CHAPTER 1
INTRODUCTION

1.1 Background of Study

This section explains the relevance and feasibility of the project, entitled "Verifying the reliability of Mathematical Models in Plant Process Control". Mathematical model are basically widely used among engineers mostly in industries since the model could generate successful outcomes and simplify the calculation process.

Plant process control is basically one of the most important factors in improving process performance. The objective of having a very good plant process control is mainly because it will attain safe and profitable plant operation. A key factor in good plant operation is the determination of the best operating conditions, which can be maintained within small variation by automatic control strategies [1]. Therefore, as engineers use an automatic control strategy, they will also use a mathematical model to analyze a system within plant process control.

In general, the most important reason for engineers using mathematical models to analyze a system in process control is the analytical expressions it provides relating the parameters of the physical system such as flows, volumes, temperatures and so forth to its dynamic behavior [1].

1.2 Problem Statement

Studies in mathematical models used in industry are very rare since people, mostly engineers are not aware of the importance of having an accurate and reliable mathematical models. Often when engineers analyze a system to be controlled or optimized, they use mathematical models.

In analysis, engineers can build a descriptive model of the system as a hypothesis of how the system could work, or try to estimate how an unforeseeable event could affect the system. Similarly, in control of a system, engineers can try out different control approaches in simulations [2].

However, engineers should understand the quality of the results, to be accurate, rather than correct [1]. Therefore, the question of reliability of mathematical models arise at the moment engineers assuming that they are going to get a correct result from the analysis conducted using the mathematical model.

1.3 Objective

The objectives in conducting this project are:

1. To verify the reliability of mathematical model of Proportional-Integral-Derivative (PID) in Plant Process Control application (PID Pressure Control) using four types control mode;
    - Proportional-Integral-Derivative (PID) control mode
    - Proportional (P-only) control mode
    - Proportional-Integral (P+I) control mode
    - Proportional-Derivative (P+D) control mode

2. To conduct research on the PID controller of pilot plants (PID Pressure Control) in the process laboratory of UTP.

1.4 Scope of Study

This project can be categorized as a research-based type. Scope of study for this project would also be ranging from preliminary studies of mathematical models and application of PID controller in plant process control system to testing the reliability of mathematical model. In order to test the reliability and identify the errors, standard simulation tools (MATLAB software) will be used. The outcome from the simulation will then be studied to determine the reliability of mathematical model of PID controller.

CHAPTER 2
LITERATURE REVIEW

2.1 Mathematical Model

Eykhoff (1974) defined a mathematical model generally as ‘a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in usable form’ [3]. On the other hand, in a process control, the following definition of mathematical model was given by Denn (1986):

> A mathematical model of a process is a system of equations whose solution, given specific input data, is representative of the response of the process to corresponding set of inputs [4].

Mathematical models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, or game theoretic models [2]. In industry, the engineers might use more than one model to do the analysis since most of the systems are complicated and require accurate results.

2.2 Reliability

Reliability refers to the consistency of a measure. A test is considered reliable if we get the same result repeatedly. For example, if a test is designed to measure a trait (such as introversion), then each time the test is administered to a subject, the results should be approximately the same [5]. Unfortunately, it is impossible to calculate reliability exactly, but there several different ways to estimate reliability.

In most cases, reliability relies heavily on statistics, probability theory, and reliability theory. Since reliability is a probability, even highly reliable systems have some chance of failure [6].

In order to simplify the method of reliability analysis, the easiest way is to evaluate the variance of the scores. In a probability study, the variance is a measurement of the spread or distribution of a set of scores;

Variance of true score / Variance of the measure [7]

The main reason for using this method in reliability test is because the outcome will always be within the range of 0 and 1. The most reliable value is 1 and 0 will indicate that the results is totally incorrect [8]. Therefore, for a test to be considered minimally reliable, its reliability coefficients must approximate or exceed 0.80 in magnitude and coefficient of 0.90 or above are considered to be most desirable [9].

2.3 PID Controller

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired setpoint by calculating and then outputting a corrective action that can adjust the process accordingly and rapidly, to keep the error minimal [10].

The PID algorithm has been successfully used in the process industries since the 1940s and remains the most often used algorithm today. This algorithm is used for single-loop systems, also termed single input-single output (SISO), which has one controlled and one manipulated variable [1]. Since parameters in all control algorithms depend on process models, control algorithm will always be in error. The PID control algorithm is a simple, single equation, but it can provide good control performance for many processes.

The PID controller calculation (algorithm) involves three separate parameters; the proportional, the integral and derivative values. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing [10].

The proportional, integral, and derivative terms are summed to calculate the output of the PID controller and the final form of the PID algorithm is:

$$MV(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t)$$

Where MV = Controller Output,

K_p = Proportional Gain,

K_i = Integral Gain,

K_d = Derivative Gain,

e = Error = Setpoint – Process Value,

t = Instantaneous Time,

τ = Dummy Integration Variable.

Figure 1.1 [10] below shows a block diagram of combination of proportional, integral and derivative modes in the process plant which represent the PID controller in general.

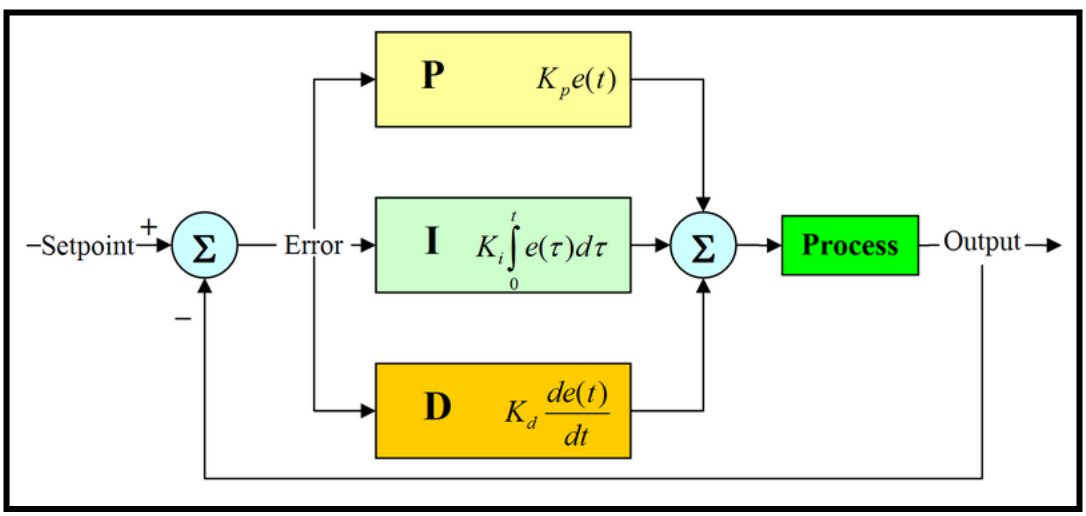


Figure 1.1: A block diagram of PID controller

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

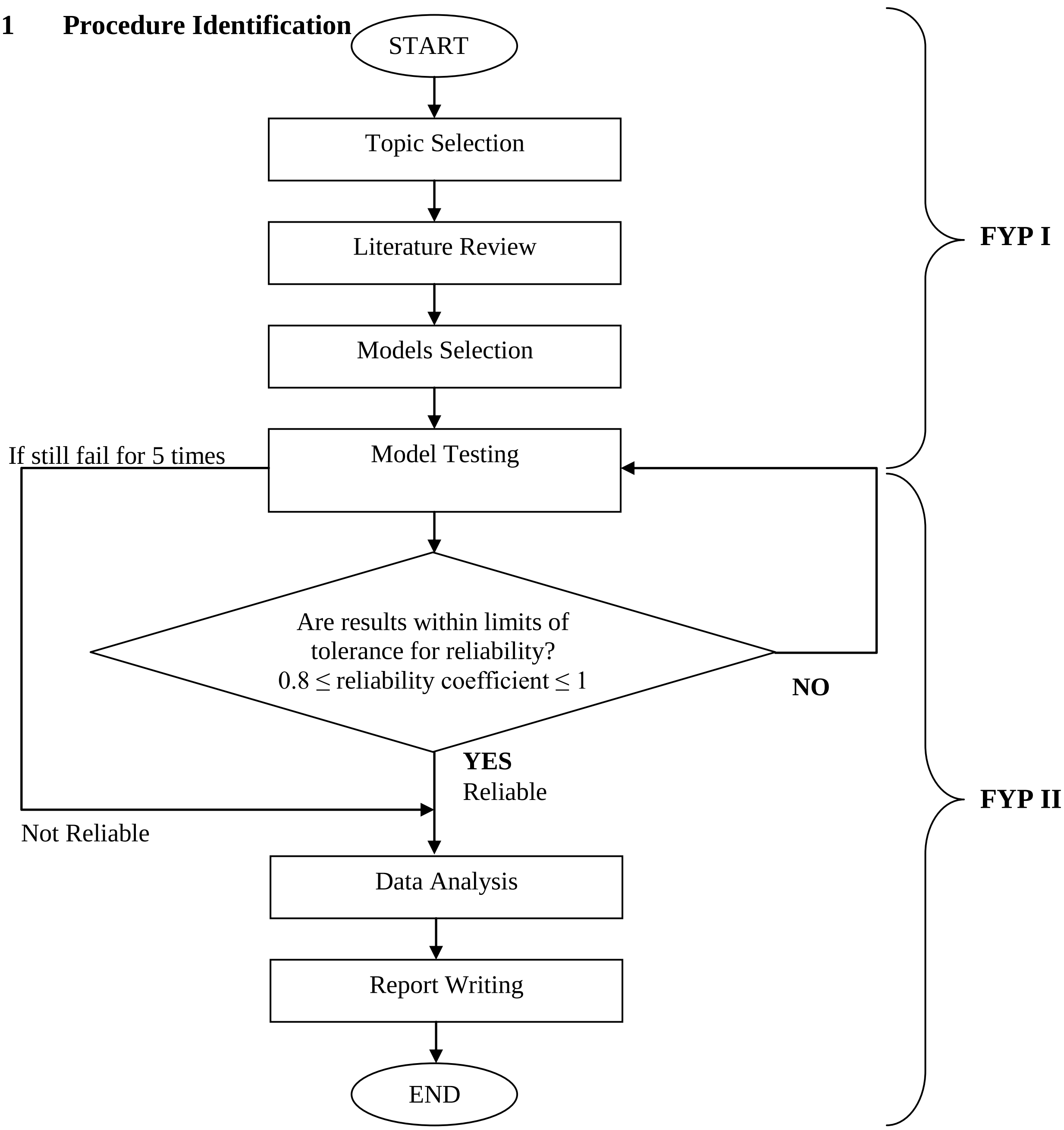


Figure 2.1: Work Process Flow Chart

3.2 Project Activities

3.2.1 Model Selection

There are various types of mathematical model used in plant process control. Throughout this project, a mathematical model from PID controller will be used for the analysis of reliability. In order to achieve the objective of this project, there will be three types of application that will be tested chosen from plant process control system.

The PID controller was chosen since it is basically widely applied in most industrial processes; it has been successfully used for over 50 years and it is used by more than 95% of the plants processes. It is a robust and easily understood algorithm that can provide excellent control performance in spite of the diverse dynamic characteristics of the process plant [12].

3.2.2 Model Testing

This is the stage where the mathematical model will be tested using standard simulation tools (MATLAB). Based on the work process flow chart, the mathematical model can be declared as reliable if the results are within limits of tolerance for reliability which is larger or equal to 0.8 and not more or equal to 1.0. However, if the results are not within the tolerance levels, the mathematical model will be tested for several times with maximum 5 trials and if it still not giving the required results, the mathematical model will be declared as not reliable.

3.2.3 Data Analysis

As soon as the results from the model testing are available, all data will be analyzed to evaluate the findings.

3.3 Tools

3.3.1 MATLAB®

MATLAB is an abbreviation for MATrix LABoratory. Matlab is a high-level programming environment that processes arrays and matrices and provides a powerful graphical environment [13].

MATLAB was selected as a testing tool since it is a high-level programming environment allows the users to program without worrying about declaring variables, allocating memory, using pointers, and compiling code and other routine tasks, which are associated with languages such as FORTRAN and the C language.

MATLAB also incorporates many built in functions that can perform a variety of complex mathematical routines, from finding eigenvalues to solving differential equations [13].

Throughout this project, Simulink application in MATLAB will be used in the model testing. Simulink is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems [14]. Furthermore, it offers modeling, simulation, and analysis of dynamical systems under a graphical user interface (GUI) environment.

With Simulink, the construction of a model is simplified with mouse operations using click and drag. Simulink includes a comprehensive block library of toolboxes for both linear and nonlinear analyses. Plus, as Simulink is an integral part of MATLAB, it is way more convenient to switch between both application and the user may take full advantage of features offered in both environments [15].

The graphical user interface for MATLAB is shown below;

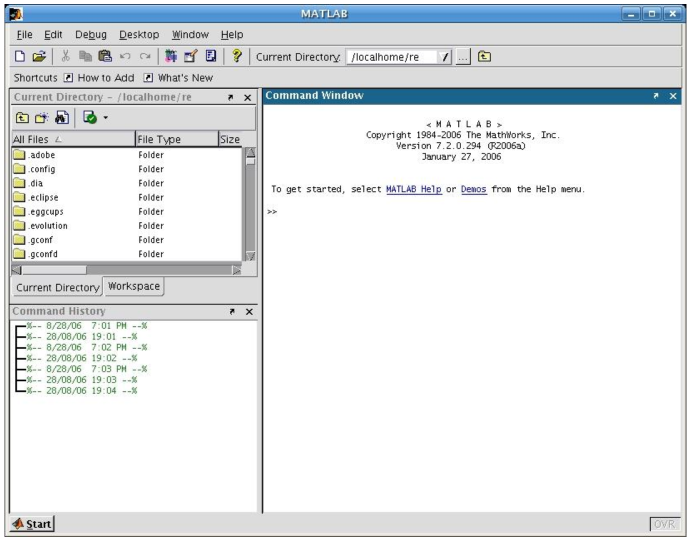


Figure 3.1: MATLAB Command Window

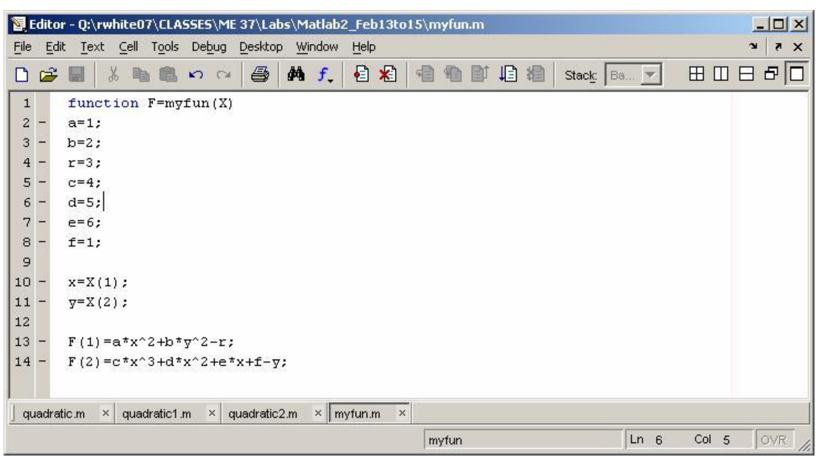


Figure 3.2: MATLAB M-File

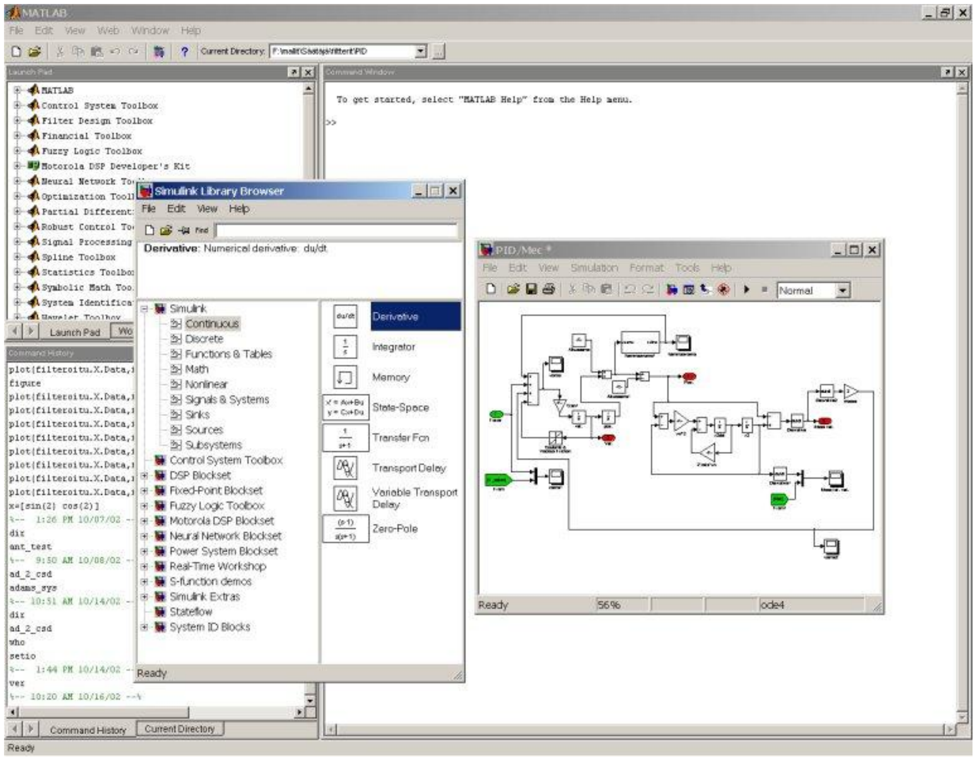


Figure 3.3: MATLAB Simulink

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Process Reaction Curve of PID Pressure Control

In order to get the PID parameter for PID pressure control, an experiment has been conducted using Pressure Plant Control (PIC 202). It is a self-contained unit designed to simulate real pressure of a compressible fluid found in industrial plants (refer to Appendix B).

The first step in getting the PID parameters is to identify the process model based on process reaction curve of PID pressure control. The experiment was conducted with five different values of manipulated variable starting from 20% to 30%. The purpose is to get the average value of transfer function that is going to be used for the simulation later.

Figure 4.1, 4.2, 4.3 shows the reaction curves for experiment with MV=10%, MV=20% and MV=30% respectively.

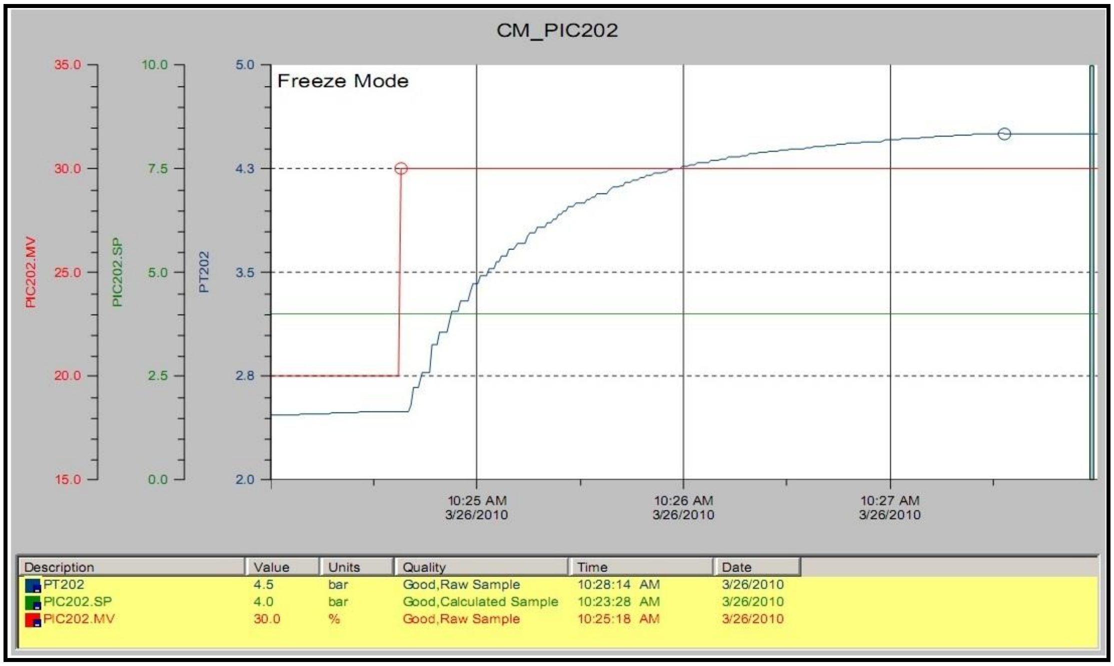


Figure 4.1: Process Reaction Curve when MV = 10%

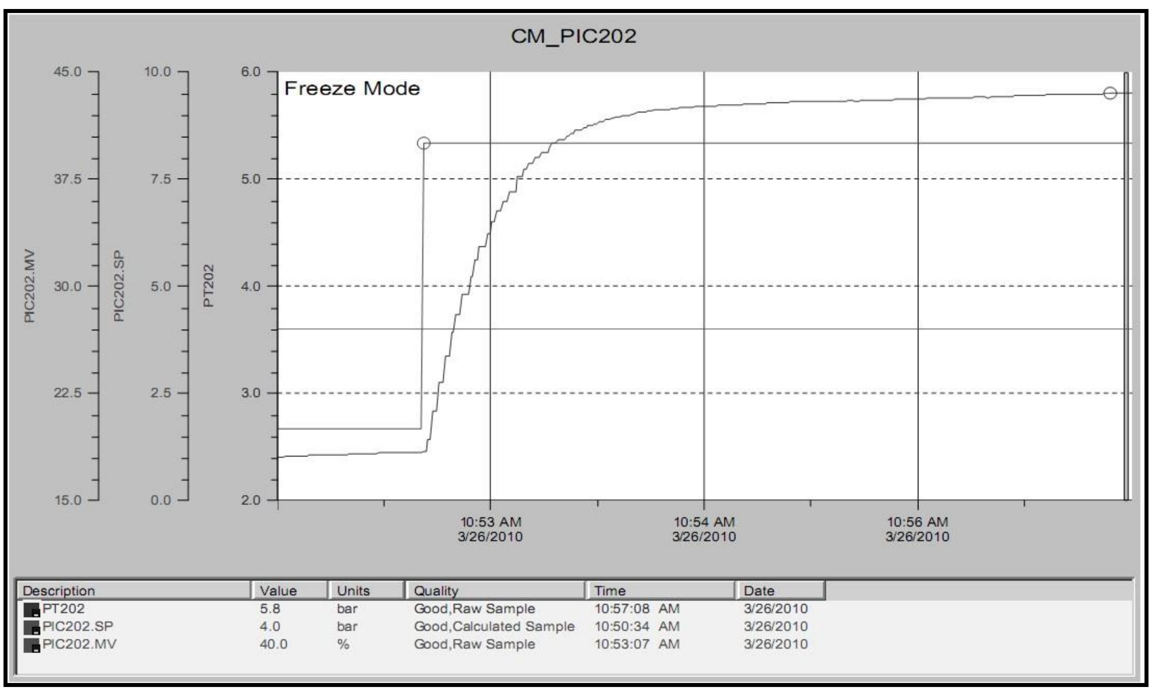


Figure 4.2: Process Reaction Curve when MV = 20%

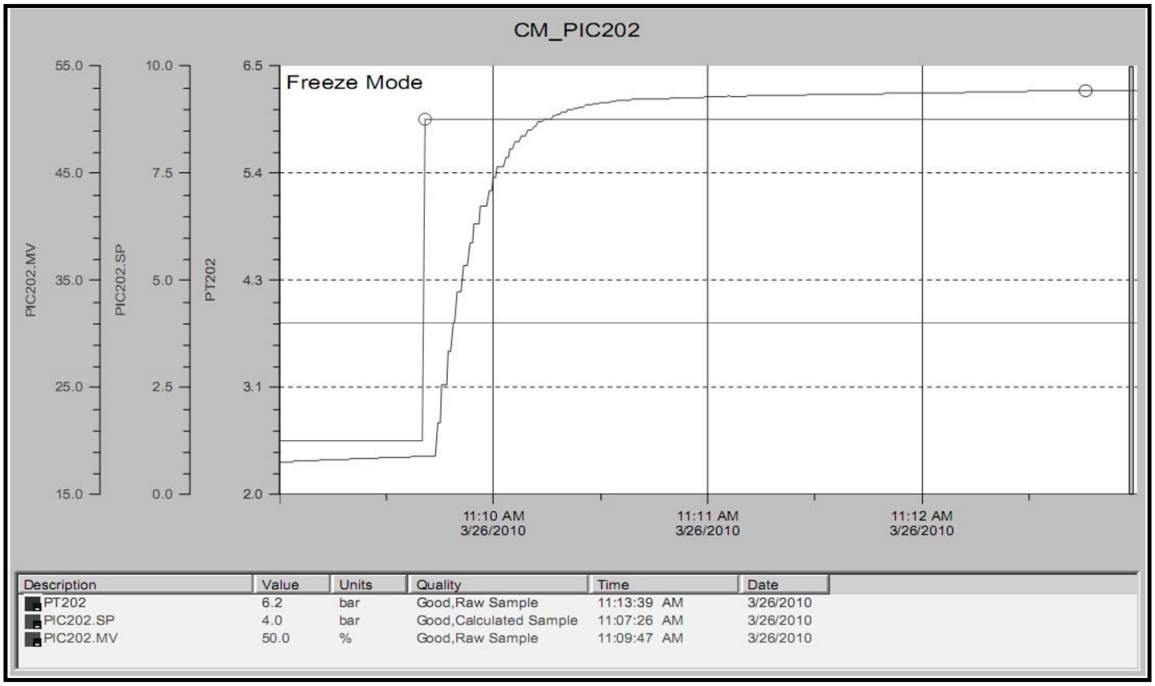


Figure 4.3: Process Reaction Curve when MV = 30%

The results for process reaction curve are tabulated as in the table 4.1:

Table 4.1: Results for Process Reaction Curve

Measurement	**Value**		
Change in perturbation / MV, σ	10.00	20.00	30.00
Change in output / PV, Δ	2.00	3.10	3.65
Maximum slope, S	25.79	10.0	3.60
Apparent dead time, θ	1.25	1.25	3.75
Calculations	**Value**		
Steady State Process Gain, $K_p = \Delta / \sigma$	0.20	0.16	0.12
Apparent time constant, $\tau = \Delta / S$	0.08	0.31	1.01
Fraction dead time, $R = \theta / \tau$	15.63	4.03	3.71

4.2 PID Parameters of PID Pressure Control

Based on the tabulated data, PID parameters of PID pressure controller can be identified using the Cohen-Coon Open Loop Correlations (refer to appendix C) for each experiment, MV = 10% until MV = 30%.

4.2.1 PID Control Mode

Table 4.2: PID Parameters for PID Control Mode

Tuning Parameters	MV = 10%	MV = 20%	MV = 30%
Proportional gain, K_c	0.17	3.63	5.08
Integral Time, T_I	1.14	1.55	4.76
Derivative time, T_D	0.12	0.26	0.81

4.2.2 P-only Control Mode

Table 4.3: PID Parameters for P-only Control Mode

Tuning Parameters	MV = 10%	MV = 20%	MV = 30%
Proportional gain, K_c	2.00	3.63	5.02

4.2.3 P+I Control Mode

Table 4.4: PID Parameters for P+I Control Mode

Tuning Parameters	**MV = 10%**	**MV = 20%**	**MV = 30%**
Proportional gain, K_c	4.43	6.57	8.92
Integral Time, T_I	0.28	0.57	1.80

4.2.4 P+D Control Mode

Table 4.5: PID Parameters for P+D Control Modes

Tuning Parameters	**MV = 10%**	**MV = 20%**	**MV = 30%**
Proportional gain, K_c	1.23	2.98	4.20
Derivative time, T_D	0.46	0.08	0.16

All these parameters value have been used in the PID Pressure Control plant and the actual response has been recorded.

4.3 Actual Response of PID Pressure Control

The actual response of PID Pressure Control was gained using all the Process Pilot Plant by subtituting all the parameter values.

4.3.1 Actual Response for PID Control Mode

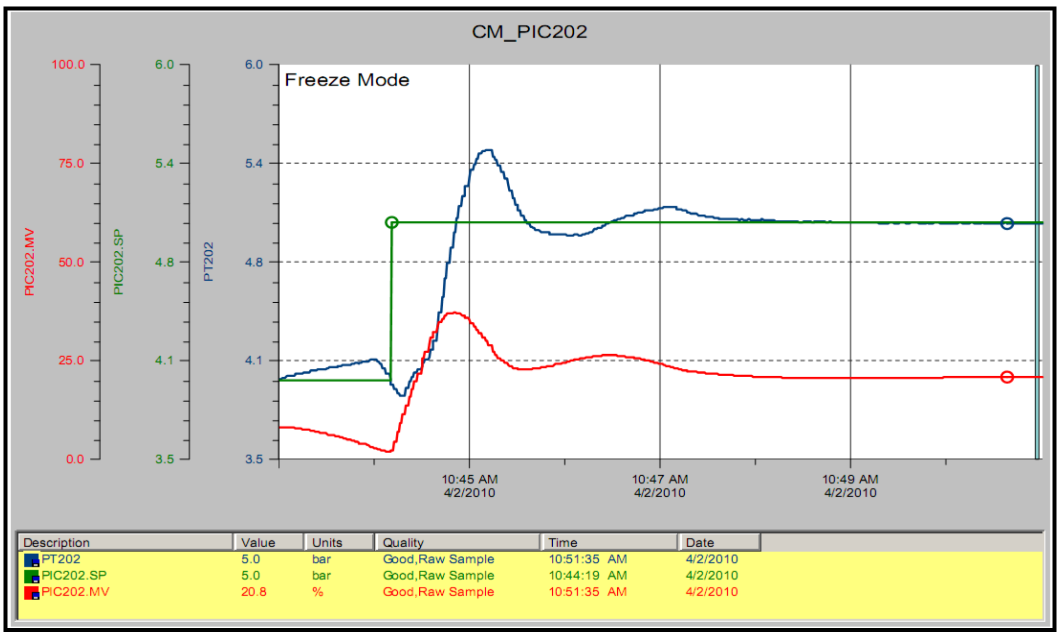


Figure 4.4: Actual Response for MV=10% using PID Control Mode

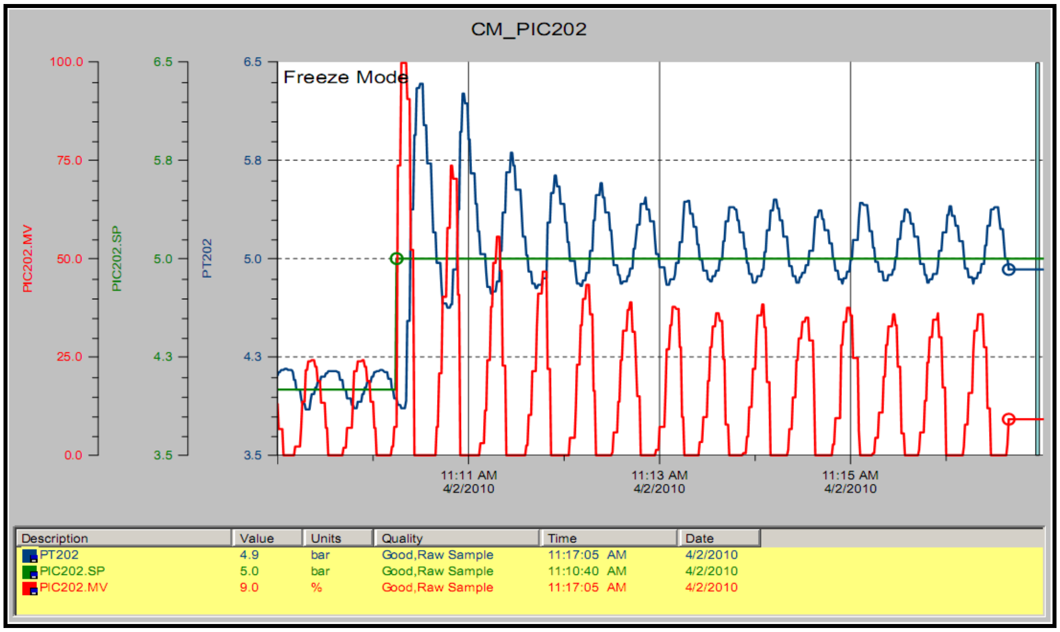


Figure 4.5: Actual Response for MV=20% using PID Control Mode

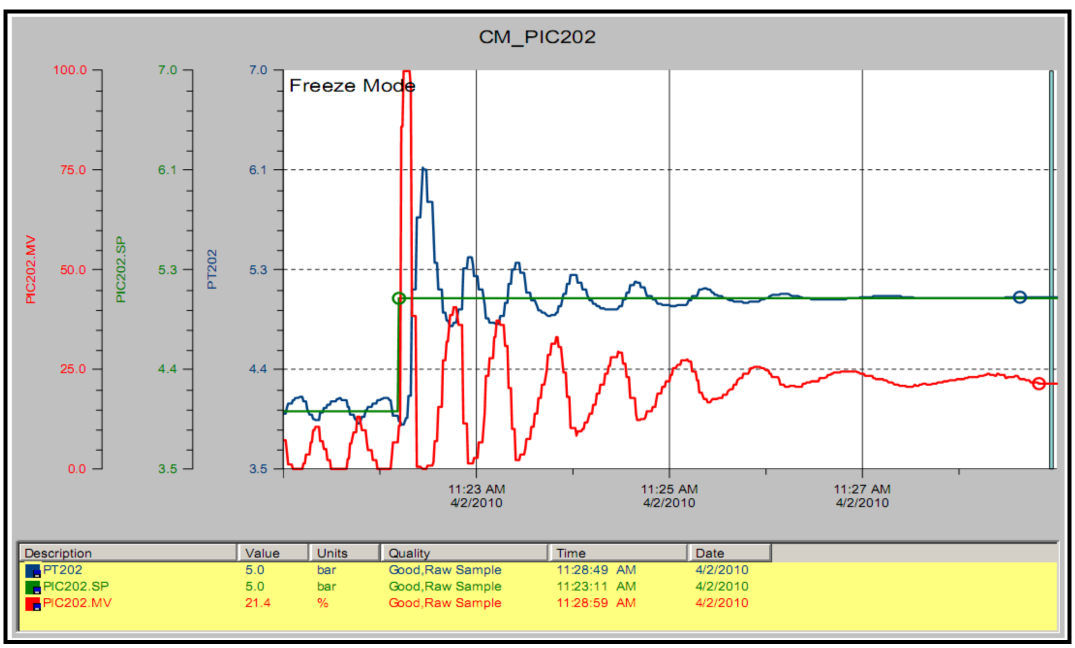


Figure 4.6: Actual Response for MV=30% using PID Control Mode

4.3.2 Actual Response for P-only Control Mode

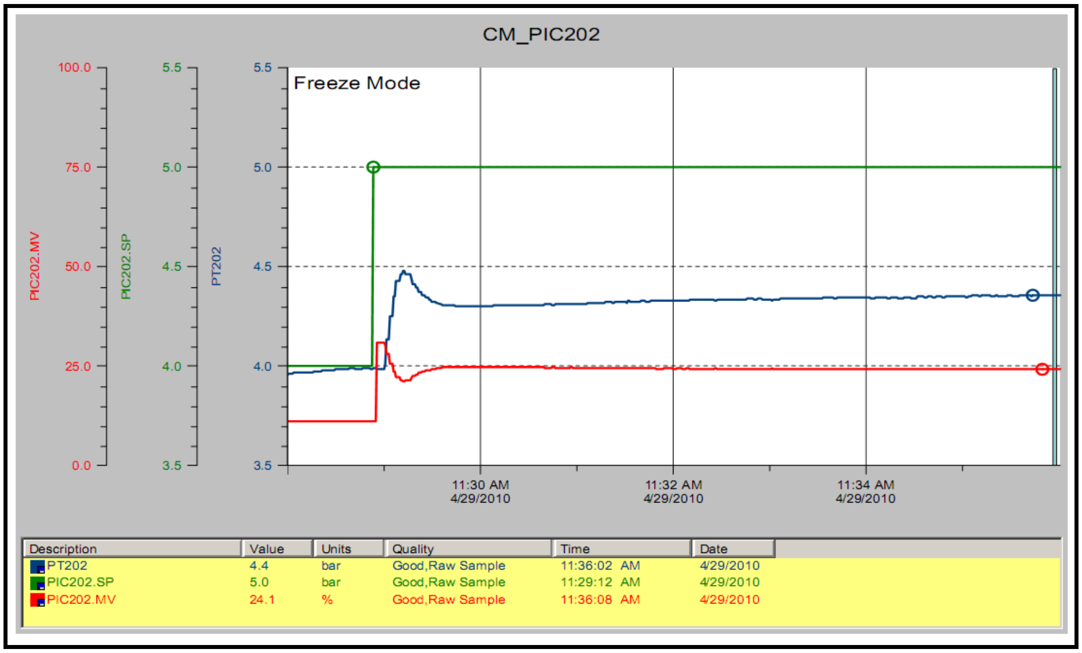


Figure 4.7: Actual Response for MV=10% using P-only Control Mode

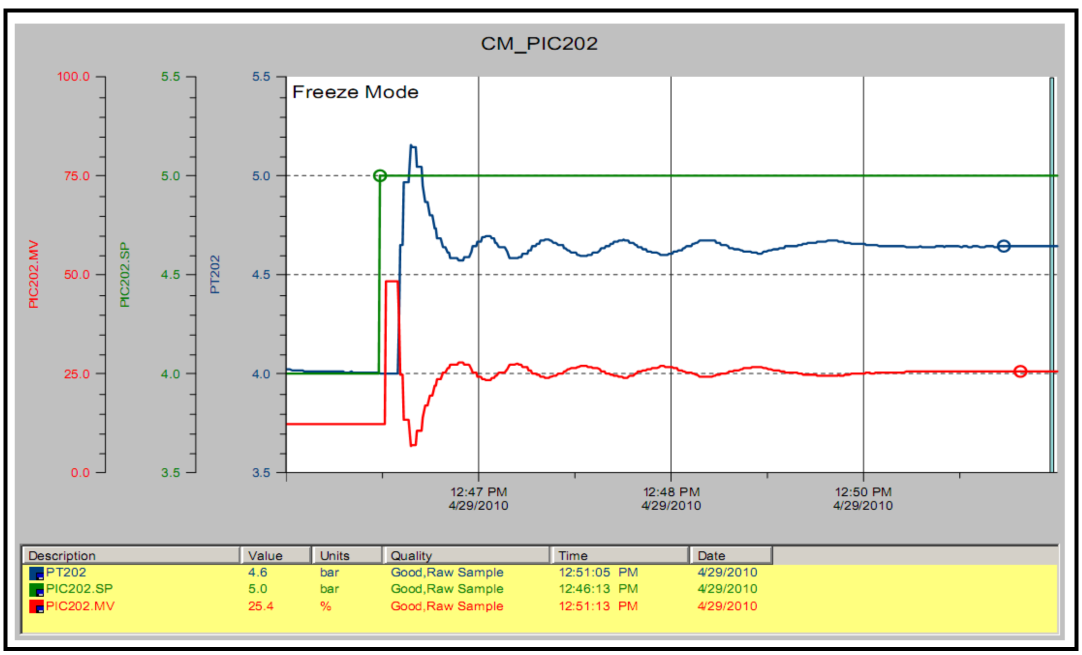


Figure 4.8: Actual Response for MV=20% using P-only Control Mode

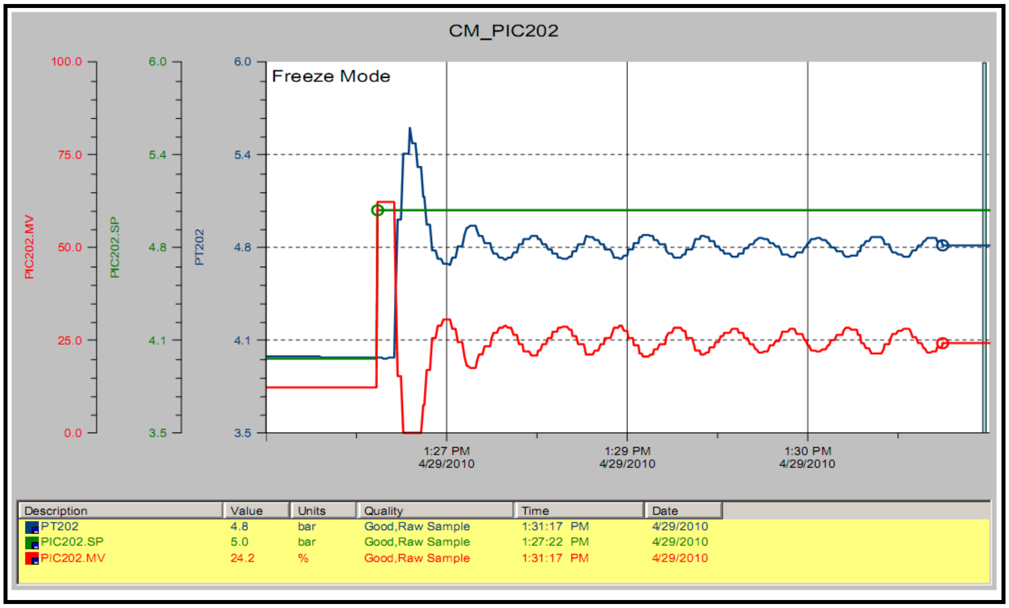


Figure 4.9: Actual Response for MV=30% using P-only Control Mode

4.3.3 *Actual Response for P+I Control Mode*

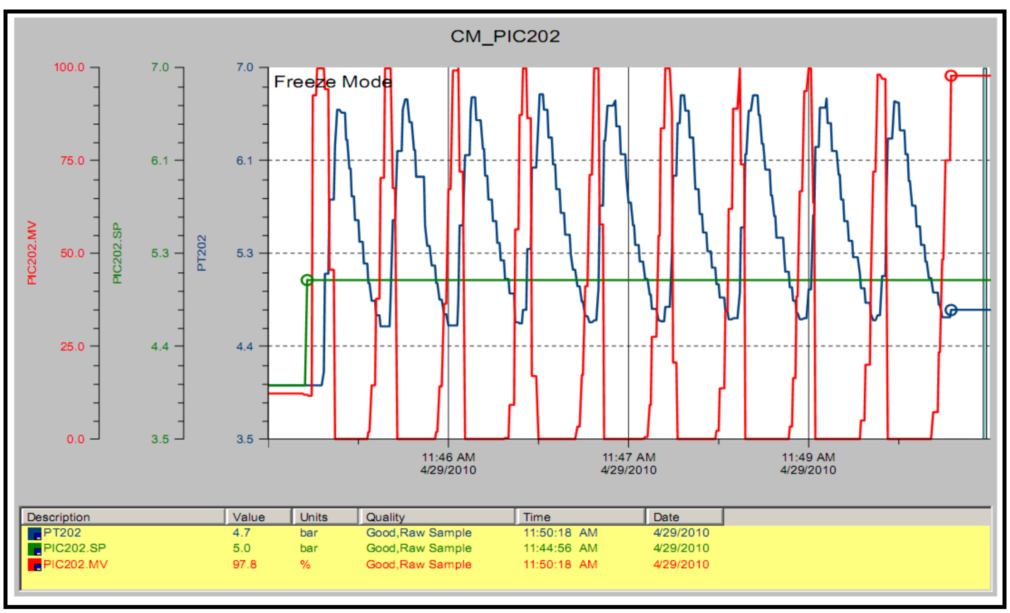


Figure 4.10: Actual Response for MV=10% using P+I Control Mode

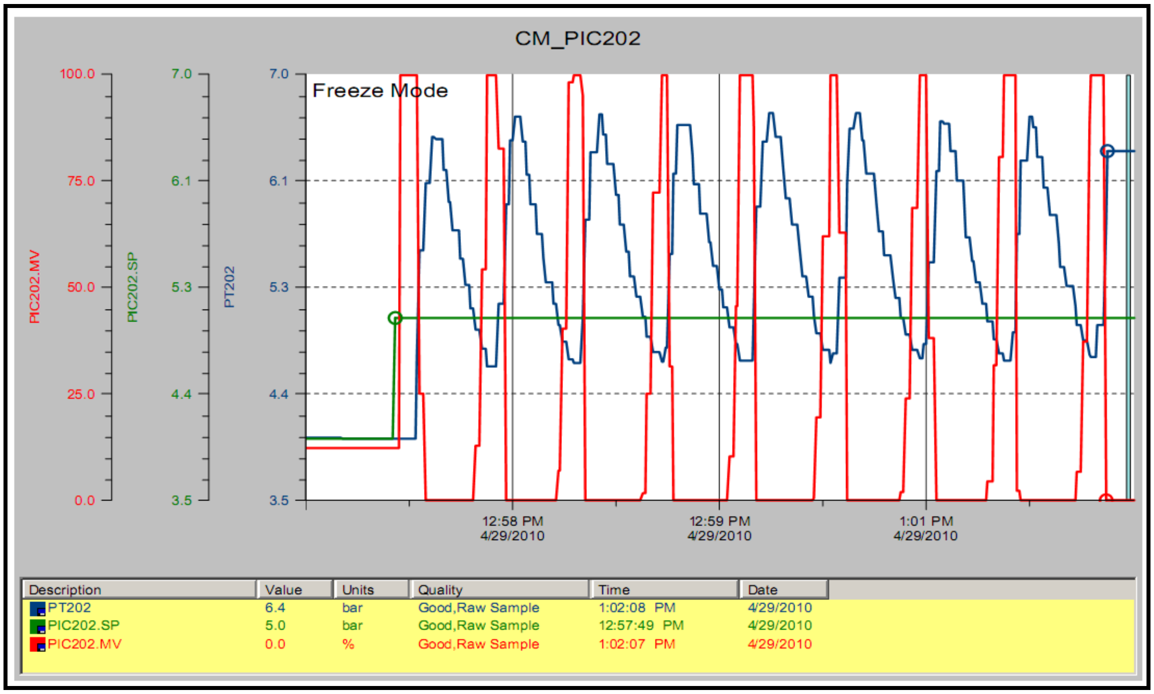


Figure 4.11: Actual Response for MV=20% using P+I Control Mode

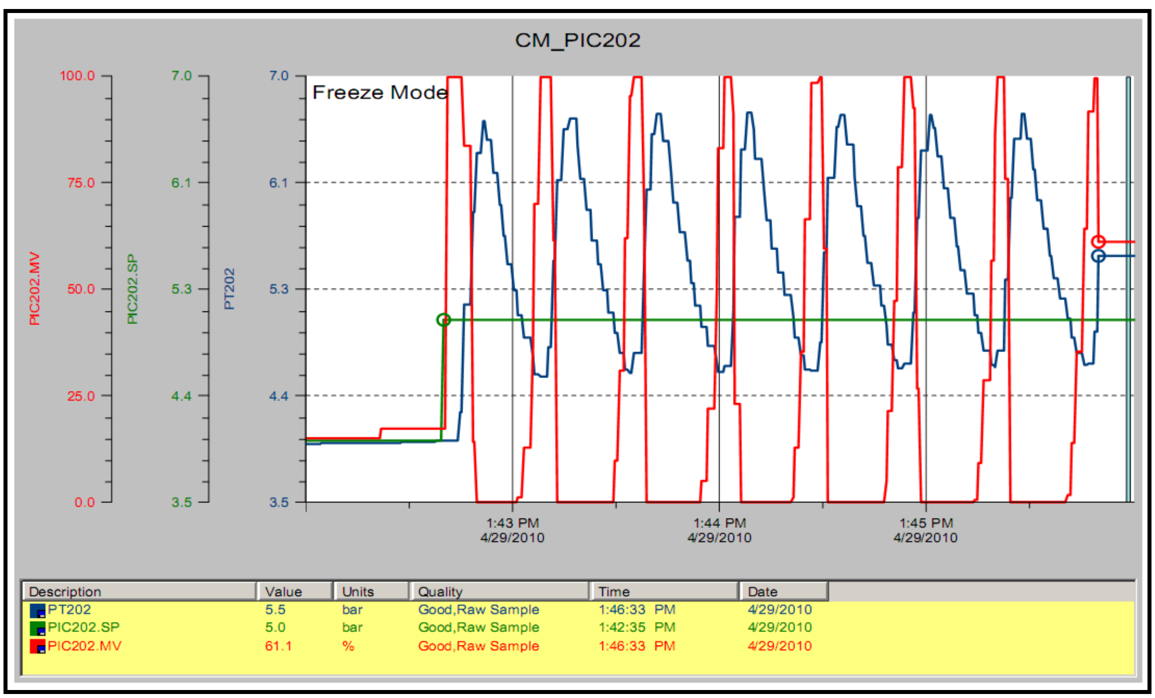


Figure 4.12: Actual Response for MV=30% using P+I Control Mode

4.3.4 Actual Response for P+D Control Mode

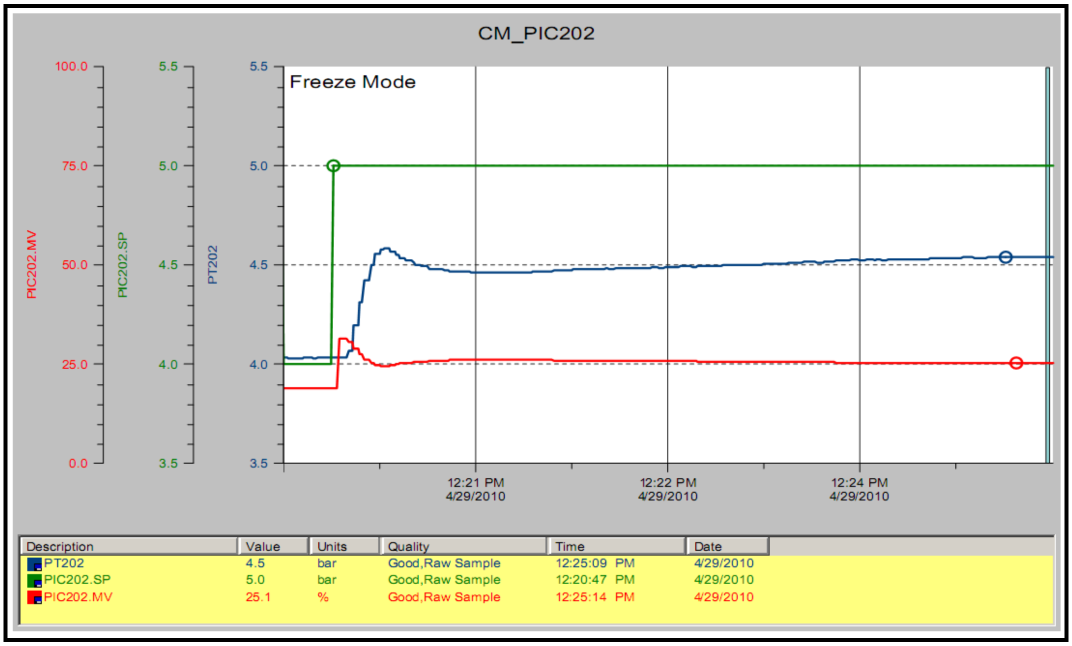


Figure 4.13: Actual Response for MV=10% using P+D Control Mode

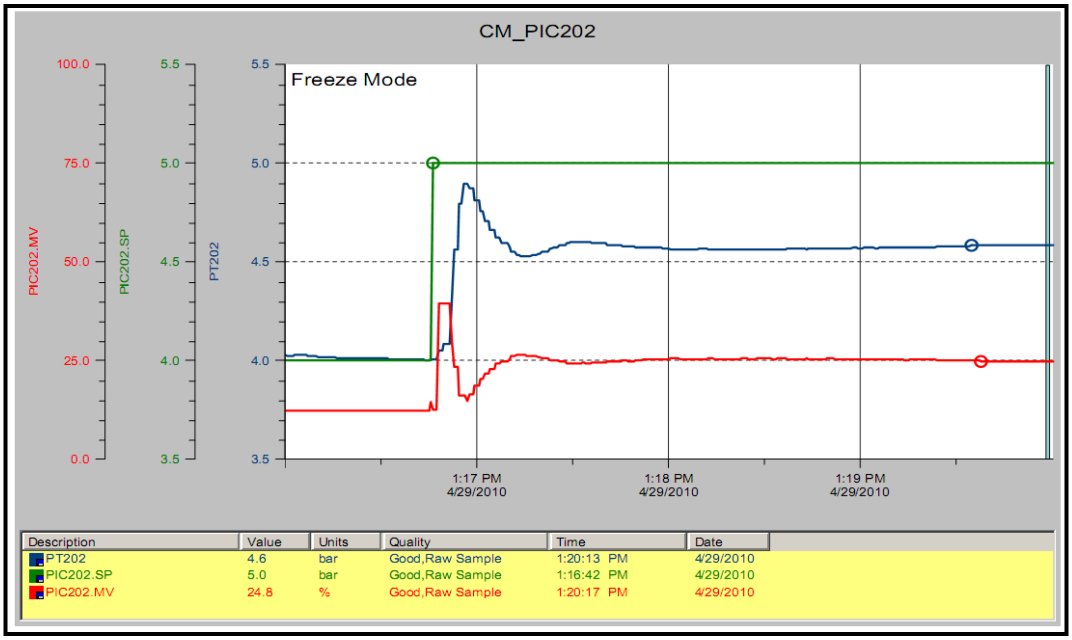


Figure 4.14: Actual Response for MV=20% using P+D Control Mode

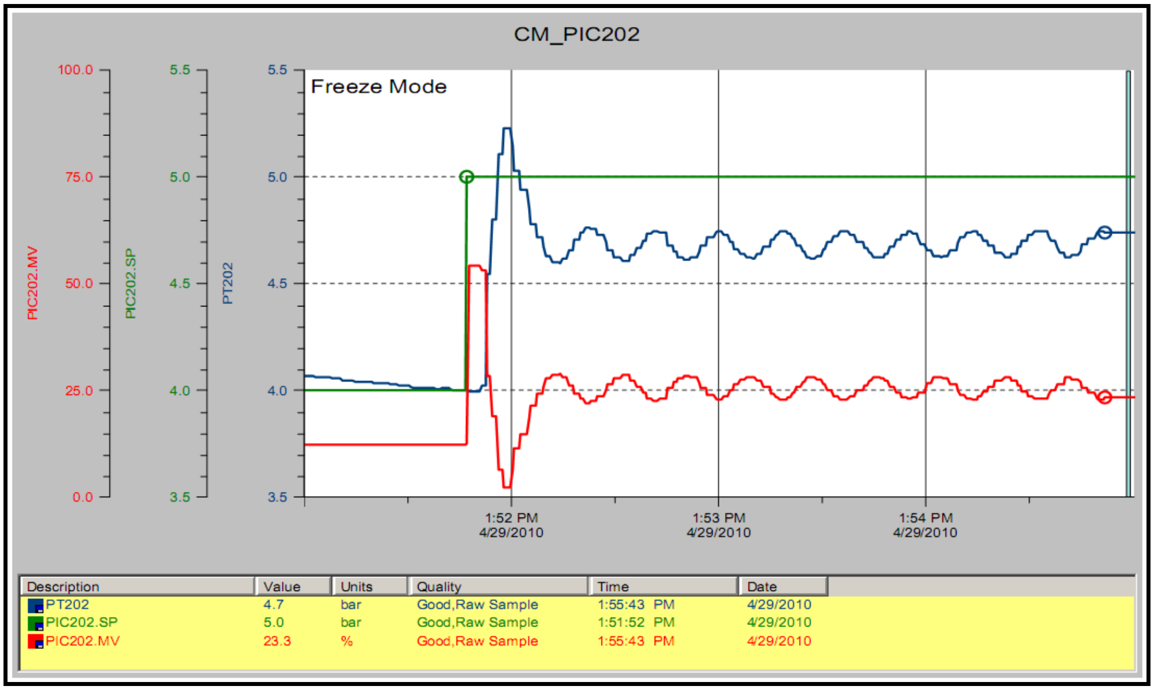


Figure 4.15: Actual Response for MV=30% using P+D Control Mode

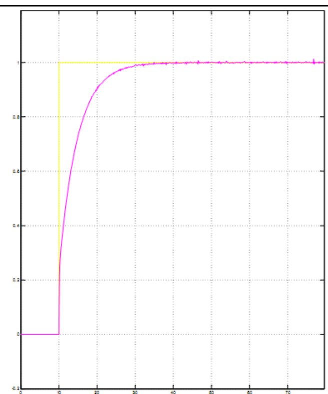
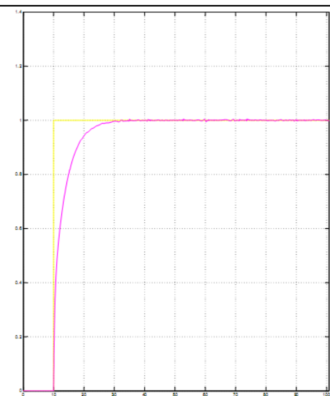
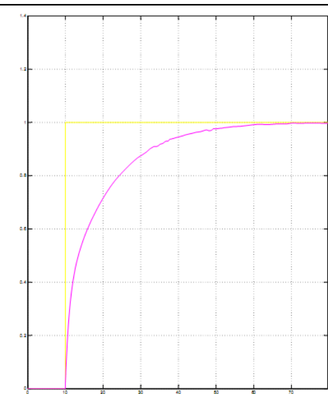
Referring to the methodology of this project, these actual response of PID Pressure Control will be compared to a simulation response from Matlab Simulink.

4.4 Simulation Response of PID Pressure Control

The simulation response of PID Pressure Control was gained using MATLAB Simulink by subtituting all parameters value from previous tables (table 4.5, 4.6, 4.7 and 4.8) into simulation model (refer to Appendix D) of PID Pressure Control.

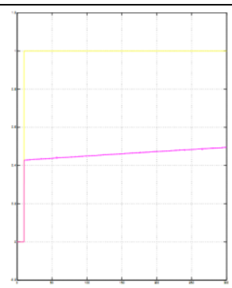
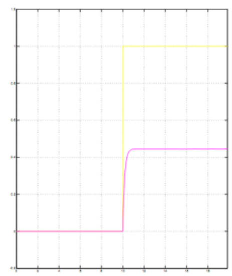
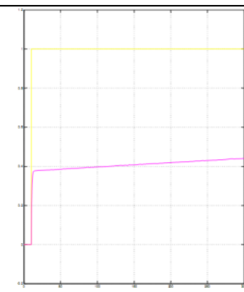
4.4.1 Simulation Response for PID Control Mode

Table 4.6: Simulation Response of PID Control Mode for MV = 10%, MV = 20%, and MV = 30%

MV = 10%	**MV = 20%**	**MV = 30%**
		

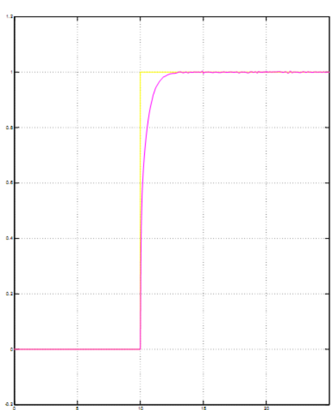
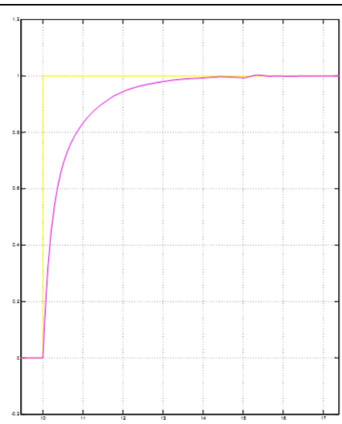
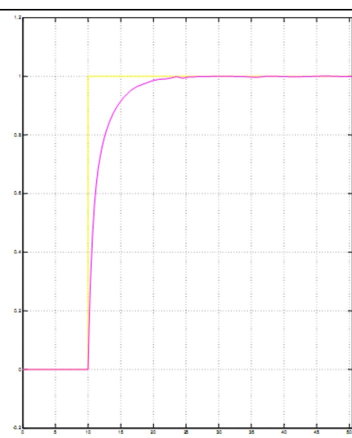
4.4.2 Simulation Response for P-only Control Mode

Table 4.7: Simulation Response of P-only Control Mode for MV = 10%, MV = 20%, and MV = 30%

MV = 10%	**MV = 20%**	**MV = 30%**
		

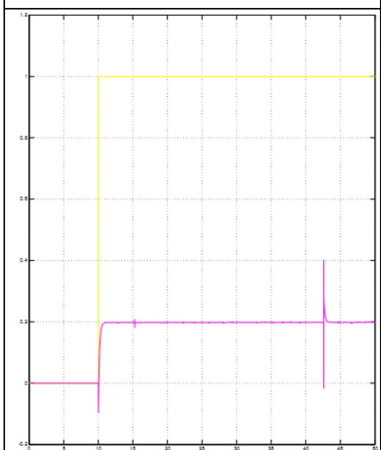
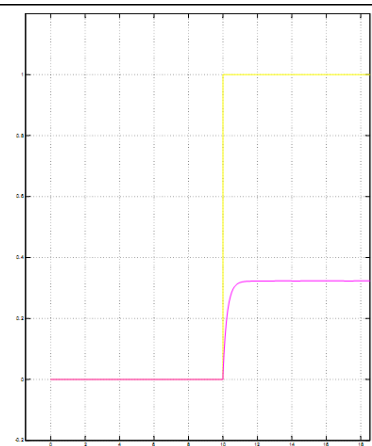
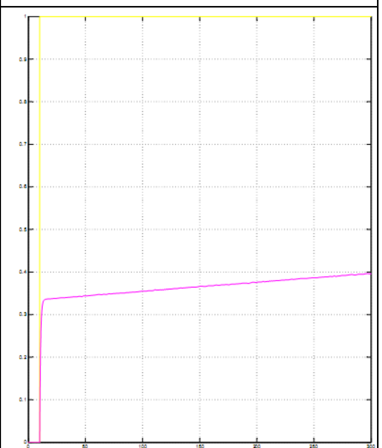
4.4.3 Simulation Response for P+I Control Mode

Table 4.8: Simulation Response of P+I Control Mode for MV = 10%, MV = 20%, and MV = 30%

MV = 10%	**MV = 20%**	**MV = 30%**
		

4.4.4 Simulation Response for P+D Control Mode

Table 4.9: Simulation Response of P+D Control Mode for MV = 10%, MV = 20%, and MV = 30%

MV = 10%	**MV = 20%**	**MV = 30%**
		

Since all of the simulation response of PID Controller for PID Pressure Control has been gained, a comparison between actual and simulation response will be done. Later, the reliability of PID controller will be discussed based on the reliabilty coefficient.

4.5 Discussion

In this experiment, four types of PID control modes has been choosen which is PID control mode, P-only control mode, P+I control mode, and P+D control mode. Therefore, the result for each control mode will be discussed throughly in this section.

Recall that for a test to be considered minimally reliable, its reliability coefficients must approximate or exceed 0.80 in magnitude and coefficient of 0.90 or above are considered to be most desirable.

4.5.1 PID Control Mode

From the experiment, a comparison between actual and simulation responses of PID control mode had been done (refer topic 4.4.1 and 4.5.1) and the reliability coefficients for each testing are as per table 4.10;

Table 4.10: Reliability Coefficient for each PID Control Mode testing

Manipulated Variable (MV)	Maximum Overshoot		Reliability
	Actual	Simulation	
10 %	0.12	0	0.88
20%	0.21	0	0.79
30%	0.20	0	0.80

The PID control mode is a three mode controller. That is, its activity and performance is based on the values chosen for three tuning parameters, one each nominally associated with the proportional, integral and derivative terms.

In this experiment, maximum overshoot of the output was calculated to find the reliability coefficient for each testing. Based on both actual and simulation response, the output shows that the overshoot only happened for actual response since there are errors that caused by several factors. The simulation response does not shows any overshoot at the output because in the simulation model, feedback gain is set as 1, which indicates that the system is a closed loop system with unity feedback and there is no error fed to the input.

In theory, the proportional term will consider the difference between output and input at any instant in time. Its contribution to the output is based on the size of errors only at time t. As errors grows or shrinks, the influence of the proportional term grows or shrinks immediately.

While for the integral term, it will continually summing the errors. By doing that, the integral term can observe how long or how far the output has drifted away from the input. Thus, even a small error, if it persists, will have a sum total that grows over time and the influence of the integral term will similarly grow.

Derivative term on the other hand will describes how steep a curve is. The derivative term describes the slope or the rate of change of a signal trace at a particular point in time. From the PID equation mentioned in the literature review, it shows that the derivative term considers the rate at which, errors are changing at the current moment.

After three different testing was done, the reliability value are set. Then, the average reliability value for this experiment was calculated. The calculation is shown as below;

Total reliability value = 0.88 + 0.79 + 0.80 = 2.47

Total experiment = 3

Therefore, Average Reliability = 0.82

From the calculation, we can conclude that the mathematical model of PID control mode is reliable with 82% true and 18% atrribute to error.

4.5.2 P-only Control Mode

From the experiment, a comparison between actual and simulation responses of P-only control mode had been done (refer topic 4.4.2 and 4.5.2) and the reliability coefficient for each testing are as per table 4.11;

Table 4.11: Reliability Coefficient for each P-only Control Mode testing

Manipulated Variable (MV)	**Maximum Overshoot**		**Reliability**
	Actual	**Simulation**	
10 %	0.08	0	0.92
20%	0.18	0	0.82
30%	0.20	0	0.80

In this experiment, P-only Control mode was used and the maximum overshoot of the output has been recorded. The same simulation model as the previous experiment (PID control mode) was used with the value of Integral term was set very large (999) and value of Derivative term was set to zero.

Theoritically, the P controller will repeat a measurement computation action procedure at every loop sample time. The objective of the controller is to produce zero error in spite of unplanned and unmeasured disturbances. Since error is equal to the difference between input and output, this is the same as saying a controller seeks to make input equal to output. The average reliability coeffecient was calculated as below;

Total reliability value = 0.92 + 0.82 + 0.80 = 2.54

Total experiment = 3

Therefore, Average Reliability = 0.85

From the calculation, we can conclude that the mathematical model of PID control mode is reliable with 85% true and 15% atrribute to error.

4.5.3 P+I Control Mode

From the experiment, a comparison between actual and simulation responses of P+I control mode had been done (refer topic 4.4.3 and 4.5.3) and the reliability coefficient for each testing are as per table 4.12;

Table 4.12: Reliability Coefficient for each P+I Control Mode testing

Manipulated Variable (MV)	**Maximum Overshoot**		**Reliability**
	Actual	**Simulation**	
10 %	0.32	0	0.68
20%	0.30	0	0.70
30%	0.30	0	0.70

By using P+I control mode, the maximum overshoot for actual and simulation response was recorded. Based on table 4.12, it is obviously shown that the P+I control mode is not reliable since all three testing result shows a reliability coefficient below than 0.8.

Based on the mathematical model, Integral action enables P+I control mode to eliminate offset, which is a major weakness of a P-only controller. The Integral mode function is to integrate or continually sum the controller error over time.

Thus, PI control mode should provide a balance of complexity and capability on the PID pressure control. However, the result gained does not support the theory. Furthermore, the P-only control mode provide a better reliable coefficient. The average reliability coeffecient was calculated as below;

Total reliability value = 0.68 + 0.70 + 0.70 = 2.08

Total experiment = 3

Therefore, Average Reliability = 0.69

From the calculation, we can conclude that the mathematical model of PID control mode is not reliable with 69% true and 31% atrribute to error.

4.5.4 P+D Control Mode

From the experiment, a comparison between actual and simulation responses of P+I control mode had been done (refer topic 4.4.4 and 4.5.4) and the reliability coefficient for each testing are as per table 4.13;

Table 4.13: Reliability Coefficient for each PID Control Mode testing

Manipulated Variable (MV)	**Maximum Overshoot**		**Reliability**
	Actual	**Simulation**	
10 %	0.05	0	0.95
20%	0.12	0	0.88
30%	0.18	0	0.82

The last experiment was conducted using P+D control mode and maximum overshoot has been recorded. Based on table 4.15, P+D control mode produce small value of maximum overshoot in which provide high reliability coeffecient.

In P+D control mode, Proportional term provides an instantaneous response to the control error while the Derivative term acts on the derivative or rate of change of the control error. This provides a fast response, as opposed to the integral action, but cannot accomodate constant errors. Therefore, P+D should work well in practice since the net effect is a slower response time with far less overshoot and ripple than a proportional controller alone. The average reliability coeffecient was calculated as below;

Total reliability value = 0.95 + 0.88 + 0.82 = 2.08

Total experiment = 3

Therefore, Average Reliability = 0.88

From the calculation, we can conclude that the mathematical model of PID control mode is not reliable with 88% true and 12% atrribute to error.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As the project has reached the stage of analyzing the result based on comparison between actual and simulation response of PID Pressure plant Control, it is fair to say that the project is complete. All the two objectives of this project which is to verify the reliability of mathematical model of Proportional-Integral-Derivative (PID) in Plant Process Control application (PID Pressure Control) using four types control mode and to conduct research on the PID controller of pilot plants (PID Pressure Control) in the process laboratory of UTP has been achieved.

The 4 types control modes that have been used in this project are Proportional-Integral-Derivative (PID) control mode, Proportional (P-only) control mode, Proportional-Integral (P+I) control mode and Proportional-Derivative (P+D) control mode. Based on the result, it can be concluded that out of the four types control modes, only one was verified as not reliable which is the Proportional-Integral (P+I) control mode while the other three control mode are verified as reliable.

The decision of the mathematical reliability that had been made in this project could not be simply taken as an absolute decision, since it requires further tests. In this experiment, the decision of PID mathematical reliability is limited to the Pressure

Control Process Plant in UTP laboratory for MV= 10%, MV=20%, and MV=30%. However, the author anticipates that the analysis outcome from this project could assist the control engineers in deciding the implementation of PID controller in their process plant.

5.2 Recommendation

These recommendations are made for the purpose of improving the current project for future researches. Several improvements should be made in terms of planning and carrying out the experiments so that better overall outcome of the project can be achieved.

Future researchers into this topic should familiarize themselves with the mathematical model itself. The procedures for determining the type of mathematical model and it properties should be known prior to the start of the research. This is to ensure that the researcher is well aware of the parameters and the expected results after executing an experiment.

It is highly recommended that the test or experiment conducted on the other process plants that is available in UTP's process plant laboratory which is Cascade Temperature Control Process Plant and Flow Control Process Plant. This is to allow further investigation on PID mathematical model reliability and at the same time to support the result of this study.

For future researchers, it is also recommended that the response for all four different modes be studied at different parameter variations. Since the PID mathematical model has been used for over fifty years, it is important that the mathematical model should be thoroughly investigated before the decision on the reliability is confirmed.

For future work, further investigation of the PID controller mathematical model is recommended where specific definition of input variables are to be determined as well as the design of the algorithm of input variables with respect to the desired output in their project.

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APPENDICES