NATURAL GAS REFUELING TECHNOLOGY (DISPENSER CONTROLLER)

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by

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CERTIFICATION OF APPROVAL

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Approved:

Assoc. Prof. Dr. Nordin bin Saad
(Project Supervisor)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

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

Liyana binti Hasnul

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ABSTRACT

The project is about designing and developing a controller to select and determine the switching time of multiple storage banks of an NGV refueling system. PLC has been chosen as the device to control due to its robustness and reliability. The controller is able to perform the switching requirements. The appropriate delays have been programmed in the PLC using timers and auxiliary relays to provide the optimal switching via offline. The thesis is mainly divided into five chapters which comprise of introduction, literature review, methodology, results and discussion, and finally, the conclusion. The introduction section highlights the importance of the approach used in the research work. Detail reviews on the equipments used in the project are provided. The procedure of the project and also the conceptual design for the hardware and software used is explained. The results of the simulation and finally, the conclusion and some recommendations to improve later on are presented.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

A dispenser controller is very important to transfer natural gas from higher pressure source to lower pressure receiver i.e. natural gas from a storage vessel to vehicle. Therefore, a suitable control strategy is required that could achieve minimum dispensing and refueling time.

The strategy used is based on time optimal control (TOC) technique which used the mass flowrate data from Coriolis flowmeter to acquire mass and mass flowrate of natural gas in pipeline [1]. In this technique, the Coriolis flowmeter is chosen because it is the only flowmeter that can measure natural gas in true mass [2]. Then, Newton's Second Law of Motion is applied as the basis for algorithm development [3]. From the Newton's Second Law of Motion, it is known that $F = ma$, where F is the force, m is the mass and a is the acceleration.

Figure 1 as shown below shows an implementation of present invention in a single bank NGV refueling. It could be seen that pressure from the storage bank and NGV vehicle attracting the load, one at the front (force from the NGV vehicle, *Fngv*) and another one at the rear of the load (force from the storage cylinder, *Fstorage*) [4].

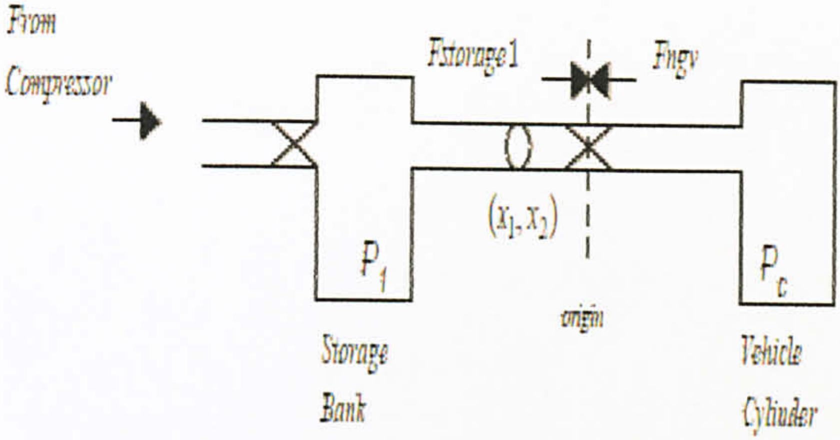


Figure 1: Implementation of present invention in single bank NGV refueling

The load could be measured by Coriolis flowmeter as a mass of natural gas that flows inside the pipeline. With higher pressure source at the rear of the load push the load forward in a positive direction whilst higher pressure source at the front of the load push it backwards in a negative direction, the total force in a pipeline when both pressures have equalized is stated as below:

$$Fstorage + (-Fngv) = F = 0 \qquad [1]$$

At the stage of mass equilibrium, the force between NGV cylinder and the storage bank would be equal. To achieve such equilibrium, longer time is required due to pressure differential which drives the system towards equilibrium. The implementation of the proposed technique in an actual NGV refueling system is shown below as Figure 2.

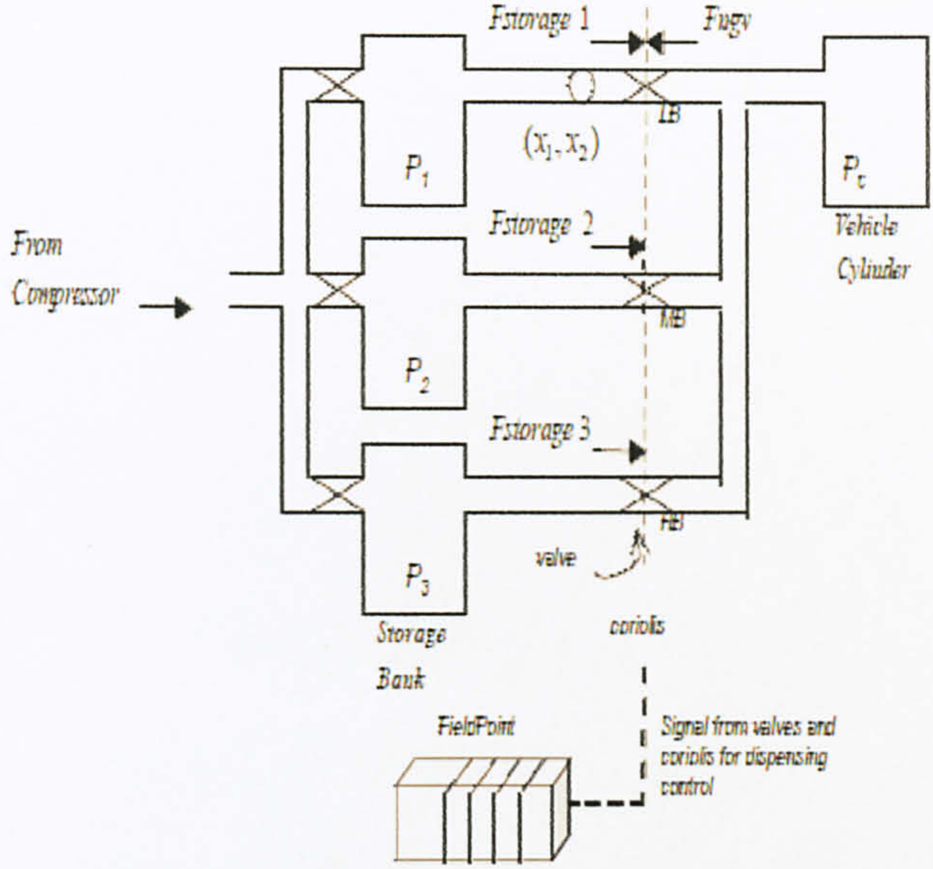


Figure 2: Implementation of present invention using same pressure source

Based on Figure 2, refueling of natural gas would start from low bank and switch to another bank wisely as the natural gas vehicle tank pressure approached the bank pressure. To apply the TOC switching algorithm developed from Figure 2, the procedure of the refueling could be simplified as shown in following section as Figure 3. TOC algorithm is a technique utilizing optimal control theory to solve the problem of specifying the amount time to turn ON switching for the NGV refueling.

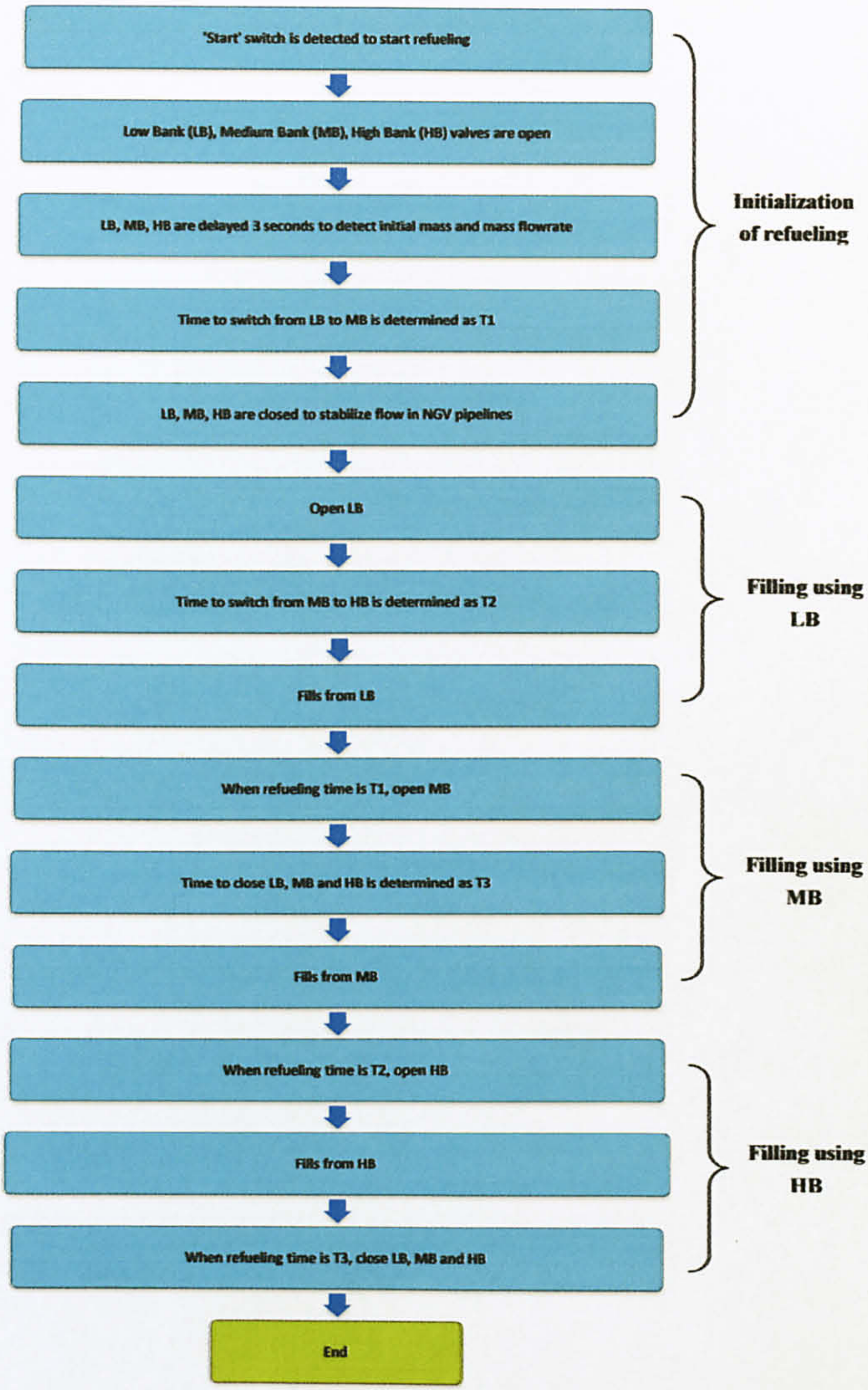


Figure 3: NGV refueling algorithm using TOC method

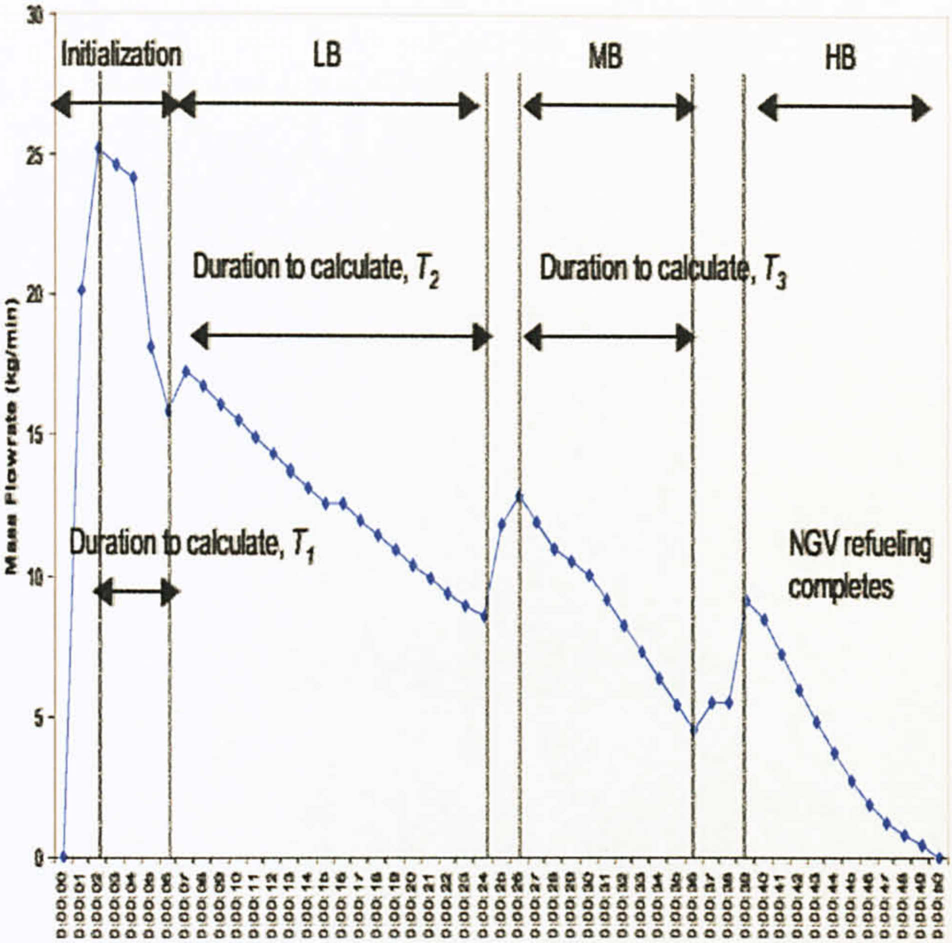


Figure 4: Result of mass flowrate for NGV refueling using TOC

Figure 4 shows measurement of mass flowrate when the NGV refueling was tested using constant pressure source as shown in Figure 2. This result is produced when TOC method is applied in NGV refueling method that was shown in Figure 3. The trend could be divided into four stages of refueling process: the initialization of refueling, the filling using low bank (LB), the filling using medium bank (MB) and the filling using high bank (HB). There are 4 different heights of spikes with different durations.

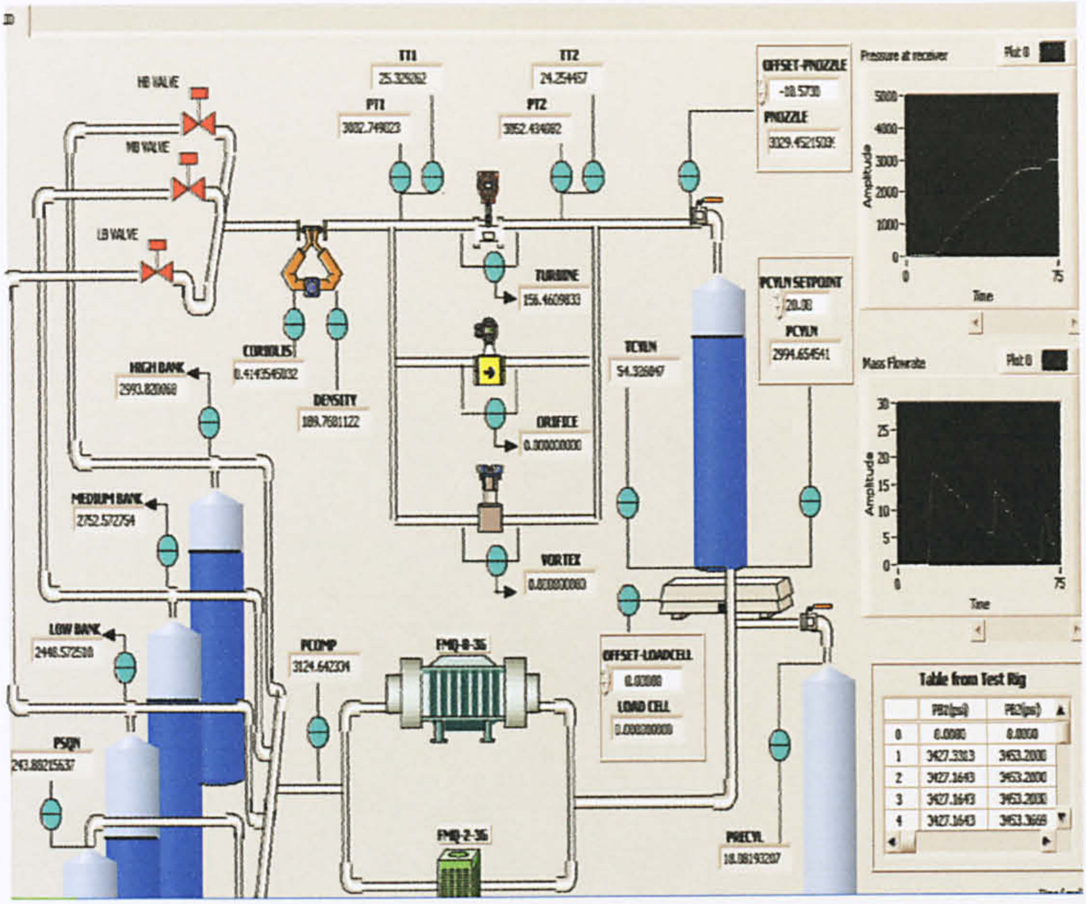


Figure 5: Simulation using LabVIEW

From Figure 5 shown as above, when the simulation is being done in LabVIEW, the result shows that to make the utilization of the compressor and buffer storage more efficient, natural gas stations usually operate using a three-stage cascaded storage system. The buffer storage is divided into three "banks" – termed as the low, medium and high pressure banks using valves controlled by the dispenser system. During refueling, the vehicle is first connected to the low-pressure bank. As the pressure in the bank falls and that in the on-board storage rises, the flow of gas decreases. When the flow rate has declined to a pre-set level, the system switches to the medium pressure bank, then finally to the high-pressure bank to complete the fill. The cascaded system results in a more complete "fill" rather than if the whole buffer storage was maintained at one pressure because it can utilize the compressor and storage with maximum efficiency.

In this project, PLC has been chosen as the device for performing as a controller to determine the switching time from one bank to another bank. This is because PLC is very accurate and reliable compared to other devices. The advantages of PLC can be listed down as follows:

- Flexible – Original Equipment Manufacturers (OEM) can provide system updates for a process by simply sending out a new program.
- Faster response time – PLCs operate in real time which means that an event taking place in the field will result in an operation or output taking place.
- Less and simpler wiring – Eliminates much of the hard wiring that was associated with conventional relay control circuits.
- Solid state – No moving parts.
- Modular design which is divided by compartments where separate modules can be plugged – easy to repair and expand.
- Capable of handling much more complicated systems.
- Sophisticated instruction sets are available for references.
- Allows for diagnostics and easy to troubleshoot if any problems occur.

1.2 Problem Statement

A minimum refueling time technique is required to transfer natural gas safely from higher pressure source to lower pressure receiver. NGV refueling system using multi-level pressure has been regarded better in terms of energy saving and efficiency, as compared to fixed-level pressure source. In this research, the main focus is to design and develop a controller using TOC algorithm to select and determine the switching time of a fixed-level pressure sources for refueling natural gas. The algorithm is based on time optimal control (TOC) technique which uses mass and mass flowrate signals acquired from Coriolis flowmeter.

1.3 Objectives

The objective of this project is to design a controller to determine switching time using TOC technique for refueling natural gas.

The objectives of the project could be summarized as follows:

- To implement TOC algorithm in programmable logic controller.
- To design TOC circuit and integrate it with programmable logic controller.
- To develop TOC program and embedded it in the programmable logic controller.

1.4 Scope of Study

In accomplishing the project, there are some scopes that need to be followed which could be summarized as follows:

- Study the control theory and its mathematical derivation of time optimal control for refueling.
- Understand the natural gas transferring process which is from higher pressure source to lower pressure receiver (using differential pressure concept).
- Develop a program based on the time optimal control theory implemented onto a PLC.
- Simulate the electronic circuit board using software i.e. PSpice, LabVIEW and Omron CX.

In this chapter, the background of study of the project, followed by the problem statement of the project, objectives of the project and the scope of studies have been discussed. In the next chapter will be discussing on the circuit designs based on the literature reviews.

CHAPTER 2
LITERATURE REVIEW

This chapter will discuss the development of a circuit design that could implement TOC for refueling natural gas and also discusses about the Optimal Control Theory. There are few elements that are important and should be considered in designing the circuit. However, the process flow of the system should be explained first before discussing the design part.

2.1 Elements

There are 4 basic elements that need to be considered when designing the circuit as shown in Figure 6 below:

1. Flowmeter sensor
2. Current-to-voltage converter
3. Programmable logic controller
4. Relay

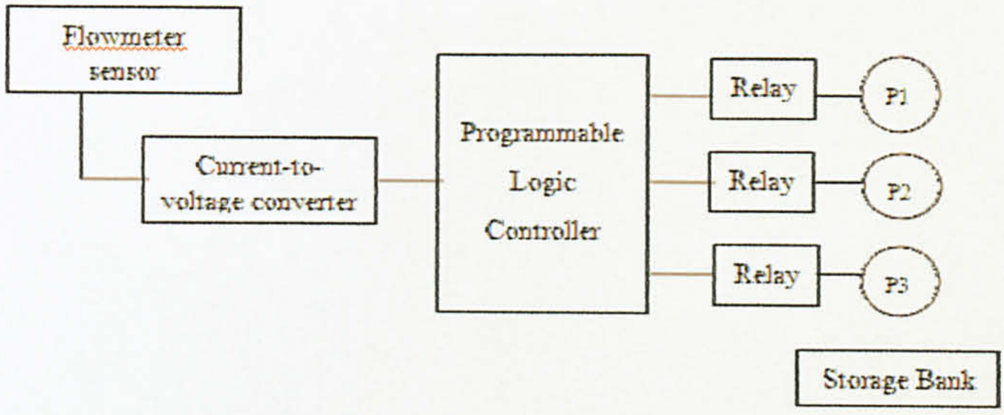


Figure 6: Overall circuit design

2.2 Flowmeter Sensor

Coriolis flowmeters are available in a number of different designs. A popular configuration consists of one or two U-shaped, horseshoe-shaped, or tennis-racket-shaped (generalized U-shaped) flow tube with inlet on one side and outlet on the other enclosed in a sensor housing connected to an electronics unit [5].

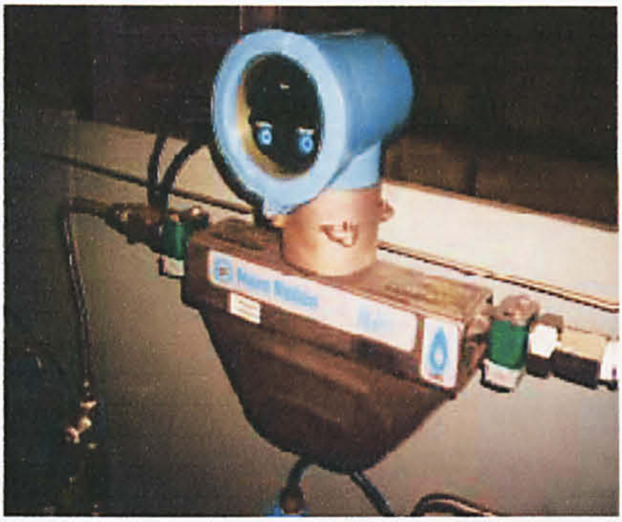


Figure 7: Micro Motion Coriolis flowmeter [6]

The Coriolis flowmeter operates based on the Coriolis force principle. A sine-wave voltage is applied to an electromagnetic drive which causes the internal flow tube of the Coriolis meter to oscillate in a direction perpendicular to the direction of the flow. When the process fluid flows through the tube, the vibration of the tube gives a slight angular rotation about its center [5].

From the process, two resultant Coriolis forces would be developed in the flow tube. On the tube where the fluid flow is away from the centre of the vibration, the resultant Coriolis force would oppose the rotational motion whilst the flow movement towards the centre would produce a Coriolis force that could aid the tube rotation. The resultant force then would produce sine wave which is measured and converted to mass flow signal. The signal could be transferred into two types i.e., amplitude and frequency. The amplitude is related to the mass flow whilst the frequency is related to the product density [5].

An advantage of Coriolis flowmeters is that it measures the mass flow rate directly which eliminates the need to compensate for changing temperature, viscosity, and pressure conditions. The vibration of Coriolis flowmeters has very small amplitude, usually less than 2.5 mm (0.1 in), and the frequency is near the natural frequency of the device, usually around 80 Hz. The vibration is commonly introduced by electric coils and measured by magnetic sensors [5].

2.3 Current-to-voltage Converter Circuit

A current-to-voltage converter is a circuit that performs current to voltage transformation. In electronic circuitry operating at signal voltages, it usually changes the electric attribute carrying information from current to voltage. Three kinds of devices are used in electronics: generators (having only outputs), converters (having inputs and outputs) and loads (having only inputs). Most frequently, voltage is used as input/output quantity [7].

Some typical applications of current-to-voltage converter are current measurements using voltage inputs, current-controlled voltage sources, and various passive and active voltage-to-voltage converters. In some cases, the simple passive current-to-voltage converter works well; but in other cases, there is a need of using active current-to-voltage converters. There is a close interrelation between the two versions - the active version has come from the passive one [7].

Ideal current-to-voltage converters have zero input resistance (impedance), so, that they actually short the input source. Therefore, in this case, the input source has to have some resistance. Ideally, it has to behave as a constant current source. Otherwise, the input source and the current-to-voltage converter can saturate.

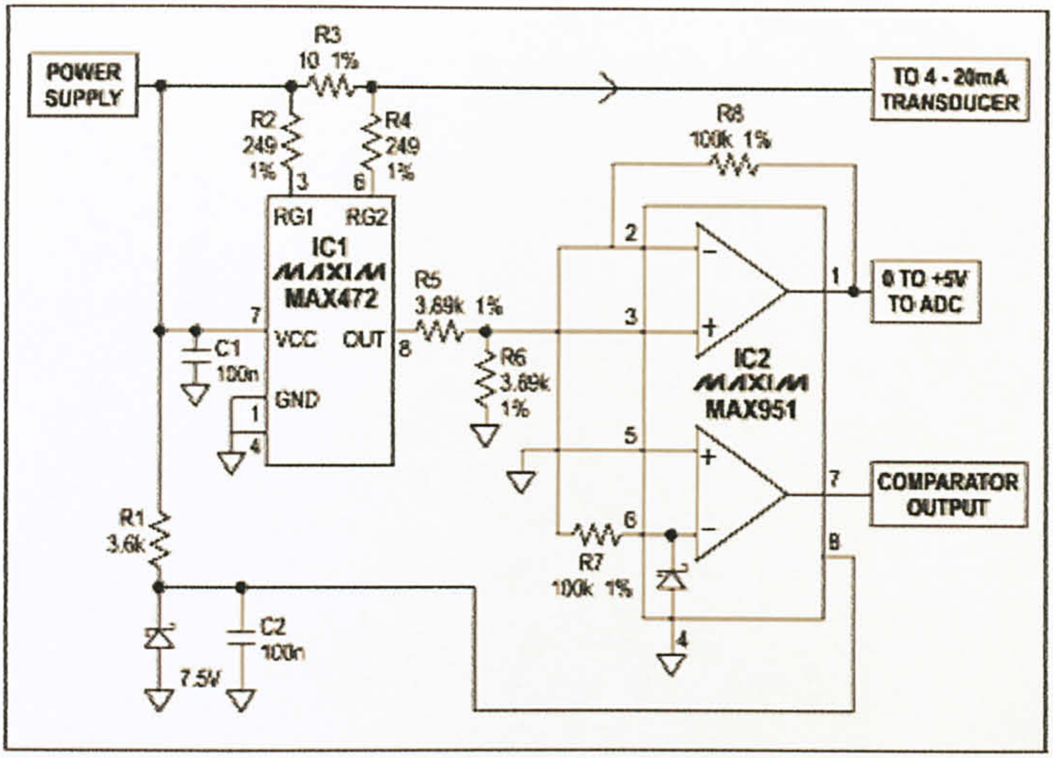


Figure 8: Circuit derives a 0-5V output from a 4-20mA current loop signal [8]

This is a simple circuit that converts a 4mA-20mA signal to a 0V-5V analog voltage ideal for conversion to digital with an analog-to-digital converter (ADC). The 4mA level from the transducer produces a 0V output and the 20mA level produces a 5V output. A current sense amplifier generates this analog 0V to 5V output. In addition, the circuit provides a comparator output that can be used to detect a zero current condition [8].

In standard process-monitoring equipment, the outputs of 4-20mA transducers must be converted to signal voltages suitable for measurement by an A/D converter. 4mA in the loop is usually calibrated as 0V for the quantity being monitored, and should therefore produce 0V at the ADC input. (Non-zero current enables the system to distinguish a broken loop from the zero-signal condition) [8].

2.4 Programmable Logic Controller

A Programmable Logic Controller (PLC) is basically a computer or Central Processing Unit (CPU) containing a program and connected to input and output (I/O) devices. The program controls the PLC so that when an input signal from an input device turns ON, the appropriate response is made. The response normally involves turning ON an output signal to some sort of output device. The input devices could be photoelectric sensors, pushbuttons on control panels, limit switches, or any other device that can produce a signal that can be input into the PLC. The output devices could be solenoids, switches activating indicator lamps, relays turning on motors or any other devices that can be activated by signals output from the PLC [9].

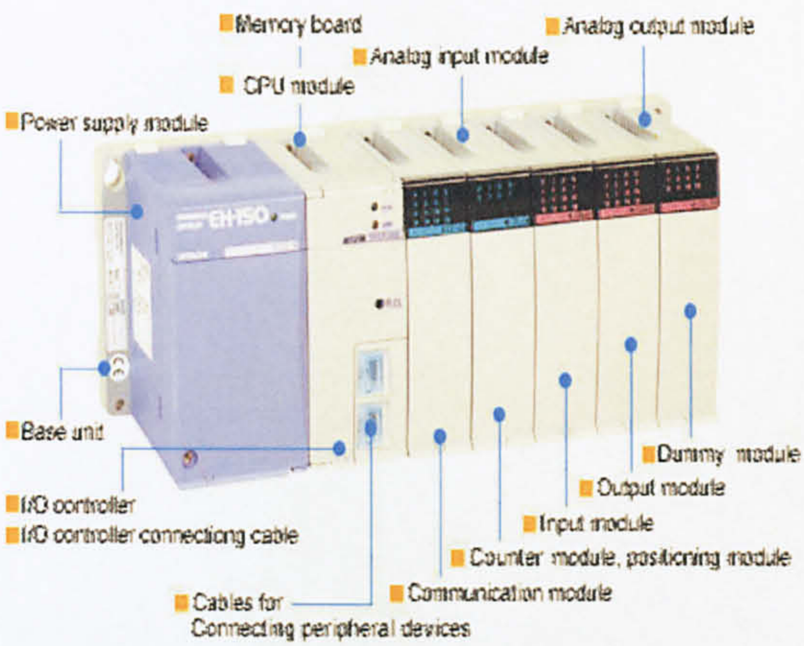


Figure 9: Programmable Logic Controller EH-150 Hitachi [10]

Figure 9 shows an example of a PLC. PLCs originate in relay-based control systems. The purpose of a PLC is to eliminate the high-cost associated with inflexible relay-controlled systems. Although the integrated circuits and internal logic of the PLC have taken place of the discrete relays, timers, counters and other devices, actual PLC operation proceeds as if those discrete devices were still in place.

PLC control provides computer capabilities and accuracy to achieve great deal more flexibility and reliability than is possible with relays [9]. It is also simple to install and troubleshoot. It requires low space requirements and power consumption. Rapid modification can be done to the program and can be carried out in parallel.

The symbols and other control concepts used to describe PLC operation come from relay-based control and form the basis of the ladder diagram programming method [9].

2.5 Relay

A relay is an electrically operated switch. Electric current through the coil of the relay creates a magnetic field which attracts a lever and changes the switch contacts. The coil current can be on or off so relays have two switch positions and they are double-throw (changeover) switches. Figure 10 shows an example of a relay whilst Figure 11 shows the circuit symbol for a relay [11].

Figure 10: Relay [12]

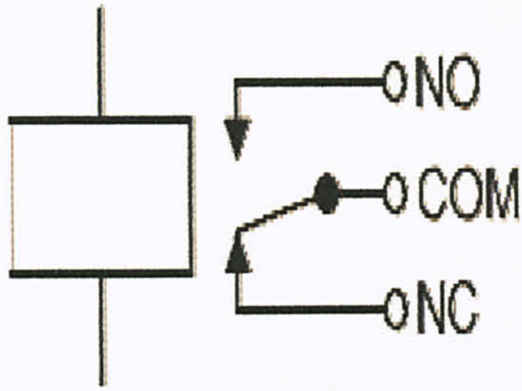


Figure 11: Circuit symbol for relay [13]

The relay's switch connections are usually labeled COM, NC and NO:

- COM = Common, always been connected, it is the moving part of the switch.
- NC = Normally Closed, COM is connected to this when the relay coil is off.
- NO = Normally Open, COM is connected to this when the relay coil is on.

Connect to COM and NO if you want the switched circuit to be on when the relay coil is on. Connect to COM and NC if you want the switched circuit to be on when the relay coil is off [13].

2.6 Optimal Control Theory

Optimal Control Theory is an extension of the calculus of variations for dynamic systems with one independent variable, usually time, in which control (input) variables are determined to maximize (or minimize) some measure of the performance (output) of a system while satisfying specified constraints. Theory is conveniently divided into two parts: optimal programming, where the control variables are determined as functions of time for a specified initial state of the system, and optimal feedback control, where the control variables are determined as functions of the current state of the system [14].

Examples of optimal control problems are: (1) determining paths of vehicles between two points to minimize fuel or time, and (2) determining feedback control logic for vehicles or industrial processes to keep them near a desired operating point in the presence of disturbances with acceptable control magnitudes [14].

Dynamic systems are conveniently divided into two categories: continuous dynamic systems, where the control and state variables are functions of a continuous independent variable, such as time or distance, and discrete dynamic systems, where the independent variable changes in discrete increments. Many discrete systems are discretized versions of continuous systems; the discretization is often made so that (1) the system can be analyzed or controlled by digital computers (or both), or (2) measurements of continuous outputs are made at discrete intervals of time (sampled-data systems) in order to share data transmission channels [14].

In this chapter, the four important elements of the circuit design based on the literature reviews which are flowmeter sensor, current-to-voltage converter, programmable logic controller, relay and Optimal Control Theory have been discussed in details. For next chapter will be discussing the methodology approaches for this project and the work plan of the project.

CHAPTER 3
METHODOLOGY

This chapter covers the flowchart of the procedures undertaken, followed by the circuit conceptual design for hardware and software, and finally the work plan for accomplishing the project. Based on the procedure flowchart as shown in Figure 12, for FYP 1, the project is mainly on research. It starts with the problem identification then, a literature review research on equipments used. Analyzing, designing and study the programmable logic controller (PLC) are coordinated after that. For FYP 2, the work consists of learning and familiarizing on software named Omron CX to program the PLC. The procedure can be simplified as shown in Figure 12.

3.1 Procedure Identification

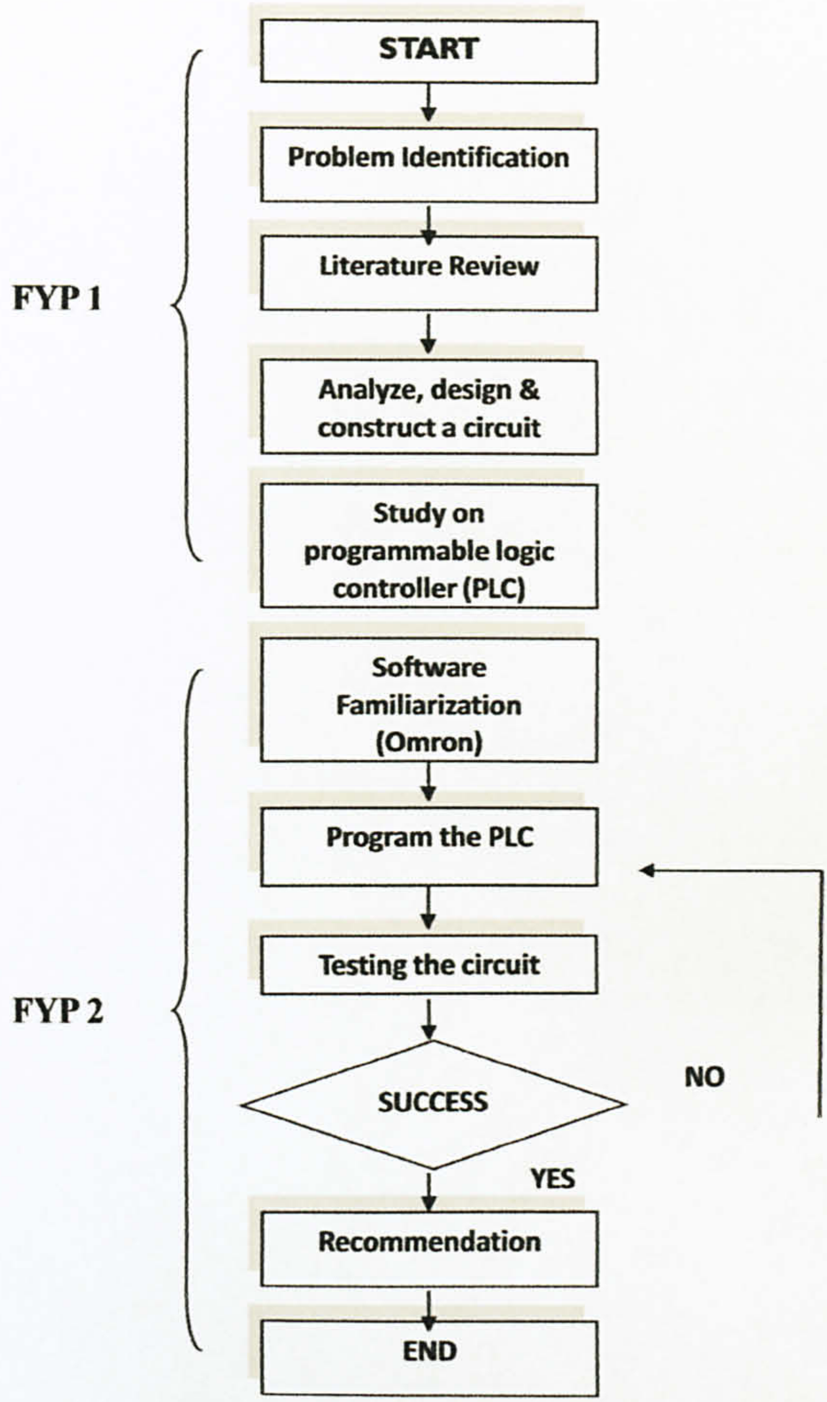


Figure 12: Flowchart of procedures

3.2 Conceptual Design

3.2.1 Hardware

Hardware used for the design of the circuit is as listed below:

Table 1: Hardware Item

Equipment/component	Purpose	Status
Converter 4-20mA to 1-5V circuit	To convert the analog input signal to analog output signal	Available in the laboratory
CQM1H-CPU Programmable Logic Controller	To control the input and output of devices for appropriate response	Available in the laboratory
Relay	To activate the valve (at least 24V)	Available and can be used in the laboratory

3.2.2 Software

Software that been used for this project are PSpice, LabVIEW and OMRON CX. At first, I planned to use Microcontroller 16F84A but, I have decided to use CQM1H Programmable Logic Controller (PLC). This is because of the accuracy and reliability of PLC compared to Microcontroller. PSpice is used for the simulation of the current-to-voltage converter circuit whilst LabVIEW is used to show the simulation for the refueling of natural gas from the storage bank to the vehicle. Omron CX is used to program the PLC to read the current from the simulator (pressure sensor) and also to determine the switching time for refueling natural gas.

3.3 Work Plan

After preparing the equipments and devices needed, the next step is to program the PLC using software named Omron CX. After the programming part is completed, I will test the programming to check if it is working as in the NGV refueling algorithm.

In this chapter, the methodology used in this project followed by the circuit conceptual design for hardware and software, and, lastly the work plan have been discussed. The next chapter will be discussing on the results obtained and discussions of the project.

CHAPTER 4
RESULTS AND DISCUSSIONS

This chapter concentrates on results and discussion of the programming of switching controller circuit in PLC.

4.1 Programmable Logic Controller

The equipment used for programming the Programmable Logic Controller (PLC) is using the Programmable Controllers model CQM1H as shown in Figure 13.

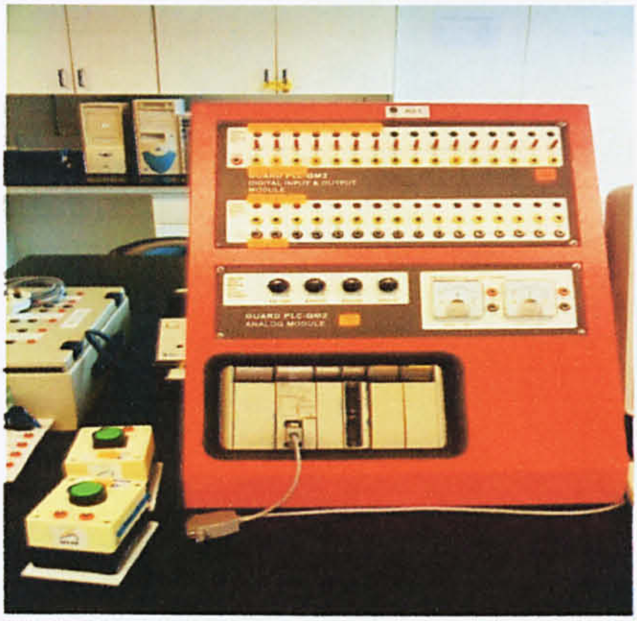


Figure 13: Programmable Controller CQM1H

Software used in programming this PLC is Omron CX. The symbols and other control concepts used to describe PLC operation are by using the ladder diagram programming method which is much similar to relay-based control diagram.

The CQM1H has an analog input output module (AIOM). The AIOM series number is MAB42. The input module has four channels while the output module has two channels.

The input module ranges is selectable either -10V to +10V, 0 to +10V or 0 to 5V/0 to 20mA. A modification to the input terminals is required if the signal to be converted is current from 0 to 20mA. It is not required for voltage conversion. The word-length of converted data is 12-bit. An initialization to the control word register is required before reading the input module.

The output module range is selectable either -10V to +10V or 0 to 20mA. The word-length of converter data for voltage and current conversions are 12 bit and 11 bit respectively. There is no initialization required to use the output module function.

Before start using the PLC, firstly, identify the inputs and outputs for the PLC. For this project, the inputs and outputs are identified as follows: The first input is a Switch button to activate the refueling of the NGV. The second input is the pressure sensor. In this case, 4-20mA simulator can be used as the pressure sensor to read the current flows from the simulator. While the output for the PLC are three relays that represents the LB, MB and HB. This is schematically as shown in Figure 14:

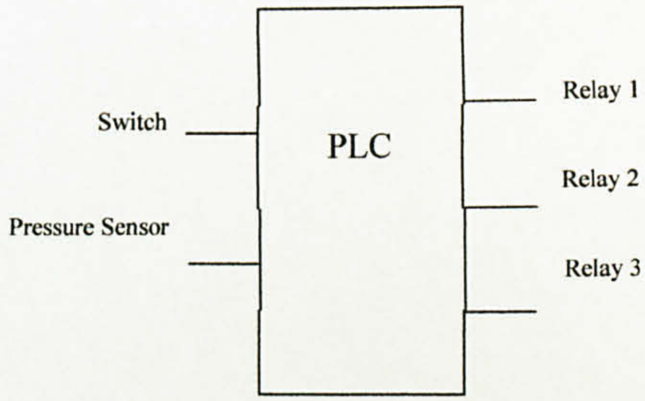
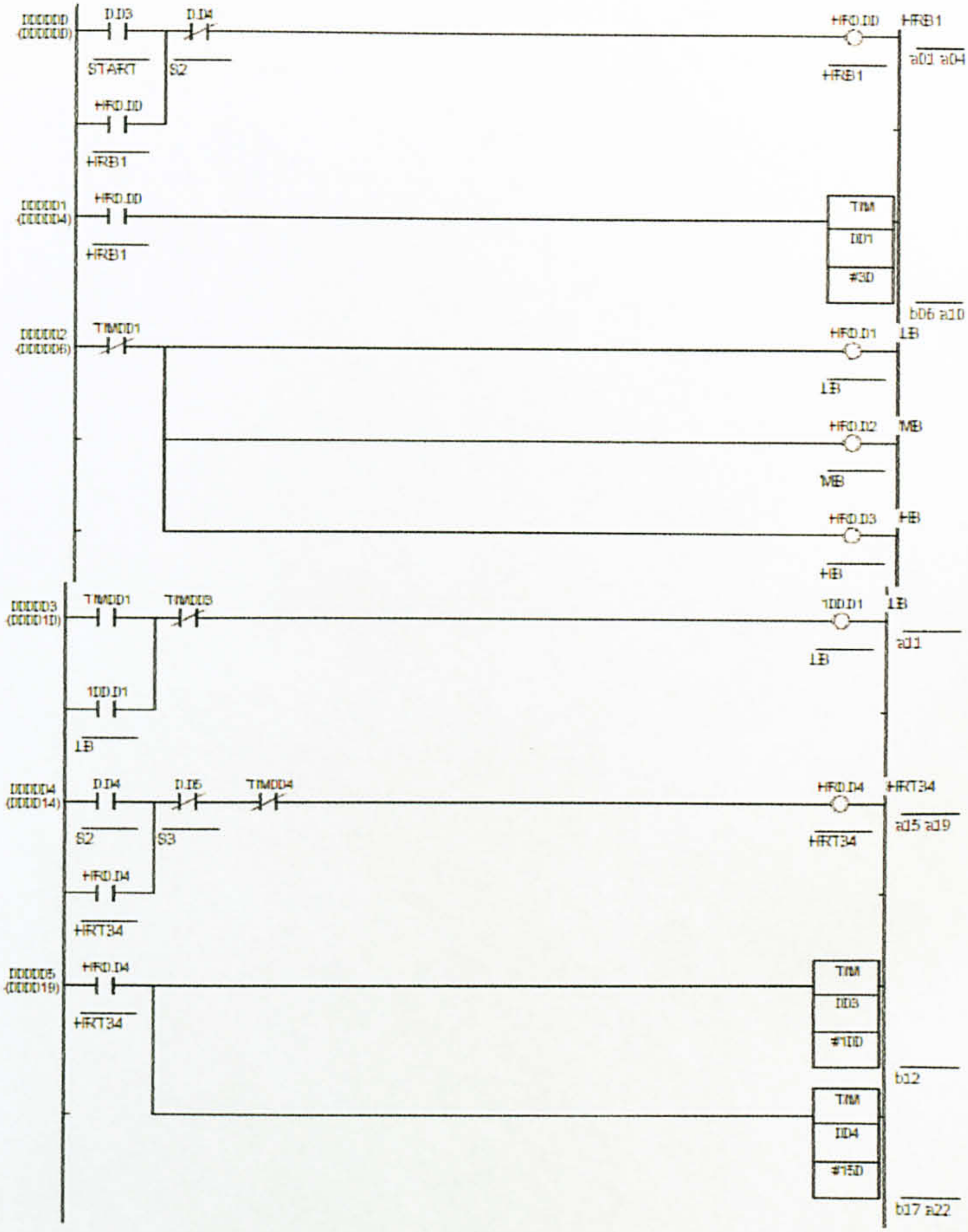


Figure 14: Diagram shows the inputs and outputs of PLC

4.1.1 Ladder Diagram

After identifying the inputs and outputs for the PLC, then, a ladder diagram programming to read current and the flowchart of TOC refueling can be developed as shown earlier in Figure 3. Figure 15 below shows the ladder diagram that has been developed to program the PLC.

In the first rung of the ladder diagram, when the START button is pushed, it will trigger Timer 1 to start counting for 3 seconds. All relays that represents the three banks: LB, MB and HB will on for 3 seconds. After 3 seconds, all relays will be off and LB will open to start filling. Timer 3 is assigned for the valve to open for 10 seconds and Timer 4 is assigned for the valve to close for 5 seconds. Since Timer 3 and Timer 4 are triggered at the same time, time delay of 10 seconds is assigned for Timer 3 and time delay of 15 seconds is assigned for Timer 4. LB will close when Timer 3 has finished counting and HRT34 will close after Timer 4 finished counting. This will switch MB to open and start filling. This process will continue until finally HB to complete the fill.



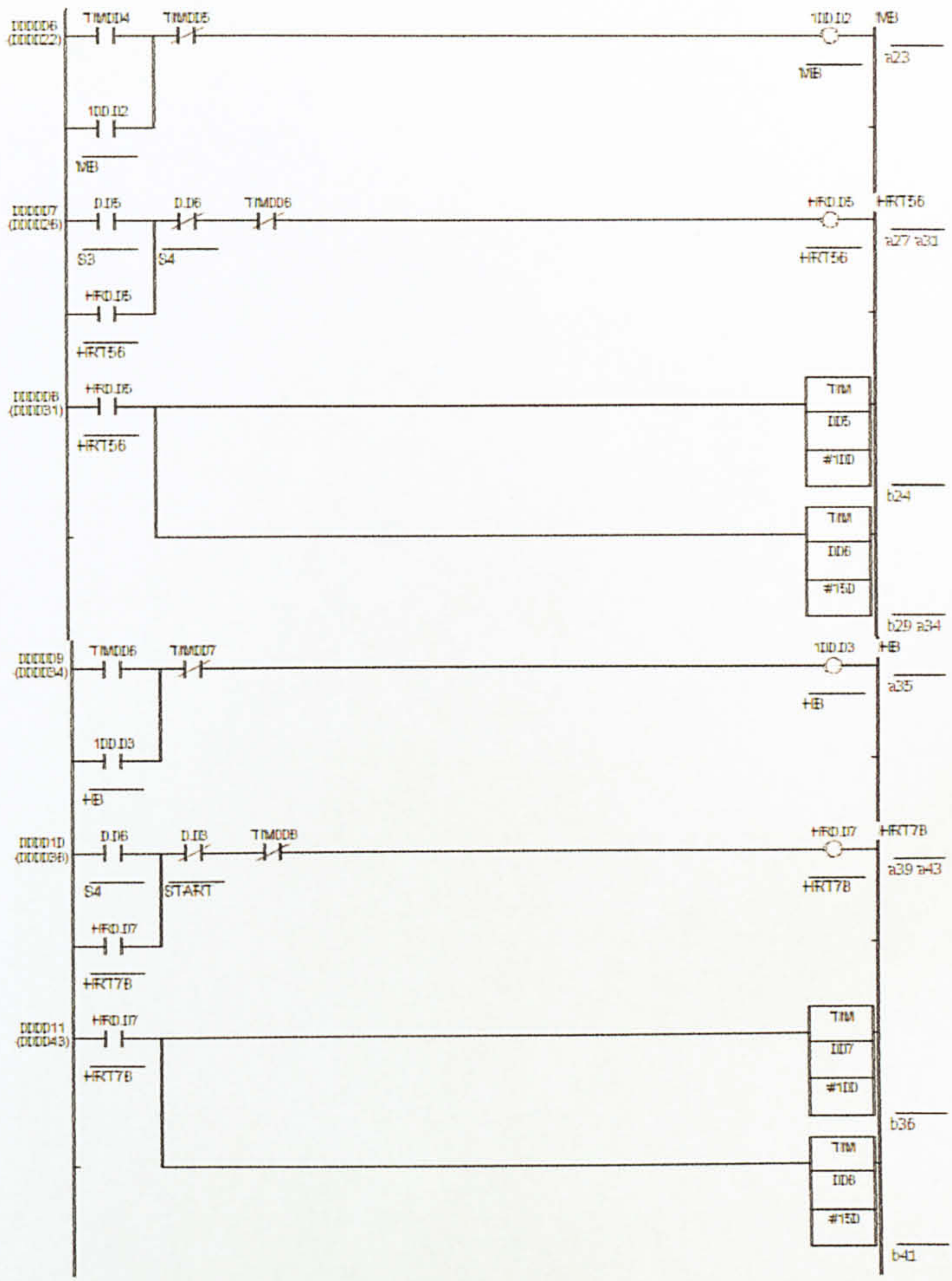


Figure 15: Ladder diagram of the program

The TOC algorithm is used to determine the time delay for T1, T2 and T3. In practical, these values will be downloading online with a modification to the ladder diagram as shown in Figure 15.

4.1.2 Boolean Equation

Boolean equations can be developed after ladder diagram programming has completed.

HRB1 = (START + HRB1).S2'

TIM01 = LB + MB + HB

LB = (TIM01 + LB).TIM03'

HRT34 = (S2 + HRT34).S3'.TIM04'

TIM03 + TIM04 = HRT34

MB = (TIM04 + MB).TIM05'

HRT56 = (S3 + HRT56).S4'.TIM06'

TIM05 + TIM06 = HRT56

HB = (TIM06 + HB).TIM07'

HRT78 = (S4 + HRT78).START'.TIM08'

TIM07 + TIM08 = HRT78

In this chapter, the results and discussion obtained while doing this project which are the ladder diagram and Boolean equation obtained from programming using the PLC has been discussed. Next chapter will discuss the conclusions and the recommendations for further improvement in the future.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

As mentioned earlier in the objective, the main purpose is to design a suitable controller that implement TOC algorithm for natural gas refueling. It is important to identify and consider many aspects before conducting appropriate lab testing. Firstly, switching algorithm is first studied; followed by development of programming the PLC for controlling the switching time of same pressure sources. Finally, the circuit would be tested.

In conclusion, the three-stage cascaded system can utilize the compressor and buffer storage with maximum efficiency. The TOC algorithm is feasible in minimizing the refueling time for NGV refueling.

5.2 Recommendations

Recommendation to complete the project is to use programmable logic controllers CQM1H which offers an advanced flexibility, powerful communication options, and has features traditionally found only in full rack PLC systems. This PLC also has advanced inner-boards, specialized I/O, and communication modules allow flexibility that no other PLC system in this class can offer.

Besides PLC, PIC microcontroller 16F84A also can be used to replace the PLC as a controller. This PIC is a powerful (200 nanosecond instruction execution) and yet easy-to-program (only 35 single word instructions) CMOS Flash/EEPROM-based 8-bit microcontroller into an 18-pin package. The microcontroller can be used for prototyping and updated without removing the device from the end product.

Another recommendation is to implement multi-level pressure sources that using different pressure for each storage tank. This can improve the energy efficiency and help to get faster refueling time compared to fixed-level pressure sources.

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www.hitachi-ies.co.jp/.../product_range.htm

[11] Relay homepage:

http://en.wikipedia.org/wiki/Relay

[12] Relay picture:

http://www.china-relay.com/images/mini-power-relay.jpg

[13] Relay webpage:

http://www.kpsec.freeuk.com/components/relay.htm

[14] Optimal Control Theory webpage:

http://www.answers.com/topic/optimal-control-theory

APPENDICES

APPENDIX A

PROJECT GANTT CHART

Table 2: Milestones for First Semester of Final Year Project

No.	Detail/Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Selection of Project Topic															
2	Preliminary Research Work			H							M					
				1							I					
3	Submission of Preliminary Report			N							D					
				1												
4	Project Work - Research										S					
											E					
5	Submission of Progress Report			B							M					
6	Seminar			R							B					
											R					
7	Project Work - Analyze and study of PLC			E							E					
											A					
8	Submission of Interim Report Final Draft			A							K					
9	Oral Presentation			K												

Table 3: Milestones for Second Semester of Final Year Project

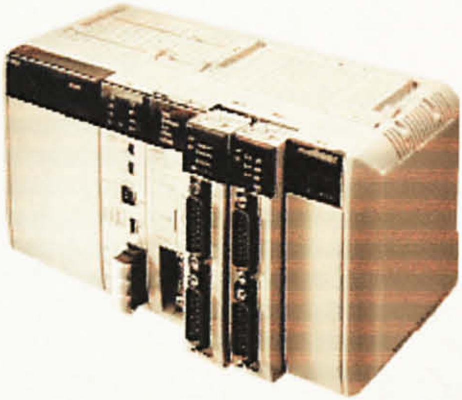
No.	Detail/Week	1	2	3	4	5	6	7	8		9	10	11	12	13	14	15
1	Project Work - Study on PLC																
2	Submission of Progress Report 1									M							
										I							
3	Project Work - Programming									D							
4	Submission of Progress Report 2									S							
										E							
5	Project Work - Programming									M							
6	Poster Exhibition									B							
										R							
7	Submission of Draft Report									E							
										A							
8	Oral Presentation									K							
9	Submission of Hard Bound Dissertation																

APPENDIX B

DATASHEET PLC CQM1H

Programmable Controller
CQM1H

The CQM1H's rack-less modular design lets you customize your control system by adding "inner boards" for advanced functions, as well as specialized I/O and communications modules. CQM1H offers the most flexibility of all PLC systems in its class.



- 4 different base CPUs to choose from; 16 DC inputs built in; expands up to 512 points
- No separate backplane required
- Inner Boards allow "customized" configuration of the CPU
- Serial communications inner board supports protocol macro feature for communication with third-party serial devices
- Supports all existing and new CQM1 I/O and specialized I/O modules
- Optional memory cassettes allow backup of sensitive data, provides a real-time clock
- ControllerLink network transmits 8 kword data packets at up to 2 Mbps; 32 nodes
- Advanced instruction set includes PID, floating point math, protocol macro instructions and more
- CompoBus/S, SYSMAC BUS and AS-interface masters support remote I/O
- Up to 15.2 kwords of program memory

Basic Configuration

Select the CPU and I/O modules (discrete, analog and dedicated special function types) then determine the power supply based on the current consumption. The I/O Control and Interface adapters give you the option of dividing the CPU and I/O system into two narrower units than the examples shown below. The CQM1H-CPU51/CPU61 models offer space-saving position and motion control solutions as well as additional analog and serial communications capabilities right at the CPU.

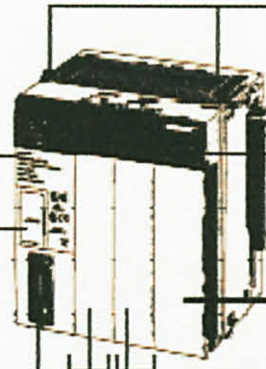
CQM1H modules are assembled with connectors on their sides.

CPUs

The four models of CPUs can be broadly divided into two groups: Models that support Inner Boards and the Controller Link Unit, and models that do not. The CPUs also vary in their program capacities, I/O capacities, memory capacities, and the presence of an RS-232C port, as shown in the *Basic Specifications* table, below.

■ NOMENCLATURE

The following illustration shows the main components of a CQM1H-CPU61 CPU.



■ OVERVIEW

Model	I/O capacity (See Note.)	Program capacity (words)	DM capacity (words)	EM capacity (words)	CPU Unit built-in inputs	Built-in serial ports		Inner Boards	Controller Link Module
						Peripheral port	RS-232C port		
CQM1H-CPU61	512	15.2 K	6 K	6 K	DC: 16	Yes	Yes	Supported	
CQM1H-CPU51		7.2 K	6 K	None					
CQM1H-CPU21	256	3.2 K	3 K					Not supported	
CQM1H-CPU11							No		

■ MAXIMUM NUMBER OF MODULES

CPU	Controller Link Module	Inner Boards	I/O Modules and Dedicated I/O Modules
CQM1H-CPU61	1 max.	2 max.	11 max. 16 max. using I/O Expansion and Control Interface modules
CQM1H-CPU51			
CQM1H-CPU21	Not supported.	Not supported.	
CQM1H-CPU11			

Note: I/O capacity = Number of input points (≤ 256) + Number of output points (≤ 256).

■ CPU UNIT SPECIFICATIONS

Characteristics

Item		Specifications
Control method		Stored program method
I/O control method		Cyclic scan and direct output/immediate interrupt processing
Programming language		Ladder-diagram programming
I/O capacity		COM1H-CPU11/21: 256 COM1H-CPU51/61: 512
Program capacity		COM1H-CPU11/21 : 3.2 kwords COM1H-CPU51 : 7.2 kwords COM1H-CPU61 : 15.2 kwords
User data memory capacity		COM1H-CPU11/21 : 3 kwords COM1H-CPU51 : 6 kwords COM1H-CPU61 : 12 kwords (DM: 6 kwords; EM: 6 kwords)
Instruction length		1 step per instruction, 1 to 4 words per instruction
Number of instructions		162 (14 basic, 148 special instructions)
Instruction execution times		Basic instructions: 0.375 to 1.125 µs Special instructions: 17.7 µs (MOV instruction)
Overseeing time		0.70 ms
Mounting structure		No backplane (Modules are joined horizontally using connectors)
Mounting		DIN Track mounting (screw mounting not possible)
CPU built-in DC input points		16
Maximum number of modules		Maximum of 11 modules total for I/O modules and Dedicated I/O modules
Inner Boards		COM1H-CPU11/21: None COM1H-CPU51/61: 2 Boards
Communications modules (Controller Link Module)		COM1H-CPU11/21: None COM1H-CPU51/61: 1 module
Types of interrupts	Input interrupts (4 inputs max.)	Input Interrupt Mode: Interrupts are executed in response to inputs from external sources to the CPU's built-in input points. Counter Mode: Interrupts are executed in response to reception of a set number of pulses (counted down) via the CPU's internal built-in input points (4 points).
	Interval timer interrupts (3 timers max.)	Scheduled Interrupt Mode: Program is interrupted at regular intervals measured by one of the CPU's internal timers. One-shot Interrupt Mode: An interrupt is executed after a set time, measured by one of the CPU's internal timers.
	High-speed counter interrupts	Target Value Comparison: Interrupt is executed when the high-speed counter PV is equal to a specified value. Range Comparison: Interrupt is executed when the high-speed counter PV lies within a specified range. Counting is possible for high-speed counter inputs from the CPU's internal input points, Pulse I/O Boards, or Absolute Encoder Interface Boards. (The High-speed Counter Board has no interrupt function, but can output bit patterns internally and externally.)
I/O allocations		I/O is automatically allocated in order from the Unit nearest to the CPU. (Because there are no I/O tables, it is not necessary to create I/O tables from a Programming Device.)

Memory Area Structure

Data area		Size	Words	Bits	Function
IR area	Input area	256 bits	IR 000 to IR 015	IR 00000 to IR 01515	Input bits are allocated to Input Units or Dedicated I/O Units. The 16 bits in IR 000 are always allocated to the CPU's built-in inputs. Bits in IR 001 to IR 015 are allocated to I/O or Dedicated I/O Units connected to the CPU.
IR area	Output area	256 bits	IR 100 to IR 115	IR 10000 to IR 11515	Output bits are allocated to Output Units or Dedicated I/O Units connected to the CPU.
	Work areas	2,528 bits min.	IR 016 to IR 089	IR 01600 to IR 08915	Work bits do not have any specific function and they can be freely used within the program.
			IR 116 to IR 189	IR 11600 to IR 18915	(A minimum 2,528 bits are available as work bits. Most bits in the IR and LR areas can be used as work bits when they are not used for their allocated functions, so the total number of available work bits depends on the configuration of the PLC.)
			IR 216 to IR 219	IR 21600 to IR 21915	
			IR 224 to IR 229	IR 22400 to IR 22915	
Controller Link status areas		96 bits	IR 090 to IR 095	IR 09000 to IR 09515	Status Area 1: Stores the Controller Link data link status information.
			IR 190 to IR 195	IR 19000 to IR 19515	Status Area 2: Stores the Controller Link error and network participation information.
MACRO operand area	Input area	64 bits	IR 096 to IR 099	IR 09600 to IR 09915	Used when the MACRO instruction, MCRO(99), is used.
	Output area	64 bits	IR 196 to IR 199	IR 19600 to IR 19915	
Inner Board slot 1 area		256 bits	IR 200 to IR 215	IR 20000 to IR 21515	These bits are allocated to the Inner Board mounted in slot 1 of a CQM1H-CPU51/61. High-speed Counter Board: IR 200 to IR 213 Serial Communications Board: IR 200 to IR 207
Analog settings area		64 bits	IR 220 to IR 223	IR 22000 to IR 22315	Used to store the analog settings when a CQM1H-AVB41 Analog Setting Board is mounted.
High-speed Counter, 0 PV		32 bits	IR 230 to IR 231	IR 23000 to IR 23115	Used to store the present values of high-speed counter 0.
Inner Board slot 2 area		192 bits	IR 232 to IR 243	IR 23200 to IR 24315	These bits are allocated to the Inner Board mounted in slot 2. High-speed Counter Board: IR 232 to IR 243 Absolute Encoder Interface Board: IR 232 to IR 239 Pulse I/O Board: IR 232 to IR 239 Analog I/O Board: IR 232 to IR 239
SR area		184 bits	SR 244 to SR 255	SR 24400 to SR 25507	These bits serve specific functions such as flags and control bits.
HR area		1,600 bits	HR 00 to HR 99	HR 0000 to HR 9915	These bits store data and retain their ON/OFF status when power is turned OFF or when the operating mode is changed.
AR area		448 bits	AR 00 to AR 27	AR 0000 to AR 2715	These bits serve specific functions such as flags and control bits.
TR area		8 bits	—	TR 0 to TR 7	These bits are used to temporarily store ON/OFF status at program branches.
LR area		1,024 bits	LR 00 to LR 63	LR 0000 to LR 6315	Used for 1:1 data link through the RS-232 port or through a Controller Link module.
Timer/Counter area		512 bits	TIM/CNT 000 to TIM/CNT 511 (timer/counter numbers)		The same numbers are used for both timers and counters. Timer numbers 000 to 015 can be used with TIMH(15) for interrupt-refreshed PVs to ensure proper timing without inaccuracy being caused by the cycle time.

Data area		Size	Words	Bits	Function
DM area	Read/ write	3,072 words	DM 0000 to DM 3071	—	DM area data can be accessed in word units only. Word values are retained when the power is turned OFF.
		3,072 words	DM 3072 to DM 6143	—	Available in CQM1H-CPU51/61 CPUs only.
	Read-only	425 words	DM 6144 to DM 6568	—	Cannot be written from the program (only from a Programming Device). DM 6400 to DM 6409: Controller Link parameters DM 6450 to DM 6499: Routing tables DM 6550 to DM 6559: Serial Communications Board Setup
	Error history area	31 words	DM 6569 to DM 6599	—	Cannot be written from the program (only from a Programming Device). Stores the time of occurrence and error code of errors that occur.
	PLC setup	56 words	DM 6600 to DM 6655	—	Cannot be written from the program (only from a Programming Device). Stores various parameters that control PLC operation.
EM area		6,144 words	EM 0000 to EM 6143	—	EM area data can be accessed in word units only. Word values are retained when the power is turned OFF or the operating mode is changed. (CQM1H-CPU61 CPU Unit only.)

Other Functions

Item	Specification
Macro instructions	Subroutines called by instructions containing arguments.
Min. cycle time	1 to 9,999 ms (Unit: 1 ms)
Cycle time monitoring	When the cycle time exceeds 100 ms, the Cycle Time Over Flag turns ON, and operation continues. (A setting can be made in the PLC Setup so that this error is not generated.) When the cycle time exceeds the cycle monitor time, operation is stopped. Cycle monitor time settings: 0 to 990 ms in 10-ms units, 0 to 9,900 ms in 100-ms units, 0 to 99 s in 1-s units. The maximum and current values of the cycle time are stored in the AR area.
I/O refreshing	Cyclic refreshing, refreshing by IORF(97), direct output refreshing (set in the PLC Setup), interrupt input refreshing. (The inputs that are refreshed can be set separately for input interrupts, high-speed counter interrupts, and interval timer interrupts in the PLC Setup.)
I/O memory status when changing operating mode	Depends on the ON/OFF status of the I/O Hold Bit (SR 25212).
Load OFF	All outputs on Output Units can be turned OFF when the CPU is operating in RUN, MONITOR, or PROGRAM mode. (Used for stopping output in emergencies, for debugging, etc.)
User-customized DIP switch setting	A pin setting on the DIP switch on the front of the CPU is stored in AR 0712. This setting can be used as an ON/OFF condition (e.g., to switch between trial operation and actual operation).
Mode setting at power-up	Possible
Debugging	Forced set/reset, differential monitoring, data tracing (scheduled, cyclic, or when instruction is executed).
Online editing	User programs can be overwritten in program-block units when the CPU is in MONITOR mode. With the CX-Programmer, more than one program block can be edited at the same time.
Program protection	Write-protection of user program and data memory (DM 6144 to DM 6655: read-only DM): Set using pin 1 of the DIP switch.
Error check	User-defined errors (i.e., user can define fatal errors and non-fatal errors using the FAL(06) and FALS(07) instructions.) (It is possible to stop operation using FALS(07) for fatal errors. User-defined error logs can be created in specific bits (logging) when using FAL(06).
Error log	Up to 10 errors (including user-defined errors) are stored in the error log. Information includes the error code, error details, and the time the error occurred.
Serial communications	Built-in mini-peripheral port: Programming Device (including Programming Console) connections, Host Links, no-protocol communications Built-in RS-232C port: Programming Device (excluding Programming Console) connections, Host Links, no-protocol communications, NT Links (1:1 mode), 1:1 Data Links RS-232C port and RS-422A/485 port on Serial Communications Board (sold separately): Programming Device (excluding Programming Console) connections, Host Links, no-protocol communications, NT Links (1:1 mode, 1:N mode), 1:1 Data Links, protocol macros