SAFETY PROCESS ANALYSIS: PST ON ESD AND ALARM & SAFETY DESIGN & EVALUATION

By

SYAMSUL FAIZAL B. IDRIS

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

AP. Dr. Nordin b. Saad
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

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.

Syamsul Faizal b. Idris

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Mr. Azhar b. Zainal Abidin	Senior Technician, UTP

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ABSTRACT

Looking from the definition of the word disaster, it is defined as an unexpected natural or man-made catastrophe of substantial extent causing significant physical damage or destruction, loss of life or sometimes permanent change to the natural environment. Putting in a scenario of a very critical process plant where every action and decision must be analyzed into every minute detail, it is where even the slightest mistake would have an effect on the major process. What more if a disaster should occurred in the plant, the effect would have been unimaginable. In the effort of avoiding such incidence, various countermeasures had been deployed to make sure that every possible case is handled. Among the main and early stage preventive device is the Emergency Shutdown Valve (ESD), place in between the upstream/downstream inventory and the processing plant. The scope of this project is to develop a reliable and efficient controller configuration for the ESD to perform Partial Stroke Testing (PST) and Full Stroke Testing (FST) as per demand. It is important for the controller to ensure the device to perform as per needed, reducing the risk of accidents and mishaps. In the fast moving pace of current technology, newer hardware improves the efficiency of the testing process, thus providing easier insight into the procedure. The use of the ABB Programmable Logic Control (PLC) together with its programming software CoDeSys provides clearer view of the procedure. The report also details the development of the controller function block such as the Proportional Band, PID and process monitoring that includes Alarm & Safety System. The analysis of an actual plant, namely the PETRONAS Carigali RESAK Plant is also included, together with its case study. The findings further demonstrate the importance of the ESD and the FST/PST procedure gained from effective procedure programming and thorough data analysis.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The project titled Safety Process Analysis: PST on ESD and Alarm & Safety System Design & Evaluation centres on the development of the controller that is needed to perform partial stroke testing (PST) and full stroke testing (FST) on emergency shutdown valve. The project is a collaborative effort between PETRONAS Group of Technical Solution (GTS) and Universiti Teknologi PETRONAS (UTP) research group, where the valve and the test rig is housed in UTP lab facility and the research is done by groups of final year students. The author is assigned to specific valve alongside the controller manufacturer that is ROTORK, and this will be discussed further in this report. Also in this report, the author will discuss some case study on Alarm & Safety System Design & Evaluation which covers the development and testing of programmable logic control (PLC), manufactured by ABB.

1.2 Problem Statement

1.2.1 Partial Stroke Testing

1.2.1.1 What is ESD?

By definition emergency shutdown (ESD) valves are designed to take the process to a safe state if certain, pre-specified operating limits are exceeded [1]. The major problem with these valves relates to the fact that they typically operate in one static position for long periods of time and only move in an emergency situation. Metal seated ball valves are used as shut-down valves. Use of metal seated ball valves leads to overall lower costs when taking into account lost production and inventory, and valve repair costs resulting from the use of soft seated ball valves which have a lower initial cost.

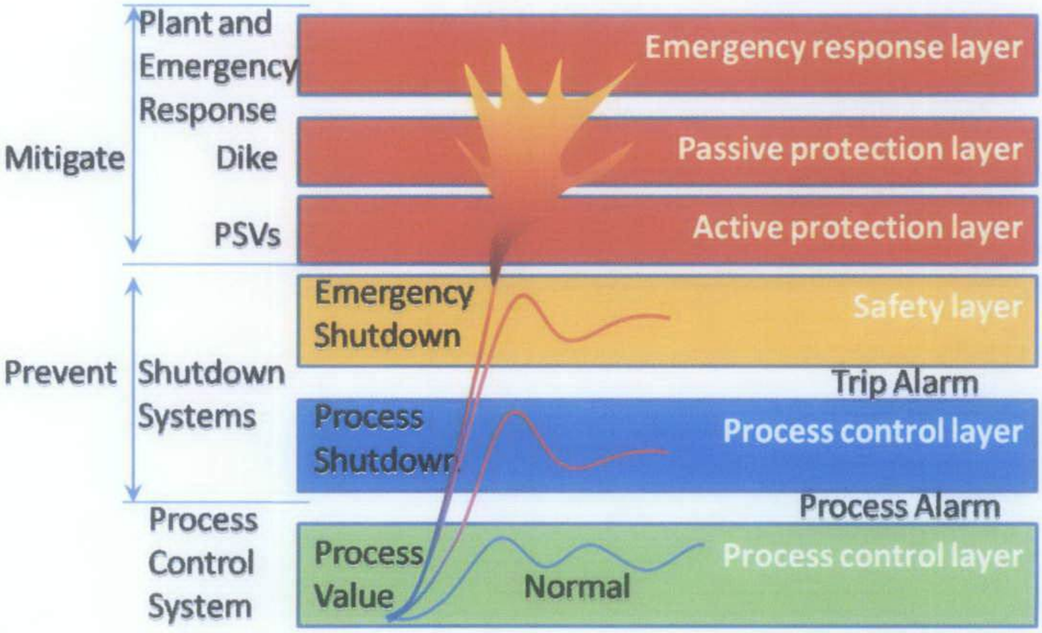


Figure 1: Safety layer as depicted in the diagram indicates the level of seriousness

1.2.1.2 Why is ESD important?

As shown in Figure 1 above, the Emergency Shutdown layer is the last defense before a plant problem went serious. Since the Piper Alpha disaster in the North Sea, design of ESD valves has been given top priority and remains to be of great concern for plant safety management. Constant improvements have been made to ensure the integrity of the ESD valves. Essentially, ESD valves should perform their duty (usually closure of valves) under plant demand condition. To meet the production bottom-line, these valves are required to remain open for months, even years, which leads to build up or corrosion in the valve internals [2].

1.2.2 Alarm & Safety System Design & Evaluation

1.2.2.1 What is PLC?

The automation of many different processes, such as controlling machines or factory assembly lines, is done through the use of small computers called a programmable logic controller (PLCs). This is actually a control device that consists of a programmable microprocessor, and is programmed using a specialized computer language. A modern programmable logic controller is usually programmed in any one of several languages, ranging from ladder logic to Basic or C. Typically, the program is written in a development environment on a computer, and then is downloaded onto the programmable logic controller directly through a cable connection. The program is stored in the programmable logic controller in non-volatile memory.

Programmable logic controllers typically contain a variable number of input/output (I/O) ports, and are usually Reduced Instruction Set Computer (RISC) based. They are designed for real-time use, and often must withstand harsh environments on the shop floor. The programmable logic controller circuitry monitors the status of multiple sensor inputs, which control output actuators, which may be things like motor starters, solenoids, lights and displays, or valves.

This controller has made a significant contribution to factory automation. Earlier automation systems had to use thousands of individual relays and cam timers. In many cases, a PLC allows all of the relays and timers within a factory system to be replaced with a single controller. Today, programmable logic controllers deliver a wide range of functionality, including basic relay control, motion control, process control, and complex networking, as well as being used in distributed control systems (DCS).

1.2.2.2 Why is PLC Important?

PLC control system is that it regards PLC as control key component, utilize special I/O module to form hardware of control system with a small amount of measurement and peripheral circuit, to realize control to the whole system through programming.

1. High Reliability

Strong anti-interference quality and very high reliability are the most important features of PLC in order to make PLC work stably in strong interferential circumstance. Many techniques are applied in PLC. Software control instead of relay control mode can decrease faults which are brought about by original electric contact spot outside working badly. Industrial grade components made by advance processing technology can resist interferences, and self diagnosis measures of watchdog circuit for protecting memory can improve performance.

2. Good Flexibility

There are several programming languages for PLC including ladder diagram, SFC, STL, ST and so on. If operator can master only one of programming languages, he can operate PLC well. Every person who wants to use PLC has a good choice. Based on engineering practice, capacity and function can be expanded by expanding number of module, so PLC has a good flexibility.

3. Quality of Strong Easy-Operating

It is very easy to edit and modify program for PLC by computer offline or online. It is very easy to find out where the fault lie by displaying the information of fault and function of Self Diagnosing Function, and all these make maintenance and repair for PLC easier. It is very easy to configure PLC because of modularization, standardization, serialization of PLC.

1.3 Objectives & Scope of Study

1.3.1 Partial Stroke Testing (PST)

This project is the continuation of the previous effort, pioneered by the final year students undertaking the Final Year Project (FYP). The main objective of this project is to develop and improve the efficiency of the PST and FST procedure developed based on the valve supplied by the vendor FISHER, METSO-NELES, MASONEILAN and the newest addition is ROTORK. As of the time of writing, the facility is currently being upgraded by the GTS to include the destructive testing for the four ESD valve. By the effort of previous batch, the no-load test is successful, thus the author is involved in the next step of the testing which is the destructive/load test.

The scopes of study are as follows:

a. Pump rating: list of pump datasheet/ spec. Supplier contact

b. Piping type-PVC does it can withstand the operating pressure

c. To check vessel capacity

d. Liquid-water

e. Pressure drop of reducer

f. Selection of flow transmitter-orifice

g. Selection of pressure gauge

h. Hook up/ installation drawing for PST valves (Flanged and Wafer type)

1.3.2 Alarm & Safety System Design & Evaluation

This project is an initiative taken under AP. Dr. Nordin b. Saad under e-science grant, which specifies the task to test and simulate the new model of PLC from ABB. As for the development of PLC, this product from ABB is the newest addition to the UTP inventory, thus needed further research on its operating efficiency and ease to use. The advantages featured by ABB PLC are:

a) Scalability
   - ABB's system designers have packed an impressive array of features into this pioneering entry-level range to deliver even better scalability and flexibility than ever before.

b) Performance
   - The AC500-eCo offers a powerful PLC system that is truly outstanding in its class, featuring a generous 128 kB user memory coupled with a fast CPU offering program processing times of 0.1 µs/instruction.

c) State-of-the-art Design
   - This future-oriented design with its slim footprint, rapid and secure cabling options and integrated diagnostic / monitoring indicators will integrate perfectly into your application. In addition, a secure connection to the system bus is ensured by means of sturdy, laterally integrated plugs.

The scopes of the study are as follows:

a. PLC initial assembly

b. Scenario testing and devising

c. PLC language programming

d. Simulation environment

e. Hardware connection

CHAPTER 2

LITERATURE REVIEW

2.1 Partial Stroke Testing (PST)

For this project, the author is assigned to work on the valve and controller manufactured by ROTORK. As the package has just arrived at UTP recently, and the presence of the vendor product specialist is needed to open the package. From the product webpage, it is confirmed that the equipment used is the Smart Valve Monitor (SVM) patented by the ROTORK Fluid System.

Figure 2: ROTORK Smart Valve Monitor (SVM)

The product is claimed as the most versatile and comprehensive partial stroke valve testing system for hydraulically or pneumatically actuated on/off valves.

Among its benefits are:

- Comprehensive valve performance monitoring system.
- Partial stroke testing in real time.
- Test all final elements as required by IEC 61508.
- Compatible with virtually any fluid power actuator.
- Assists with SIL compliance—extends shutdown intervals.
- Completely transparent to normal valve operation.
- Facilitates strategic maintenance.

In default, positioned systems (POS) is used to detect the fault on the valves, but PST has proven to assist more on the fault detection and furthermore help to analyze the current fault situation efficiently. The table below indicates the type of faults that can be detected by the PST together with the SVM from ROTORK, compared to the current POS.

Table 1: Comparison on Fault Detection Capability between POS and PST

FAULT	PST with SVM	POS
VALVE		
Valve Seized	√	√
Increased Breakout Torque	√	√
Polymerization of Valve Seat	√	
Increased Packing Friction	√	
Valve Stem Shear	√	
Valve Seat Leakage		
ACTUATOR		
Broken Spring	√	√
Cylinder Damage	√	√
Internal Cylinder Corrosion	√	
SOLENOID AND/OR QUICK EXHAUST VALVE(QEV)		
Exhaust Blockage	√	
Solenoid Mechanism Wear	√	
Damaged Tubing	√	

2.1.1 Perceived Advantages of PST:

- May provide an improvement to the Safety Integrity Level of the Safety Instrumented Function [3].
- Provides predictive maintenance data for future maintenance planning.
- May allow extension of the full stroke test (FST) which allows longer interval between plant turnaround.
- May reduce the need for valve bypasses for ESD valves.
- Valve is always available to respond to a process demand during the test period.

2.1.2 Perceived Disadvantages of PST:

- Tests only a portion of the valve DU failures (30% to 70%)
- Not applicable to tight shut-off valves where it only operates at on/off operation.
- May increase spurious trip rate.
- Incorporates additional equipment with its own testing requirements (Safe and dangerous failures).
- If PST always strokes 30%, dirt and buildup of heavy components forms at 30% of stroke.

2.2 Alarm & Safety System Design & Evaluation

2.2.1 PLC Introduction

A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or lighting fixtures. PLCs are used in many industries and machines. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory. A PLC is an example of a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result.

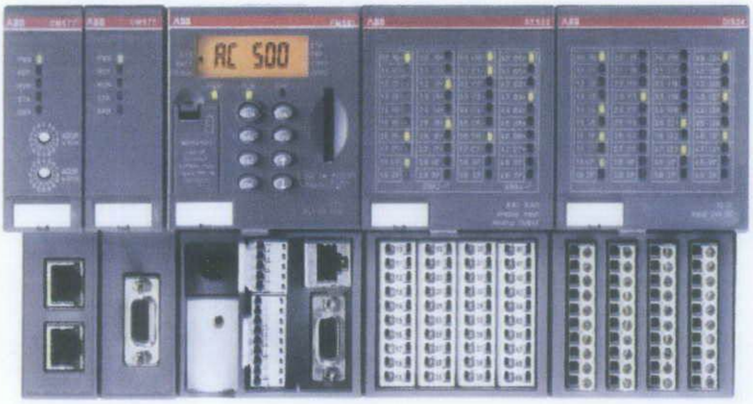


Figure 3: ABB PLC AC500 Hardware

As a side project, the author was assigned to a group of 4, together with the other final year students who are also doing PST, to test a new Programmable Logic Control from vendor ABB. The task was to develop an example of a plant operation, and to incorporate the controlling element to the PLC thus testing the logic programmed in the PLC.

2.2.2 AC500 Introduction

ABB new Programmable Logic Control which is the AC500 PLC range is known to have performed in the industry through testimonials from its users on the ABB website. The product features versatile scalability between add-on products with the PLC itself, thus reducing the cost of a whole upgrade if needed. It is also equipped with 128kb of user memory for faster in-PLC processing, together with the fast 0.1µs/instruction. This would improve the instruction execution for any cases defined. The compatibility of the PLC connections, either through Ethernet or serial port, the task will be handled thoroughly.

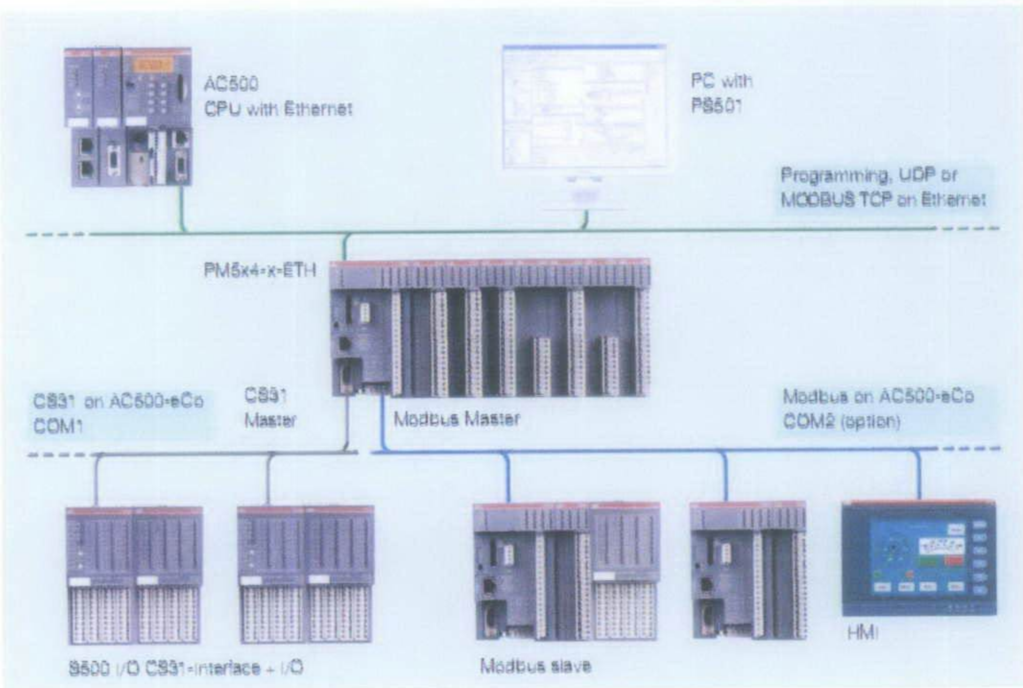


Figure 4: Example of PLC connection for the AC500

2.2.3 Features of PLC

The main difference from other computers is that PLCs are armored for severe conditions (such as dust, moisture, heat, cold) and have the facility for extensive input/output (I/O) arrangements. These connect the PLC to sensors and actuators. PLCs read limit switches, analog process variables (such as temperature and pressure), and the positions of complex positioning systems. Some use machine vision. On the actuator side, PLCs operate electric motors, pneumatic or hydraulic cylinders, magnetic relays, solenoids, or analog outputs. The input/output arrangements may be built into a simple PLC, or the PLC may have external I/O modules attached to a computer network that plugs into the PLC.

2.2.4 PLC System Scale

A small PLC will have a fixed number of connections built in for inputs and outputs. Typically, expansions are available if the base model has insufficient I/O. Modular PLCs have a chassis (also called a rack) into which are placed modules with different functions. The processor and selection of I/O modules is customized for the particular application. Several racks can be administered by a single processor, and may have thousands of inputs and outputs. A special high speed serial I/O link is used so that racks can be distributed away from the processor, reducing the wiring costs for large plants.

2.2.5 PLC Communications Standard

PLCs have built in communications ports, usually 9-pin RS-232, but optionally EIA-485 or Ethernet. Modbus, BACnet or DF1 is usually included as one of the communications protocols. Other options include various fieldbuses such as DeviceNet or Profibus. Most modern PLCs can communicate over a network to some other system, such as a computer running a SCADA (Supervisory Control and Data Acquisition) system or web browser.

PLCs used in larger I/O systems may have peer-to-peer (P2P) communication between processors. This allows separate parts of a complex process to have individual control while allowing the subsystems to co-ordinate over the communication link. These communication links are also often used for Human Machine Interface (HMI) devices such as keypads or PC-type workstations.

2.2.6 PLC Programming Standards and Language

PLC programs are typically written in a special application on a personal computer, and then downloaded by a direct-connection cable or over a network to the PLC. The program is stored in the PLC either in battery-backed-up RAM or some other non-volatile flash memory. Often, a single PLC can be programmed to replace thousands of relays.

Under the IEC 61131-3 standard, PLCs can be programmed using standards-based programming languages. A graphical programming notation called Sequential Function Charts is available on certain programmable controllers. Initially most PLCs utilized Ladder Logic Diagram Programming, a model which emulated electromechanical control panel devices (such as the contact and coils of relays) which PLCs replaced. This model remains common today.

IEC 61131-3 currently defines five programming languages for programmable control systems: FBD (Function block diagram), LD (Ladder diagram), ST (Structured text, similar to the Pascal programming language), IL (Instruction list, similar to assembly language) and SFC (Sequential function chart). These techniques emphasize logical organization of operations.

CHAPTER 3

METHODOLOGY

3.1 Partial Stroke Testing

3.1.1 Procedure Identification for Partial Stroke Test

Before starting the project, full understanding of the project is determined as to guarantee that every action taken is being considered with sufficient knowledge and option consideration in mind. The brochure and the manual provided by the vendor is studied and understood, thus giving an overview of the actual product in hand. This would later save time during handling of the actual item.

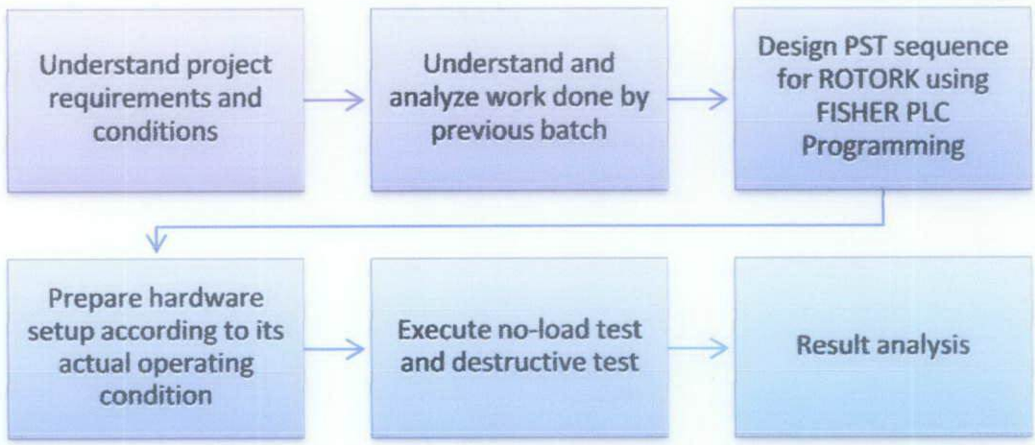


Figure 5: Procedure Identification

It is understood that hand-to-hand maneuver with the item is preferred, but some knowledge in the back of the mind would help.

As this project is a continuation of the previous batch effort, every data and research previously done proved to be useful in developing future procedure and simulations. Every mistake done in the past is an opportunity to develop more understanding on the project behavior and the consequences of every action. As per time of writing, the plant facility upgrade is currently being researched by the PETRONAS GTS, and it is an effort and research done by the previous batch through computer modeling and simulation testing.

For the ROTORK valve, the package needs to be opened with the presence of the vendor personnel but is yet to be done. Once the package is unpacked, it needs to be assembled and mounted to the facility properly. The same done for the other 3 valves, the ROTORK valve will be wired to the FISHER PLC assembly going into the PC terminal. The same PLC assembly is used because of simplicity and compatibility of the FISHER software with various valves manufacturer. In this stage, the Partial Stroke Testing sequence will be developed with the software provided by ROTORK.

Once the PST sequence is developed, the actual hardware is set up to its designed configuration to proceed with the no-load and the load testing. Once the testing is done, the next step which is data mining and analysis is done to extract useful information for the project.

3.1.2 Partial Stroke Testing & Probability of Failure on Demand

One of the primary uses of partial stroke testing techniques is to extend full closure intervals. These intervals are defined by evaluating the required Safety Integrity Level (SIL) and the average Probability of Failure on Demand (PFD_{avg}) in conjunction with the following equation:

$$PFD_{avg} = [DC_{PC} * \lambda_D * (TI_{PC}/2)] + [(1 - DC_{PC}) * \lambda_D * (TI_{FC}/2)] \quad \textbf{Equation 1}$$

DC_{PC} = Diagnostic Coverage of the PST

λ_D = Total Dangerous Failure Rate

TI = Test Interval of Full or Partial Closure

Note: λ_D failure rates are measure in FITs (10^{-9} failures/hour)

There are two components of the PFD_{avg} calculation that relate to the test intervals of the partial closure (TI_{PC}) and full closure (TI_{FC}). The weight if each component is directly dependent upon the diagnostic coverage of the PST. As the DC_{PC} increases, the weight of the full closure component decreases and the TI_{FC} is extended.

The DC_{PC} for a PST is defined by IEC 61508 as follows:

$$DC_{PC} = \lambda_{DD}/\lambda_{TOTAL} \quad \textbf{Equation 2}$$

λ_{DD} = Dangerous detected rate of the PST

λ_{TOTAL} = Total dangerous failure rate

3.1.3.1 Tools and Equipment Used

The equipments involved in this project are:

1. ROTORK Ball Valve
2. ROTORK Butterfly Valve
3. ROTORK Smart Valve Monitor
4. FISHER PLC Assembly
5. PC Terminal

3.1.3.2 Plant Example

An example of an existing plant with an accredited SIL rating and approved full closure testing regimes is considered and the improvement contributed by the partial stroke testing can make to the established full closure intervals is studied. Positioned based systems and the ROTORK SVM are examined.

The PFD equations can be applied to the plant to allow an extension of the TI_{FC} and maintain the required SIL rating [4]. When the plant has no partial stroke testing, Equation 1 is simplified to:

$$PFD_{avg} = [\lambda_D * (TI_{FC}/2)] \qquad \textbf{Equation 3}$$

Since the SIL rating of the plant cannot be changed, the PFD_{avg} must remain the same both before and after the PST has been applied. This mean that Equation 1 = Equation 3 as shown below:

$$[\lambda_D * (TI_{FC}/2)] = [DC_{PC} * \lambda_D * (TI_{PC}/2)] + \left[(1 - DC_{PC}) * \lambda_D * \left(TI_{FC}{}^{NEW}/2\right)\right]$$

$TI_{FC}{}^{NEW}$ is the extended full closure regime when PST is applied. Equation 3 can be rationalized to yield Equation 4:

$$TI_{FC} = [DC_{PC} * TI_{PC}] + \left[(1 - DC_{PC}) * TI_{FC}{}^{NEW}\right] \qquad \textbf{Equation 4}$$

Solving for $TI_{FC}{}^{NEW}$ gives:

$$TI_{FC}{}^{NEW} = TI_{FC} - \frac{[DC_{PC}*(TI_{PC})]}{1-DC_{PC}} \qquad \textbf{Equation 5}$$

If the example plant has a current testing regime of TI_{FC} = 6 months, and we choose to conduct a PST every 2 months, the relationship between $TI_{FC}{}^{NEW}$ and DC_{PC} can be plotted. This will determine the effectiveness of any partial stroke testing system.

3.2 Alarm & Safety System Design & Evaluation

3.2.1 Procedure Identification for Alarm & Safety System Design & Evaluation

A case study to investigate the design and the development of a plant alarm and safety system are conducted. An industrial controller, PLC, is utilized to perform the appropriate control of the value. Figure 6 illustrated the process flow chart that emanate from this case study.

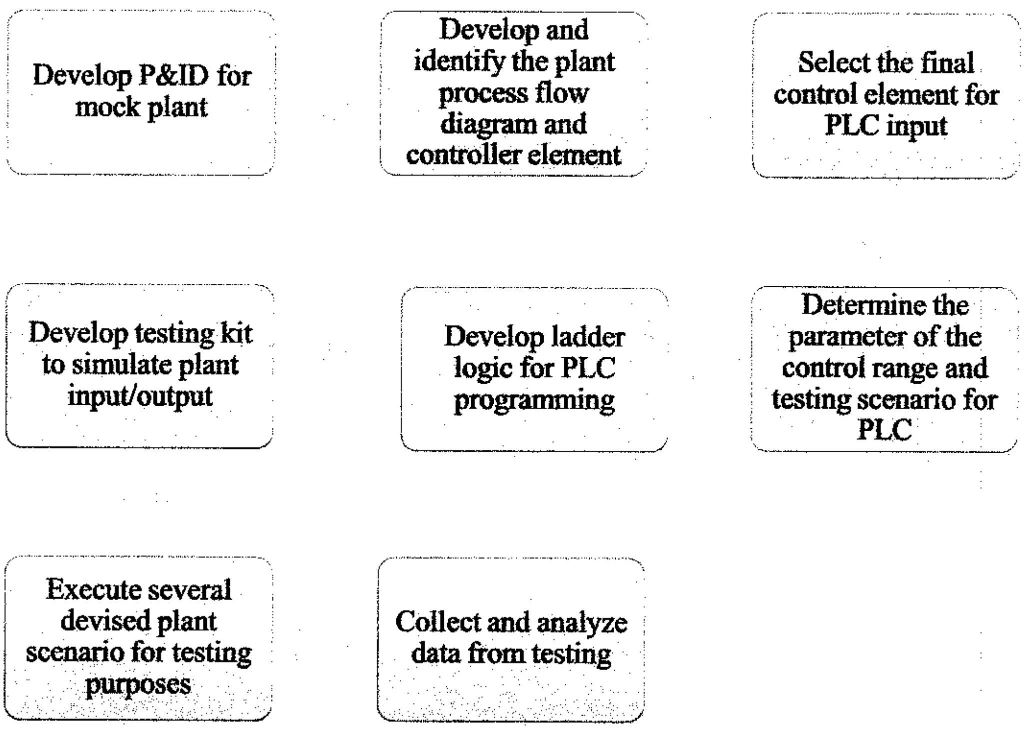


Figure 6: Procedure Identification

To start the project, first a mock plant needs to be developed to simulate the plant environment for the PLC. In developing the plant, a P&ID of the plant is devised and confirmed by the project supervisor. Once the diagram is confirmed, then the next step is to specify the correct loop and instrument tagging for each instrument. This is important as it helps to identify the correct instrument that needs to be attended more compared to the other. In this stage, several final control elements are chosen as the input to the PLC. For the sake of simulation, only the first half of the plant is chosen for the operating region and 4 control elements are chosen.

Once all the control elements are chosen, the control range and parameter of each element is specified. Then, the alarm set point for each process variable is selected for three levels, which is LOW, HIGH and HIGH HIGH alarm. Every alarm set point needs to be synchronized with each other so that there will be no conflicting alarm amongst the control elements.

When all the control parameters has been set, the next step is to develop the programming for the PLC, and the language chosen for this project is the ladder logic diagram. Compared to the other 4 languages, the ladder logic diagram is easier to be programmed and when there is problem, the error locating and the troubleshooting process are made simpler with the easy-to-access ladder diagram.

After the logic ladder diagram had been programmed, the program will be uploaded to the PLC for initialization. After the PLC had been initialized, the simulation of the mock plant is run through with several previously developed scenarios of the plant. Every data and response from the PLC will then be gathered and compiled for further data mining and analysis.

3.2.1 AC500 Program Testing

To test the new PLC hardware from ABB, a simple plant test subject is devised and two parameters is specified which needs to be controlled.

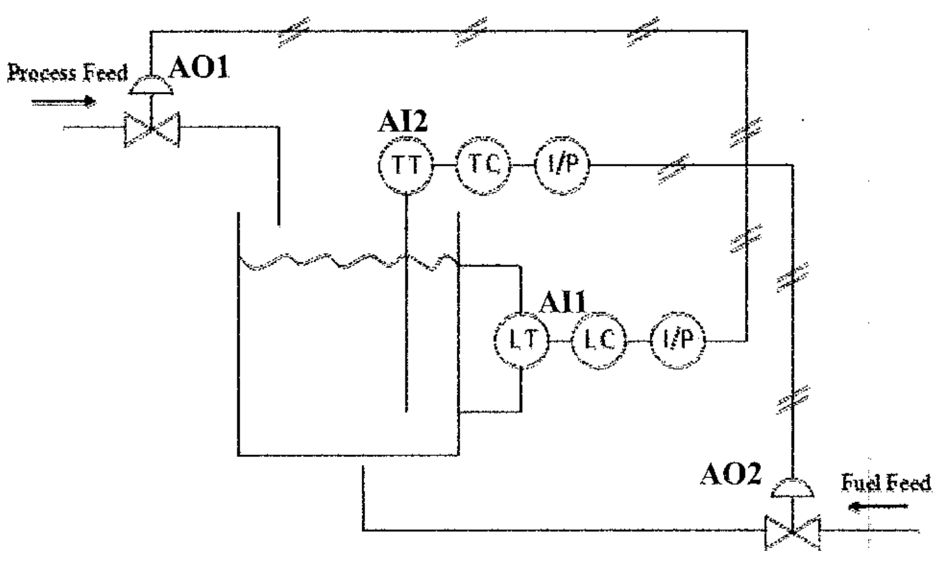


Figure 7: Simple Plant Feed Diagram

The input to the PLC is specified as **"AI1"** for the level transmitter reading, and **"AI2"** for the temperature transmitter reading. The output of the PLC is then specified as **"AO1"** which is the control valve that is controlling the process feed intake and as **"AO2"** which controls the fuel feed. In this program, only simple parameters will be defined to simulate simple interaction between the sensor and the final control element using the PLC as the controller. **"AI3"** and **"AO3"** is defined as backup variable.

To start on the project testing, the software used in this project is CoDeSys by 3S, version 2.3.9.11. The software is capable of handling simple as well as complex PLC programming using all six languages that is:

i. Ladder Diagram (LD)
ii. Sequential Function Charts (SFC)
iii. Function Block Diagram (FBD)
iv. Structured Text (ST)
v. Instruction List (IL)
vi. Continuous Function Charts (CFC)

The next project description detail out the step needed to execute a simple analog input/output project hardware simulation.

1. Create a new project and choose target setting **"PM571 V1.2"** (remember to always choose the PLC target with the latest version).

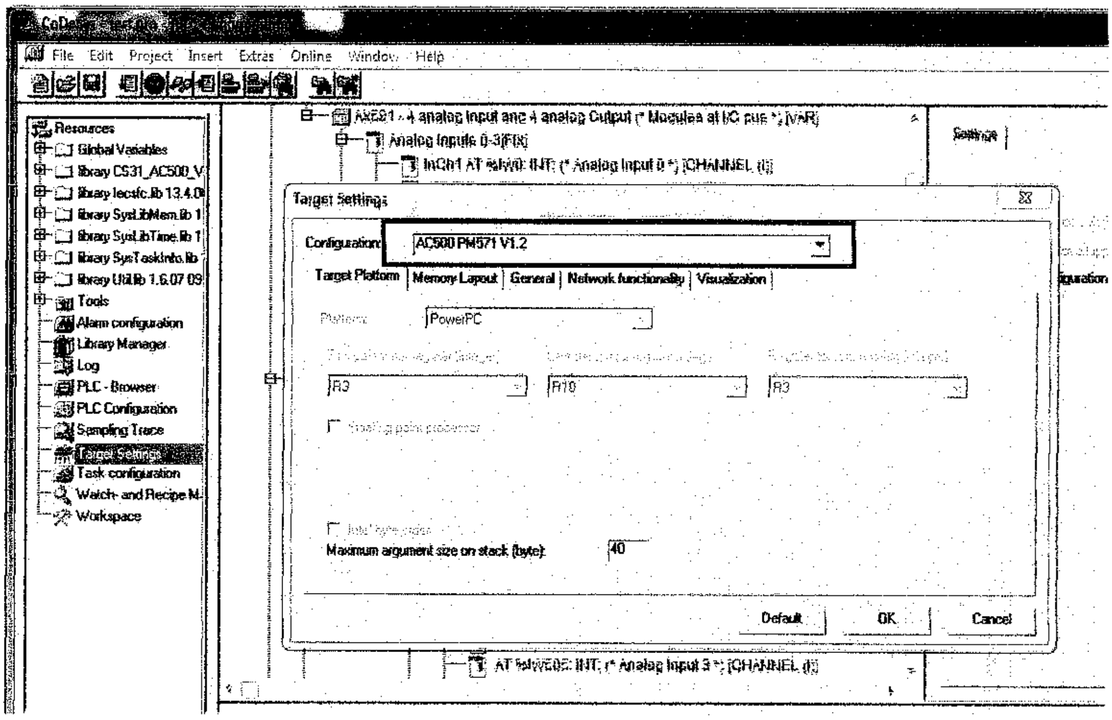


Figure 8: Choosing PLC hardware version

2. Select the **Resources** button in Control Builder and open the PLC configuration window shown below.

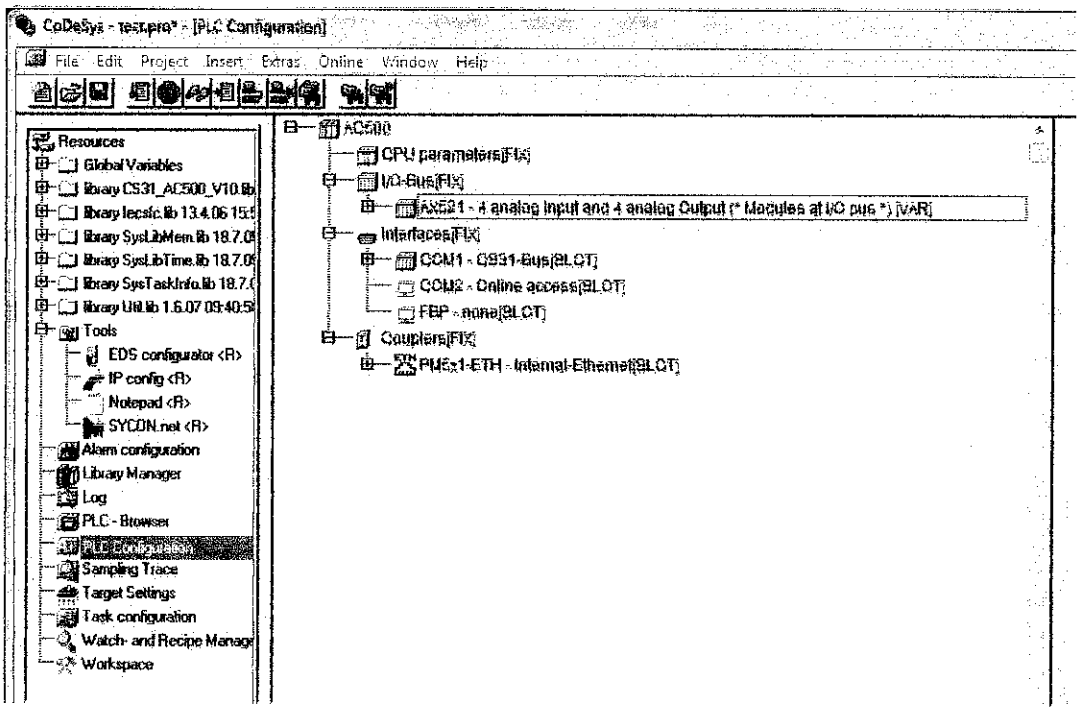


Figure 9: Navigating to the PLC Configuration

3. Select the I/O bus and append in the first I/O sub element with a right mouse click.

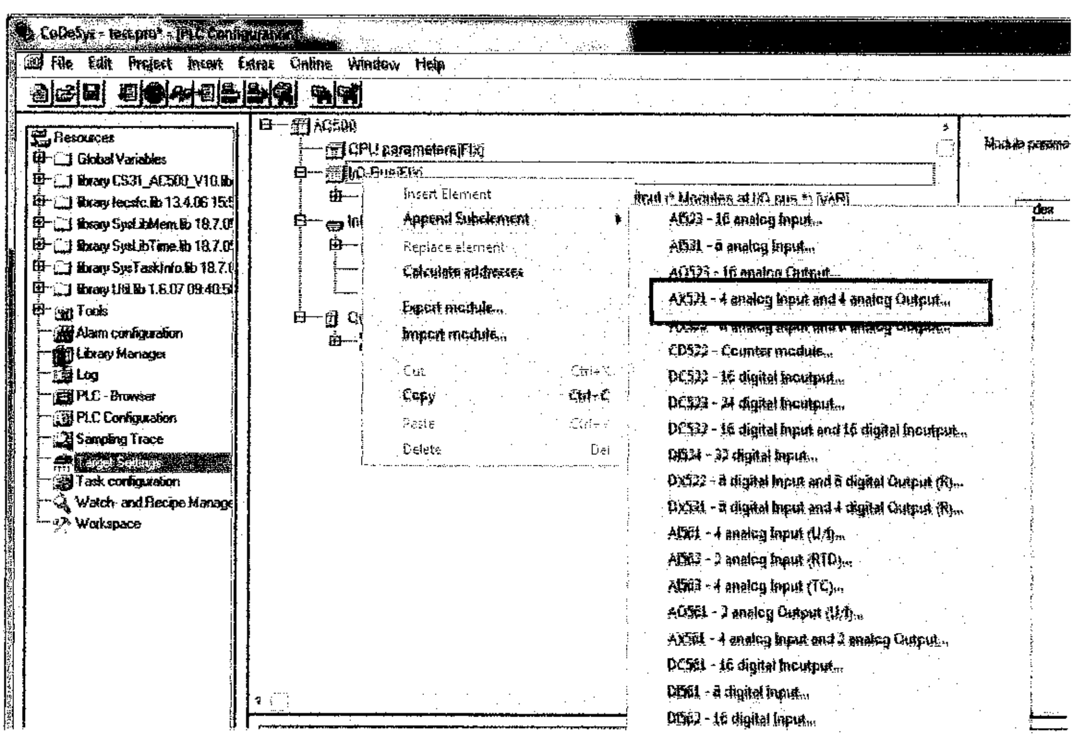


Figure 10: Hardware module options

Repeat this process of appending in sub element I/O modules for the AX 521 – 4 analog Input and 4 analog Output. In this testing, only the module AX 521 is chosen as the project only deals with analog I/O.

4. Highlight the AX 521 module, and check the module parameters whether it caters to the project need or not.

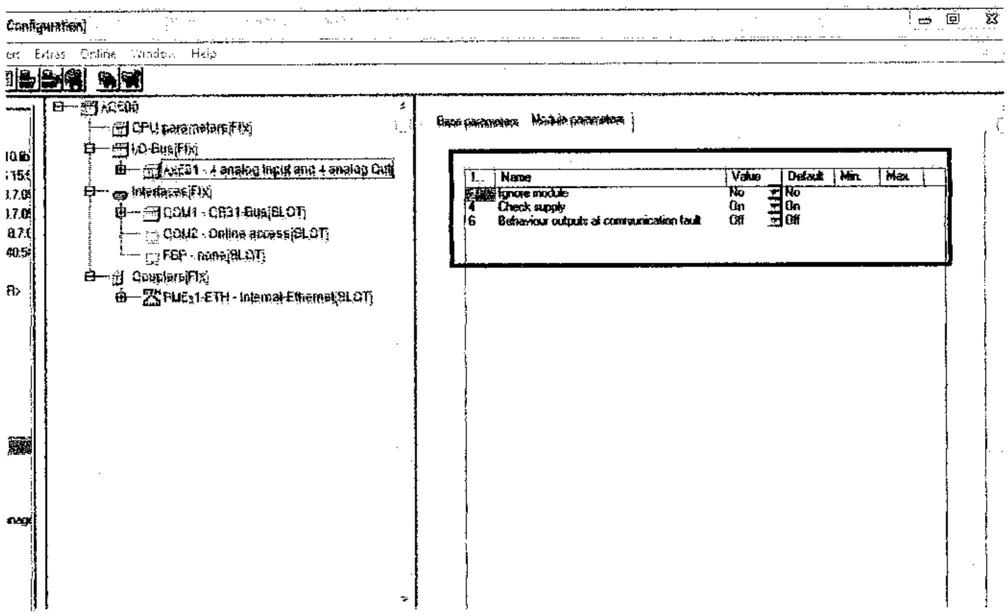


Figure 11: Module parameters checking

5. Next, append the sub element for the Ethernet connection that will be used to upload the program into the AC500 through the RJ45/CAT5 cable that is the PM5x1-ETH –Internet-Ethernet [SLOT] under the Couplers [FIX] category.

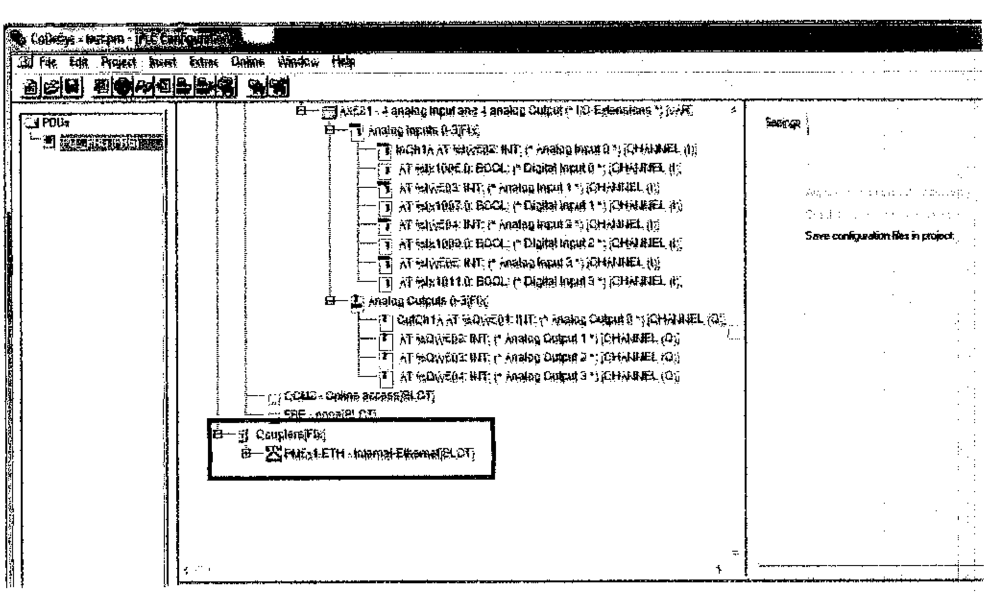


Figure 12: Ethernet slot definition

6. Assign the desired Input assignment according to the AX521 hardware module to its program variable.

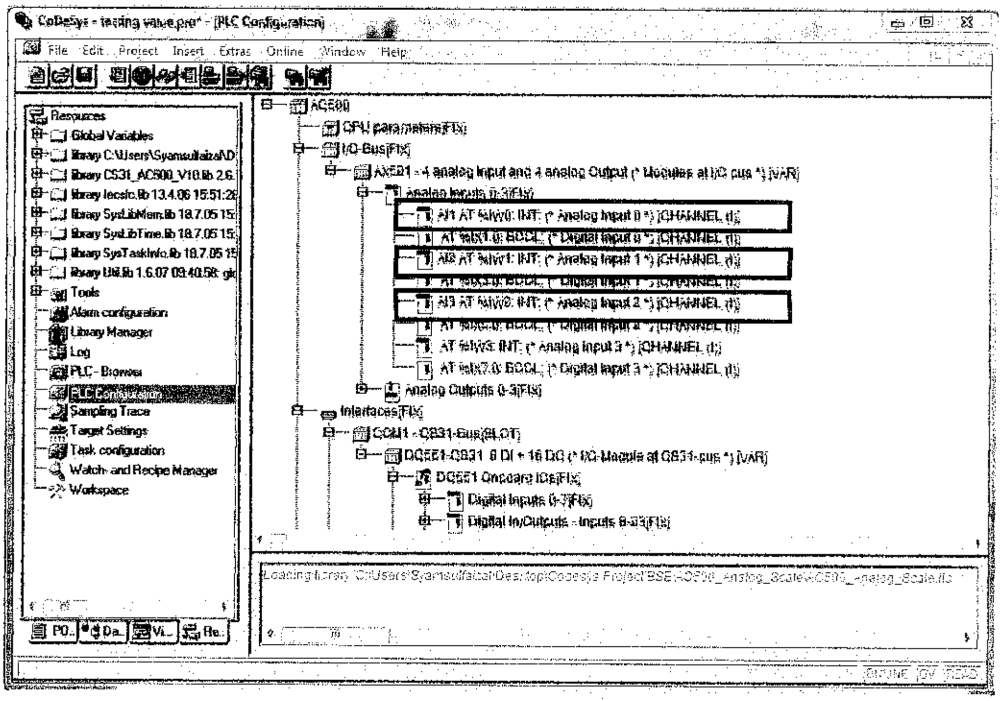


Figure 13: Input assignment

In this step, we define out Input as **"AI1"** and **"AI2"**. These are the two inputs that will simulate the two sensor input into the PLC.

7. Assign the Output of the project, which are the **"AO1"** and **"AO2"**.

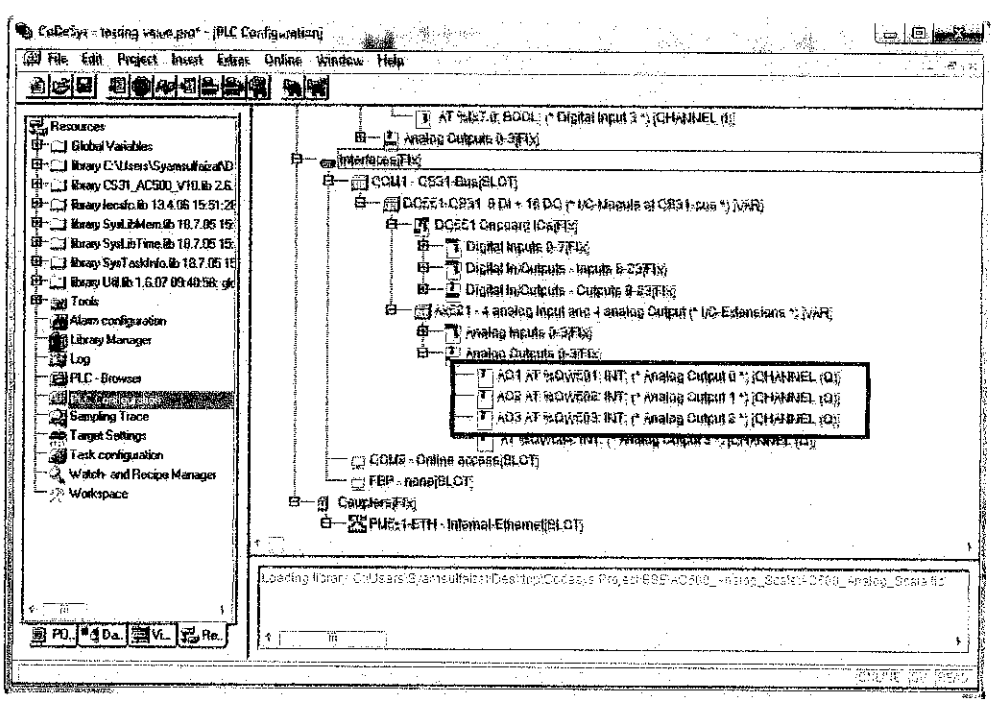


Figure 14: Output assignment

8. To define the Ethernet connection that will be used in this project, we must define the IP address of the PLC module and assign a static IP for the PC Terminal so that the terminal can connect to the PLC. To do that, select the **"Communication Parameters"** option under the **"Online"** dropdown menu.

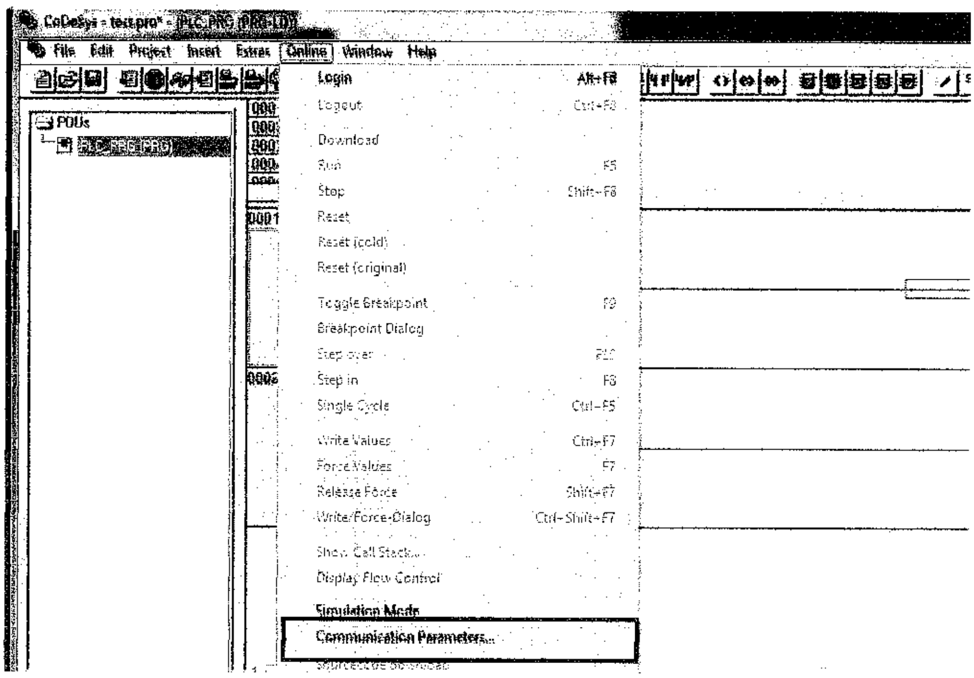


Figure 15: Navigating to communication parameters option

9. Define the Ethernet connection that will be used from the option box and select TCP/IP protocol for the connection.

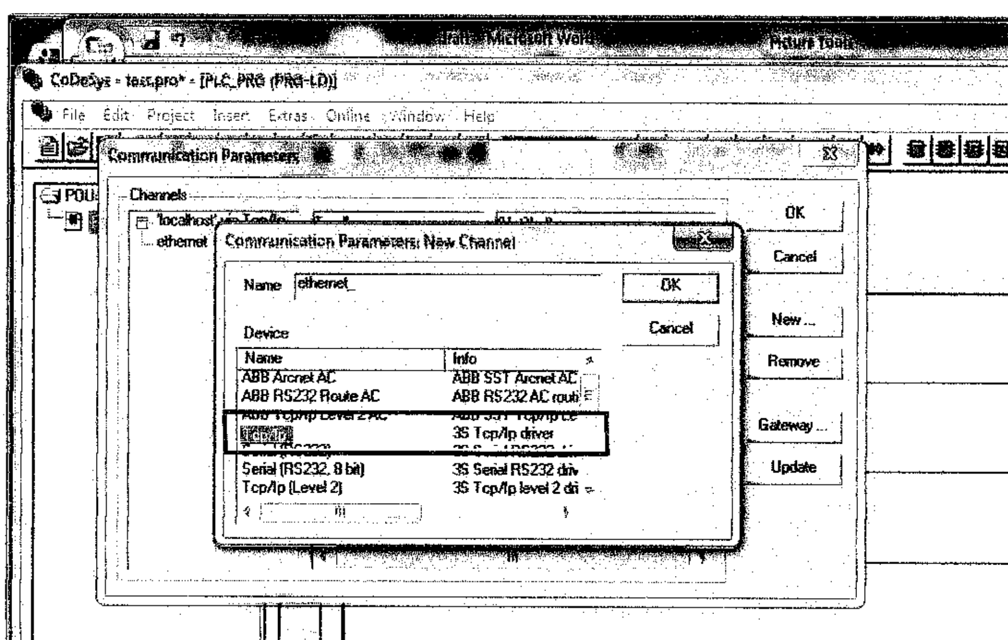


Figure 16: Protocol options for programming

10. Confirm the port number for the connection which is the default value for the Ethernet connection, 1021 and the IP address of the PC Terminal is tally with the module IP address.

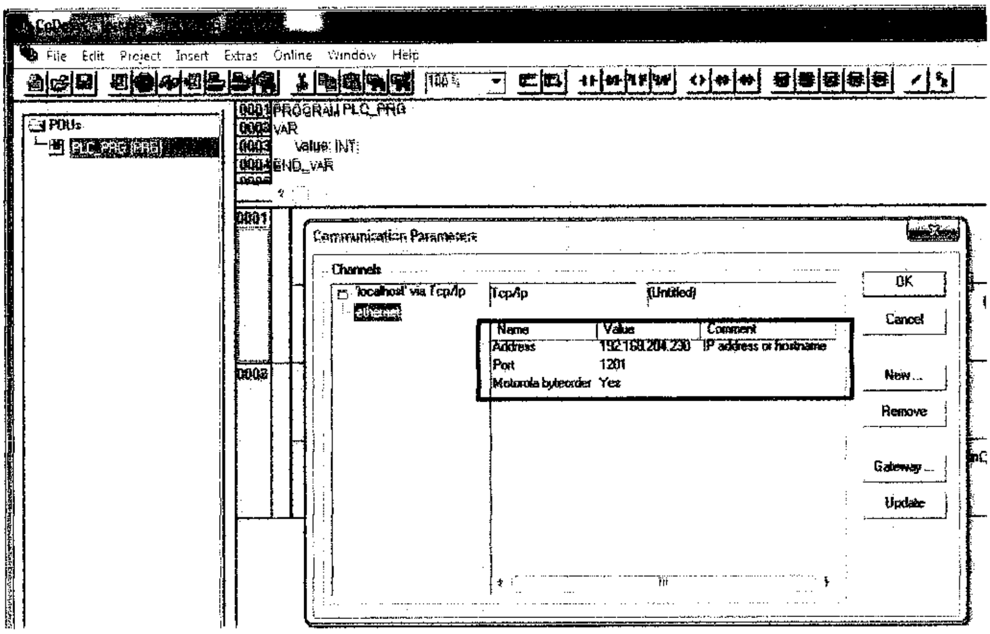


Figure 17: Address and port determination

11. To check whether the IP address of both the PC Terminal and the PLC module is tally, select the **"Resources"** tab below and click on the **"IP Configuration"**. The connected module should appear in the window together with its settings. Be reminded that the IP address between the devices must not differ more than 5 bits for easier configuration.

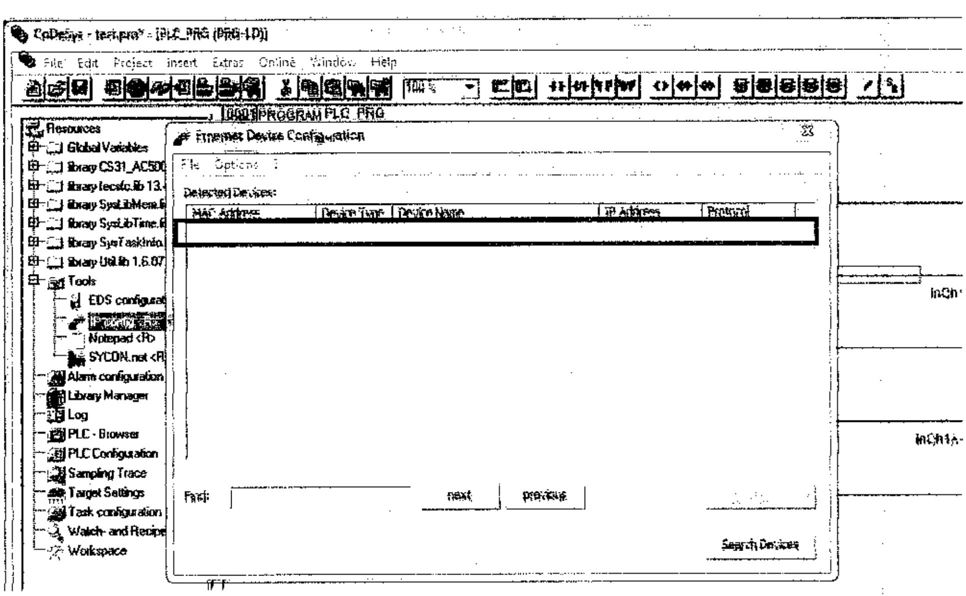


Figure 18: Device appearance

12. After all the configuration has been done, the program is developed. In this project, the Continuous Function Chart (CFC) programming language is used.

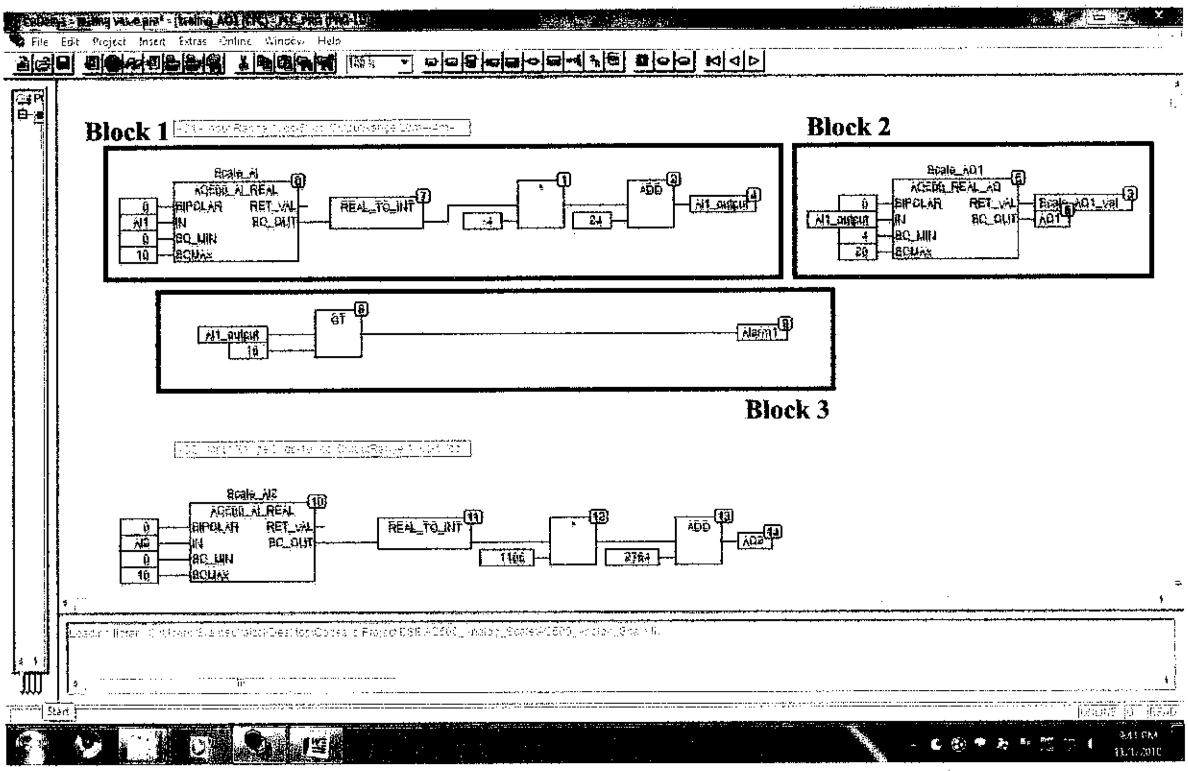


Figure 19: Program simulation overview

The program is divided into three main functional blocks which are:

i. <u>Block 1: Input Scaling and Linear Relationship Between I/O</u>

When the input **AI1** channels the value given by the transmitter/sensor from the simulation plant, it gives out a value that is not understood by the PLC. To translate the value into usable data, a scaling block is defined to channel the value from the input into the PLC for data processing. The raw value for the AC500 PLC ranges from 0 to 27648, which offers a wide range of data scalability. Once the data is accepted by the PLC, a relationship between the input and the output is defined and in this case, a linear one. The linear relationship is given by:

$$y = mx + c,$$

$$\text{where } m = \frac{y_2 - y_1}{x_2 - x_1}$$

The output is represented by the variable ***y*** and the input is represented by the variable ***x***. The ***m*** variable represents the slope which stands for the data relation between the input and the output. The output for this block is **AI1_output**.

ii. Block 2: Output Scaling

For the raw value of the PLC to be understood by the output device, the data is then scaled again through the scaling block. The output for this block is **AO1**.

iii. Block 3: Alarm Level Detection

The alarm system processing is defined in the internal module and does not involve the I/O processing. The data that goes to the output scaling block which is **AI1_output** is compared to a certain value of warning and if the data exceeds the limit, it gives out the binary value of 1 to **Alarm1**.

3.2.1 AC500 Program Block Description

The main scaling block used in this program is the AC500_AI_REAL. The diagram and description below explains more on the function of the block.

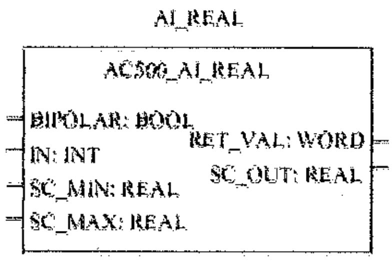


Figure 21: AC500 block diagram

Table 2: AC500 I/O Description

Variables	Data Type	Description
INPUT VARIABLES		
BIPOLAR	BOOL	BIPOLAR= 1, Range is from -27648 to 27648 and if BIPOLAR=0, Range is from 0 to 27648
IN	INTEGER	Analog Input (Range 0-27648)
SC_MIN	REAL	Minimum Scale Value
SC_MAX	REAL	Maximum Scale Value
OUTPUT VARIABLES		
RET_VAL	WORD	Return Value = 0 means No Error, Return Value = 8 means AI is out of Range
SC_OUT	REAL	Scaled Output Value in the SC_MIN and SC_MAX Range

The FB is intended to scale the analog input (0-27648) to required scale in the real format. Using BIPOLAR input, AI range -27648 to 27648 can also be used. In case if the Analog Input is within the range, the return value will be 0 and if the AI is out of range return value will be 8.

Continuing on the program function blocks, stated below is the Greater Than (GT) block and the REAL_TO_INT block.

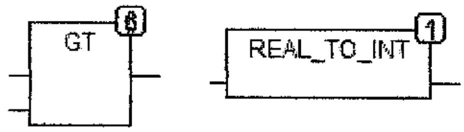


Figure 20: GT and REAL_TO_INT block diagram

The first one is the Greater Than (GT) block. This block compares the incoming value from the process @ other function blocks with the value set. If the incoming value is greater than the value set, the GT block outputs the Boolean value 1. If not, it stays at Boolean value 0. The function block REAL_TO_INT translates the value of REAL format (process analog value) to a more understandable value for the PLC that is the INT (integer) format. The REAL value goes from 0 – 27648 and the INT consists of all positive round value.

The next step in the PLC programming is to include the PID function block in the process control to imitate the actual process from the field.

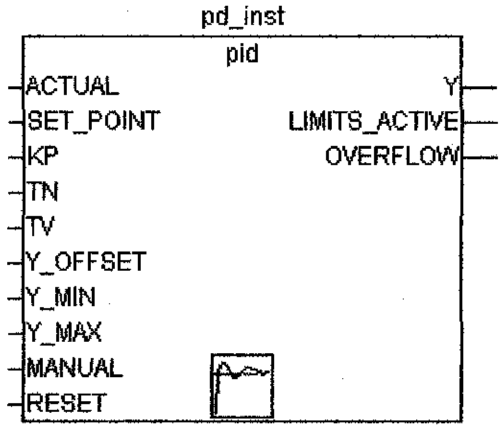


Figure 22: PID function block from CoDeSys

By integrating the PID function block into the simulation, one can monitor the output and analyze the situation better related to the actual process on the field. Each parameters will be controlled e.g. gain, offset and speed of the output. The goal is to manipulate the function block to conform to the current programming environment.

As an addition, the use of Proportional Band (PB) is introduced to better assist the output control. PB is actually related to the gain (Kp). The percentage of output control is specified as the band, according to the user input.

$$PB = \frac{100\%}{Gain\ (K_p)}$$

By using PB, user can specify the appropriate range of sinusoidal wave of the output. From this practice, a better approach to the output analyzing is obtained, thus improving the effectiveness and time saving from unnecessary process calculation.

After all the variables, input and output has been designed and tested to work, next is the simulation of the process from the use of Visualization feature in the CoDeSys.

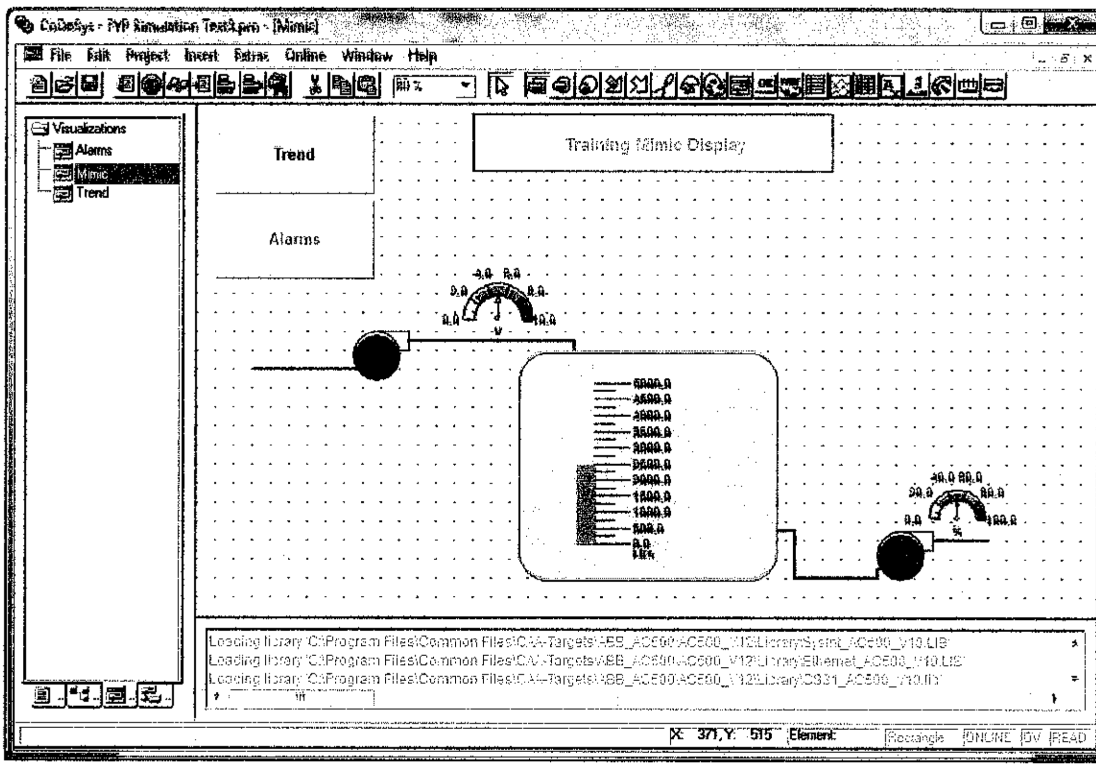


Figure 23: Process visualization

The example above only demonstrates simple process flow between the two pumps and the process variable is represented by the level in the tank. To simulate continuous input variation, a testing kit is needed to generate the needed input to the PLC.

3.2.2 Building the Testing Kit

To start building the testing kit, which is to simulate the input coming from the actual hardware, there will be two main sources which are the voltage source ranging from 1 – 5 Volts, and current source ranging from 4 – 20 mA. For the testing part, each source is designed independently. The first one is the voltage source.

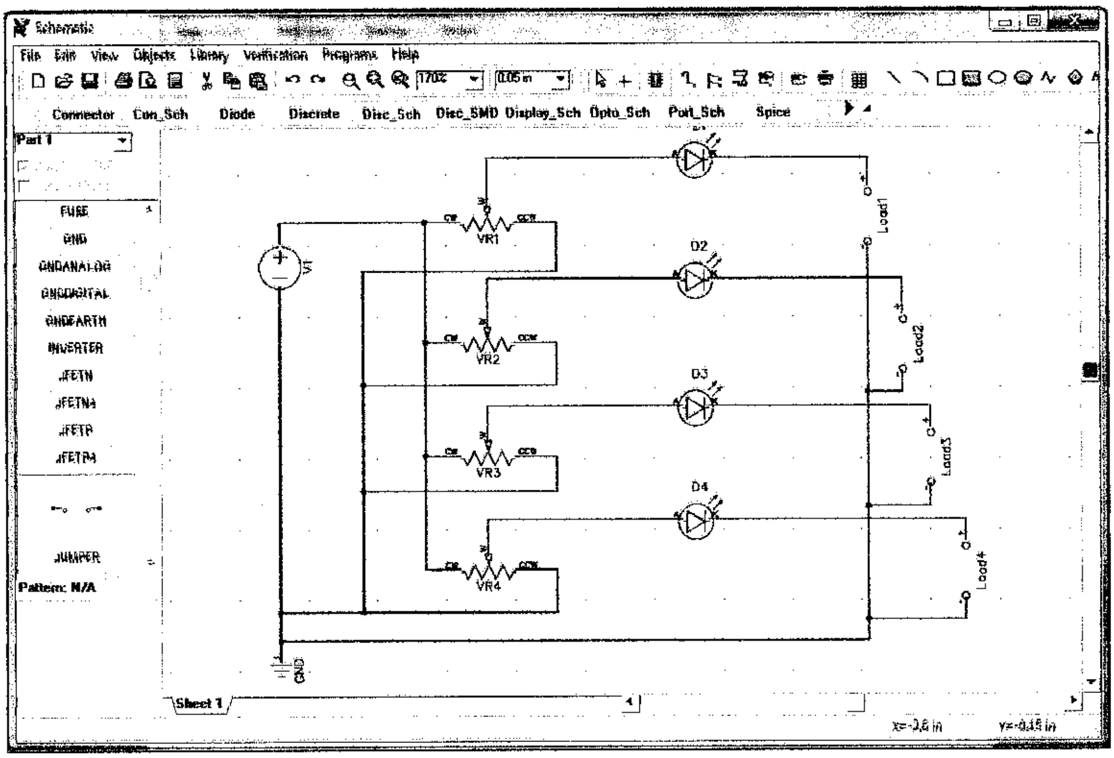


Figure 24: Voltage source schematic

In designing the voltage source circuit, the theory of potential difference between terminals is applied. As we can see from the figure above, the potentiometer is not wired ordinarily. According to its initial schematic, the input from the potentiometer is wired from the positive side of the supply, the negative side is wired to the load/LED, and the moving terminal is wired to the ground. From this practice, the output voltage can only be varied according to its stated resistance value. This here would involve unnecessary calculation to determine the exact value that the potentiometer will produce in accordance to its supply.

What we can do instead is, wired the variable terminal to the load side and the output to the ground. By doing it this way, we can actually vary the output voltage from the minimum to the maximum without the need to verify the resistance value of the potentiometer.

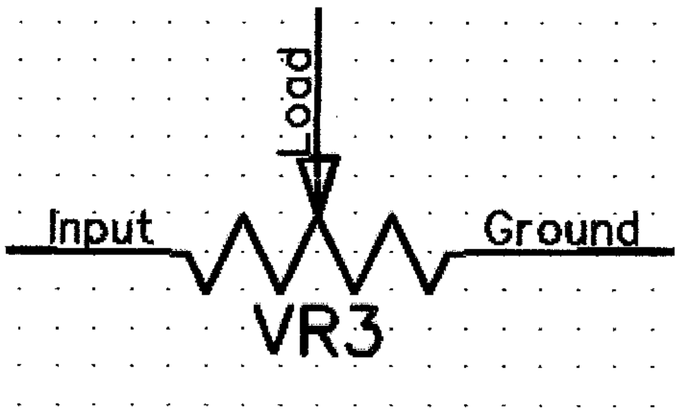


Figure 25: Example of potentiometer wiring

From this practice, we can actually use any value of potentiometer desired without being limited to any certain value of resistances. The output of this circuit will be between 0 – 5 Volts. Appropriate labeling of the potentiometer turning angle would give a better adjustment for output of 1 – 5 Volts.

For the current source, the circuit schematic is obtained from the forum of PLCSnet.com that discusses the appropriate current source circuit to generate the right amount of current for input simulation.

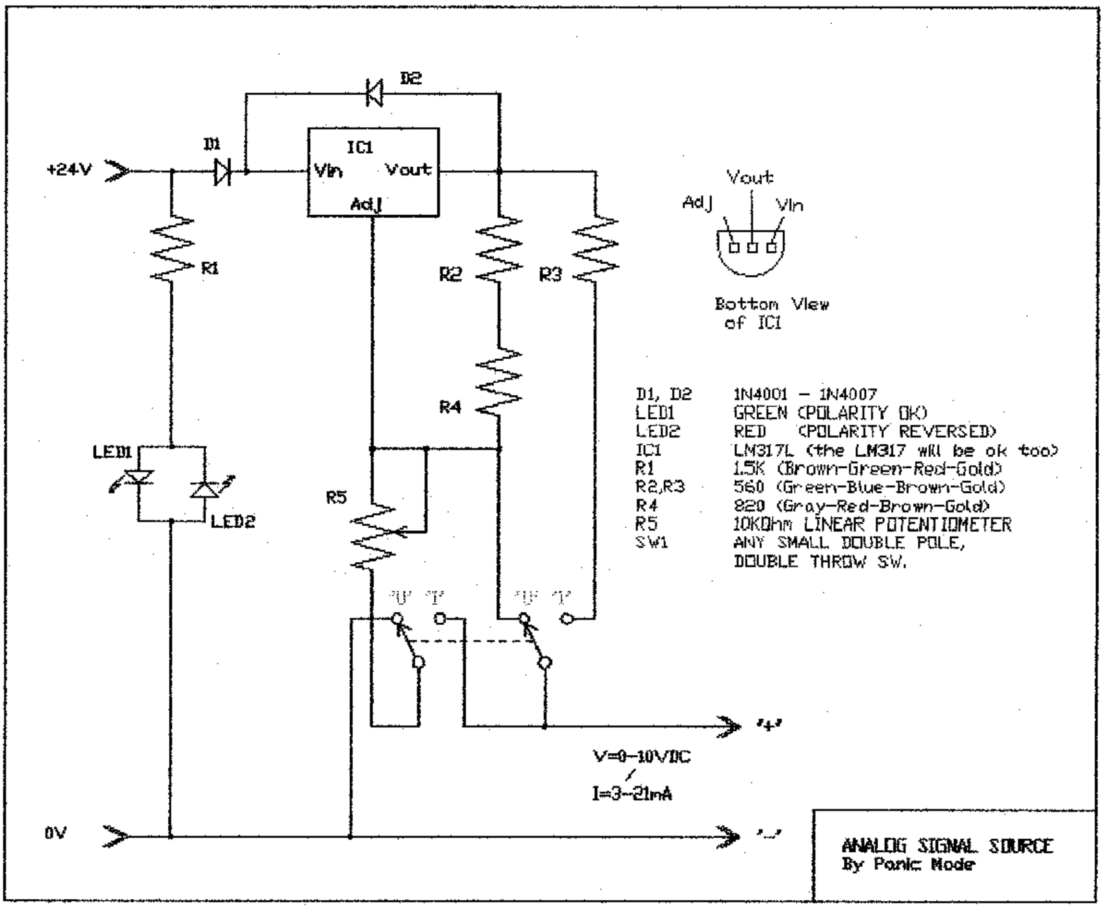


Figure 26: Current source circuit schematic

Looking at the schematic, we can see that the resultant circuit is capable of generating either 0 – 10 Volts or 3 – 21 mA. Moreover, it is capable of changing its polarity from the use of Double Pole Double Throw (DPDT) switch. LED1 is used to indicate forward polarity of the circuit while LED2 is used to indicate reverse polarity of the circuit. By the time of writing, this circuit only works in computer simulation and the actual circuit is still in progress because proper voltage supply to the circuit is needed to generate the desired output rating.

CHAPTER 4

RESULT AND ANALYSIS

4.1 PST Safety Data Analysis

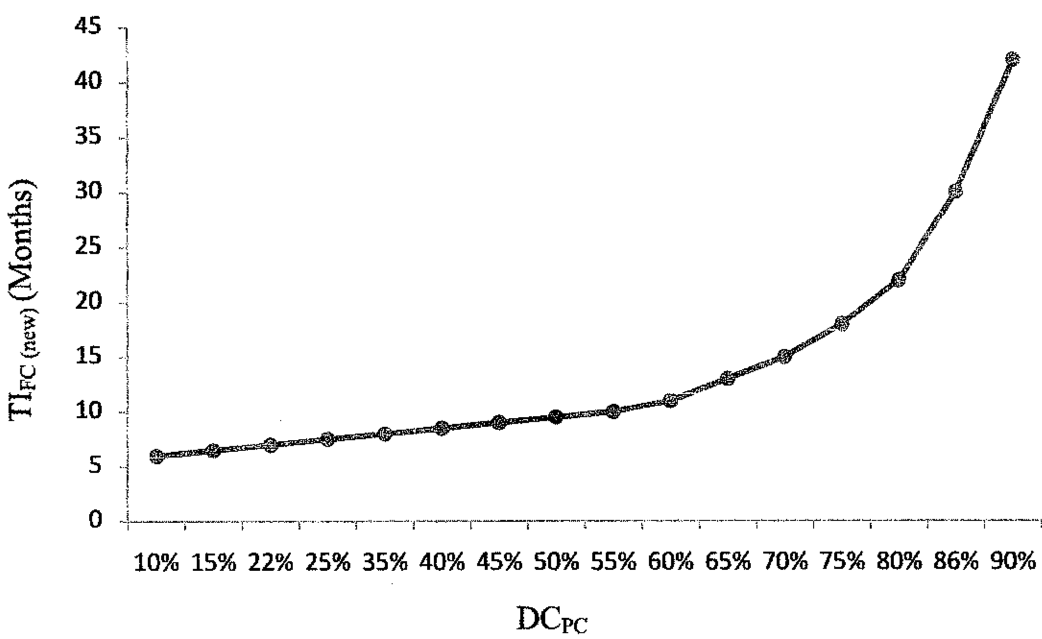


Figure 27: Effect of DC_{PC} on TI_{FC}

The graph shows that TI_{FC}^{NEW} increases exponentially with the diagnostic coverage and that no significant gains are realized until the DC_{PC} reaches 75%. We can standardize DC_{PC} for a PST system by taking data from exida's *Safety Equipment and Reliability Handbook (2nd edition)* [5] for a generic ball valve, actuator and generic SOV and applying it to calculate a system DC_{PC}, as shown in Table 3. Note that functional safety standard IEC 61508 states that all final elements must be tested.

Table 3: Diagnostic coverage compared

FAILURE RATE	PST USING POSITIONER				PST WITH SVM			
	Valve	Actuator	SOV	Total	Valve	Actuator	SOV	Total
λ_{DD}	*810*	*426*		*1236*	*810*	*426*	*2400*	*3636*
λ_{DU}	*540*	*34*	*2400*	*2974*	*540*	*34*		*574*
λ_{SD}	*1650*	*919*		*2569*	*1650*	*919*	*3600*	*6169*
λ_{DD}			*3600*	*3600*				
			$DC_{PC} = 29\%$				$DC_{PC} = 86\%$	

λ_{DD} *is the dangerous detected rate of the PST.*

λ_{DU} *is the dangerous undetected rate of the PST.*

λ_{SD} *is the safe detected rate of the PST.*

λ_{DD} *is the safe undetected rate of the PST.*

In Figure 5, diagnostic coverage of a positioned PST system is compared with that of the SVM system. It is evident that the gains are vast with SVM but only marginal with a positioner.

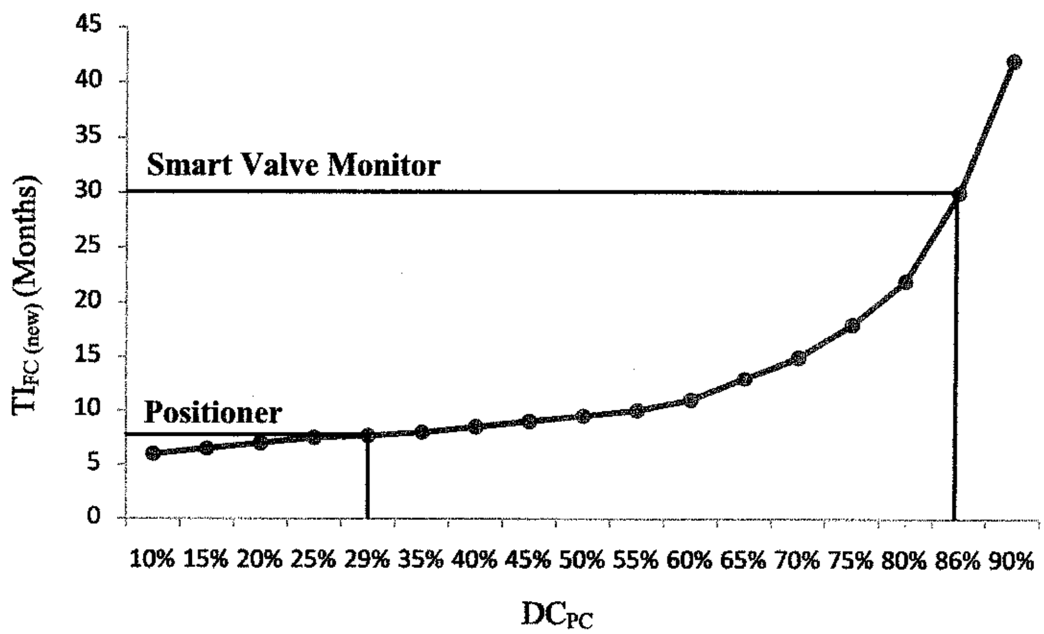


Figure 28: Effect of DC_{PC} on TI_{FC} – Positioner vs. SVM

The actual improvement to the closure interval can now be determined. Analysis shows that TI_{FC} for positioner type PST system is increased from 6 to 8 months. This reduces the number of full closures required over a 10-year period by only 25%, from 20 to 15, eliminating only 5 full closures.

With the SVM system, the full closure period is extended from 6 to 31 months; more than a 5-fold increases. Only 4 full closures are required over a 10-year period. This gives the operator very significant savings in plant downtime.

4.2 PLC Plant Example

4.2.1 Plant Simulation Introduction

A P&ID together with its Cause & Effect Matrix is obtained for the simulation example of the ABB CoDeSys PLC software. The purpose of using a real-world example of the P&ID instead of a mock up plant is to take into account all the variables involved and the proper connections of all the tanks and pipes. This is also to ensure that the design programmed is applicable and can be implemented for use with all actual plant operation [6].

The overall operation diagram of the PST and FST is as depicted below.

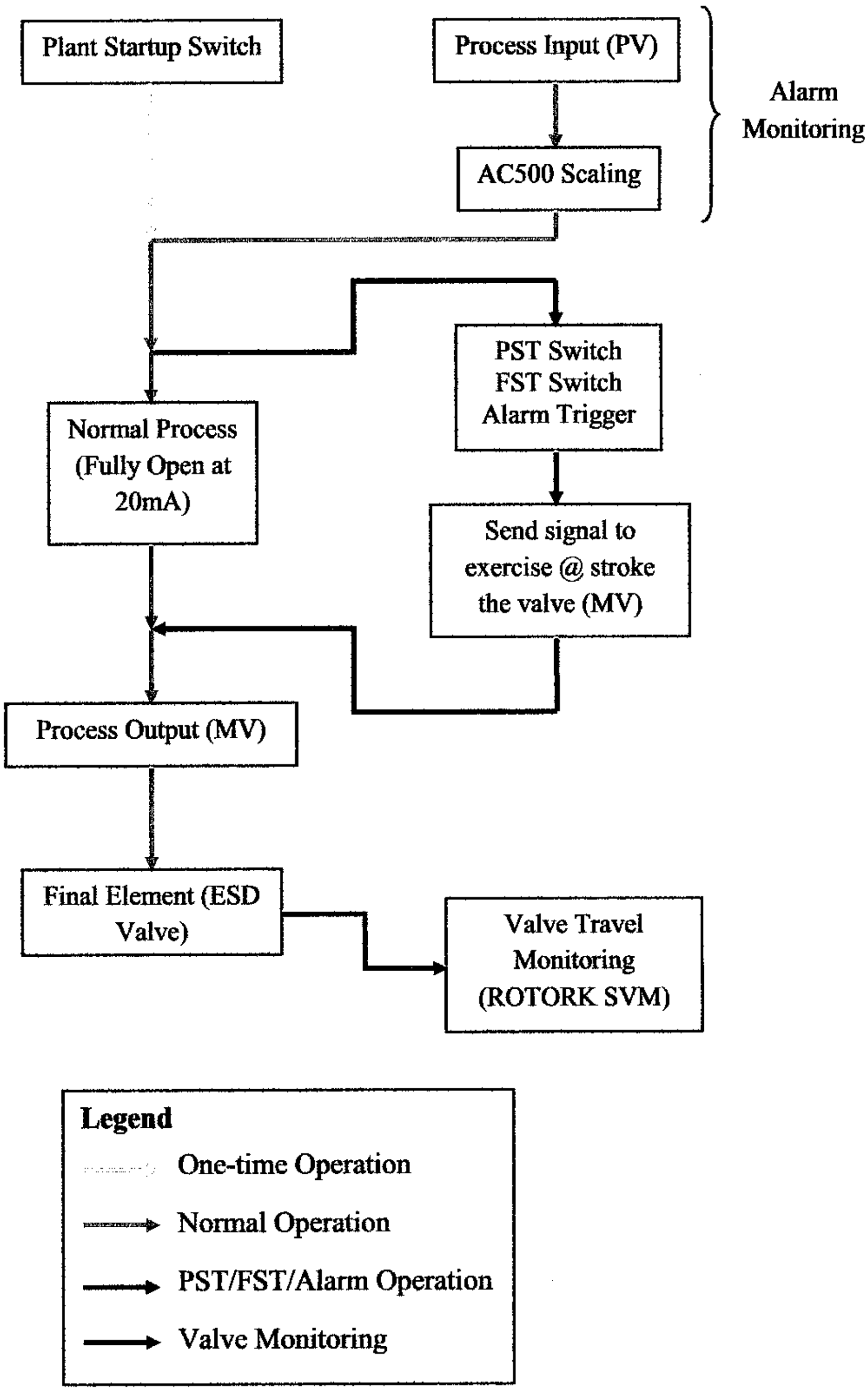
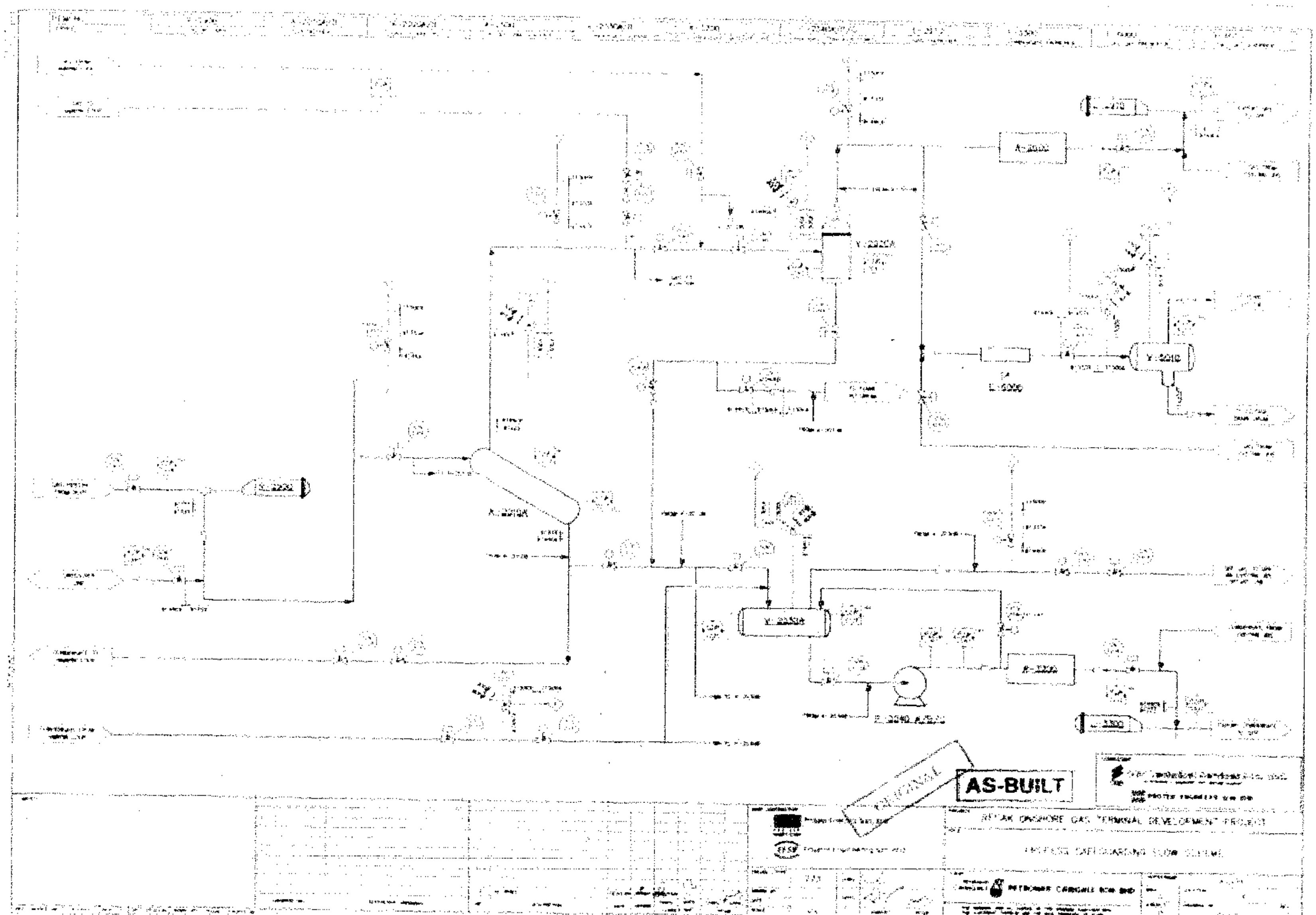
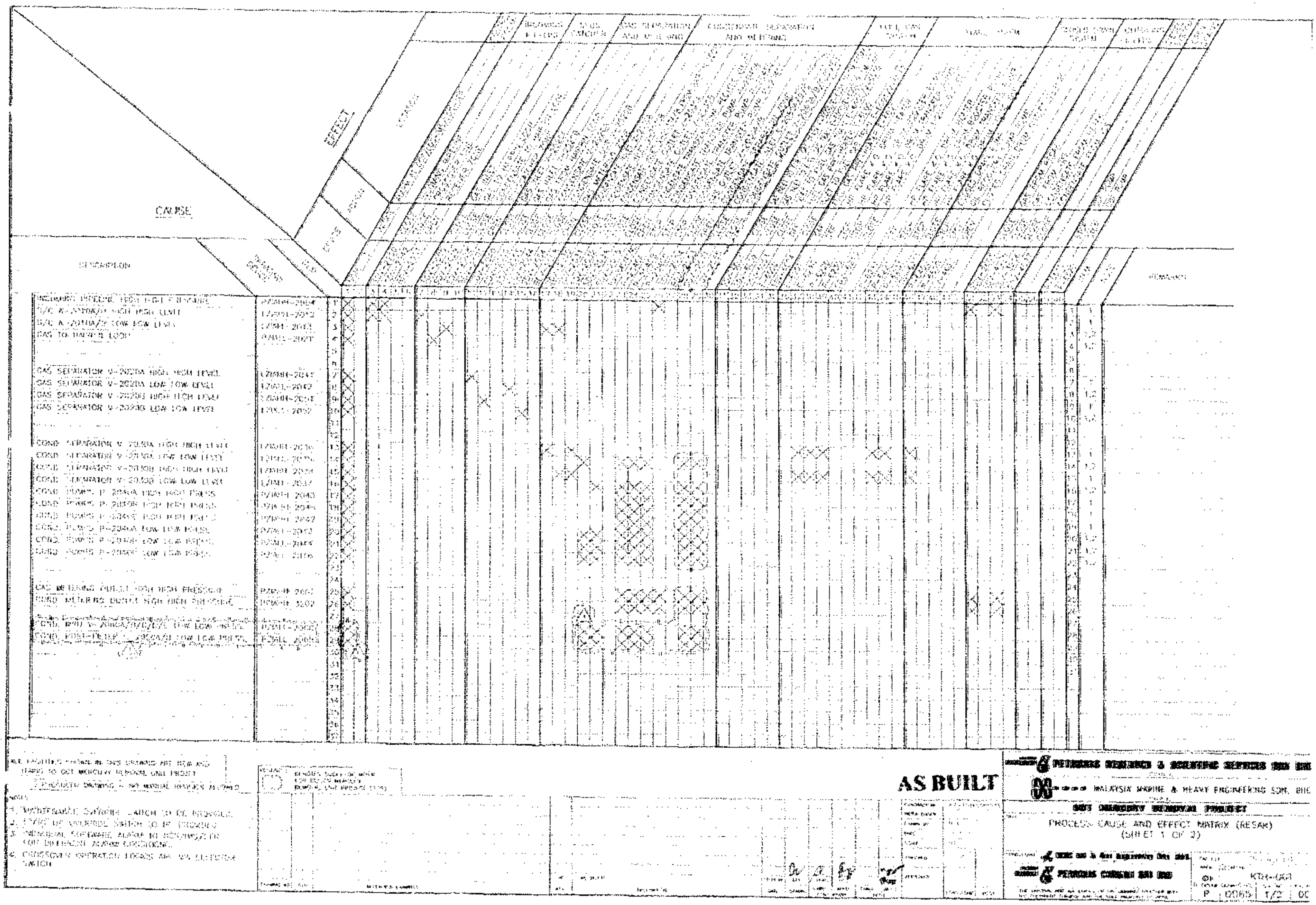


Figure 29: PST/FST Flow Diagram

4.2.2 Plant Diagram & Description

Referring to the above diagram, we can relate the process to the P&ID together with its Cause & Effect (C&E) Matrix. The next two pages display the P&ID and the C&E for reference. The full document of the plant can be found in the Appendix.


AS-BUILT
ORIGINAL


CAUSE
EFFECT
AS BUILT
MALAYSIA MARINE & HEAVY ENGINEERING SDN. BHD
PROCESS CAUSE AND EFFECT MATRIX (RESAK)
(SHEET 1 OF 2)

In this plant diagram, two cases were studied to simulate the PST/FST programming. The first one is "**Incoming Pipeline High-High Pressure**". The tag "**Incoming Pipeline**" refers to the incoming upstream/downstream inventory. The pressure of the incoming inventory need to be monitored extensively because very high pressure and flow rate is maintained throughout the pipeline to make sure that it goes to the processing plant in a timely manner. Listed below is the case description in detail together with its causing initiating device and the affected device, namely the ESD valve.

Case 1 Description:
i. Incoming Pipeline High-High Pressure
Initiating Device:
i. PZIAHH-2904 (Pressure Transmitter)
Affected Valve/Equipment / Action:
i. SDV-2900 (ESD) / Close ii. SDV-2942 (ESD) / Close iii. SDV-2004 (ESD) / Close iv. SDV-2605 (ESD) / Close v. SDV-3205 (ESD) / Close

In normal operation, the pressure of the incoming pipeline is monitored so that it does not exceed certain value. When the transmitter does read above the certain level @ high-high level, it sends a signal to the alarm switch for all five of the ESD valves. When the valves detect the signal, it abruptly closes to prevent further overpressure of the pipeline to spread to other equipments, causing damages and process stray.

The second case is the "**Cond. Separator V-2030A High-High Level**". In this case, the separator vessel for the process records high-high alarm, which means that the overpressure of the vessel might cause it to burst from pressure. To stop this from happening, the corresponding pumps that supply to the vessel are stopped, the heat exchanger is turned off and the ESD valve connected is closed.

Case 2 Description:
i. Cond. Separator V-2030A High-High Level
Initiating Device:
i. LZIAHH-2306 (Level Transmitter)
Affected Valve/Equipment / Action:
i. SDV-2030 (ESD) / Close ii. SDV-2032 (ESD) / Close iii. E-6210 (Heat Exchanger) / Off iv. P-6220 (Pump) / Stop v. P-6230 (Pump) / Stop vi. P-6221 (Pump) / Stop vii. P-6231 (Pump) / Stop viii. P-6400 (Pump) / Stop

4.2.3 PLC Program & Description

For each case, the same program applies to both of them, whereas only the tags of the corresponding equipment need to be altered to each case. The following diagrams (Figure 30 - 32) are programmed using two programming languages, which are Ladder Diagram (LD) and Functional Block Diagram (FBD). Among the reason that these two languages were used are:

- Simple to understand
- Based on simplicity to achieve the purpose e.g. signal *conditioning to use CFC*

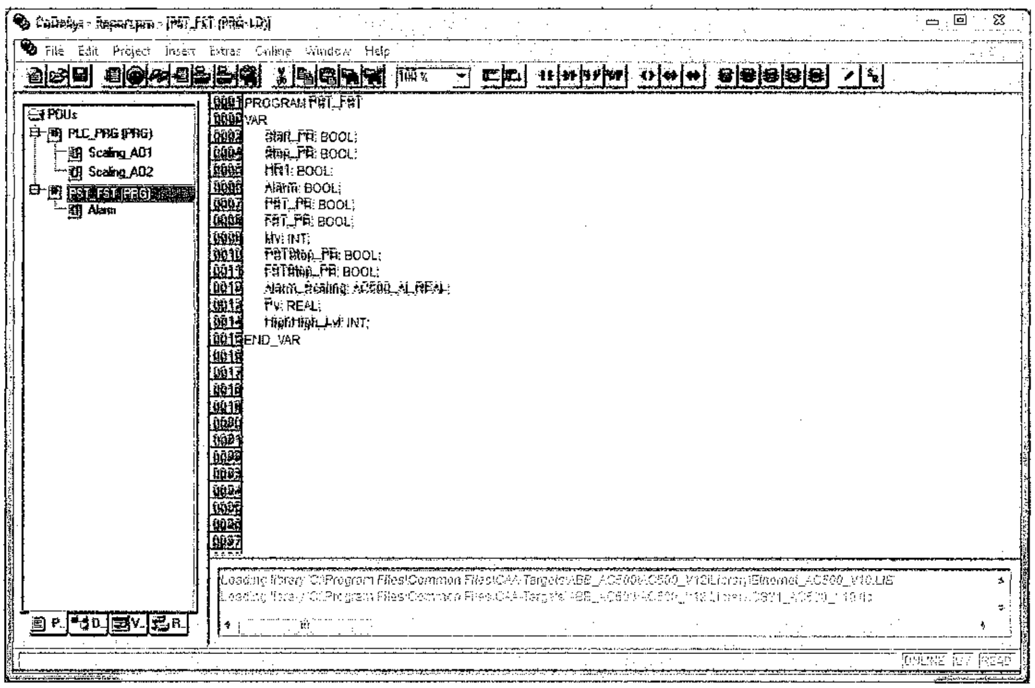


Figure 30: Variable declarations

Before starting on the program, all the necessary variables need to be declared to be used in the program. The declaration of the variable is important to ensure that each and every process data is represented in its appropriate form. Among the variable type used are:

i. **BOOL** – Represented by the number 0 and 1, or TRUE and FALSE
ii. **INT** – Ranges from negative infinity to positive infinity, but only round number (e.g. -1222, 1222 but not 0.23, 123.44)

iii. **REAL** – Includes all number from negative infinity to positive infinity

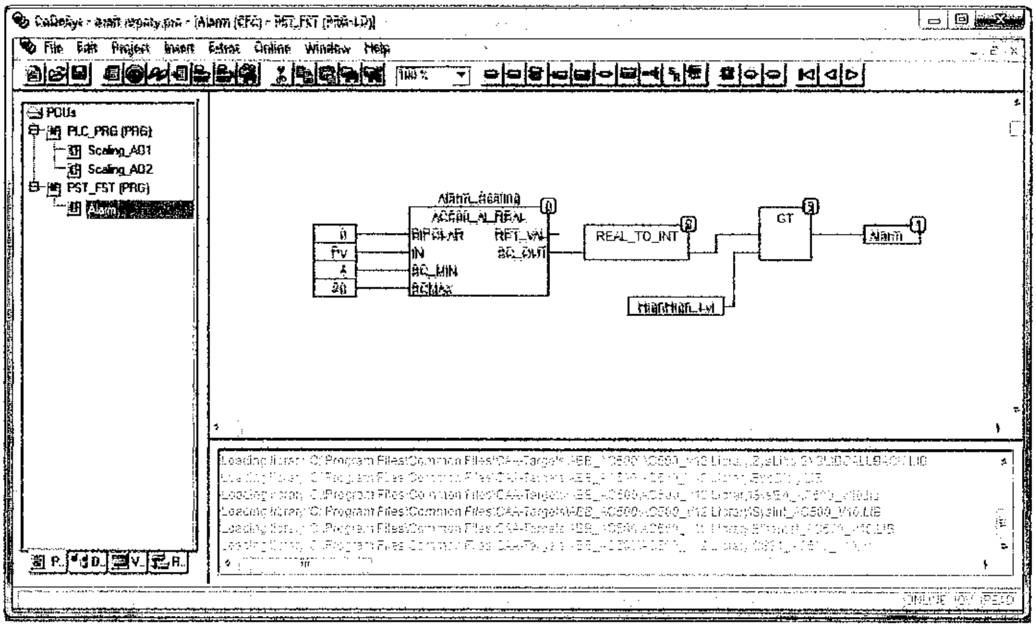


Figure 31: Alarm/Trip Signal block

In normal operation, the pressure of the incoming pipeline is monitored continuously. The process is as explained below:

i. The output from the pressure transmitter (**PV**) is fed into the scaling block to scale the value.

ii. The zero and the span of the **PV** are determined by the value specified at **SC_MIN** for the minimum value, and **SCMAX** for the maximum value which is 4 – 20.

iii. The **BIPOLAR** specifies whether the data originates from the negative range (value **0**) of from the positive range (value **1**).

iv. Once the data is processed by the block, the scaled value is then converted to **INT** type through the **REAL_TO_INT** block.

v. After that, the data is compared with the pre-specified value of the **HighHigh_Lvl** alarm value. If the value from the process is greater than the alarm, the **GT** block outputs **BOOL 1**. If not, it will output **BOOL 0**.

vi. The value is then sent to the alarm switch at the ladder diagram, either turning the alarm ON or leaving it at OFF position.

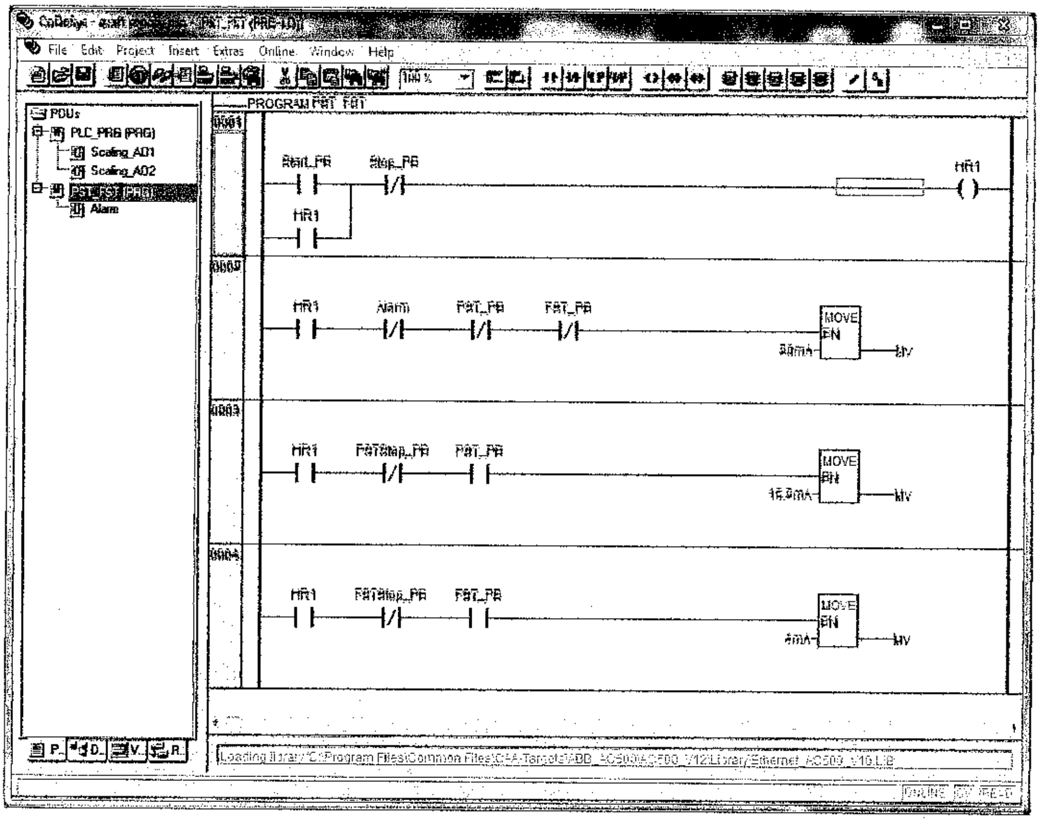


Figure 32: LD for the PST/FST/Alarm (Trip Signal) Sequence

To explain this figure, it is best to proceed by rung:

i. Rung 1

- This rung contains the process initialization of the whole program, thus includes the **Start** and **Stop** pushbutton. It also includes the holding relay 1 (**HR1**), an internal function in the PLC to keep the input at current state.

ii. Rung 2

- After the program is initialized, this rung turns on and run. This represents the normal operation of the whole process. In this rung contains the **Alarm/Trip Signal switch**, **PST switch**, and **FST switch**. If any of the switches is triggered, this rung turns off and it moves on to the next rung.

iii. Rung 3

- This rung contains the PST sequence. When the **PST_PB** is switched on, the rung turns on and then the **MOVE** block is energized. When the block is energized, it moves the value of 15.2 mA of signal to the MV variable, meaning the final element (ESD valve). The value 15.2 mA represents 30% of valve travel as the valve is air-to-open. Once the valve has reached 30% stroking, the **PSTStop_PB** is turned on to end the procedure and return the valve to its original position (100% opening).

iv. Rung 4

- This rung contains the FST sequence. It is very much the same with the PST sequence, but with the difference in the signal sent to the MV that is 4 mA (0% opening / full stroking).

Once the program has done its cycle, the value **MV** is passed on to the final element of each case, namely the ESD valve, the heat exchanger and the pumps. This will initiate the shutdown process of the corresponding case.

4.3 Proportional Control Gain

4.3.1 What is Proportional Band?

When we talk about the proportional action of a controller, we generally refer to the proportional gain. The action means that the controller moves in proportion to the error between setpoint (SP) and process output (PV). In further optimizing the process more towards the effective way, the introduction of using the proportional band controller instead of the gain (K_p) controller gives the process a more accurate way of staying inside the desired range as specified by the equation:

$$PB = \frac{100\%}{K_p} \qquad \textbf{Equation 6}$$

The bigger the gain specified, the smaller the proportional band. Speaking in layman terms, proportional band is the range of operation for a certain process value to be accepted as appropriate for its condition. If the value were to exceed above or go lower than its specified value, the corresponding output value (in this case, the controlled value is PV and the output value is MV) MV will go to either 100% or 0% of its value, depending on the process relationship between the PV and MV.

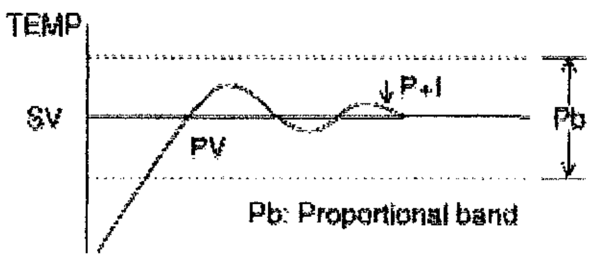


Figure 33: Proportional band

Using the CoDeSys software, the function block of the proportional band can be declared and defined in terms of Continuous Function Chart (CFC) language since the function of the proportional band is not provided in the software.

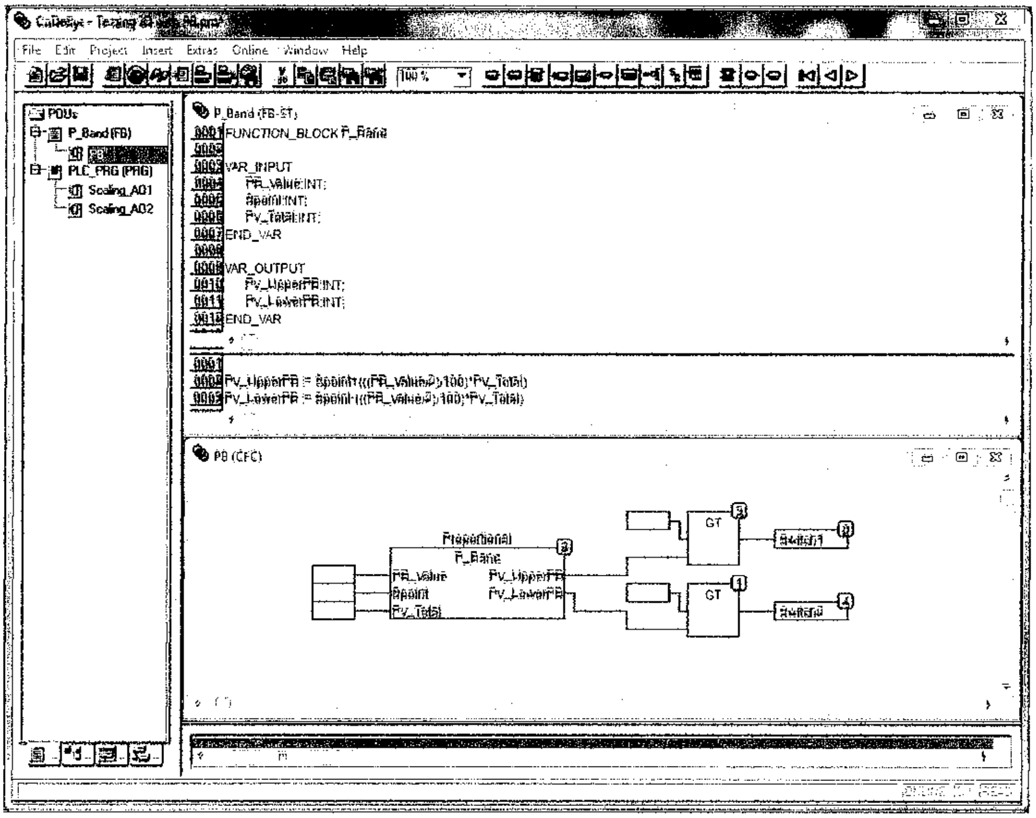


Figure 34: Declaration of Proportional Band Function Block

At first, the function block is declared in the form of structured text (ST) language. Only when it is declared can the function block be called later in the program. Once the block is declared, the corresponding variable is treated as the block input:

a. **PB_Value**: The percentage value of the proportional band that will be used.
b. **Spoint**: The setpoint value of the case study.
c. **PV_Total**: Total range of the process variable (PV).

After all the variable had been specified, the following equation is used to obtain the **PV_UpperPB** and **PV_LowerPB**:

$$PV\_UpperPB := Spoint + (((PB\_Value/2)/100) * PV\_Total) \quad \textbf{Equation 7}$$

$$PV\_LowerPB := Spoint - (((PB\_Value/2)/100) * PV\_Total) \quad \textbf{Equation 8}$$

From the equation, two values are obtained namely the **PV_UpperPB** and **PV_LowerPB.** These two values represent the upper range of the proportional band, starting from the setpoint value and the lower range of the proportional band, also starting from the setpoint value.

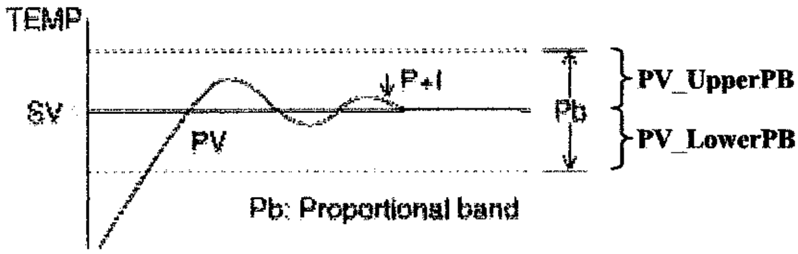


Figure 35: Proportional band with specified variable

After the value is obtained, it is compared with the current value of PV using the Greater Than (GT) block. If any of the blocks is energized, either **Switch1** or **Switch2** will be energized, leading to the next diagram.

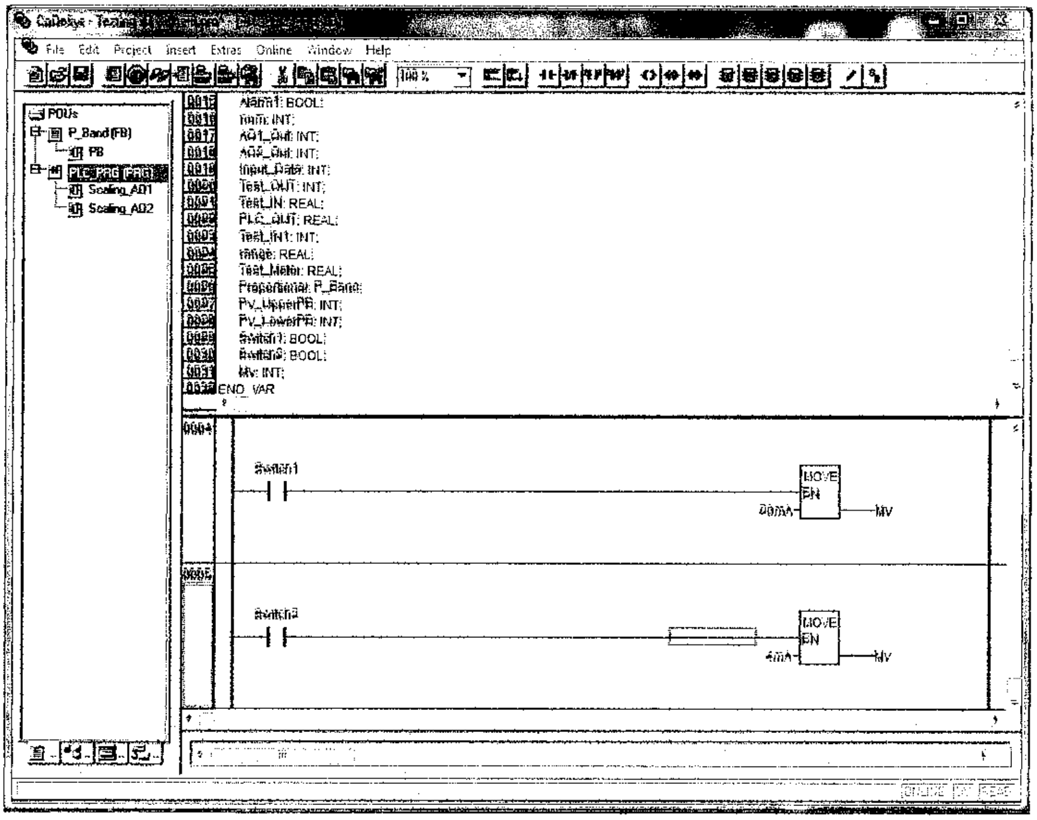


Figure 36: Proportional band LD Switch

If either **Switch1** or **Switch2** is activated previously, it will energize the **MOVE** block and move the value of either 20 mA for the upper band, or 4 mA for the lower band. When the value is transferred, it will override the normal relationship between the PV and MV, thus forcing the MV to become either fully open or fully closed.

4.3.2 Proportional Control Testing

Once all the programming has been done, the controller is tested with the following condition (PI Mode):

- Proportional Band = 20%
- Setpoint = 50%
- Initial PV = 50%
- Initial MV = 50%
- Integration Time, $T_i = 20$
- Derivation Time, $T_d = 0$

The following graphs are obtained:

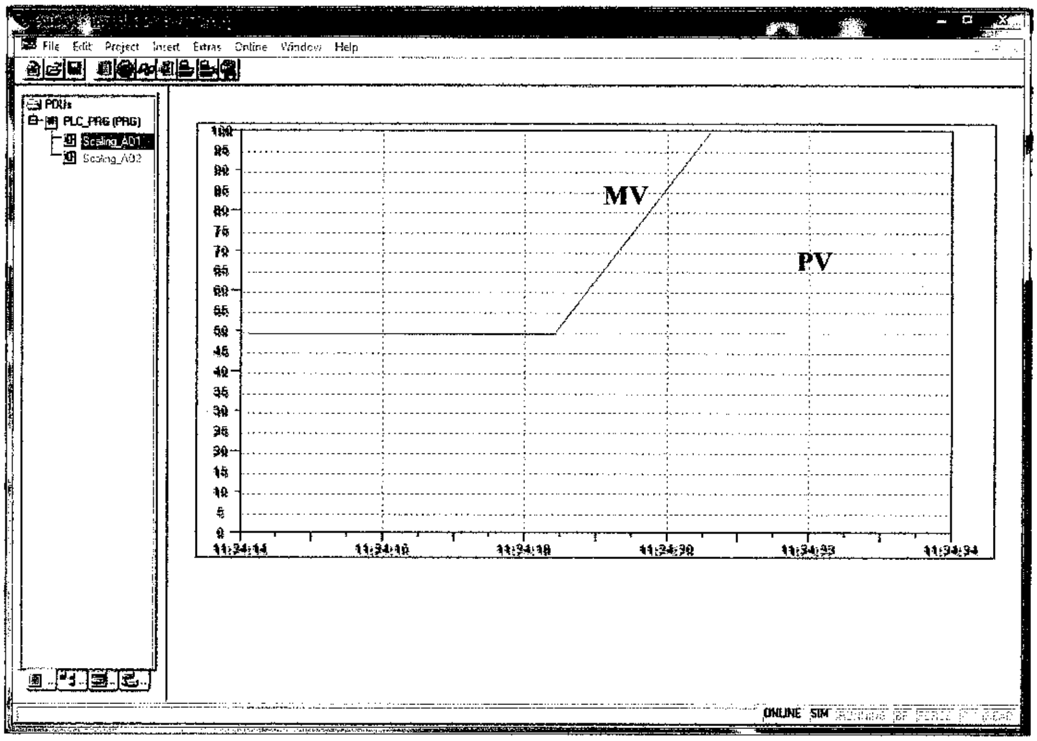


Figure 37: Testing Upper Proportional Band (PV = 62%)

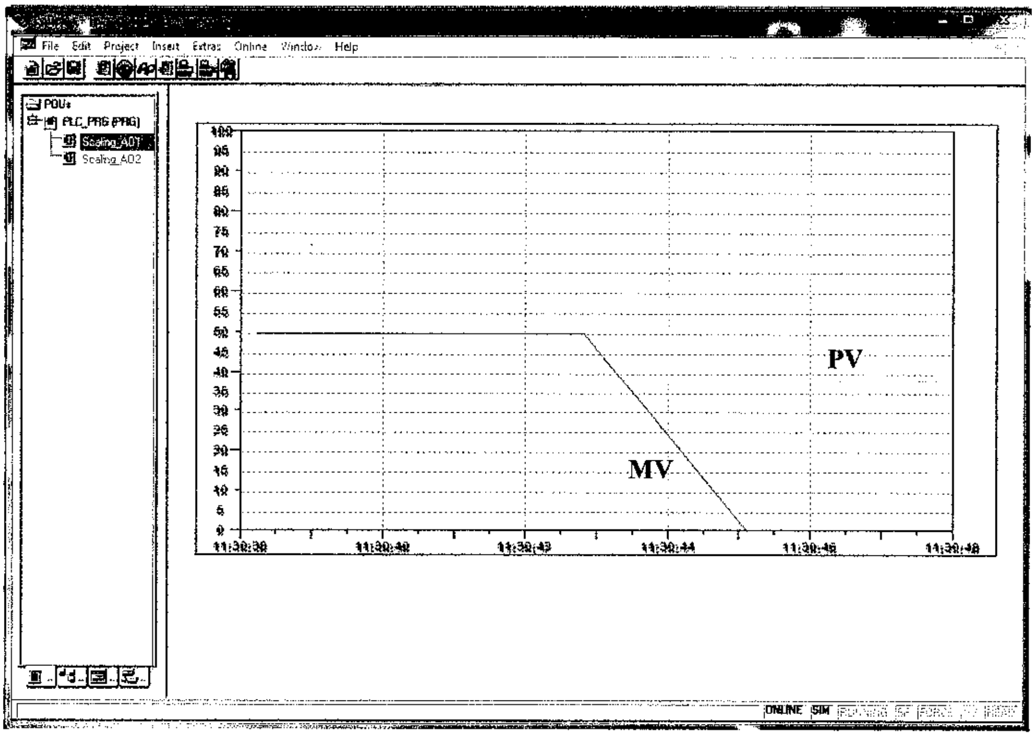


Figure 38: Testing Lower Proportional Band (PV = 38%)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Below is the summary of the project outcomes:

5.1.1 Reliability analysis of the Partial Stroke Testing procedure

- Using the data obtained from the research provided by the Exida's Safety Equipment Reliability Handbook (SERH) (2^{nd} edition), we can conclude that the PST procedure does improves the performance of the ESD valve significantly, thus elongating the period of between each plant turnaround. This will further reduce the cost of equipment servicing done, say in a time period of 5 to 10 years.

5.1.2 Implementation of newer PLC hardware

- Under AP. Dr. Nordin b. Saad e-science grant, the acquisition of the ABB PLC further drives the project to a deeper level of understanding on the technology involving the PLC. From here, the use of other programming language such as the CFC and the ST that is not used often is explored, thus enabling easier approach on the programming and making it time-saving for project debugging and upgrading.

5.1.3 Analysis of an actual plant P&ID related with ESD valve

- Using an actual P&ID obtained from PETRONAS personnel, namely the OGT Mercury Removal Project in Kerteh, the situation of a plant responding to a situation where the action of an ESD valve is important. The corresponding valves or equipments involved can be determined from the Cause & Effect matrix compiled together with the P&ID.

5.1.4 Function block programming using multiple programming language

- In optimizing the program for the PST procedure, multiple programming languages are used to display the flow of the procedure more clearly. The approach of multiple languages also demonstrates the ability of the new ABB PLC to handle cross language processing of a program efficiently. The definition of a new Proportional Band block using the CFC language helps to improve the process flow more accurately.

5.2 Recommendations

5.2.1 Interactions between vendor and UTP

- The actual interaction between the vendor ROTORK and UTP seems quite minimal, as proved by the valve package sent over by them. The valve seems to have been in its box since August 2010, and the presence of the vendor personnel is required as such the package needs to opened and setup according to the manufacturer specification.

5.2.2 More hardware setup provided

- In the case of the PLC hardware purchased from ABB, the hardware is a new technology in UTP, thus requires more assistance from the vendor ABB. The expertise of operating the PLC is scarce, thus actually slows down the progress of the project.

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2. **OREDA, "Offshore Reliability Data Handbook,"** 4th Edition. Prepared by SINTEF Industrial Management and published by DNV- Det Norske Veritas, Norway, 2002.

3. **"Guidelines for Safe Automation of Chemical Processes"**, Center for Chemical Process Safety, American Institute of Chemical Engineers, New York, NY 10017, 1993.

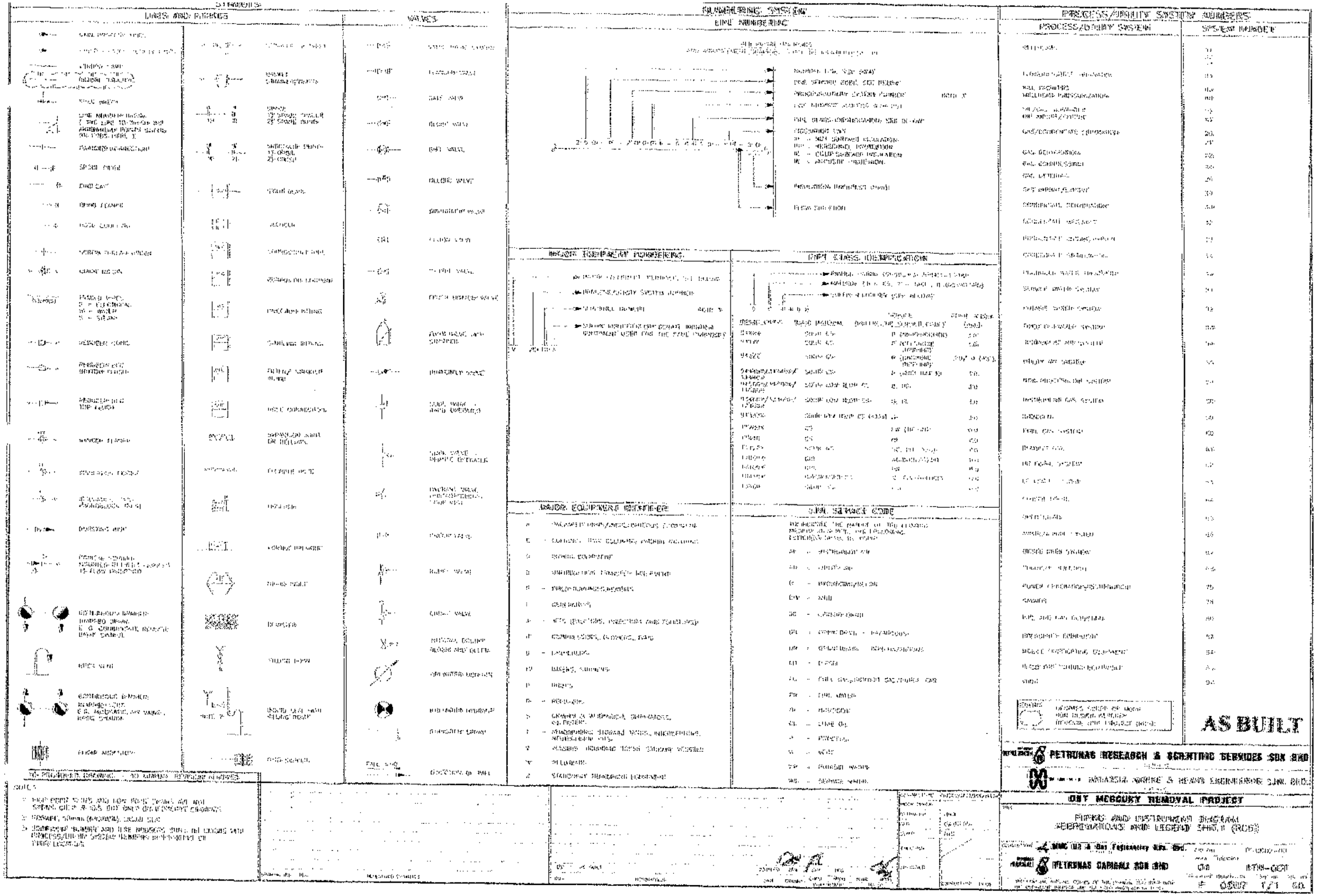
4. **Guidelines for Chemical Process Quantitative Risk Analysis**, Center for Chemical Process Safety, American Institute of Chemical Engineers, New York, New York, 1989.

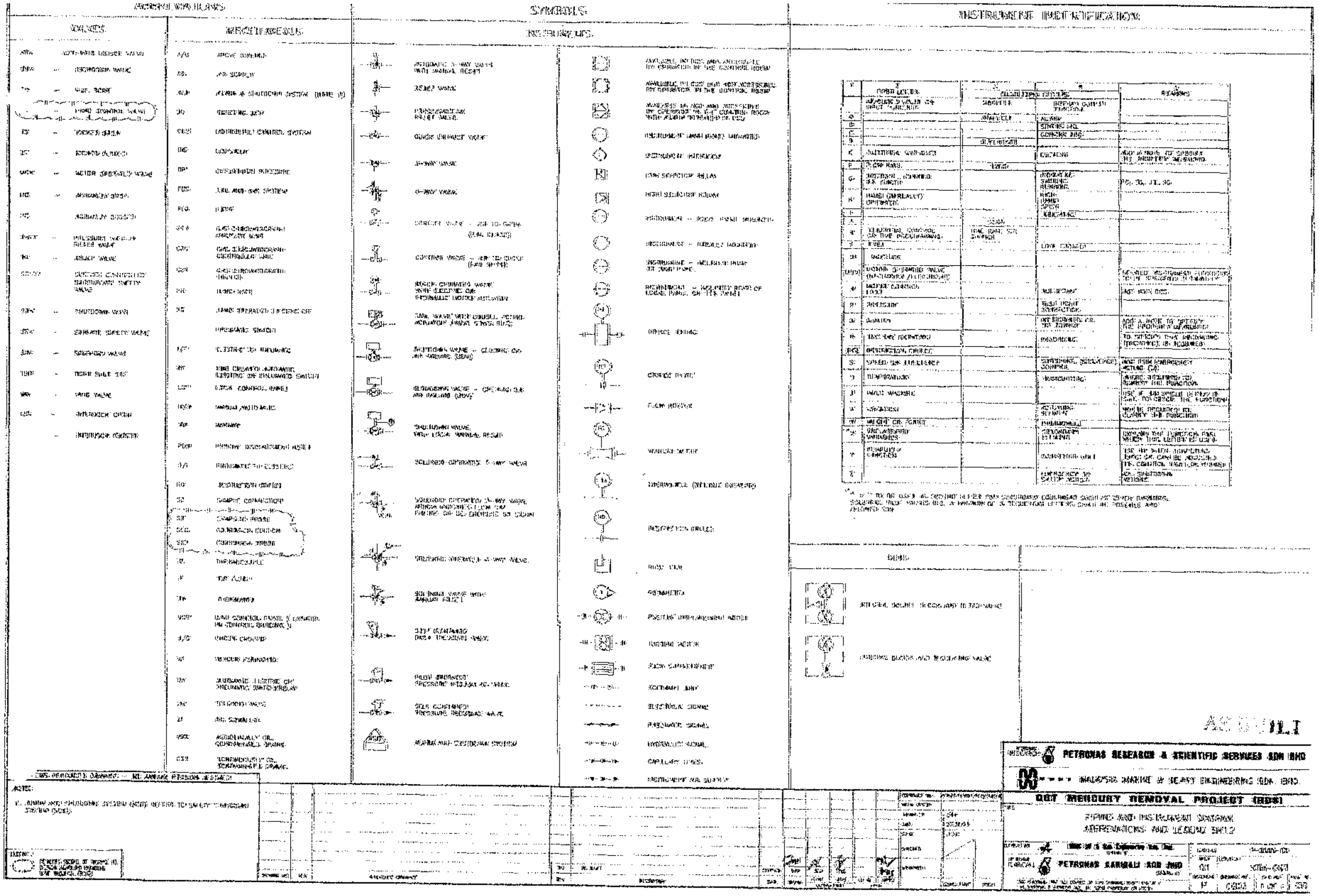
5. **exida's Safety Equipment Reliability Handbook**, 2nd Edition, Functional Safety - An IEC 61508 SIL 3 Compliant Development Process, http://www.exida.com, 2005.

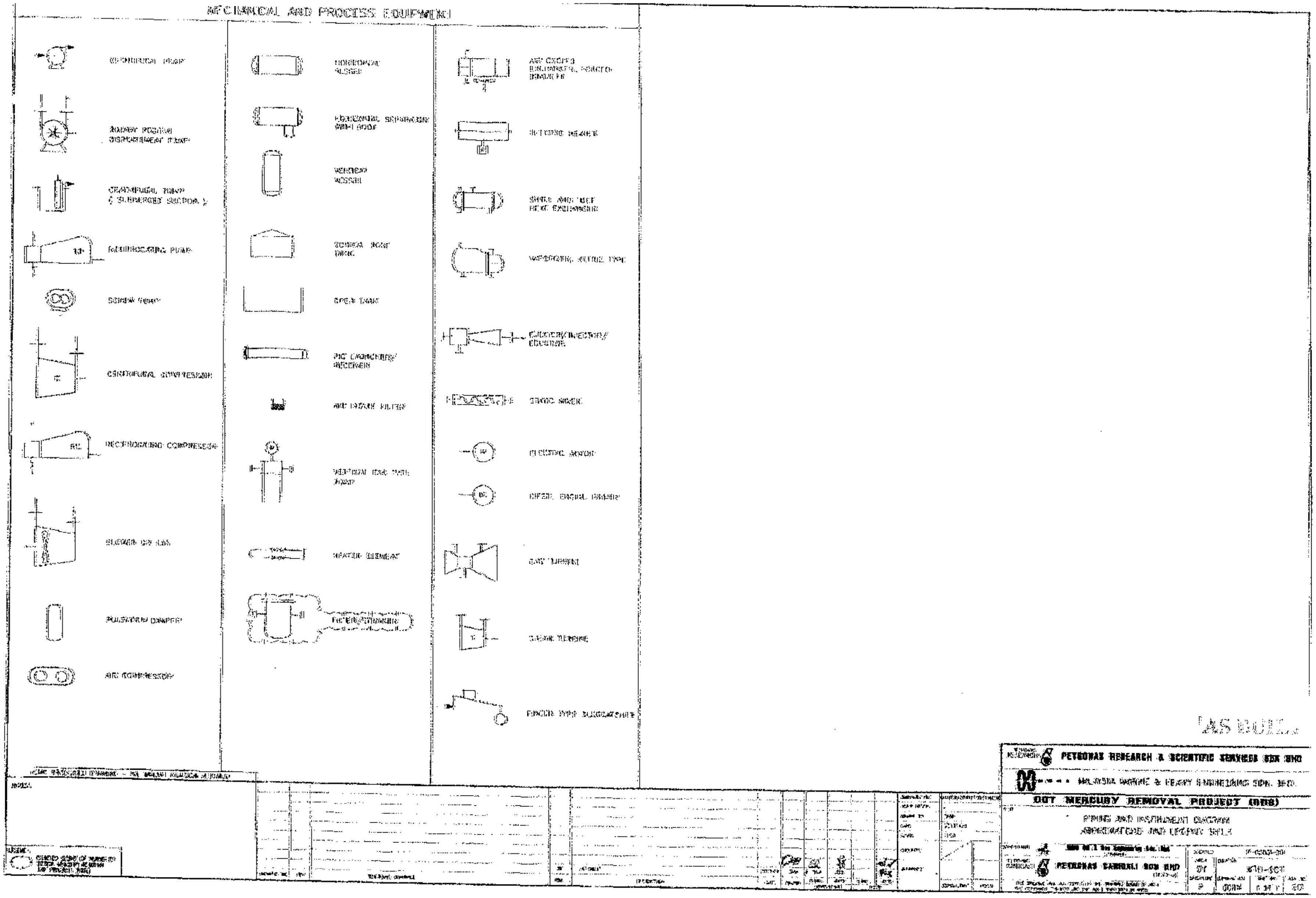
6. **OGT Mercury Removal Project**, PETRONAS Research & Scientific Services Sdn. Bhd., PETRONAS Carigali Sdn. Bhd., Kerteh, 2005.

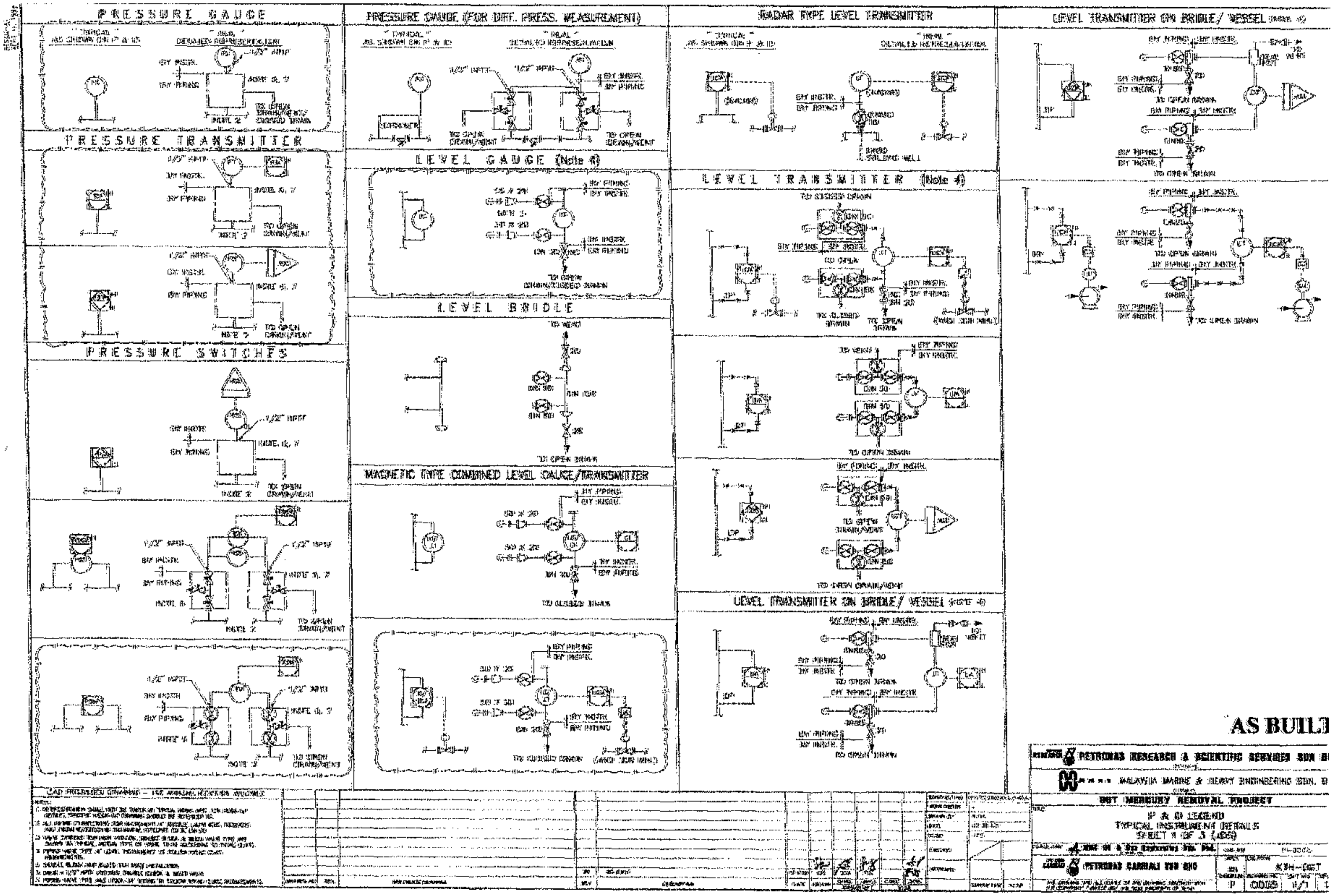
GANTT CHART

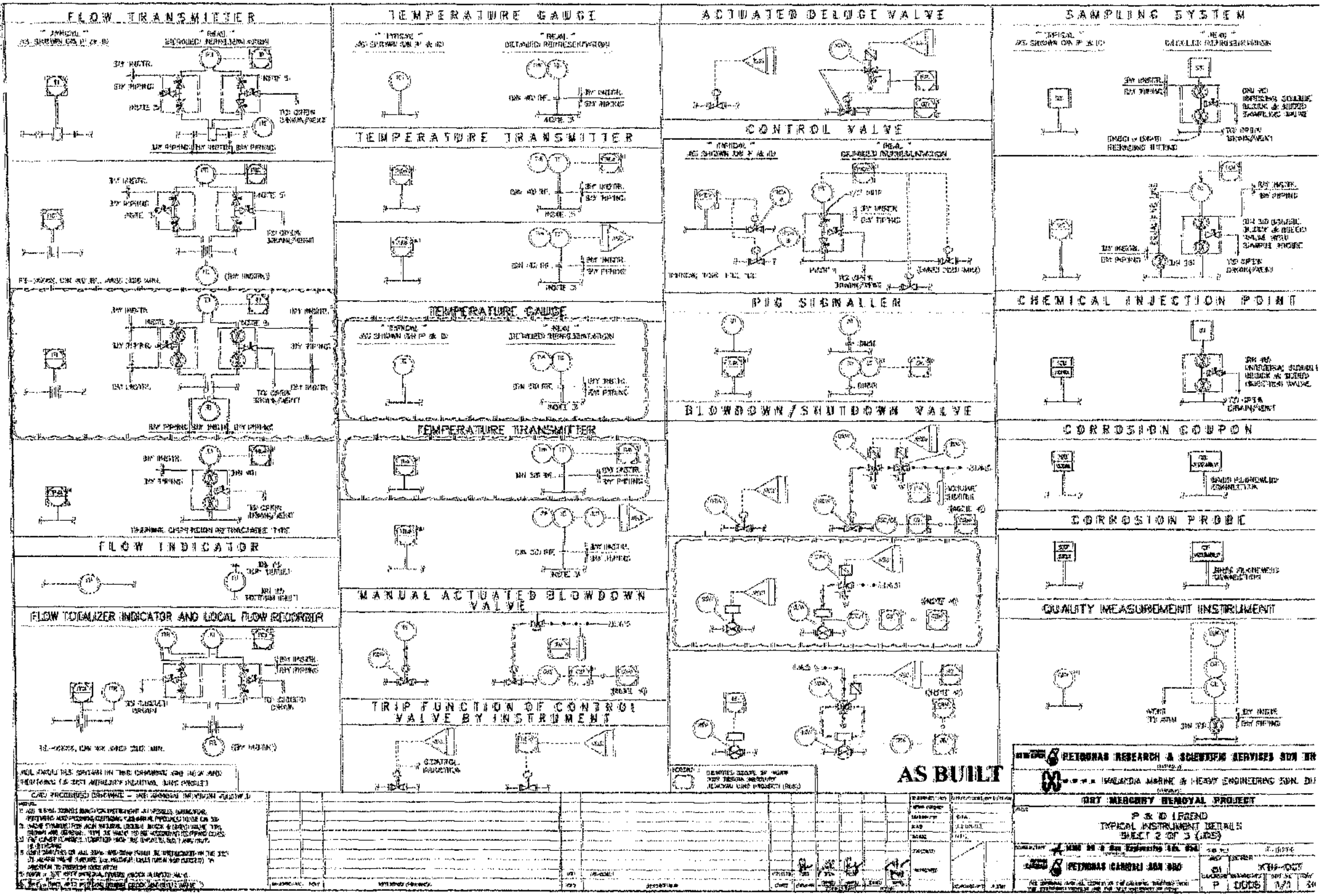
Date/Agenda	23/1	30/1	6/2	13/2	20/2	27/2	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	1/5
Project Consultation	x														
Testing Kit Building & Project Simulation		←					→								
Progress Report Submission								x							
Kit & Programming Revision									←			→			
Draft Report Submission													x		
Final Report Submission														x	
Technical Paper Presentation														x	
Viva															x

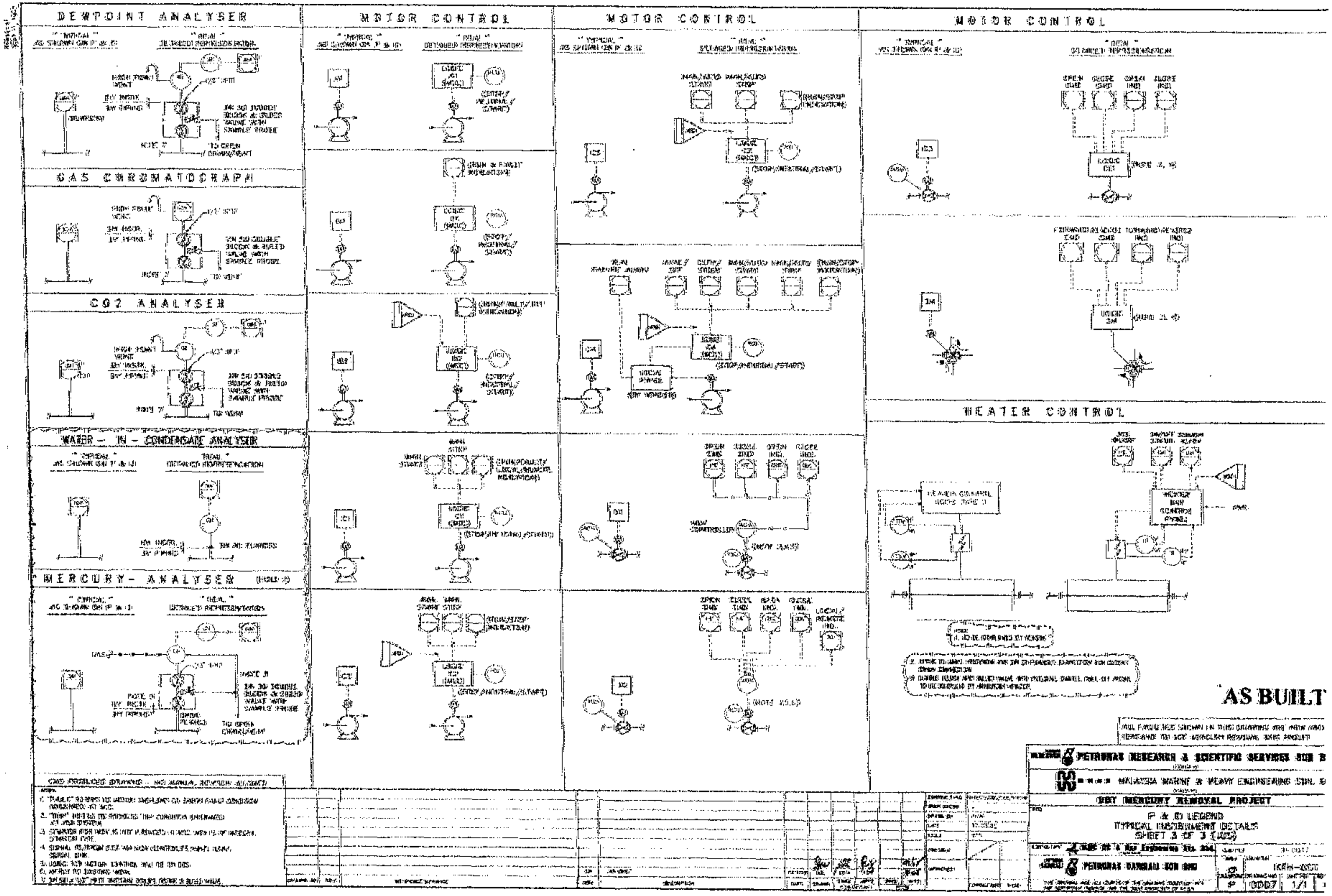

SYMBOLS
LINES AND FITTINGS
VALVES
NUMBERING SYSTEM
LINE NUMBERING
MAJOR EQUIPMENT NUMBERING
PIPE CLASS IDENTIFICATION
MAJOR EQUIPMENT IDENTIFIER
LINE SERVICE CODE
PROCESS/UTILITY SYSTEM NUMBERS
PROCESS/UTILITY SYSTEM
SYSTEM NUMBER
AS BUILT
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN BHD
DHT MERCURY REMOVAL PROJECT
PIPING AND INSTRUMENT DIAGRAM
ABBREVIATIONS AND LEGEND SHEET (RCGS)
PETRONAS CARIGALI SDN BHD

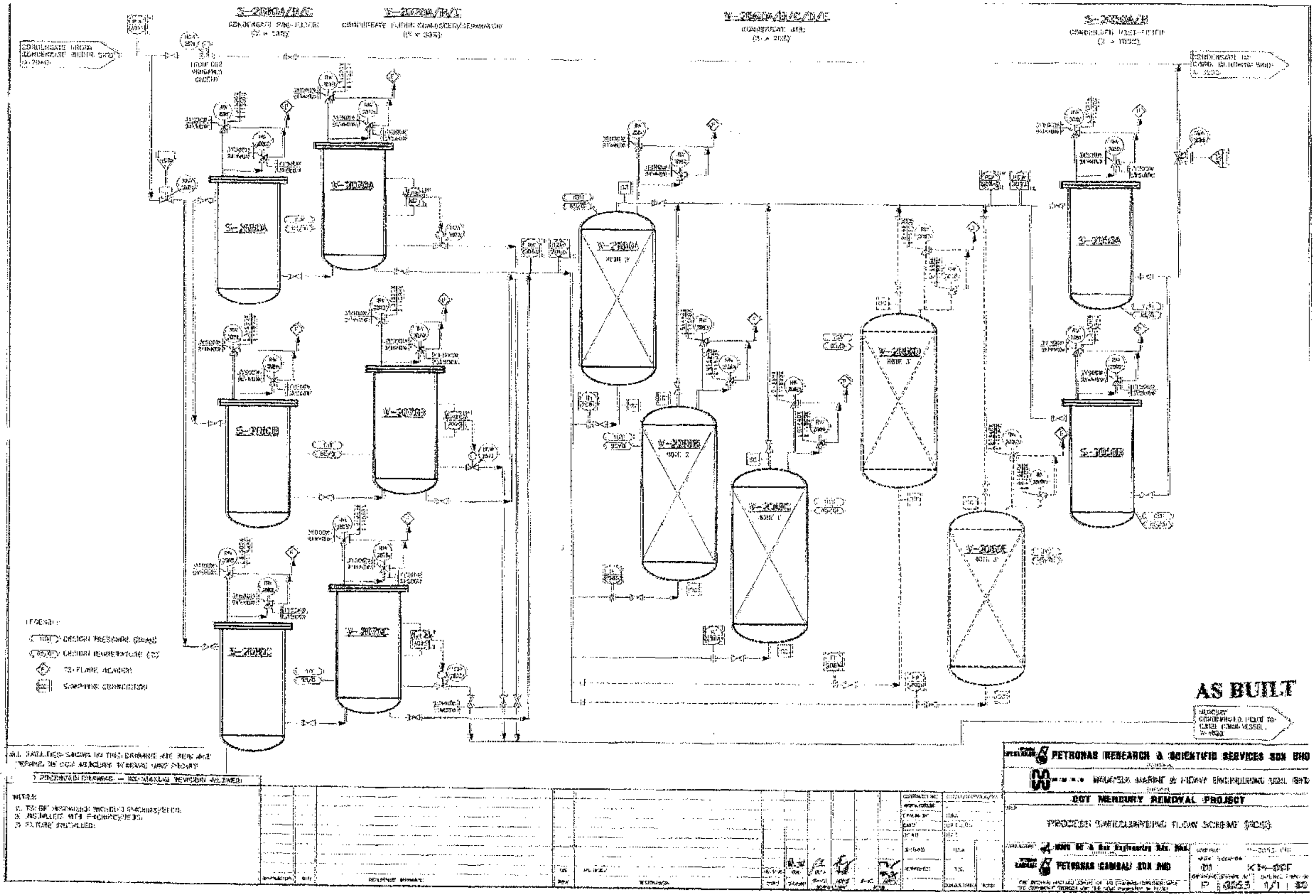

ABBREVIATIONS
VALVES
MISCELLANEOUS
SYMBOLS
INSTRUMENTS
INSTRUMENT IDENTIFICATION
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN BHD
MALAYSIA MARINE & HEAVY ENGINEERING SDN. BHD.
OGT MERCURY REMOVAL PROJECT (RDS)
PIPING AND INSTRUMENT DIAGRAM
ABBREVIATIONS AND LEGEND SHT.2
PETRONAS CARIGALI SDN BHD

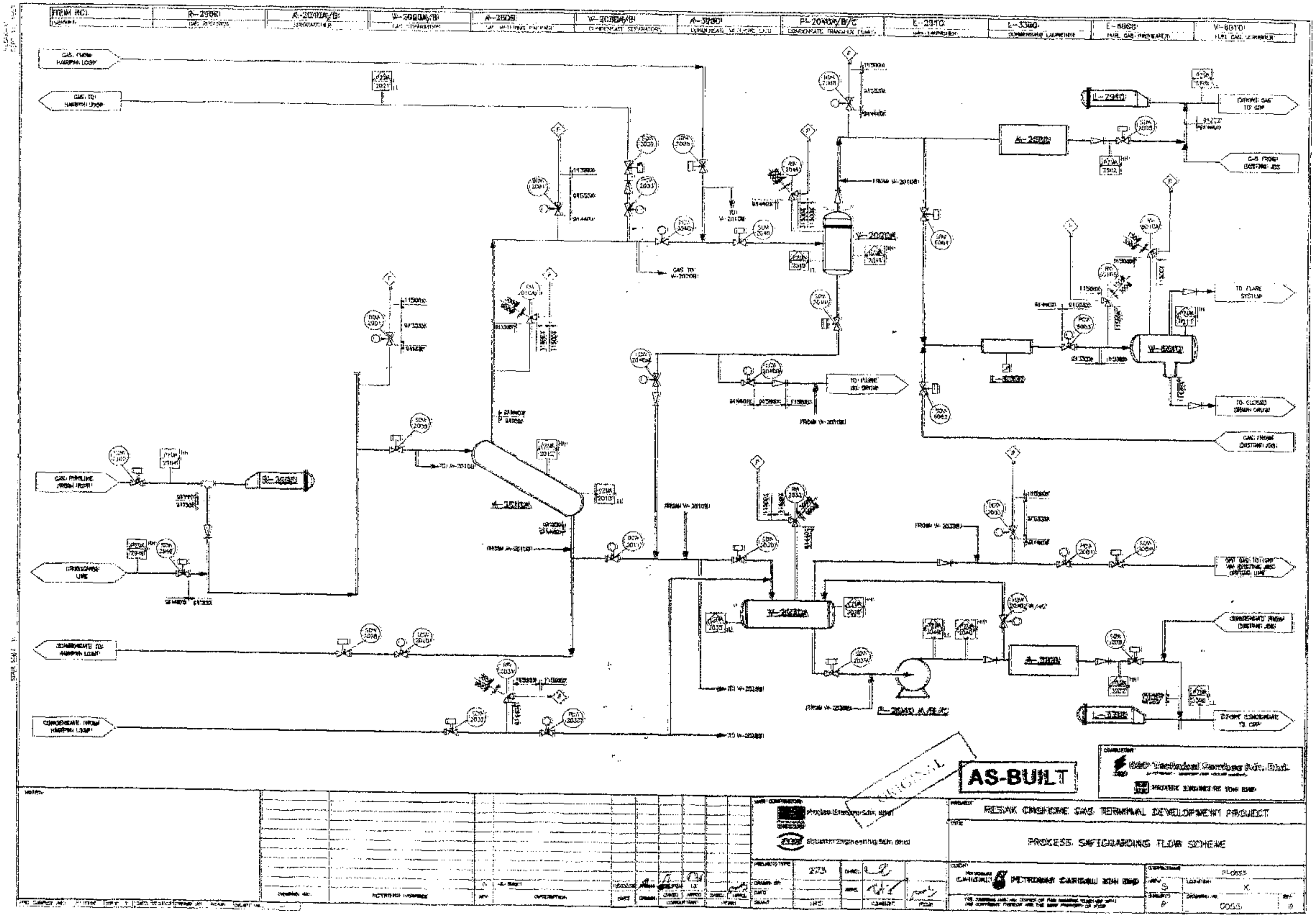

MECHANICAL AND PROCESS EQUIPMENT
SCREW PUMP
RECIPROCATING COMPRESSOR
AIR COMPRESSOR
OPEN TANK
ELECTRIC MOTOR
STEAM TURBINE
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN BHD
MALAYSIA MARINE & HEAVY ENGINEERING SDN. BHD.
OGT MERCURY REMOVAL PROJECT (MRS)
PIPING AND INSTRUMENT DIAGRAM
PETRONAS CARIGALI SDN BHD

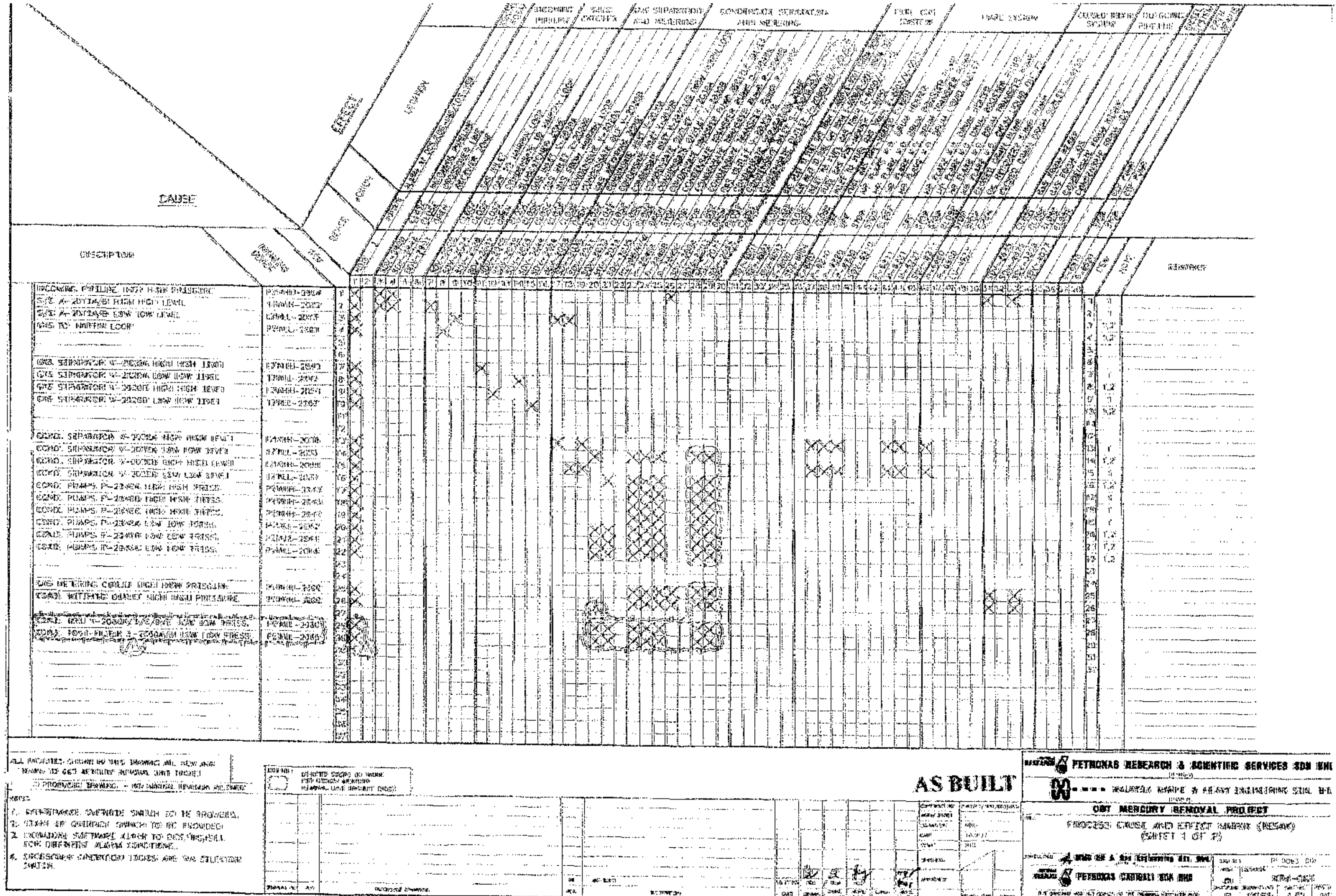

PRESSURE GAUGE
PRESSURE GAUGE (FOR DIFF. PRESS. MEASUREMENT)
RADAR TYPE LEVEL TRANSMITTER
LEVEL TRANSMITTER ON BRIDLE/ VESSEL
PRESSURE TRANSMITTER
LEVEL GAUGE (Note 4)
LEVEL TRANSMITTER (Note 4)
LEVEL BRIDLE
PRESSURE SWITCHES
MAGNETIC TYPE COMBINED LEVEL GAUGE/TRANSMITTER
AS BUIL
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN B
MALAYSIA MARINE & HEAVY ENGINEERING SDN. B
P & ID LEGEND
TYPICAL INSTRUMENT DETAILS

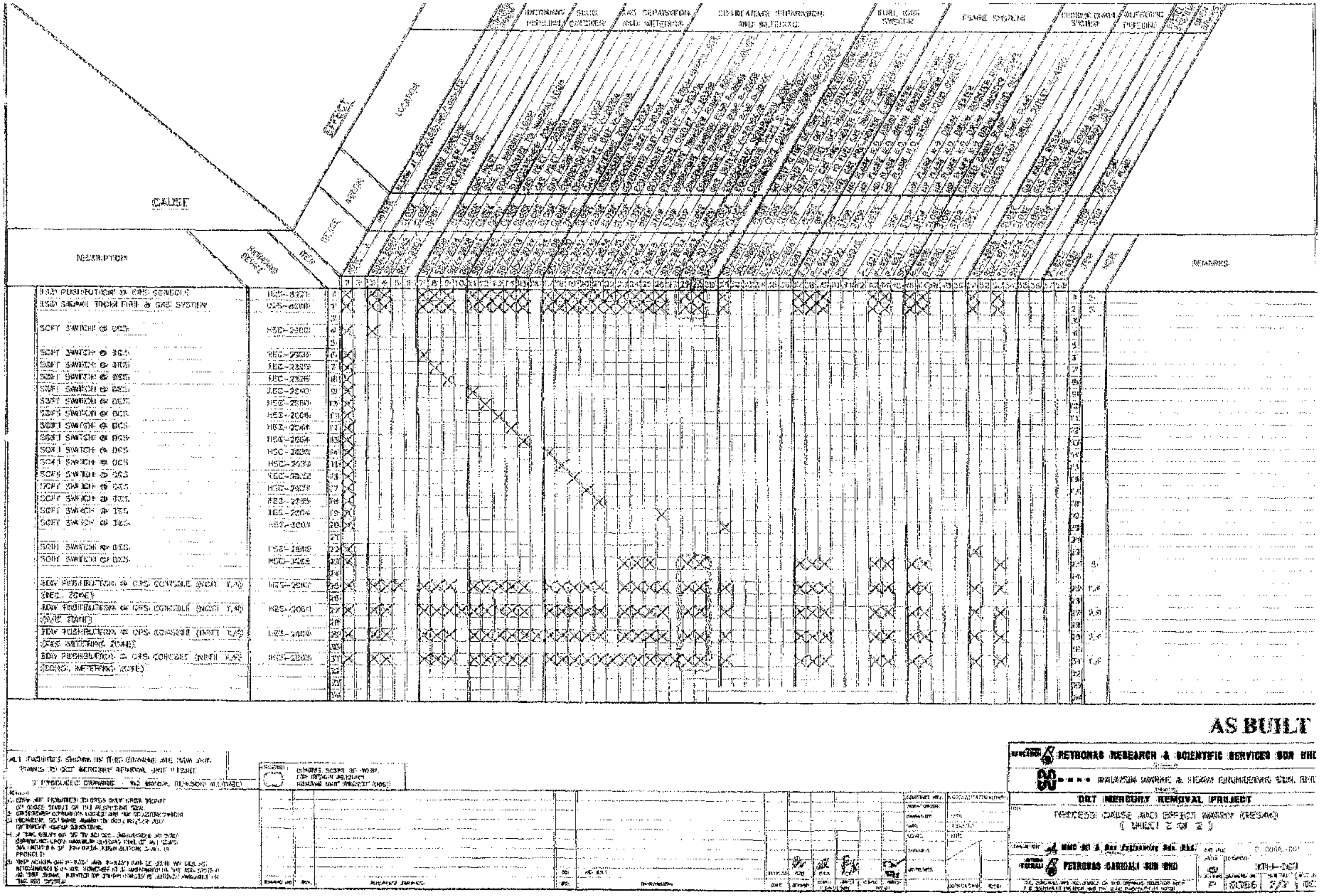

FLOW TRANSMITTER
TEMPERATURE GAUGE
ACTUATED DELUGE VALVE
SAMPLING SYSTEM
TEMPERATURE TRANSMITTER
CONTROL VALVE
CHEMICAL INJECTION POINT
PIG SIGNALLER
BLOWDOWN/SHUTDOWN VALVE
CORROSION COUPON
CORROSION PROBE
FLOW INDICATOR
MANUAL ACTUATED BLOWDOWN VALVE
QUALITY MEASUREMENT INSTRUMENT
FLOW TOTALIZER INDICATOR AND LOCAL FLOW RECORDER
TRIP FUNCTION OF CONTROL VALVE BY INSTRUMENT
AS BUILT
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN BHD
MALAYSIA MARINE & HEAVY ENGINEERING SDN. BHD
DRY MERCURY REMOVAL PROJECT
P & ID LEGEND
TYPICAL INSTRUMENT DETAILS
SHEET 2 OF 3 (JDS)


DEWPOINT ANALYSER
GAS CHROMATOGRAPH
CO2 ANALYSER
WATER - IN - CONDENSATE ANALYSER
MERCURY - ANALYSER
MOTOR CONTROL
MOTOR CONTROL
MOTOR CONTROL
HEATER CONTROL
AS BUILT
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN B
MALAYSIA MARINE & HEAVY ENGINEERING SDN. B
DRY MERCURY REMOVAL PROJECT
P & ID LEGEND
TYPICAL INSTRUMENT DETAILS
SHEET 3 OF 3
PETRONAS CARIGALI SDN BHD


AS BUILT
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN BHD
DOT MERCURY REMOVAL PROJECT
PETRONAS (CARIGALI) SDN BHD
LEGEND:
DESIGN PRESSURE
DESIGN TEMPERATURE
TO FLARE HEADER
SAMPLING CONNECTION
NOTES:


AS-BUILT
RESAK ONSHORE GAS TERMINAL DEVELOPMENT PROJECT
PROCESS SAFEGUARDING FLOW SCHEME
PETRONAS CARIGALI SDN BHD


CAUSE
DESCRIPTION
AS BUILT
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN BHD
OGT MERCURY REMOVAL PROJECT
PETRONAS CARIGALI SDN BHD


CAUSE
EFFECT
DESCRIPTION
REMARKS
AS BUILT
PETRONAS RESEARCH & SCIENTIFIC SERVICES SDN BHD
DRT MERCURY REMOVAL PROJECT
PROCESS CAUSE AND EFFECT MATRIX (RESAK)
(SHEET 2 OF 2)
PETRONAS CARIGALI SDN BHD