INTELLIGENT CONTROLLER FOR CONTROLLING PRESSURE GAS PLANT USING PI-FUZZY

AHMAD AIZAT BIN AZRA'I

ELECTRICAL & ELECTRONICS ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
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By

AHMAD AIZAT B AZRA'I

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

Assoc. Prof. Dr. Nordin Saad
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.

AHMAD AIZAT B AZRA'I

ABSTRACT

This report is discusses the progress on "Intelligent Controller for Pressure Gas Plant Using PI-FUZZY". The main aim of this project is to develop the controller because there are several occasions where the control variable has not been to what it should be due to the controller performance that exhibit poor result. In general, the pressure control is a dynamic and nonlinear process where frequent controller tuning is necessary. The scope of study involved detailed study on Empirical model, PID controller, Fuzzy logic and also integration of PID controller with Fuzzy. At the early stage of the project, the author had identified and familiarized with the pilot pressure plant and MATLAB / Simulink tools. Some study on how to model a plant using empirical modeling method had been conducted. In order to model the pressure plant using empirical modeling, several experiments were conducted to achieve the best Process Reaction Curve (PRC). When the Process Reaction Curve had been obtained, the modeling work using both method of empirical modeling which are Method 1 and Method 2 were performed. The model developed in MATLAB is verified to ensure that the output response of the model is almost the same with the Process Reaction Curve. Fuzzy control will be added to the existing PID controller and the membership functions of the Fuzzy are developed based on the knowledge and experience towards the plant's behavior. After complete the membership functions, then the author continue with the Fuzzy rules and several performance tests will be conducted to observe the performance of the proposed intelligent controller. The intelligent controller's performance will be compared with the conventional controller and the results are there is no overshoot, the settling time is much faster than the conventional controller and lower Integral Absolute Error (IAE).

ACKNOWLEDGEMENTS

In the name of ALLAH, the Most Graceful and Most Merciful,

First, I would like to express my greatest gratitude to my supervisor, Dr Nordin B Saad for his expert guidance, attention and suggestion, supports and advices regarding the project and difficulties faced during the project execution.

Not forget to mention, I would like to thank several lecturers who help me during the project especially to Mr. Mr Tri Chandra Setyo Wibowo for his assistance in developing the block diagram of MATLAB Simulink on Xpc Target and also Dr. Mahidzal Dahari.

Special thanks to the Instrumentation and Control lab Technician, Mr. Azhar bin Zainal Abidin for his guidance, supports and concern during the project works.

To my family, thank you. Without your enormous supports and concern, all my effort on preparing this final year project would not be successful. Last but not least, my appreciation goes to the individual or groups that have helped me in any possible way to complete this project. Above all, I would like to thank God for making it is possible for this project until this.

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LIST OF ABBREVIATIONS

PID	Proportional, Integral and Derivatives
PT	Pressure Transmitter
PIC	Pressure Indicator Controller
PRC	Process Reaction Curve
SP	Set Point
PV	Process Variable
MV	Manipulated Variable
MF	Membership Function

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In UTP, there are several pilots plants specifically built to study process control. The pilot plant closely resembles the actual plant with all the transmitter and control valves but in laboratory scale. The gaseous pressure plant in the process control laboratory in Electrical and Electronics (EE) Department of UTP will be used to study and apply real control via MATLAB / Simulink. The main component of this plant is pressure vessel, pressure transmitter and control valve.

The aim of this project is to conduct modeling and simulation of a pressure pilot plant. There are various methods that can be used to model the plant for example neural network, system identification and empirical method. In this project, the modeling part is done based on the pressure plant input and outputs. The simulation will involve with validation and testing the functionality of the model.

In process control, the main objective is to regulate the value of some quantity. To regulate means to maintain that quantity at some desired value regardless of external influence. The desired value is called the reference value or set-point [1]. After designing stage has done, the system need to be simulated to check the functionality and the convenience of the system. MATLAB / Simulink are the tool that will be used in this project. In order to perform real-time rapid prototyping, the Simulink need to be connected to xPC Target. This will provide a high performance, host-target prototyping environment that enables the connecting Simulink and State-flow models to physical systems and execute them in real time on PC.

By using the model developed, the current pressure controller performance will be analyzed before Fuzzy controller being integrated. After done the testing, Fuzzy membership functions and rules will be developed based on the knowledge and experience towards the plant. Next, it will be integrated with the conventional PI controller and the new intelligent controller's performance will be tested.

So basically this project is not only to develop an intelligent controller that integrate PI controller with Fuzzy controller but to start from scratch until an intelligent controller being produced. This is because in order to do any testing or simulation of the conventional controller, the plant need to be modeled first and then the simulation part can be done. After done the modeling part and tune the conventional controller then can proceed to the development of PI-Fuzzy controller.

1.2 Problem Statement

The study of monitoring and control using intelligent system is receiving attention especially on issues of the effectiveness and reliability of the controller. There are several occasions where the control variable has not been to what it should be due to the controller performance that exhibit poor result. In general, the pressure control is a dynamic and nonlinear process, frequent controller tuning is necessary based on the process operating conditions [2].

The plant that will be used in the process control lab is the pressure gas plant. The control strategy to be implemented is PI and will be further modified with fuzzy control. The fuzzy system is designed to track the variation parameters in a feedback loop and tune the classical controller to achieve a better control action for load disturbances and set point changes.

1.3 Objective & Scope of Study

1.3.1 Objective

To develop a fuzzy controller and integrate it with conventional PID controller so that the controller can automatically tune itself without human intervention based on the process operating conditions.

1.3.2 Scope of Study

Basically the scope of study is on:

- PID controller.
- PID controller tuning.
- Fuzzy Logic Controller.
- Implementation in MATLAB / Simulink.

CHAPTER 2
LITERATURE REVIEW

2.1 PID Controller

A Proportional-Integral-Derivative controller (PID Controller) is common controller for feedback loop process in an industrial system. The controller works by comparing the measured value from a process with the reference set point value. The difference of the measured value and set point value is called error signal. It is used to calculate a new value for the manipulated input of the process so that the measured value will be within the desired set point. PID controller can adjust process outputs based on the data history and rate of change of the error signal. A proportional controller will have the effect of reducing the rise time and will reduce but never eliminate the steady-state error. An integral control will have the effect of eliminating the steady state error but it may take the transient response worse. A derivative control will have the effect of increasing the stability of the system, reducing the overshoot and improve the transient response [3].

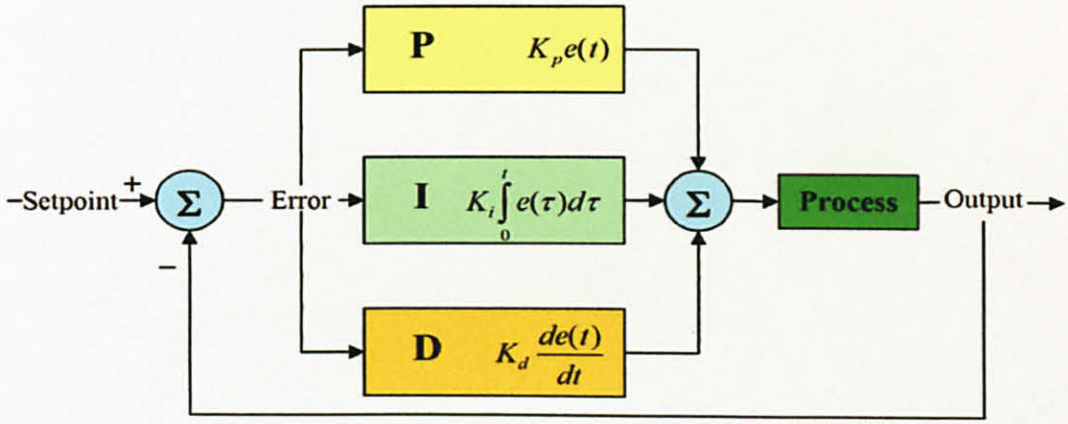

Figure 1: PID Controller

2.2 Open Loop Test

In open loop control or manual operation, the measured values of process variable are displayed to the operator who has the ability to manipulate the final control element by making an adjustment in the control room. The purpose of open loop is to evaluate the process reaction curve for identifying dynamic models.

2.3 Closed Loop Test

The closed loop control system provides a form of feedback loop to the process under control. A process is measured and compared with the set point value and if there is any error then the final control element will be adjusted accordingly.

2.4 Empirical Model

The gaseous pressure empirical model is developed based on process reaction curve obtained from the experiment. Gaseous pressure transfer function can be expected to be a first order and dead time model. The three process parameters can be estimated by performing a single test on the process input. The gain can be calculated as simple as the long-term change in process output divided by the change in process input. The time delay is the amount of time, after the input change before a significant output response is observed. The general transfer function is:

K_p = Process Gain θ = Dead Time τ = Time Constant

$$G(s) = \frac{K_p e^{-\theta s}}{\tau s + 1}$$

2.5 Process Reaction Curve

The purpose of using process reaction curve is to identify the dynamic model which will be used on the first-order with dead time model. The process reaction curve characteristics are [4]:

1) Input magnitude must large enough to give an output signal-to-noise ration greater than five.
2) Experiment duration is at least $\theta + 4\tau$
3) The model is restricted to first-order with dead time.
4) Must have perfect step input.

2.6 Fuzzy Logic

A fuzzy control system is a control system based on fuzzy logic. It is a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 0 and 1 (true and false) [5].

2.7 Membership Function

The membership function is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system.

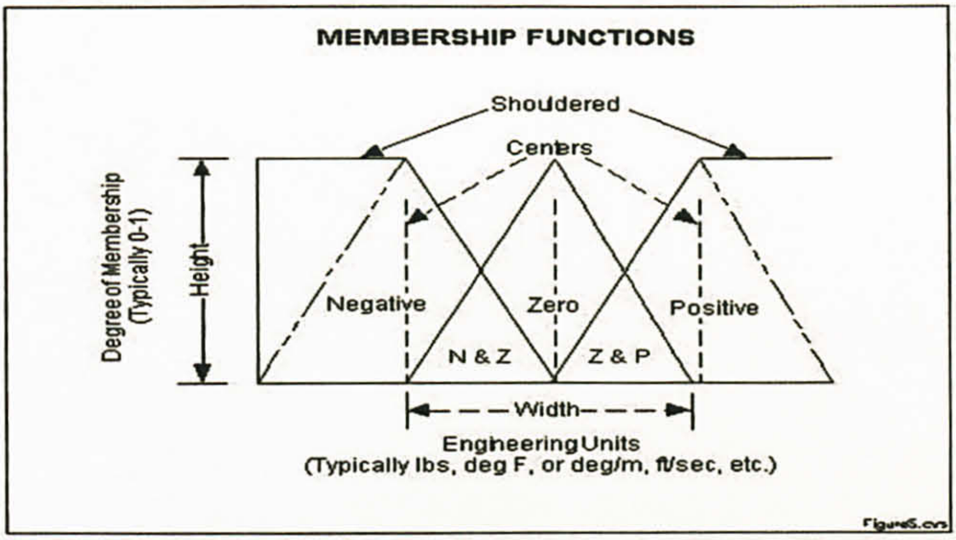

Figure 2: Membership Function Diagram

2.8 Fuzzification / Defuzzification

Fuzzification and defuzzification involve mapping the fuzzy variables of interest to "crisp" numbers used by the control system. Fuzzification translates a numerical value for the error, e(k) or error rate, De(k) into a linguistic value such as positive large with a membership grade. Defuzzification takes the fuzzy output of the rules and generates a "crisp" numerical value used as the control input to the plant.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

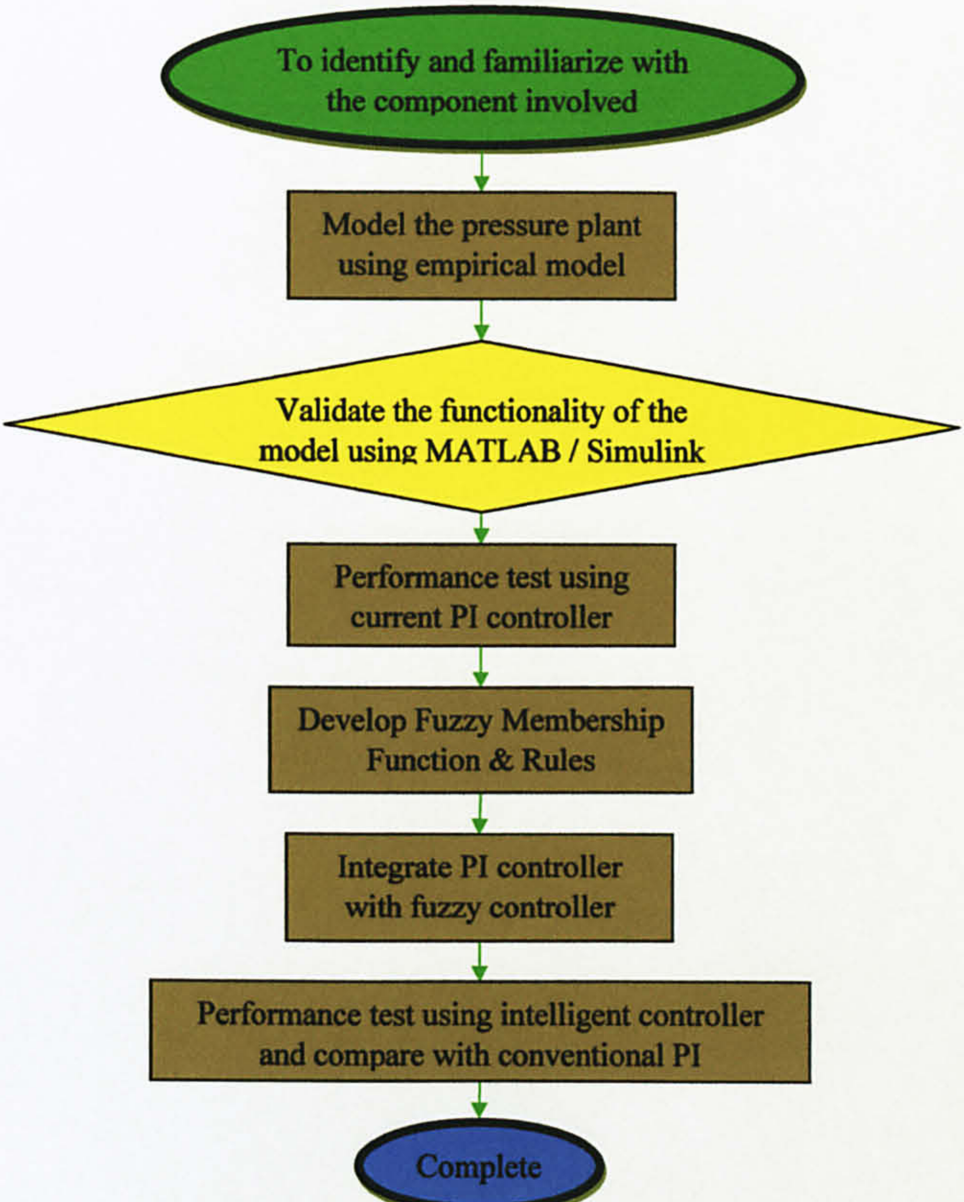

Figure 3: Project Flowchart

3.2 Tools & Equipment Required

- Hardware
  - Gas Pressure Pilot Plant
  - Xpc Target
- Software
  - MATLAB / Simulink

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results & Discussions

After done several experiments, then the best Process Reaction Curve is as below:

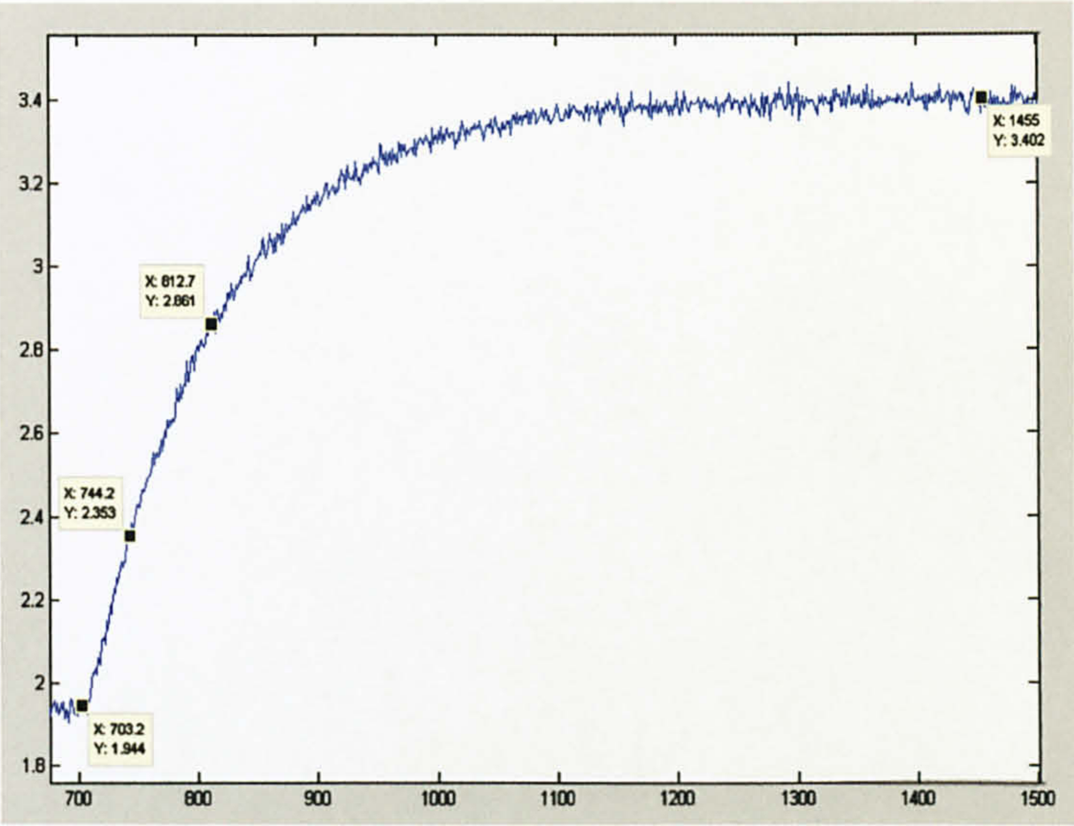

Figure 4: Process Reaction Curve

- The best Process Reaction Curve was obtained after several experiment and with this, the plant model can be obtained by simply substitute the value into the first order equation.

$$K_p = \frac{\Delta}{\delta}$$

$$K_p = \frac{3.402 - 1.944}{40 - 30} = \frac{1.458}{10} = 0.1458 bar / \% opening$$

$0.63\Delta = 0.919 + 1.944 = 2.863 bar$ $\quad 0.28\Delta = 0.408 + 1.944 = 2.352 bar$

$t_{63\%} = 812.7 - 700 = 112.7 s$

$t_{28\%} = 744.2 - 700 = 44.2 s$

$\tau = 1.5(t_{63\%} - t_{28\%}) = 1.5(112.7 - 44.2) = 102.75 s$

$\theta = t_{63\%} - \tau = 112.7 - 102.75 = 9.95 s$

$$G(s) = \frac{K_p e^{-\theta s}}{\tau s + 1} = \frac{0.1458\, e^{-9.95 s}}{102.75 s + 1}$$

- After obtained the plant model, next step is to verify the model and below is the block diagram and also the result of the verification which is almost the same with the real time response.

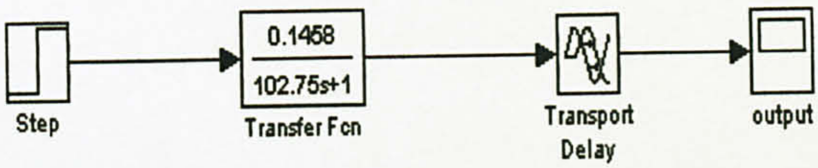

Figure 5: Model Verification Block Diagram

$$K_P = \frac{\Delta}{\delta}$$

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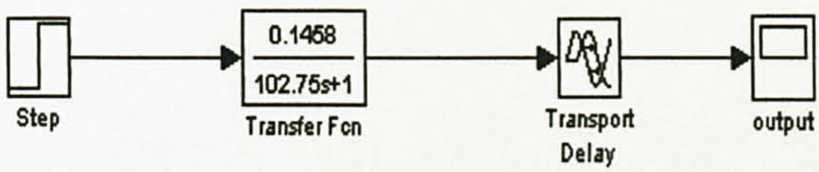


Figure 5: Model Verification Block Diagram

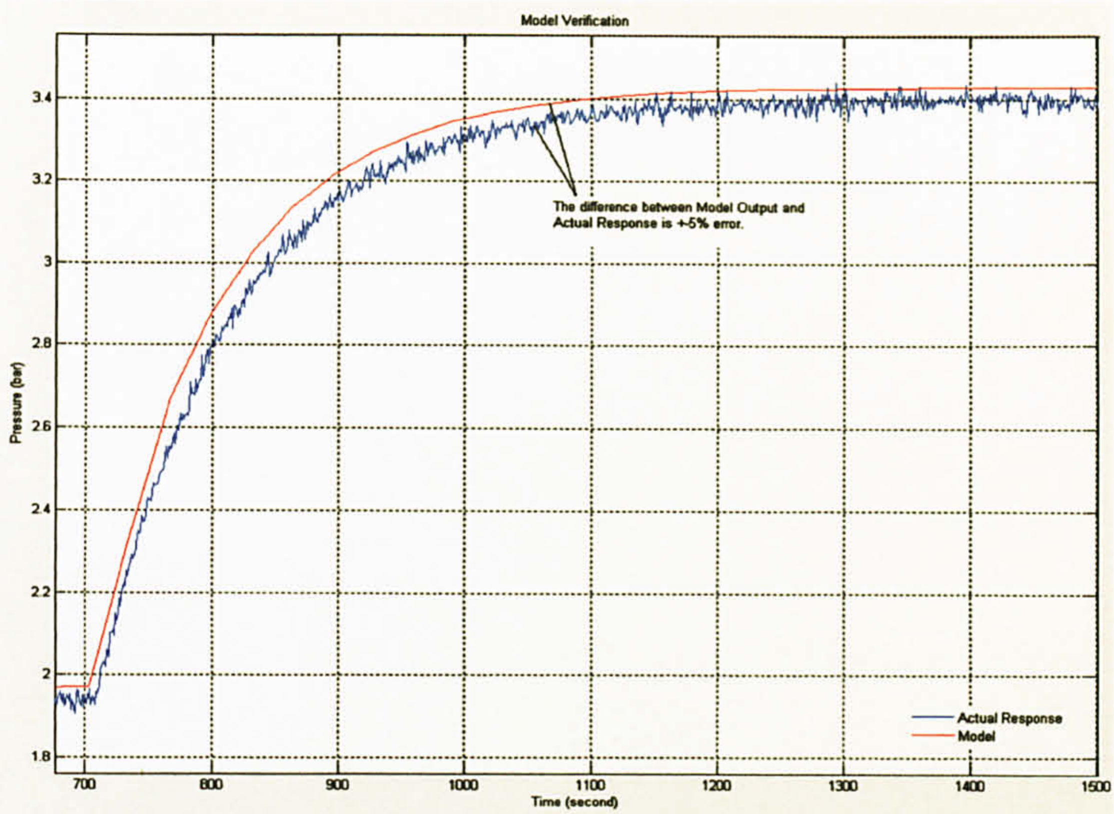


Figure 6: Model Verification

- Once the model had been verified and acceptable, then the next step is to find the basic PI tuning parameters for the model by using the Bode Plot method.

- The Bode plot method is a method where the model is being put at the critical frequency which is the frequency between stable and unstable. The critical frequency is -180 degree.

- From the bode plot, value of magnitude and frequency can be obtained. Then substitute the value into the Ziegler-Nichols tuning correlation.

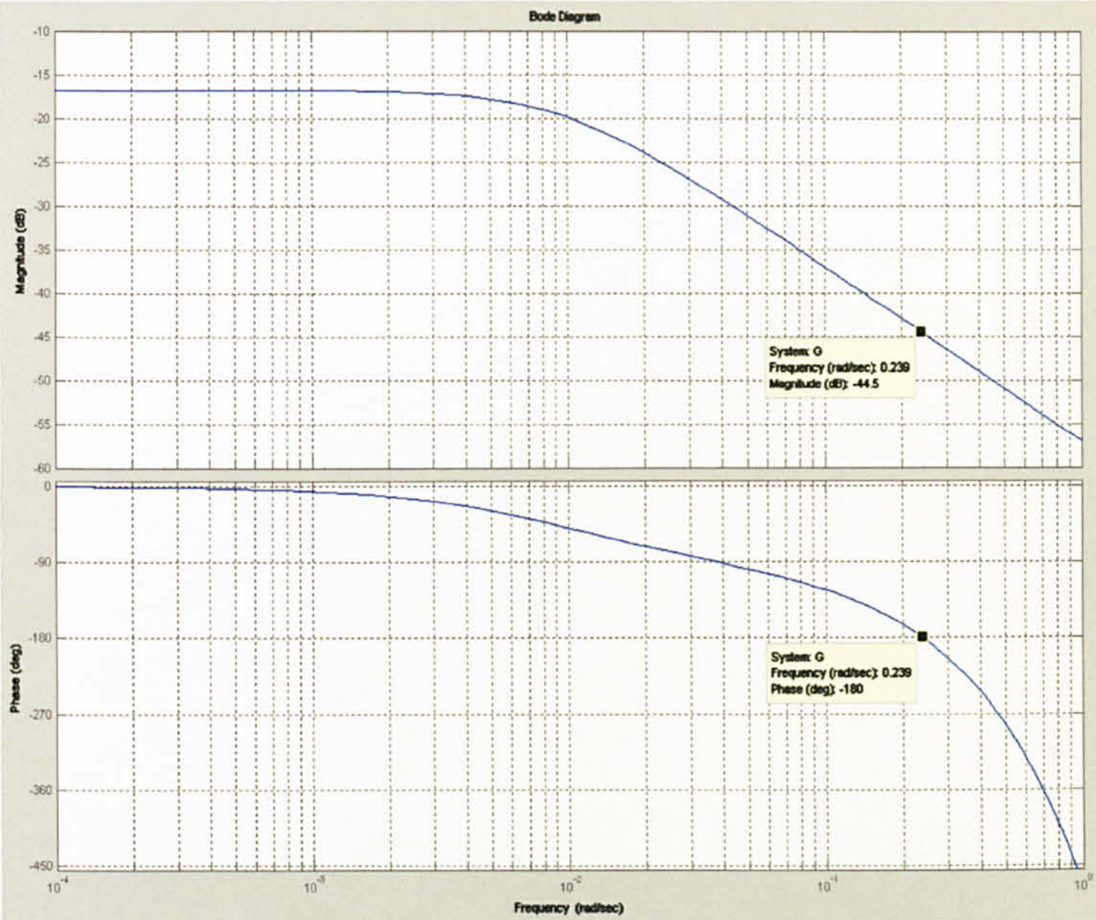


Figure 7: Ultimate Sensitivity Test

- Magnitude = -44.5 dB
- Frequency = 0.239 rad/sec

$$K_u = \frac{1}{AR_c} = \frac{1}{10^{\frac{-44.5}{20}}} = 167.88$$

$$P_u = \frac{2\pi}{f \times 60} = \frac{2\pi}{0.239 \times 60} = 0.438$$

- Ziegler –Nichols Tuning Parameters :

$$K_c = \frac{K_u}{2.2} = \frac{167.88}{2.2} = 76.30 \qquad T_i = \frac{P_u}{1.2} = \frac{0.438}{1.2} = 0.365$$

- Once the PI tuning parameters had been obtained, then the parameters will be put into the PID controller and the output response will be recoreded as the conventional PI controller performance.

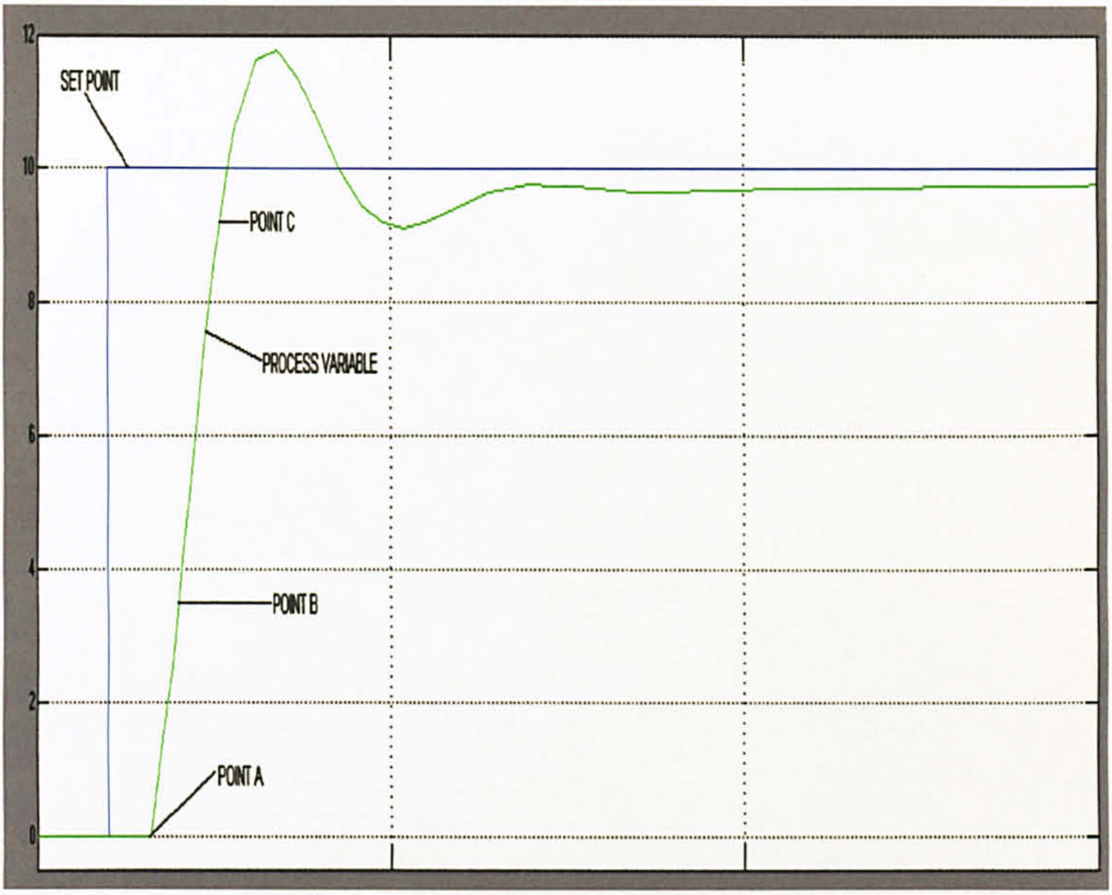


Figure 8: Conventional PI Controller Performance

- After completed the conventional PI controller performance, so basically the first part of the project had been accomplished and now can proceed with the second part which is development of hybrid controller using Fuzzy controller.

- In order to develop a Fuzzy controller, we must first determine the structure of the fuzzy such as how many input and output, the controller size and also the rules.

- After done some research and discussion, the input was decided to be the error and also change of error while the output is the tuning parameter which is Proportional Gain and also Integral Time.

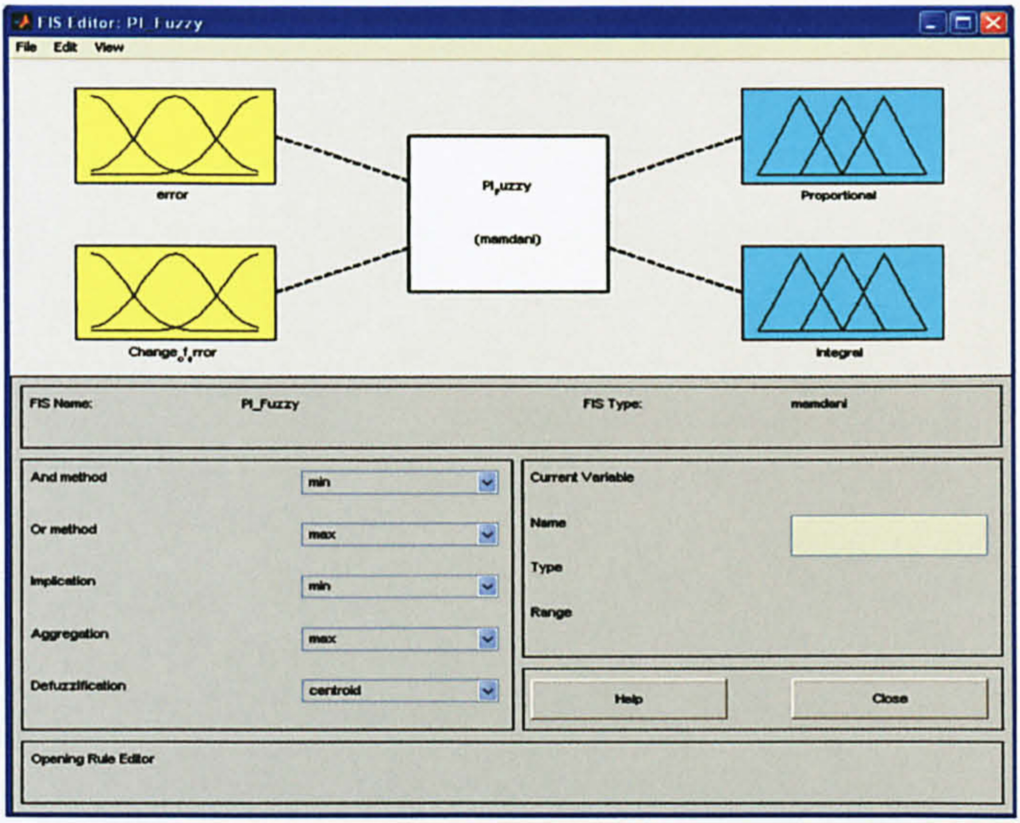


Figure 9: FIS Editor

- Membership function values for error were obtained by experience or knowledge on the plant itself.

Table 1: Membership Function Value for Error

Error (e)	Proportional Gain (Kp)	Integral Gain (Ti)	Grouping
1	36.6	0.35	Normal
2	36.8	0.35	
3	36.9	0.34	Low
4	35.9	0.29	
5	34.5	0.25	
6	34.5	0.21	High
7	34.3	0.18	
8	33.7	0.159	

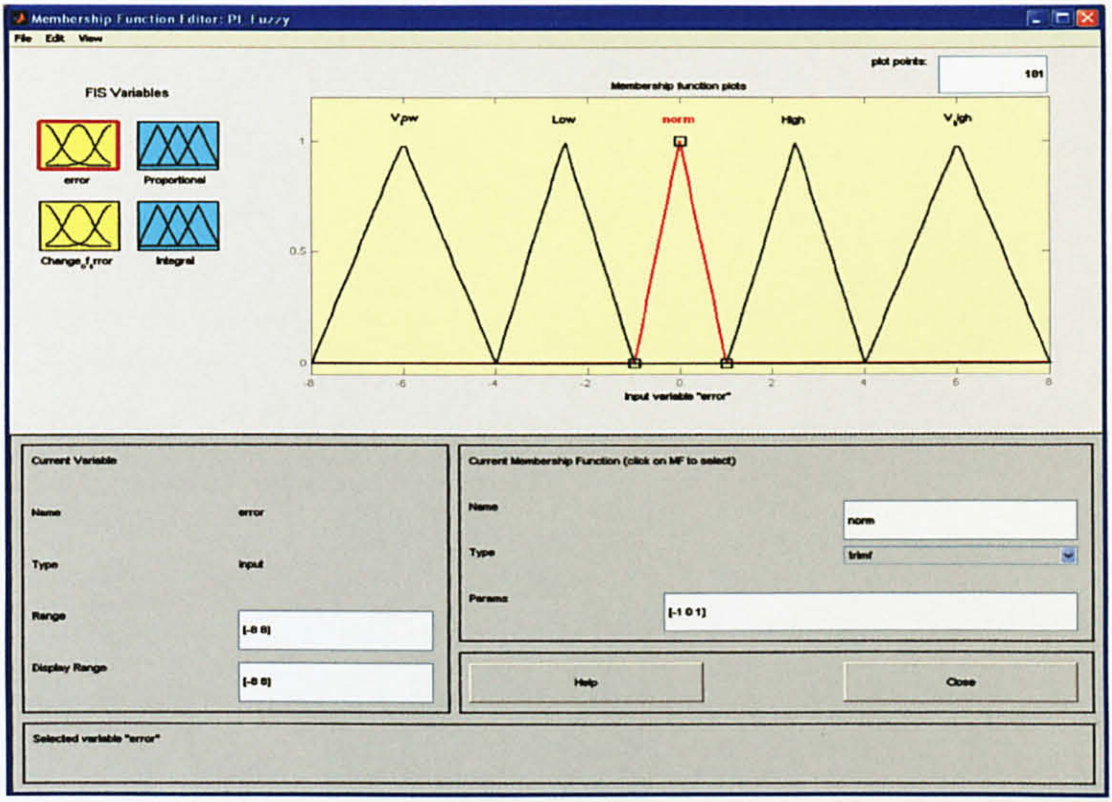


Figure 10: Membership Function for Error

- After completed the membership function for error, then proceed with the membership function for change of error.

Table 2: Value for Membership Function of Change of Error

ERROR	PROPORTIONAL, (Kp)	INTEGRAL, (Ti)	AVG ΔERROR	GROUPING
1	35	0.37	0.0410	Normal
2	35	0.33	0.0498	Low
3	35	0.25	0.0559	
4	35	0.18	0.0699	
5	35	0.13	0.0717	V_Low
6	35	0.09	0.0793	
7	35	0.06	0.0801	
8	35	0.03	0.0811	

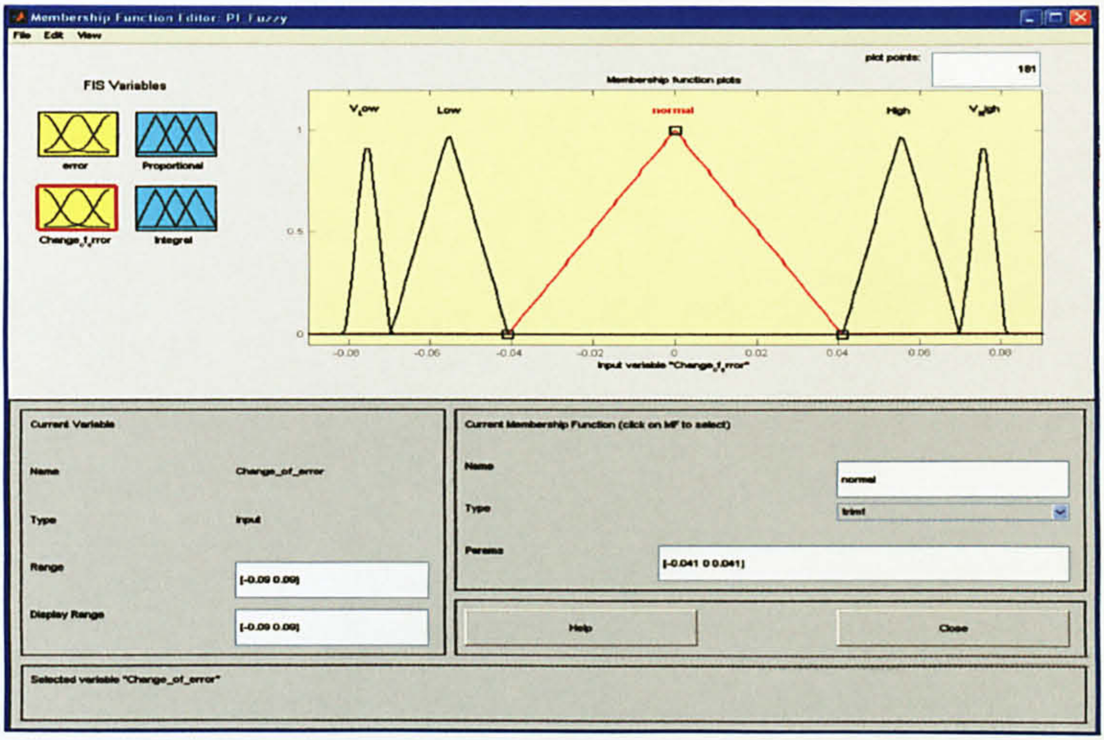


Figure 11: Membership Function for Change of Error

- After completed the membership function for Δerror, then proceed with the membership function for the Proportional Gain, Kp.

- Basically this membership function is the value from table 1 and it was transformed into graphical approaches.

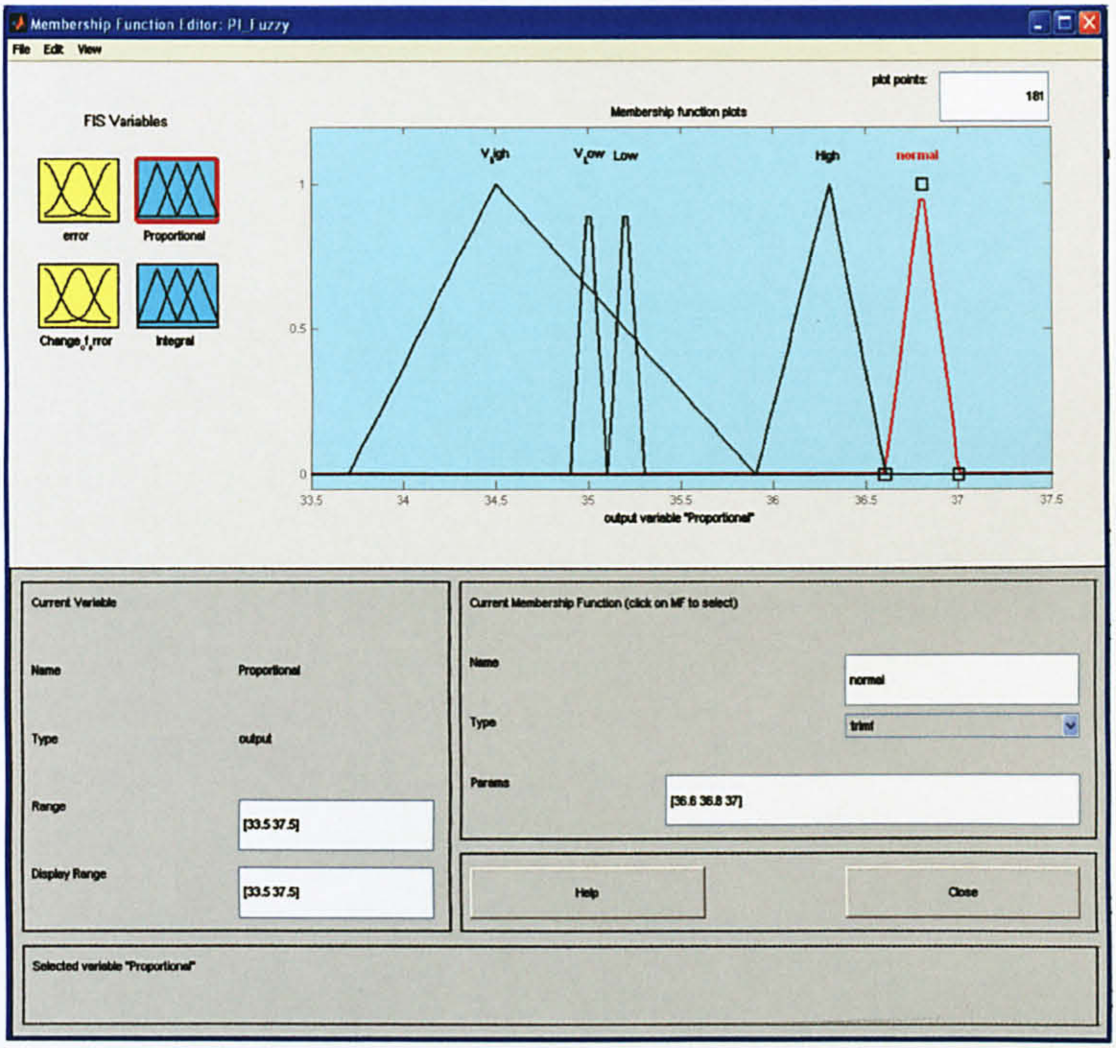


Figure 12: Membership Function for Proportional Gain, *Kp*

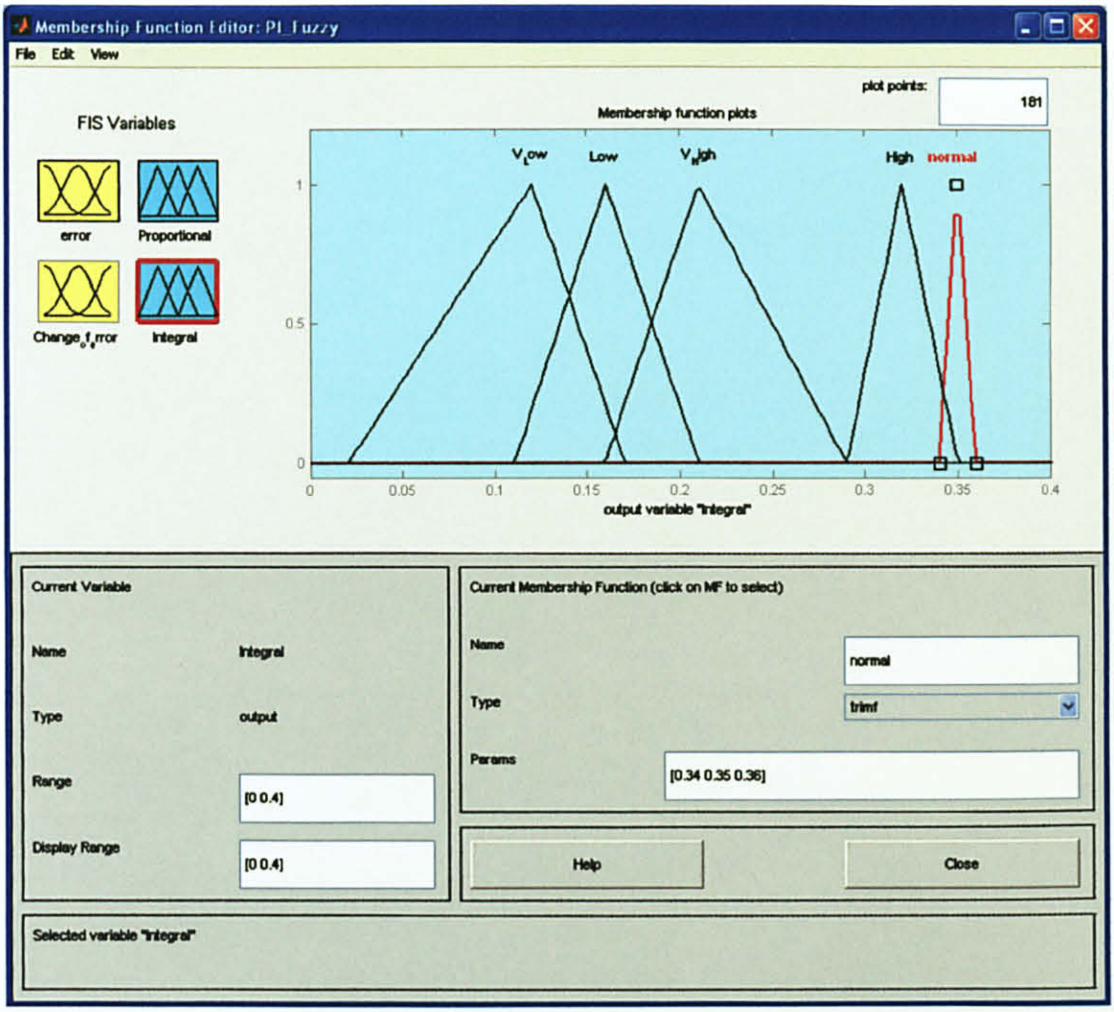


Figure 13: Membership Function for Integral, *Ti*

- After completed the membership function for integral, then proceed with the fuzzy rules.

- Because the fuzzy matrix is 5x5 so there will be 25 sets of rules.

Table 3: Fuzzy Rules Table

ΔError / Error	V_Low	Low	Normal	High	V_High
V_Low	VL	VL	VL	H	N
Low	L	L	L	H	N
Normal	N	N	N	H	N
High	H	H	H	H	N
V_High	VH	VH	VH	H	N

- VL=Very Low, L=Low, N=Normal, H=High, VH=Very High

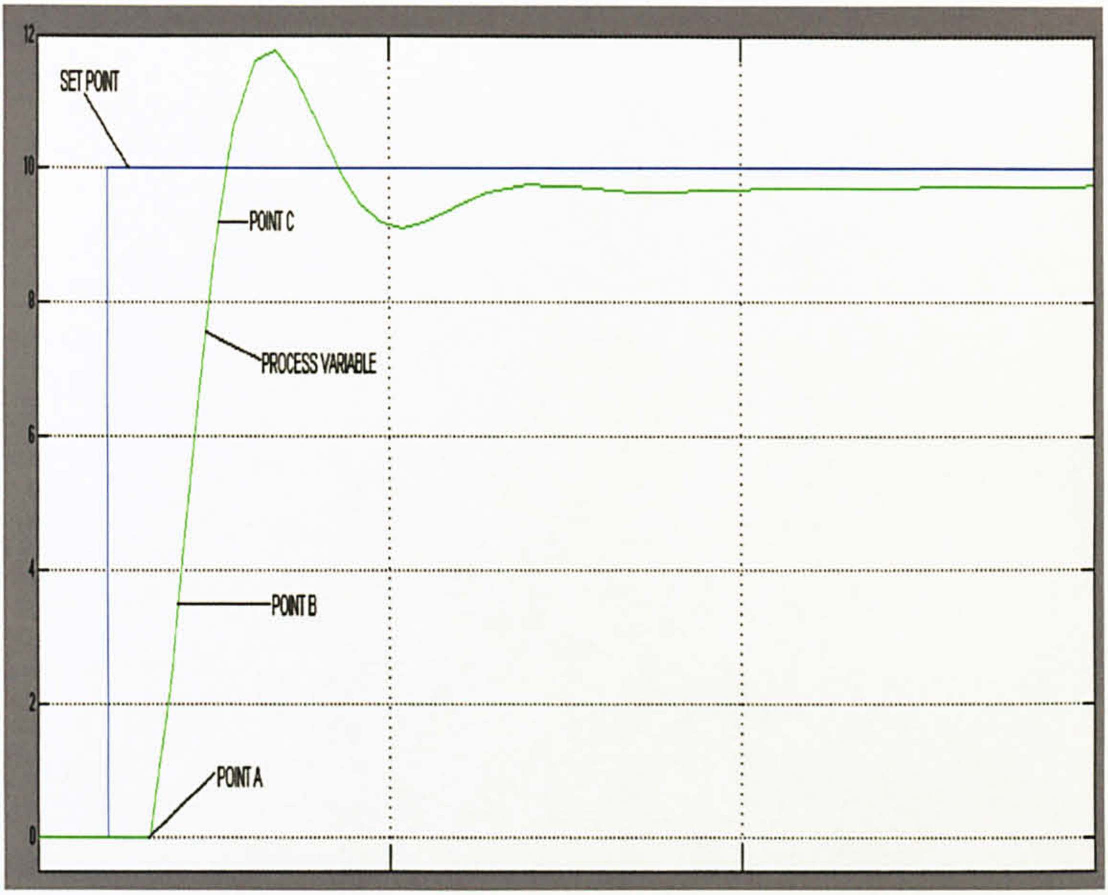
- Fuzzy rules table was developed based on the facts as below :

Table 4: Effect of Increasing Kp, Ti, and Td to Speed and Stability

	SPEED	STABILITY
Kp (Increase)	Increase	Decrease
Ti (Increase)	Decrease	Increase
Td (Increase)	Increase	Increase

- For this project, the maximum pressure can be set at the plant is 8bar, so the set point was set to be 8bar and each level of error will be tuned for the best results. When the error is very high, we want the response to be fast and neglect the stability first by increasing proportional gain and reducing integral gain. Once the output error reduced until the region normal, and then stability is much more prioritized by increasing integral gain and reducing proportional gain.

- After obtained the fuzzy rules table, then the data in the table being converted into sets of rules in the FIS.



- POINT A – error is very high so we want the output to be much more faster in term of rising time by increasing Proportional gain (*Kp*). At this particular point, we consider more on the speed rather than stability.

- POINT B - error is high and we still want the process variable to achieve the set point faster but not too fast until it will produce overshoot. So we will consider to increase Integral Time (*Ti*) and lower the Proportional gain (*Kp*).

- POINT C – error can be categorized in the normal group. At this point, we are considering more towards the stability which mean the Proportional gain will be reduced while the Integral Time will be increase so that it will archive faster settling time.

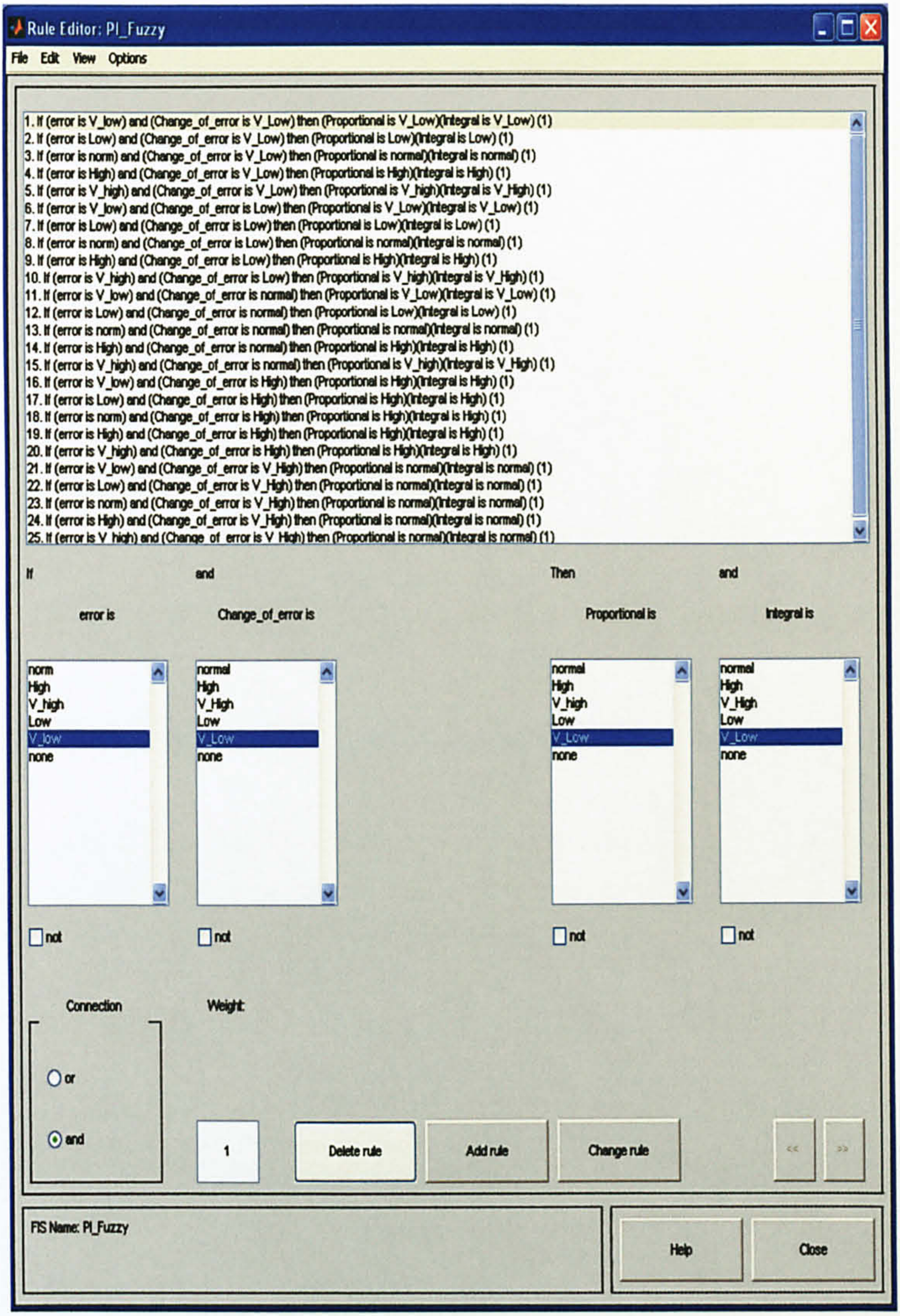


Figure 14: Fuzzy Rules

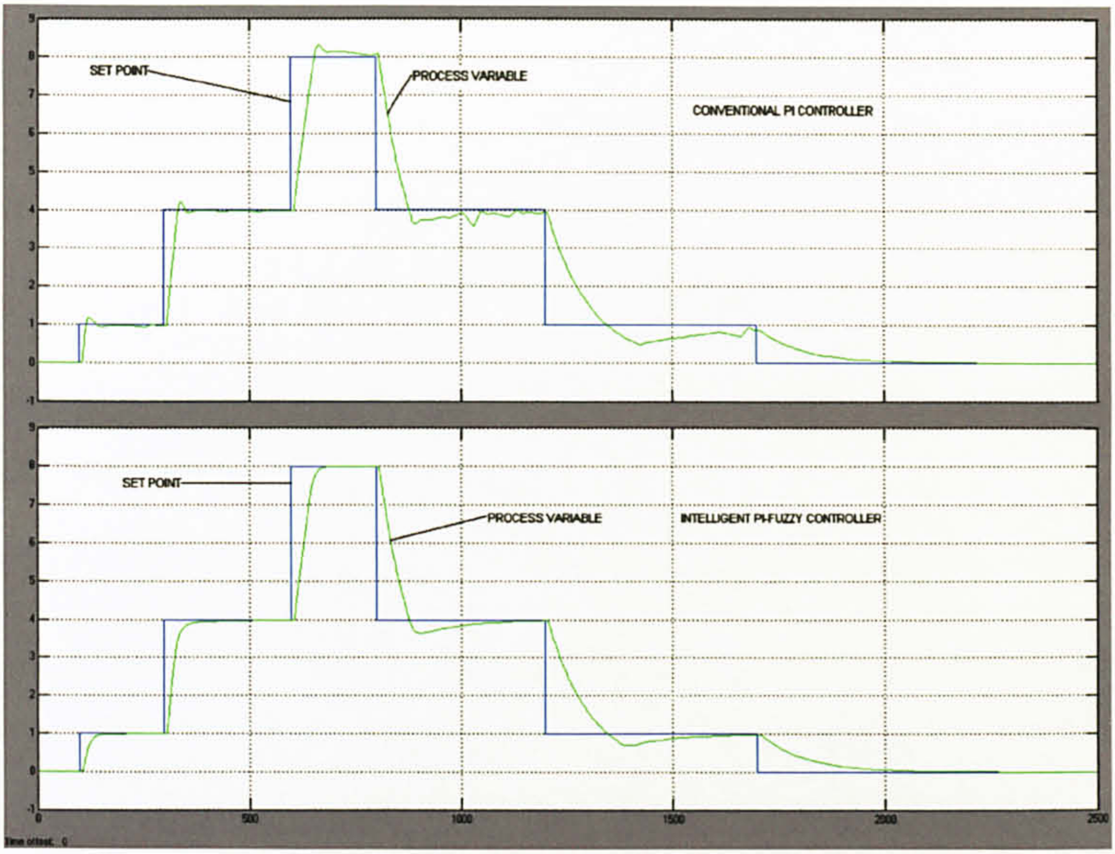


Figure 15: Intelligent Controller output Compared with Conventional PI Controller

- Once all the necessary information in Fuzzy controller has been completed, then the Fuzzy controller will be integrated with the conventional PI controller and compared the both controller performance as above.

- The block diagram of intelligent controller shown in the appendix F.

- From the output, we can see that there is no overshoot when the step input increase and the settling time is much faster than the conventional controller.

- Same goes when the step input decrease, the overshoot is small but the most important thing is that the settling time is much faster than conventional controller.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

PI-Fuzzy is a controller with an outstanding performance that does not need human interaction for tuning purpose. The performance increase in term of faster settling time, can eliminate overshoot and will have lower integral Absolute Error (IAE) for various process operating condition. It also can be used for other application that requires high performance controller.

5.2 Recommendation

My recommendation is that try to improve the fuzzy controller for better controller performance by developing much bigger matrixes, membership function and fuzzy rules. There are lots more that can be add into the fuzzy so that the level of intelligence can be increased.

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[5] Kevin M. Passino, "Fuzzy Control", Addison-Wesley

[6] Training book of LabVIEW and MATLAB / Simulink

APPENDICES

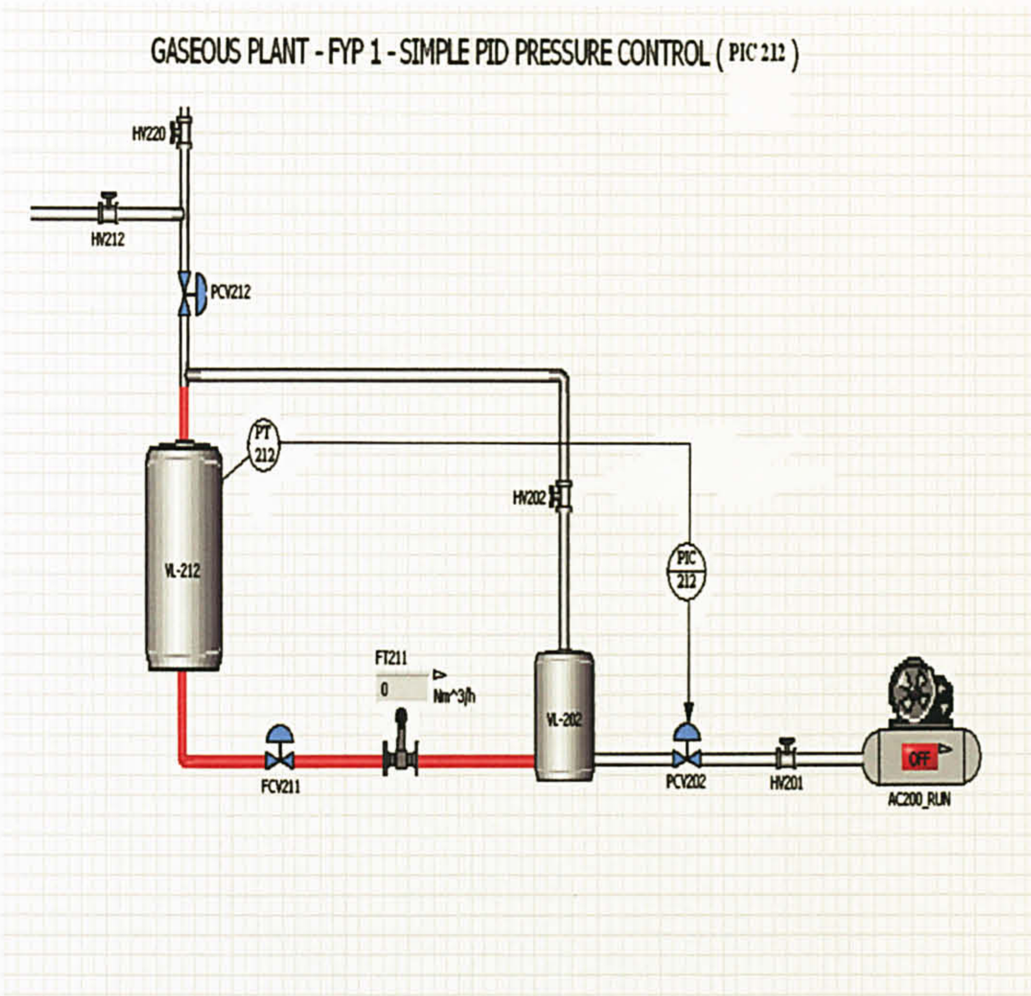
APPENDIX A

XPC TARGET

APPENDIX B
PRESSURE PILOT PLANT

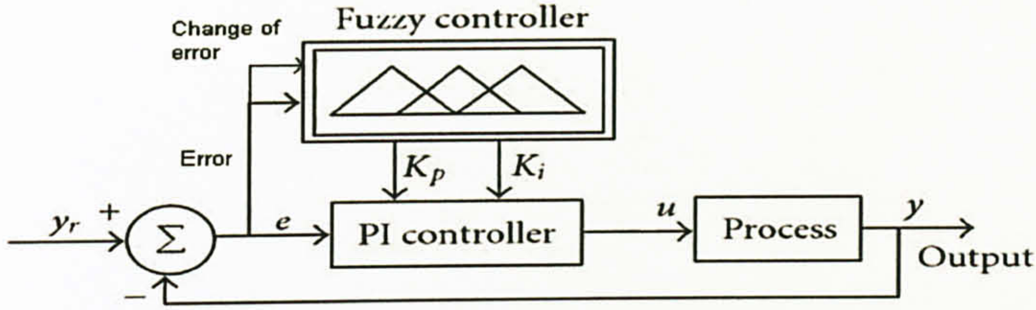
APPENDIX C

P&ID OF PRESSURE GAS PLANT



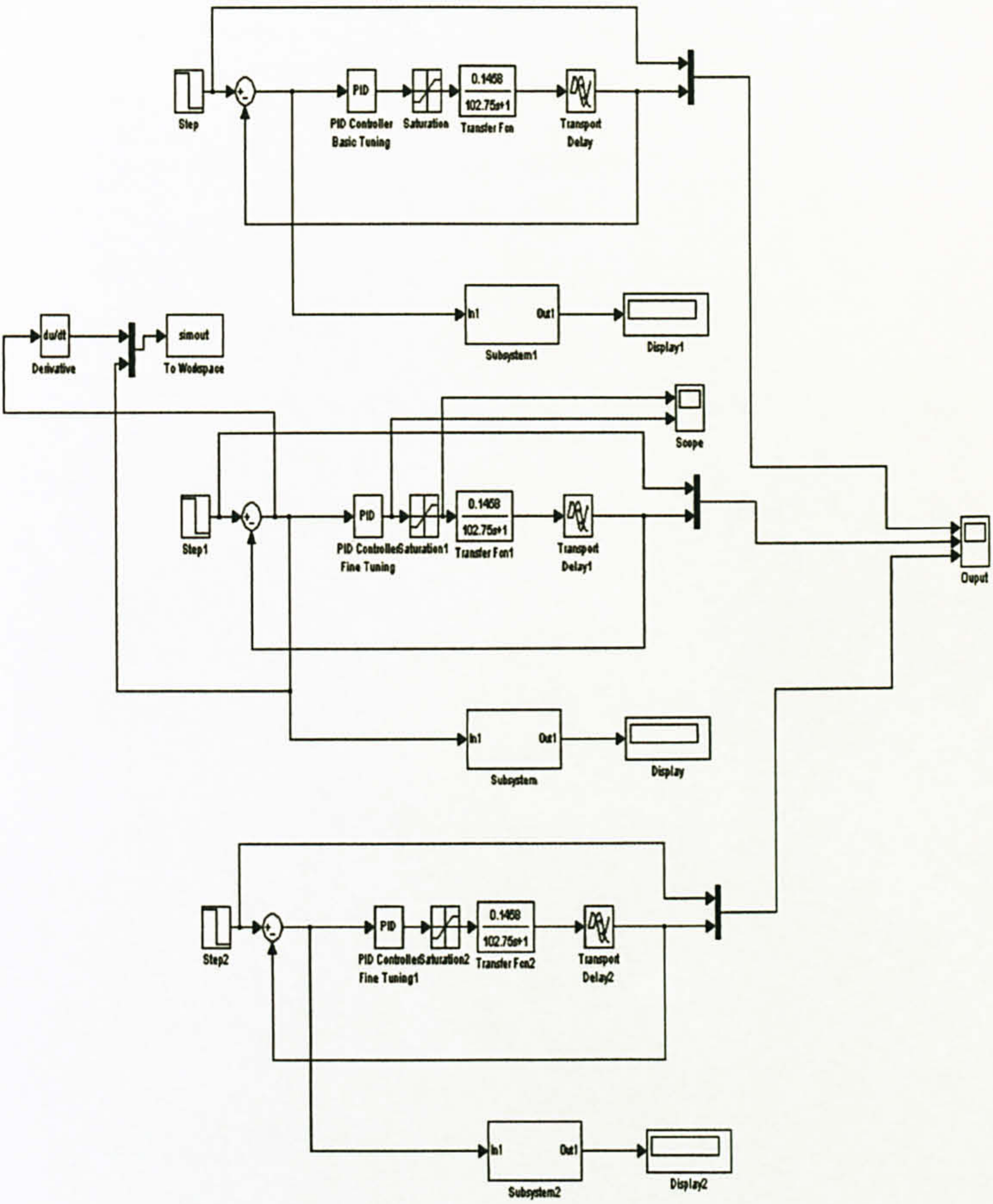
APPENDIX D

PI-FUZZY CONTROLLER STRUCTURE [2]



APPENDIX E

TUNING COMPARISON BLOCK DIAGRAM



APPENDIX F
PI-FUZZY BLOCK DIAGRAM