PLANT CONTROLLER TUNING: INVESTIGATION OF TUNING METHOD

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By

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CERTIFICATION OF APPROVAL

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Approved by,

(Ir Dr Idris bin Ismail)

(Project supervisor)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

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.

MOHAMAD YASSER BIN MOHAMMED ANUAR

ABSTRACT

This report discusses the research done and basic understanding of the proposed topic, which is **Plant Controller Tuning: Investigation of Tuning Method.** There are varieties of tuning method for a process plant, such as the linear(conventional) and non-linear tuning method. In this paper, the testing will be done on-line in UTP Pilot air plant in building 23. The problem PID parameters using conventional method are fixed from the beginning of transient response until steady state. There are many methods that have been implemented so that PID will auto tuned accordingly and have been proven to increase performance significantly in terms of error correction, response and delays. This writing will discuss 2 PID tuning methods that may be used to control a process plant which is the conventional PID controller tuning method which includes Ziegler-Nichols, Mc Millan, Parr and Mc Avvoy, and non-linear methods which include Fuzzy Logic tuner and Neural Network tuner. Further study also will be done on the combination of these tuners. Later in this project, a GUI will be developed to ease the process of choosing the best method for tuning method. The method of completing the project includes plant modeling of the pilot air plant, optimized the controller to its best performance example tuning of PID controller, next step will be comparing all the tuning methods and decide which is the best method. Result analysis will then be developed to show the difference between the performances of these methods. In this writing, fuzzy logic seem to improve the performance of PID significantly. But there are some advantage and disadvantage that will be shown throughout this writing.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my greatest gratitude to Allah the Almighty for the courage to put my plucky efforts in the Final Year Project. I would like to thank the following individual or groups for giving me moral support through out the semester.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

LIST OF ABBREVIATIONS

GUI	Graphical User Interface
IAE	Integral Absolute Error
ISE	Integral Squared Error
Kc	Proportional Gain
NB	Negatively Big
NS	Negatively Small
PB	Positively Big
PI	Proportional Integral
PID	Proportional Integral Derivatives
PS	Positively Small
Td	Derivative Time
Ti	Integral Time
UTP	Universiti Teknologi PETRONAS
Z	Zero

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Controllers are widely used in most of the application in the real world. The controller task is to produce the required system inputs that in turn result in the desired systems output. System is a collection of interacting component [1].The interconnection of the system with the controller is called the control system. There are two types of control system which is the open loop and closed loop control system. Controlled loop must be calibrated to perform according to the design of the process. There are many types of controller used in the industry, the most common controller used is the Proportional Integral Derivative (PID) controller. PID controller parameters determine its performance. In industry the parameter are fixed throughout the whole response. In this paper, non-linear tuner (fuzzy logic and neural network) will be integrated with PID so that the parameter will be automatically tuned according to the desired response

1.1.1 PID Controller

PID is one of the most common control algorithm used in industry. PID controller is based on microprocessor which provides features such as automatic tuning, gain scheduling and continuous adaptation. PID consists of 3 terms which is Proportional, Integral and Differential. The weighted sum of these elements is used to adjust the process via control element such as the position of a control valve or the power supply of a heating element. By "tuning" the three elements, PID can provide control action designed for specific process requirements. Evaluation of the PID controller is based on few criteria such as the responsiveness of the controller to an error, degree of overshoot, and the degree of oscillation.

1.1.2 Fuzzy Logic

Fuzzy Logic implements linguistic, non-formally expressed control laws. Fuzzy logic is easily understood with the term IF-THEN statement, it defines the sets of facts that must be true before a set of action cam be executed.

1.1.3 Neural Network

Artificial neural networks consist of interconnecting artificial neurons (programming constructs that mimic the properties of biological neurons). Artificial neural networks can be used for solving artificial intelligence problems without necessarily creating a model of a real biological system.

1.2 Problem Statement

PID requires proper tuning of its parameters in order to get the required output. The problem is PID parameters are kept constant throughout the whole response. The response will have two states which is transient state and steady state, the parameter of PID should be change or adapted according to the state the response is in. Several method that is going to be study so that PID parameter can be tuned according to the states are fuzzy logic tuner and neural network tuner. These tuner will then be compared with the best conventional method of PID tuning and at the same time a GUI will be develop to represent the process and which tuning method produce the best result.

1.3 Objective

To determine the best tuning method via choosing the appropriate controller and at the same time to produce a Graphical User Interface (GUI) for the researcher to predict or select the proper optimization method for a process.

1.4 Scope of Study

In this writing, the writer will study on different type of tuning method and study which method is the best in achieving the required result. The study will include research and comparison between different conventional tuning method and compare it with non-linear tuning method. The study will include the research on PID controller, this includes its component (Proportional, Integral and Differential) its stability and its conventional tuning method. Fuzzy Logic tuner will also be studied it include creating the sets of logic and implementing it on the plant. Neural network tuner will also be studied on how to tune the PID according to its state of response.

Plant modeling also will be done by the writer. Data received from the plant available in UTP will then be model to produce a transfer function, this transfer function is then implemented offline first using MATLAB and the optimization method will then be based on this transfer function. A GUI also will be developed. This GUI will help the user to choose which optimization method going to be used for a desired plant. This selection is based on many criteria such as the settling time, stability and overshot percentage.

CHAPTER 2
LITERATURE REVIEW

2.1 PID Controller

The ability of Proportional Integral Derivative (PID) controllers to compensate most practical industrial processes has led to their wide acceptance in industrial application. The PID controller has several important functions, it provides feedback, it has the ability to eliminate steady state offsets through integral action, and it can anticipate the future through derivative action. PID control is an important ingredient in distributed control system. PID is sufficient for processes where the dominant dynamics are of the second order, it needs an integral action to provide zero steady state offset and an adequate transient response by proportional action. A typical case of derivative action improving the response is when the dynamics are characterized by time constants that differ in magnitude, derivatives action can profitably be used to speed up the response. "Van Overschee and De Moor (2000) report that 80% of PID controllers are badly tuned; 30% of PID controllers operate in manual with another 30% of the controlled loops increasing in the short term variability of the process to be controlled (typically due to too strong integral action) The author state that 25% of all PID controller loops use default factory setting, implying that they have not been tuned at all" [2]. It has been found empirically that PID controller is a useful structure. The PID algorithm can be described as eq(1):

$$u(t) = K\left(e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d \frac{de(t)}{dt} \right) \text{---- eq(1)}$$

Where u is the control variable and e is the control error ($e=y_{sp}-y$). The control variable is thus a sum of three terms: the P-term(which is proportional to the error), the I-term (which is proportional to the integral of the error) and the D-term (which is proportional to the derivative of the error). The controller parameter are the proportional gain K, integral time T_i and derivative time T_d. [3]

- **Proportional term**

In the case of pure proportional control, the control law equation reduce to

$$u(t) = Ke(t) + u_b \text{----eq(2)}$$

The control action is simply proportional to the control error. The variable u_b is a bias or a reset. When the control error e is zero, the control variable takes the value $u(t) = u_b$. Bias u_b is often fixed to $(u_{max}+u_{min})/2$, but sometimes be adjusted manually so that the stationary control error is zero at a given setpoint.[3]

- **Integral Action**

The integral action is to make sure that the process output agrees with the setpoint in steady state. With proportional control, there is normally a control error in steady state. With integral action, a small positive error will always lead to an increasing control signal, and a negative error will give decreasing control signal no matter how small the error is.

A simple argument shows that the steady state error will always be zero with integral action. Assume that the system is in steady state with constant control signal(u_0), and a constant error(e_0), it follow the PID algorithm formula, the control signal is given by[3]:

$$u_o = K\left(e_0 + \frac{e_0}{T_i}t\right) \text{----eq(3)}$$

As long as $e_0 \neq 0$, this clearly contradicts the assumption that the control signal u_0 is constant. A controller with integral action will always give zero steady state error.[3]

- **Derivative Action**

The purpose of derivative action is to improved the closed loop stability. The instability mechanism can be described intuitively as follows. Because of process dynamics, it will take some time before a change in the control variables noticeable in the process output. Thus, the control system will be late in correcting for an error. The basic structure of a PD controller is

$$u(t) = K\left(e(t) + T_d \frac{de(t)}{dt}\right) \text{-----eq(4)}$$

A Taylor series expansion of e(t+T_d) gives

$$e(t + T_d) \approx K\left(e(t) + T_d \frac{de(t)}{dt}\right) \text{------eq(5)}$$

The control signal is thus proportional to an estimate of the control error at time T_d ahead, where the estimate is obtained by linear extrapolation.

2.2 Fuzzy Logic

Fuzzy logic is another controller that can be applied to tune the PID controller of the plant. It uses linguistic variables. Ordinary Boolean logic deals with quantities that are either true or false. Fuzzy logic attempts to develop a method for logic reasoning that is less sharp. This is achieved by introducing linguistic variable and associates it with membership function which will take the value of '0' and '1' [3].

Fuzzy logic has three basic structures figure below shows how an input signal is connected to the structure thus produce and output.

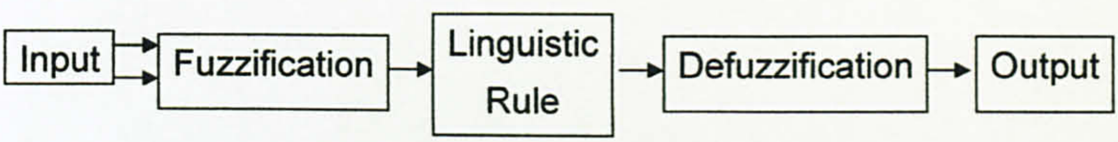


Figure 1: Fuzzy Logic Concept[7]

In fuzzification, the input were group according to its range or behavior. The group is called 'membership function'. Error and the derivatives of the error can be set as the input of the controller. The control error, which is a continuous signal, is fed to a linear system that generates the derivative of the error. The error and its derivatives are converted to so-called 'linguistic variables' in a process called fuzzification[3].

Linguistic rules are based on the linguistic variable that are assigned earlier in the fuzzification process it can ranged from 3 variable to even 8 variables or more. Variable such as Negative, Zero, Positive or Negative large, Negative medium, Negative, Zero, Positive, Positive medium, Positive large. The control strategies is expressed in terms of a function that maps linguistic variables to linguistic variables [3]. The rules can also be expressed in table form:

Table 1: Fuzzy Set of Rule

e \ de	NB	NS	Z	PS	PB
NB	*BN*	*NB*	*NS*	*Z*	*Z*
NS	*NB*	*NS*	*NS*	*Z*	*Z*
Z	*NB*	*NS*	*Z*	*PS*	*PB*
PS	*Z*	*Z*	*PS*	*PS*	*PB*
PB	*Z*	*Z*	*PB*	*PB*	*PB*

Defuzzification function as a converter to convert all the linguistic rules in to real number, thus this is used to control the variable. This can be done in several different ways consider a linguistic variables A with the membership function $f_A(x)$. Defuzzification by mean value gives the value [3]

$$x_0 = \frac{\int x f_A(x)dx}{\int f_A(x)dx} \text{-----eq(6)}$$

Defuzification by centroid gives a real variable x_0 that satisfies

$$\int_{\infty}^{x_0} f_A(x)dx = \int_{x_0}^{\infty} f_A(x)dx \text{-----eq(7)}$$

2.3 Neural Network

Neurocomputing also called brain-like computation. Neural network purpose are to build a structure of computers that is similar to organization of the brain. Brain is the most complex natural information processing system. It is able to perform computation in a very efficient way [3].

Neural network have the abilities to self-learning the process is the main factors that this controller become increasingly important and in demand. According to Psaltis, et al [8], neural network controller self learning method can be categorized into two parts which is general learning and specialized learning. A general learning, the network is trained offline to learn the plant inverse dynamics where a set of input and a set of output is obtained and thus a set of training pattern are selected. A specialized learning is more complex where it is applied while the plant is online, this means that a set of actual output sample is obtained and the weight is adjusted so that the output of the controller agrees with the actual output.

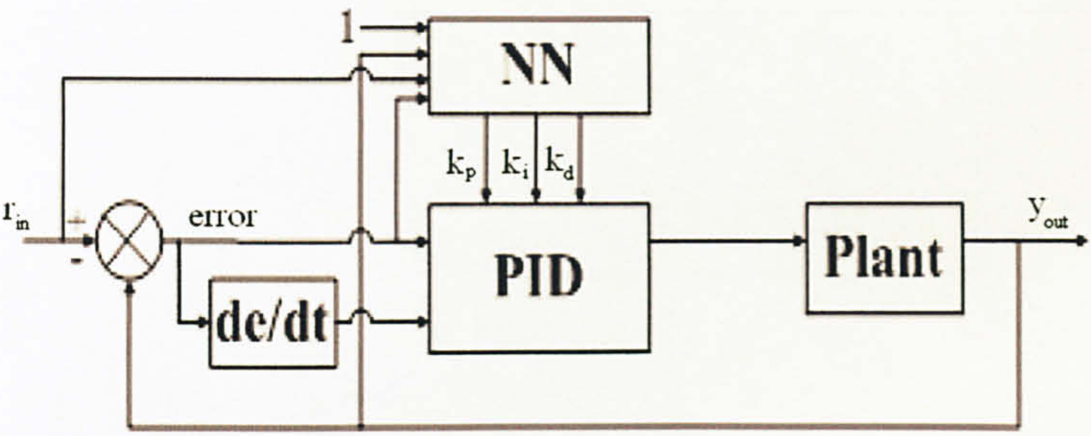


Figure 2: A feedback neural network tuner scheme [9].

A research has been done by Jiaming K and Jinhao L [9]. shows that a neural network is a good controller in terms of error correction caused by disturbance. The neural network is also good in terms of response compared to the conventional controller PID. The research have been done using multilayered back propagation while offline or via general learning as mentioned earlier.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The solution method to determine the most proper optimization method using different type of controller and developing GUI for choosing the proper optimization method are stated below:

1. Plant Modeling
2. Develop Simulink Model and Tune PID Using Several Method
3. Select Best Response and Compare Between The Best Response
4. PID Tuning Result and Analysis
5. Develop GUI for all the method tested.

The experiment will be based on pressure pilot air plant which is located in building 23 in UTP. This project is to controlled the pressure level in VL 212 tank which is shown below in the schematic diagram:

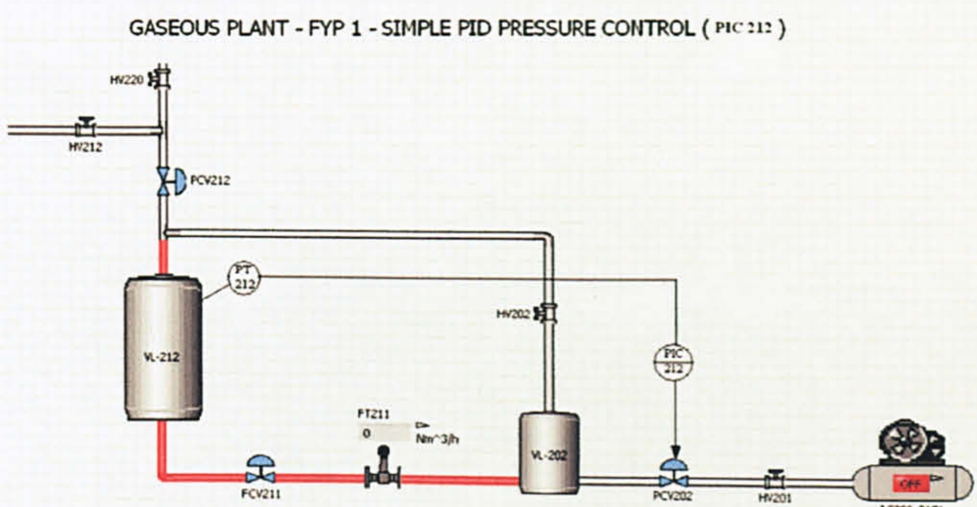


Figure 3: Schematic Diagram of Pressure Pilot Plant in Block 23 in UTP

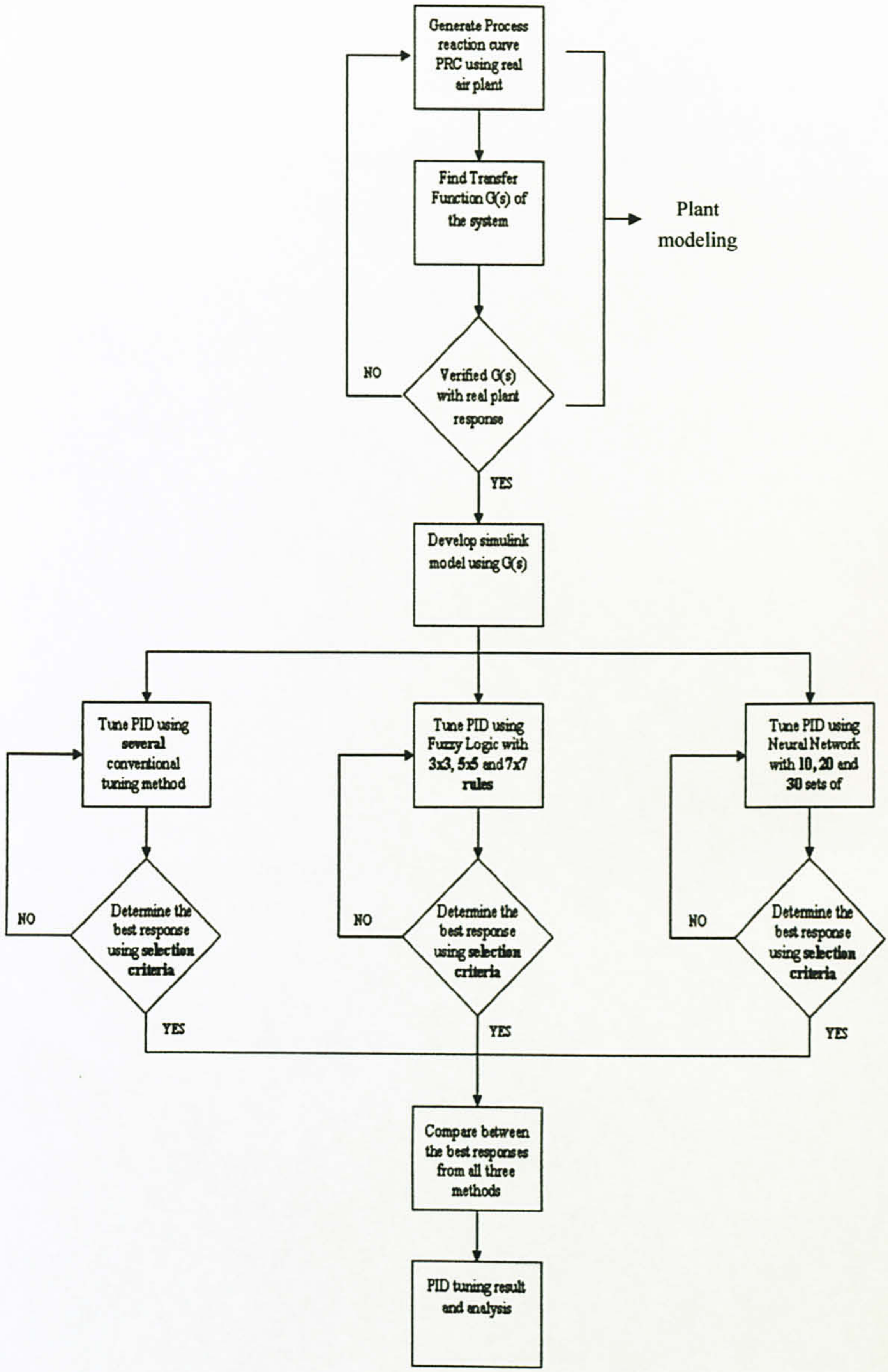
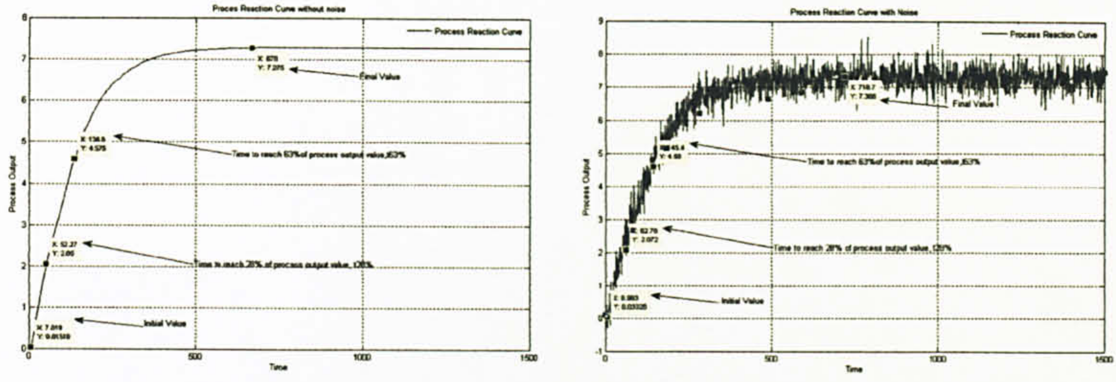


Figure 4: Flow Chart

3.1.1 Plant Modeling

Plant modeling is essential for this project as the accuracy of the model determines the quality of tuning when applied to the real time plant. An open loop test has been done to the pilot air plant in UTP to obtain its model.



(a) Process Reaction Curve without Noise (b) Process Reaction Curve with Noise

Figure 5: Process reaction Curve without(a) and with(b) noise

In this writing, the model will be done using **method 2** proposed by Marlin, Thomas E (2000), here is how the model is calculated:

$$\tau = 1.5(t_{63\%} - t_{28\%})$$
$$Kp = \Delta / \delta$$
$$\theta = t_{63\%} - \tau$$
$$\therefore G(s) = \frac{Kpe^{-\theta s}}{\tau s + 1}$$

Where,

- Input Change, δ
- Output change,Δ
- Time constant, τ
- Dead time, θ
- Gain, K_p
- Time at 63% and 28% of response, $t_{63\%}, t_{28\%}$
- 1[st] order transfer function, G(s)

3.1.2 Develop Simulink Model and Tune PID Using Several Method

PID controller is tune using several method which is Ziegler Nichols [4], Mc Avoy[2], Parr [6], and Mc Millan[2]. In PID controller, there are many algorithms such as P, PI, PD and PID based on all its elements. The author had decided to test based on just two algorithms which is PI and PID. The methods of tuning chosen are as shown below:

Table 2: Tuning Method Parameter Calculation for PID Algorithm

	K_c	T_i	T_d
Ziegler Nichols [4]	$0.6K_u$	$P_u/2$	$P_u/8$
Mc Avoy	$0.54K_u$	P_u	$0.2P_u$
Parr(pg191)	$0.5K_u$	P_u	$0.25P_u$
Parr(pg193)	$0.5K_u$	$0.34P_u$	$0.08P_u$
Mc Millan	$0.5K_u$	$0.5P_u$	$0.125P_u$

Table 3: Tuning Method Parameter Calculation for PI Algorithm

	K_c	T_i
Ziegler Nichols [4]	$0.45K_u$	$P_u/1.2$
Parr(pg191)	$0.5K_u$	$0.43P_u$
Parr(pg192)	$0.33K_u$	$2P_u$
Mc Millan	$0.3571K_u$	P_u

K_u, is the ultimate gain. This gain brings the system into marginally stable state at the critical frequency. The period of oscillation of the system at marginally stable is called ultimate period, P_u. Both K_u and P_u can be obtained from the transfer function using bode plot.

Comparison of all the tuning method chosen will be based on the process output response. The best tuning method is obtain from the best criteria of IAE and having overshoot less then 50%.

Fuzzy Logic tuner is developed using MATLAB toolbox function. In fuzzy logic the steps taken to developed it shown below:

- Developed membership function
- Developed the rules of tuner
- Implement it to tune PID
- Continue to develop fuzzy with more different set of rule 3x3, 5x5 and 7x7

Neural network is then developed. Steps taken in developing neural network tuner are as below:

- Develop training data or take data from the best fuzzy tuning method
- Train networks with data selected.
- Develop network with different numbers of neurons in hidden layer

3.1.3 Select Best Response and Compare Between The best response

Control loop efficiency are test using method such as Integrated Absolute Error (IAE), and Integrated Squared Error (ISE). The Criterion is a natural choices in many case [3]. The drawback of this method is that it require significant computations or simulation of the process meaning that it requires a large amount of time for simulation before an accurate result is obtain

$$IAE = \int_{0}^{\infty} | e(t) | \, dt \quad \text{----- eq (8)}$$

The best response will be the smallest **IAE value** and the **overshoot** of both Manipulated Variable (MV) and Control Variable (CV) does not exceed 50%. In the real world situation, percentage of overshoot will affect the cost and life cycle of final elements.

Settling time should be considered. Settling time is an important factor in a critical process where certain pressure is required to produce a product at a specific time.

3.1.4 PID Tuning Result and Analysis

All the method of tuning will then be analyze, the analysis will be based on performance, error, overshoot and difficulty in constructing the tuner.

3.1.5 Develop Graphical User Interface (GUI)

Develop GUI for user to select the proper optimization method for a desired process. The GUI is develop using GUIDE application available in MATLAB. Since developing a GUI is necessary in this project, the author decide to develop a GUI for PID controller, this GUI will later on be connected to another GUI that user will be able to chose the optimization method for a specific process.

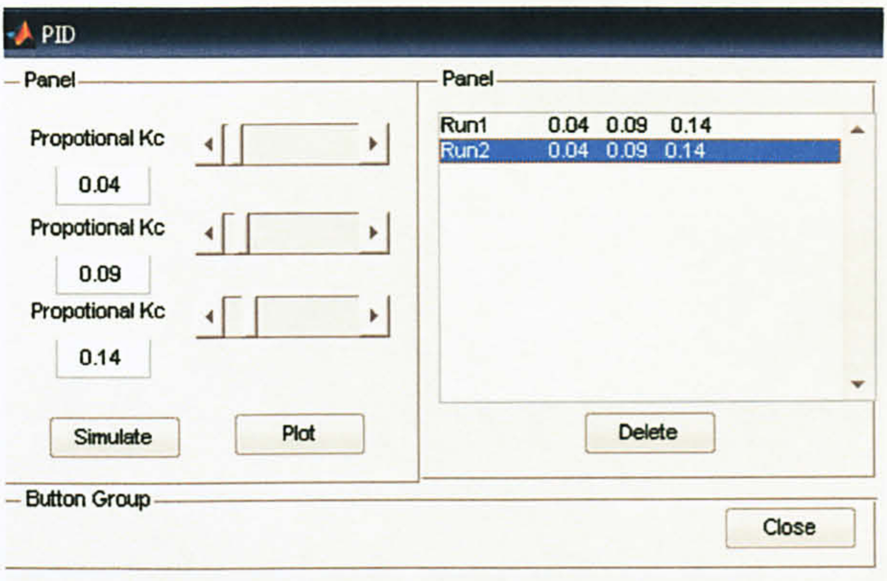


Figure 6:GUI Editor

There are still some issues with the GUI. A button must be created so that it can load all the necessaries data such as P,I and D into the online system in order for it to be applied to a real time plant.

3.2 Tools and Software Used

The software used to solve the equation and for comparative analysis:

1. **MATLAB™** - Matlab is a numerical computing environment and programming language which allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other language

2. **Pressure Gaseous Pilot Plant**- A plant which is located on 23-00-08, this plant is used to study the characteristic of variable pressure. This is where the controller is applied online.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Plant Modeling

The transfer function is obtained using **method 2** as explain earlier in the methodology. Here is the calculation used to obtain the transfer function:

$$G(s) = \frac{0.1458e^{-6.75s}}{102.75s + 1} \text{ ----eq(9)}$$

$$\begin{aligned}
&\Delta = 3.402 - 1.944 = 1.458 \\
&\delta = 40\% - 30\% = 10\% \\
&Kp = 1.458/10 = 0.1458 \\
&t_{63\%} = 109.5 \\
&t_{28\%} = 41 \\
&\tau = 1.5(109.5 - 41) = 102.75 \\
&\theta = 109.5 - 102.75 = 6.75
\end{aligned}$$

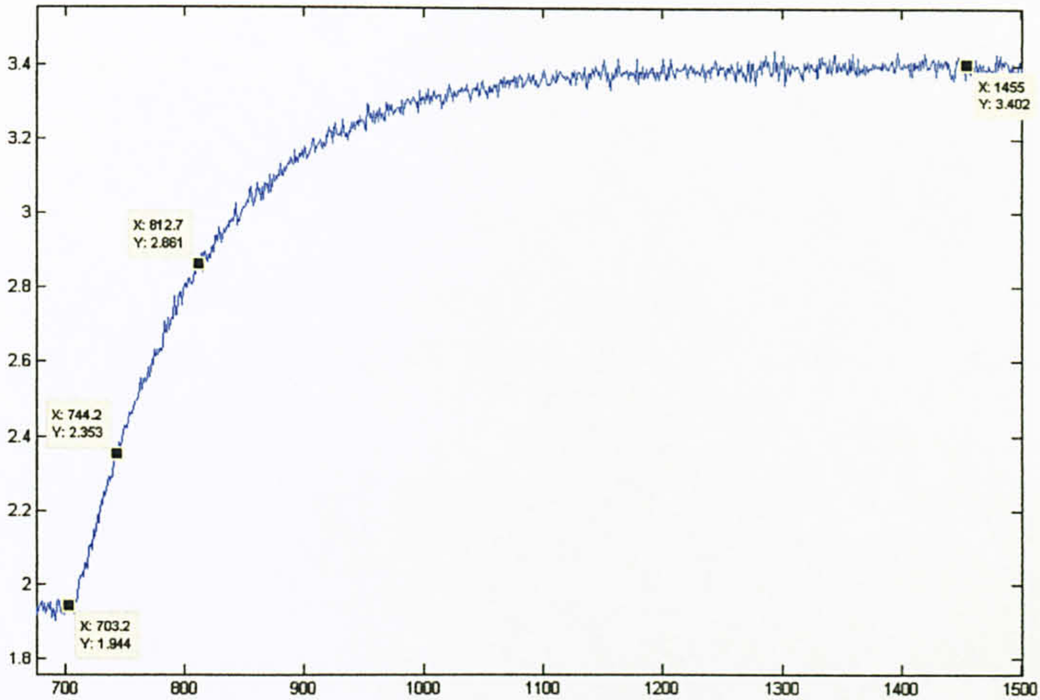


Figure 7: Process reaction Curve

To verify the model is according to the model, the model is then plotted with the process reaction curve of the real time plant.

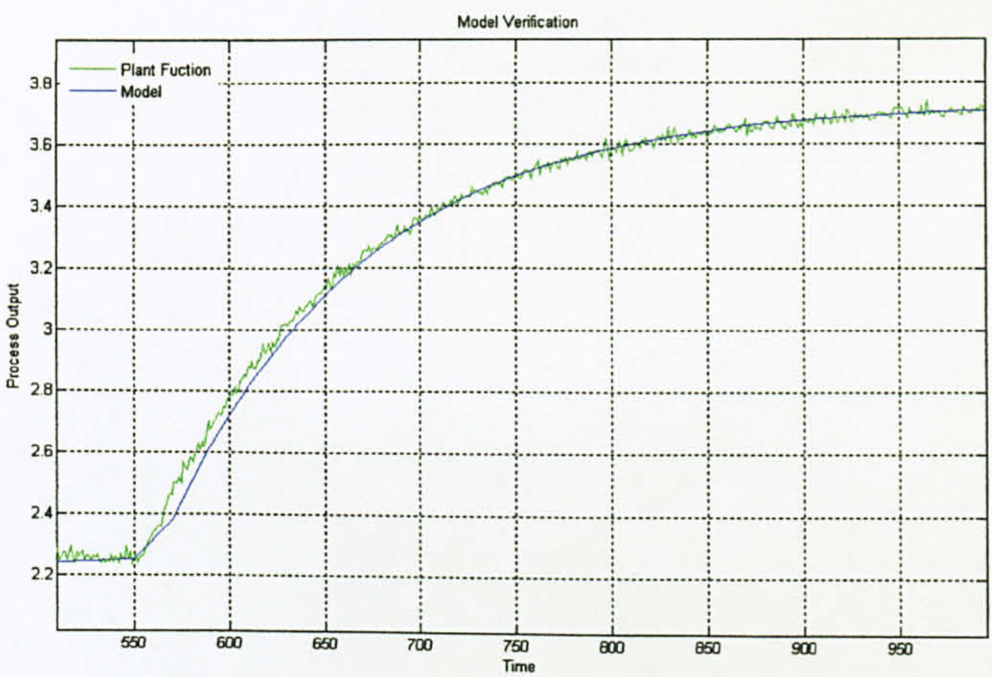


Figure 8: Verification of Model

The shape of the actual response and the model response are same, so the model is verified that it is according to the actual plant. The model is not in the same line as the actual response is due to setting up the parameter of bias.

The model then be used in simulink for testing, here is the model of simulink for testing.

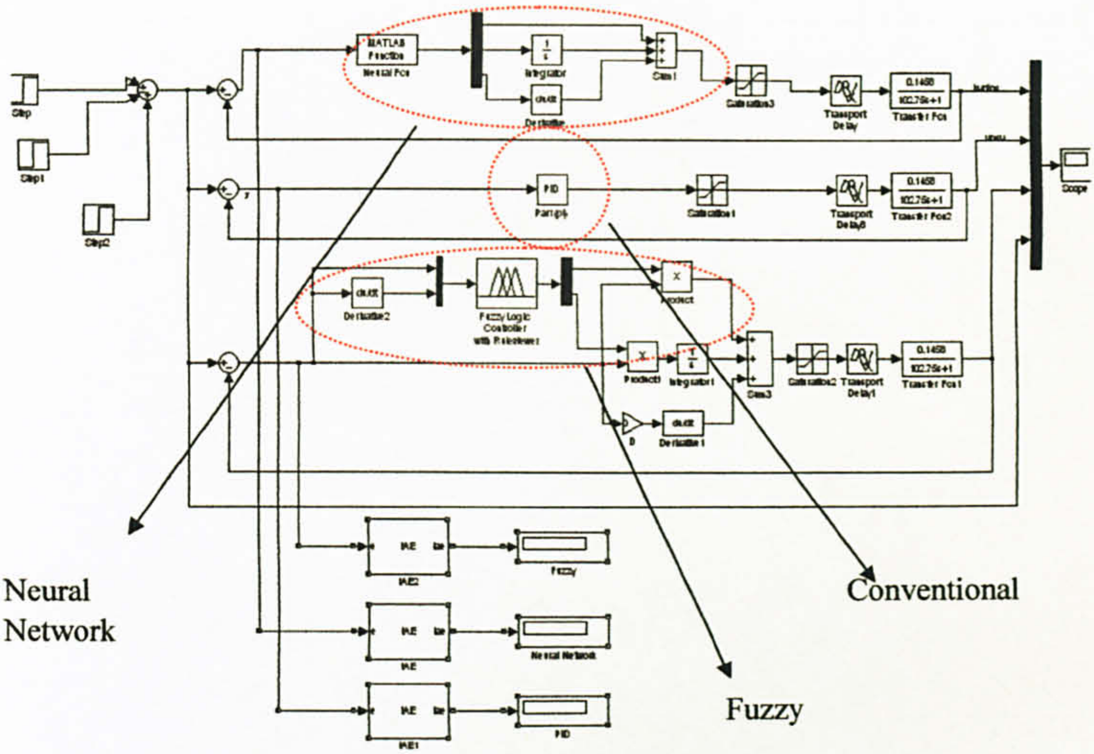


Figure 9: Simulink Model for all methods of tuning

4.2 Conventional Tuning method

There are many methods that can be found in Adian O [2], but there are only few method that are applicable to this plant because of the normalized delay value is less then 0.1

$$\frac{\tau}{T} < 0.1 \text{ ------eq(10)}$$

This parameter had reduced the number of method that can be used for tuning the plant.

The K_u and P_u are first need to be obtained using bode plot, diagram below shows a bode plot obtained from the transfer function of the model:

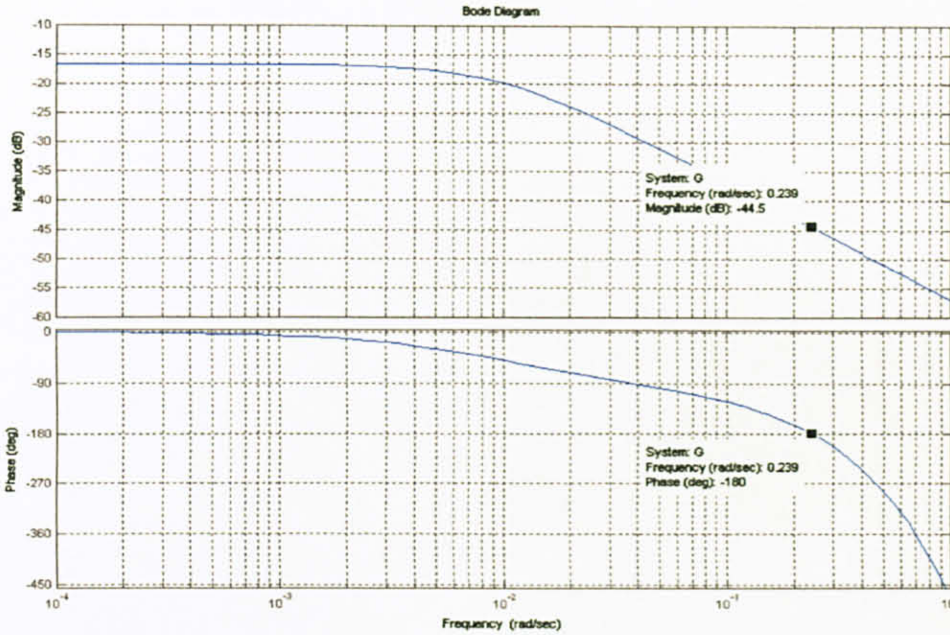


Figure 10: Bode Plot

From this bode plot, the value of Ku can be obtained using the formula

$$K_u = \frac{1}{anti\log\left[\frac{magnitude}{20}\right]} = \frac{1}{anti\log\left[\frac{-44.5}{20}\right]} = 167.88$$

$$P_u = \frac{2\pi}{60[frequency]} = \frac{2\pi}{60[0.238]} = 0.44$$

Here are the parameters calculated and used in process of tuning using PID algorithm, the table also shows the value of IAE and ISE for the method:

Table 4: Value of Parameter Kc,Ti and Td

PID	Kc	Ti	Td	IAE
Z-N	100.73	0.22	0.027	643
Mc Avoy	90.66	0.44	0.088	659.9
Parr (pg191)	83.94	0.44	0.11	660.8
Parr (pg 193)	83.94	0.1496	0.035	694.4
Mc Millan	83.94	0.22	0.055	642.2

Here are the parameters calculated and used in process of tuning using PI algorithm, the table also shows the value of IAE for the method:

Table 5: Value of Parameter Kc and Ti

PI	Kc	Ti	IAE
Z-N	75.546	0.3667	631.1
Parr (pg 191)	83.94	0.189	653.5
Parr (pg192)	55.4	0.88	799.7
Mc Millan	59.95	0.44	608.1

From the table, we can see that the best conventional tuning method is from Mc Millan

4.3 Fuzzy Logic

The next step is to develop a fuzzy logic tuner, according to Visioli [11], a fuzzy logic tuner can be developed using model as displayed below:

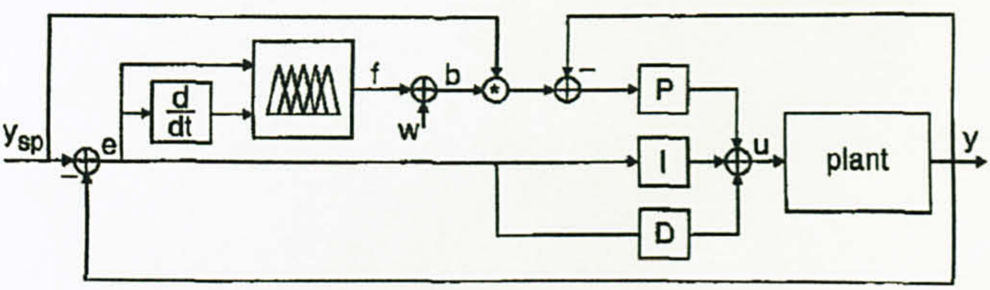


Figure 11: Fuzzy Tuner [11]

As stated in section plant modeling, the simulink model has already been done. The model implemented is a bit different from Visoli's model as the model develop also tuned the integral parameter. In order to implement fuzzy, the membership function must first be assigned. A variety of membership function was design based on it dimension of rules which 3x3, 5x5 and 7x7. 3x3:

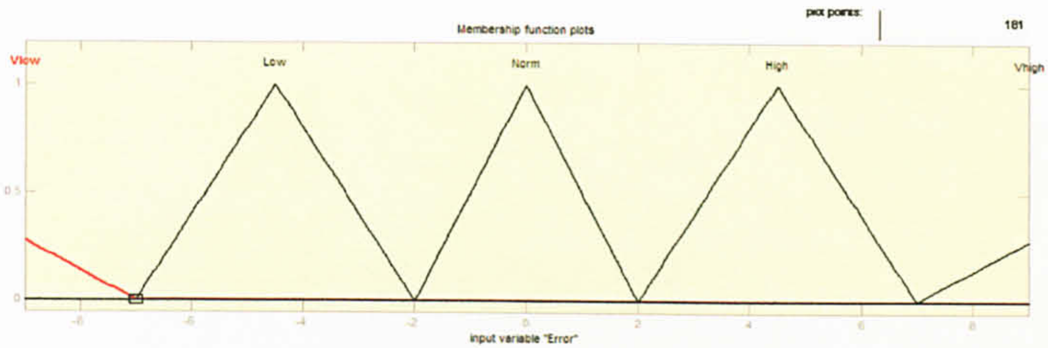


Figure 12: Error MF for 5x5

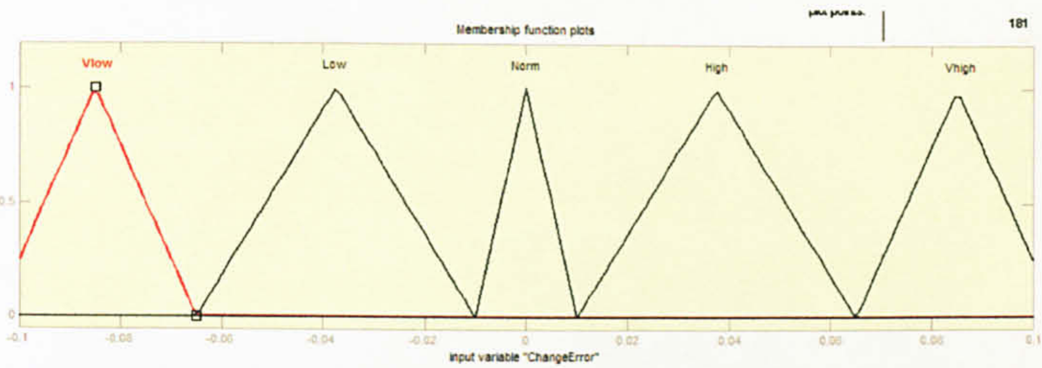


Figure 13: Change of Error MF for 5x5

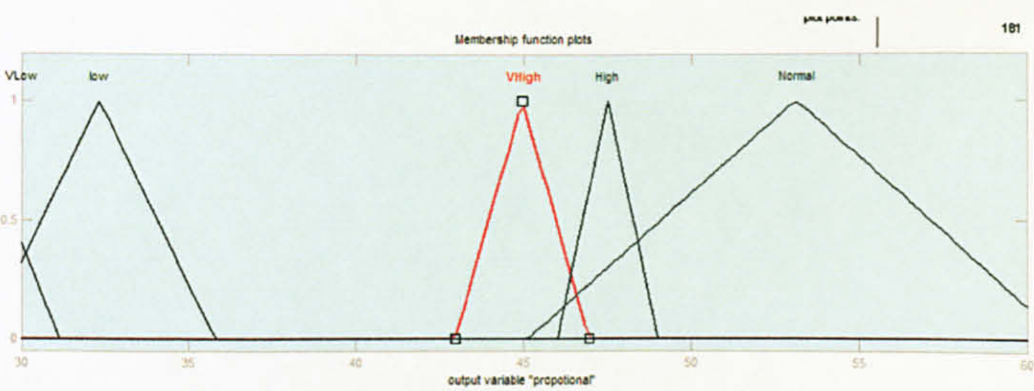


Figure 14: Proportional MF for 5x5

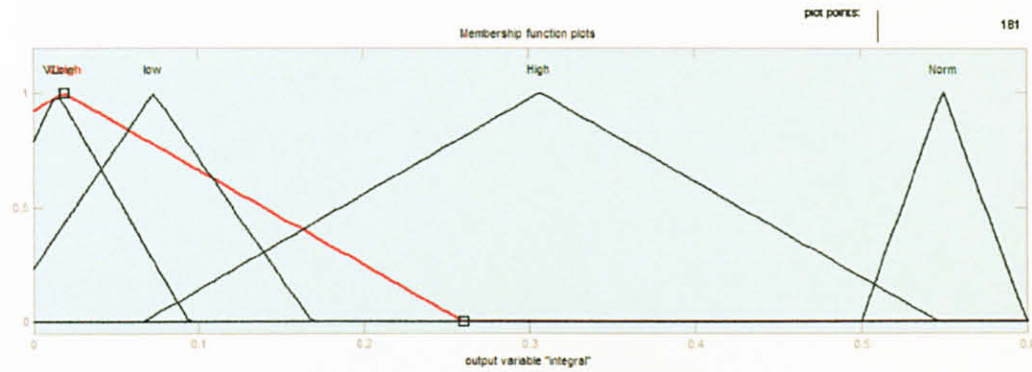


Figure 15: Integral MF for 5x5

Table 6: Rules of 5x5 Fuzzy Logic

e \ de	Vlow	Low	Norm	High	Vhigh
Vlow	VH	VH	VH	L	VL
Low	H	H	H	L	VL
Norm	H	N	N	L	VL
High	H	H	H	L	VL
Vhigh	VH	VH	VH	L	VL

Table 7 shows the rule of 5x5 fuzzy logic that seems to suit the plant response and is according to rule of thumb purposed by K J Astrom and T Hagglund [11]

Table 7: Rule of Thumb

	Speed	**Stability**
Kp Increases ↑	Increases	Reduces
Ti Increases ↑	Reduces	Increases
Td Increases ↑	Increases	Increases

From these rules of thumb, we can conclude that the higher the level of error (when the system in transient state) , the smaller value of constant Kp and Ti.. as the value of Ti becam smaller, the process become more faster to reach steady state and as Kp value become smaller, it tends to make the system more stable or lessen its percentage of overshoot.

When the error is quite small (Almost reach steady state), the value of Kp and Ti should be increase. When the value of Ti is increase, the system tends to become more stable and as Kp increase the speed of the system tends to increase if there are any change on setpoint.

Figure 14,15 and 16 shows the result of comparison between 3 different fuzzy rules and comparison with PID tune using Mc Millan

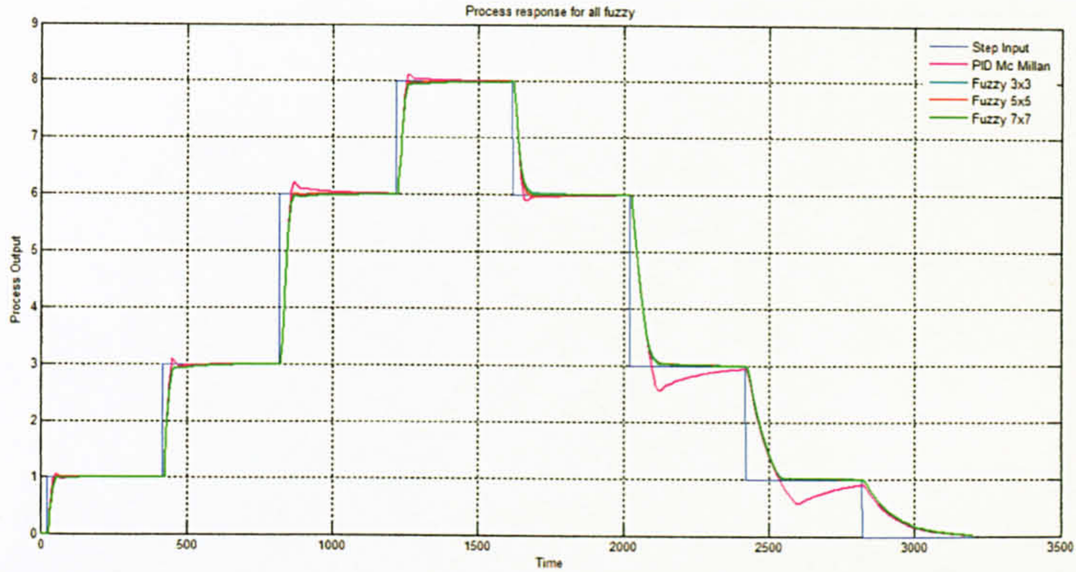


Figure 16: Comparison between conventional PID method Mc Millan and 3 different fuzzy rules 3x3, 5x5 and 7x7

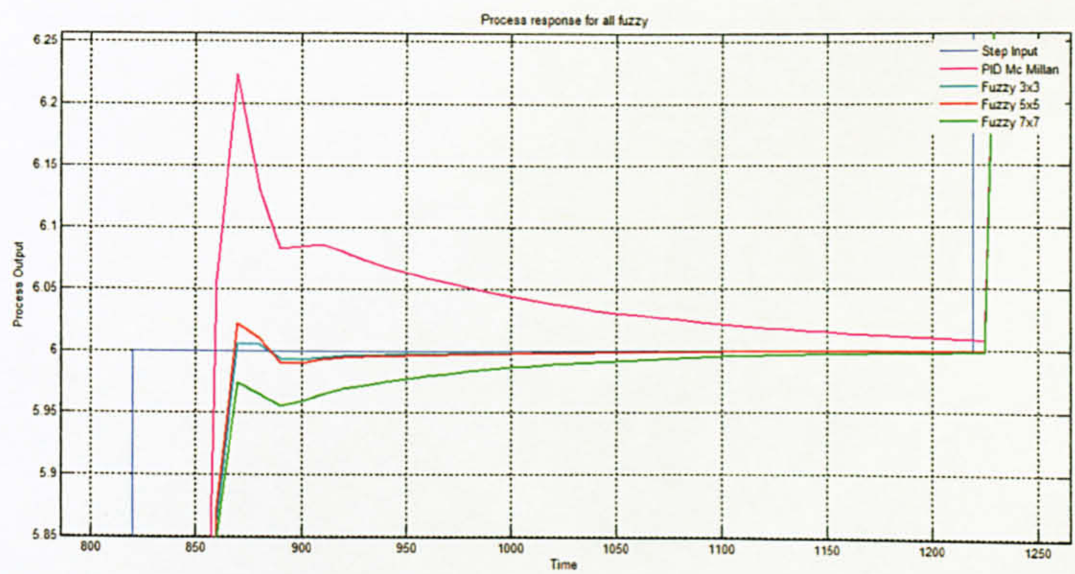


Figure 17: for setpoint of 6 bar

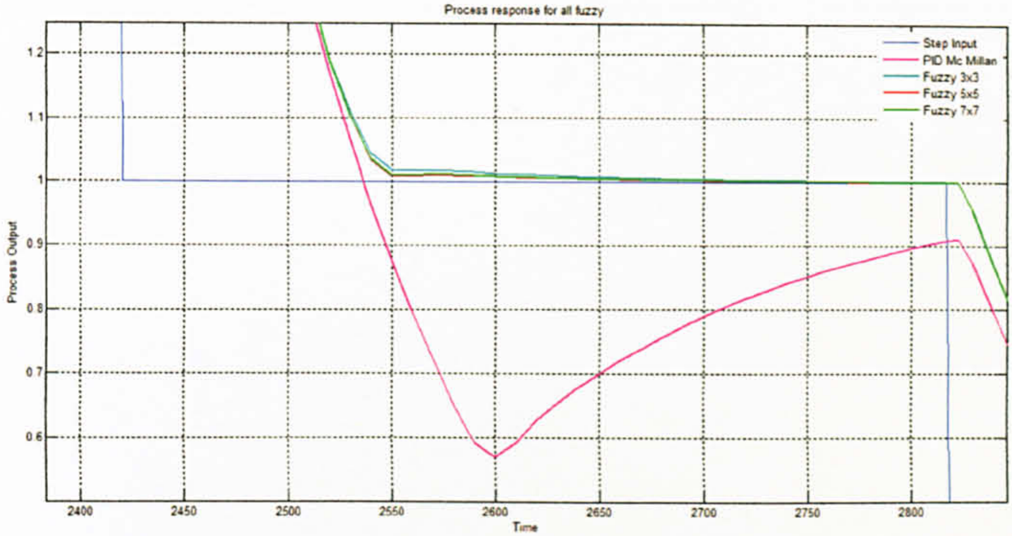


Figure 18: For setpoint decrease from 3 bar to 1 bar

From the plot we can clearly see that fuzzy tuner using 5x5 rules significantly improve the response of PID controller. The result has improved significantly by 18%. These figures are obtained from comparison between IAE value states below in the table 8:

Table 8: Comparison between PID and Fuzzy

Method	IAE Values
Mc Millan	608.1
3x3 fuzzy	546.4
5x5 fuzzy	539.2
7x7 fuzzy	549.4

4.4 Neural Networks

For neural network, the model has been developed and it is shown in the plant modeling section. The network will consist of one input error and 3 output P,I and D the tuning parameter for PID controller. Figure 17 shows the developed network:

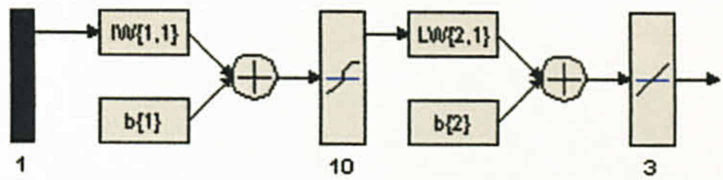


Figure 19: Neural Networks Using 10 Neurons

The network was first train with a set of data developed by the author according to experience in tuning PID. After the network have been train, it is then applied to the simulink model the result is obtain

In this project, the configuration of neural network is varied by its number of neurons which is at 10 neuron, 15 neuron and 30 neurons. From the result obtained, the best configuration is from 10 neurons. Table below show numerical comparison of IAE value

Table 9: Comparison between Different Neurons Configurations

Methods	IAE
10 neurons	559.6
15 neurons	564.3
30 neurons	564.6
Mc Millan	608.1

Below shows the graphical result of controller tuning compared with conventional tuning method and Fuzzy 5x5:

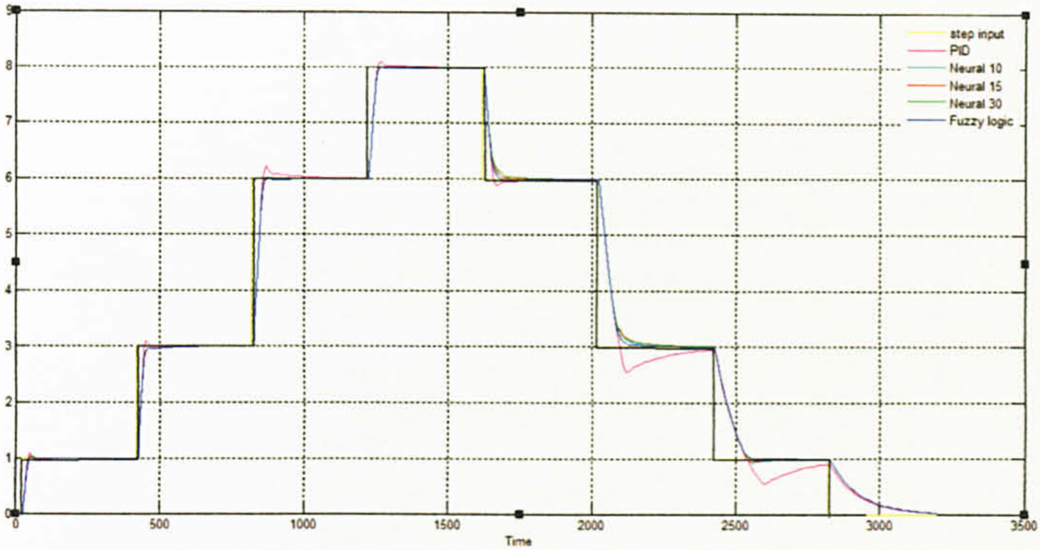


Figure 20: Comparison between neural network with neurons of 10, 15 and 30 compared to Mc Millan method and Fuzzy logic 5x5 method

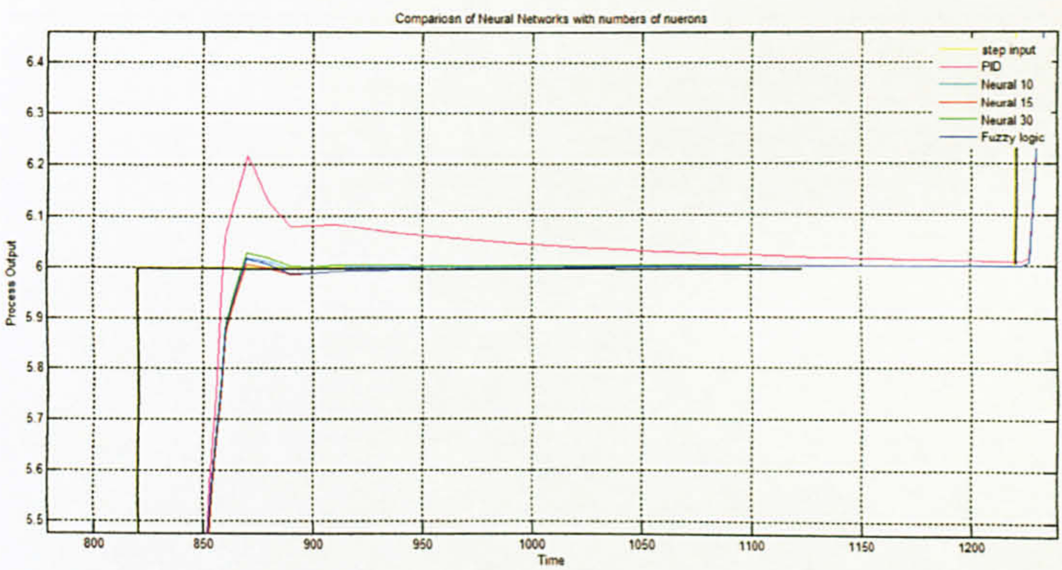


Figure 21: Setpoint changes from 3 bar to 6 bar

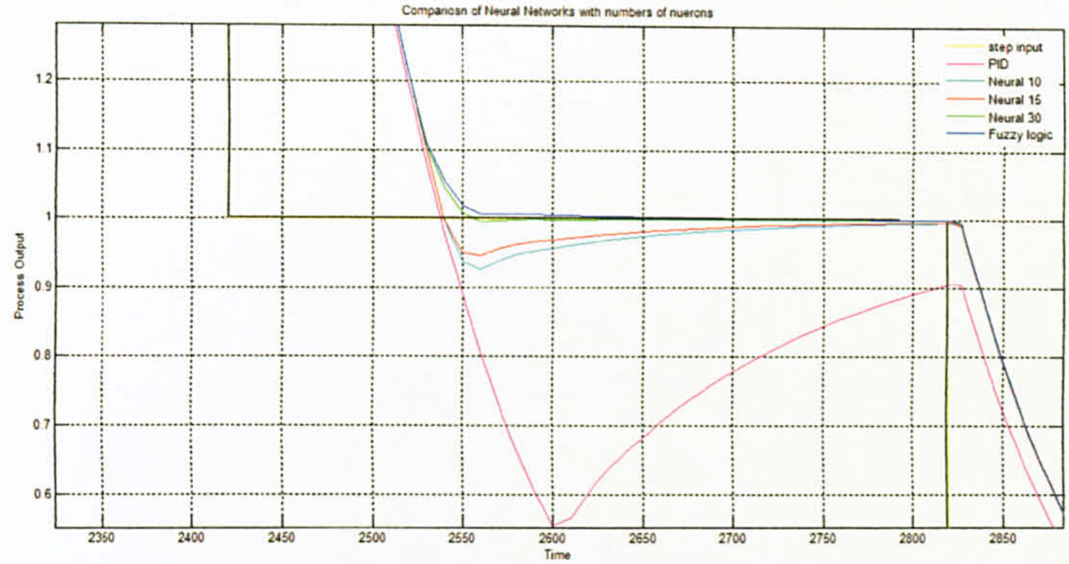


Figure 22: Setpoint changes from 3 bar to 1 bar

Both graphical and numerical have shown that the best number of neurons to be used for neural network tuner would be 10 neurons. But results have shown that fuzzy generates slightly better result compared to neural networks. With higher neurons in the hidden layers, the complexity of the system becomes more complicated. With a more complicated system, the system needs more training in order to obtain the best result, since the level of training is et to constant at 100 epochs, the effectiveness of neural networks in handling error with higher number of neurons in hidden layer is reduce.

4.5 Comparison Result

From the simulation done, the best method from each method is compared together and the result is shown below:

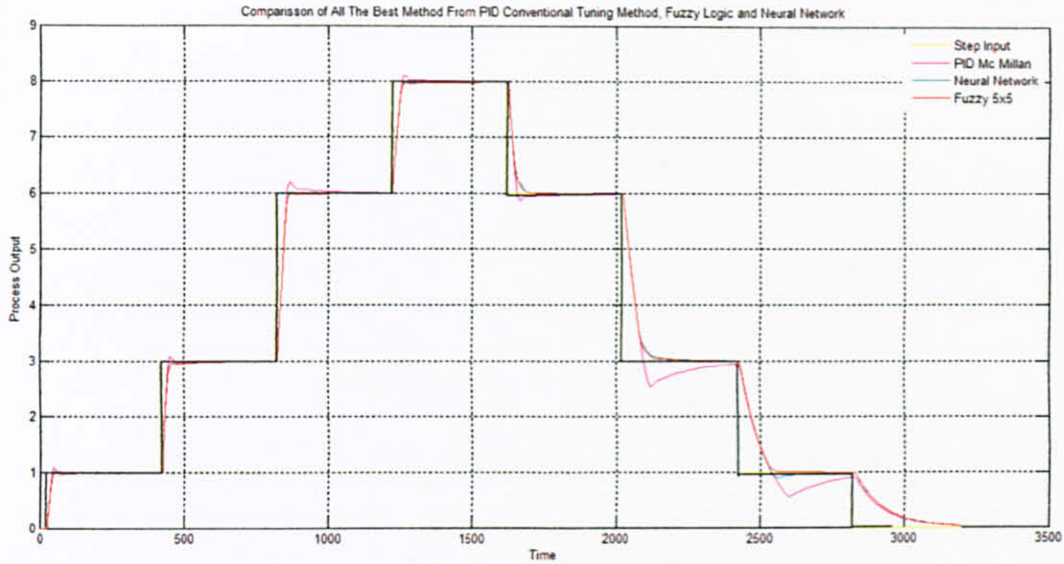


Figure 23: Comparison between Mc Millan Tuning Method, Fuzzy logic 5x5 and Neural Network with 10 neurons

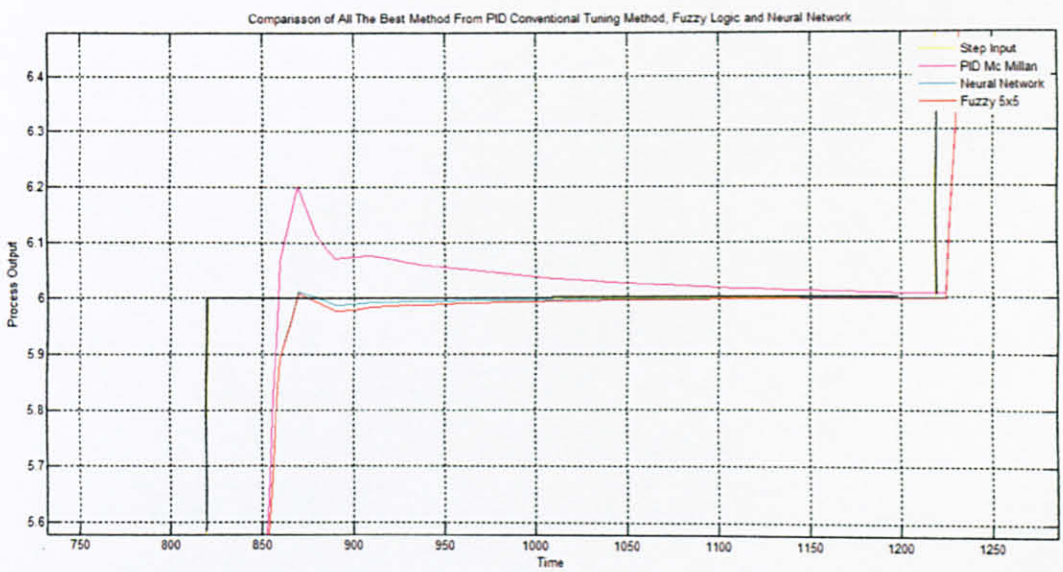


Figure 24: Setpoint changes from 3 bar to 6 bar

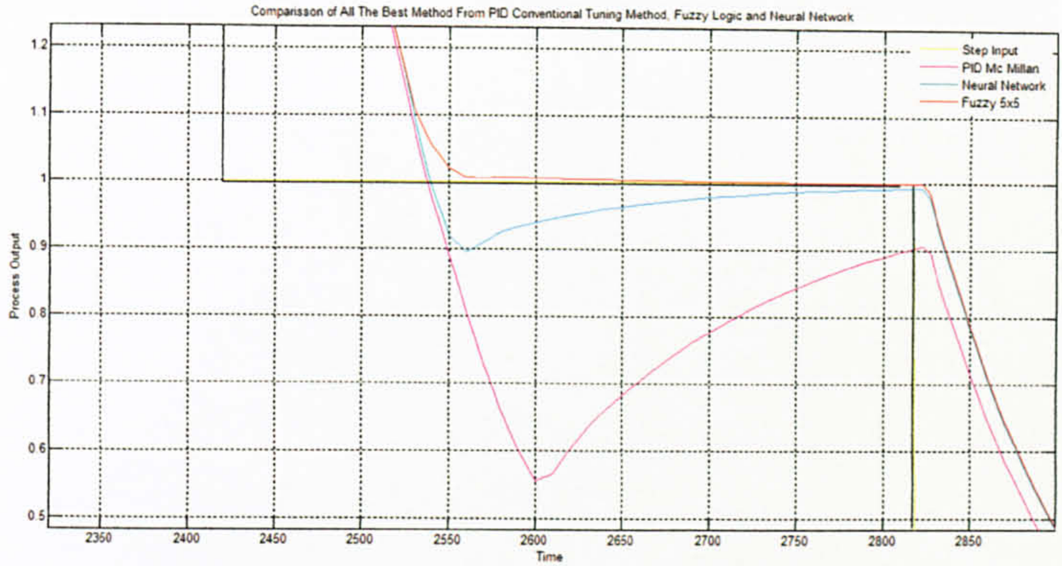


Figure 25: Setpoint changes from 3 bar to 1 bar

Table 10: IAE comparison between all method

Methods	IAE
10	559.6
Mc Millan	608.1
Fuzzy	545.3

Simulation result has shown that Fuzzy logic creates the best result for tuning PID. From the result obtain, it is clear that both fuzzy logic and neural networks have increase the efficiency of PID controller. In this case, the fuzzy have improve the performance of PID by 10.3% based on the value of IAE obtained.

With this result obtain, the fuzzy logic is then applied to the real-time air plant in building 21 figure below shows the real time result of 5x5 fuzzy compared to PID tuned with Mc Millan

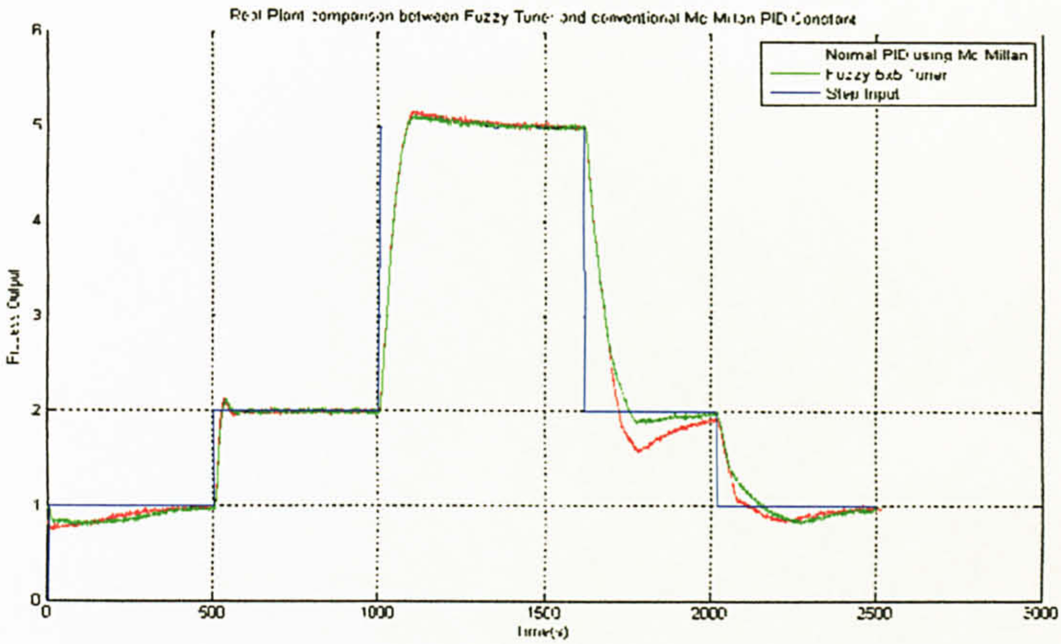


Figure 26: Real Time Plant Result

Figure 24 have shown that fuzzy logic improves the performance of PID significantly.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

5.1.1 Plant Modeling

Plant Modeling have been done, there are two most common modeling method stated in [13] which is **Method 1** and **Method 2** both of this method will generate a first order transfer function of the plant. Method 2 was chosen in this writing as method 2 reduces the human error that might occur in determining the dead time constant.

The first order transfer functions are:

$$G(s) = \frac{0.1458e^{-6.75s}}{102.75s+1} \text{ -----eq(11)}$$

Verification of the model have been shown in the result and the result obtain is almost accurate and similar with the response of the plant.

5.1.2 Conventional Tuning Method

There are several conventional tuning method that have been tested in this writing. The most popular tuning method used in industries are Ziegler-Nichols. But in this writing, the best tuning method is from **Mc Millan**. It have improved the PID perfomrnce significantly.

Mc Millan Method have improve the performance of PID based on the total error generated IAE and the overshoot and settling time have been reduce compared to other conventional tuning methods.

The problem with conventional method is that the parameter of K_p T_i and T_d are kept constant through out the whole process. In a process there are two states which is transient and steady state. Using conventional method, the parameters are kept constant during both states.

5.1.3 Fuzzy Logic

In Improving the performance of PID, fuzzy logic tuner can be implemented to the PID, using fuzzy, the parameters of PID can be set according to the states the process is in.

Fuzzy logic tuner is developed using linguistic rules. Rules of thumb in table 7 have been used to develop the set of rules that is used in fuzzy logic. In this writing 3 combination of rules have been used which are 3x3, 5x5 and 7x7. The best result obtained is from **5x5 rules**. It improves the PID performance by 10.3%.

The higher the number of rules, the more complex the system would be and the more difficult in establishing the membership function.

5.1.4 Neural Network

Neural Networks operate similarly with human brains, it uses neurons to compute its output. The neurons first need to be trained so that a good output will be generated. The neurons are located in the hidden layer. In this writing 10,15 and 30 neurons were tested and the best result obtained is from **10 neurons** in the hidden layer

With neural networks, number of training epochs also affects the performance of the tuner. With higher number of neurons higher number of training epochs also needed, but in this writing the number of training is set constant at 100 epochs.

Problems with neural networks, it needed data for training purpose in order for the tuner to run correctly. In this writng the writer uses that data obtained from fuzzy logic to trained the networks.

5.1.5 *Summary of All Tuning Method*

Table 11: Summary of comparison between all the method of tuning

	Advantage	Disadvantage	Remarks
PID Controller tuned using Mc Millan	Commonly used in industry. Easy to obtained tuning parameter based on the model obtain from the plant	Requires proper tuning to achieve perfect result. Tuning parameter kept constant for both state of process transient and steady state.	To improve the performance using fuzzy logic and neural networks.
Fuzzy Logic Tuner	PID parameter are tune according to the states of the process. Easy to understand as it uses linguistic rules and experience in tuning PID	Become hard to construct when larger rules is implemented. Based on experience and no specific steps to establish the tuner.	Improve significantly the performance of PID
Neural Network	Improve the performance of PID. With MATLAB's GUI. Easy to construct.	Need to generate data for training of networks. Uses data from fuzzy logic in this writing. Requires sufficient training for better performance.	Have potential to become best tuner, but need sufficient amount of training and a good set of data for training.

5.2 Recommendation

- Plant Modeling implemented using 2^{nd} order or higher order. There are other methods to obtain the model of the plant, most of them will model the plant in 2^{nd} order or higher. With higher order of modeling it is expected that the result would be more accurate.
- More Conventional Tuning Method should be try and used in the experiment. There are lots of new tuning methods this days to obtained the best performance for PID. This tuning method should be experimented and tested.
- Fuzzy logic should be implemented in more systematic way. Steps for developing a fuzzy logic tuner should be established.
- Neural networks should be trained with higher epochs of training and more accurate set of data for training should be used.
- Development of GUI needs to be further improved by adding few more buttons to it to make it running on the real time plant and more parameter for testing the performance should be added such as percent of overshoot, settling time and rise time.

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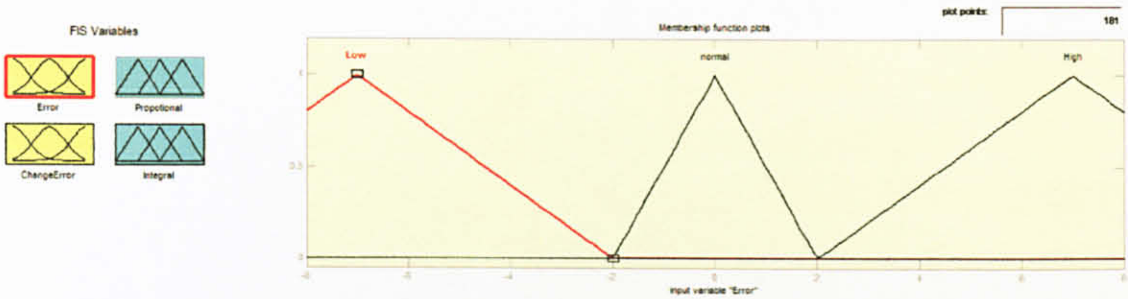
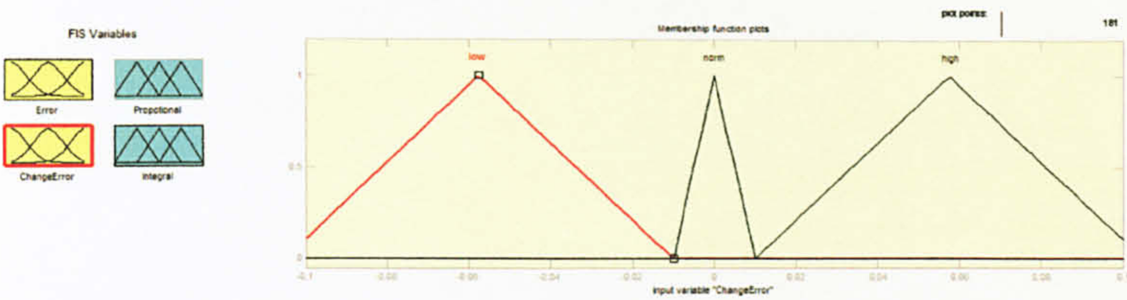
APPENDICES

APPENDIX A – Membership Function and Rules for Fuzzy Logic Other Than 5x5

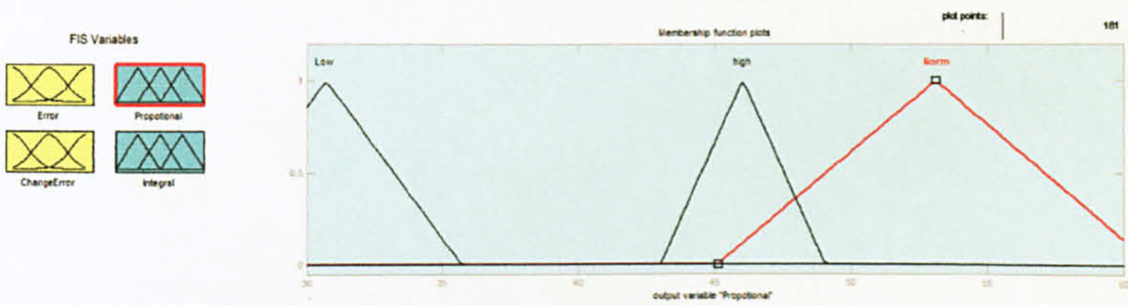
Membership functions for 3x3 fuzzy logic:



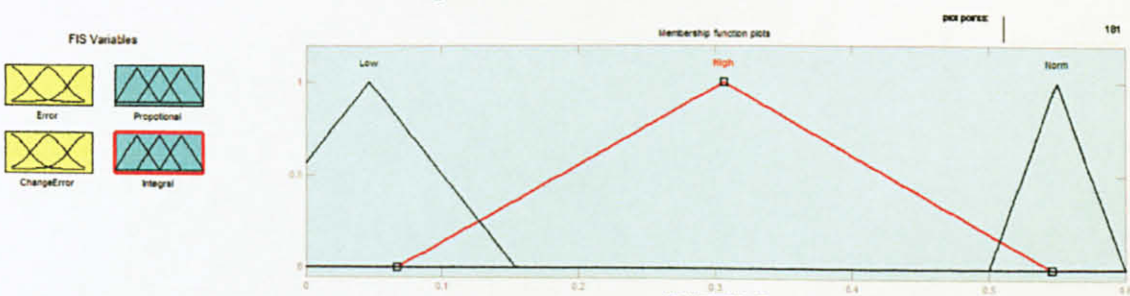
Error MF For 3x3



Change of error MF for 3x3

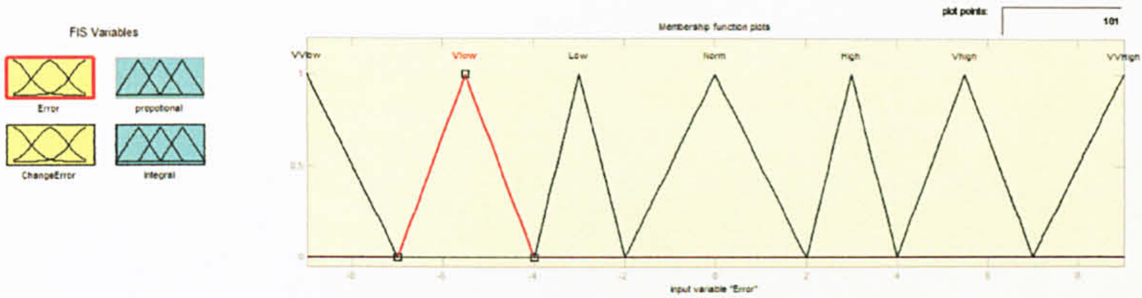


Propotional MF for 3x3

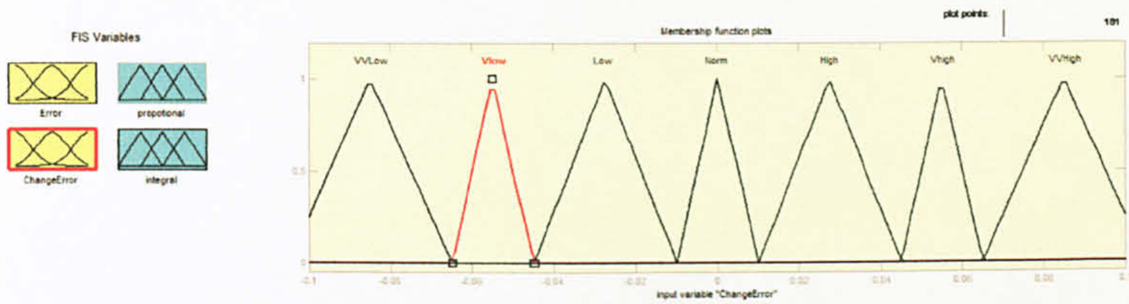


Integral MF for 3x3

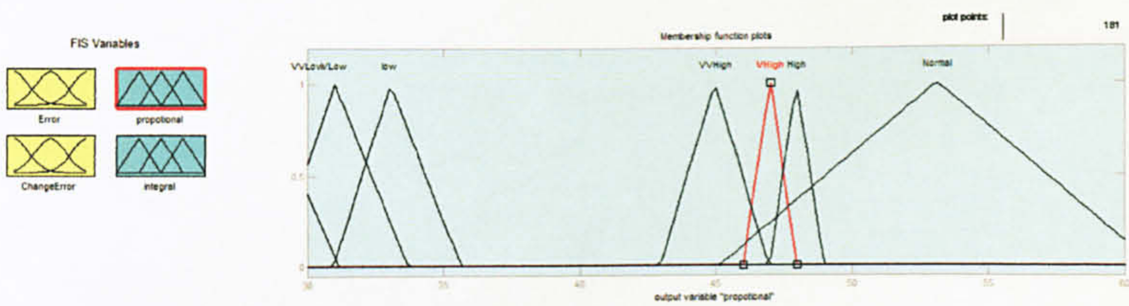
Membership functions for 7x7 fuzzy logic:



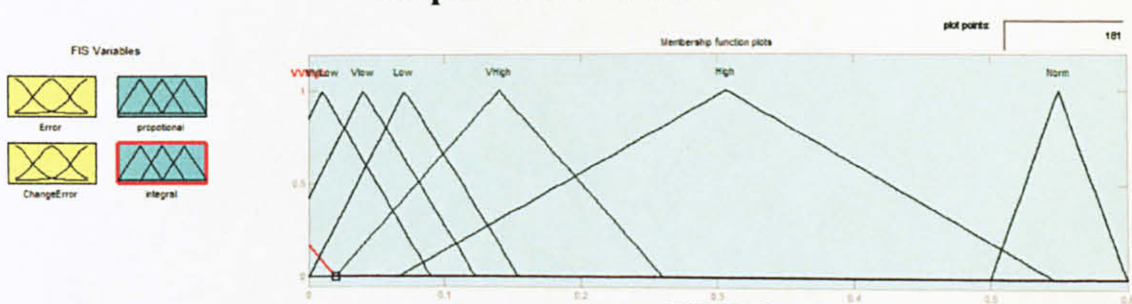
Error MF for 7x7



Change of Error MF for 7x7



Proportional MF for 7x7



Integral MF for 7x7

The 3x3 rules:

de / e	Low	Norm	High
Low	H	H	L
Norm	H	N	L
High	H	H	L

The 7x7 rules

de / e	VVlow	Vlow	Low	Norm	High	Vhigh	VVHigh
VVlow	VVH	VVH	VVH	VVH	L	VL	VVL
VLow	VH	VH	VH	VH	L	VL	VVL
Low	H	H	H	H	L	VL	VVL
Norm	VH	H	N	N	L	VL	VVL
High	H	H	H	H	L	VL	VVL
Vhigh	VH	VH	VH	VH	L	VL	VVL
VVhigh	VVH	VVH	VVH	VVH	L	VL	VVL

Note: VVL= Very very low, VL=Very Low, L=Low, N=Normal, H=High, VH= Very High, VVH= Very very High