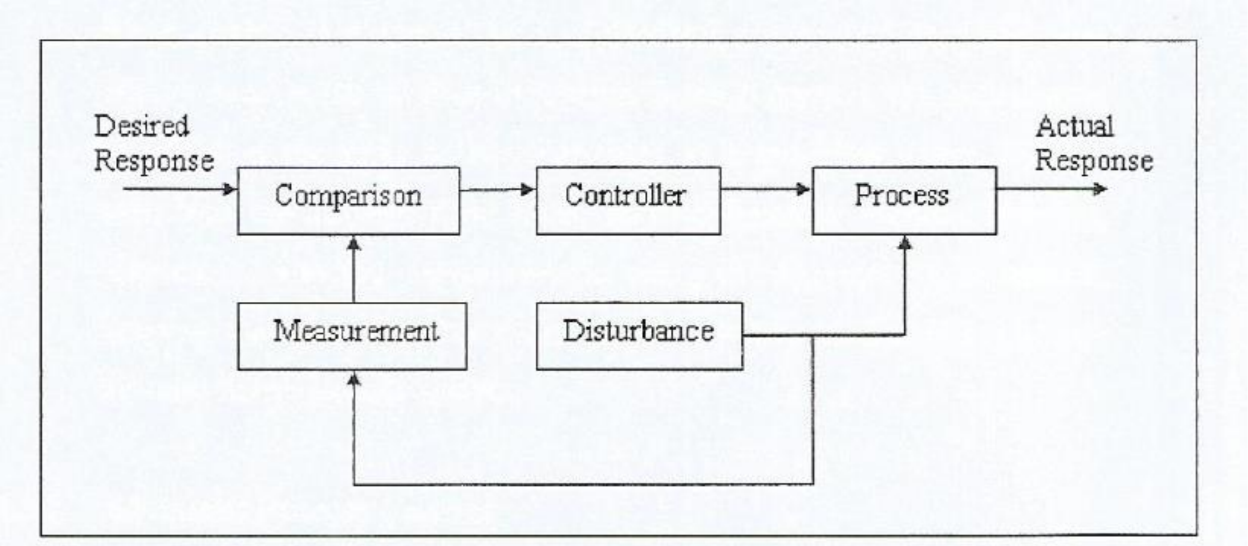


Figure 2- A basic diagram of a feedforward control system

Cascade Control

This is a control strategy which uses a secondary measurement point and a secondary feedback controller. This utilizes multiple feedback loops and is particularly useful when the disturbances are associated with the manipulated variable or when the final control element exhibits nonlinear behavior.

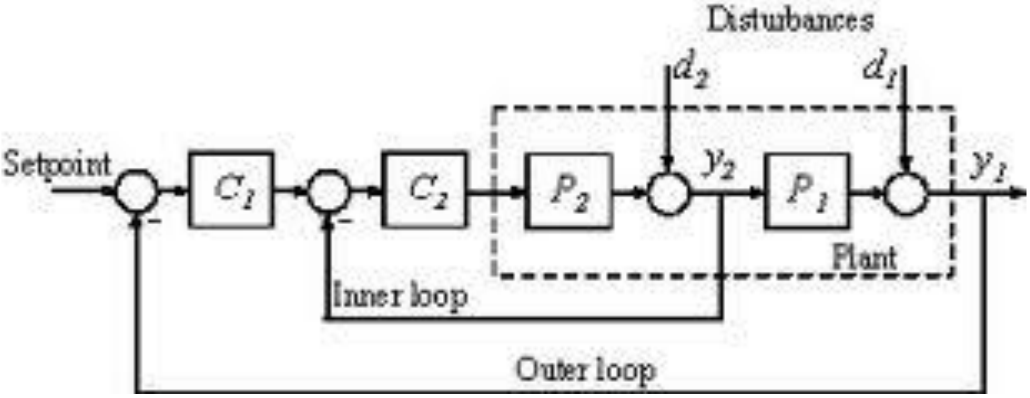


Figure 3- A basic diagram of cascade control

Smith Predictor Control

Smith's strategy consists of an ordinary feedback loop plus an inner loop that introduces two extra terms directly into the feedback path. The first term is an estimate of what the process variable would look like in the absence of any disturbances. It is generated by running the controller output through a process model that intentionally ignores the effects of load disturbances. If the model is otherwise accurate in representing the behavior of the process, its output will be a disturbance-free version of the actual process variable. The overview of smith predictor control is as Figure 4.

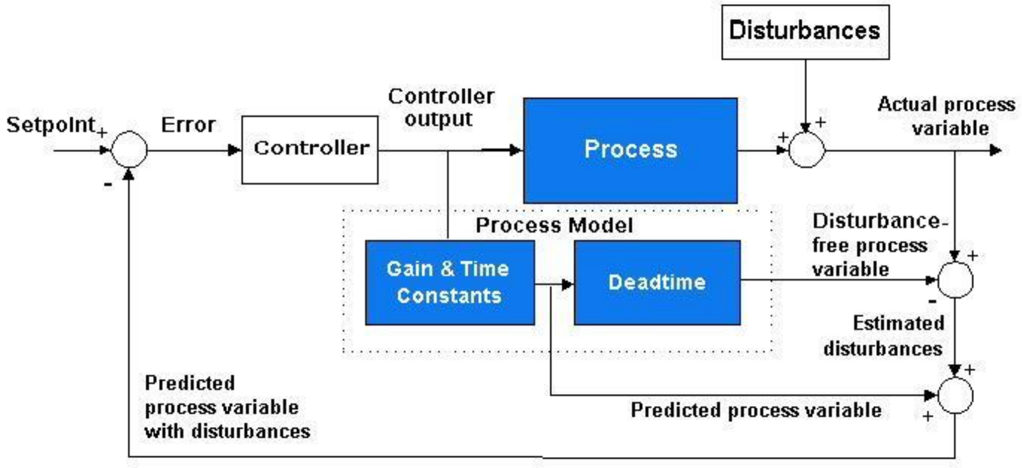


Figure 4- A basic diagram of smith predictor control

Integral Model Control (IMC)

IMC is an analog system; an integral control system integrates the error signal to generate the control signal. If the error signal is a voltage, and the control signal is also a voltage, then a proportional controller is just an analog integrator. In a digital control system, an integral control system computes the error from measured output and user input to a program, and integrates the error using some standard integration algorithm, then generates an output/control signal from that integration. The overview of IMC is as Figure 5.

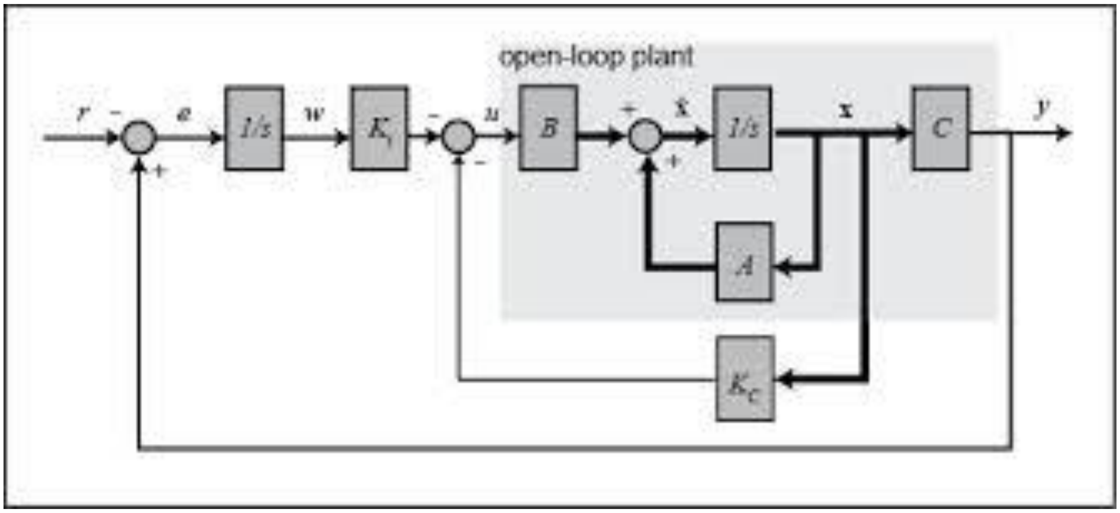


Figure 5- A basic diagram of Integral Model Control (IMC)

2.4 Concept of Fuzzy Logic

According to Zadeh (George & Yuan B 1995;Jamshidi, Ross, & Vadiee 1993;Ross, Booker, Parkinson 2002;Zadeh 1965d), by Ross (Ross 1993) has defined fuzzy logic is a set of collection of elements in a universe of information where the boundary of the set contained in the universe of information where the boundary of the set contained in the universe is ambiguous, vague and thus fuzzy in some aspects. In a classical set, the boundary is certain and rigid so that the boundary can be used to establish, in an unambiguous fashion, the set to which the elemet belongs.

Let X denote the ground set or universe of discourse and let an element of that universe be denoted as ‘x’. Set A is a group of real numbers between 0 and 1 which is a subset of the universe, X. Figure 2.6 shows the graphical representation of the membership function of the classical set for this case and Figure 2.7 shows a corresponding graphical membership function of the fuzzy set.

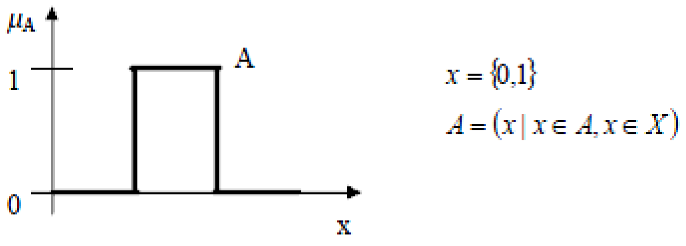


Figure 2.6- Membership function of a classical set

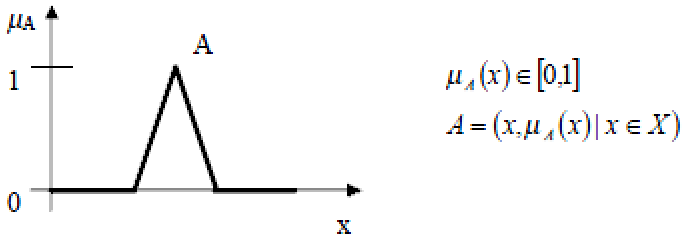


Figure 2.7- Membership function of fuzzy set

Figure 6- Membership function

As shown in the Figure 2.7, there are only two elements for set A which is 0 and 1. For the fuzzy set, besides the value of 0 and 1, set A has other values between these extremes, as shown in the figure. These values will depend on the membership function of set A. Figure 2.8 shows some other examples of membership functions that are available and commonly used in fuzzy logic systems.

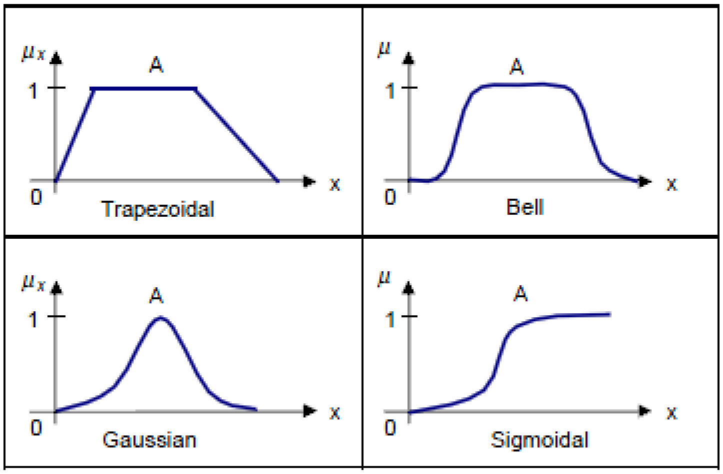


Figure 2.4: Typical membership function for fuzzy logic systems

Figure 7- Typical membership function for fuzzy logic systems

The simplest membership function which is applicable to most process system is the triangular membership function, as shown in Figure 2.8. At the moment there are no proper rules or laws that can determine which membership function is most suitable for a given system or application.

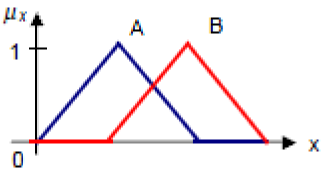
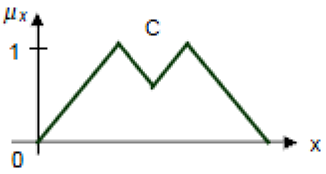
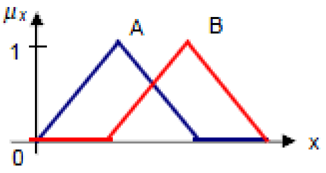
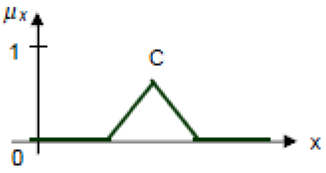
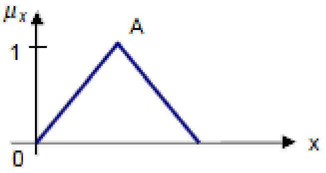
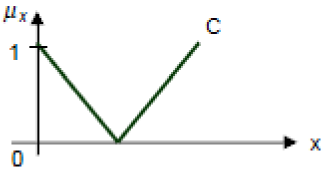
Table 1 shows the basic notations involved in fuzzy sets and provides a basis for a comparison between classical and fuzzy set operation. Table 2 shows the graphical representation of the membership function of each fuzzy set operation given in Table 1.

Table 1- Comparison between classical and fuzzy set

Descriptions	**Classical Set**	**Fuzzy Set**
Union	$A \cup B = \{x \mid x \in A \text{ or } x \in B\}$	$\mu_{A \cup B}(x) = \mu_A(x) \vee \mu_B(x)$ $= Max[\mu_A(x), \mu_B(x)]$
Intersection	$A \cap B = \{x \mid x \in A \text{ and } x \in B\}$	$\mu_{A \cap B}(x) = \mu_A(x) \wedge \mu_B(x)$ $= Min[\mu_A(x), \mu_B(x)]$
Complement	$\overline{A} = \{x \mid x \notin A,\ x \in X\}$	$\mu_{\overline{A}}(x) = 1 - \mu_A(x)$

These two tables provide some basic ideas of fuzzy set operation. Zadeh explained these fuzzy set operations and provided some relevant theorems in his paper on Fuzzy Sets (Zadeh 1965e).

Table 2- The graphical representation of fuzzy set operations

Set Operation	Set A and Set B	Set C
Union		
Intersection		
Complement		

2.5 Controller Types

In a digital controller, the pneumatic signals sent by the field control elements will be transformed into digital signals periodically by an analog-to-digital converter (ADC). A digital control algorithm is then used to calculate the controller output, a digital signal. Before the output is sent to the final control element, this digital signal is converted back to the corresponding signal by a digital-to-analog converter.

2.5.1 Proportional Control

For proportional control, the controller input is proportional to the error signal, as per equation below,

$$p(t) = \overline{p} + K_c e(t)$$

In this control action, the controller gain K_c can be adjusted to make the controller output changes as sensitive as desired to deviation between the set point and controlled variable. The bias is adjusted to the nominal steady-state value as when there are no errors involved (when e(t) is zero); the controller output will be zero.

2.5.2 Proportional and Integral Control

Integral control is also referred to as reset or floating control, where the controller output depends on the integral of the error signal over time. The action is actually used in the conjunction with proportional control as a proportional –integral controller; resulting the equation below,

$$p(t) = \overline{p} + K_c \left[e(t) + \frac{1}{\tau_I} \int_0^t e(t^*) dt^* \right]$$

Integral control action is widely used as it provides an important practical advantage; elimination of offsets. When integral action is used, controller output *P* will obtain a value causing the steady-state error to be zero, after a set-point change or sustained load disturbance has occurred.

2.5.3 Proportional, Integral and Derivative Control

In derivative control, it is used to anticipate the future behavior of the error signal by considering the rate of change. This control action is combined with proportional and integral action to form the ideal PID controller; as all modes of control action conjugate with each other, forming the equation below,

$$p(t) = \overline{p} + K_c \left[e(t) + \frac{1}{\tau_I} \int_0^t e(t^*)dt^* + \tau_D \frac{de}{dt} \right]$$

A proportional controller will react to only the deviation, making no distinction as to the time period over which the deviation occurred. By providing anticipatory control action, the derivative control mode tends to stabilize the controlled process. However, if the process is defined as a noisy process where there is high-frequency, random fluctuations will result in the derivative of the measured variable to change wildly thus derivative action will amplify the noise. As the result, the derivative control is seldom for flow control since the loops responds quickly and the flow measurements tend to be noisy.

CHAPTER 3-METHODOLOGY

3.1 Fuzzy Logic Control System

Generally, the development of the fuzzy logic systems or control schemes involves three steps or process, as shown in Figure 8. The first step is the fuzzification process. This process involves a domain transformation in which the system inputs or crisp inputs are converted into fuzzy set inputs. In the pH neutralization process the system inputs are actually the measured process variables such as the pH value in the reactor tank, the flowrates of the streams and the conductivity values of the solutions. In this process each input will be transformed into its own group of membership functions or fuzzy sets. Thus the development of the controller must include the important system inputs, determining the type of membership function, as well as establishing the degree of the membership function for the input set.

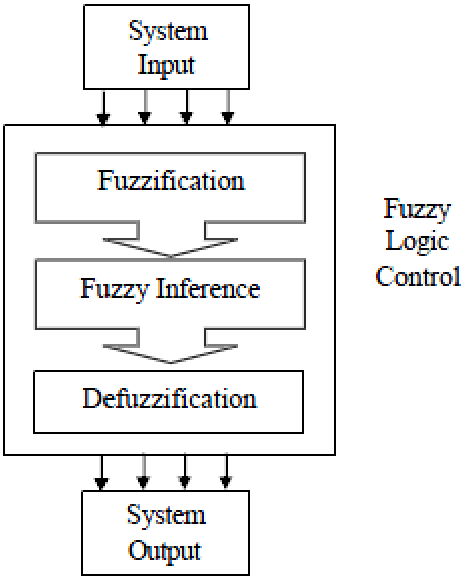


Figure 8- General procedures of designing a fuzzy system

The second step is the Fuzzy Inference process which is described as a process that forms the mapping of the fuzzy input and output sets. The main process involves establishing the relevant Fuzzy Set and Fuzzy Operator, as well as developing a set of “if-then rule statements”. The last process prior to the next step is the aggregation process in which all the results of implication of each rule are combined into a single fuzzy set.

The third step is an inverse process of the first step and called “defuzzification”. The process involves transforming the fuzzy set output into the system output so that the output signal can be used to drive some actuators by the controller. The final output from the defuzzification process is a single value.

3.2 Fuzzy Inference System for The pH Controller

Figure 9 shows the MATLAB/Simulink representation of the overall system for control. Generally the idea of the control approach adopted is that when the current pH value is below the desired value the Fuzzy Logic pH Controller will provide a new set point for the Fuzzy Logic Flow Controller.

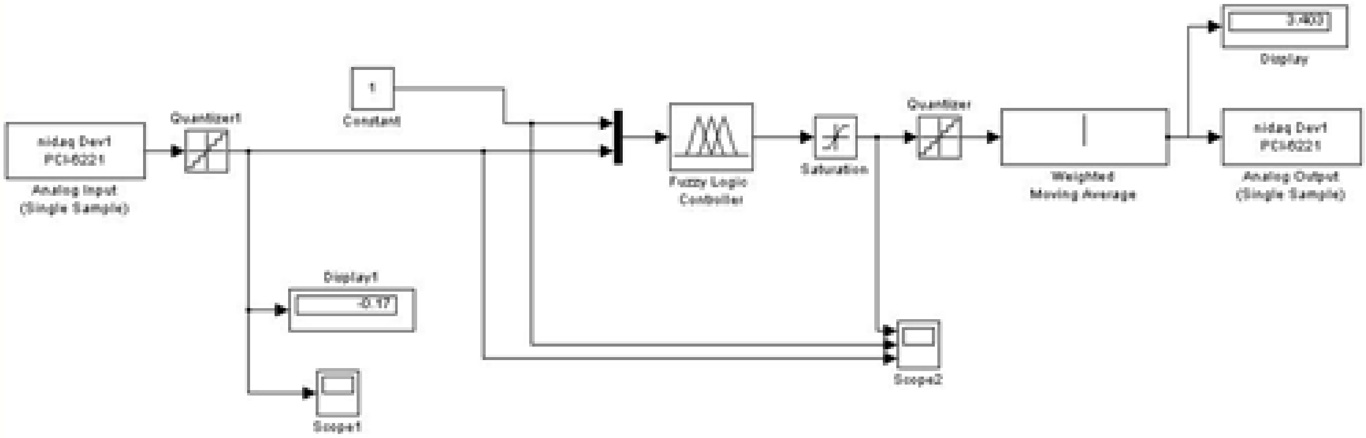


Figure 9- SIMULINK block diagram of the pH controller

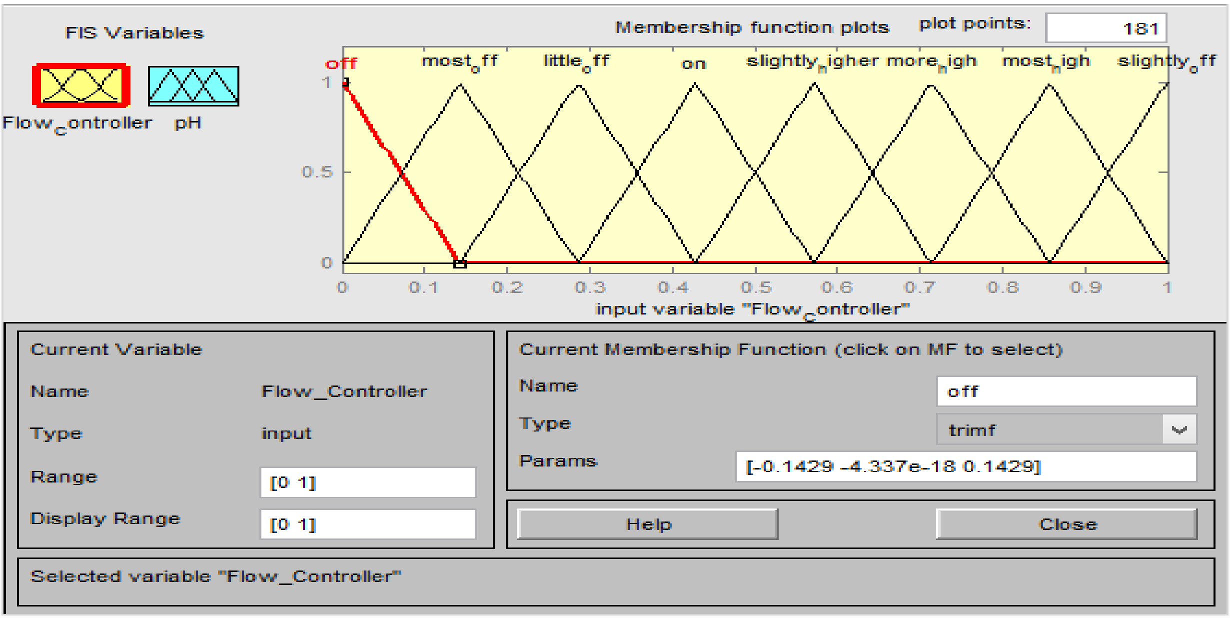
3.3 The Development of Fuzzy Logic Controller (FLC)

In this project, Fuzzy Logic Control (FLC) was developed by using Mamdani Fuzzy inference method. The FLC was designed individually as such to perform for servomechanism problem (set-point changes).

In the development of FLC, the input and output variables must first be defined by using the FIS Editor. For this project, the input is the flow controller and the output is the pH.

The process transfer function is used to relate between the amount heating duties required to the temperature of the fluid inside the thermal reactor. For the input and the output of FLC, each of them has their own membership function. The value of this function determines the element that belongs to the fuzzy set.

There are many types of membership function; triangular and trapezoidal are considered in the development of FLC. For the input membership function, triangular was used while for the output membership function the trapezoidal was used. Each of the input and output consists of numbers of membership function. Membership function was designed by using the Membership Function Editor for which each membership can be assigned with different types and values. Moreover, the range of the input and the output is very important in order to define the type and value of the membership function.



Current Variable

Name: Flow_Controller

Type: input

Range: [0 1]

Display Range: [0 1]

Current Membership Function (click on MF to select)

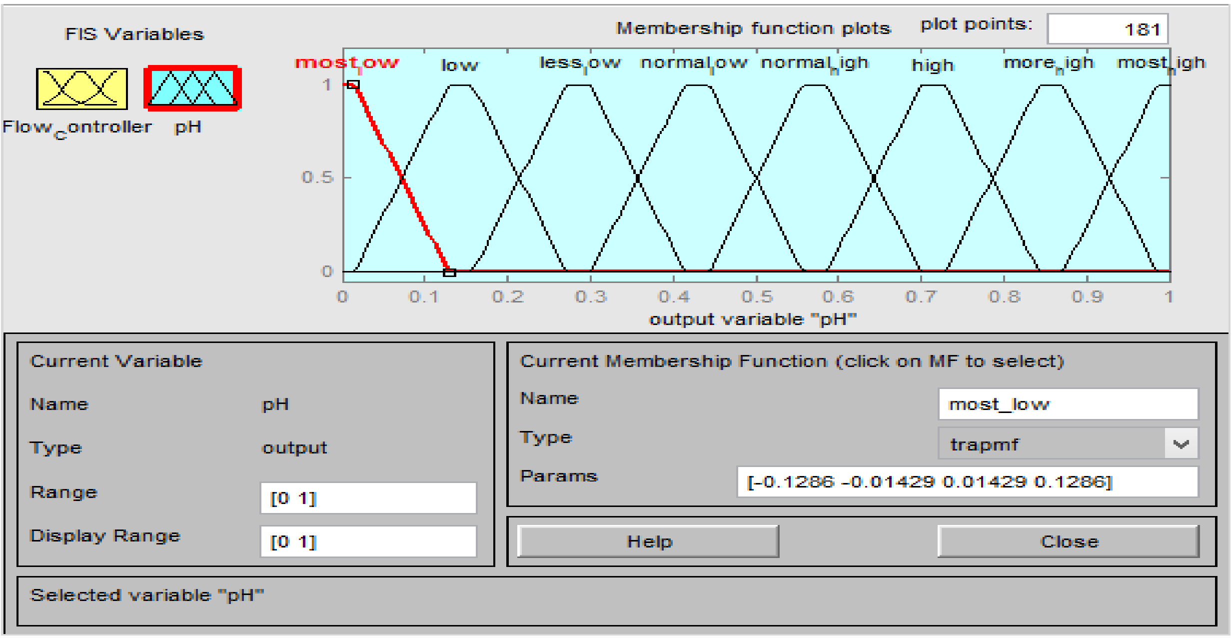
Name: off

Type: trimf

Params: [-0.1429 -4.337e-18 0.1429]

Selected variable "Flow_Controller"

Figure 10- Input variable for membership functions (Step input: Set-point Changes)



Current Variable

Name: pH

Type: output

Range: [0 1]

Display Range: [0 1]

Current Membership Function (click on MF to select)

Name: most_low

Type: trapmf

Params: [-0.1286 -0.01429 0.01429 0.1286]

Selected variable "pH"

Figure 11- Output variable for membership functions (Step input: Set-point Changes)

Each of the membership functions for the input and the output variable are connected by using Rule Editor. The FLC will give the control response based on the input and the output which are connected by using these rules. Furthermore, the Fuzzy Inference System enables the view of the Rule Viewer and Surface Viewer in which will provide assistance for the further improvement of the FLC design.

List of Rules for Step input: Set-point Changes:

1. If (Flow Controller is off) then (pH is most_low)
2. If (Flow Controller is most_off) then (pH is low)
3. If (Flow Controller is little_off) then (pH is low)
4. If (Flow Controller is most_off) then (pH is less_low)
5. If (Flow Controller is most_off) then (pH is normal_low)
6. If (Flow Controller is most_off) then (pH is normal_high)
7. If (Flow Controller is little_off) then (pH is normal_high)
8. If (Flow Controller is on) then (pH is high)
9. If (Flow Controller is slightly_higher) then (pH is more_high)
10. If (Flow Controller is more_high) then (pH is most_high)
11. If (Flow Controller is slightly_off) then (pH is high)
12. If (Flow Controller is off) then (pH is normal_high)

3.4 Process Flow Chart of The Process

The methodology of this project can be summarized in the process flowchart as the following:

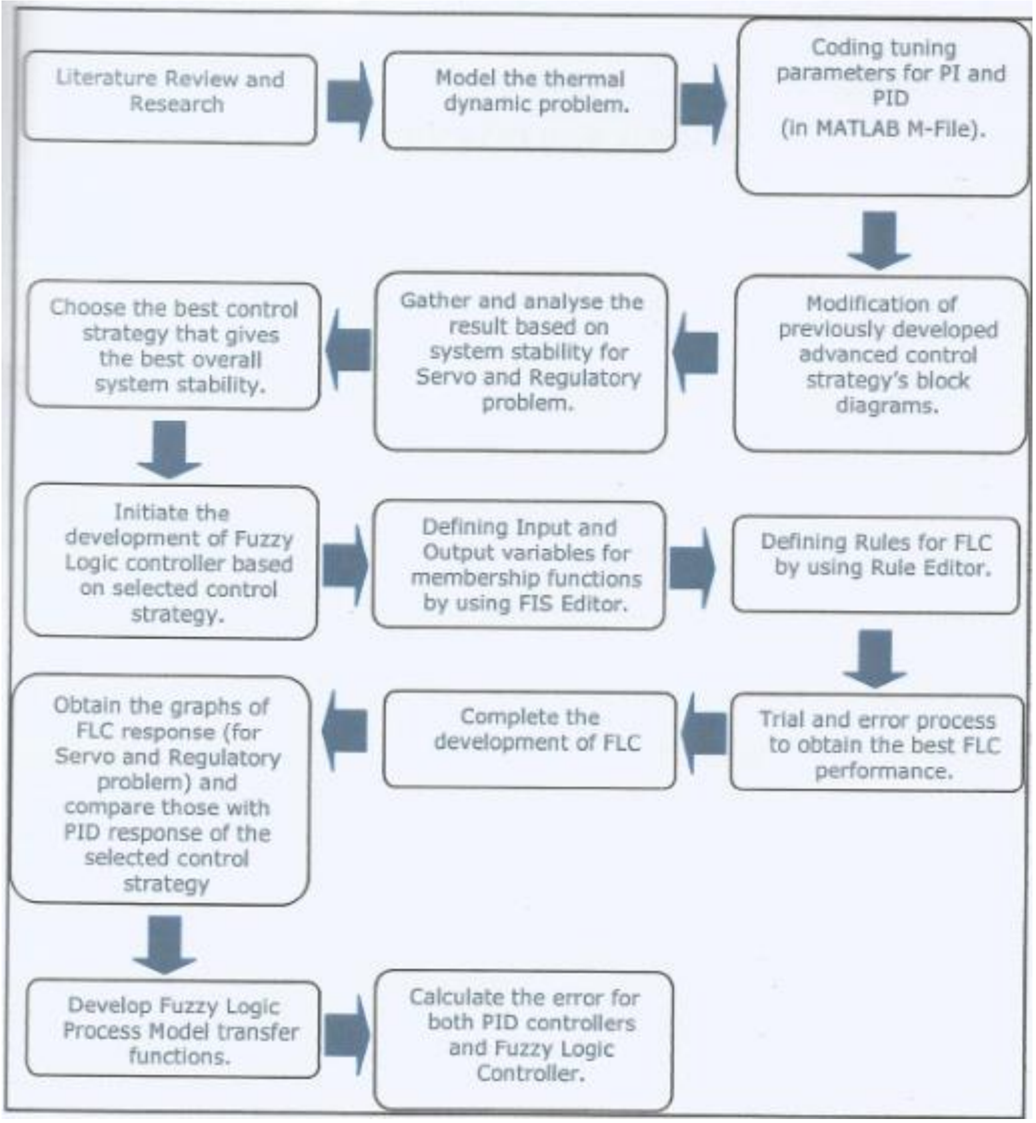


Figure 12- Process flowchart of Fuzzy Logic

CHAPTER 4-RESULT AND DISCUSSION

4.1 Result

4.1.1 Results for The Best Control Scheme and The Best Controller Tuning

The stability response result obtained for every control strategies will be presented in graphical form. Only those graphs which producing stable response will be taken into consideration and presented.

In this section, only the graphs producing overall stability according to the type of control scheme that their represented will be presented. The complete results of system stability based on each control schemes studied are in the Appendix section of this report.

Some of the general criteria of selection for the system stability are as the following:

- Producing stable responses
- Not much oscillation
- The value of error is the less

Generally, the selection criteria will be much according to the following Figure 13.

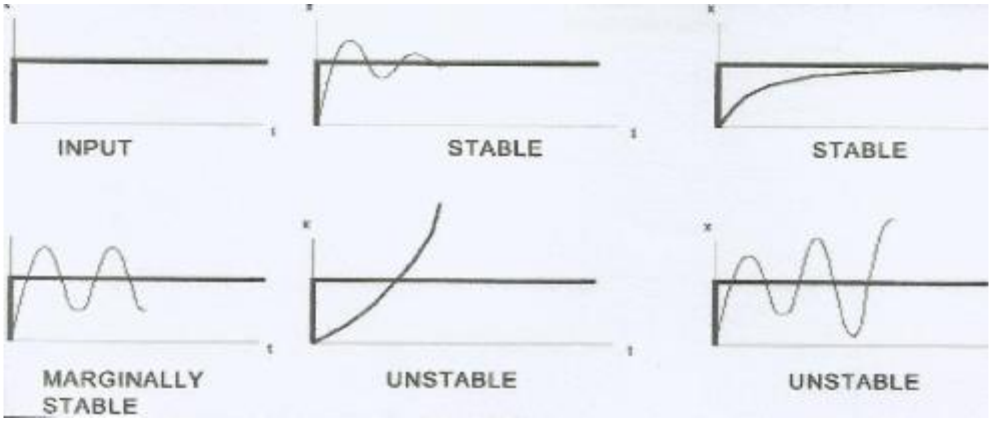


Figure 13- Typical types of stability responses resulting from an input

Based on the following result obtained, only feedback and cascade control that give the best tuning for pH control. The remaining control such as feedforward, smith predictor and IMC controller give unreadable result for pH measurement. Thus, from different type of tuning method apply to those controller, it is observed that feedback and cascade controller give a better performance and a less value of error with less overshoot. Below is the diagram of the result obtained from different type of tuning method.

For feedback control, the result obtained are shown in the Appendix. For the best feedback controller strategies are shown in the below figure.

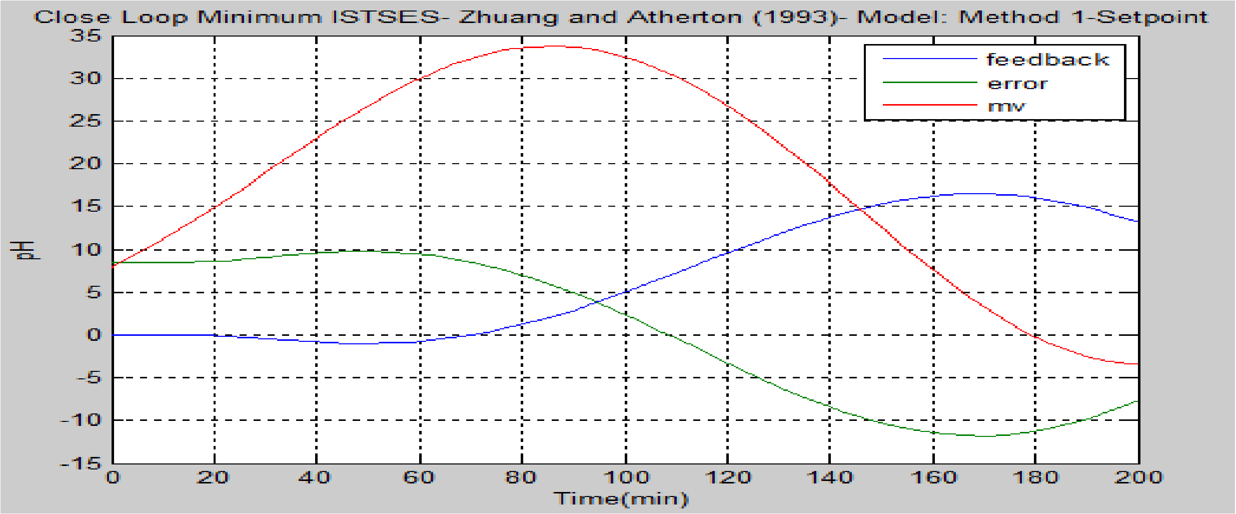


Figure 14- Close Loop Minimum ISTSES- Zhuang and Atherton (1993)

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the below table.

For the feedback controller:

Tuning Method	**Error Value**
Close Loop IMC Response	617.0210
Close Loop ISE Response	214.5983
Close Loop Minimum ISE - Murrill(1967)	110.6768
Close Loop Minimum ISE-Zhuang and Atherton(1993)	101.6442
Close Loop Minimum ISTSE- Zhuang and Atherton (1963)	178.6421
Close Loop Minimum ISTSES- Zhuang and Atherton (1993)	51.5970

Table 3- Error value for feedback controller

From the above table, it can conclude that the **Close Loop Minimum ISTSES- Zhuang and Atherton (1993)** has the less error with the value of **51.5970** and it is the best controller tuning method for feedback controller.

While for cascade control, for the best cascade controller strategies are shown in the below figure.

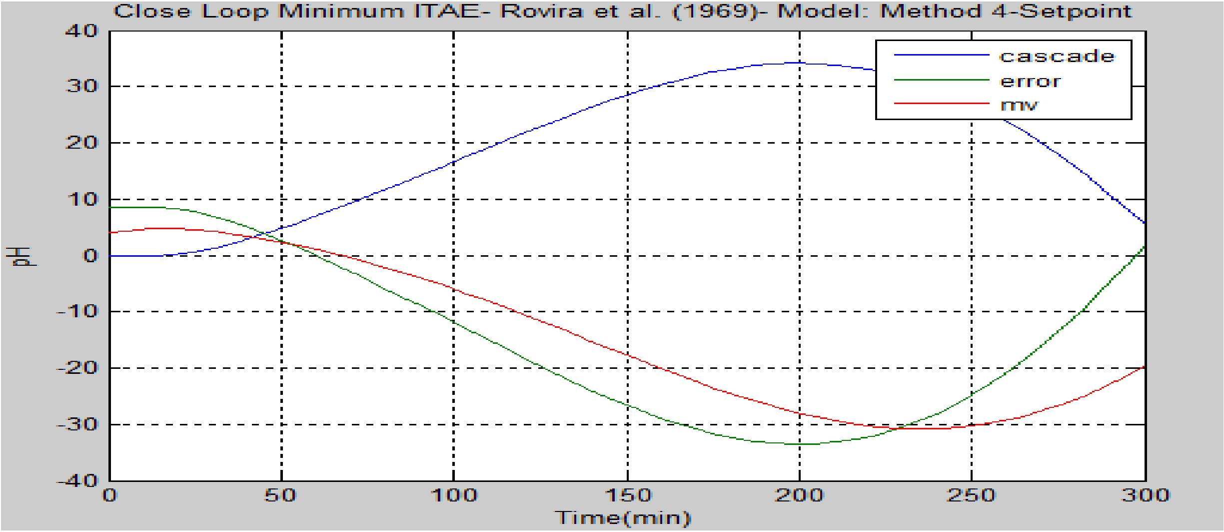


Figure 15- Close Loop Minimum ITAE-Rovira et.al. (1963) Model Method 4

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the below table.

For the cascade controller:

Tuning Method	Error Value
Close Loop IAE Response	5020.1
Close Loop Chien wt al. (1952)- Servo Model Method 2	4604.3
Close Loop Minimum IAE- Marlin (1995)- Model Method 1	4183.4
Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4	2826.7
Close Loop Minimum ITAE- Wang et al. (1995)- Model Method 1	4603.2

Table 4- Error value for cascade controller

From the above table, it can conclude that the **Close loop Minimum ITAW-Roviea er al. (1969)- Model Method 4** has the less error with the value of **2826.7** and it is the best controller tuning method for cascade controller.

4.1.2 Results for The Development of Fuzzy Logic Controller (FLC)

The Feedback Control Scheme block diagrams with the Fuzzy Logic Control used to analyze the response and performance of FLC are presented as in the following figures in the appendices. For the best result for feedback control block diagrams with Fuzzy Logic Control are:

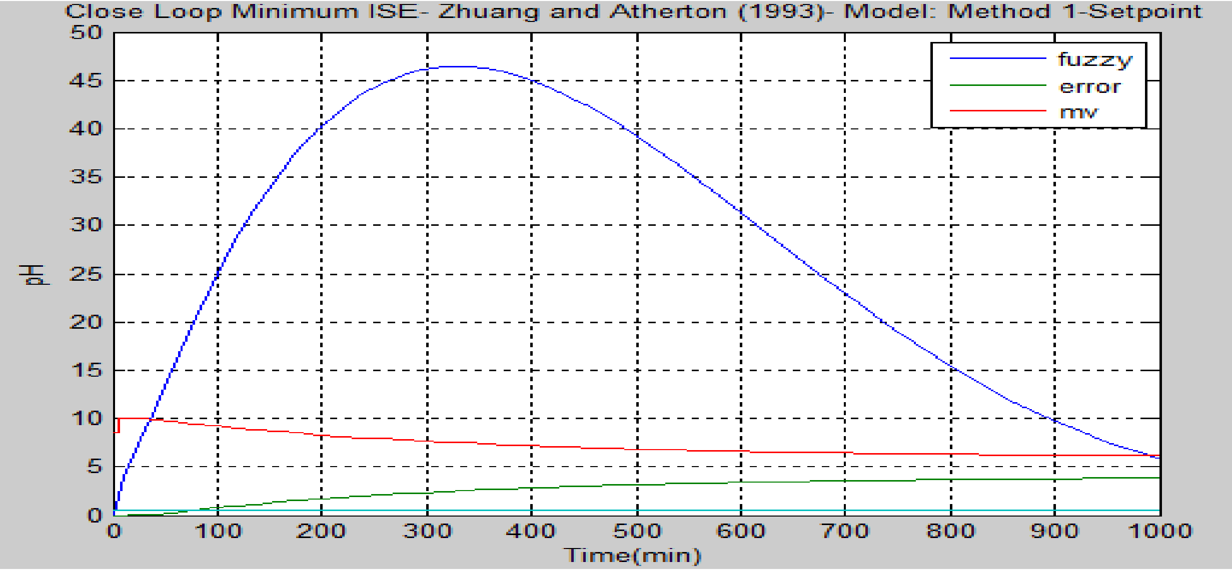


Figure 16- Close Loop Minimum ISE-Zhuang and Atherton (1993)- Model Method 1

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the below table.

For the feedback control with fuzzy logic control:

Tuning Method	**Error Value**
Close Loop IAE Response	123.5636
Close Loop IMC Response	145.1214
Close Loop Chien wt al. (1952)- Servo Model Method 2	186.2456
Close Loop Hay (1998)- Servo Tuning Model	102.3965
Close Loop Minimum IAE- Marlin (1995)- Model Method 1	112.0245
Close loop Minimum ISE- Wang et al. (1995) Model Method 1	165.2301
Close Loop Minimum ISE-Zhuang and Atherton (1993)- Model Method 1	102.2546
Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4	95.1245
Close Loop Minimum ITAE- Cheng and Hung (1985) Model Method 8	76.1238
Close Loop Minimum ITAE- Wang et al. (1995) Model Method 1	142.2302
Close Loop Minimum ISTSE-Zhuang and Atherton (1993) Model Method 1	31.0265
Close Loop Minimum ISTSES-Zhuang and Atherton (1993) Model Method 1	98.3278

Table 5- Error value for feedback with fuzzy logic controller

From the above table, it can conclude that the **Close Loop Minimum ISTSE-Zhuang and Atherton (1993) Model Method 1** has the less error with the value of **31.0265** and it is the best controller tuning method for feedback controller with fuzzy logic controller.

For the best result for cascade control block diagrams with Fuzzy Logic Control are:

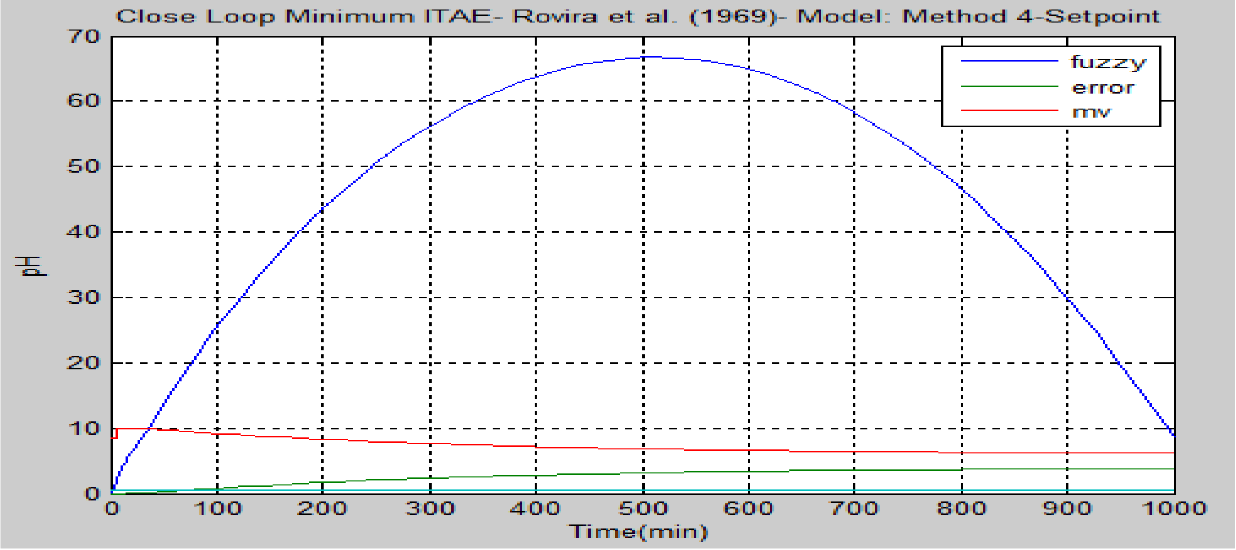


Figure 17- Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4

The error has been calculated by using MATLAB Simulink Environment and the value are shown in the below table.

For the cascade control with fuzzy logic control:

Tuning Method	**Error Value**
Close Loop IAE Response	3012.3
Close Loop Chien wt al. (1952)- Servo, Model Method 2	3412.9
Close Loop Hay (1998)- Servo Tuning Model	3012.5
Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4	2503.6
Close loop Minimum ITAE- Wang et al. (1995) Model Method 1	3106.9

Table 6- Error value for cascade with fuzzy logic controller

From the above table, it can conclude that the **Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4** has the less error with the value of **2503.6** and it is the best controller tuning method for feedback controller with fuzzy logic controller.

4.2 Discussion

Characteristic	**Control Scheme**	
	Feedback Control	**Fuzzy Logic Control**
Oscillation	Significant Oscillation	Less oscillation
Error Value	51.5970	31.0265

Characteristic	**Control Scheme**	
	Cascade Control	**Fuzzy Logic Control**
Oscillation	Significant Oscillation	Less oscillation
Error Value	2826.7	2503.6

Table 7- The comparison of response between feedback and cascade control scheme with Fuzzy Logic Control scheme

From the analysis, FLC provides better result than feedback and cascade control. FLC is one of the advanced process control approach but differ in terms of its mechanism to control the process. The conventional existing PI and PID controller use tunning formulas provided by many tuning handbooks, while Fuzzy Logic Control uses Fuzzy Logic Controller (FLC) with its own Fuzzy Set to control the process.

The FLC functions were developed based on the Fuzzy Inference System (FIS) in which consist of Membership Function Editor, Rules Editor, Rule Viewer and also Surface Viewer.

The Fuzzy Logic Controller (FLC) developed was optimized to perform with the step input changes. But unfortunately, it is discovered that the FLC designed for the step input can be considered unworkable for several tuning methods. This is because Matlab produces error while running the simulation for that particular design. Thus, for the sake of simplicity, only the results for step input change were taken into consideration.

In the process of designing the Fuzzy Logic Controller (FLC), the most important aspect that needs to be considered is the proper formulation of the fuzzy rules to give the best performance of FLC. The advantages of FLC is that it has a better control on the controller as it could adjust and set the controller according to the current desired value. It will respond according to the range value of the input and the output of the membership functions and the rules that connect the input and the output of the membership functions.

CHAPTER 5-CONCLUSION

Fuzzy Logic Control is the latest advanced control scheme. From this project, it is concluded that cascade control scheme is robust and useful in the process control. However, there are certain areas in process control in which the existing advanced process control scheme give less effective control response. The Fuzzy Logic Control is one of the alternatives that can be employed to overcome this as it has the ability to cover wider range processes because it uses human-like techniques to define the process. Based on this project, the Fuzzy Logic Control should be considered as a new solution approach in the process control field and it also can be applied in the larger scale in the industry.

Based on the problem encounter during the development of Fuzzy Logic Controller (FLC), it's suggested that new FLC should be designed specifically to handle the several tuning methods. This would ensure that the FLC can be used specifically and be performed in solving solve for all the tuning methods.

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Waller, K. V., and Gustafsson, T. K., Fundamental properties of continuous pH control, *ISA Trans.* 22(1), 25-34, 1983

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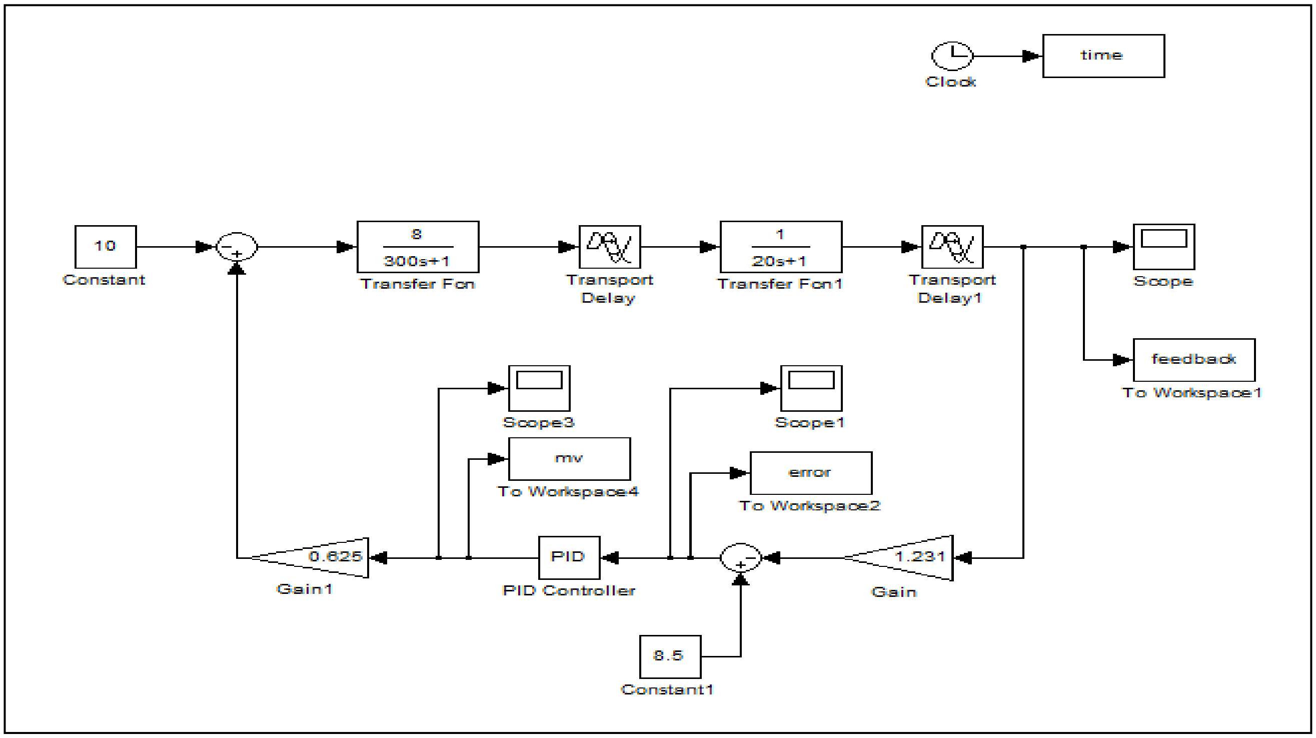
Nasser M Ramli, Muhammad Syamil Abdul Aziz 2008, Fuzzy Logic For Thermal Dynamics, Bachelor Hons, Universiti Teknologi Petronas

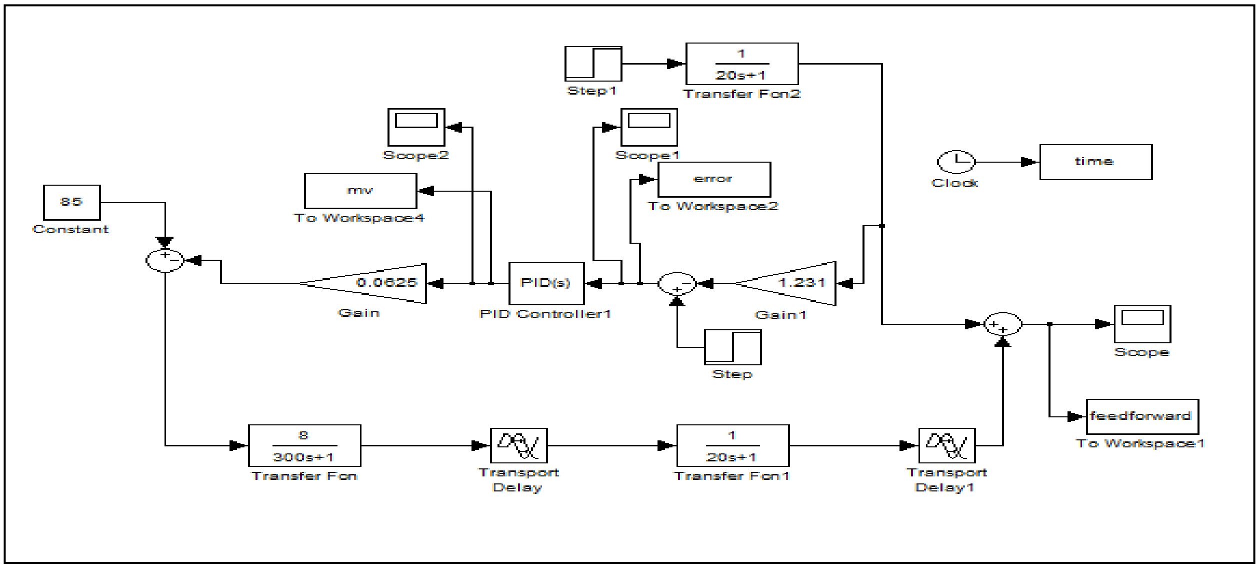
Cheng Ling and Thomas F Edgar (1997), "Real time control of a water gas shift reactor by model based on fuzzy logic gain schedulling", Journal of Process Control v7 239-253

APPENDICES

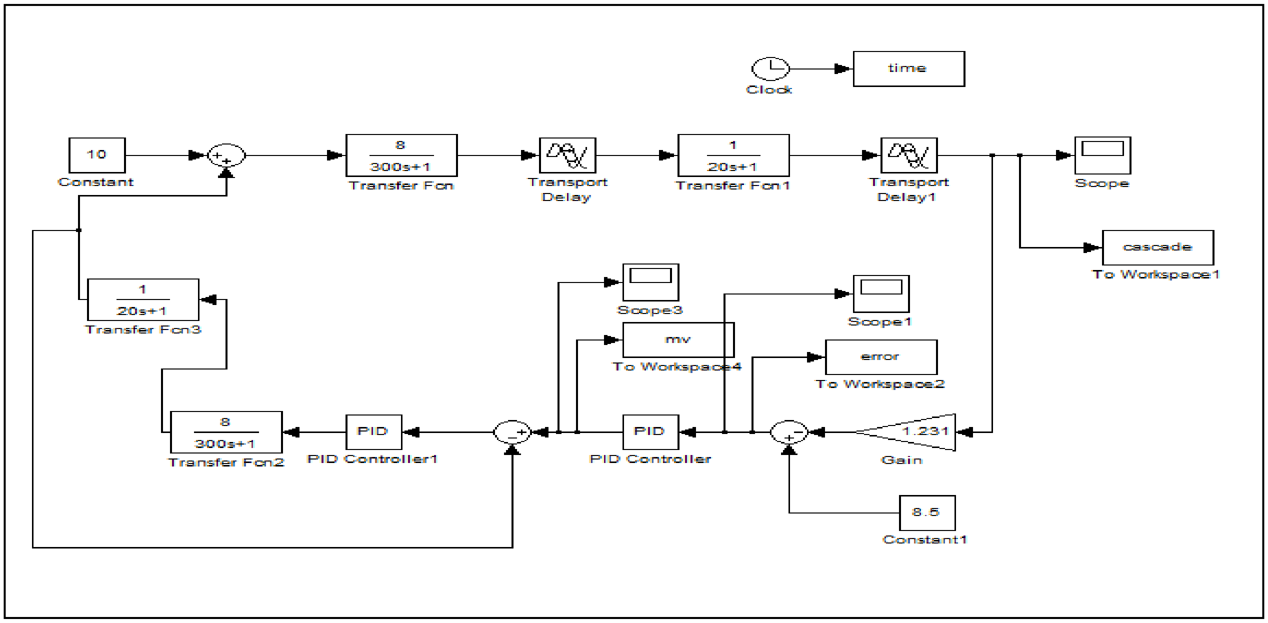
Appendix 1: Block Diagram



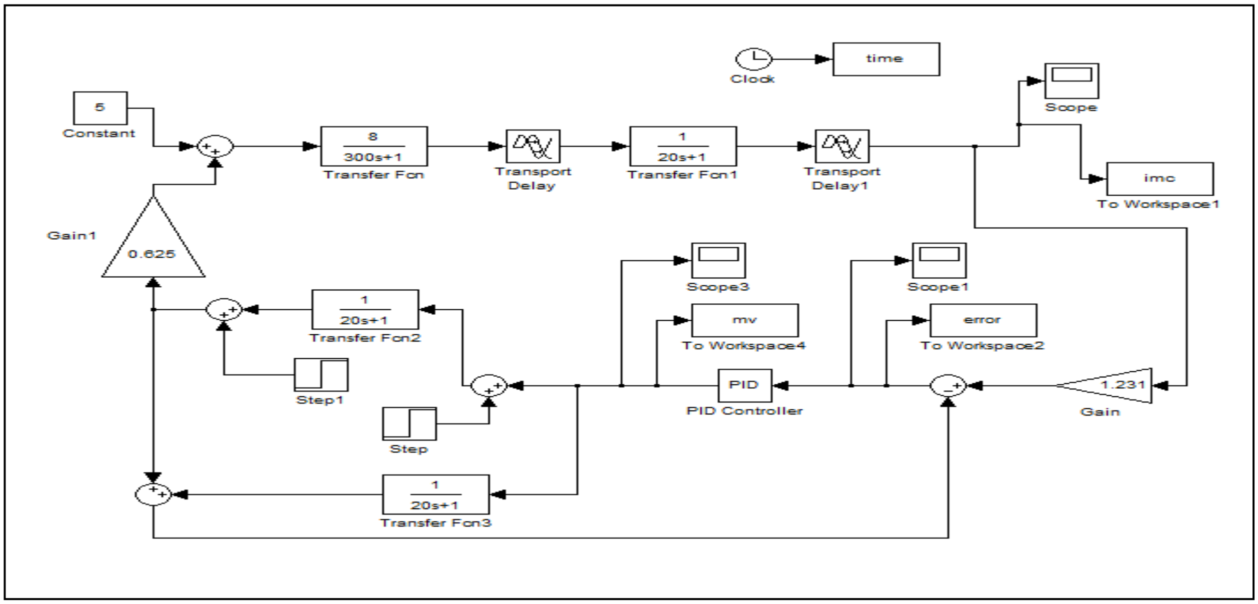
A feedback control diagram



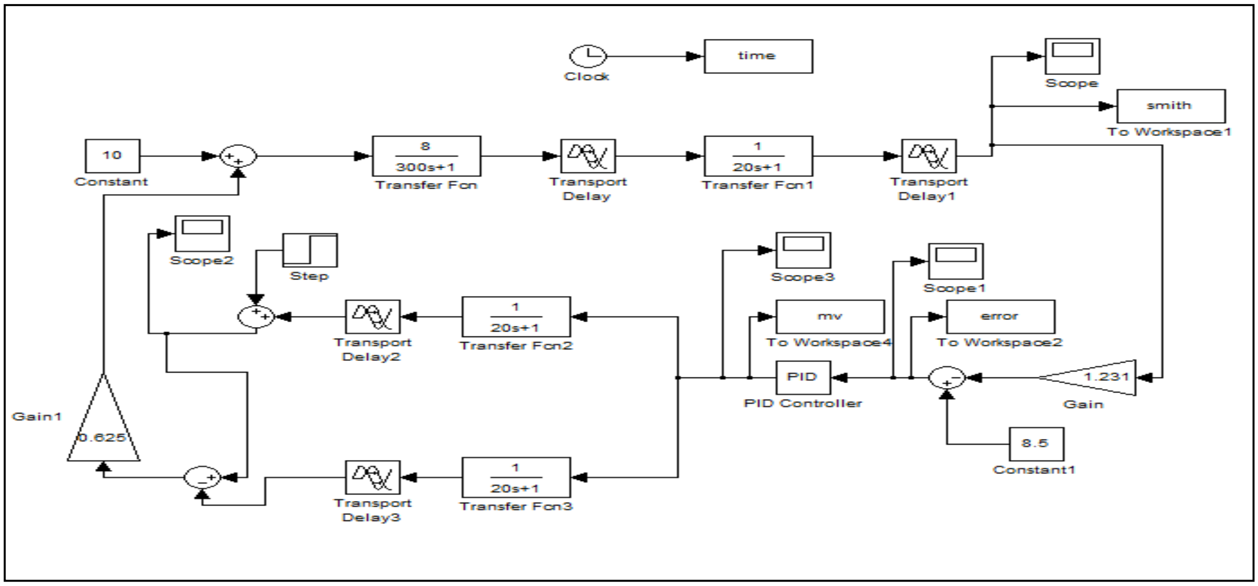
A feedforward control diagram



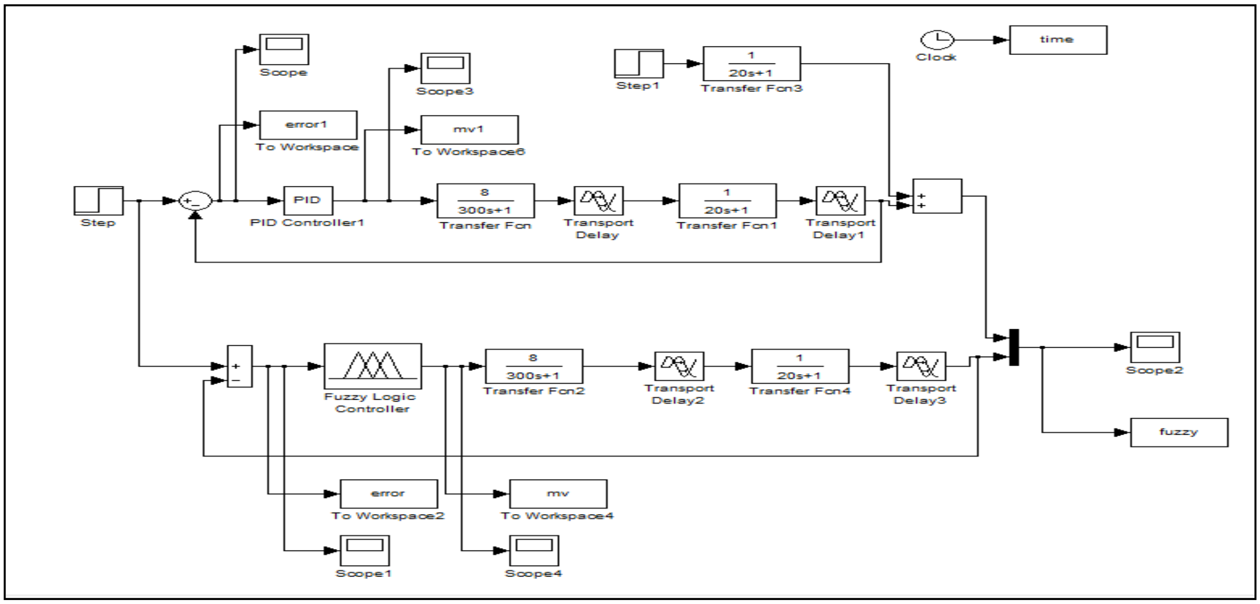
A cascade control diagram



An IMC diagram

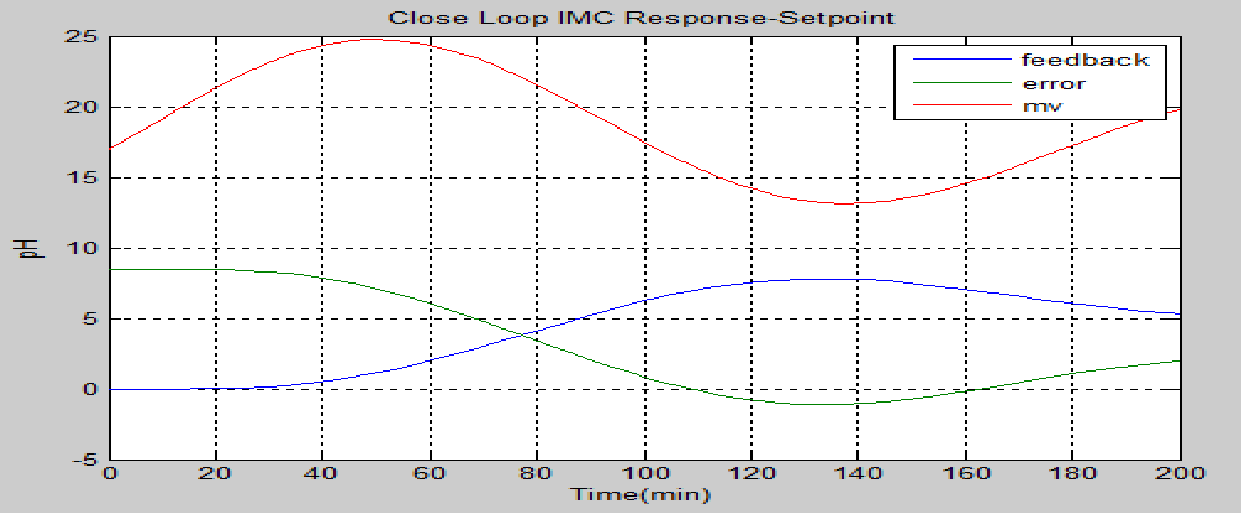


A smith predictor control diagram

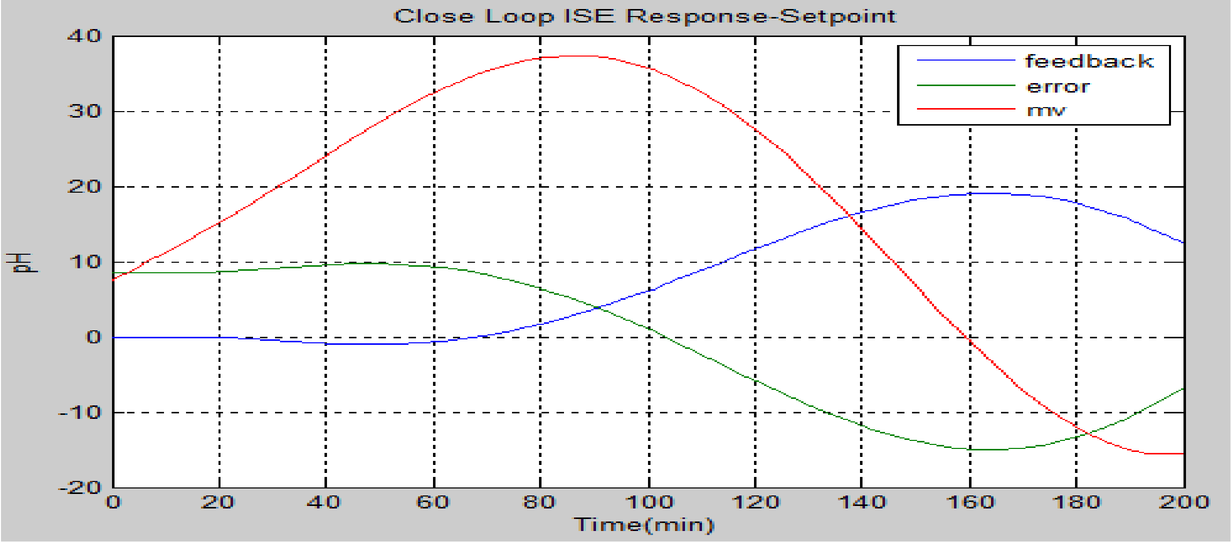


A fuzzy control diagram

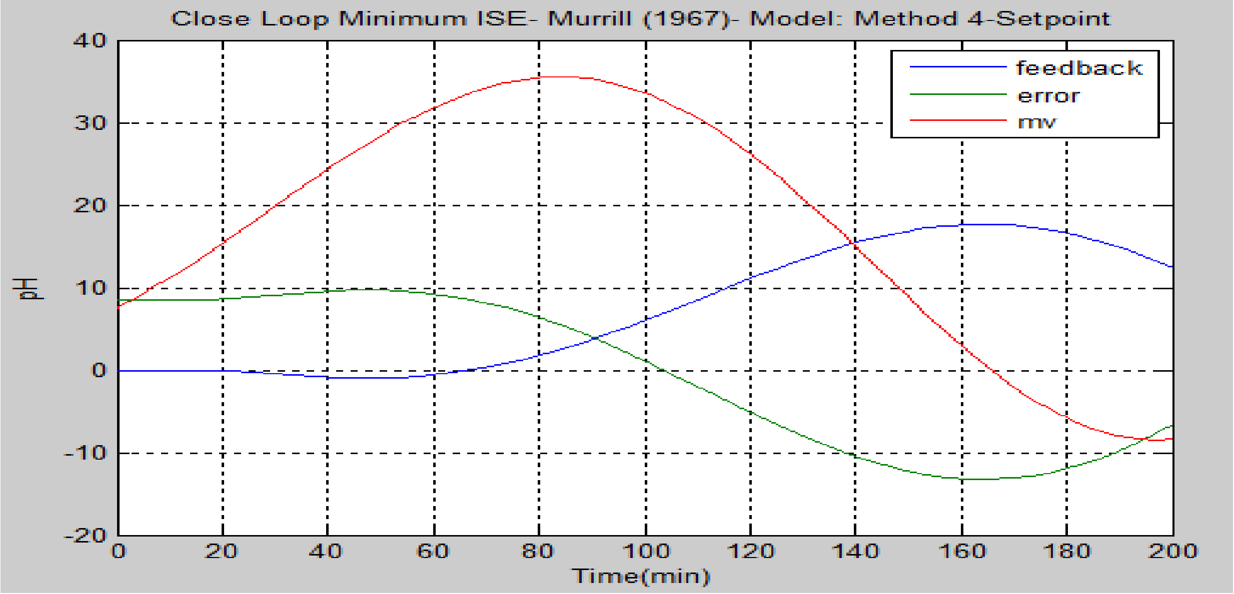
Appendix 2: Feedback Controller



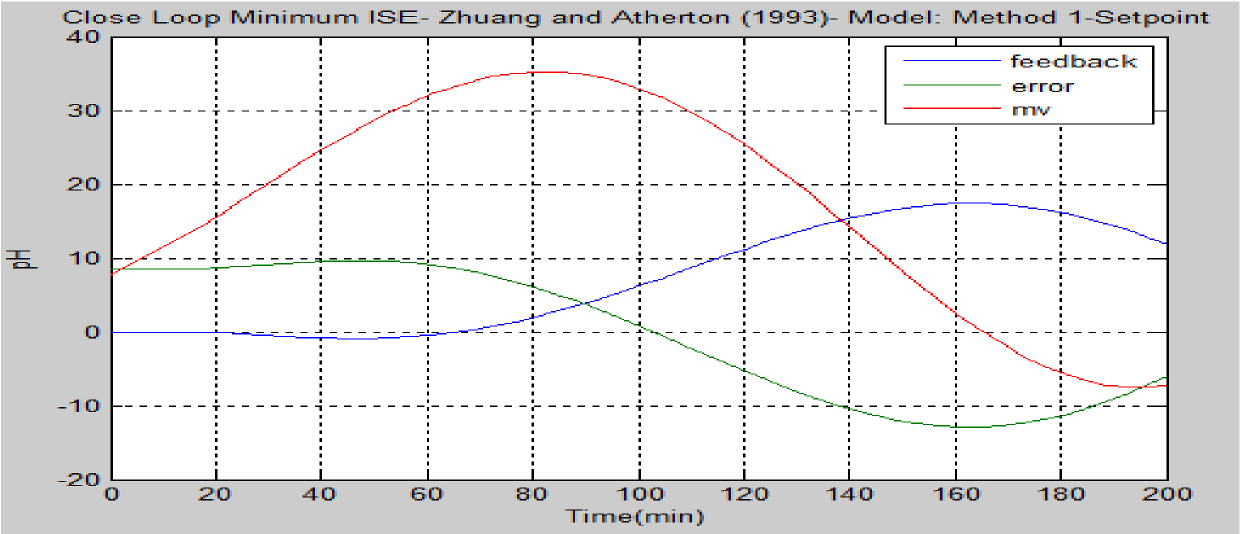
Close Loop IMC Response



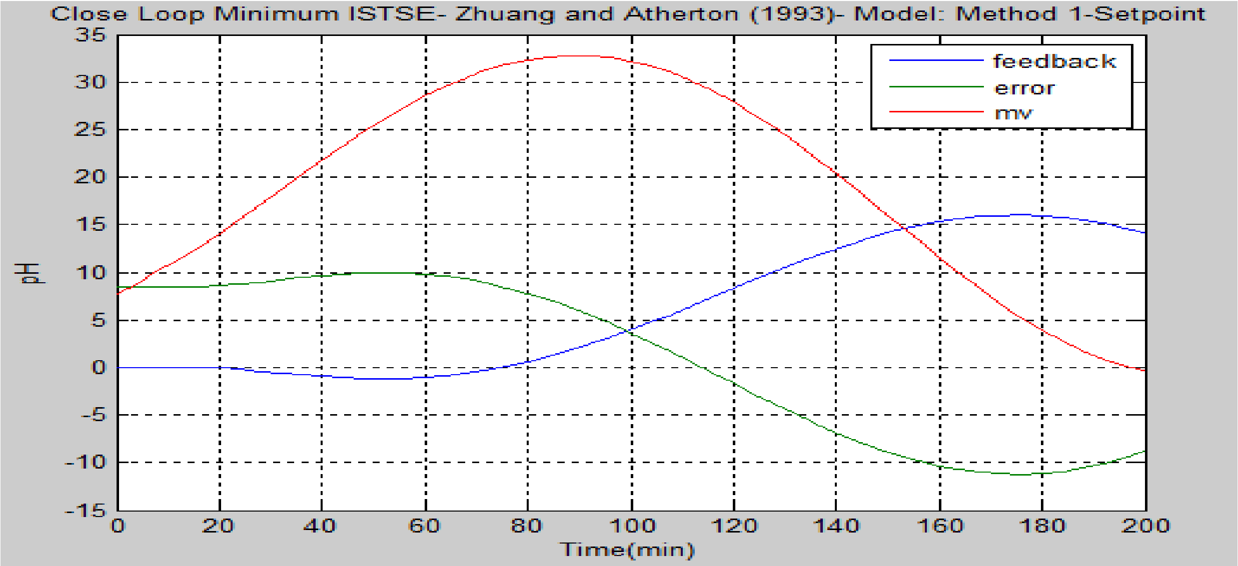
Close Loop ISE Response



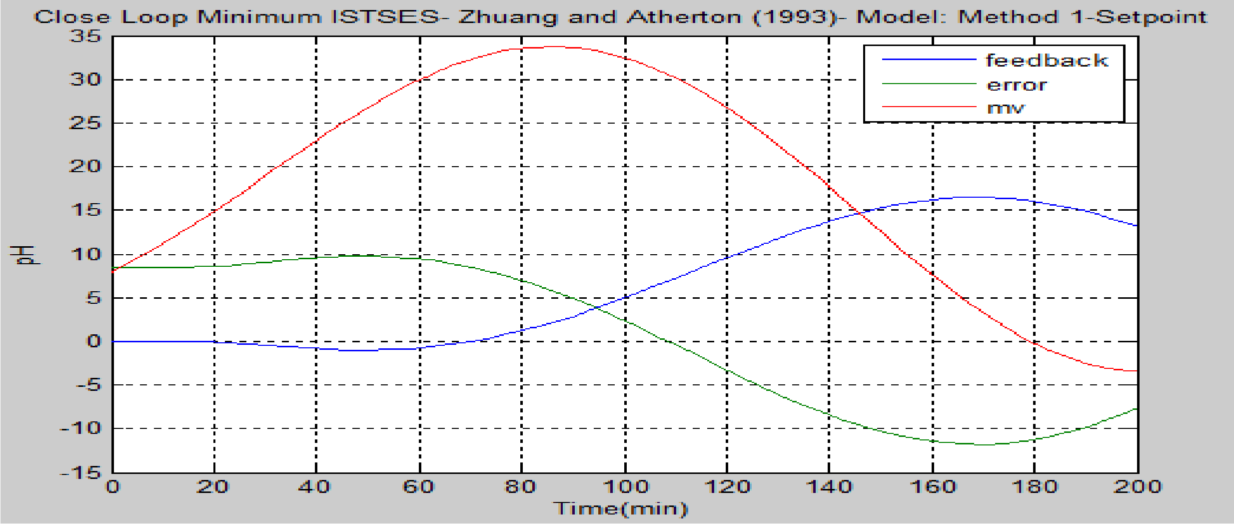
Close Loop Minimum ISE - Murrill(1967)



Close Loop Minimum ISE-Zhuang and Atherton(1993)

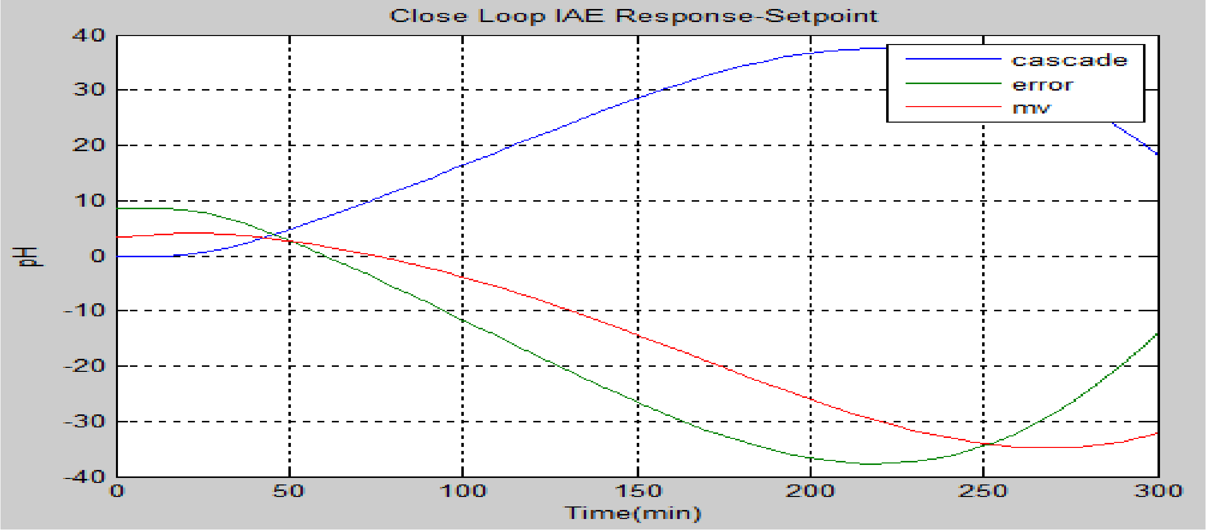


Close Loop Minimum ISTSE- Zhuang and Atherton (1963)

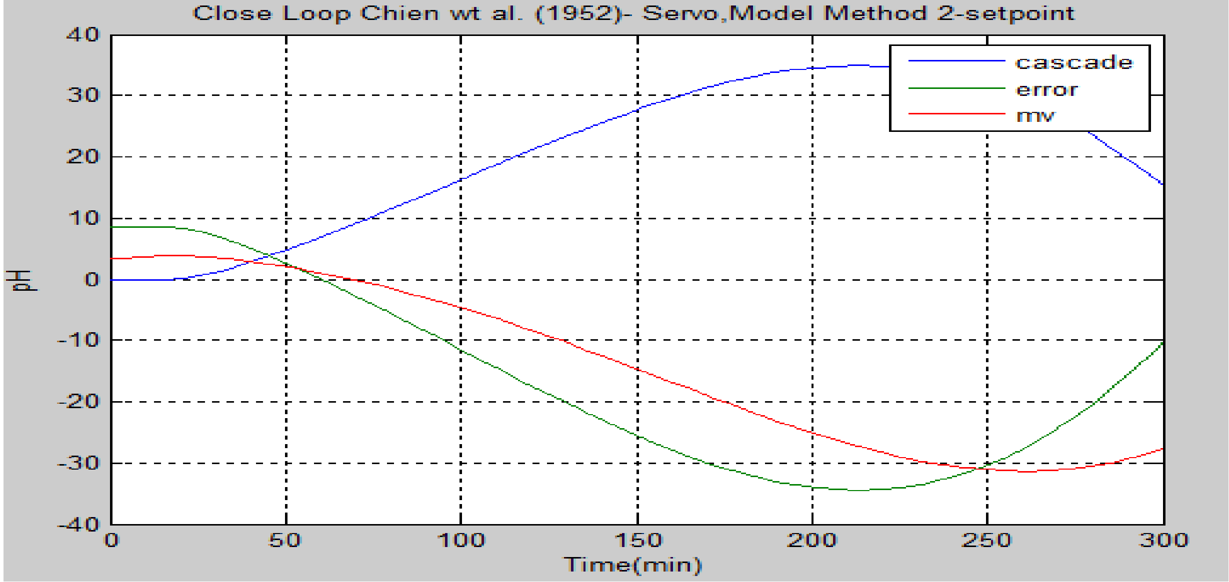


Close Loop Minimum ISTSES- Zhuang and Atherton (1993)

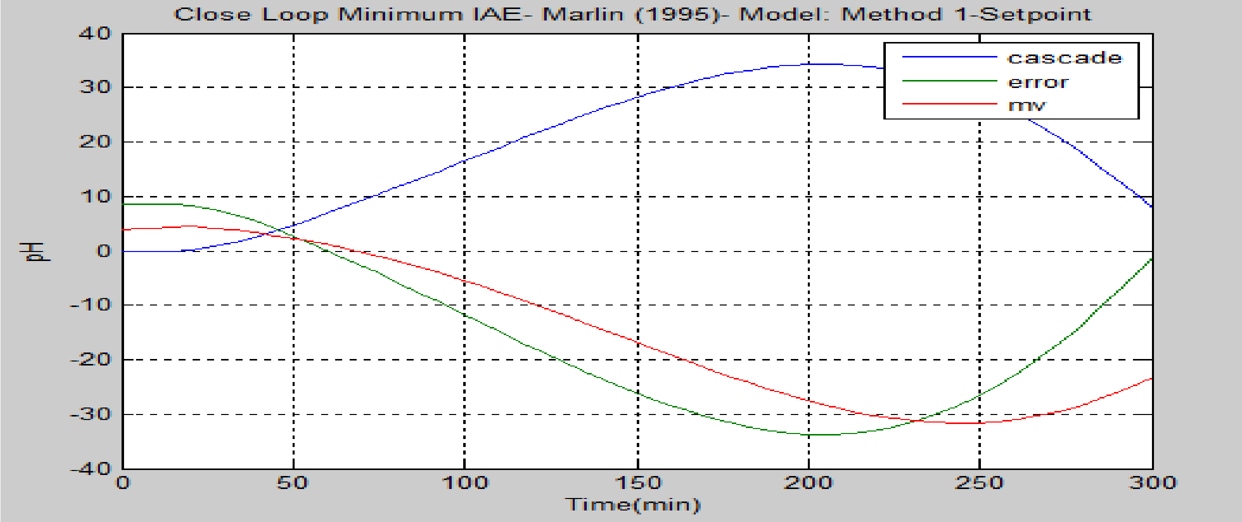
Appendix 3: Cascade Controller



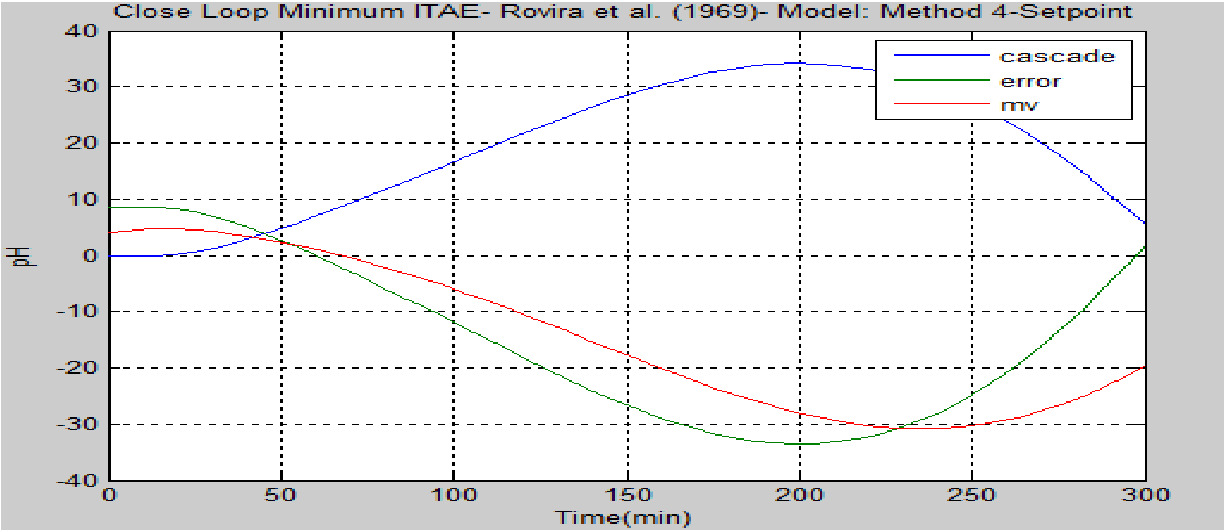
Close Loop IAE Response



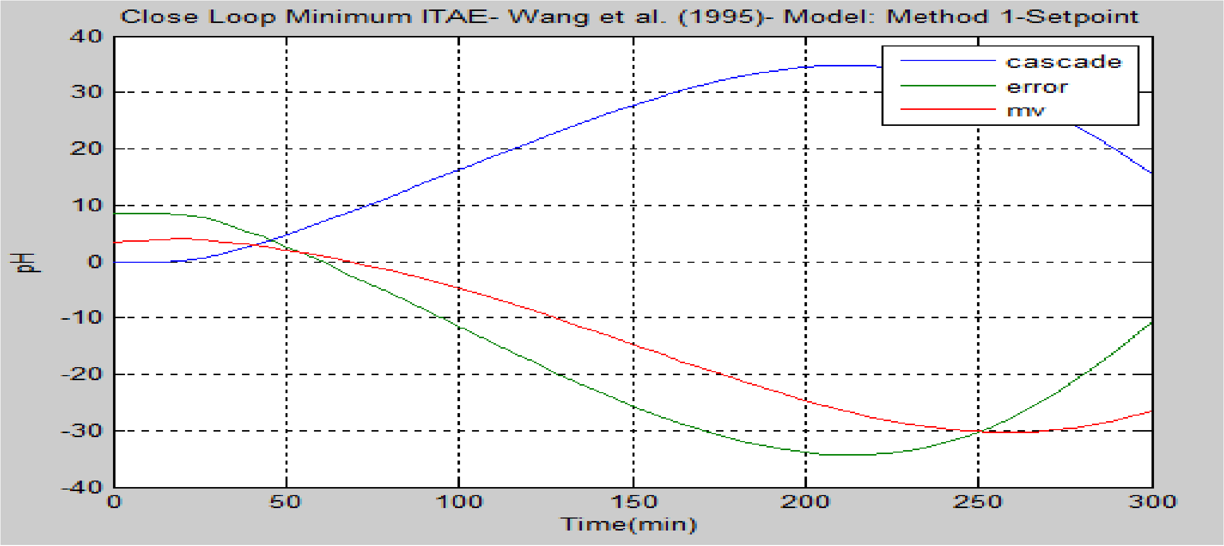
Close Loop Chien wt al. (1952)- Servo Model Method 2



Close Loop Minimum IAE- Marlin (1995)- Model Method 1

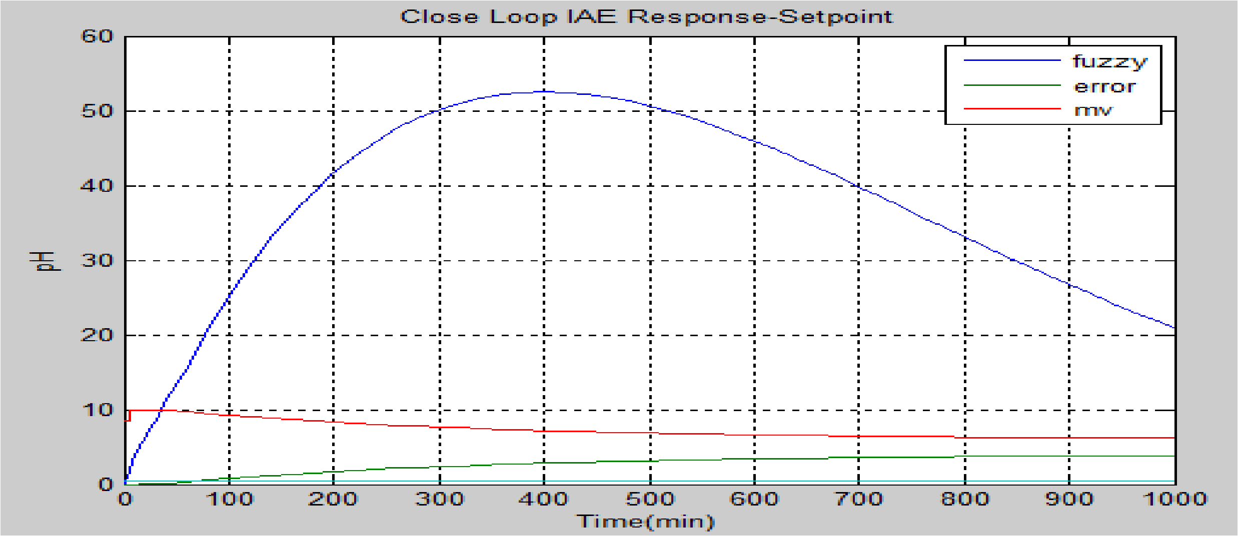


Close Loop Minimum ITAE- Rovira et al. (1969)- Model Method 4

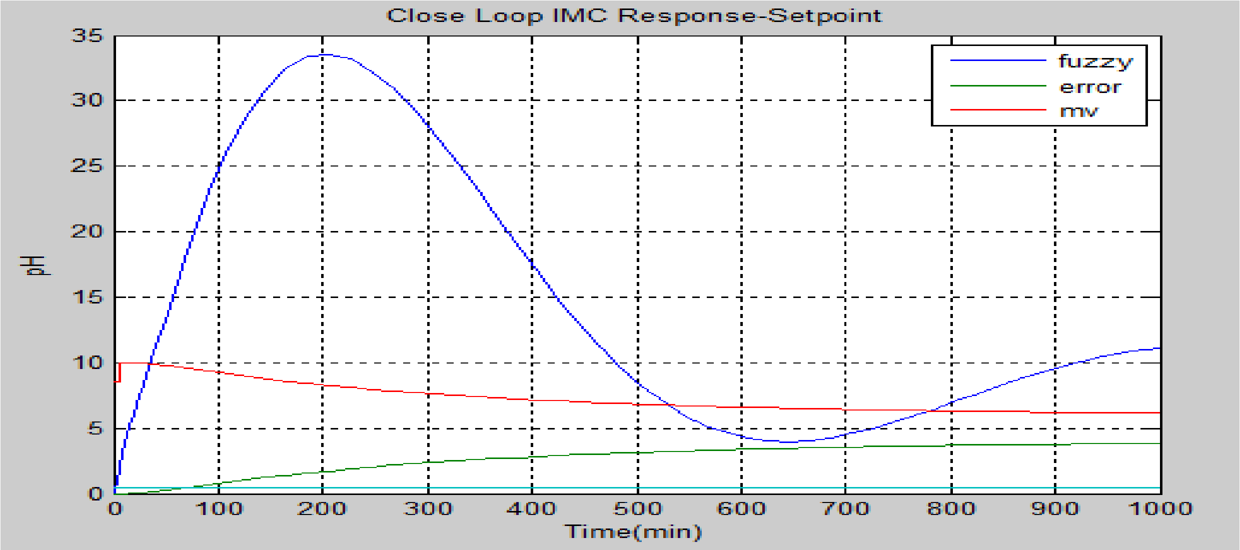


Close Loop Minimum ITAE- Wang et al. (1995)- Model Method 1

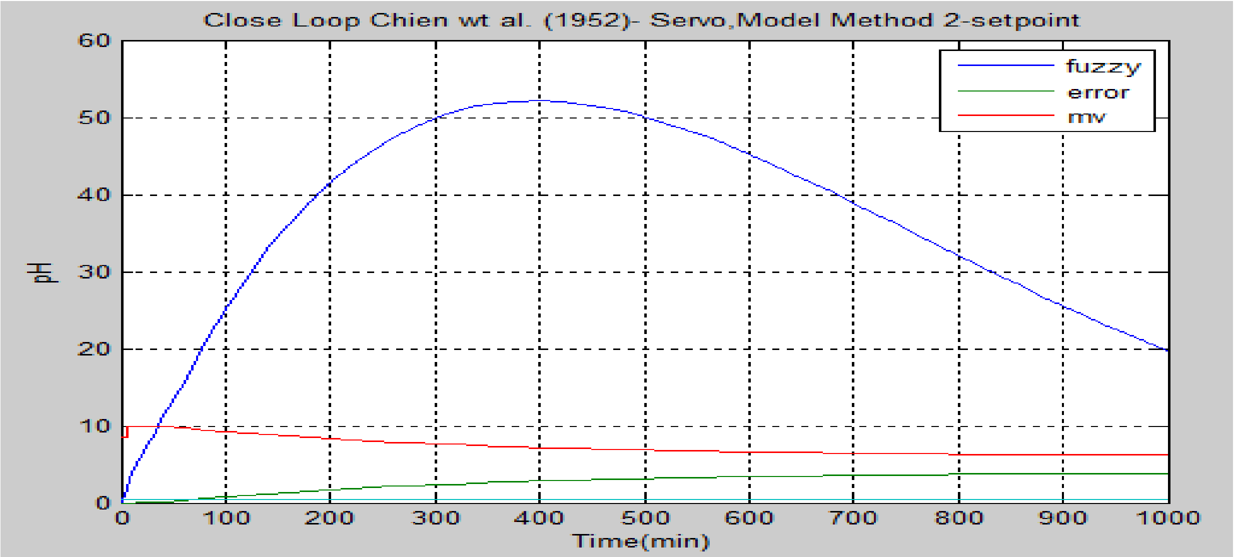
Appendix 4- Feedback Control with the Fuzzy Logic Controller



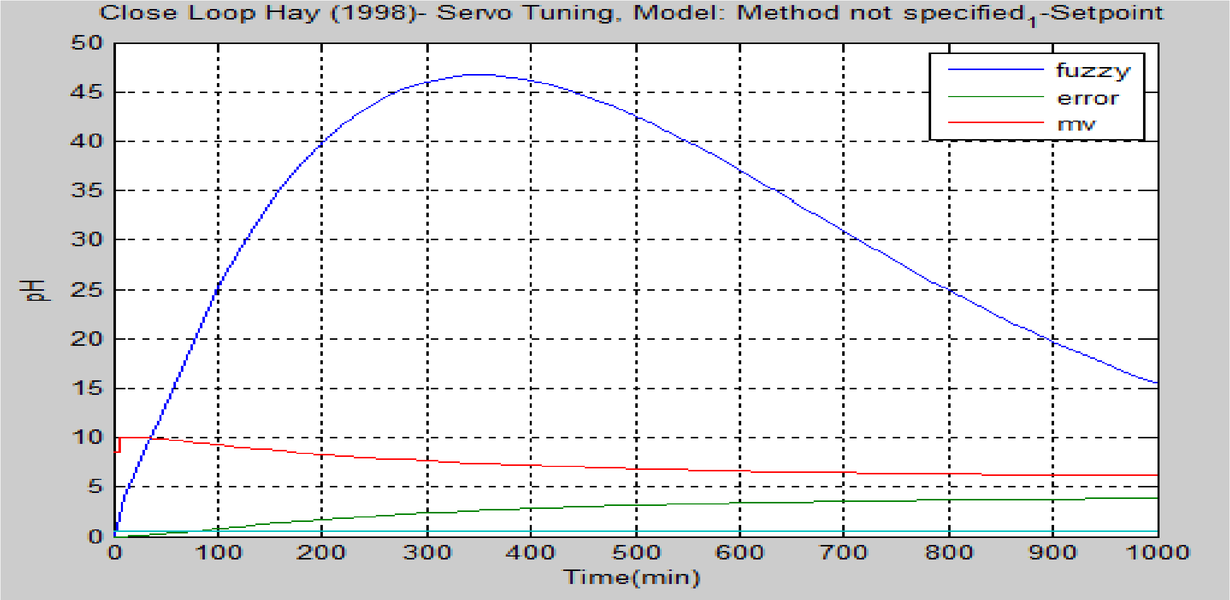
Close Loop IAE Response



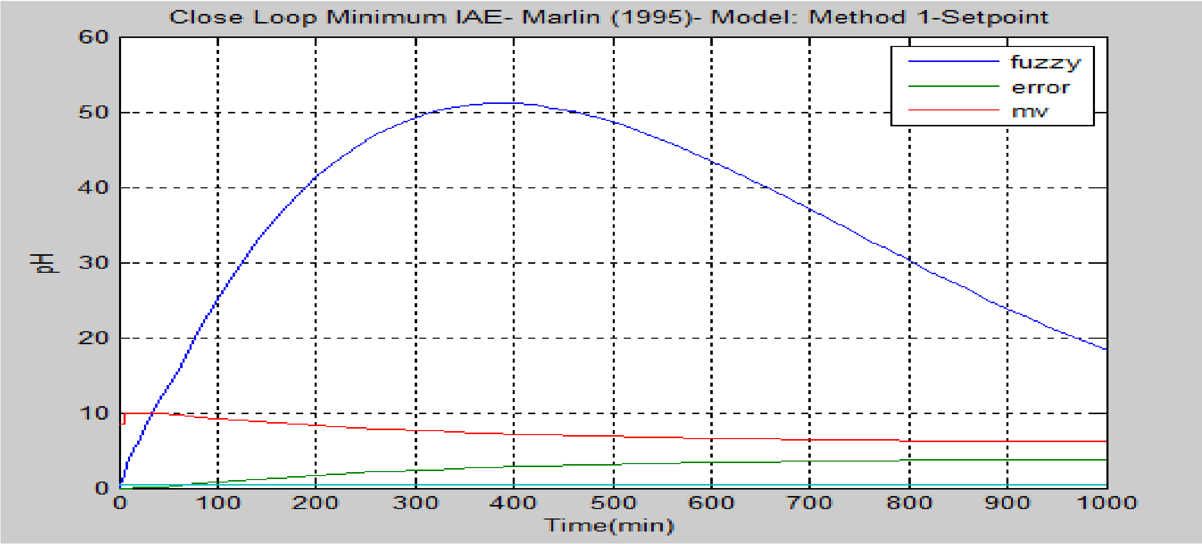
Close Loop IMC Response



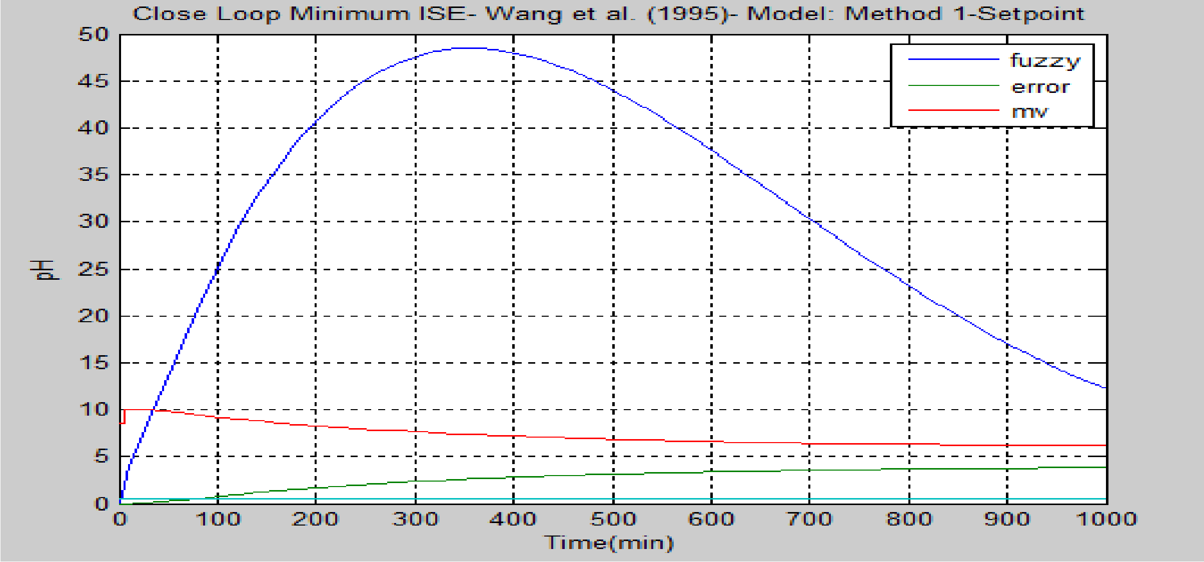
Close Loop Chien wt al. (1952)- Servo Model Method 2



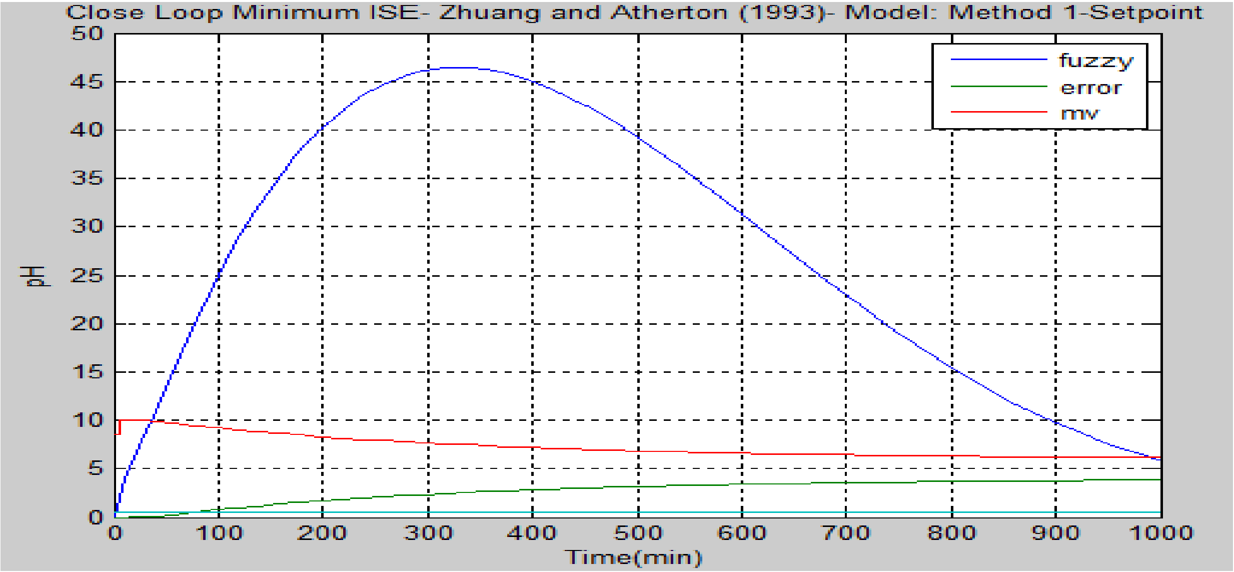
Close Loop Hay (1998)- Servo Tuning Model



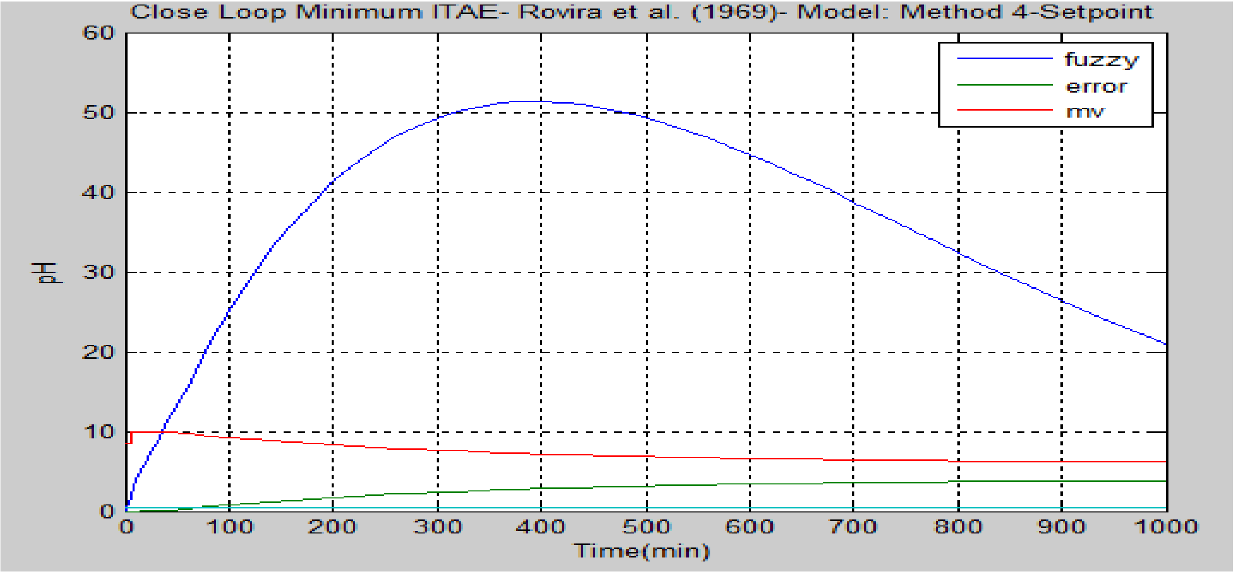
Close Loop Minimum IAE- Marlin (1995)- Model Method 1



Close loop Minimum ISE- Wang et al. (1995) Model Method 1



Close Loop Minimum ISE-Zhuang and Atherton (1993)- Model Method 1



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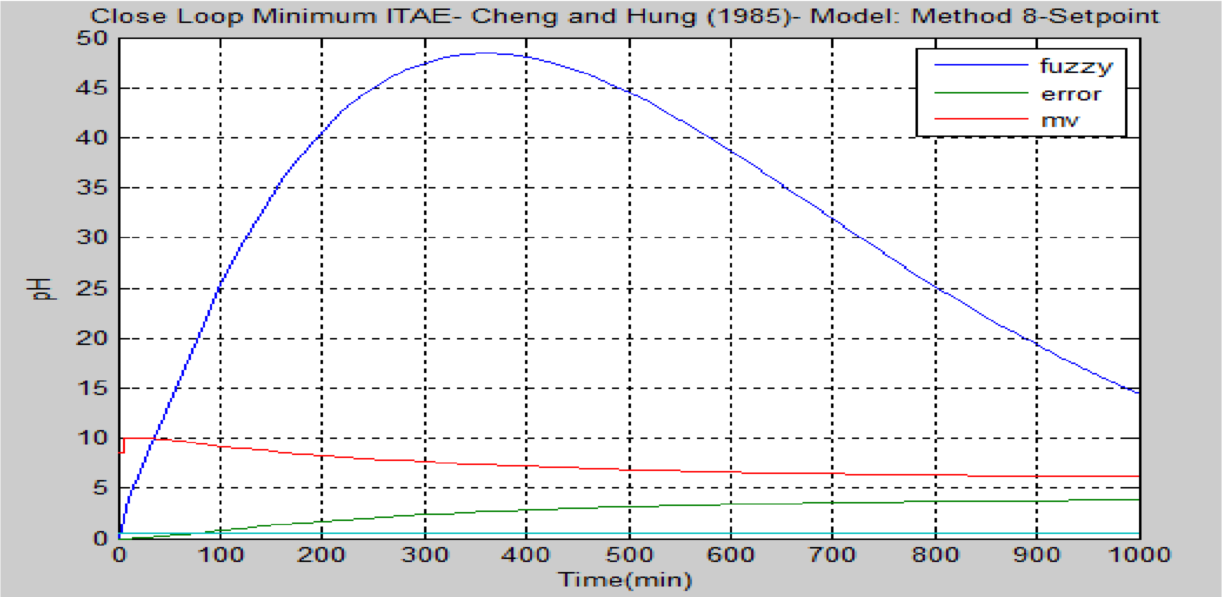
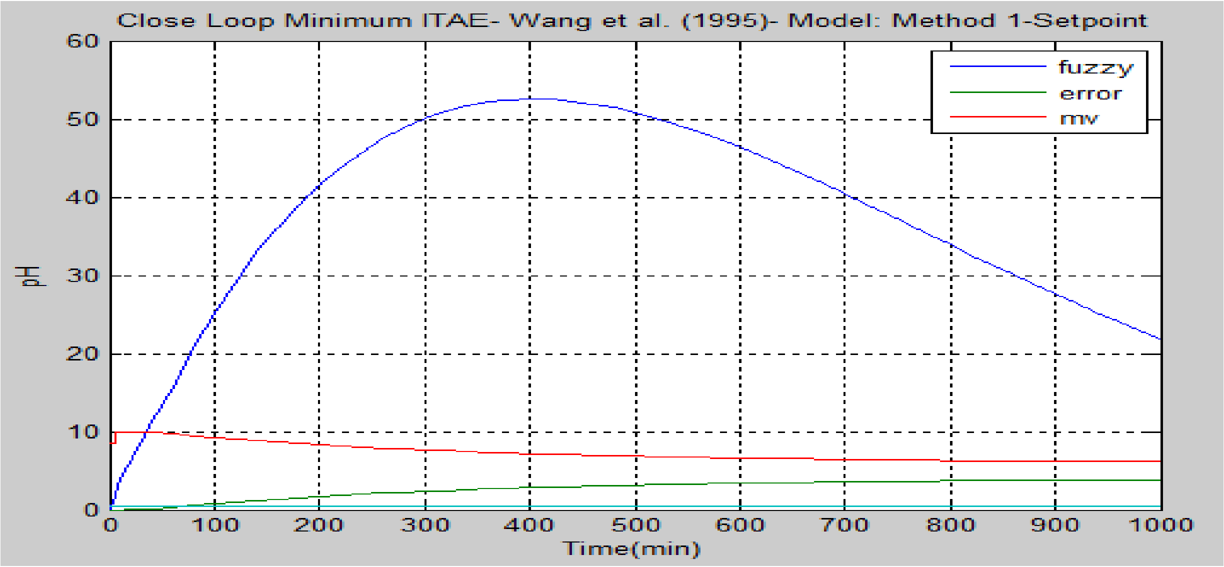
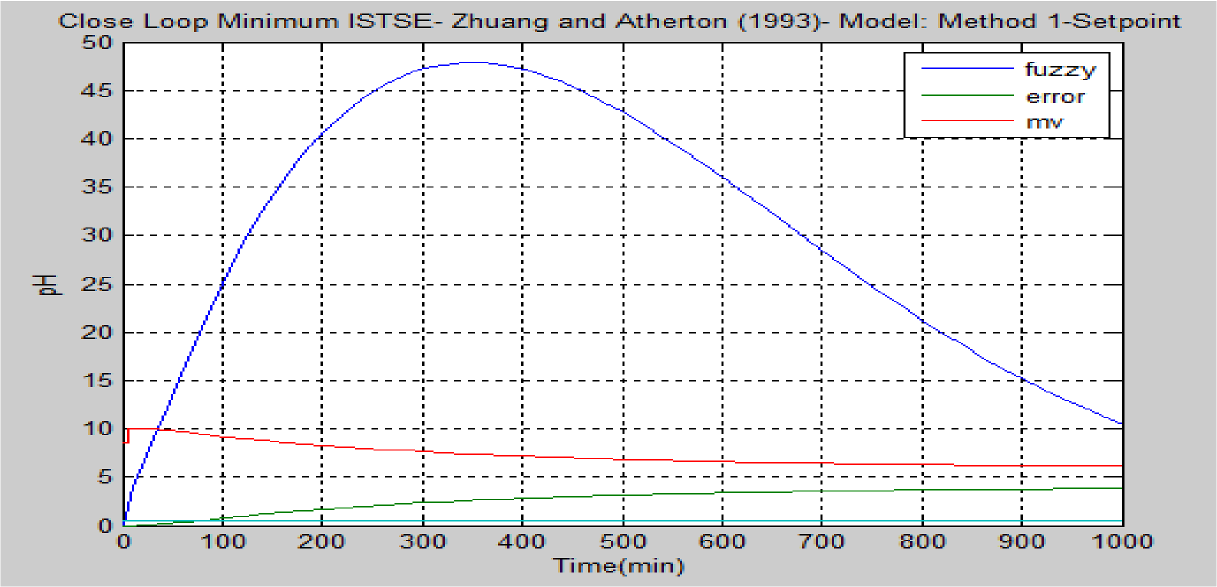


Close Loop Minimum ITAE- Cheng and Hung (1985) Model Method 8



Close Loop Minimum ITAE- Wang et al. (1995) Model Method 1



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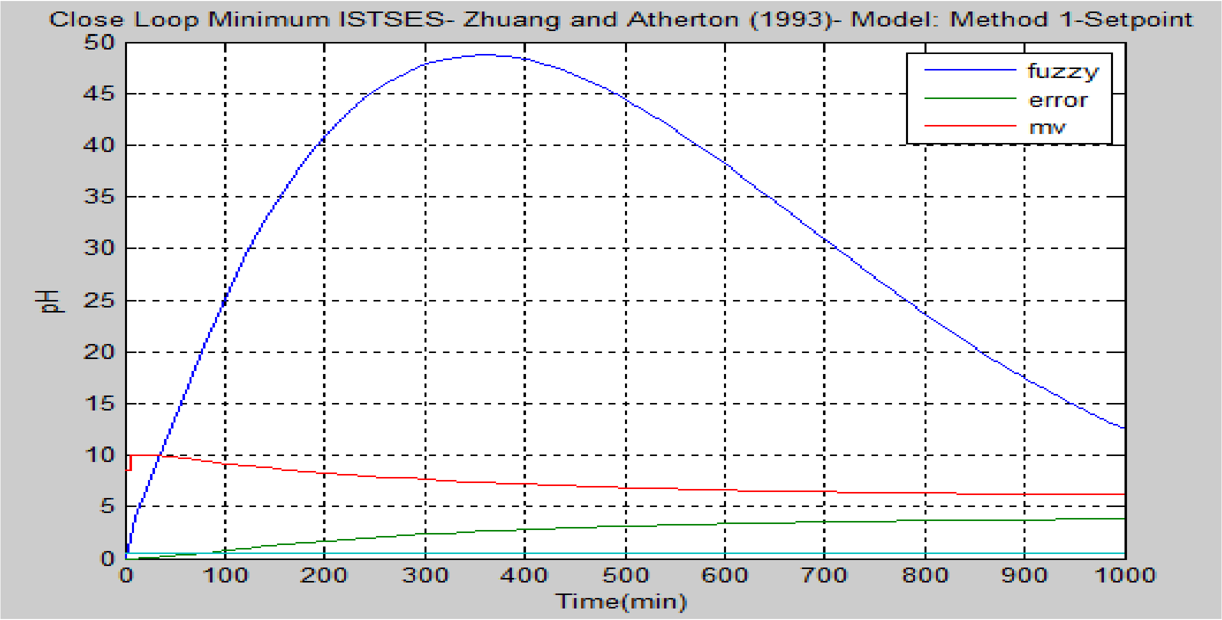
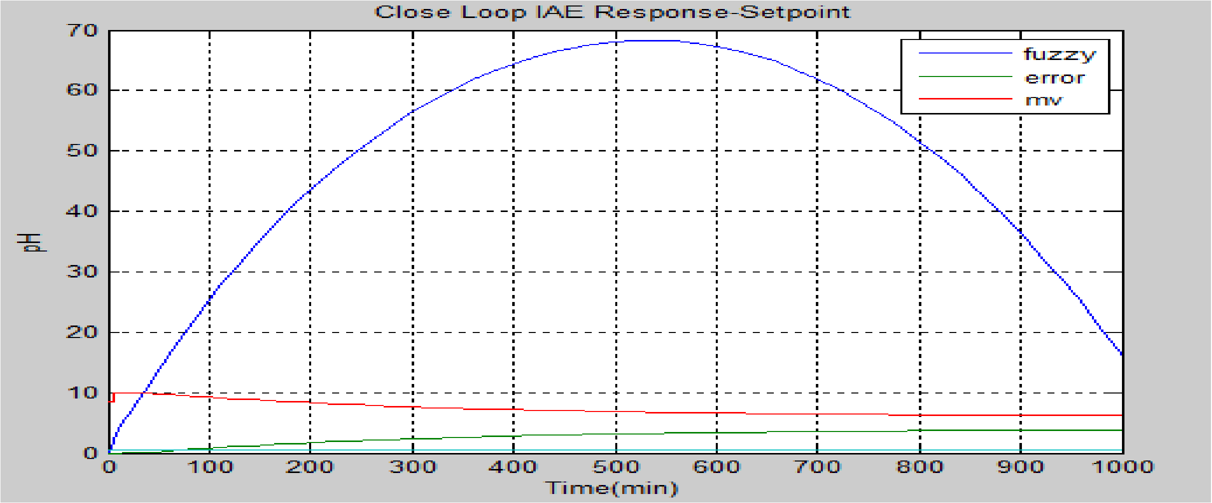
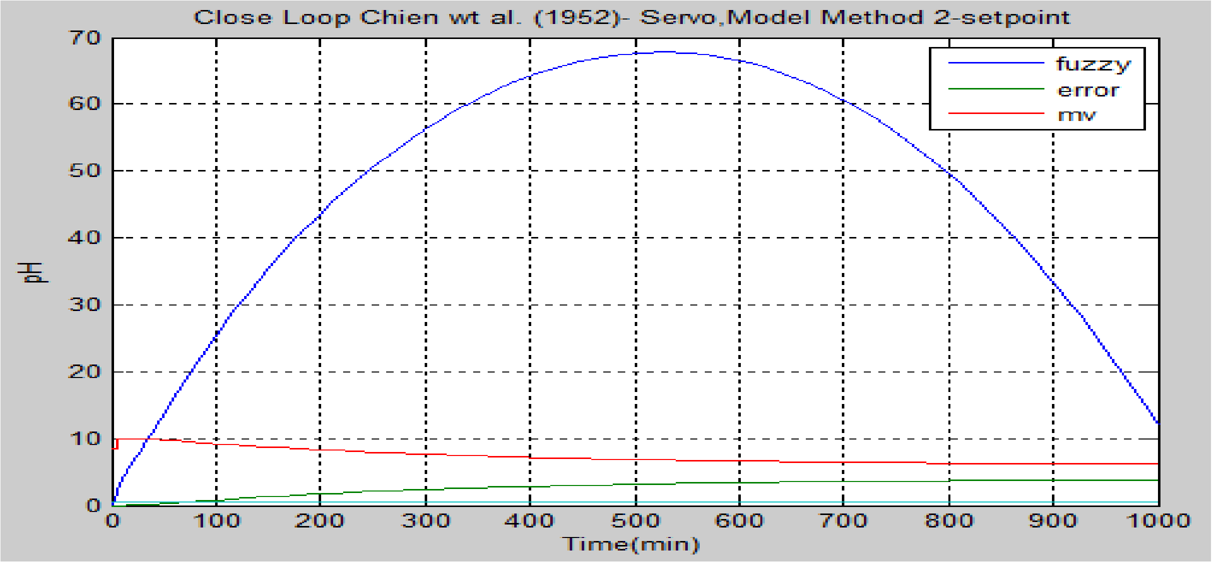


Close Loop Minimum ISTSES-Zhuang and Atherton (1993) Model Method 1

Appendix 5: Cascade Control with the Fuzzy Logic Controller



Close Loop IAE Response



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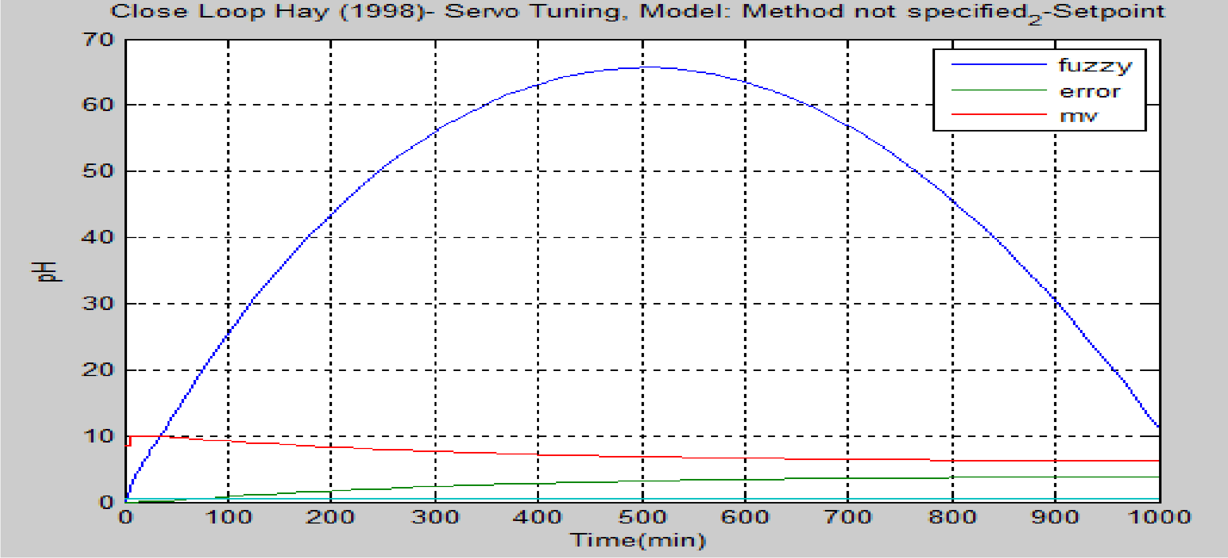

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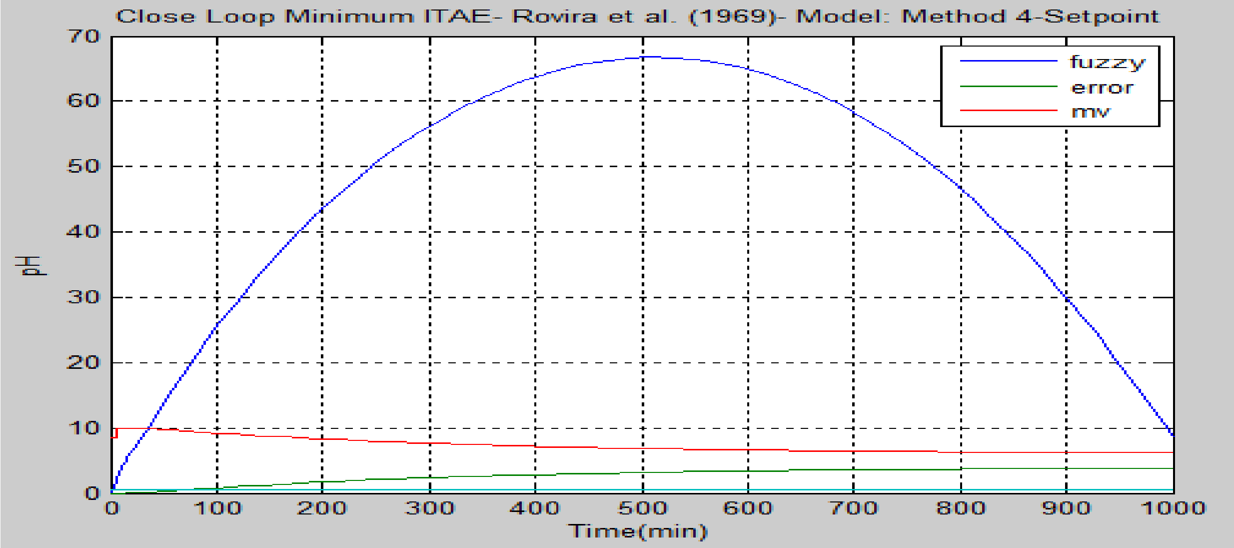

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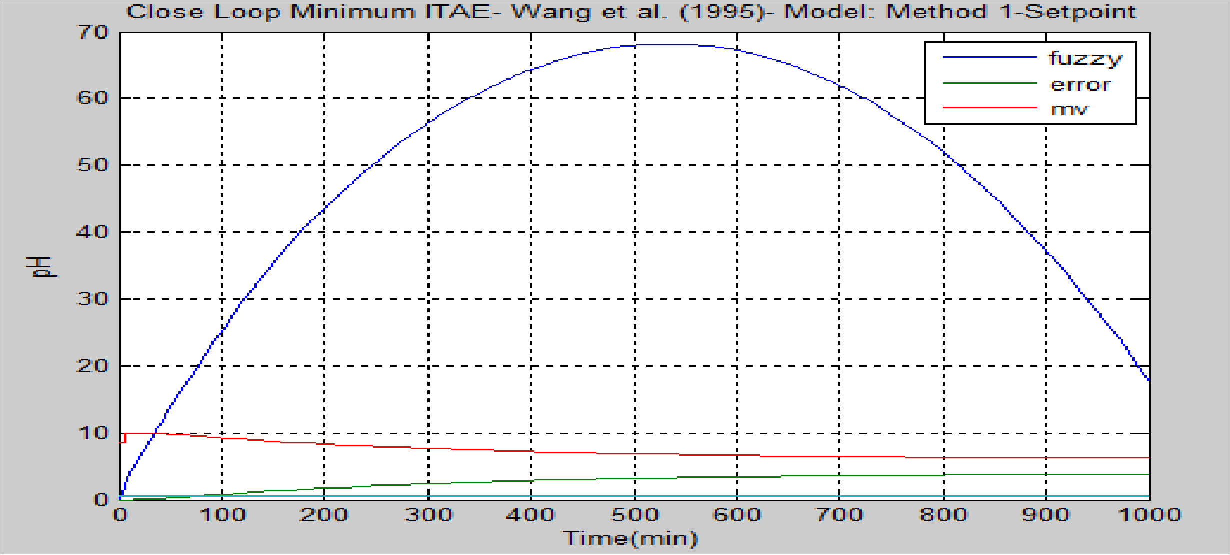

Close loop Minimum ITAE- Wang et al. (1995) Model Method 1