DEVELOPMENT AND IMPLEMENTATION OF ADVANCED PROCESS CONTROLLERS (APC) FOR FLOW APPLICATION

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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FINAL DISSERTATION

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Approved by,

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(Dr Rosdiazli Bin Ibrahim)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2012

CERTIFICATION OF ORIGINALITY

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

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MUHAMMAD IQBAL BIN AB GHAFAR

ABSTRACT

The main objective of this project is to improve the capability of conventional PID controller for flow control by developing and implementing Advanced Process Controllers (APCs) which consist of Fuzzy Logic Controller (FLC) and Adaptive Neuro-Fuzzy Inference System (ANFIS). Flow is one of the most difficult process variables (PV) to control because the properties of a fluid can easily change. This can lead the system to become non-linear process dynamic. When disturbances present, flow control will become more difficult to control and the conventional PID controller will not be the best option. As a solution, in this project APCs will be developed and the controllers' performance will be compare with the conventional PID controller. Development of the controllers will be based on MATLAB/Simulink Toolboxes. Then, the designed controllers will be implemented onto the PcA SimExpert Mobile Pilot Plant SE231B-21 - Flow Control and Calibration Process Unit. In addition, for having better maintenance and data trend collection for the process, Human Machine Interface (HMI) will be developed by using MATLAB/Simulink. In designing the controllers, it will involve data gathering, designing and tuning membership functions and develop rule base. Based on the experiment results, APCs show better control performance as compared to PID controller.

ACKNOWLEDGEMENTS

First and for most, I want to express my deepest gratitude to my project supervisor, Dr Rosdiazli Bin Ibrahim who had support, guide and encourage me to successfully completed this project. He always expects for high quality works and this project is no exception. He continuously challenges me to learn new things and come out with new ideas in order to produce a high quality project.

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LIST OF ABBREVIATION

ANFIS	Adaptive Neuro-Fuzzy Inference System
ANN	Artificial Neural Network
DCS	Distributed Control System
DP	Differential Pressure
FIS	Fuzzy Inference System
FLC	Fuzzy Logic Controller
FODT	First Order Dead Time
GUI	Graphical User Interface
HMI	Human Machine Interface
IAE	Integral Absolute Error
LCP	Local Control Panel
LSE	Least Square Error
MV	Manipulated Variable
MF	Membership Function
PC	Personal Computer
PD	Proportional + Derivative
PI	Proportional + Integral
PID	Proportional + Integral + Derivative
PRC	Process Reaction Curve
PV	Process Variable
SP	Set point

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Instrumentation control is a discipline in automated measurement and control [2]. Basically control is an action to maintain a process's set point by controlling the output signal from the controller to final element. The basic operation for any control system is the ability of sensors to measure the process and take any necessary action to overcome the offset. In a basic design, a negative feedback control system will consist of controller, final element, plant and sensor [1].

In this project, performance of flow control in pilot plant will be conducted by using a few kinds of controllers in order to find the best control performance. Flow was selected because it is an important application in plant industries. Some of the flow applications in industry are

- Regulate the amount of feed to a vessel
- Regulate the level of a tank
- Regulate the heat transfer in a heat exchanger by controlling the amount of steam

The existing pilot plant use PID controller to control flow rate since it is effective and economical. However, more time will be wasted in fine tune the controller because it involved with mathematical calculation. Process flow can be non-linear dynamic process due to different type of sensors, changes of the fluid properties as well as the existence of impurities [3]. For this reason, flow controller need to be robust in order to optimize the performance of the plant under different circumstances.

The key to solve this problem is by implementing a new control strategy. Since there are many kind of technology can be used, only Fuzzy Logic System (FLS) and Adaptive Neuro-Fuzzy Inference System (ANFIS) will be considered. Basically, the controllers' comparison is based on three technologies era which can be defined as below,

Table 1: Type of Controllers

Controller technology	Type of controller
Conventional	PID
Present	FLC
Future/hybrid	ANFIS

The reason for selecting those advanced technologies is because its simplicity, easy to implement and able to provide good quality control.

1.2 Problem Statement

The measurement of fluid flow is the most complex type of process variable measurement in instrumentation control [1]. Problems may arise due to changes in fluid properties such as density, viscosity and conductivity. The existence of impurities in the process fluid also can lead to a difficulty in flow control.

Due to those variables that could affect flow control, it can cause the system to become non-linear dynamic process. Because of this, flow controllers need to be robust in order to optimize the performance of the mobile pilot plant. The existing PID controller exhibit slow settling time and rise time, it will be worsen when the system become non-linear due to the present of disturbances. In addition, designer needs to do mathematical calculations in order to fine tune the PID controller and it will have poor performance if the parameters improperly tuned [5].

Besides that, the existing PID controller is mounted on the Local Control Panel (LCP) and there is no graphic or visual from where the data can be viewed. This make monitoring, controlling and tuning controller is difficult. As a solution, the new controller will have access from a PC through MATLAB/Simulink for easy maintenance.

1.3 Significant of Project

The idea of this project is to design and implement advanced control strategies to flow control system on a pilot plant. Fuzzy Logic Controller (FLC) is selected because designer able to build a model of a human control expert which capable of controlling the plant without thinking in terms of a mathematical model. The control expert can specify his control actions in the form of linguistic rules [14]. For a hybrid controller, the author proposed ANFIS controller. This is because the controller has a learning capability. This controller is based on the fuzzy system which is trained by learning algorithm derived from Artificial Neural Network (ANN) theory.

1.4 Objectives and Scope of Study

The objectives of the project:

- To design and develop PID, Fuzzy Logic and Adaptive Neuro-Fuzzy Inference System (ANFIS) controllers by using MATLAB/Simulink
- To implement advanced control strategies and obtain data trend from a pilot plant
- To analyse and compare the controllers performance between PID, FLC and ANFIS

The scope of study:

- Plant based on PcA SimExpert Mobile Pilot Plant SE 231B-21 located at Block 23
- Controllers will be connected to pilot plant via USB-1208 FS Personal Measurement Device for DAQ with desktop
- Controllers development and data trend will be done by using MATLAB/Simulink

1.5 Relevancy of Project

This project is applicable in Instrumentation and Control System since it focuses on the design of Advanced Process Controllers which can be implemented in industrial process control. Although these technologies have successfully proven in research level, but in implementation level onto real plant it still not widely used. So, this project is relevance regarding the industry demand which control performance of flow control is very crucial.

CHAPTER 2
LITERATURE REVIEW

2.1 Flow measurement

Fluids are substances which capable of flowing and conform to the shape of containing vessel [3]. Fluid may be liquids, vapors or gases. There are four basic characteristics and physical properties of fluid, which are:

- Density
- Specific gravity
- Compressibility
- Fluid velocity

In process control, flow is one of the main process variables (PV) that been measured. Flow measurement is a process of measuring the quantity of fluid that passes a particular point in a given interval of time.

There are few factors that can affect flow rate in a pipe, some of them are:

- Velocity of the fluid
    - The faster the fluid flow rate, the greater the volume of flow
- Friction of fluid with contact with pipe
    - Pipe friction can reduce the flow rate
    - The smoother, cleaner and larger a pipe is, the less effect pipe friction has on the overall fluid rate
- Density of fluid
    - Fluid with more dense require more head pressure to maintain a desired flow rate

Flow may refer to differential pressure based flow, volumetric flow (the number of fluid volumes passing by per unit time) and mass flow (the number of fluid mass units passing by per unit time).

In a differential pressure based flow, the relationship between flow rate and differential pressure for any fluid-accelerating flow element is non-linear;

- a doubling of flow rate will not result in a doubling of differential pressure
- a doubling of flow rate will result in a quadrupling of differential pressure

Volumetric flow rate (Q) equation:

$$Q = k\sqrt{\frac{P_1 - P_2}{\rho_f}} \tag{2.1}$$

where,

Q = volumetric flow rate

k = constant of proportionality

P_1 = upstream pressure (absolute)

P_2 = downstream (absolute)

ρ_f = fluid density

The quadratic relationship between flow and pressure drop is because of fluid acceleration created by an Orifice plate. Thus, a mathematically "condition" or "characterize" is needed for the differential pressure instrument in order to arrive at an expected value for flow rate. In a new design of DP transmitters, there is already square-root function built in. Below is the structure of DP transmitter tapping on pipeline.

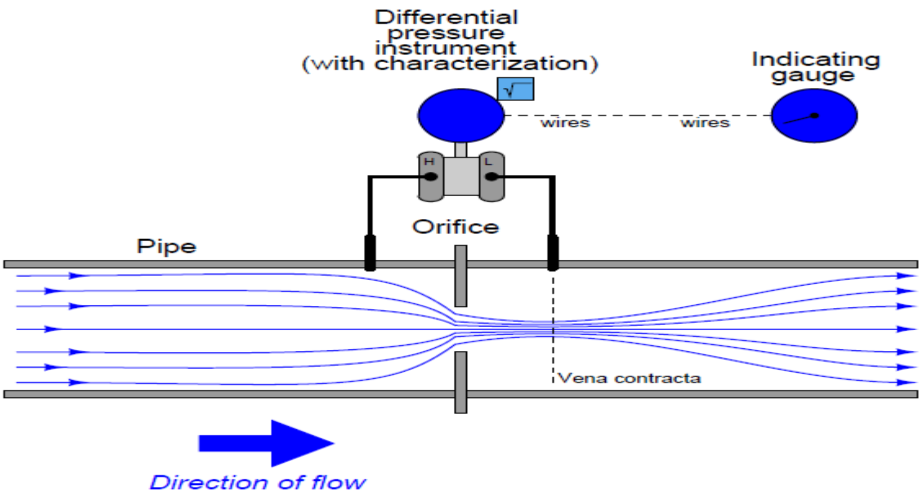


Figure 1: DP Transmitter Structure

Table 2: Type of Flow Transmitter

Flow measurement technology	**Operating principle**	**Linearity**
Differential pressure	Fluid mass self-acceleration Potential kinetic energy exchange	$\sqrt{\Delta P}$
Vortex	von Karman effect	Linear
Coriolis	Fluid Inertia, coriolis effect	Linear

2.2 Closed loop system

In process control, closed loop system is used in order to make a system to be in automatic mode. The automatic mode means, the value of a process variable (PV) - measured by sensor will be continuously feedback to the system input which the value is compared with a desired set point (SP). The difference between process variable and set point is known as error (E). Controller function as an error compensator which the error will be reduce until PV= SP. A signal called manipulated variable (MV) is send to final element in order to control the process. Below is a diagram of a single closed loop system.

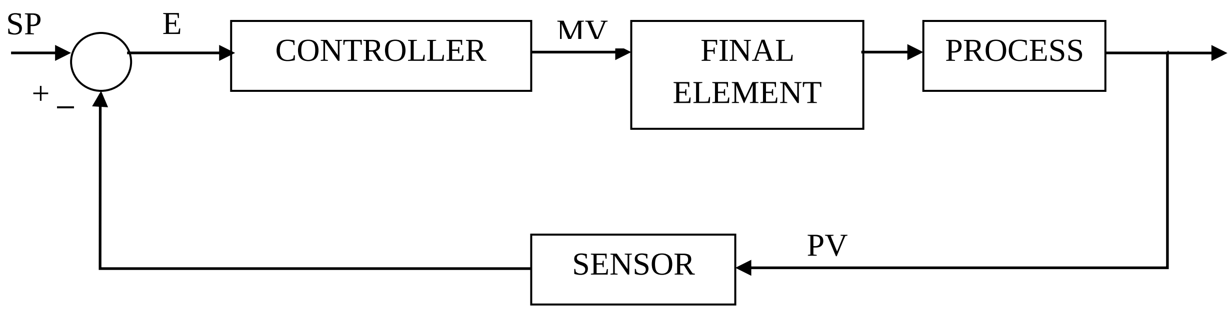
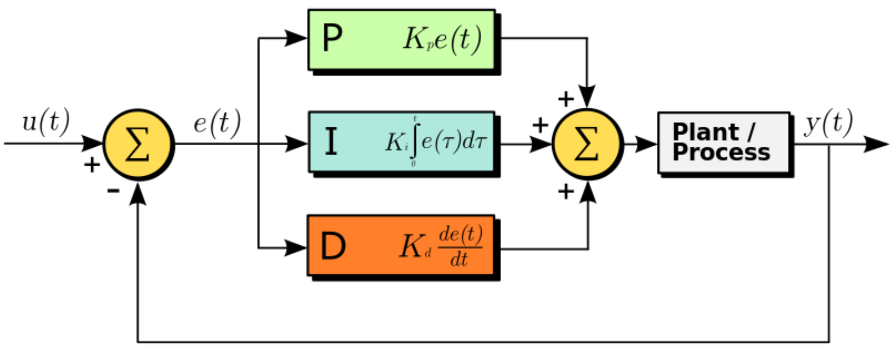


Figure 2: Negative Feedback Closed Loop

2.3 Conventional PID controller

Since 1940s, PID algorithm has been successfully used in process industries and it remains as the most often used algorithm until today [4]. This is due to its simplicity, easy understanding and robustness to disturbances. PID is stand for proportional-integral-derivative which each mode has their own usage in obtaining stable and zero offset system.

Below is a PID controller structure in a closed loop system.



y(t) = Process variable (PV)

u(t) = Set point (SP)

e(t) = error (E)

Figure 3: PID Controller Closed Loop System

Proportional mode; K_C

Proportional mode provides a rapid adjustment to the manipulated variable. It does not provide zero offset even though it reduces the error. It function to speeds the dynamic response and can cause instability if tunes improperly.

Integral mode; T_i

The main and important function of integral mode is to achieve zero offset. This mode adjusts manipulated variable in a slower manner than the proportional mode, thus giving poor dynamic performance. If tune improperly, it will cause instability.

Derivative mode; T_D

Derivative mode does not influence the final steady state value of error but it provides rapid correction based on the rate of change of the controlled variable. In addition, it can cause undesirable high frequency variation in the manipulated variable.

Those three modes are summed in order to calculate the output of the PID controller. The final form of the PID algorithm is as below:

$$\text{MV}\ (t) = \text{K}_\text{C}\left(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + \text{T}_\text{d}\frac{d\ e(t)}{dt}\right) + \text{I} \qquad (2.2)$$

Fine tuning for PID controller is very crucial. If the tuning result is poor, it will cause unacceptable performance. There are a few methods of PID controller tuning, which are:

i. Manual tuning
ii. Ziegler-Nicholes Open-loop / Closed-loop
iii. Cohen-coon
iv. Ciancone

2.4 Fuzzy Logic Controller

Fuzzy Logic Controller was invented by Lotfi A. Zadeh in 1965 [10]. He decided to extend two-valued logic, from {0, 1} to continuous interval [0, 1]. The main reason of FLC is to developed a model of a human control expert which capable to control the plant without thinking in terms of a mathematical model.

Fuzzy control is a control algorithm based on fuzzy logic. Below are simple descriptions for the algorithm:

- Fuzzy logic = Computing with words rather than numbers
- Fuzzy control = Control with sentences rather than equations

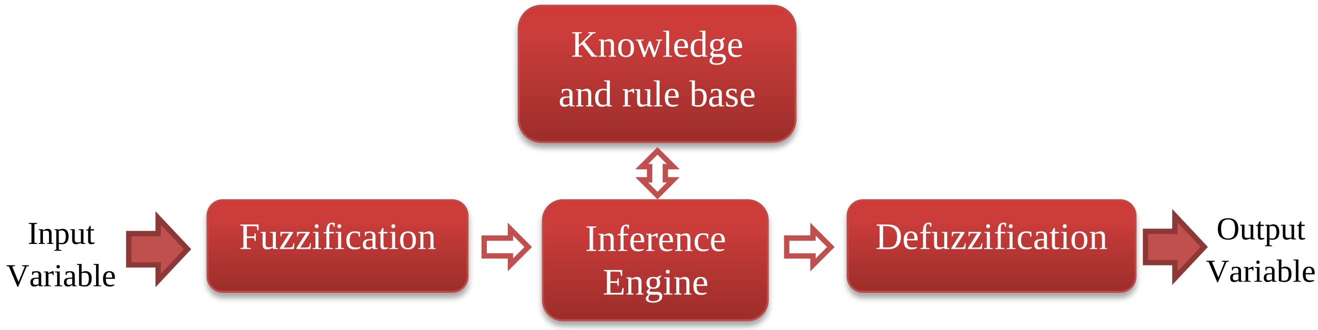


Figure 4: Block Diagram of Fuzzy Inference System (FIS)

Table 3: FLC Subsystems

Fuzzification	converts each piece of input data to degree of membership by lookup in membership function
Rule base	store the linguistic knowledge needed based on control expert's control action in order to control the plant by using fuzzy logic The rules are in *if* – *then* format; *if* < condition > *then* < conclusion >
Inference engine	decide the best control action by combining the outputs of each rules into a single fuzzy set
Defuzzification	convert the resulting fuzzy set to a number that can be sent to the process as a control signal

There are two types of FIS which are Mamdani method and Takagi-Sugeno method [12]. The main difference between these two is the Takagi output membership functions are either linear or constant while for Mamdani, the output is fuzzy sets.

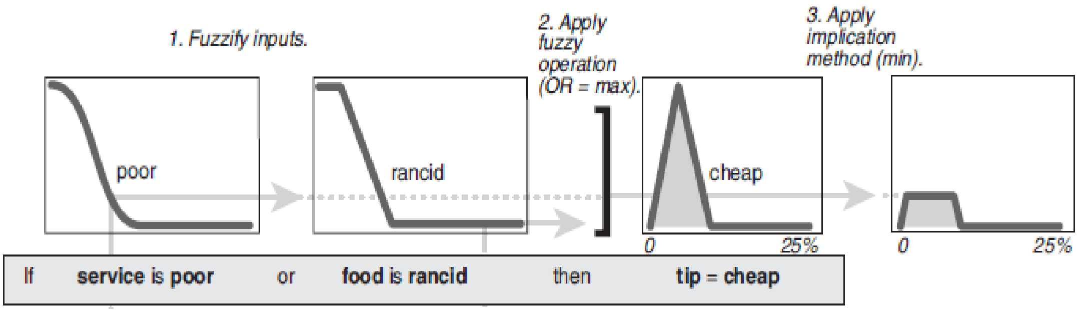


Figure 5: Mamdani Method

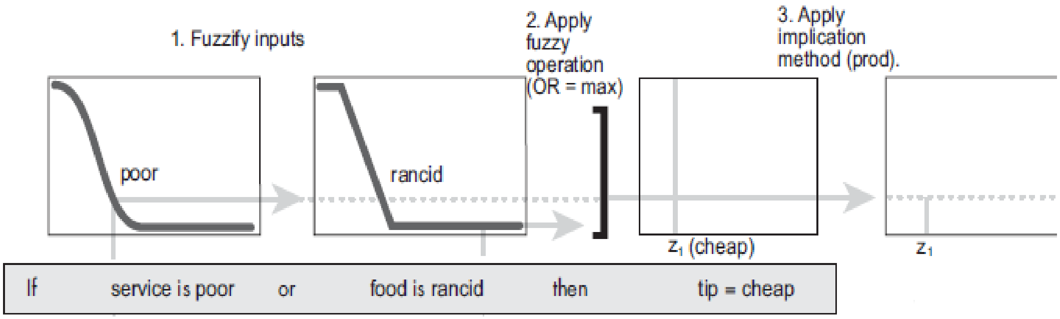


Figure 6: Takagi-Sugeno Method

The condition of good rule base depends on the knowledge of the control expert, but the translation of these rules into fuzzy set theory framework is not standardized and random choices concerning, for example:

i. Shape of membership function
ii. Universe of discourse for each fuzzy set
iii. Degree distribution of each membership function.

Usually, in a process to developed FLC, try and error is one of the approaches which fuzzy parameter selection would be done. In addition, expert knowledge is one of the parameters that can effect on FLC modeling. Therefore, due to those constraints, a new method needs to be developed in order to reach optimization and better decision about FLC parameters.

2.5 Adaptive Neuro-Fuzzy Inference System (ANFIS) Controller

ANFIS stand for *Adaptive neuro-fuzzy inference system* which is an adaptive network. An adaptive network is network of nodes and directional links. Related with the network is a learning rule. It's called adaptive because some or all of the nodes have firing strength which affect the output of the node [19]. These networks are learning a relationship between inputs and output.

The benefit of fuzzy logic had been proved since it prepare a powerful tool that can solve a process control without involving any mathematical algorithm but using expert knowledge which translated into linguistic rules, *if-then* format [6][7]. As mention in section 2.4, one of the biggest problems in developing FLC is the shape and location of membership function for each fuzzy set which solve by trial and error method only. Fortunately, there is a technology that has learning capability which is *Artificial Neural Network (ANN).*

ANN algorithm is inspired by the brain process information activities which consist of a large number of highly processing elements (nodes) that function like neurons and are connected together with weighted connection that are analogous to synapses [11]. ANN consists of three layers which are input, hidden and output layer. Those three layers consist of a collection of neurons. Each neurons are connected together with some weight which represents the strength of a connection.

Adaptive Neural based Fuzzy Inference System (ANFIS) was developed by Roger Jang in 1993. ANFIS is a multilayer feed forward network where each node performs a particular function on incoming inputs. The ANFIS architecture is shown as below.

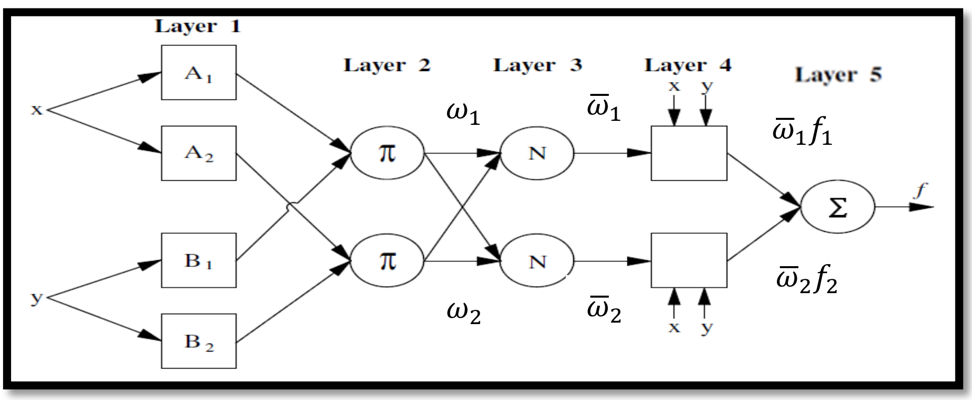


Figure 7: ANFIS Architecture

The circular nodes represent nodes that are fixed whereas the square nodes have parameters to be learnt / adjusted. This model will provide:

- RHS (*consequent parameters*) tuning by implementing the first order Takagi-Sugeno fuzzy logic as a network
- LHS (*premise parameters*) tuning by using back-propagation algorithm

The above system has x and y as inputs while *f* is the output function. The system contains two rules of Takagi-Sugeno type.

Rule 1: *If x is* A_1 *and y is* B_1*, then* $f_1 = p_1x + q_1y + r_1$

Rule 2: *If x is* A_2 *and y is* B_2*, then* $f_2 = p_2x + q_2y + r_2$

Each node of each layer in the ANFIS structure has same function family as described below:

Layer 1

The output of each node is:

$$O_{1,i} = \mu_{A_i}(x) \qquad for\ i = 1,2$$
$$O_{1,i} = \mu_{B_{i-2}}(y) \qquad for\ i = 3,4 \qquad (2.3)$$

$O_{1,i}(x)$ is the membership degree for *x* and *y* inputs. The membership functions can be any shape but for illustration purposes, bell shaped function will be used which given by:

$$\mu_A(x) = \frac{1}{1 + \left|\frac{x - c_i}{a_i}\right|^{2b_i}} \qquad (2.4)$$

where a_i, b_i, c_i are parameters to be adjusted. These are the *premise parameters*.

Layer 2

Every node parameters in this layer is fixed. This is where the t-norm is used to 'AND' the membership degree.

$$O_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y), \quad i = 1,2 \tag{2.5}$$

Layer 3

Layer 3 also contains fixed nodes which calculate the ratio of the firing strengths of the rules:

$$O_{3,i} = \overline{w}_i = \frac{w_i}{w_1 + w_2} \tag{2.6}$$

Layer 4

The nodes in this layer are adaptive and perform the consequent of the rules:

$$O_{4,i} = \overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i) \tag{2.7}$$

The parameters in this layer (p_i, q_i, r_i) are to be determined and are referred to as the *consequent parameters*.

Layer 5

There is a single node here that computes the overall output:

$$O_{5,i} = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{2.8}$$

[23][24]

The ANFIS learning algorithm can be divided into two steps, forward pass and backward pass.

- Forward pass
  - Initial values of the premise parameters are given (fixed), then the consequent parameters calculated by using least squares estimate (LSE)

- Backward pass
  - Based on the output parameters obtained, error of the system can be calculated. Error is the difference between the actual and desired output of the system. At this state, consequent parameter is fixed and premise parameter is computed using back-propagation algorithm. The BP algorithm of the network propagates the error back from output layer to input layer. The premise parameters are updated by using the gradient descent method. This leads to a change of the membership functions shape.

With the construction of ANFIS, the advantages of FIS and ANN are combined together in a single system. This approach can overcome the constraints in designing the system separately. Learning capability is an advantage to FIS, in the other hand the formation of linguistic rule base is an advantage to ANN [17]. This integrated neuro-fuzzy system shared data structures and knowledge representation.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Project Flowchart

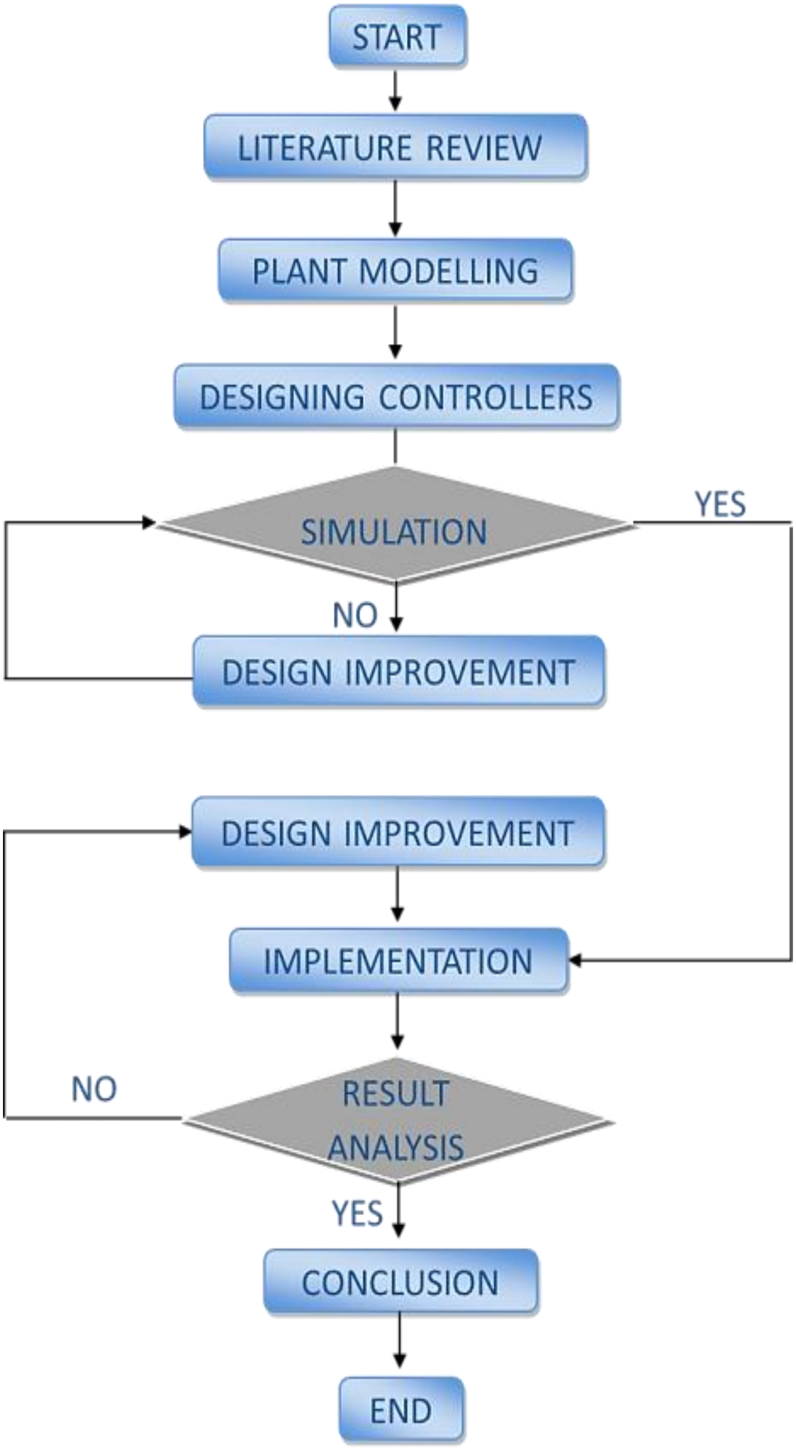


Figure 8: Project Activities Flow

3.2 Project Activities

Activity	Description
Preliminary research	Gathering information regarding the project and research on hardware and software used during the project. Result from this process will be the literature review from thesis, journal papers, certified scholars and reference books for PID, FLC and ANFIS. And also research on MATLAB/Simulink manuals.
Literature review	Making clear the objective of the project. Determine project direction by referring to the research that had been done. Understanding functions and benefit for each controllers and find its potential for implementation on real plant.
Designing controllers	Controllers will be developed by using MATLAB/Simulink. Designing controllers involving development of PID, FLC and ANFIS. From the knowledge of the plant, FLC structure will be developed base on try and error method. While construction for ANFIS, input output data will be used from the result of PID controller.
Simulation	Simulation will be done by using MATLAB/Simulink. It uses Fuzzy Inference System (FIS) and ANFIS Toolbox.
Design improvement	If controllers not give satisfactory result, improvement will be taken.
Implementation	Connecting computer with the pilot plant using Data Acquisition (DAQ) card. Cables termination, jumpers and resistors will be done to ensure the interfacing.
Conclusion	The performances of FLC and ANFIS will be determined by comparing their result with PID controller result. The new controllers need to provide better performance than conventional controller.

3.3 Gantt Chart and Key Milestone

Table 4: Gantt Chart and Key Milestones

NO	DESCRIPTION	FYP 1														FYP 2														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Literature study and review - Study on plant process - Study on PID, FLC and ANFIS Controllers - Study on MATLAB/Simulink																													
2	Submit extended proposal																													
3	Development of controllers and simulation																													
4	Viva: proposal defence																													
5	Submit draft report FYP 1																													
6	Submit final report FYP 1																													
7	Implement controllers onto pilot plant																													
8	Collect data result and analysis the data																													
9	Apply disturbances into plant process																													
10	Data analysis																													
11	Submit draft report FYP 2																													
12	Submit final report FYP 2																													
13	Viva																													

3.4 Tools and Equipment Required

Below are the hardware and software that will be used during the project on progress.

- PcA SimExpert Mobile Pilot Plant SE 231B-21 - Flow Control and Calibration Process Unit
- A desktop
- Data Acquisition Card (DAQ); USB-1208FS
- 250 ohm resistor and jumper cables
- MATLAB with Data Acquisitions, Fuzzy Logic and ANFIS Toolboxes

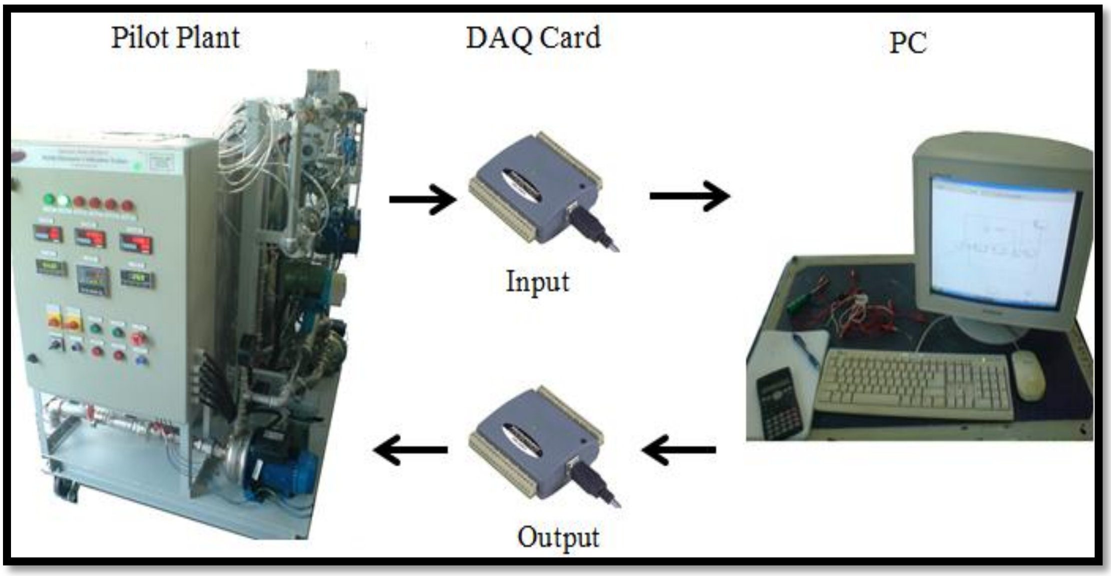


Figure 9: Plant Setup

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Piping & Instrumentation Diagram (P&ID)

The Piping & Instrumentation Diagram (P&ID) for the *PcA SimExpert Mobile Pilot Plant SE231B-21 – Flow Control and Calibration Process Unit* is as shown below.

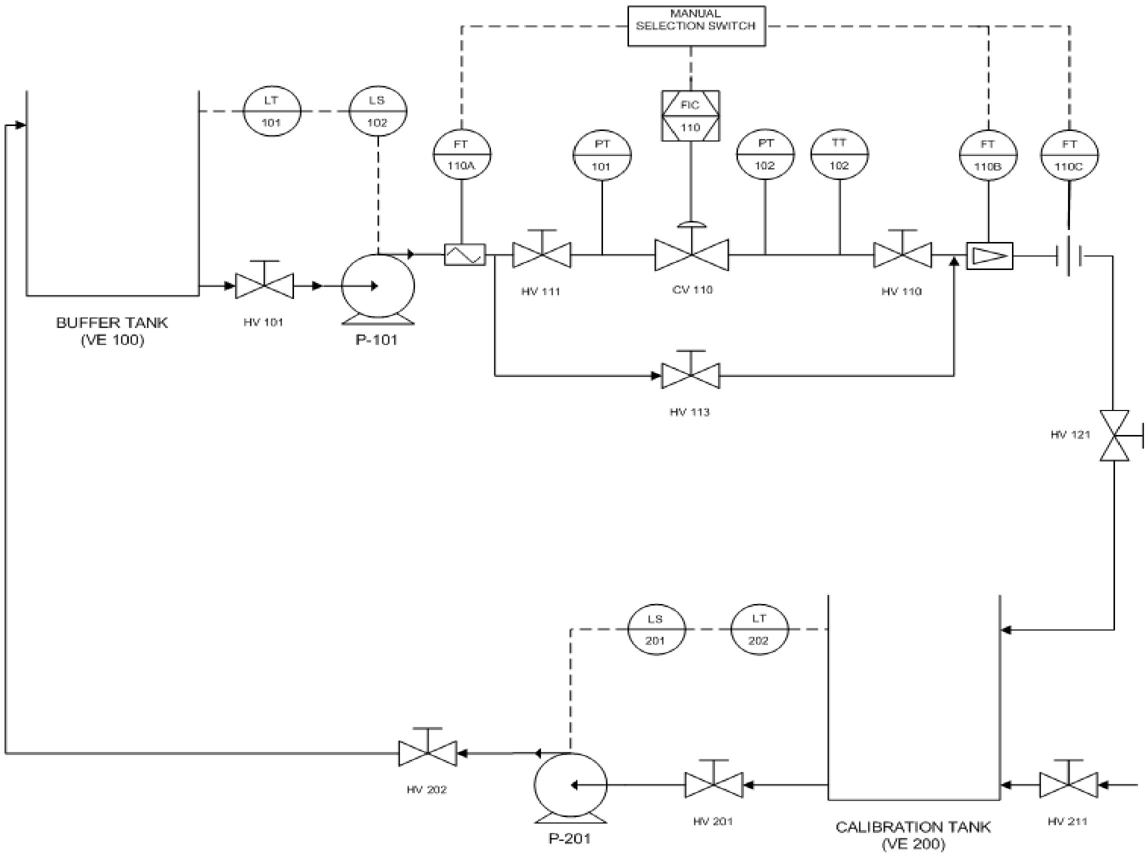


Figure 10: P&ID for Mobile Pilot Plant

4.2 Plant Process Description

Based on the P&ID shown in Figure 10, the pilot plant has simple process which is to transfer the fluid (water) from Buffer Tank – VE 100 to the Calibration Tank – VE200 while the fluid flow between these two tanks will be controlled. Pump P-101 and P-201 will turn on at the same time in order to make sure the level in both tanks does not overflow and can be maintained at a predetermined level. The pilot plant consists of three type of flow transmitters which are Coriolis, Vortex and Differential Pressure (Orifice). These three flow transmitter; Coriolis Flowmeter (FT-110A), Vortex Flowmeter (FT-110B) and DP Flowmeter (FT-110C) can be used interchangeably by selecting either one by using Manual Selection Switch. The closed-loop feedback of the pilot plant is controlled by FIC-110 which the flow inside the pipeline will be measured by FT-110A, FT-110B or FT-110C. The FIC-110 will receive analog signal from one of the three flow transmitter. Then the controller will send output signal to control the opening of the Control Valve (CV-110).

The level switch LS-101 and LS-201 will used as a fail-safe measure which function to sound alarm whenever the fluid level in both tanks are too low or too high from the desired limit points. When this conditions occur, the pump P-101 and P-201 will be turn off in order to stop the flow process. The pressure transmitter PT-101 and PT-201 are used to measure the flow pressure before and after the CV-110. The fluid level in the tanks will be measure by Level Transmitter LT-101 and LT-201. The pilot plant also consists of several hand valves which used to manually allowing or blocking flow of the fluid in the process lines.

4.3 Controller Simulink Model

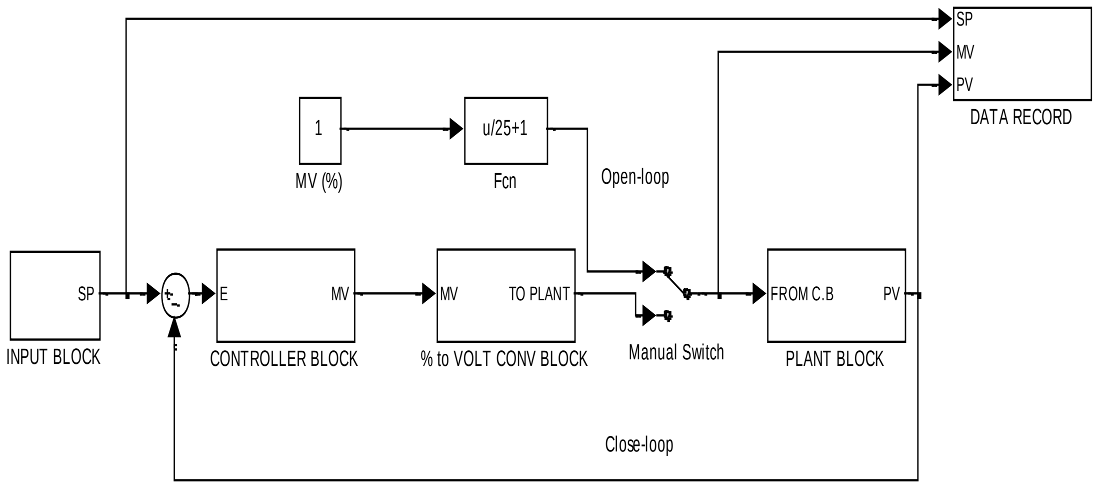


Figure 11: Simulink Model

The above model is used to enable plant control from Matlab/Simulink. This model can be used for closed-loop controlled or open-loop controlled purpose which by controlling the manual switch. Operator can insert set point value at Input Block and data acquisition can be obtained at Data Record Block.

Controller Block is where the controllers which are PID, Fuzzy and ANFIS will be located. Since the output from the controllers are in percentage unit while the DAQ Card just only can be measure in voltage unit, % to Volt Conversion Block will be used to perform conversion from percentage to voltage unit.

In order to obtain online data from pilot plant, Data Acquisition Toolbox which are Analog Input and Analog Output block will be used to perform the task. Because the signal that received from the plant is in voltage unit while the data records need to be display in liter per minute (*l*/min) unit, a conversion function block will be used. All the blocks connection can be refer at Appendix.

Below are the procedures to obtain conversion function formula.

i. Measure and record valve opening percentage, input voltage and flow rate values

Table 5: Parameters Reading

Valve opening percentage (%)	Input voltage (V)	Flow rate (*l*/min)
0	0	1
10	0	1
20	0	1
30	15.9	2.04
40	23.2	2.49
50	30.1	2.91
60	35.7	3.26
70	40.0	3.51

ii. Plot graph flow rate versus voltage

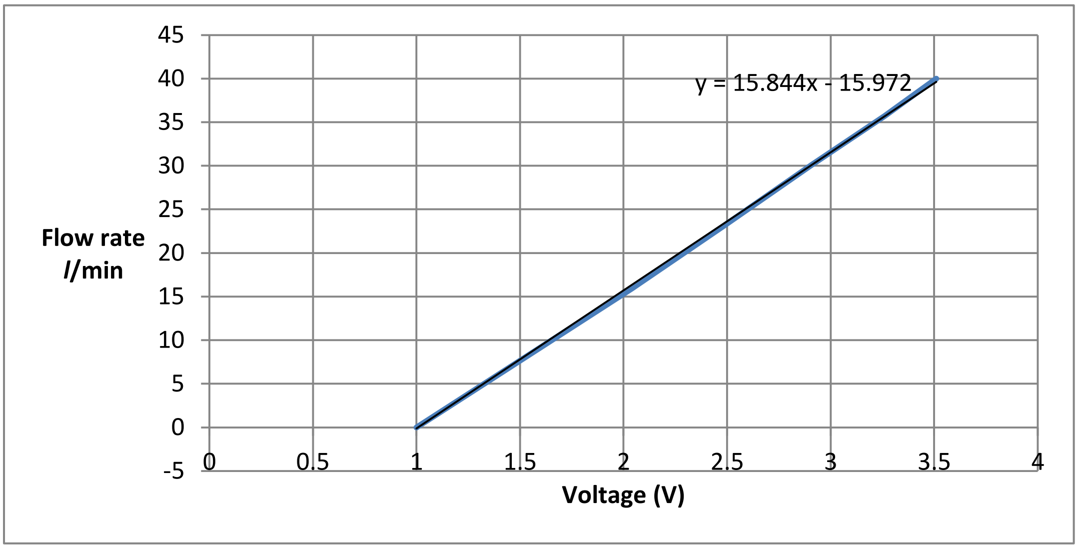


Figure 12: Graph Flow Rate versus Voltage

iii. Obtain a linear equation from the graph

The equation y=15.844x – 15.972 will be used as the conversion function from voltage to liter per minute (*l*/min).

The content of each subsystem can be referred at Appendix C.

4.2 Plant Modeling Technique

Basically there are three plant modeling techniques can be used which are:

i. Mathematical modeling
ii. Empirical modeling
iii. Statistical modeling

However, for this pilot plant, Empirical modeling is preferred compare to the other methods. This is because Empirical Modeling is simple and it places a greater emphasis on the human cantered construction of models.

4.2.1 Empirical Modeling

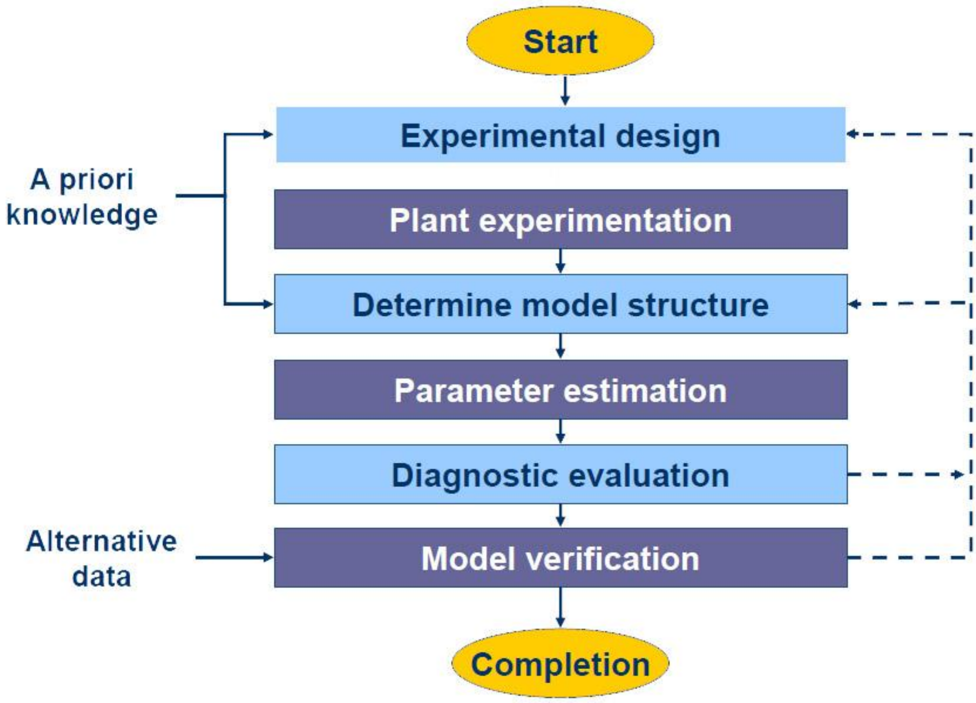


Figure 13: Empirical Modeling Flow Chart

The above figure shows the steps that need to be taken in order to perform Empirical Modeling. There are basically two methods in Empirical Modeling which are:

i. Method I: use Process Reaction Curve (PRC) slope to determine time constant and dead time obtained from the graph

ii. Method II: use the time at 28% and 63% of the Process Reaction Curve (PRC) to determine time constant and dead time

Empirical Modeling can be done by obtaining the Process Reaction Curve (PRC) of the plant process and Cohen-Coon Open Loop tuning method then used to obtain PID parameters.

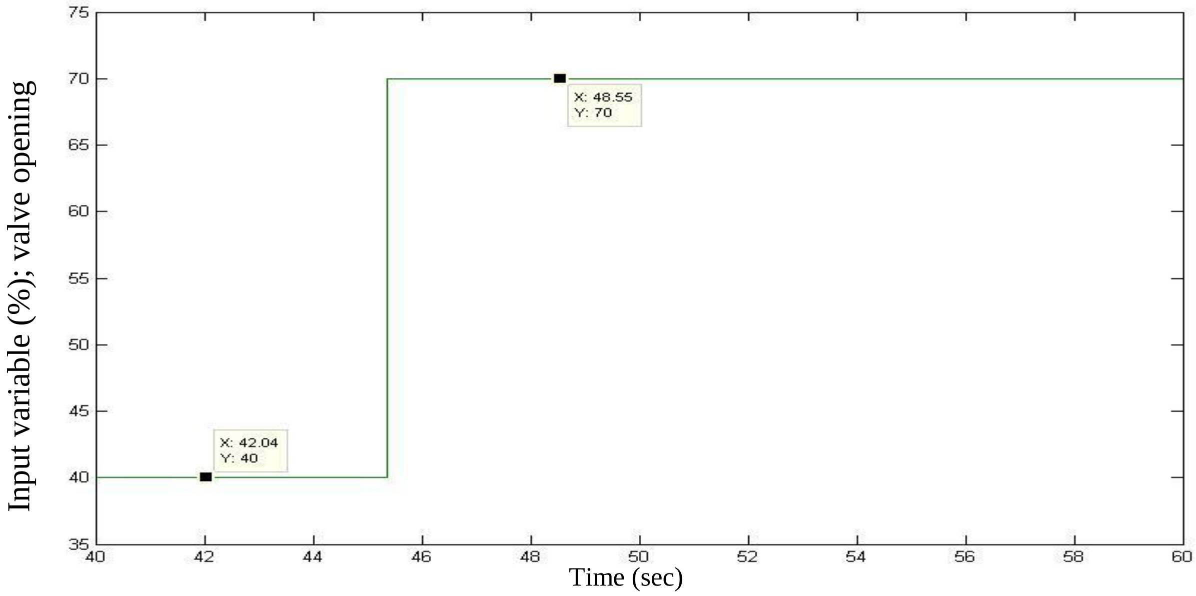


Figure 14: Change in MV (valve opening %)

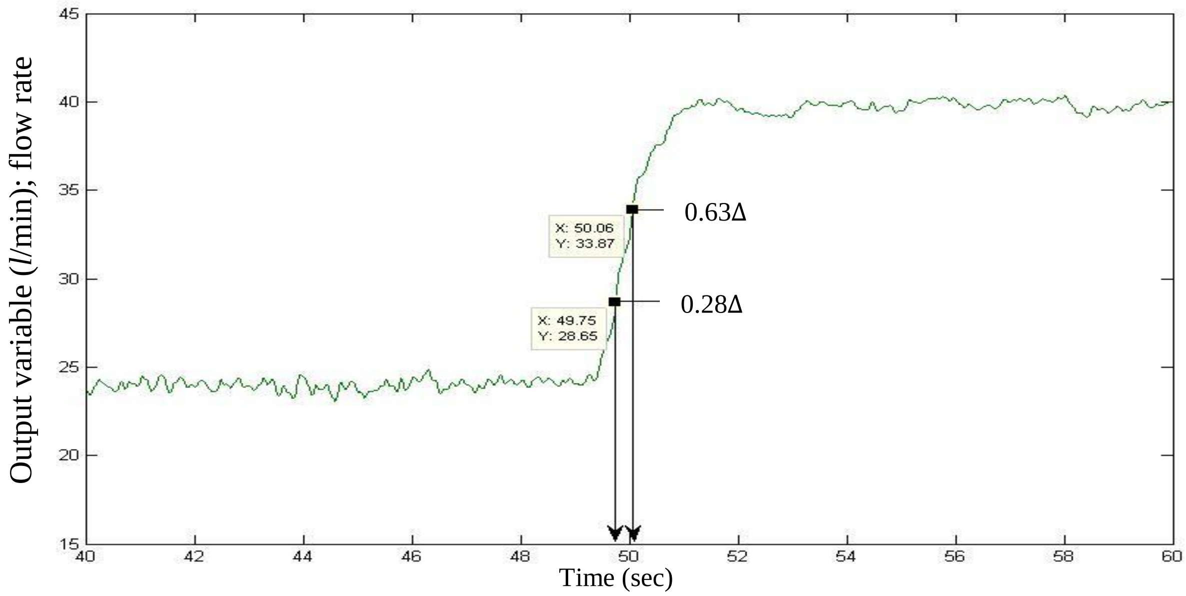


Figure 15: Change in PV (flow rate *l*/min)

The above PRC is acceptable because it meet the following criteria:

- The input change is a perfect step change
- The input (MV) value is large enough to allow an output (PV) signal to noise ratio (SNR) greater than 5
- The plant process is long enough which is more than $\theta + 4\tau$
- The process reach final steady state after step change
- The output (PV) change back to the initial condition after the input (MV) step down to the previous condition, as shown in the figure below:

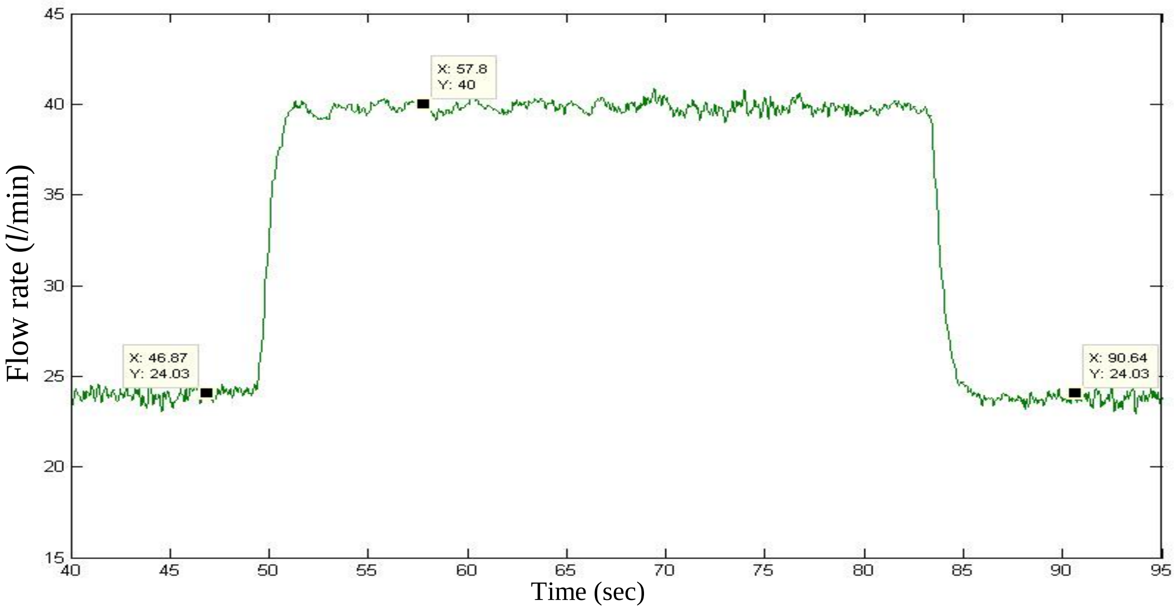


Figure 16: PV back to Initial Value

Below are the calculations of the Empirical Modeling by using Method II.

MV (σ) = 30%

PV (Δ) = 15.49 *l*/min

0.63Δ = 9.578 *l*/min + 24.28 *l*/min = 33.87 *l*/min
From graph, x coordinate for 33.87 *l*/min is 50.06 s

0.28Δ = 4.337 *l*/min + 24.28 *l*/min = 28.62 *l*/min
From graph, x coordinate for 28.62 *l*/min is 49.75 s

$t_{0.63}$ = 50.06s – 45.36s = 4.7s

$t_{0.28}$= 49.75s – 45.36s = 4.39s

$K_P = \frac{\Delta}{\sigma} = 0.516$

$\tau = 1.5\,(t_{0.63} - t_{0.28})$ = 0.465

$\theta = t_{0.63} - \tau$ = 4.235s

R = $\frac{\theta}{\tau}$ = 9.108

From the PRC, the First Order Dead Time (FODT) of the process is as below:

$$G_P(s) = \frac{0.516e^{-4.235s}}{0.465s + 1}$$

The obtained FODT was used in the simulation circuit which represents the process of the pilot plant.

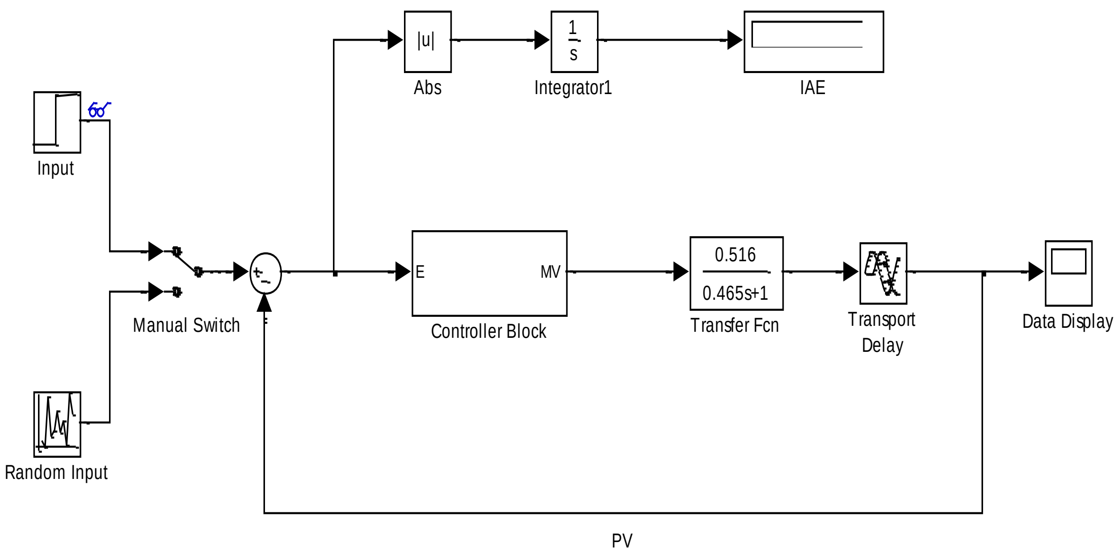


Figure 17: Simulation Plant Modeling

4.3 Controllers Development

4.3.1 PID Controller

Table 6: PID Tuning Parameters

Tuning Parameters	**P**	**PI**	**PID**	**PD**
Proportional, $\boldsymbol{K_p}$	0.859	0.353	0.764	0.589
Integral, $\boldsymbol{T_i}$	-	1.270	4.274	-
Derivative, $\boldsymbol{T_D}$	-	-	0.579	2.078

The above tuning parameters were calculated by using Cohen-coon Open Loop tuning method. After a few simulations had been done, PI parameter was selected because it response with zero steady state error, stable and no overshoot.

4.3.2 Fuzzy Logic Controller (FLC)

The Fuzzy Logic Controller (FLC) for this project was constructed by using Fuzzy Toolbox in Matlab/Simulink. There is only one input which is error and one output for the FLC. Below is the IF – THEN rules for the controller.

Table 7: FLC Rules Base

Input	**Output**
NL	NL
NI	NI
NM	NM
NS	NS
Z	Z
PS	PS
PM	PM
PI	PI
PL	PL

N= Negative; P= Positive; Z= Zero; S= Small; M= Medium; L= Large

By increasing the number of membership functions in the system, it helps to ensure better control performance and better accuracy at smaller errors. Therefore, 9 membership functions are used.

The figures below show the membership functions for the FLC input and output.

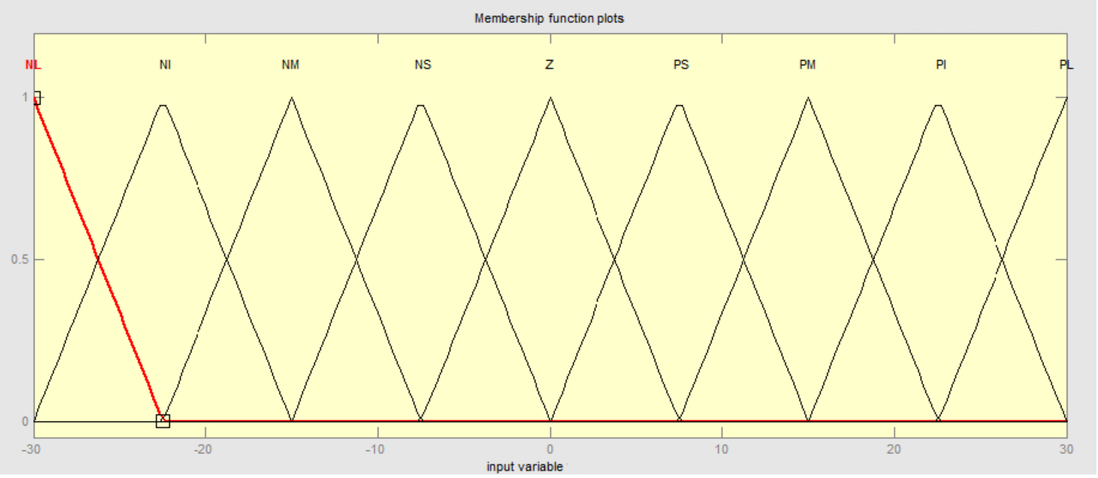


Figure 18: MF for Input

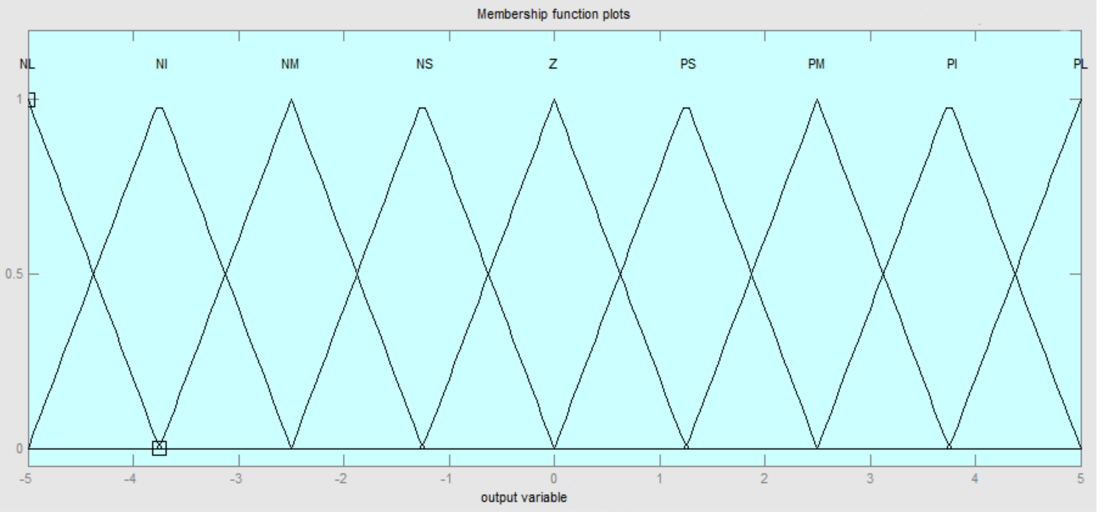


Figure 19: MF for Output

The operating range for the orifice transmitter is from 15 *l*/min to 45 *l*/min. So, the largest error wouldn't exceed ±30 *l*/min. This is the reason why the limit [-30 30] is used as the input range. Meanwhile for the output, from the fine tuning, it is found that [-5 5] range give the best control performance.

4.3.3 Adaptive Neuro-Fuzzy Inference System (ANFIS) Controller

For the ANFIS controller development, the author had used ANFIS Editor Graphical User Interface (GUI) which can be access by using *anfisedit* command. Below is the ANFIS Editor window.

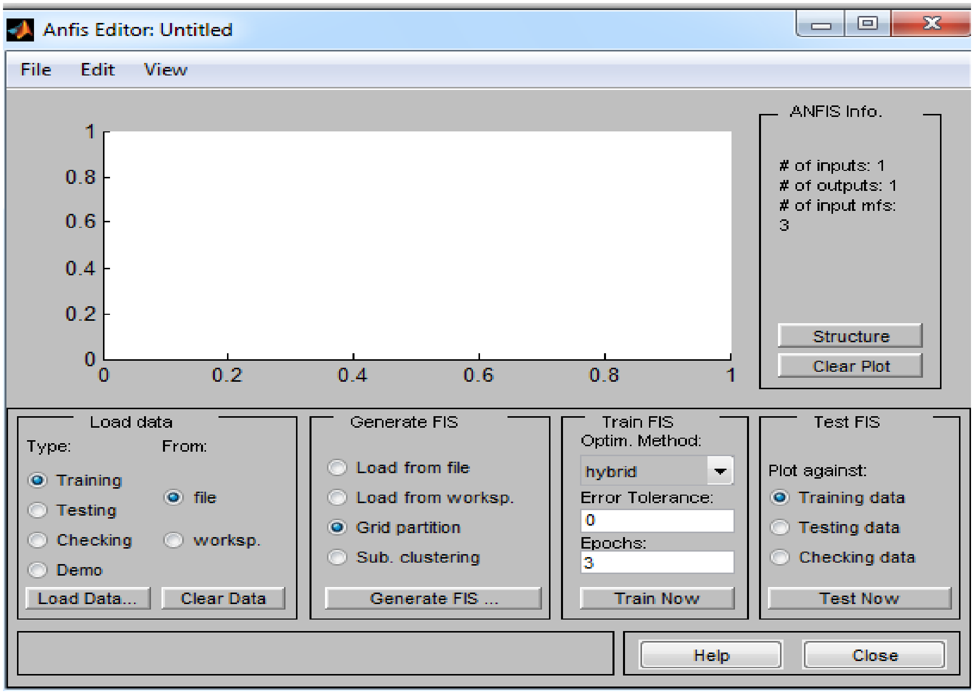


Figure 20: ANFIS Editor GUI

The controller has two inputs and one output. The inputs are from Step Change and Error of the process while the output is the controller response. Data training was obtained based on the PID controller performance. In order to make sure the ANFIS controller can be control with various inputs, the data training need to be collected from multiple inputs process. The loaded data in the ANFIS Editor is shown in the figure below:

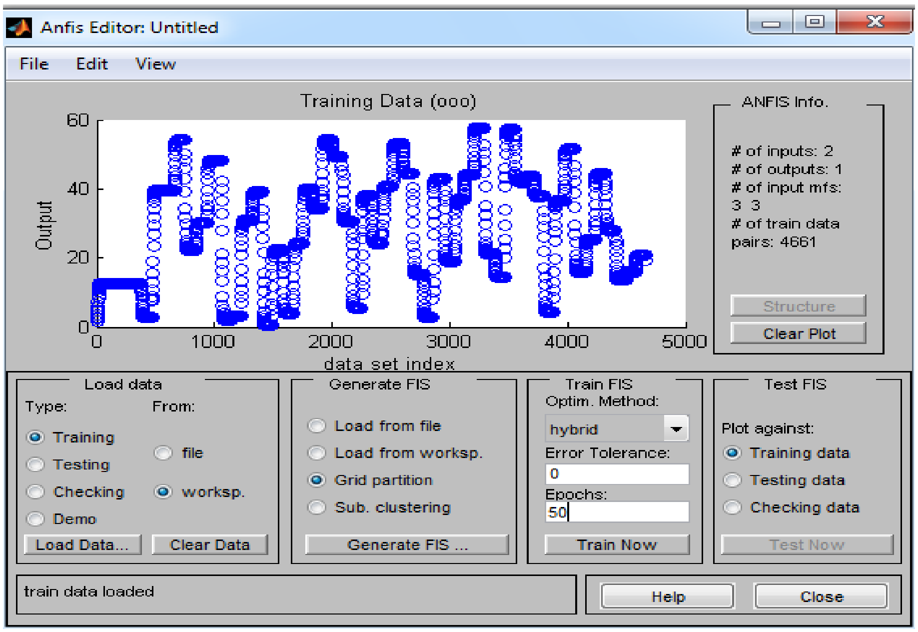


Figure 21: Loaded Data

The Fuzzy Inference System (FIS) was generated based on Grid partition. The parameters for both inputs are as below:

- Number of MF = 9 for each input
- Input MF type = Triangle
- Output MF type = Linear

For the training process:

- Optimization method = hybrid
- Error tolerance = 0
- Epochs = 50

Below is the generated ANFIS model structure:

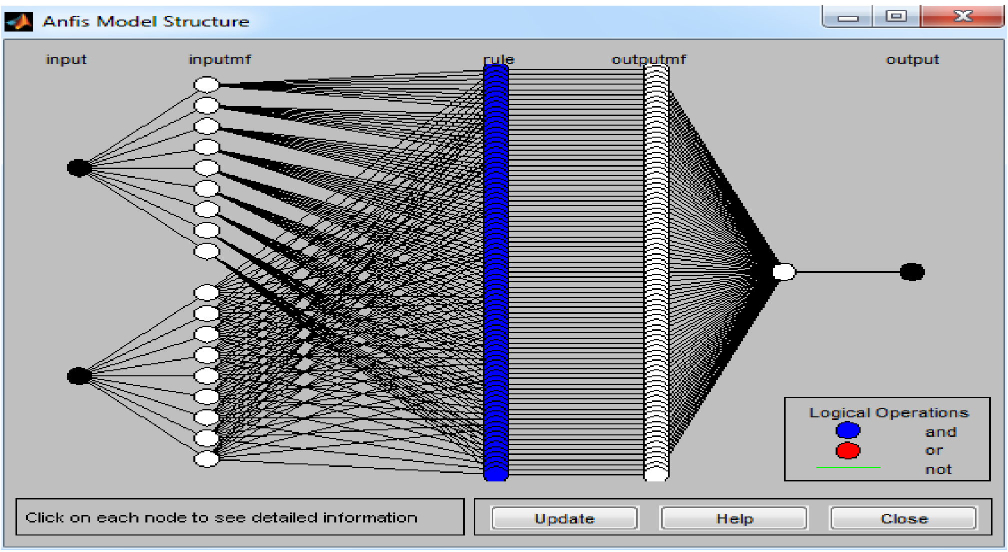


Figure 22: ANFIS Model Structure

4.4 Results and Findings

This project had been divided into two phases which were simulation phase and plant implementation phase. The reason simulation phase was carried out is because to save project duration. During this phase, controllers were developed and fine-tuned until the best controller performance is achieved. When the simulation result is satisfying, the controllers then will be implemented to the pilot plat. Because the real process consists of unwanted external disturbances, fine tuning procedure needs to be done until the controllers give the best results.

4.4.1 Simulation phase

Below is the result for the PID, FLC and ANFIS controllers for the simulation phase.

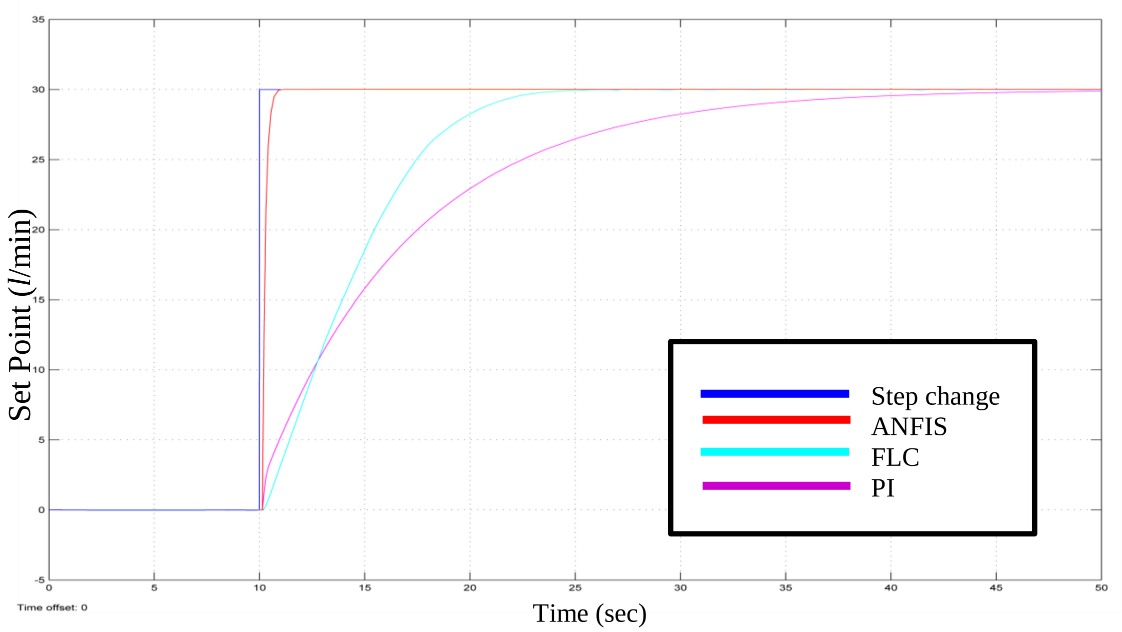


Figure 23: Simulation Result for Step Change Input

Table 8: Simulation Control Performance Comparison

Control Performance	PI	FLC	ANFIS
IAE	205.3	134.3	8.82
Rise Time,	40s	14s	1.5s
Settling Time,	40s	14s	1.5s
Overshoot (%)	-	-	-

Based on the results obtained, the ANFIS controller has the best performance compare to PI and FLC controller.

4.4.2 Implementation phase

Figures below show the controllers' performance based on the step change set point as input. All three controllers are subjected to the same conditions and set point from 20*l*/min to 40*l*/min. The reason step change set to occur at second 70 is because to allow the controllers to achieve the steady state condition before it change to the new set point.

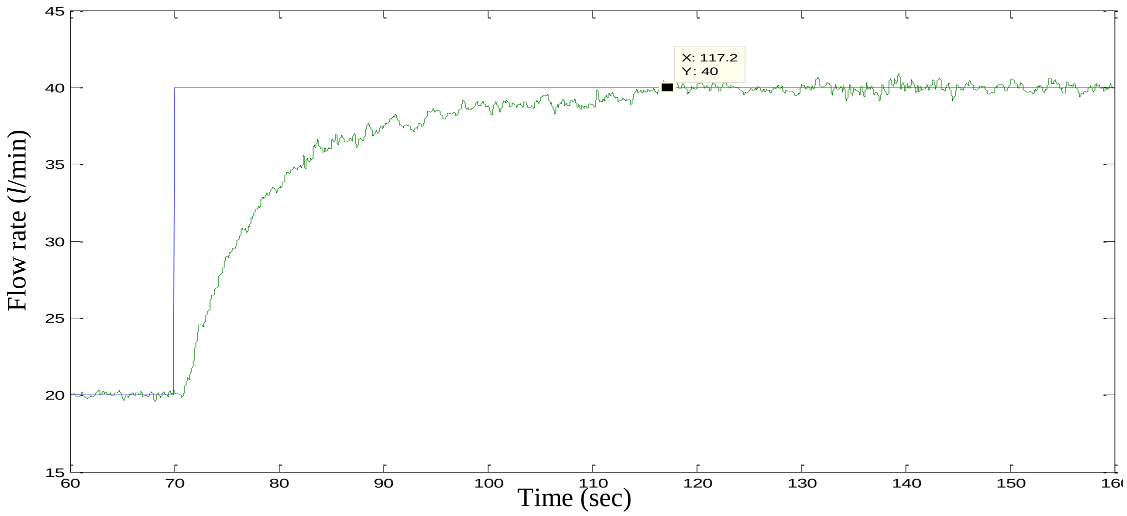


Figure 24: PI Response due to Step Change

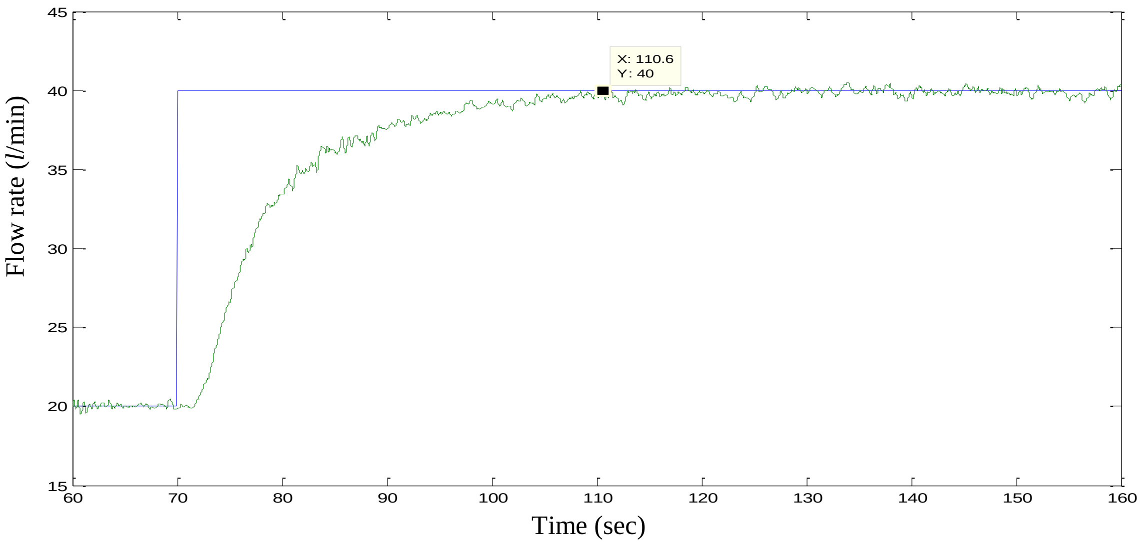


Figure 25: FLC Response due to Step Change

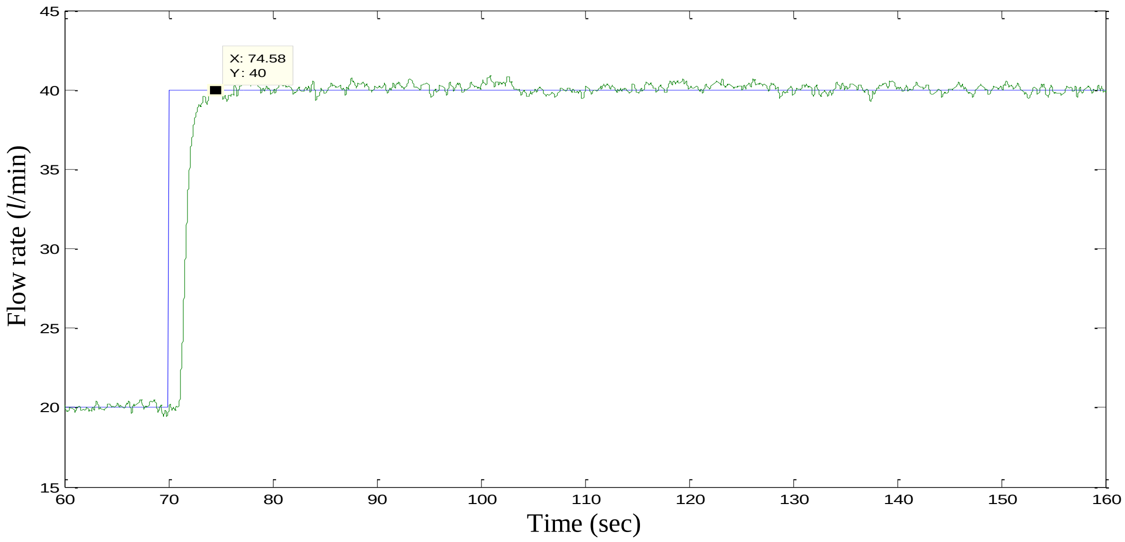


Figure 26: ANFIS Response due to Step Change

From the result shown in Figure 22 - 24, the control performance can be studied where the ANFIS controller gives a better performance compare to PI and FLC controller. This is due to the ANFIS gives the best settling time, rise time and integral of absolute error (IAE).

Table 9: Plant Control Performance Comparison

Control Performance	**PI**	**FLC**	**ANFIS**
IAE	Large	Intermediate	Small
Rise Time	47.2	40.6	4.5
Settling Time	47.2	40.6	4.5
% Overshoot	0%	0%	0%

To evaluate the controllers' robustness, the system has been tested to random set point changes by using the "uniform random number" block in Simulink. The operating range is set 15*l*/min to 40*l*/min and the sample time at 70 seconds. This allows the controllers to settle to steady state. Below are the results for the random set points test.

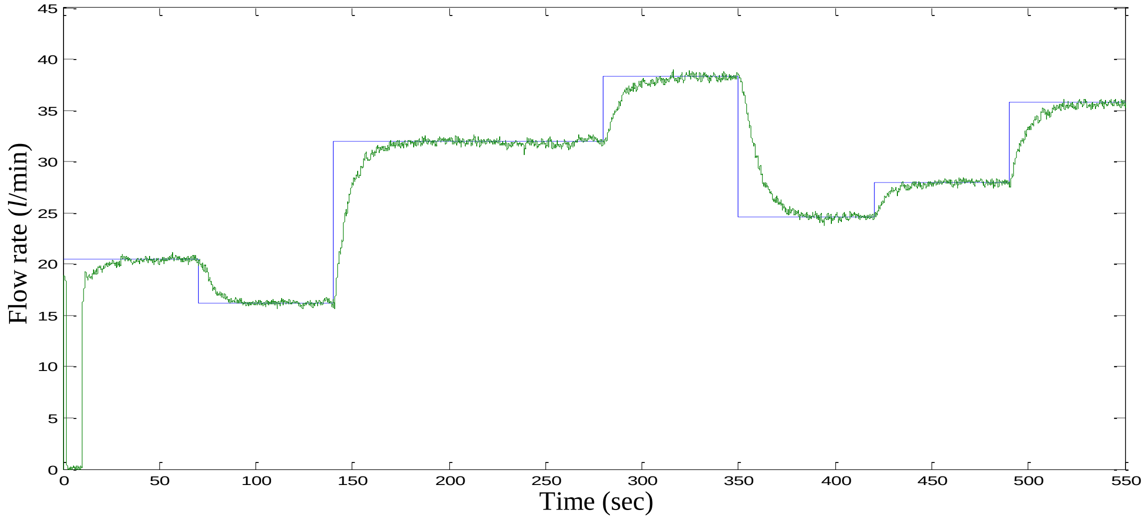


Figure 27: PI Response due to Random Step Change

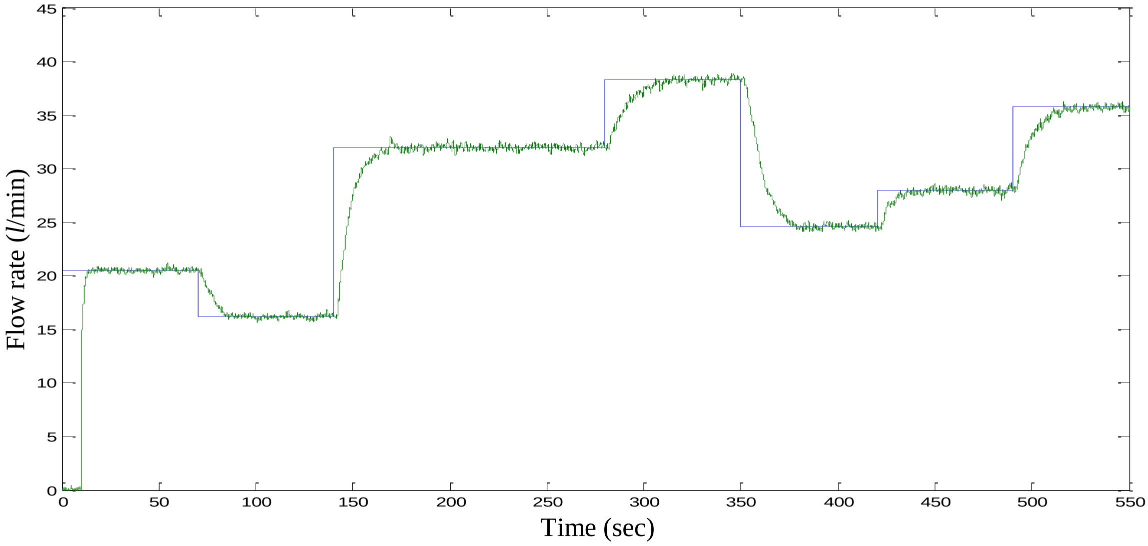


Figure 28: FLC Response due to Random Step Change

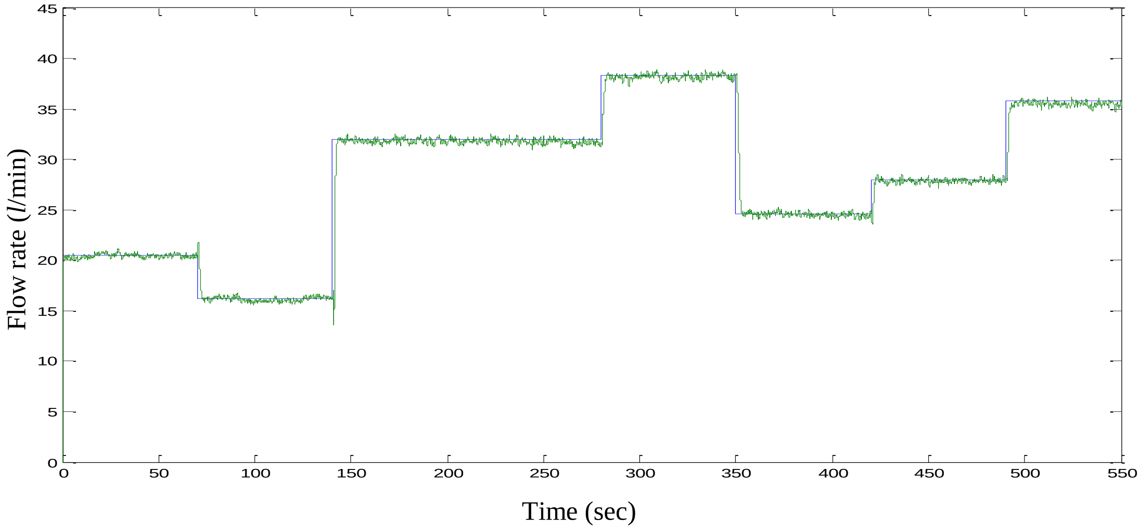


Figure 29: ANFIS Response due to Random Step Change

4.4.3 Bubble Disturbance Effect

Bubbling effect is one of the common disturbances that can affect liquid flow rate and flow measurement. Bubble disturbance caused by the superposition of single pulses generated by each bubble which are randomly distributed in the liquid flow [25]. In this section, control performance for PID, FLC and ANFIS will be conducted in order to prove Advanced Process Controllers; FLC and ANFIS still have better control response compare to PID controller even though the system become non-linear. The bubbling effect was applied by feeding air through a tube into the Buffer Tank VE 100 (refer Appendix B). The air feed at the bottom of the Buffer Tank will create bubble and some of them will escape into the process line. As a result, the liquid flow will contain bubble and it will cause disturbance to the flow meter measurement and control.

The following diagrams show the controllers' performance under the bubbling effect with the same process condition as the previous experiment.

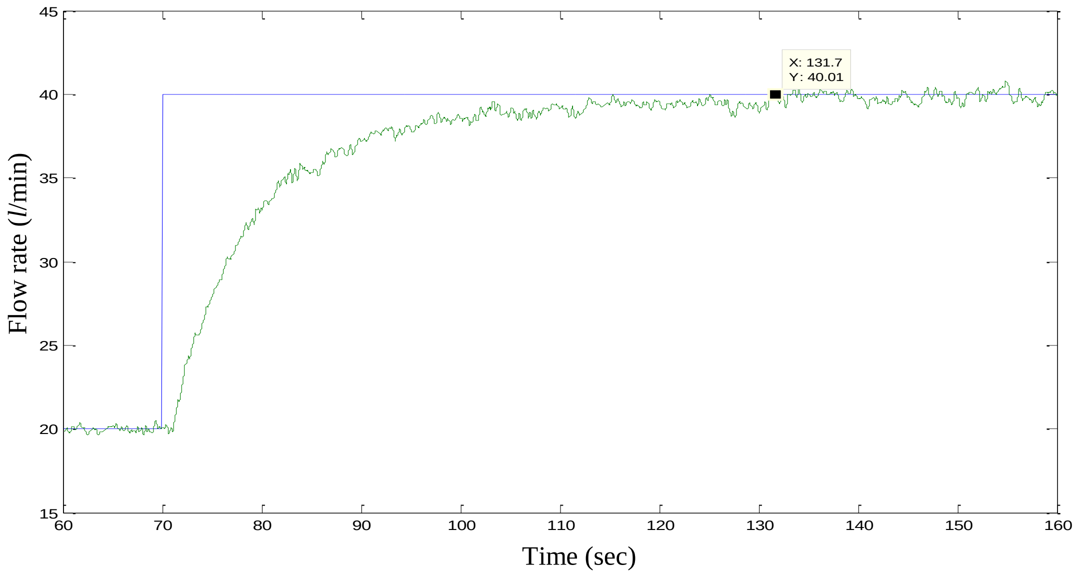


Figure 30: PI Response with the Present of Disturbance

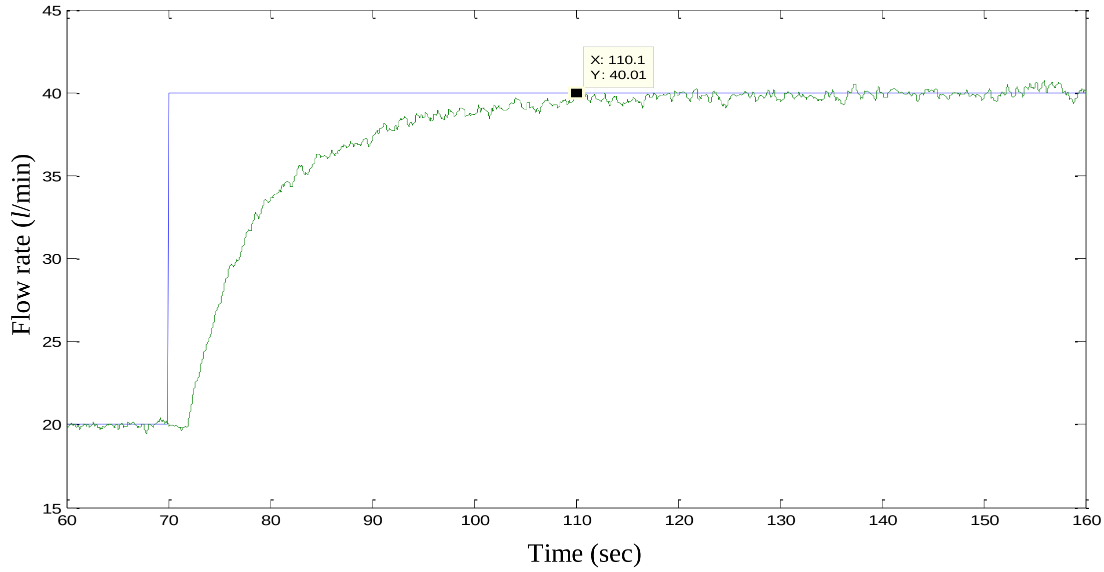


Figure 31: FLC Response with the Present of Disturbance

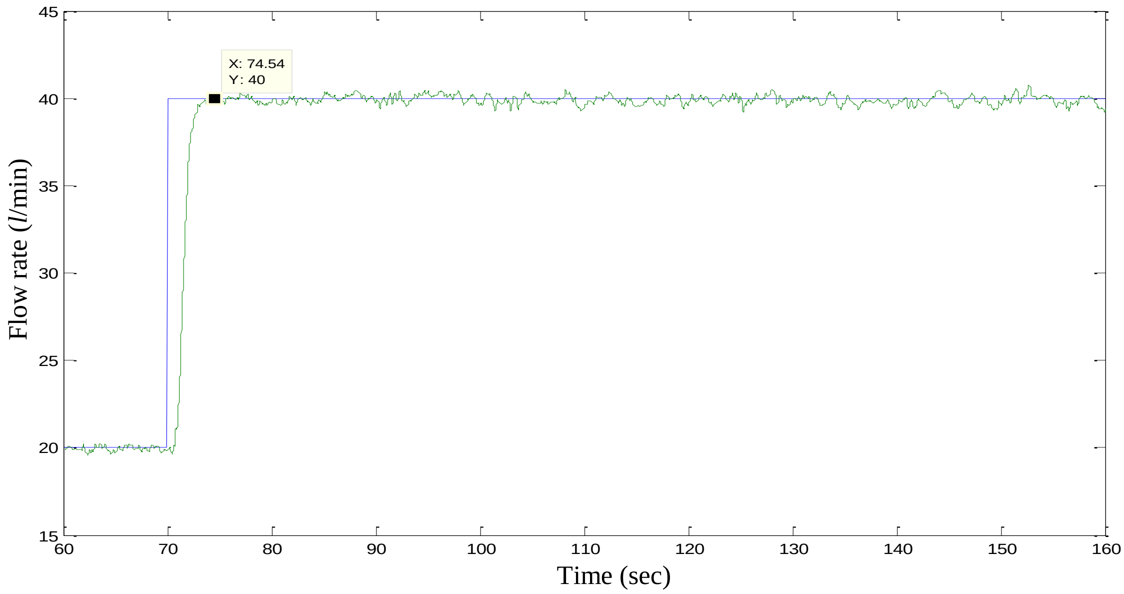


Figure 32: ANFIS Response with the Present of Disturbance

Table 10: Control Performance with the Present of Disturbance

Control Performance	**PI**	**FLC**	**ANFIS**
IAE	Increase	Constant	Constant
Settling Time	61.7	40.1	4.54
Rise Time	61.7	40.1	4.54
% Overshoot	0%	0%	0%

Based on the above table, PI controller response exhibits longer settling time, rise time and increase in IAE under bubbling noise disturbance. Meanwhile, Fuzzy Logic and ANFIS controller show more stable reading even under the same condition. Based on the results, it is proven that when a system become non-linear, PID controller will give poor performance while Advanced Process Controllers still provide stable control response.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From this project, it proves that Advanced Process Controllers such as Fuzzy Logic Controller (FLC) and Adaptive Neuro-Fuzzy Inference System (ANFIS) have better control performance compare to the conventional PID controller. Meanwhile, hybrid controller; ANFIS is the best controller among them. This is because the FLC is lack with a tuning method while the ANFIS is a combination of benefits from two technologies which are learning capability is an advantage to FIS, in the other hand the formation of linguistic rule base is an advantage to ANN.

The advantages of Advanced Process Controllers are derived from the simulation and implementation results in term of step change and random set point input. Better control performances, overall stability and robustness can be anticipated from the Advanced Process Controllers.

The development of this project is also meet the industrial demands and applications, therefore Advanced Process Controllers which are FLC and ANFIS are the alternative controllers that can be used on the real plant in order to replace the conventional PID controller. In addition, the DCS-HMI by using Matlab/Simulink is more users friendly and more economical to be used compared to the standard industry DCS structure. The objectives of this project which are to develop and implement PID, FLC and ANFIS controller onto the mobile pilot plant, to compare the controllers' performance and to develop a DCS-HMI system have been achieve successfully.

5.2 Recommendations

In the future, the performance of the controllers can be tested under different disturbance such as with the present of slurries in the flow. The solids in the liquid are expected to disturb the normal operation of the flow system and the flow measurement. Apart from that, the performance of different flow meters in the mobile pilot plant such as coriolis, vortex and DP can be compared.

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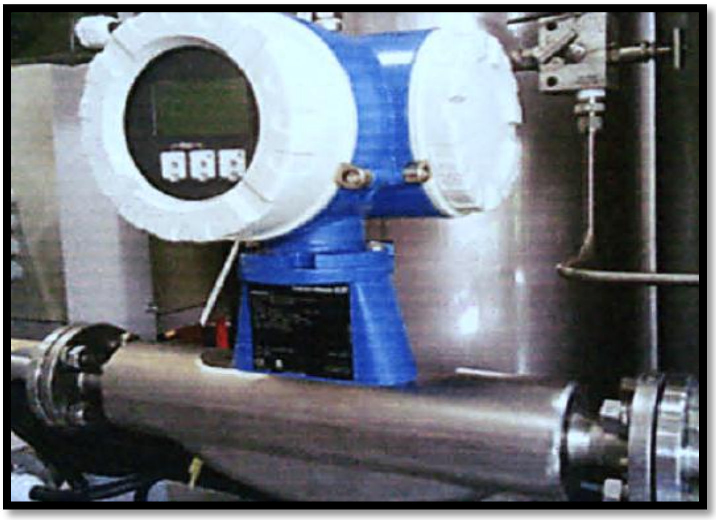
APPENDICES

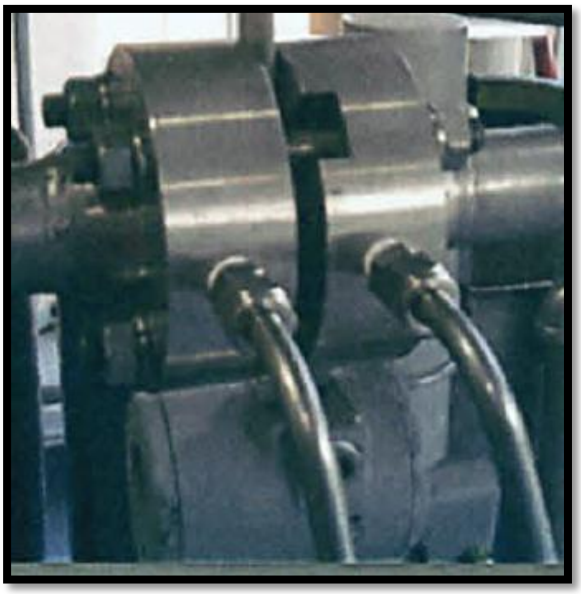
APPENDIX A – Pilot Plant Devices and Instruments

Mobile Pilot Plant

Vortex Flow Meter

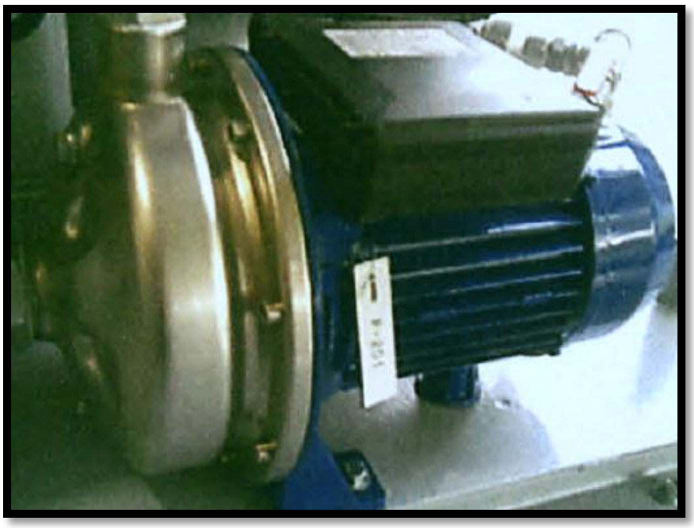


Coriolis Flow Meter



DP Flow Meter

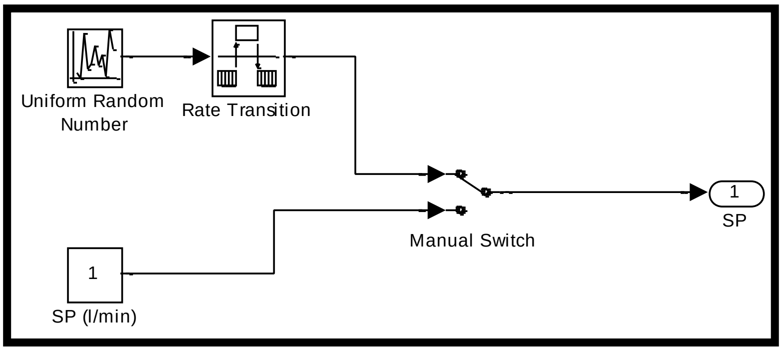
Control Valve



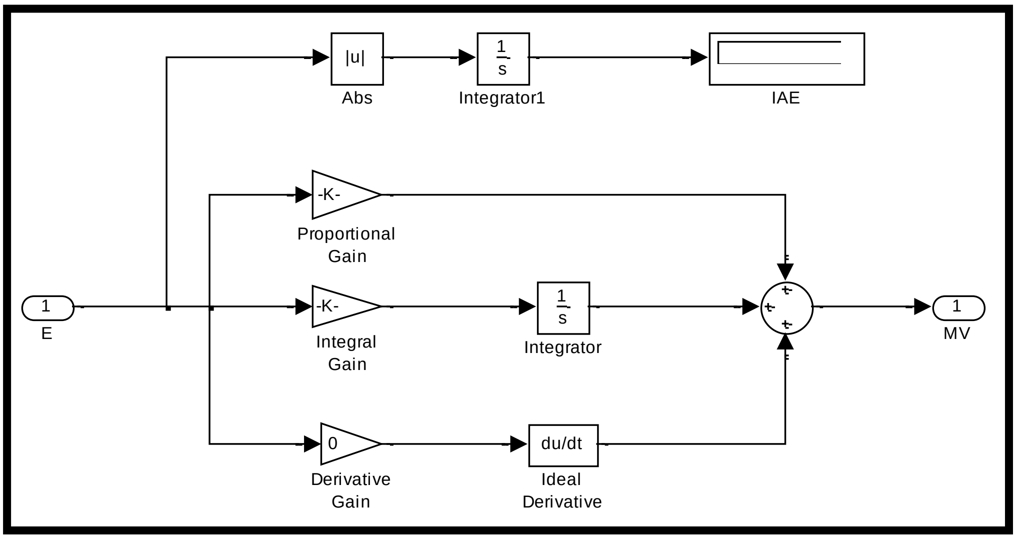
Pump

APPENDIX B – Bubbling Effect Set Up

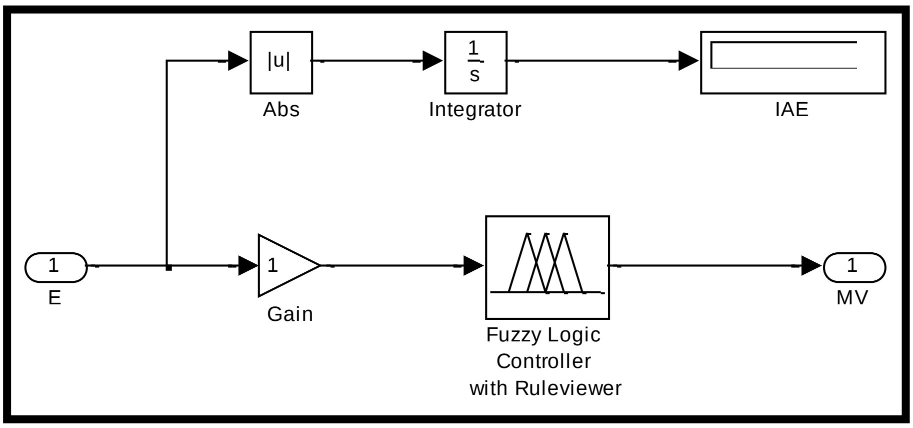
APPENDIX C – Simulink Model Subsystem



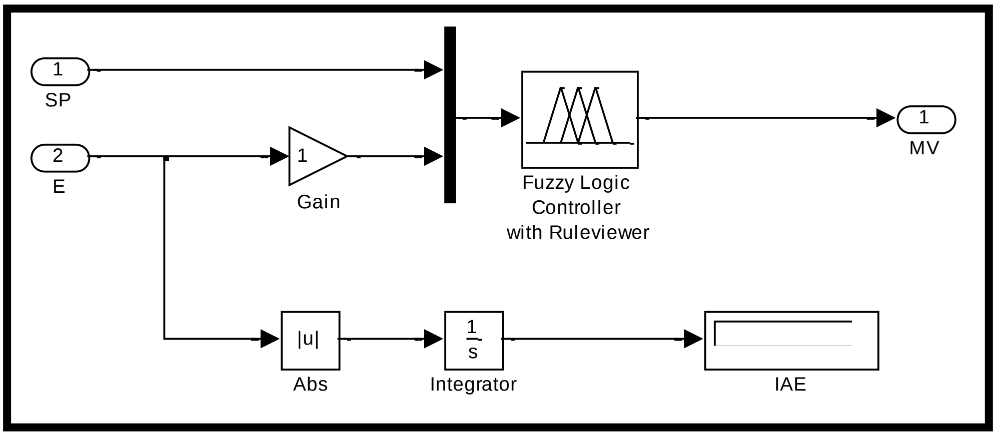
Input Subsystem



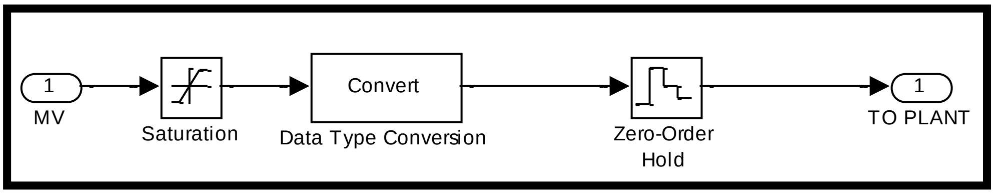
PID Controller



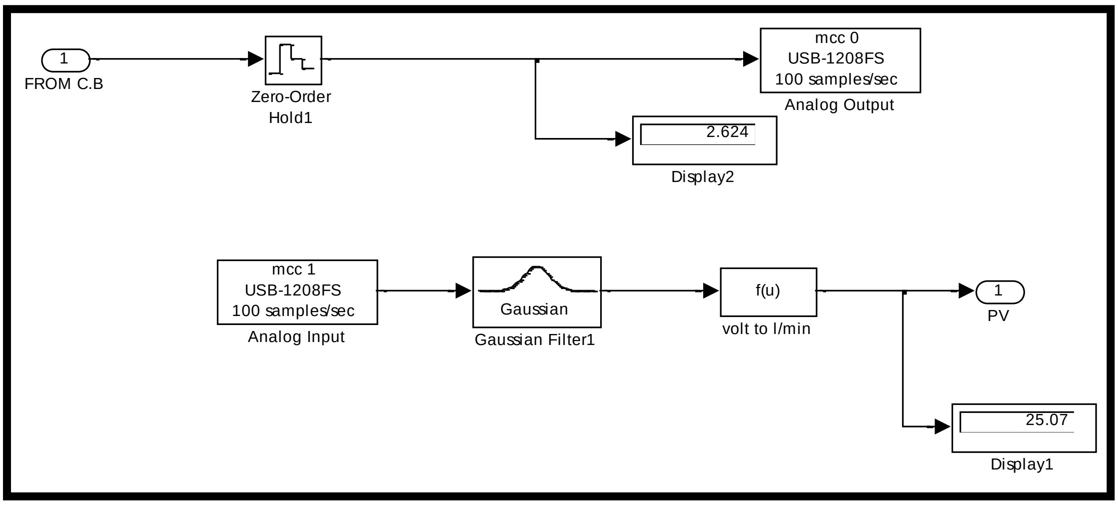
Fuzzy Logic Controller



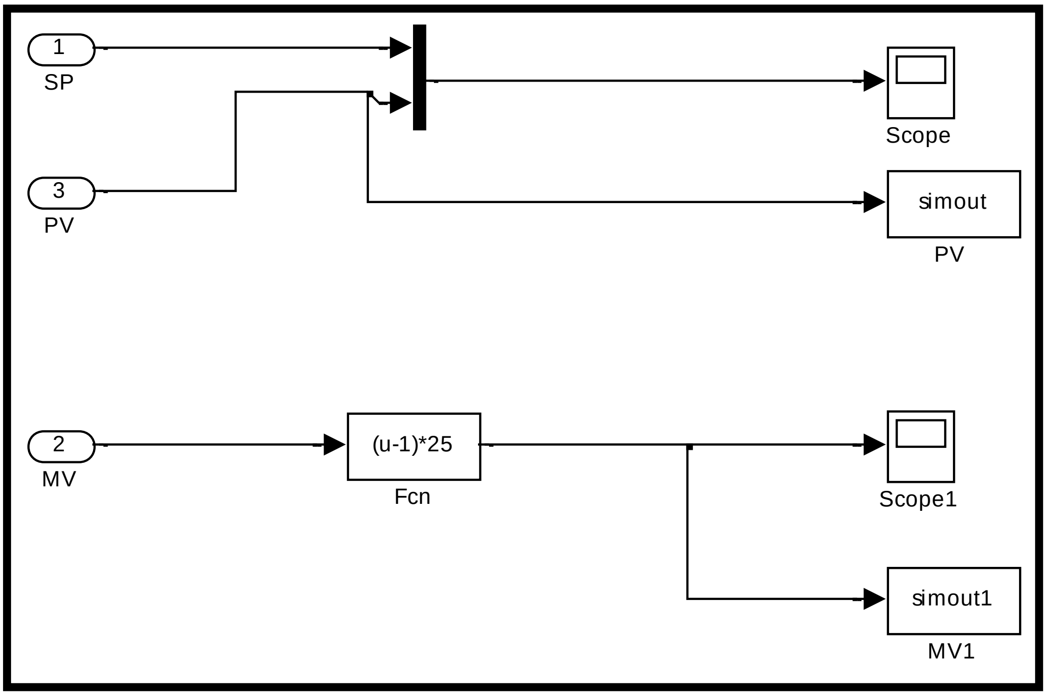
ANFIS Controller



% to Volt Conversion Subsystem



Plant Subsystem



Data Record Subsystem

APPENDIX D – USB 1208FS Block Diagram and Pin outs

4-channel differential mode pin out

8-channel single-ended mode pin out

4-channel differential mode

Pin	Signal Name	Pin	Signal Name
1	CH0 IN HI	21	Port A0
2	CH0 IN LO	22	Port A1
3	AGND	23	Port A2
4	CH1 IN HI	24	Port A3
5	CH1 IN LO	25	Port A4
6	AGND	26	Port A5
7	CH2 IN HI	27	Port A6
8	CH2 IN LO	28	Port A7
9	AGND	29	GND
10	CH3 IN HI	30	PC+5V
11	CH3 IN LO	31	GND
12	AGND	32	Port B0
13	D/A OUT 0	33	Port B1
14	D/A OUT 1	34	Port B2
15	AGND	35	Port B3
16	CAL	36	Port B4
17	GND	37	Port B5
18	TRIGIN	38	Port B6
19	SYNC	39	Port B7
20	CTR	40	GND

8-channel single-ended mode

Pin	Signal Name	Pin	Signal Name
1	CH0 IN	21	Port A0
2	CH1 IN	22	Port A1
3	AGND	23	Port A2
4	CH2 IN	24	Port A3
5	CH3 IN	25	Port A4
6	AGND	26	Port A5
7	CH4 IN	27	Port A6
8	CH5 IN	28	Port A7
9	AGND	29	GND
10	CH6 IN	30	PC+5V
11	CH7 IN	31	GND
12	AGND	32	Port B0
13	D/A OUT 0	33	Port B1
14	D/A OUT 1	34	Port B2
15	AGND	35	Port B3
16	CAL	36	Port B4
17	GND	37	Port B5
18	TRIGIN	38	Port B6
19	SYNC	39	Port B7
20	CTR	40	GND