SUPERVISORY CONTROL FOR CONVENTIONAL UNITARY AIR CONDITIONING SYSTEM

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A project report submitted in
fulfillment of the requirement for the award of the
Degree of Master of Engineering

Faculty of Electrical & Electronic Engineering
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JULY 2012

ABSTRACT

The Supervisory control for conventional unitary air conditioning system is conceptually designed based on Programmable Logic Control (PLC) system. The advantage of PLC system is that it allows online monitoring continually and updates or modification can be performed interactively. This supervisory mode is applied to the conventional unitary air conditioner to avoid the frequent interruption or adjustment of the fan speed or temperature set point by users normal practice which has contributed to the surge of energy consumption due to the frequent on/off of the compressor. Three experiments have been performed at different control methods to simulate user's daily practice. The first control method is the Variable Set point with high speed fan, the second control method is the Fixed Set point with high speed fan and the third control method is a Supervisory Control; a fixed set point with variable fan speed. The experiments have been conducted for eight (8) hours and the statistic data of accumulated energy consumption based on one unitary air conditioner with capacity of 1 Horse Power are acquired and sampled at the time interval of 30 minutes for the analysis. From these experiments, the supervisory control has consumed 4.2 *kWh* per day which is 82.35% compared to normal consumption of 5.1 *kWh*. This result translated into 0.9 *kWh* or 17.65% of total energy saving per day. The consistency of the air compressor operation in this control method has become a major factor in achieving indoor temperature steadiness whilst improving the energy savings.

ABSTRAK

Supervisory Control bagi sistem penghawa dingin jenis konvensional ini adalah direka berdasarkan penggunaan sistem Pengawal Bolehaturcara Logik (PLC). Sistem PLC digunakan kerana kelebihannya yang membenarkan pemantauan atas talian serta pengubahsuaian program secara interaktif. Mod *Supervisory* diaplikasikan ke dalam sistem penghawa dingin jenis konvensional bagi mengelak kekerapan pengguna mengubah kelajuan kipas serta suhu yang mana tindakan ini boleh menyumbang kepada kenaikan penggunaan tenaga secara mendadak disebabkan kekerapan pemampat angin dihidup/dimatikan semasa penghawa dingin beroperasi. Tiga ujikaji telah dijalankan pada kaedah pengawalan yang berbeza bagi melihat kesan penggunaan harian pengguna iaitu kaedah pertama adalah nilai rujukan berubah-ubah dengan kipas berkelajuan tinggi, kaedah kedua adalah nilai rujukan tetap dengan kipas berkelajuan tinggi dan kaedah ketiga adalah *Supervisory Control*; nilai rujukan tetap dengan kelajuan kipas berubah-ubah. Ujikaji dijalankan selama lapan (8) jam, data statistik terhadap penggunaan tenaga direkod dan disampelkan kepada sela masa 30 minit untuk tujuan analisa. Hasil ujikaji menunjukkan kaedah kawalan ketiga telah mencatatkan penggunaan tenaga sebanyak 4.2 *kWh* sehari iaitu 82.35% berbanding dengan penggunaan harian biasa iaitu 5.1 *kWh*. Keputusan ini diterjemahkan lagi kepada penjimatan tenaga sebanyak 0.9 *kWh* atau 17.65% sehari. Ketetapan pemampat angin beroperasi di dalam kaedah ini telah menyumbang kepada faktor utama tercapainya kemantapan suhu dalam bilik serta penambahbaikan terhadap penjimatan tenaga.

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LIST OF ABBREVIATIONS

PLC	-	Programmable Logic Controller
PID	-	Proportional + Integral + Derivative
PI	-	Proportional + Integral
DCS	-	Distribution Control System
AI	-	Artificial Intelligence
Clo	-	Insulative Clothing Value
MRT	-	Mean Radiant Temperature
HVAC	-	Heating, Ventilation, and Air Conditioning
SCT	-	Supervisory control theory
DES	-	Discrete Event Systems
SCADA	-	Supervisory Control and Data Acquisition
NEMA	-	According to The National Electrical Manufacturers Association
I/O	-	Input/Output
CPU	-	Central Processing Unit
ROM	-	Read Only Memory
RAM	-	Random Access Memory
EPROM	-	Erasable Programmable Read Only Memory
PC	-	Personal Computer
VFD	-	Variable Frequency Drives
RPM	-	Rotation Per Minute
kWh	-	Kilo Watt Per Hour

CHAPTER 1

INTRODUCTION

1.1 Introduction

Most offices, classrooms and laboratories nowadays are equipped with unitary systems such as multi-unit or split unit type air conditioner due to the natural demand for thermal comfort. In Malaysia, the number of air conditionings used has increased significantly from 13,251 units in 1970 to 253,399 in 1991, and predicted to be about 1,511,276 in year 2020 [1] thus, has substantially increased the electricity consumption. Therefore, Malaysian government has ordered all government offices to set their air-conditioner temperature no lower than 24 degree Celsius to cut electricity bills and also to give nature a helping hand.

Many factors can affect the electricity consumption such as the frequent on/off of a compressor for an air conditioner that may lead to instantaneous power surge [2]. Research shows that the compressor consumes around 90% of the total energy consumption of an air conditioning system [3]. Since these unitary air conditioners are designed based on the indoor temperature instead of human comfort condition [4] therefore, the frequent of adjusting the fan or the temperature mode (thermostat) by users in the same room may affect the frequent starting and stopping (on/off) of the compressor.

Conventionally, unitary air conditioner systems are installed with PID or on/off control system to control the temperature in a specific room/area and the traditional method is also applied to start or stop (on/off) the air conditioner system.

1.2 Problems statement

Frequent of adjusting the fan or the temperature mode (thermostat) by users in the same room may affect the frequent on/off of the compressor of an air conditioner that contributes to the surge of energy consumption. To avoid this interference, a supervisory control technique is needed. Instead of adjusting the thermostat frequently, the fans speed of the air-conditioner can be controlled to provide a comfortable condition to the indoor temperature whilst the air compressors remain on/off.

This project aim is to design a supervisory control technique for a conventional unitary air conditioner using Programmable Logic Controller (PLC) approach to achieve both the steadiness in the room temperature and energy savings in Kuching Sarawak Polytechnic, Malaysia.

1.1 Objectives of project

The objectives of this project are identified and stated as follows:

1. To estimate the energy consumption of a conventional unitary air conditioner based on user’s daily practice.
2. To design a supervisory control technique for conventional unitary air conditioner by using PLC approach.
3. To compare the accumulated energy consumptions of a conventional unitary air conditioner based on user’s daily practices and the proposed supervisory control technique.

1.3 Scopes of project

The scopes of project emphasize the specific methodology applied in every objective identified earlier.

1. The accumulated energy consumption will be analysed via experiments. Two different experiments will be conducted by using two different set points. First experiment will simulate the user’s daily practice by applying variable set point

which is the interrupted set point (Disturbance) where the temperature is varied between 18˚C and 26˚C with fan on high speed mode.

The estimated accumulated energy consumption reading obtained in this experiment will become the reference point to other experiments afterward. Second Experiment is the Fixed Set Point where the temperature set point is fixed to 24˚C with fan on high speed mode. The accumulated energy consumption for both experiments will be measured by using a Power Meter.

2. The PLC is used as the control technique to control the speed of the fan according. Experiment will be conducted to test the PLC program. The test apparatus will be equipped with an OMRON PLC CQM1H-CPU21 linked to a personal computer via an USB-RS232 serial communication port to provide the supervisory control mode.

3. The third experiment will be conducted where the temperature set point is fixed and the fan speed is varied consistently to simulate the condition for the PLC program. The accumulated energy consumed by this experiment will be compared to the accumulated energy consumption obtained in experiment 1 and 2.

1.5 Organization of the thesis

This thesis is composed of five chapters covering introduction, literature review, methodology, analysis and result and the last chapter is a discussion and conclusion.

Chapter 1 explains background of the focus study of the project where the number of air conditionings used has increased significantly increment of air conditioners and an overview of the project and the effect control method to the energy consumption when a conventional air conditioner is used. It also consists of the problems statement, objectives and also scope of the project.

Chapter 2 provides recent literature reviews of work done by researchers that related to PLC and other AI Controller and some theoretical information involved that convey to the development of this project. All the journals and the books that have some attachment to this project are used as references to guide and help in completing this project. Each of this part is explained based on this finding.

Chapter 3 explains the specific methodology for every project scope and objective are elaborated by presenting and emphasizing the details of methods applied. Here, the block diagrams and flowcharts related to each objective or scope are also elaborated and revealed.

Chapter 4 gives every detail of the results based on the experiments and testing implemented in Chapter 3 is analyzed. The results are visualized by using Microsoft Excel and PLC program is tested by using Cx-programmer Version 8.2.

Chapter 5 presents the overall discussion on the results obtained and comparison may be done based on the literature reviews discussed in chapter 2. Here, the overall conclusion of development of the project is also enclosed together with suggestion and recommendation for future work or enhancement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides reviews of work done by researchers and some theoretical information involved that convey to the development of this project.

2.2 Reviews of the research studies related to PLC

Table 2.1 shows a list of studies conducted by different researcher. These papers are selected based on the practical application and the control techniques implemented in the studies. The reviews are made to see the focus of studies regarding the air conditioning system. Here, the techniques used and Practical applications are investigated to review types of improvement in the air-conditioning system and the table also reveals the application of PLCs technique is preferable for the practical application and which becomes the main focus of this project.

Table 2.1: A List of the Research Studies

No	Authors and year	Title of studies	Techniques used	Practical Application	Remarks
1.	Po-Jen Cheng, Chin-Hsing Cheng, Tzai-Shiang Chang (2011)	Variant-Frequency Fuzzy Controller for Air Conditioning Driver by PLC	Fuzzy Controller & PLC	Experiment is done using PLC and Fuzzy Logic control	Speed variation of a compressor for temperature & humidity balance. Outcomes showed no significant result on energy efficiency.
2.	Zhijian Hou; Zhiwei Lian (2009)	Application of Temperature Fuzzy PI Controller Based on PLC	PI and Fuzzy-PI Controller & PLC	Simulation is done using PID Module in PLC	Comparison of PI and Fuzzy PI Controller response. Fuzzy-PI control gives a better performance.
3.	C.B. Chiou, C.H.Chiou, C.M. Chu, S.L. Lin (2009)	The application of fuzzy control on energy saving for multi-unit room air-conditioners.	Fuzzy Controller & PLC	Experiment is done using PLC and Fuzzy Logic control	Comparison of Fuzzy & On/Off control performance; Energy saving is proven in the result.
4.	Wang Jin; Wang Gang ; Tang Changliang ; Liu Sichang (2009)	Design of Ice-Storage Air Conditioning Control System Based on PLC & Touching Screen	Distribution Control System (DCS) & PLC	Experiment is done using PLC	Control performance of the Ice-storage air conditioner can be monitored through the DCS
5.	Zhang Liang; Liu Jianhua; Wu Ruofei; Gong Xiaobing (2009)	Design of Performance Testing System for Train Air Conditioning	Fuzzy-PID Control & PLC	Simulation is done using Fuzzy-PID control and PLC	Using touch screen system to get precise adjustment of temperature & humidity in train chamber is achieved

The paper, *Variant-Frequency Fuzzy controller design for air conditioning driver by PLC* [5] reveals only the capability for full control of speed variation of compressor for any required range of temperature and humidity which balances the requirement of comfort but does not show any significant result in terms of energy efficiency. However, more sophisticated command structures are conceivable with the use of PLC.

In the *Application of temperature fuzzy PI controller based on PLC* [6] shows the design of fuzzy-PI controller of temperature in air conditioning and the way of cultivating this controller on PLC. This design is done based on simulation where the fuzzy-PI controller can be exploited in the using the module of PID controller in PLC. The result of this controller is then compared to the PI controller in terms of temperature control performance. This paper only stressed on the performance of each controller but does not emphasize the technique used in the system even though the application of PLC is mentioned in the research work.

The experiment system mentioned in the paper titled *the application of fuzzy control on energy saving for multi-unit room air-conditioners* [2] reveals the capability of PLC in converting analogue signals to digital signals by an analogue input module. The result proves the reliability of the PLC system when the experiment is conducted.

In the *Design of Ice-Storage Air Conditioning Control System Based on PLC and Touching Screen* [9] reveals that PLC based control system is not only capable of running stably and reliably, but also has higher control accuracy. The touching screen can communicate precisely with PLC, and monitor and control the statuses of ice-storage air conditioning system promptly via MPI (multi-point interface) protocol.

PLC has been used to control various industrial processes due to their simplicity of programming. The control algorithms normally used in that PLC are simple but yet effective ones such as those of the PID or compensator types. [8]. From the review, PLC is still widely preferable because of its good reliability and flexible to program when combining it to any Artificial Intelligence Control or other control methods. The use of PLC has greatly reduced the cost of implementing new control circuits on the plant floor and has reduced the time needed to make various changes circuit as demanded by any given process. It also provides supervisory control where the system can be monitored whenever the failure occurs in the system. Therefore, PLC is adopted in this proposed project as the core hardware control to the system designed.

2.3 Thermal Comfort Factor

Thermal comfort is defined as the state of mind in humans that expresses satisfaction with the surrounding environment [11]. They are six comfort condition or variables [12] (Activity Level, Air Velocity, Insulative Clothing Value (Clo), Ambient Air Temperature, Mean Radiant Temperature (MRT) and Relative Humidity) producing a single comfort index called Thermal Comfort. Many control strategies of HVAC (Heating, Ventilation, and Air Conditioning) system have been designed not only improves thermal comfort but also reduces system energy consumption.

In the *Field Studies on Thermal Comfort of Air Conditioned and Non Air-Conditioned Buildings in Malaysia* [13], the study showed that respondents in the tropic environment such as Malaysia may have a higher heat tolerance since they accepted the thermal conditions which exceeded the standard. It is therefore convenient for some naturally ventilated buildings in Malaysia to use fans (mechanically ventilated) instead of air-condition to improve the indoor thermal condition with the interest to reduce energy consumption in buildings. It is also proven that the respondents are able to adapt to the environment that they are used to. In this paper it is agreed that in Malaysia, some buildings built have traditionally relied on a combination of cross-ventilation and mechanical ventilation by fans (the air movement) to achieve thermal comfort and as an interest to reduce energy consumptions in buildings.

The higher air movement which is also known as air velocity is an effective factor in providing comfort to the indoor. Therefore, in this proposed project, Supervisory Control includes this as the key factor in the control strategies to reduce the cooling need, thus allowing energy saving.

2.4 Definition Of Supervisory Control

Supervisory Control definition according to McGraw-Hill Dictionary of Scientific & Technical Terms is defined as a control panel or room showing key readings or indicators (temperature, pressure, or flow rate) from an entire operating area, allowing visual supervision and control of the overall operation. Supervisory control allows operator continually monitors and interactively updates or modifies the program. The most important aspect of Supervisory Control is its ability to ‘package’ information for visual display to human operator [14]. Supervisory control theory (SCT) introduced by Ramadge and Wonham provides a powerful framework for control of Discrete Event Systems (DES). The theory enables synthesis of closed loop control systems for DESs by making some assumptions on the system that is to be controlled, and on the supervisor that is to control the system.

2.5 Programmable Logic Controller (PLC) As A System Controller

In Supervisory Control and Data Acquisition (SCADA) systems and Distributed Control Systems, PLCs are implemented as local controllers within a supervisory control scheme. PLC is an industrial computer used to monitor inputs and the decisions are made based on its program or logic, to control (turn on/off) its outputs to automate a machine or a process. According to The National Electrical Manufacturers Association (NEMA), a programmable logic controller is defined as a digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions for implementing specific functions such as logic, sequencing, timing, counting, and arithmetic to control, through digital or analog input/output modules, various types of machines or processes. The common advantages why PLC is used extensively in almost all industrial processes because it is:

i. Rugged

   Designed to withstand vibrations, temperature, humidity, and noise.

ii. I/O interface

   Interfacing for inputs and outputs already inside the controller.

iii. Easily programmed

   It has an easily understood programming language.

The basic structure of PLC is shown in Figure 2.1. Basic structure consists the following elements:

i. Central Processing Unit (CPU)
ii. Memory
iii. Power supply
iv. Input/Output sections
v. Programming Devices

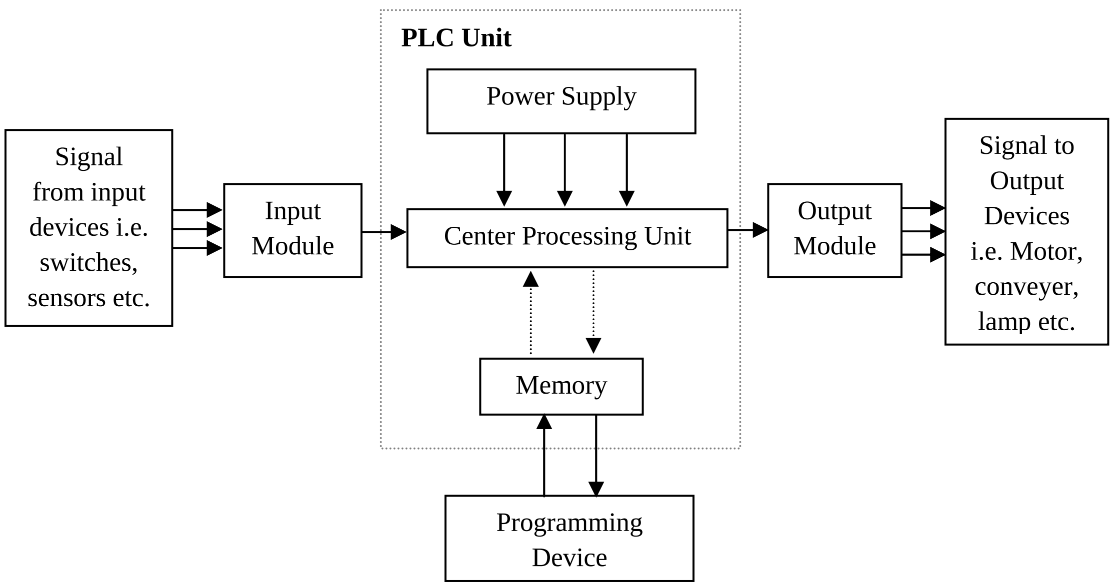


Figure 2.1 The basic structure of PLC

2.5.1 Central Processing Unit, CPU

The function of the CPU is to control the operation of memory and I/O devices and to process data according to the program or in other words, it is responsible for reading inputs, executing the control program, and updating outputs. It is always referred to as the *processor* consists of the arithmetic logic unit, timing, program counter, address stack, and instruction register.

2.5.2 Memory

The memory of a PLC basically consists of Read Only Memory (ROM) ; Permanent storage for the operating system and the fixed data used by the CPU and Random Access Memory (RAM); stores data/information on the status of input and output devices and the values of timers and counters and other internal devices. The PLC program is a high-level program which is written in Ladder Diagram. Then, the Ladder Diagram is converted into binary instruction codes so that they can be stored in RAM or Erasable Programmable Read Only Memory (EPROM). Each successive instruction is decoded and executed by the CPU. The PLC memory is organized into three regions: input image memory (I), output image memory (Q), and internal memory (M). The PLC program uses a cyclic scan in the main program loop such that periodic checks are made to the input variables.

The program loop starts by scanning the inputs to the system and storing their states in fixed memory locations (I). The PLC program is then executed rung-by-rung. Scanning the program and solving the logic of the various rungs determine the output states. The updated output states are stored in fixed memory locations (Q). The output values held in memory are then used to set and reset the physical outputs of the PLC simultaneously at the end of the program scan.

2.5.3 Power Supply

The power supply is the section that provides the PLC with the voltage and current it needs to operate. In this project, the PLC model CQM1H-CPU 21 is used where the power supply used in the I/O devices work at 24 Vdc. Some PLC controllers have electrical supply as a separate module, while small and medium series already contain the supply module, depending on models of PLC.

2.5.4 Input/Output Sections

Each input and output connection point on a PLC has an address used to identify the I/O bit depending on the model of the PLC. CQM1H-CPU 21 has 16 bits I/O to be used as shown in Figure 2.2 and Figure 2.3; the PLC model used in this Supervisory Control Method. Sensors and switches are among the famous Input Devices while Indicator lamps, Buzzer, Relay Contacts, Motors are commonly used as the Output devices.

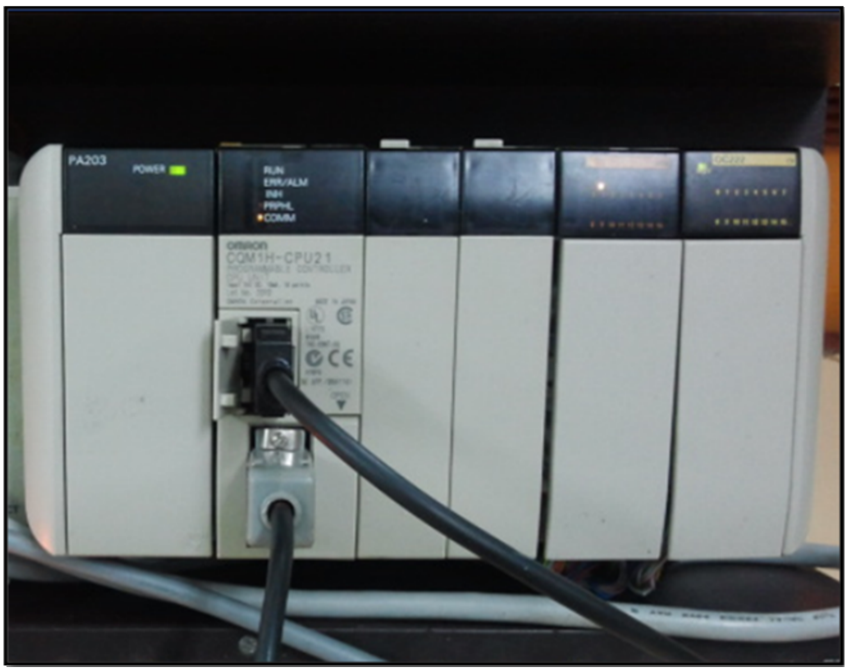


Figure 2.2 CQM1H-CPU 21

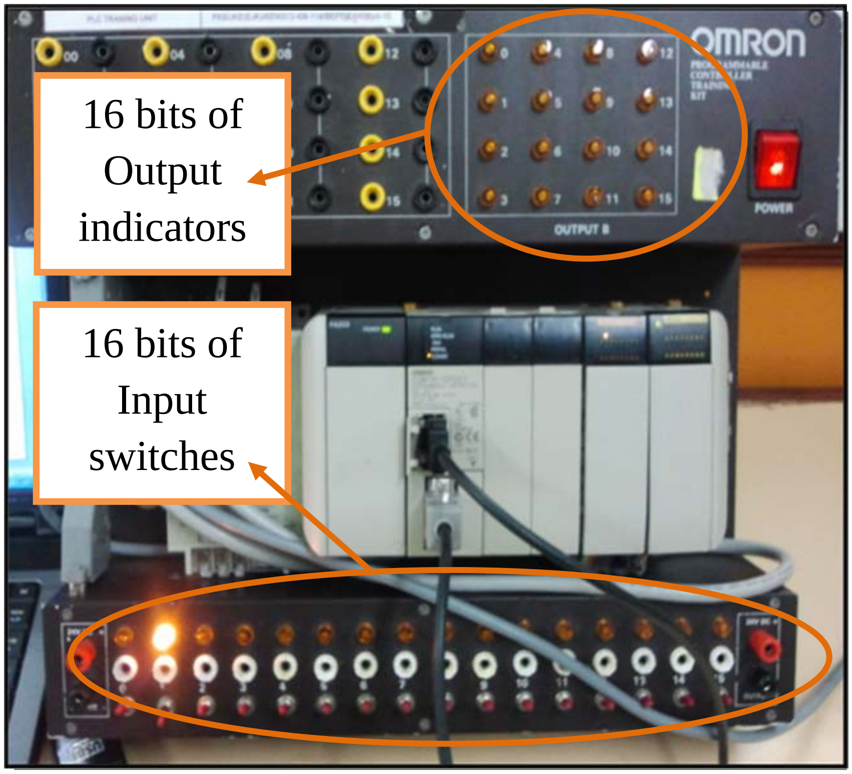


Figure 2.3 CQM1H-CPU 21for the program testing

The Input Data and Output Data for OMRON PLC model CQM1H-CPU 21 used in this project is differentiated by the first digit as illustrated below:

Input Data

00000~00015

1st digit is ‘0’ represents input data

2nd and 3rd digits represent channel

4th and 5th digits represent input bits on the PLC

Output Data

10000~10015

1^{st} digit is '1' represents input data

2^{nd} and 3^{rd} digits represent channel

4^{th} and 5^{th} digits represent input bits on the PLC

2.5.5 Programming Devices

The programming device is used to enter the required program into the memory of the processor. They are two types of programming devices as shown in Figure 2.4; Programming Console and Personal Computer (PC). Programming Console can be used to write the PLC program in Statement List called Mnemonic Code while Computer can be used to write PLC program in Ladder.

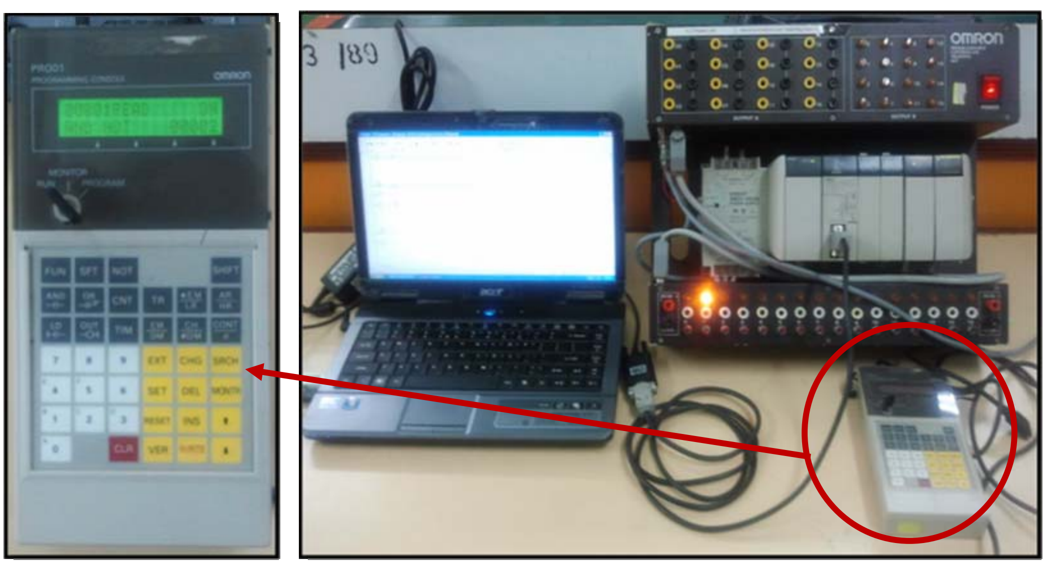


Figure 2.4 The Programming Console

2.5.5.1 Statement List

Statement List is a programming language used in PLC known as Mnemonic Code where the statement is an instruction or a directive for the PLC. It is one of the earliest techniques involved mnemonic instructions. Program is direct derived from a complete Ladder Diagram and entered into PLC through a programming device called programming Console (shown in Figure 2.4).

There are several basic operations applied in Statement List while writing the PLC program as listed below:

*LOAD (LD) instruction – Beginning of every rung

* AND instruction – Inputs arranged in series form

* OR instruction – Inputs arranged in parallel form

* OUT instruction – For the outputs

* FUN 001 instruction – To END the program

* NOT instruction – For Normally Closed Contacts

2.5.5.2 Ladder Diagram

Ladder Diagram as illustrated in Figure 2.5 below consists of two vertical lines representing the power rails. Circuits are connected as horizontal lines between these two verticals.

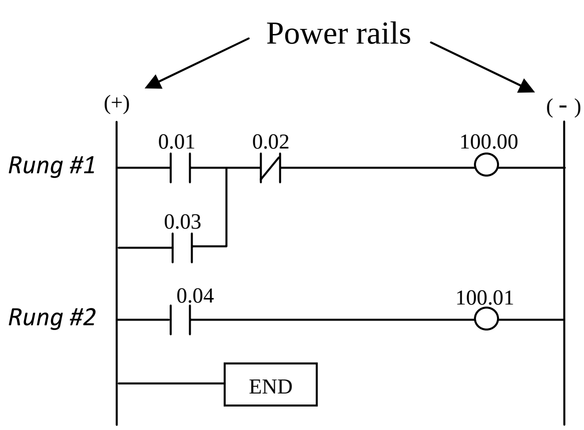


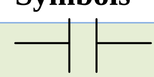
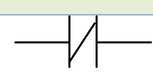
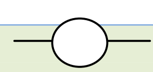
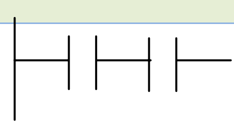
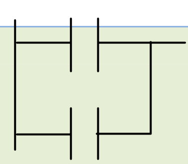
Figure 2.5 The Feature of A Ladder Diagram

Ladder diagram features refer Figure 2.5:

- Power flows from left to right.
- Contact can not be placed on the right of output.
- Each rung contains one output at least.
- A particular input/output can appear in more than one rung of a ladder.
- The inputs/outputs are all identified by their addresses, the notation used depending on the PLC manufacturer

Symbols involve in the Ladder Diagram construction are:

Table 2.2 The Symbol and the denotation used in Ladder Diagram

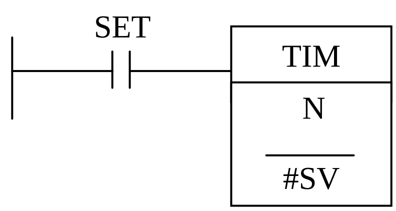
Symbols	**Denotation**
	Normally Open Contact
	Normally Closed Contact
	Output
	Series Form
	Parallel Form

2.5.5.3 TIMER And COUNTER

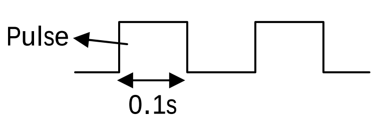
Timer - TIM

The TIM instruction can be used as an On-Delay timer in the same manner as a relay circuit. It is a decrementing ON-delay timer instruction which requires a timer number (N) and a set value (SV) ranging from 0000 to 9999 pulses or 0 to 999.9 seconds.

Symbol



In Mnemonic Codes, the set value data (in seconds) will be converted into pulses i.e. 0~999.9seconds is equivalent to 0000 ~9999 pulses. How the conversion is done? Refer to the following diagram; In PLC system, 1 pulse scan time is 0.1s. If a timer is set to 4seconds therefore 40 pulses will be obtained and the set value data for the timer is 0040.



Calculation:

0.1s → 1 pulse

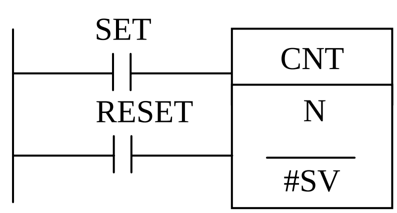
$$1s \rightarrow \frac{1\ p}{0.1s} \times 1s = 10 \text{ pulses}$$

$$\therefore 4s \rightarrow 4 \times 10 = 40 \text{ pulses}$$

Counter - CNT

Counter is a preset decrement counter i.e. it decrements one count every time an input signal goes from Off (0) to On(1). The counter must be programmed with a count input (S), a reset input (R), a count number (N) and a set value (SV) that can be range from 0000 ~ 9999. Numbers (N) of a timer and counter refer to specific address in memory and must not be duplicated (same number can not be used for a timer and a counter at the same time).

Symbol



2.6 Unitary Air Conditioner

The conventional room air conditioner unit consists of two a.c.single phase motor; one is for the compressor and one is for the air fan. The compressor motor is on an ON/OFF cycle mode operation whereas the air fan runs continuously. The bimetallic type thermostat and its setting decide the state of the compressor motor.

It trips the compressor motor when the inside temperature exceeds the thermostat setting by a small value (due to the thermostat hysteresis) and compressor motor is switched on when the inside temperature goes below the setting by the same small value.

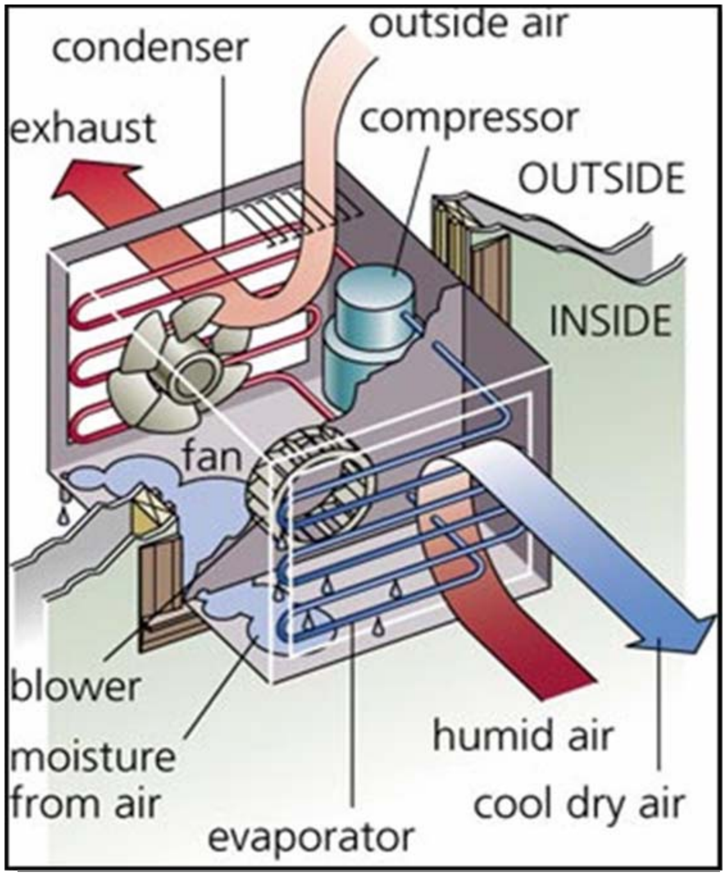


Figure 2.6: Basic components of air conditioner unit

The basic components of a room air conditioner unit are the compressor, air cooled condenser, expansion valve, evaporator, two motor and air filter as shown in Figure 2.6 [17]. The refrigerant absorbs heat from the evaporator and rejects it to the condenser. The fan draws in air from outside and circulates it over the condenser to cool it. The fan also draws in outside air through the compressor compartment for ventilation of the conditioned space.

The amount of ventilating air is controlled by a damper position in its path. The room air enters the evaporator chamber, goes over the cooling coils and comes back into the room through the air filter.

2.7 Elementary Diagram For The Conceptual Design Of The Project

Air conditioner blower is a single-phase versions an induction or asynchronuous motor. Their speed is determined by the frequency of the supply current. The frequency can be changed by a sophisticated electronic Variable Frequency Drives (VFD) which is designed to provide power ac power but at a frequency that can be controlled. Therefore, the ability to the frequency gives us the ability control the speed of the fan. The higher the frequency, the higher the RPM the motor will turn.

Figure 2.7 and Figure 2.8 show the elementary diagrams [21]that can be used to test the functional of the PLC program to simulate the operation of the blower speed control of the air conditioner. An elementary diagram is a simplified circuit illustration. Devices and components are not shown in their actual positions. All control circuit components are shown as directly as possible, between a pair of vertical lines representing the control power supply. Components are arranged to show the sequence of operation of the devices and how the device operates. This form of electrical diagram is sometimes referred to as a “schematic” or “line” diagram.

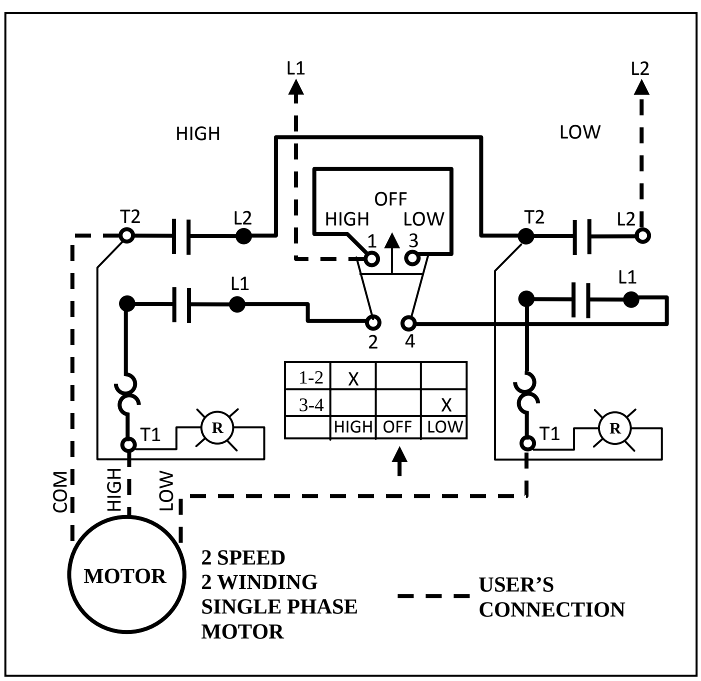


Figure 2.7 AC 2-Speed Manual Motor Starters: Class 2512 Type Fspeed

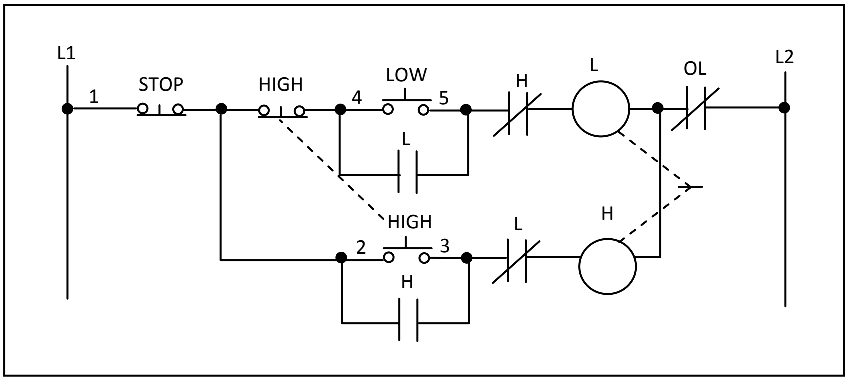


Figure 2.8 The 3-wire control of a 2-speed starter

From Figure 2.8 shows the 3-wire control of a 2-speed starter with a High-Low-Stop push button station. This scheme allows the operator to start the motor from rest at eithr speed or to change from low to high speed. The stop button must be operated before it is possible to change from high to low speed. This arrangement is to prevent excessive line current and shock to motor and driven machinery, which results when motors running at high speed are reconnected for a lower speed. The term “3-wire” control is derived from the fact that in the basic circuit, at least three wires are required to connect the pilot devices to the starter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the specific methodology for every project scope and objective are elaborated by presenting and emphasizing the details of methods applied. Here, the block diagrams and flowcharts related to each objective or scope are also elaborated and revealed. The results and the analysis will be discussed in the following chapter 4.

3.2 Measurement of Energy Consumption

In the normal operation of a conventional air conditioning (On/Off control), when the motor of the compressor is turn off; the room temperature slowly increases, the power requirements by the compressor and the motor are zero. Significant energy saving is obtained when the motor is not working. The longer the motor of the compressor is off more energy saving is obtained. The compressor normal On/Off operation is depending on the stability of indoor temperature. A constant/fixed temperature set point is a major factor contributes to a stable indoor temperature. Besides this, the use of fan is also convenient as a natural ventilation system to improve the indoor thermal condition with the interest to reduce energy consumption in buildings [13]. In this project therefore, it is interesting to carry out an investigation on adequacy of varying the air conditioner fan speed to achieve both the steadiness in the room temperature and energy savings.

To visualize this, three experiments are conducted at three different control methods. The first control method is the Variable (Disturbed) Set point, the second control method is the Fixed Set point and the third control method is a Supervisory Control; a fixed set point with variable fan speed. These experiments are conducted based on different temperature set point to the air conditioner. The control strategy is using air conditioner remote control to vary the set point manually. The experiments are performed continuously for eight (8) hours and the statistic data of accumulated energy consumption are acquired by using the Electric Power Meter and then sampled at the time interval of 30 minutes for the analysis.

The specifications of the Electric Power Meter for this project are summarized in Table 3.1. The experiments are conducted in a room with dimension L3.05m X W3.05m X H2.8m. The space consists of one split unit indoor air conditioner with specifications shown in Table 3.2.

Table 3.1: Power Meter Specifications

Detail	**Specification**	**Remarks**
Voltage	240V ac 50Hz	
Max. current	13A	
Max. load	3120W	
Typical Power Consumption	< 0.5W	
Voltage range	200-276V ac	+/- 0.5%
Current range	0.005-16A	+/-0.5%
Power range	0.1-3680W	+/-0.5%
kWh range	0-9999.9 kWh	
Frequency range	45-65Hz	

Table 3.2: Split Unit Air Conditioner Specifications

Detail	Specification	Remarks
Rated Voltage	220-240V AC	
Rated Frequency	50Hz	
Phase	Single	
Maximum Input	1100W	
Rated Input	820-850W	
Rated Current	3.8-3.5A	
Climate Designation	Type T1	
Refrigerant	22	460g
Maximum Operating Pressure	HI 2.6MPa	LO 1.5MPa

3.3 Control Method 1: Variable Set Point

The objective of this experiment is to obtain the accumulated energy consumption with the temperature set points are varied to simulate the interruption by users based on daily practice. This experiment is conducted during mid day with average outdoor temperature of 36˚C.

Figure 3.1 shows the flowchart of the experiment using control method 1. For the first 1 hour, the temperature set point is set to 18˚C with fan on high speed mode to cool up the room. After 1 hour, the data of accumulated energy consumption is taken and the temperature set point is increased to 26˚C. The temperature set points are varied continuously and data is taken for every interval of 30 minutes upon the changing of temperature set point at 18˚C and 26˚C alternately.

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