SELF-CLEANING AIR FILTER SYSTEM FOR GAS TURBINE

By

MOHD KHAIRUL BIN KAMARUDDIN

DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme

In Partial Fulfilment of the of the Requirements

For the Degree

Bachelor of Engineering (Hons)

(Electrical & Electronics Engineering)

Universiti Teknologi PETRONAS

Bandar Sri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

SELF-CLEANING AIR FILTER SYSTEM FOR GAS TURBINE

By

MOHD KHAIRUL BIN KAMARUDDIN

A project dissertation submitted to the Electrical & Electronics Programme

Universiti Teknologi PETRONAS

In partial fulfilment of the requirement for the

Bachelor of Engineering (Hons)

(Electrical & Electronics Engineering)

Approved:

____

Dr. Wong Peng Wen

Project Supervisor

UNIVERSITI EKNOLOGI PETRONAS

TRONOH, PERAK

DECEMBER 2012

CERTIFICATION OF ORIGINALITY

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

____

(MOHD KHAIRUL KAMARUDDIN)

ABSTRACT

The project objective is to come out with a new system of self-cleaning air filter system which can operate more efficient compare to the existing self cleaning system. The old self cleaning system is only use the application of timer in boosting of pulse air to clean the filter and this will be a problem as it will shorten the filter lifetime. There is no term of universal filter that can stop all kind of impurities or the air. Application of stage filtration system could be the best way to encounter this problem. This report is about the study of self cleaning air filter system for gas turbine. Self cleaning system is the systems that can self clean the filter at the air intake of the gas turbine while the filter is to dirty. This new system of self cleaning system is operating by using differential pressure transmitter that can measure the dirty level of the filter. The study upon controller tuning method, Programmable logic Controller (PLC), configuration of differential pressure transmitter and the real operation of gas turbine should be done to make sure this project realizable. The author also needs to design the controller by using either using PLC or PID controller. By doing some empirical modelling on process reaction, the author can get the transfer function of the system. The author also needs to choose either PLC is applicable in this project. Some pressure sensor experimental test need to be done to choose the best and efficient sensor that fulfil the criteria to measure the air flow in open area. Site visit had been done at PGB, CUF for the gas turbine real operation. Apart from that, the author also know that the air flow inside the filter house is about 4-5bar. Moreover, from this site visit, the author also gets to know that the system of this self cleaning is a local controller system which means the controller is independent and no access to the control room. The author also takes into consideration to build a small distillation column in this project as it is exist in PGB,CUF self cleaning filter system.

ACKNOWLEDGEMENT

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

In the name of Allah, the Most Gracious and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing the Final Year Project – Self-Cleaning Air Filter System for Gas Turbine.

The authors would like to express the deepest appreciation to:

Project Supervisor: Dr. Wong Peng Wen for her time and effort to guide me to complete this project. His expertise as a senior lecturer and his willingness to share his knowledge is highly appreciated by me.

Lab Technician: MrAzhar for his time to teach me to program the PLC and to configure the PLC and All the equipment such as differential transmitter, relay and solenoid valve. Thank you also for sharing his knowledge and expertise on the PLC and the wiring of the PLC.

Many thanks to **Universiti Teknologi PETRONAS**, especially the **Electrical & Electronics Engineering Department** for giving me the opportunity to embark on this project in which has equipped students with essential skills for self-learning.

Last but not least, heartfelt gratitude to the **authors' family** who have been giving the courage and moral support to complete this research successfully.

Thank you.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

SCAFS	Self-Cleaning Air Filter System
PLC	Programmable Logic Controller
FYP	Final Year Project
I/O	Input/output
TIM	Timer
NC	Normally Close
NO	Normally Open
MCB	Manual Circuit Breaker
dP	Differential Pressure
TX	Transmitter
PID	Proportional, Integral & Derivative Controller

CHAPTER 1

INTRODUCTION

1.1. Background of Study

Gas Turbine is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine and a combustion chamber in between.

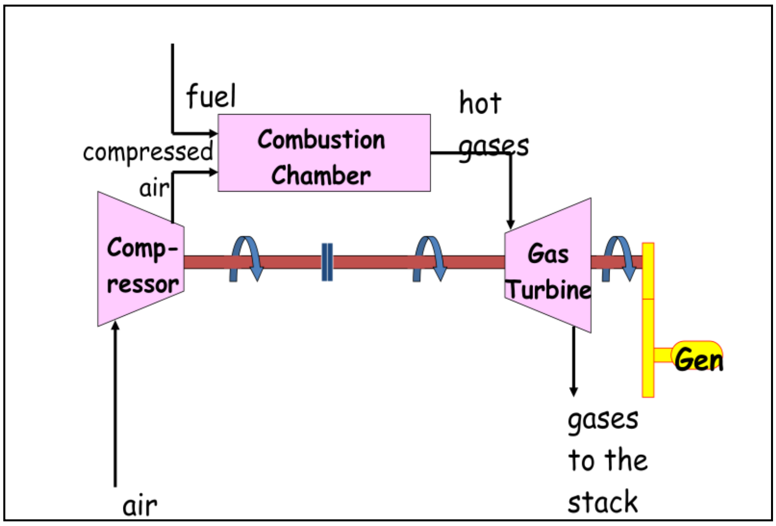


Figure 1: Gas Turbine basic component

Gas Turbine is operate by drawn the fresh air into the compressor so that it will increase the pressure and temperature. The high-pressure air then proceeds into the combustion chamber, where the fuel is burned at constant pressure. The resulting high-temperature gases then enter the turbine, where they expand to the atmospheric pressure trough a row of nozzle vanes. This expansion cause the turbine blade to spin, which then turn a shaft that connected to the generator to generate electrical energy. The exhaust gases leaving the turbine in the open cycle are not re-circulated.

Focusing to the air intake, the air coming into the compressor must be cleaned of impurities such as dust and smoke. Those could stick at the turbine blades of the compressor or turbine the resulting of reducing the power and efficiency of the gas turbine.

Unlike in Malaysia, the countries with four seasons have different air impurities depends on the weather. For example, when they (four season's country) have winter, the snow will be the impurities of their air. Without a properly air intake system of the gas turbine, this will reduce the efficiency of the gas turbine. Same goes to the countries that have gas turbine at the desert. The sand dust will be the problem for the gas turbine operation.

Self-cleaning air filter system for the gas turbine air intake could be the best way to improve the efficiency of gas turbine. This system also can make the gas turbine more eligible to operate in any weather condition.

1.2. Problem Statement

1.2.1. Air impurities

In four season's country such as the country in Europe, they have different air impurities depending on the season they have. This might be a big problem for the gas turbine operation as it will reduce the power generation and also reduce the efficiency of the gas turbine. During winter season, the snow could be the major problem. The carbon dust produced by vehicle, factory and open burning also will contaminate and at the same tie will be the impurities in the air. Those will block the air for entering the gas turbine. With the implementation of Self-cleaning Air filter system for gas turbine, this problem will be encountered easily as this system will self clean the air filter by boosting high pressure air (5 to 12 bars) to the air filter and resulting on having a clean filter. The filtration systems also need to be in consideration as the impurities of the air could be in different size. Size of filter (in micron) could be the best way to encounter this problem.

1.2.2. Filter lifetime

Nowadays, most invented self-cleaning air filter system was design by using timer which means the cleaning process (boosting air to the filter) will be operate by using timer. This kind of system will later damage the filter as it will still boosting the high pressure air to the filter although the filter did not have any impurities on it. This might reduce the lifetime of the filter. By implementing the new system of differential pressure sensor on the filter, the filter will only being clean if the differential pressure between atmospheric air (before filtering) and filtered air (after filtering) is high. This will ensure the expanded lifetime of the filter.

1.2.3. Maintenance work

Gas turbines without a proper air filter system always in a big problem with the maintenance work. The impurities from the air will stick at the turbine blades of the compressor or turbine the resulting of reducing the power and efficiency of the gas turbine. This also make the gas turbine is not in a good condition to operate and need some maintenance work. As we can see the gas turbine was not smoothly operated because it needs to be shut down for having maintenance work. This also could make the company will lose their profit as they need to spend more money for the maintenance work. By considering smooth operation and high profit as the control objectives, the self-cleaning air filter system will ensure that the turbine can operate in a longer time. Maintenance work also can be reduced as well as the cost of maintenance and man power will also be reduce.

1.3. Objectives

The following are the main objectives to be achieved in this project:

1. To build a new self-cleaning air filter system (SCAFS) by using differential pressure concept.
2. To choose the best controller for SCAFS.

3. To design ladder diagram for the PLC to control SCAFS.
4. To interface PLC control system with the SCAFS machine hardware.
5. To design a prototype to run the SCAFS.
6. To indentify the relevancy of the product in the power generation and air craft area.

1.4. Scope of Project

1.4.1. Scope of Study

i. Do research and literature review on Self-cleaning Air Filter System for Gas Turbine which focus more on the control objectives and problem encountered.
ii. Study on PID and PLC controller.
iii. Study on PLC and ladder diagram.
iv. Hardware development.
v. Study on differential pressure transmitter configuration.
vi. Do the sensor testing experimentation.
vii. Study on flow measurement.

1.4.2. Relevancy of the Project

Studies made on the title of the project shows that the Self-cleaning Air Filter System for Gas Turbine is invented by engineers due to encounter the problem on the air intake of the gas turbine. It also uses to improve the efficiency of the gas turbine. Furthermore, it can reduce the maintenance cost. Through the time, this system also can be implemented inside the vehicle and also for the daily equipment such as air conditioner.

1.4.3. Feasibility of the Project.

Earlier on before this project was started, discussions have been made on how to make the project feasible within the time frame. Since this project is individual project, the author needs to work smart. However, appropriate planning and schedule must be obeyed in order to complete this project during this two semesters. In addition, some tools and software are already available to be used.

CHAPTER 2

LITERATURE REVIEW

2.1. Consequences for poor inlet filtration

2.1.1. Erosion

Erosion is one of the causing or reducing turbine performance. Due to poor inlet filtration system, this will lead the turbine blades to face the erosion problem. Erosion will occur when some particles of the air impurities with the size of 10 μm or lager impact the rotating or stationary compressor blade surface inside the compressor [2]. These particles then will lead the changing of the shape or geometry of the surface of the blades. This is because of the impact of tiny particles from the air impurities. This may cause in removing of tiny particles of the turbine blades. Those will affect the turbine efficiency. Erosion is non-reversible process and thus will make the blades had to change to the new one to make sure it operate originally [2].

2.1.2. Fouling

Fouling of compressor blades also will lead to reducing of turbine efficiency. We can relate that with our ceiling fan at home. If the fouling of the fan blades increases the fan speed will be slower. Usually some particles from the air impurities with the size of 2 to 10 μm always are the cause of fouling of compressor blades for example such as smoke, oil mist, carbon and sea salts [2]. By introducing of self cleaning air filter system, the filtration system will be more effective and also help in preventing of fouling.

In addition, a problem in the turbine blade fouling also occurs when the filter failed to stop some submicron particles from entering the gas turbine. Compressor washing is the best solution to solve this problem. Although this solution give the big impact to the compressor performance but it cannot make the compressor to operate back to the original condition.

2.2. Self-cleaning Air filter system

All of the filters are required to be replaced once they reach the end of their lifetime. In some environments, the amount of contaminants can be excessive to the point where the filters would have to be replaced frequently to meet the quality of the filtration. An example is a desert with sand storms. In the 1970s, the self-cleaning filtration system was developed for the Middle East where gas turbines are frequently facing with sand storms problem [2]. Since then, this system has been continually developed and utilized for gas turbine inlet air filtration.

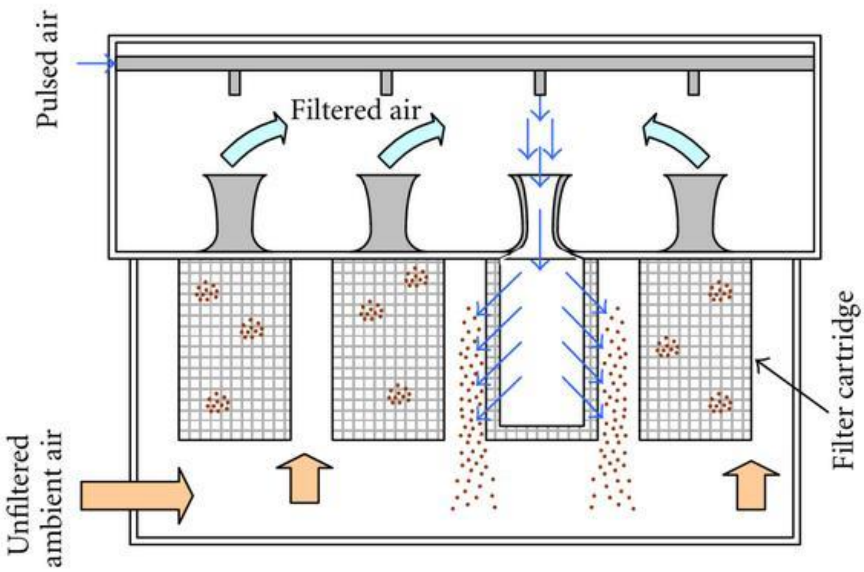


Figure 2: operation of an updraft self-cleaning filters

Common of self-cleaning air filter system nowadays operates by boosting pulse air rages from 5.5 to 6.9 barg to the filter by following timer [2]. In this project, the author had introduced the implementation of differential pressure (dP) transmitter into the system. This dP transmitter then will cooperates with timer to clean the air filter. When the system receive the error (high dP) which is means the filter is too dirty, the controller then will send the solution signal to the solenoid valve as it will release the pulse air to the filter to clean it. This action will follow the timer to synchronous the boosting of the pulse air from top level to the low level of the filter stage. The boosting of the air (or pulse) occurs for a length of time between 100 and 200 ms. With this type of cleaning, the filter can be brought approximately like the original condition. This kind of solution also make the filter lifetime become longer than before. It is because when the old self-cleaning system that use timer only will boost the air to the filter even though the filter is not dirty. This will break the filter medium and also lead to the poor air filtration system.

2.3. Stage filtration

Even though the filter technology nowadays is great, there is no term of universal filter that can stop all kind of impurities or the air [2]. Thus, the author came out with the idea of multistage filtration system. This stage filtration system has two or more filter that connect in series depending on the impurities of the air. The filter order of the filter is from the low efficiency filter to the higher efficiency filter. In these design, the first stage filtration or we usually call it as pre-filter is a weather lover which means it can stand all the impurities that come from the changing in weather such as snow during the winter season. The second stage filter may be medium performance filter that can stop the smaller particles with size of 2-5 microns. In this stage also have coalescer that is use for removing water particles. The third stage filtration usually the high efficiency filter which is use to remove smaller particles with the size of lower than 2 microns [2]. Figure 3 shows a generalize view of multistage filtration arrangement.

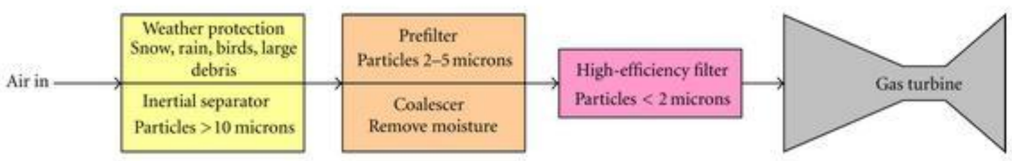


Figure 3: Multistage filtration system

2.4. Pressure sensor

Criteria or the pressure sensor that need by the author for his project is the sensor that can measure the air flow pressure in the open area (not in the pipeline) to connect it to the differential pressure transmitter. The measurement efficiency of the sensor also had been taken to be consideration.

By consulting Mr. Azhar, Lab technician, the author had two choices either to use diaphragm sensor or barometer as the pressure sensor. The author not yet decides which sensor the he might use in his project as the sensor needs to be order from the supplier. Apart from that, the author cannot test both of the sensors as the sensor is not available in UTP. The author had planned to do this sensor testing experiment during next semester when the equipment assembly is complete.

Barometer is a sensor that uses the atmospheric air pressure as the reference to measure the air pressure [7]. The standard atmospheric air pressure is usually 14.7psi.

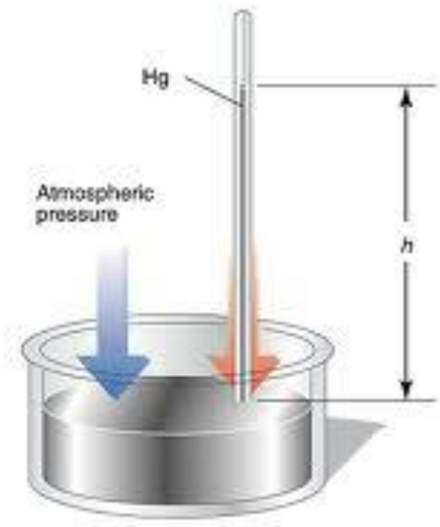


Figure 4: Mercury Barometer

Standard pressure calculation of a barometer is by using P = pgh + 14.7psi (atmospheric pressure) and (p = density of the medium, g = gravitational acceleration, h = high of the column)[8]. But, in this project, the author will use the electronic barometer sensor that mostly available in market.

Figure 5: Electronic barometer

Furthermore, the diaphragm type pressure sensor is also need to take into consideration. This type of sensor operates by measuring the pressure that hit the diaphragm. It does not to do calibration because it has been factory calibrated [8].

Figure 6: Diaphragm type pressure sensor.

2.5. Controller Tuning Method.

2.5.1. Ziegler-Nichols

Ziegler –Nichols controller tuning method can be gain by increasing the proportional gain K_P, until it reach ultimate gain K_u, which means the output or measured variable, MV, is oscillating. The K_u is then use in calculating the controller parameters by using below formula. P_u is time for 1 oscillation period [6].

Control Modes	K_c	T_I	T_D
P only	$0.5K_u$	9999	0
P + I	$0.45K_u$	$P_u/1.2$	0
P + I + D	$0.6K_u$	$P_u/2$	$P_u/8$

After get all the parameters, the author need to test the controller performance by using all those 3 control modes which are P, PI or PID. The best result can be seen in the trend produce.

2.5.2. Cohen-Coon

The Cohen-Coon method is easier as it only use the process reaction curve to calculate the controller parameters. Controller parameter can be calculated by using below formula [6]. R is the apparent dead time which is equal to dead time over apparent time constant.

Control Modes	Parameters
P only	$K_C = \left(\frac{1}{RK_p}\right)\left(1+\frac{R}{3}\right)$
P + I	$K_C = \left(\frac{1}{RK_p}\right)\left(\frac{9}{10}+\frac{R}{12}\right)$
	$T_I = \theta\frac{(30+3R)}{(9+20R)}$
P + I + D	$K_C = \left(\frac{1}{RK_p}\right)\left(\frac{4}{3}+\frac{R}{4}\right)$
	$T_I = \theta\frac{(32+6R)}{(13+8R)}$
	$T_D = \theta\frac{4}{(11+2R)}$
P + D	$K_C = \left(\frac{1}{RK_p}\right)\left(\frac{5}{4}+\frac{R}{6}\right)$
	$T_I = \theta\frac{(6-2R)}{(22+3R)}$

Measurement
Change in perturbation / MV, σ
Change in output / PV, Δ
Maximum slope, S
Apparent dead time, θ
Calculations
Steady State Process Gain, $K_P = \Delta / \sigma$
Apparent time constant, $\tau = K_P / S$ or $\tau = 1.5(t_{0.63\Delta} - t_{0.28\Delta})$
*Fraction dead time, $R = \theta / \tau$

Equation 1: Cohen-coon Equation

2.5.3. Empirical Modelling

Empirical modelling is the analysing of the process reaction curve to get the transfer function of the system [6]. Empirical modelling is important in generating a process block diagram for the simulation testing. All the data can be extracted from the process reaction curve by this method.

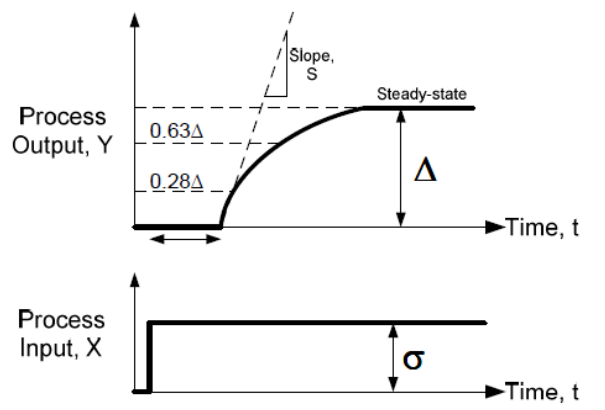


Fig. A-5: First-Order Process Reaction Curve

Figure 7: Example of Process reaction curve and method how to analyze

The data then will be calculated by using below formula.

Measurement
Change in perturbation / MV, σ
Change in output / PV, Δ
Maximum slope, S
Apparent dead time, θ
Calculations
Steady State Process Gain, $K_P = \Delta / \sigma$
Apparent time constant, $\tau = K_P / S$ or $\tau = 1.5(t_{0.63\Delta} - t_{0.28\Delta})$
*Fraction dead time, $R = \theta / \tau$

Equation 2: Empirical Equation Formula

2.6. Flow Measurement

2.6.1. Pressure Differential Meters

Differential Pressure (dP) operates on the principle that a restriction placed in a flow line produces a pressure drop proportional to the flow rate squared. A dP transmitter is used to measure the pressure drop, *h*, produced by the restriction. The flow rate, *q*, is proportional to the square root of the measured pressure drop.

Special passages transfer the air pressure on each side of the orifice plate to the opposite side of a diaphragm unit in a d/p transmitter. A displacement detector senses any motion resulting from the imbalance of the forces on a force arm (due to pressure difference across the orifice). An amplifier converts this displacement signal into an adjustment of the current input to the force transducer that restores the balanced conditions. Current, I, proportional to the pressure drop across the orifice plate, is used as the output signal of the p transmitter. However, the application of dP concept in SCAFS is a bit different. The orifice plate that use to separate the upstream and downstream of the air flow is replaced by the filter. The unfiltered air will recognized as the upstream flow and the filtered air will recognized as downstream flow.

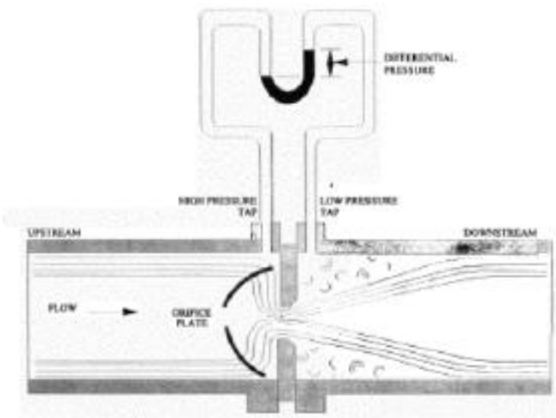


Figure 8: Mechanism of dP flow meter

2.7. Programmable Logic Controller (PLC)

Proper planning and studying of the PLC system will ensure the success of this project. PLC is solid-state system designed to perform logic function such as sequencing, timing, counting and arithmetic to control machine and processes which is previously done by hardwired relay system. []

Figure 9: PLC OMRON CPM1A

Figure 9 shows one example type of PLC. PLC is operated by the instruction input from the input device such as push button, switches, sensors and others used to detect the operation condition of the equipment, output device such as solenoid valves, motor and so on. PLC is used in many industries and machine.

Unlike general-purpose computers, the PLC design for multiple input and output arrangements, extended temperature range, 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. The PLC plays an important role as the brain of the automated manufacturing process.

2.7.1. Component of PLC

The typical PLC contains four major components as following:

- CPU module
- Power supply
- Rack/Bus
- Input/output modules.

2.7.2. Application of PLC

PLC can be applied in so many industries such as below:

- Product boxing in industries
- Food industries
- Automotive industries
- Product bottling
- Textile industries.

2.7.3. PLC Ladder Diagram

Ladder logic diagram is a programming language that represents a programme by a graphical diagram based on the circuit diagrams of relay-based logic hardware. It is primarily used to develop software for PLC used in industrial control application.

Ladder logic is widely used to program PLCs, where sequential control of a process or manufacturing operation is required. Ladder logic is useful for simple but for critical control system or for reworking old hardwired relay circuits. Ladder logic can be thought of as rule-based language rather than procedural language.

A “rung” in the ladder represents a rule. A ladder diagram consists of horizontal rungs between two vertical rails which represent the power rails. Each rung contains instruction elements that examine memory bits and at least one output element that control a memory bits. Each rung must start with an input(s) and end with at least one output. Figure 10 shows an example of simple PLC ladder diagram.

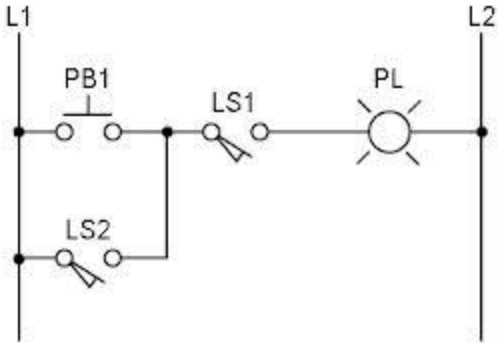


Figure 10: An Example of Ladder Diagram

2.8. Literature Analysis

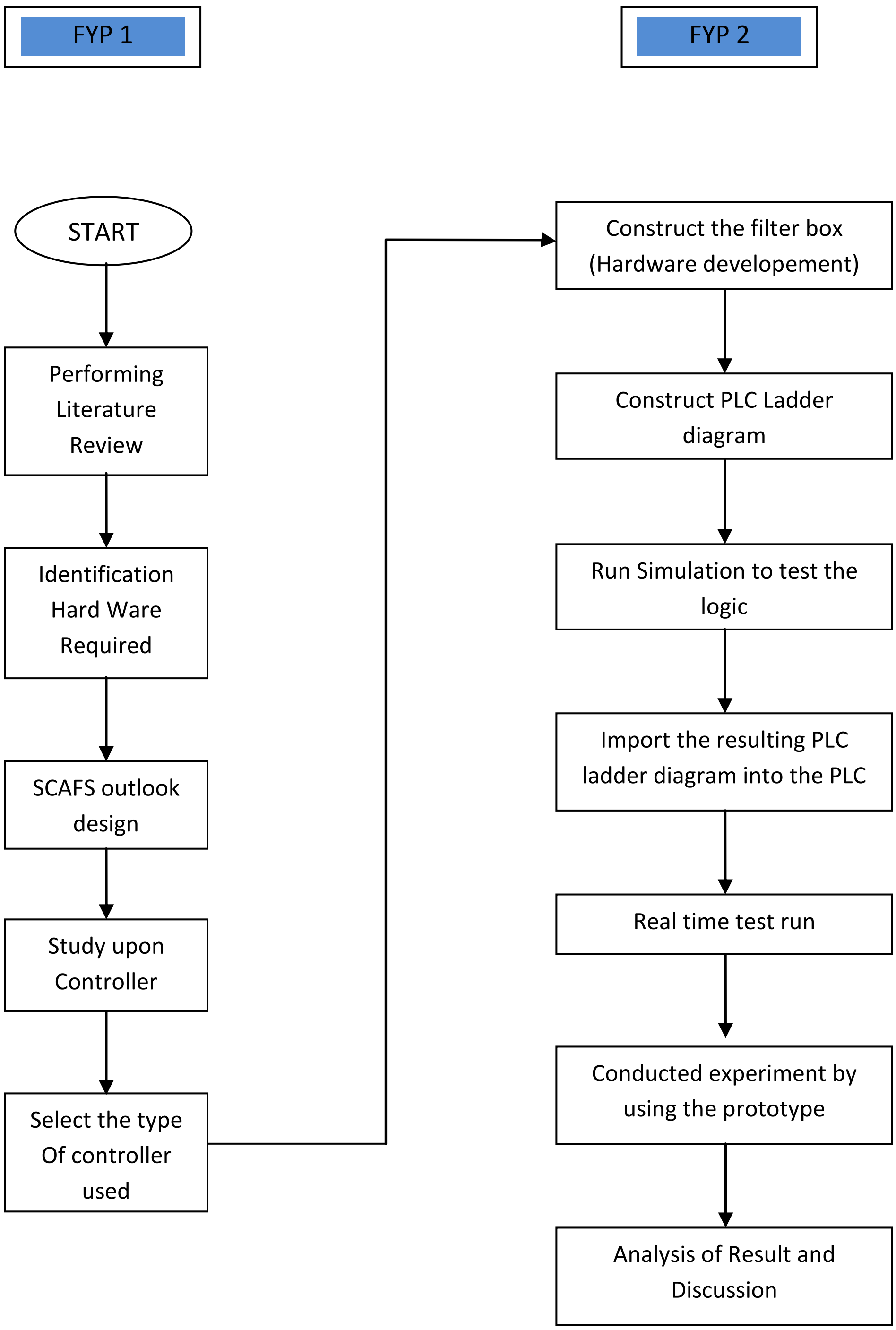
Table 1: Literature Analysis

Project Block	Description	Reference
Filter Block	Stage Filtration System	Mellissa . W (2011), Rainer . K (2011), Klaus . B (2011)
	Effect upon poor filtration system	Klaus . B (2011)
Controller Block	Control Analysis and PID Tuning	Ir. Dr. Idris Ismail (2012)
	Programmable Logic Circuit (PLC)	AP. Dr. Nordin Saad (2012)
Self Cleaning System Block	Differential Pressure Implementation	Azhar (2012)
	Gas Turbine Thermal Efficiency	Bari'asyraf (2011)

CHAPTER 3

METHODOLOGY

3.1. Procedure Flowchart



3.2. Procedure Identification

The procedure identification explains the procedure flowchart as in part 3.1. In this project, a few steps indentified were used as a guide on completing the project for the whole process.

Step 1: Literature review (SCAFS and Controller)

Step 2: Identified of hardware required

- Identify for suitable equipment needed for the prototype such as solenoid valve, relays, PLC and filters.

Step 3: SCAFS outlook design

- Draft the design of SCAFS machine including the dimension and size.

Step 4: Study upon the controller (PID and PLC)

Step 5: Select the type of controller used

- Used to choose PLC as the controller as it has fast reaction and easy to configure compare to PID controller.
- PLC can be use as the local controller without using the distributed control system (DCS).

Step 6: Construct the filter box

Step 7: Construct the PLC ladder diagram

- Obtain the entire SCAFS machine based on the operation path.

Step 8: Run simulation to test the logic

- Construct a ladder diagram on the Automation Studio software to test the PLC logic.

Step 9: Import the resulting PLC ladder diagram into the PLC

Step 10: Real time test run

Step 11: Conduct experiment by using the prototype

- Having the experiment by test it using the different air impurities

Step 12: Analysis of result and discussion

3.3. Research Methodology

At the early stage of the project, research on Self-cleaning System for Gas Turbine is made trough general reading on article made by previous scholar on the Self-cleaning System and related subjects on the topic itself. Throughout this reading, a couple techniques should be utilised. Some of the common techniques mention in the past and recent studies are by using timer, weather protection for Gas Turbine, Anti-icing protection, high efficiency filters and using differential pressure transmitter for the new system. Out of these five techniques, timer has widely used for this self-cleaning system, but differential pressure is better as it will longer the lifetime of the filter itself. Later, the author also needs to do some research for choosing the type of pressure sensor that will be used in this project.

Apart from that, the author also needs to focus more on the controller performance test and choosing the controller part. Thus, a study is also made with the help of project supervisor to understand the basic of PLC configuration and ladder diagram construction. In addition, the author also must also study on how to use the Automation Studio software to make the simulation test of the controller logic.

3.4. Gas Turbine Air Filter House Site Visit

The author had done site visit to the real gas turbine air filter house at PETRONAS GAS BERHAD, CUF KERTEH. During the site visit, the author can see the activity of changing solenoid valve in the filter house. This activity only can be done during the shutdown which is will be held once in 2 years or 18000 of running hour. This shut down called Hot Gas Path Inspection (HGPI).

The result of this site visit is the author gets to know the real operation of the gas turbine especially for the self-cleaning air filter system. In this PGB, CUF plant, they only use timer type self-cleaning system. One of the Instrument Engineer there told the author that the timer type self cleaning filter system is not really efficient as it will damage the filter as the author had describe in the problem statement before.

Other than that, the author also know that the air flow inside the filter house. This is one of the important findings for the author as to design the new self-cleaning system, the author need to know the real air flow inside the filter house. This can make the controller performance test and the configuration of differential pressure transmitter will be easy to be done. By knowing the air flow inside the air filter house, the author then need to calculate the normal running pressure drop inside through the filter that will be design by the author.

Moreover, from this site visit, the author also gets to know that the system of this self cleaning is a local distribution system which means the controller is independent and no access to the control room. It designed like this to make sure the fast reaction compare to the distribution control system (DCS).

The author also take into consideration to build a small distillation column in this project as it is exist in PGB,CUF self cleaning filter system. This small distillation column use to reuse small amount of the air from the compressor to be the pulse air for use in boosting of air to clean the filter in this self cleaning filter system. This distillation column use to separate water vapour from the air to make sure the pulse air is dry air. The use of dry air is more efficient for the pulse air as it will prevent the filter to get wet and some dust will stuck permanently at the filter thus will shorten the lifetime of the filter. This distillation column also makes the self cleaning system to be more efficient as it does not need to use the plant/instrument air to become the pulse air.

Figure 11: Solenoid valve uninstall work

Figure 12: solenoid valve in the air filter house

Figure 13: cable socket repairing

3.5. Tools and Equipment Required.

To be mentioned on this section are hardware and software being used in this project. These software and hardware are the most commonly used application. The tools and component required to build an SCAFS machine are as follows:

1. Programmable Logic Controller (PLC)
   - Output: 24 V-dc
   - Purpose: Control the automation system of SCAFS

2. Power supply 24 V-dc
   - Figure 14 shows the OMRON Power Supply 24 V-dc
     - Purpose: Supply 24V-dc power to the output of PLC such as solenoid valve and indicator light.

Figure 14: OMRON Power Supply 24 V-dc

3. Indicator equipment
   - START and STOP button switch, valve indicator light and transmitter light indicator.
   - Output: 24 V-dc

4. Solenoid Valve (x4)
   - Figure XX shows the solenoid valve that being used in this project. The solenoid converts electrical energy into mechanical energy which, in turn, opens or closes the valve mechanically. []
   - Purpose: Control the boosting air to the filter.

Figure 15: Solenoid Valve

5. Transformer
   - Purpose: step-down 240 V-ac to 24 V-ac

6. Relays
   - Purpose: Act as switching mechanism

7. Air Filter
   - Purpose: to filter the air and at the same time act such orifice plate in the flow measurement system.

8. Differential Pressure Transmitter
   - Purpose: Measure the air flow inside the filter box

Figure 16: Differential Pressure Transmitter

9. Filter Box
   - Purpose: Act as the filter house to test the validity of SCAFS.

10. Vacuum Cleaner
    - Act as the air intake compressor to make sure there is air flow inside the filter box.

Other tools:

- PVC pipe ½”
- Fitting ½” to ¼”
- Colourless tube
- Wire
- Air regulator

Software:

1. CX-Programmer version 3.1
2. Automation Studio

3.6. Filter Box construction

The filter box to test the SCAFS is made from metal and had been sealed to make sure there is no incoming air intake except from the intake windows. The filter box had been air sealed by using the silicon gum. The dimension of this filter box is 150cm x 50cm x 50cm. Its look like a cube but it comes with the air suction tube, intake windows and the dust outlet. The construction of the filter box as shown below:

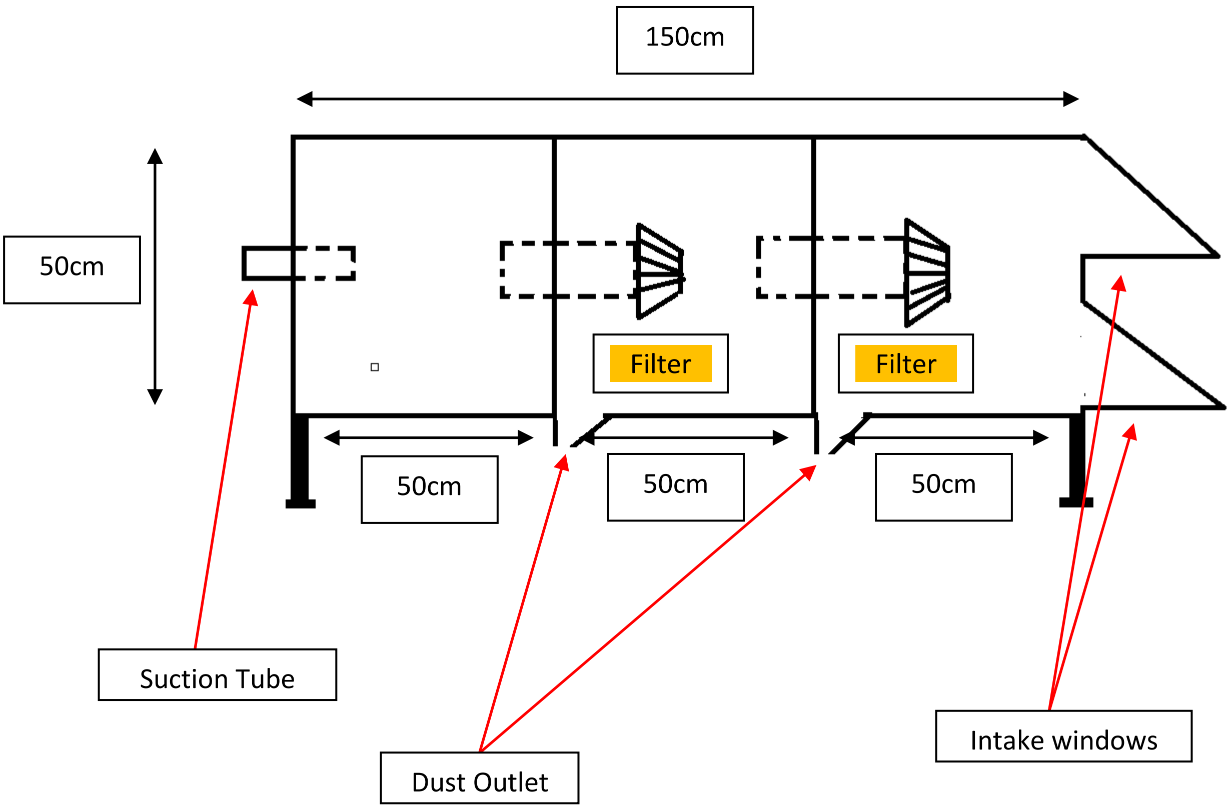


Figure 17: Filter Box Construction

CHAPTER 4

RESULT AND DISCUSSION

4.1. SCAFS Prototype

4.1.1. SCAFS Machine Block Diagram

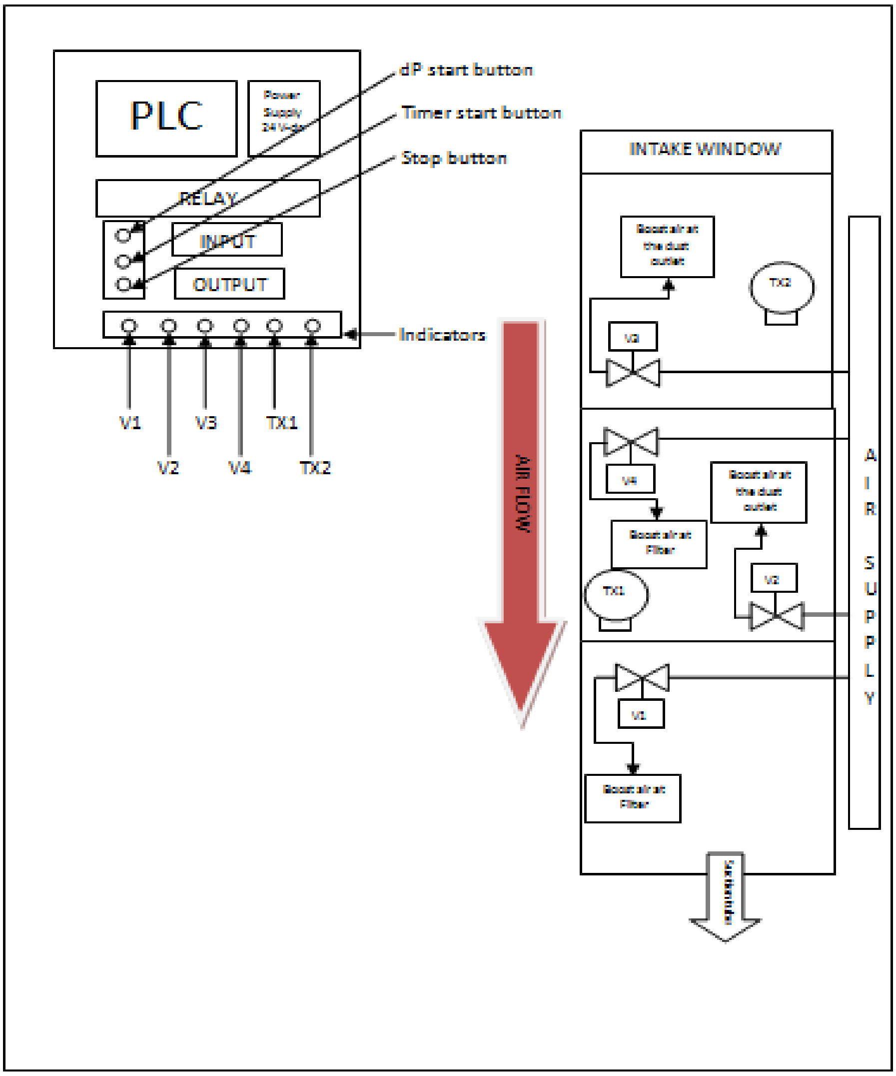


Figure 18: SCAFS prototype block diagram

Figure 18 shows block diagram for SCAFS prototype in this project. The purpose using the 24 V-dc supplies is to supply 24 V-dc to the output of the PLC such as solenoid valve, light indicator, push button and the transmitter (TX). Shows in figure, the air flow inside the filter box. Also shows the position of solenoid valve (V1, V2, V3 and V4) and Transmitter (TX1 and TX2). The filter box also divided into 3 parts which Part 1 has V3 in it act as the upstream flow of the TX2. Part 2 consist of V4 and V2 act as the upstream flow of TX1 and downstream flow of TX2. Part 3 act as the downstream flow for TX2 consist of V1.

The measurement of the dirtiness of the filter can be determined by the differential pressure meter. The more dirty the filter, the higher the differential pressure between upstream and downstream flow. Still this is not the final version which means that there are room for improvement.

4.1.2. SCAFS prototype Controller Board

Figure 20 below show the design for monitor or control board for SCAFS prototype. The control board controls the sequence of the output of PLC such as indicator light, solenoid valve and transmitter. The IO interface between the PLC and hardware will illustrate like below.

The V1 indicator light is ON when the air is boosting inside the filter. This is to show that the solenoid valve 1 is energized/functioned. Same goes to the V2, V3, and V4 indicator light to shows that those solenoid valves are energized. For TX1 and TX2 indicator light, it shows that the transmitter is ON and those are means the sensor is ready.

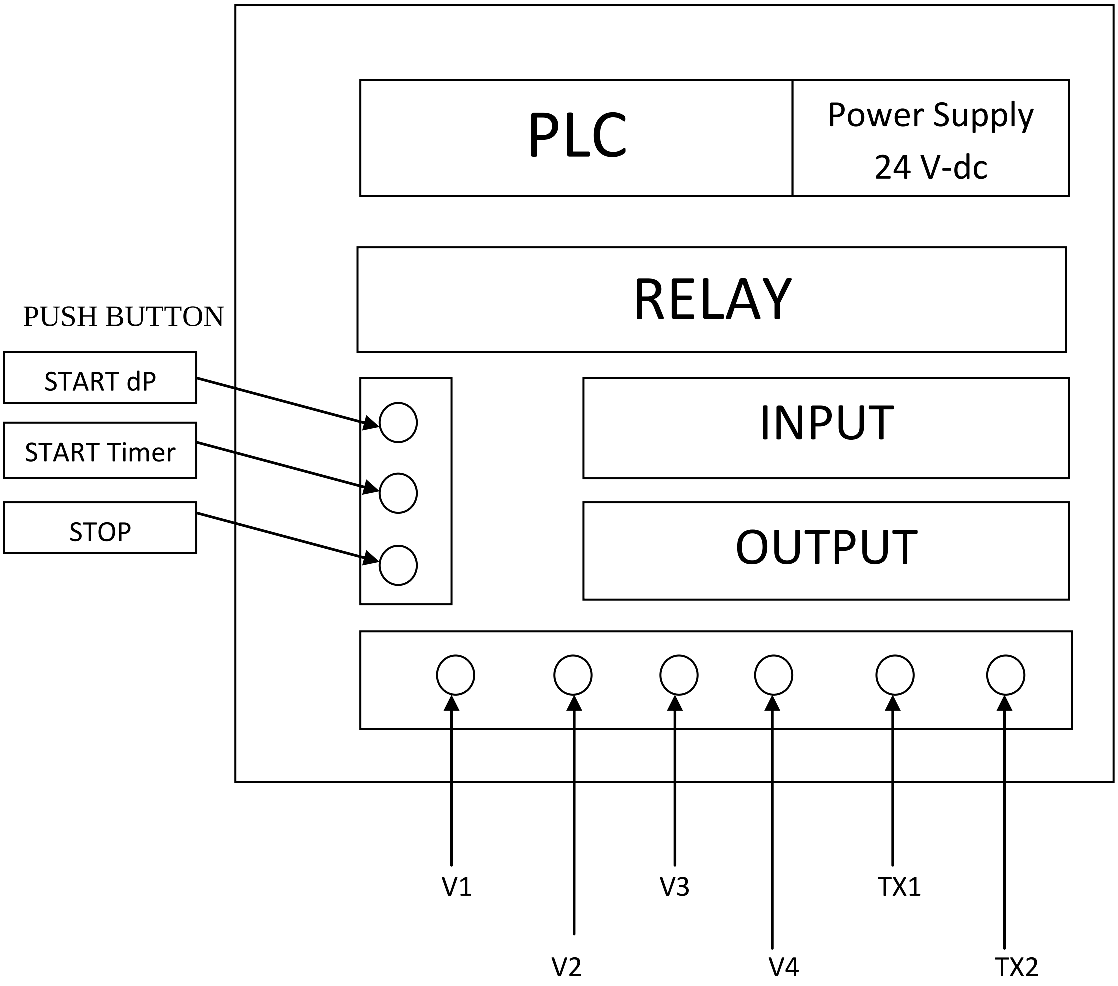


Figure 19: SCAFS prototype Control Board

4.1.3. Safety Feature

In SCAFS prototype control board, the manual circuit breaker was installed to provide safety mechanism to the prototype. This safety feature may enhance not only the safety of the plant but also the hardware equipment. The circuit breaker is an absolutely essential device in the modern world. Whenever the wiring has too much current flowing through it, this simple machine cut the power.

Figure 21 below shows the circuit breaker that being used in this SCAFS prototype project. C60N Manual Circuit Breaker (MCB) is an all new high performance current limiting device with the ability to disconnect short circuits of up to 10kA which is the newest model in 21st century. []

Figure 20: C60N Mini Circuit Breaker

4.1.4. SCAFS work flow

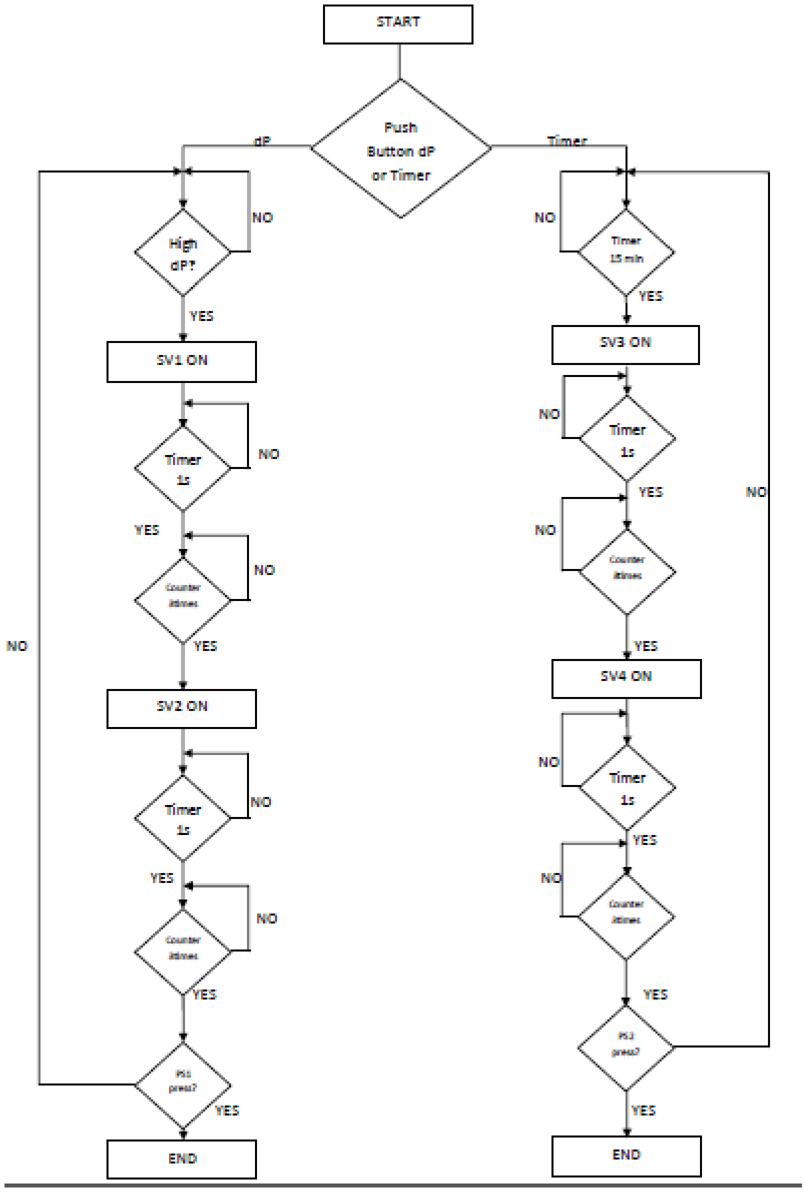


Figure 21: SCAFS Work Flow

Figure 22 above show the work flow of the SCAFS prototype in the PLC logic. After one of the start buttons (either dP or Timer) is pushed, the transmitter or sensor will be ON. The indicator of the TX1 and TX2 will be ON for the entire process until the push button stop is pushed. There are two mode in SCAFS prototype process which are either dP mode or timer mode. Below are the descriptions of the work flow for both modes.

MODE 1: dP Mode

i. The push button of dP mode is pushed
ii. Transmitter TX1 and TX2 is ON (sensor is ON)
iii. dP is high upon the filter is dirty
iv. TX will contact the relay switch to give the signal to the PLC
v. SV1 is ON for 1 second
vi. SV1 is OFF for three seconds
vii. Repeat step v and vi three times
viii. SV2 is ON for 1 second
ix. SV2 is OFF for 3 seconds
x. Repeat step vii and ix three times
xi. Sensor detect low dP
xii. All solenoid valve in standby mode
xiii. Repeat step from step ii

MODE 2: Timer Mode

i. Timer mode push btton is pushed
ii. Timer for 15 min
iii. SV1 is ON for 1 second
iv. SV1 is OFF for three seconds
v. Repeat step v and vi three times
vi. SV2 is ON for 1 second
vii. SV2 is OFF for 3 seconds
viii. Repeat step vii and ix three times
ix. Repeat step i

The operation for V3 and V4 is the same as above. V3 will do the same process as V1 and V4 will do the same process as V2. This process will continue looping back to the 2nd step until the push button stop is pushed.

4.2. CX-Programmer OMRON PLC

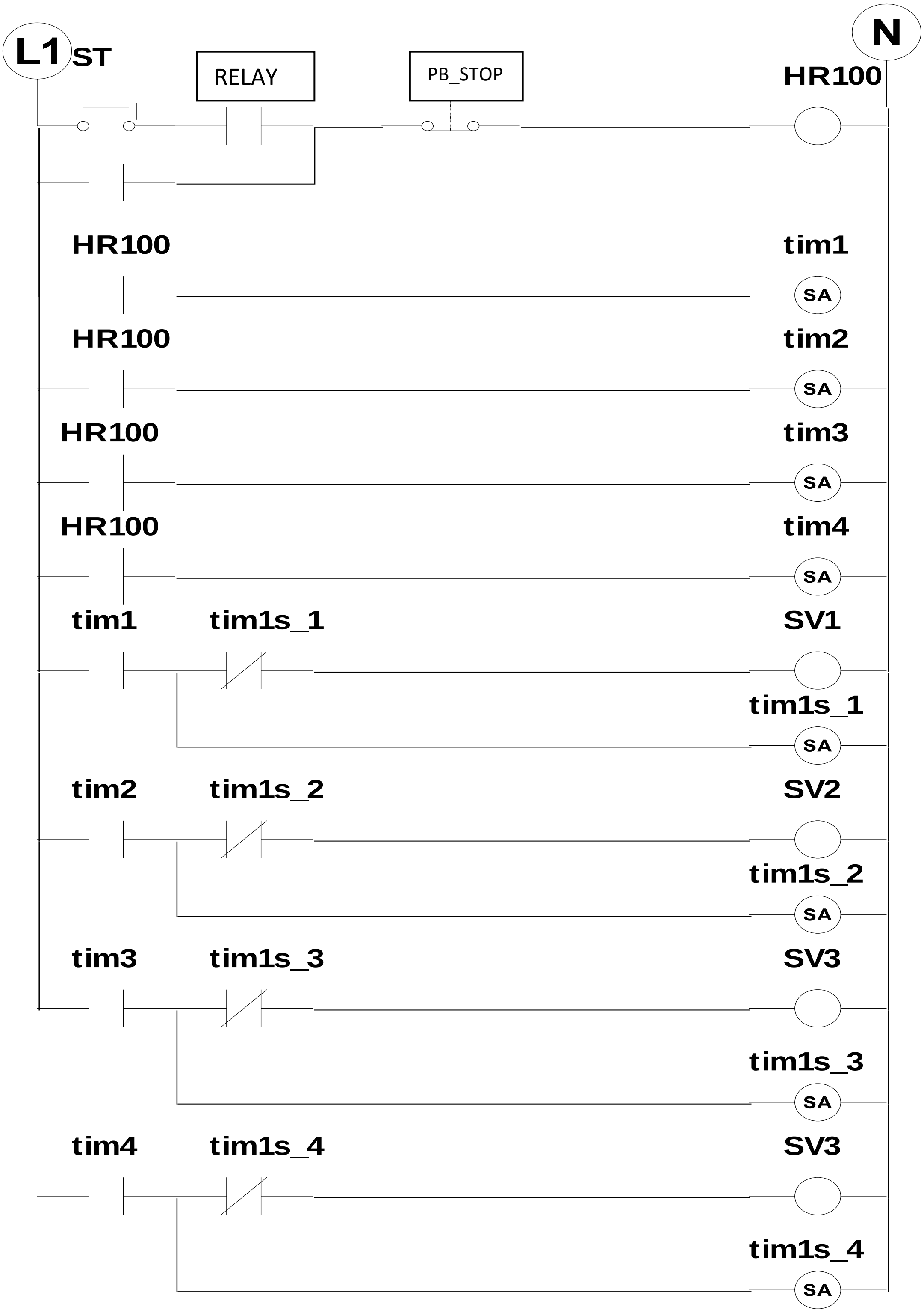
For this project, the study is focused on the use of OMRON PM 1A. Proper planning and studying of PLC system will ensure the success of the end product. CX-Programmer is used for programming purpose. It provides comprehensive programming environment, testing and debugging of any automation system. Using the CX-Programmer, the ladder diagram for the PLC program was constructed. Online capabilities are also available such as program uploading, downloading and multi rung editing.

4.2.1. Ladder diagram

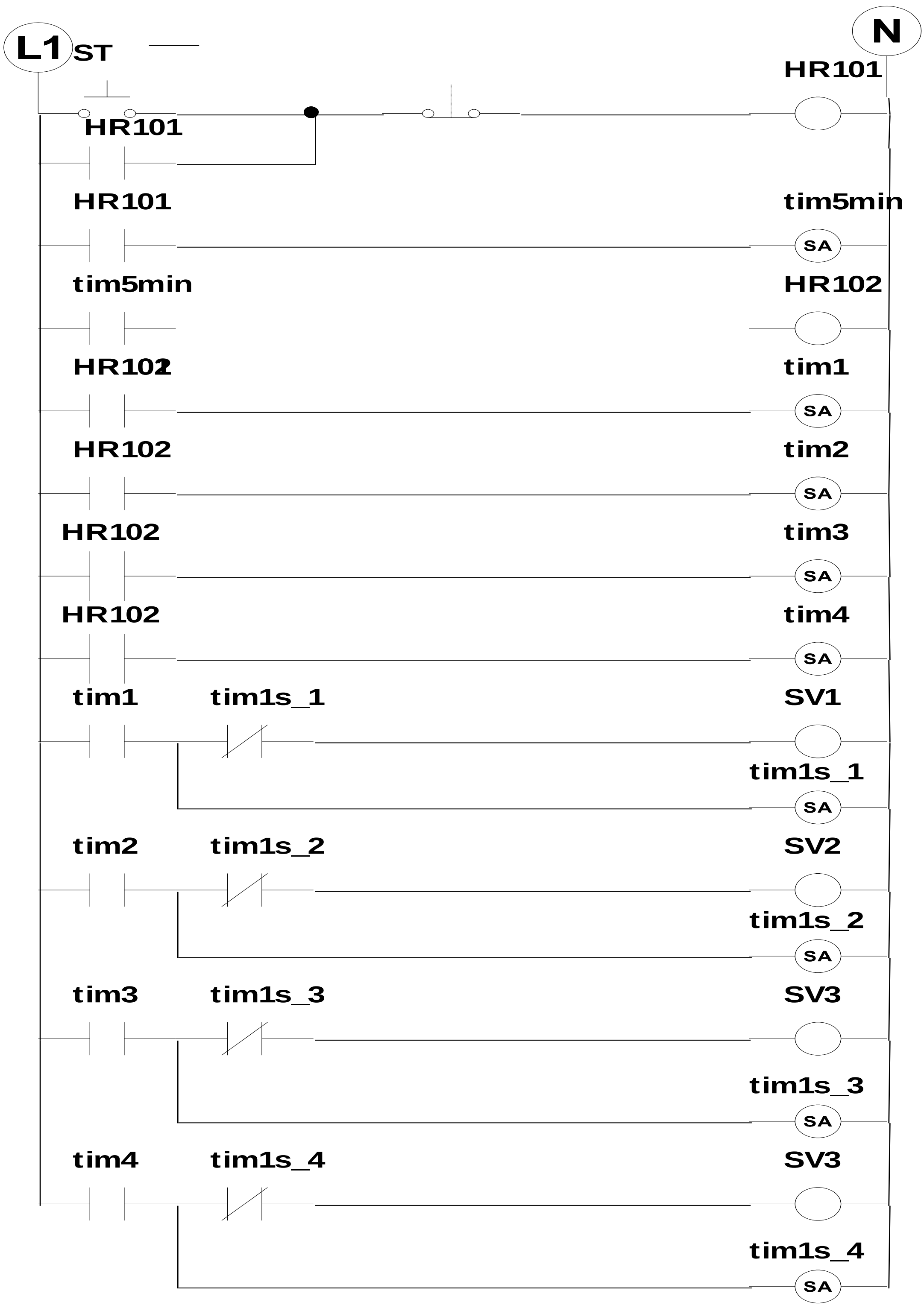
The software used in the design on the ladder diagram in CX-Programmer Version 3.1. The ladder diagram was developed based on the flowchart created. Once the simulation with the PLC training kit is completed, the ladder diagram is loaded into OMRON PLC CPM 1A with cable RS 232.

Figure XX and Table XX below shows the ladder diagram of SCAFS prototype and the list of input and output used in PLC ladder diagram. Using the CX-Programmer, the ladder diagram was being constructed. The program can be further improved for future purpose. Basically, the ladder diagram attached is a working system. The PLC ladder diagram was uploaded into CPM 1A ONRON PLC modules and tested for verification of the program.

The ladder diagram for SCAFS prototype in Figure XX has been developed by follow the workflow that been design before.



dP Mode ladder diagram



Timer Mode ladder diagram

Figure 22: Ladder Diagram for SCAFS

Table 2: List of Inputs and Outputs

Input	Description	Output	Description
0.01	START_dP	10.01	SV1
0.02	START_TIM	10.02	SV2
0.03	STOP	10.03	SV3
0.04	RELAY1	10.04	SV4
0.05	RELAY2		

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This Self-Cleaning Ait Filter System (SCAFS) prototype using PLC as project that provides student a good learning and practical experience in working with hardware and software. It provide student with the opportunity to interfacing the device as well as working with protocol. The construction of the prototype starts from the filter box construction, hardware assembly and wiring interfacing between input/output devices with PLC. The operation of SCAFS is controlled by the PLC through the designed ladder diagram. Changes of the ladder diagram or modification of the hardware and path were done accordingly to obtain optimum performance.

The main objectives of this project had been successfully achieved. The main contribution of this work as follows:

- Develop a controller for SCAFS prototype
- Interface all the component of the project
- Handle important task in proposing a project up until the completion process.

This SCAFS had been successfully designed to improve the filtration system of the air intake of a gas turbine. This SCAFS also can improve the performance of the gas turbine also longer the running time of the gas turbine. This system also can be applied in other internal combustion engine such as car engine, aircraft engine and others in future development. This new system also very useful for the power generation industries to optimizes the power production.

5.2. Recommendation

This section presents recommendation for future improvement of this project. Although this project has achieved its objectives including choosing and constructing the best controller for the system, it still have a bright future. There a lot of improvement can be made on this system.

- Combine both of dP and timer mode for more better result of the self cleaning of the filter. By combining both of those modes, the filter can be always in a clean condition. The filter lifetime will not affected as the filter is been monitored by using the dP sensor.

- Use the dP transmitter to indicate the lifetime of the filter. Put the lower and upper range of the differential pressure during the new installation of the filter. If the differential pressure between the filtered air and unfiltered air is lower that the low range stated earlier, it means the filter is not in good condition and need to change the filter. This system is very useful to monitor the filter condition.

- For future development, this system can be applied to other internal combustion engine such as car engine, aircraft engine and others. In future development, this system can be made in small scale and can be applied in the car engine air intake. The boosting air can be gained from the waste gate of the turbo compressor. In the future, the can not only can go faster with the turbo compressor, but also can clean their own filter and longer its filter lifetime. This also can save the cost of the filter service.

REFERENCES

[1] http://www.emea.donaldson.com/en/gasturbine/selfcleaning/index.html

[2] Technology Review of Modern Gas Turbine Inlet Filtration Systems (Melissa Wilcox, Rainer Kurz, and Klaus Brun)

[3] http://en.wikipedia.org/wiki/Gas_turbine

[4] http://www.sztwt.net/show/31.html

[5] http://www.hindawi.com/journals/ijrm/2012/128134/ref/

[6] PLANT PROCESS CONTROL SYSTEM. LECTURE: PID controller tuning method. (IR. Dr. Idris Ismail)

[7] **http://en.wikipedia.org/wiki/Barometer**

[8] http://www.orangesearch .com/differential-pressure-diaphragm-models.htm

[9] "manual circuit breaker", http://wzkibox.enmade-in-china.com,

[10] Industrial Automation Control System. LECTURE: Flow measurement & PLC (Dr. Nordin Saad & Dr. Rosdiazli)

\

APPENDIXES

APPENDIX I

FYP 1 Gantt Chart

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Topic Selection								**Mid Semester Break**							
2	Review on e-tongue															
3	Submission of Extended Proposal						★									
4	Proposal Defence										★					
5	Study on the PID controller															
6	Study on the PLC controller															
7	Submission of Interim Report														★	

★ Milestones

Processes

APPENDIX II

No	Detail / Week	1	2	3	4	5	6	7	Mid Semester Break	8	9	10	11	12	13	14
1	Hardware developement				■	■	■	■								
2	Choosing of the controller	■	■			■	■	■		■	■					
3	Developing of the ladder diagram						■	■		■						
4	Submission of Progress Report									★						
5	Test Run											■	■	■	■	■
6	Electrex												★			
7	Viva															★
8	Submission of Final Report														★	

■ Processes

★ Milestones

APPENDIX III

4. UNIT SPECIFICATIONS AND COMPONENTS

❑ General Specifications of CPM1A CPUs Unit

Item		10-point I/O	20-point I/O	30-point I/O	40-point I/O
Supply voltage	AC type	100 to 240 VAC, 50/60 H			
	DC type	24 VDC			
Operating voltage range	AC type	85 to 264 VAC			
	DC type	20.4 to 26.4VDC			
Power consumption	AC type	30 VA max.		60 VA max.	
	DC type	6 W max.		20 W max.	
Inrush current		30 A max.		60 A max.	
External power supply (AC type only)	Power supply voltage	24 VDC			
	Power supply output capacity	200 mA		300 mA	
Insulation resistance		20 MΩ min. (at 500 VDC) between the external AC terminals and protective earth terminals.			
Dielectric strength		2,300 VAC 50/60 Hz for 1 min between the external AC and protective earth terminals, leakage current: 10 mA max.			
Noise immunity		1,500 Vp-p, pulse width: 0.1 to 1 µs, rise time: 1 ns (via noise simulation)			
Vibration resistance		10 to 57 Hz, 0.075–mm amplitude, 57 to 150 Hz, acceleration: 9.8 m/s^2 (1G) in X, Y and Z directions for 80 minutes each (i.e. swept for 8 minutes, 10 times)			
Shock resistance		147 m/s^2 (20G) three times each in X, Y and Z directions			
Ambient temperature		Operating: 0 ° to 55 °C Storage: –20 ° to 75 °C			
Ambient Humidity (operating)		10% to 90% (with no condensation)			
Ambient environment (operating)		With no corrosive gas			
Terminal screw size		M3			
Power supply holding time		AC type: 10 ms min; DC type: 2 ms min. (A power interruption occurs if power falls below 85% of the rated voltage for longer than the power interruption time.)			
CPU weight	AC type	400 g max.	500 g max.	600 g max.	700 g max.
	DC type	300 g max.	400 g max.	500 g max.	600 g max.

Note : The specifications of the Expansion I/O Unit are the same as for the CPU except that the power is supplied from the CPU and the weight is 300g.

4-1

www.PAControl.com

APPENDIX IV

Instruction available in CPM1A and CPM2A

• Sequence Instructions

Sequence Input Instructions

Instruction	Mnemonic	Code	Function
LOAD	LD	0	Connects an NO condition to the left bus bar.
LOAD NOT	LD NOT	0	Connects an NC condition to the left bus bar.
AND	AND	0	Connects an NO condition in series with the previous condition
AND NOT	AND NOT	0	Connects an NC condition in series with the previous condition
OR	OR	0	Connects an NO condition in parallel with the previous condition.
OR NOT	OR NOT	0	Connects an NC condition in parallel with the previous condition.
AND LOAD	AND LD	0	Connects two instruction blocks in series.
OR LOAD	OR LD	0	Connects two instruction blocks in parallel.

Note: 0: Instruction keys allocated to the Programming Console.

Sequence Output Instructions

Instruction	Mnemonic	Code	Function
OUTPUT	OUT	0	Outputs the result of logic to a bit.
OUT NOT	OUT NOT	0	Reverses and outputs the result of logic to a bit.
SET	SET	0	Force sets (ON) a bit.
RESET	RESET	0	Force resets (OFF) a bit.
KEEP	KEEP	11	Maintains the status of the designated bit.
DIFFERENTIATE UP	DIFU	13	Turns ON a bit for one cycle when the execution condition goes from OFF to ON.
DIFFERENTIATE DOWN	DIFD	14	Turns ON a bit for one cycle when the execution condition goes from ON to OFF.

Note: 0: Instruction keys allocated to the Programming Console.

Sequence Control Instructions

Instruction	Mnemonic	Code	Function
NO OPERATION	NOP	00	---
END	END	01	Required at the end of the program.
INTERLOCK	IL	02	If the execution condition for IL(02) is OFF, all outputs are turned OFF and all timer PVs reset between IL(02) and the next ILC(03).
INTERLOCK CLEAR	ILC	03	ILC(03) indicates the end of an interlock (beginning at IL(02)).
JUMP	JMP	04	If the execution condition for JMP(04) is ON, all instructions between JMP(04) and JME(05) are treated as NOP(00).
JUMP END	JME	05	JME(05) indicates the end of a jump (beginning at JMP(04)).

APPENDIX V

Timer/Counter Instructions

Instruction	Mnemonic	Code	Function
TIMER	TIM	0	An ON-delay (decrementing) timer.
COUNTER	CNT	0	A decrementing counter.
REVERSIBLE COUNTER	CNTR	12	Increases or decreases PV by one.
HIGH-SPEED TIMER	TIMH	15	A high-speed, ON-delay (decrementing) timer.

Note: 0: Instruction keys allocated to the Programming Console.

Data Comparison Instructions

Instruction	Mnemonic	Code	Function
COMPARE	CMP	20	Compares two four-digit hexadecimal values.
DOUBLE COMPARE	CMPL	60	Compares two eight-digit hexadecimal values.
BLOCK COMPARE	(@)BCMP	68	Judges whether the value of a word is within 16 ranges (defined by lower and upper limits).
TABLE COMPARE	(@)TCMP	85	Compares the value of a word to 16 consecutive words.

Data Movement Instructions

Instruction	Mnemonic	Code	Function
MOVE	(@)MOV	21	Copies a constant or the content of a word to a word.
MOVE NOT	(@)MVN	22	Copies the complement of a constant or the content of a word to a word.
BLOCK TRANSFER	(@)XFER	70	Copies the content of a block of up to 1,000 consecutive words to a block of consecutive words.
BLOCK SET	(@)BSET	71	Copies the content of a word to a block of consecutive words.
DATA EXCHAGE	(@)XCHG	73	Exchanges the content of two words.
SINGLE WORD DISTRIBUTE	(@)DIST	80	Copies the content of a word to a word (whose address is determined by adding an offset to a word address).
DATA COLLECT	(@)COLL	81	Copies the content of a word (whose address is determined by adding an offset to a word address) to a word.
MOVE BIT	(@)MOVB	82	Copies the specified bit from one word to the specified bit of a word.
MOVE DIGIT	(@)MOVD	83	Copies the specified digits (4-bit units) from a word to the specified digits of a word.