SUPERVISORY CONTROL FOR CONVENTIONAL UNITARY AIR CONDITIONING SYSTEM

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I would like to dedicate this project report to my family and my in-laws especially to my beloved husband and daughter. I will always appreciate all they did and their words of guidance will always be remembered

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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

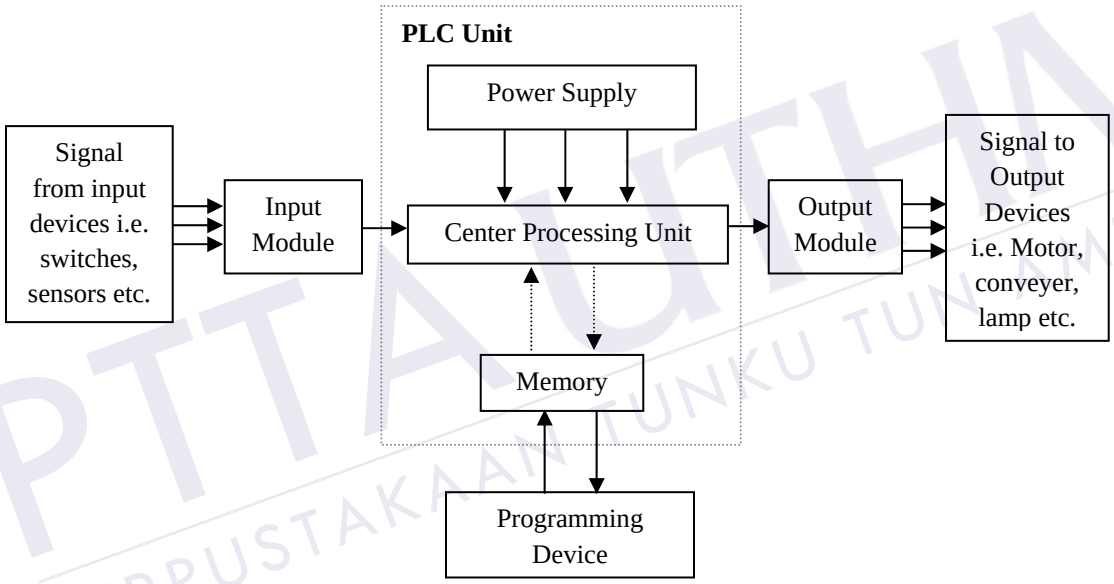

Figure 2.1 The basic structure of PLC

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.

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For control method 3, the further enhancement to control method 1 and 2 has shown that the accumulated energy consumption of 4.2 *kWh* which is 82.35*%* compared to normal consumption of 5.1 *kWh*. The result has been translated into 0.9*kWh* or *17.65*% of total energy saving per day. It can be concluded that this method is the most prefferable to be implemented in the conventional unitary air conditioner compared to control method 1 and 2.

Simulation process done based on the conceptual design of the supervisory control technique for conventional unitary air conditioner by using PLC approach is successfully done based on the results obtained in the PLC program testing scheme. The consistency of the fan speed simulated by the outputs of the PLC improving the air movement thus the steadiness to the indoor temperature is achieved. Therefore, it can be concluded that control method is the major factor contributes to the steadiness in the room temperature thus achieves the energy savings.

5.3 Future Work Recommendation

For the future recommendation of the project, the hardware simulation can be performed to simulate the real situation of the renovation of conventional unitary air conditioner control method. The enhancement to the project also can be done by implementing the Ethernet system to control groups of the conventional unitary air conditioners thus provides a SCADA system in an organization.