DESIGN AND DEVELOPMENT OF AUTOMATIC EVAPORATION PAN SYSTEM FOR HYDROLOGICAL STATION

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ABSTRACT

One of the most common method in measuring evaporation is using evaporation pan. Traditionally the measurement of the evaporation is conducted manually. The automatic version of the evaporation pan measurement is not very common although many studies of using various mechanism have been carried out. In 2016, 4 units of automatic evaporation pan system has been installed at selected Department of Irrigation and Drainage Malaysia (JPS) Hydrological Stations. After 2 years of installation, the installed system is still facing some problems and deficiency that need to be improved and enhanced. Apart from that, the control mechanism of the automation process is carried out using remote terminal unit (RTU) with the built-in controller function which is normally expensive and is not commonly used for other JPS hydrological stations. This study is aimed to review and evaluate the existing automatic evaporation pan system installed in JPS besides developing new type of controller using programmable logic controller (PLC) to control the existing automation process. Methods used for the study are evaluation of the suitability, durability and reliability of the existing system components, data analysis between manual and automatic system and PLC program design using CX-Programmer software. The existing automatic evaporation pan system which adopts its own design shows high automation efficiency and less process errors although it contains 3.5% of higher water volume compared with the standard manual pan which is not connected to any parts. It is found also that all the components installed outdoors in the Malaysian tropical climate exposed to high tear and wear process. Thus, best quality and highly durable components and workmanships are required to increase the lifespan despite regular maintenance. Lastly, the PLC automation of evaporation pan has been successfully simulated using the real-time clock function and the instructions such as scaling and value comparison of the PLC CX- Programmer software.

ABSTRAK

Pan penyejatan adalah satu kaedah yang paling biasa digunakan untuk mengukur kadar penyejatan. Secara tradisionalnya, pengukuran penyejatan dijalankan secara manual. Pengukuran secara automatik tidak digunakan secara meluas walaupun banyak kajian berkenaannya telah dijalankan. Pada tahun 2016, sebanyak 4 unit sistem penyejatan automatik telah dipasang di beberapa Stesen Hidrologi milik Jabatan Pengairan dan Saliran Malaysia (JPS). Sistem yang telah 2 tahun dalam pemasangan tersebut masih menghadapi beberapa masalah dan kekurangan yang perlu diperbaiki dan dipertingkatkan. Selain itu, mekanisme kawalan proses automasi tersebut yang menggunakan *remote terminal unit* (RTU) yang dilengkapi dengan sistem pengawal yang tersendiri kebiasannya mahal dan tidak selalu digunakan untuk stesen hidrologi JPS yang lain. Kajian ini akan menilai sistem penyejatan automatik sedia ada yang dipasang tersebut selain merekabentuk pengawal jenis baru yang menggunakan *programmable logic controller* (PLC) untuk mengawalselia proses automasi pan penyejatan. Kaedah-kaedah yang digunakan adalah terdiri daripada penilaian kesesuaian, ketahanan dan kebolehpercayaan komponen sedia ada, analisis data antara sistem manual dan automatik serta rekabentuk program PLC dengan menggunakan perisian CX-Programmer. Sistem pan penyejatan automatik yang sedia ada yang mempunyai rekabentuknya yang tersendiri ini menunjukkan kecekapan automasi yang tinggi dan ralat yang rendah walaupun mengandungi 3.5% jumlah air yang lebih berbanding sistem manual yang standard. Didapati juga kebanyakan komponen yang dipasang di iklim Malaysia terdedah kepada proses penuaan semulajadi yang tinggi. Oleh itu, komponen yang dipasang perlulah mempunyai kualiti dan ketahanan yang tinggi bagi meningkatkan jangka hayat. Akhir sekali, automasi dengan menggunakan PLC telah berjaya disimulasikan dengan menggunakan mod fungsi yang terdapat dalam perisian *CX-Programmer* seperti *real time clock, scaling* dan *value comparison*.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviation	Description
JPS	Department of Irrigation & Drainage Malaysia
RTU	Remote Terminal Unit
PLC	Programmable logic controller
CIO	Common Input Output
HR	Holding Relay
GSM	Global System for Mobile Communication
WL	Water level
RF	Rainfall
ET	Evapotranspiration
E	Evaporation rate
HP	Hydrological Procedure
WMO	World Meteorological Organization
FTP	File Transfer Protocol
CSV	Comma separated variables
MEMS	Micro Electro Mechanical System
O&M	Operation and maintenance

LIST OF APPENDICES

CHAPTER 1

1. INTRODUCTION

1.1 Background

The quantity of water evaporated from an open water surface or from the ground which is defined as evaporation is one of the important hydrological data (which is data related to the water cycle and water resources of the earth such as rainfall, river level, evaporation etc.) used for environmental studies such as drought monitoring, irrigation scheduling etc. An evaporation pan system which is one of the common evaporation measurement methods typically consists of a standard sized evaporation pan made of aluminium (as shown in the figure 1.1 below), rain gauge, water storage tank and other components. Department of Irrigation and Drainage Malaysia or *Jabatan Pengairan dan Saliran* Malaysia (JPS) is a National Water Resources Agency responsible to collect and store the evaporation data from its hydrological stations nationwide apart from other hydrological data such as rainfall, water level, river discharge, water quality etc.

Figure 1.1: Typical evaporation pan installed at JPS hydrological station

Currently there are 56 units of evaporation pan hydrological stations available throughout Malaysia. Most of them are still operating manually and are not upgraded yet to an automatic operation. It means that once a day JPS Staffs need to be presented at the site to take the measurement of the actual evaporation pan water height and rainfall collected in order to calculate the evaporation rate daily manually.

The workers will fill the water into the evaporation pan to replace the water evaporated in order to measure the evaporated water. The Table 1.1 shows the inventory of evaporation pan hydrological station as of September 2018 throughout Malaysia with the corresponding mode of operation.

In 2016 as a pilot project for Peninsular Malaysia JPS has installed 4 units of automatic evaporation pan system at selected evaporation pan hydrological stations nationwide. The brief information about the JPS/IP/H/09/2014 Project is included in the Appendix 1.

The system will measure the evaporation data automatically from the connected water level sensor and rainfall gauge using Remote Terminal Unit (RTU) and send the collected data telemetrically to the server at JPS Ampang Control Centre. The automation process of the system is programmed using the built-in RTU Program in order to carry out the entire data collection and operation automatically. The system is also equipped with photovoltaic solar power system to power up the station.

Table 1.1: Inventory of JPS evaporation pan hydrological station September 2018

No	Station Name	District	State	River Basin	Latitude	Longitude	Mode Operation
1	Pejabat Pertanian Batang Merbau	Tanah Merah	Kelantan	Sg. Kelantan	05° 48' 45"	102° 01' 15"	Manual
2	Serdang, Gunung Barat Bachok	Bachok	Kelantan	Sg. Semerak	05° 56' 30"	102° 20' 30"	Manual
3	Seri Bandi	Kemaman	Terengganu	Sg. Tebak	04° 21' 45"	103° 20' 50"	Manual & Auto
4	Sek. Men. Sultan Omar di Dungun	Dungun	Terengganu	Sg. Paka	04° 45' 45"	103° 25' 10"	Manual
5	Klinik Bidan Chalok Barat	Setiu	Terengganu	Sg. Setiu	05° 24' 40"	102° 49' 25"	Manual
6	Sek. Men. Keb. Pengkalan Nyireh	Besut	Terengganu	Sg. Besut	05° 47' 50"	102° 33' 55"	Manual
7	Rumah Pam Pahang Tua di Pekan	Pekan	Pahang	Sg. Pahang	03° 33' 40"	103° 21' 25"	Manual
8	Stor JPS Raub	Raub	Pahang	Sg. Pahang	03° 48' 20"	101° 50' 50"	Manual
9	Setor JPS Sikamat di Seremban	Seremban	N. Sembilan	Sg. Linggi	02° 44' 15"	101° 57' 20"	Manual
10	T/A 2, Sg. Burong	Kuala Selangor	Selangor	Sg. Bernam	03° 28' 03"	101° 08' 17"	Manual
11	Loji Air Kuala Kubu Bahru	Hulu Selangor	Selangor	Sg. Selangor	03° 34' 33"	101° 39' 56"	Manual & Auto
12	Loji Air Sg.Layang	Johor Bahru	Johor	Sg. Johor	01° 33' 25"	103° 55' 30"	Manual
13	Benut di Johor Barat	Pontian	Johor	Sg. Air Baloi	01° 39' 00"	103° 15' 50"	Manual & Auto
14	Pintu Kawalan Tg. Agas	Muar	Johor	Sg. Muar	02° 03' 05"	102° 34' 40"	Manual
15	Stor Baru Jps. Kluang	Kluang	Johor	Sg. Endau	02° 01' 10"	103° 19' 30"	Manual
16	Stesen Telemetri Bandar Kluang	Kluang	Johor	Sg. Johor	02° 02' 18"	103° 19' 21"	Manual
17	Stor JPS Endau	Mersing	Johor	Sg. Johor	02° 39' 00"	103° 37' 15"	Manual
18	Stn. Petak Ujian Tg. Piandang	Kerian	Perak	Sg. Kurau	05° 04' 40"	100° 23' 10"	Manual
19	Rumah Jps. Padang Mat Sirat	Langkawi	Kedah	Sg. Melaka	06° 20' 35"	99° 43' 45"	Manual
20	Padang Katong	Kangar	Perlis	Sg. Perlis	06° 26' 45"	100° 11' 15"	Manual
21	Kuamut Meteorological Stn.	n/a	Sabah	n/a	05° 13' 10"	117° 29' 20"	Manual
22	Keningau Meteorological Stn	n/a	Sabah	n/a	05° 20' 45"	116° 09' 40"	Manual
23	Ulu Dusun Meteorological Stn.	n/a	Sabah	n/a	05° 47' 25"	117° 45' 45"	Manual
24	Sandakan Meteorological Stn.	n/a	Sabah	n/a	05° 53' 50"	118° 03' 30"	Manual
25	Kota Kinabalu Meteorological Stn	n/a	Sabah	n/a	05° 56' 40"	116° 03' 00"	Manual
26	Inanam Meteorological Stn.	n/a	Sabah	n/a	05° 59' 45"	116° 06' 55"	Manual
27	Trusan Sapi Meteorological Stn	n/a	Sabah	n/a	05° 54' 10"	117° 22' 25"	Manual
28	Kinabalu Park Meteorological Stn.	n/a	Sabah	n/a	06° 00' 20"	116° 32' 30"	Manual
29	Aman 5 Bridge	Kuching	Sarawak	Sg. Sarawak	1º 10' 56.9" N	110º 15' 22.2" E	Manual & Auto
30	Bau	Kuching	Sarawak	Sg. Sarawak	1º 25' 5.60" N	110º 08' 58.4" E	Manual & Auto
31	Buntal DID	Kuching	Sarawak	Sg. Sarawak	1º 42' 6.60" N	110º 21' 41.40" E	Manual & Auto
32	Kuching Airport	Kuching	Sarawak	Sg. Sarawak	1º 29' 27.4" N	110º 20'56.5" E	Manual
33	Kuching Third Mile	Kuching	Sarawak	Sg. Sarawak	1º 31' 46.4" N	110º 20' 31.8" E	Manual & Auto
34	Sri Aman	Sri Aman	Sarawak	Lupar	1º 14' 33.2" N	111º 27' 25.03" E	Manual
35	Nanga Tutong II	Sri Aman	Sarawak	Lupar	1º 14' 11" N	111º 55' 39" E	Manual
36	Stumbin	Sri Aman	Sarawak	Lupar	1º 18' 3.94" N	111º 23' 18.37" E	Manual
37	Sibu	Sibu	Sarawak	Rajang	2º 16' 24.79" N	111º 50' 27.17" E	Manual & Auto
38	Sibu New Airport	Sibu	Sarawak	Rajang	2º 15' 32.1" N	111º 58' 54.2" E	Manual
39	Kebuloh	Miri	Sarawak	Baram	4º 7' 7.90" N	113º 57' 27.10" E	Manual
40	Miri Airport	Miri	Sarawak	Baram	4º 18' 58.1" N	113º 58' 33.5" E	Manual
41	Miri DID	Miri	Sarawak	Baram	4º 25' 58.00" N	113º 59' 52.90" E	Manual
42	Paya Selanyau	Miri	Sarawak	Sibuti	4º 5' 46.4" N	113º 51' 22.7" E	Manual
43	Limbang DID	Limbang	Sarawak	Limbang	4º 44' 46.1" N	114º 59' 57.679" E	Manual
44	Belaga	Kapit	Sarawak	Rajang	2º 42' 22.20" N	113º 46' 41.60" E	Manual
45	Belaga II	Kapit	Sarawak	Rajang	2º 42' 22.20" N	113º 46' 41.60" E	Manual & Auto
46	Kapit New Head Works	Kapit	Sarawak	Rajang	2º 1' 3.50" N	112º 56' 58.80" E	Manual & Auto
47	Song	Kapit	Sarawak	Rajang	2º 00' 43.5" N	112º 32' 22.9" E	Manual & Auto
48	JPS Samarahan	Samarahan	Sarawak	Samarahan	1º 27' 45.30" N	110º 29' 18.30" E	Manual
49	Paya Paloh	Samarahan	Sarawak	Samarahan	1º 26' 32" N	110º 29' 30" E	Manual
50	Semera	Samarahan	Sarawak	Samarahan	1º 33' 21.3" N	110º 40' 13.7" E	Manual
51	Bunan Gega	Samarahan	Sarawak	Sadong	0º 54' 59.30" N	110º 32' 13.80" E	Manual
52	Gedong	Samarahan	Sarawak	Sadong	1º 13' 36.40" N	110º 41' 28.70" E	Manual
53	Bintulu New Airport	Bintulu	Sarawak	Kemena	3º 07' 14.73" N	113º 01' 16.921" E	Manual
54	Nanga Besar	Mukah	Sarawak	Rajang	2º 37' 48.43" N	111º 25' 16.43" E	Manual
55	Sungai Talau	Mukah	Sarawak	Oya	2º 49' 14.34" N	111º 54' 38.25" E	Manual
56	Mukah JKR	Mukah	Sarawak	Mukah	2º 54' 17.50" N	112º 5' 26.14" E	Manual

1.2 Problem Statement

The 4 units of the automatic evaporation pan system installed in JPS are still facing some problems and deficiency that need to be improved and enhanced before the remaining manual evaporation pan stations are being upgraded to automatic operation in the future. Apart from that the control of the automation process of the evaporation system is carried out using remote terminal unit (RTU) with the built-in controller function which is normally expensive and is not commonly used for other JPS hydrological stations such as river and rainfall stations that normally function only for data collection and telemetry.

Thus, it is aimed that through this study the existing design of the automatic evaporation pan system installed at JPS could be reviewed and evaluated systematically besides designing new type of controller using PLC to control and monitor the existing automatic automation program.

1.3 Objectives of the Study

All in all, there are 3 objectives that could be obtained from this study which are as follows:

i) To review the existing automatic evaporation pan system design installed at JPS hydrological station.

ii) To evaluate the existing automatic evaporation pan system in terms of optimum design, components reliability and suitability.

iii) To propose a new controller using PLC and ladder diagram to control and monitor the existing automation program.

1.4 Scope of the Study

The Research project will be carried out in 2 phases. The first phase of the research will be about the evaluation study of the newly installed 4 units of automatic evaporation pan system at the JPS hydrological station in 2016 which is considered as the pilot project for the automated evaporation pan system in JPS for peninsular Malaysia. The evaporation pan system will be evaluated and reviewed in terms of the automation process performance, components reliability and performance, problems encountered, quality and reliability of the data collected, operation and maintenance issues and others. Altogether there will be 2 major methods have been planned in order to evaluate the existing system effectively which are as follows:

i) Evaluation of the suitability, durability and reliability of the system components

ii) Data analysis and comparison between manual and automatic system

The second part of the research will be about the development of a new controller using programmable logic controller (PLC) and ladder diagram to control and monitor the automation and measurement of the existing evaporation pan system. The developed PLC program will be simulated and the real implementation of the PLC controller at site will be discussed.

1.5 Research Plan

It is intended and planned to carry out the entire project during the 1st Semester of the 2018/19 session. The first part of the project which is the evaluation study regarding the existing automatic evaporation pan system will be done first before continuing with the final part of the research that is the development of a new controller using PLC.

During the evaluation study literature review process will be carried out to ensure all the information, documentation, literature etc. related to the project are gathered and reviewed effectively. Site visit at the existing automatic evaporation pan station will be conducted as well as reviewing the existing design, technical specification of the components involved and other relevant documentation in order to understand well the existing project.

Then the existing system design will be evaluated systematically before carrying out the development of the new controller using PLC. Finally, the conclusion of the findings and the recommendations suggested for future references will be discussed as the final part of the research. The Figure 1.2 shows the sequence of the activities involved in this study:

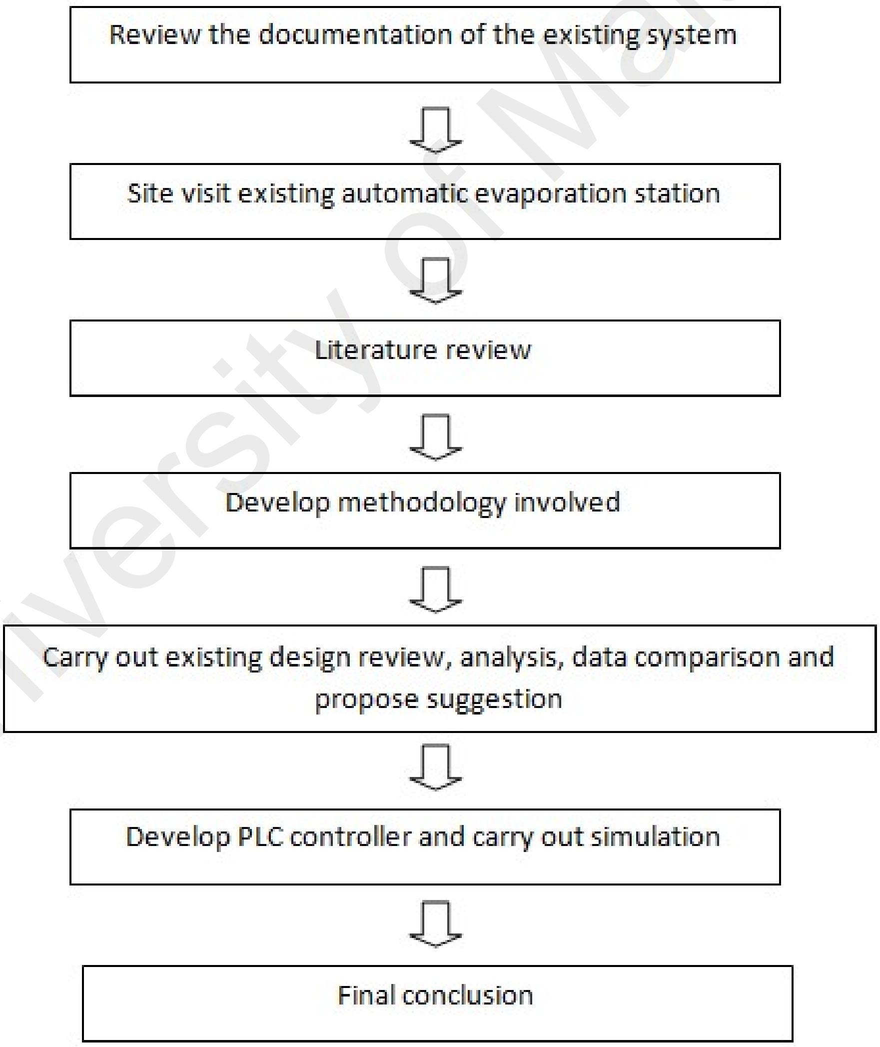

Figure 1.2: Research activities involved

CHAPTER 2

2. LITERATURE REVIEW

The detail of this chapter will cover the background and function of *Jabatan Pengairan dan Saliran* (JPS) or famously known as Department of Irrigation and Drainage, hydrological station, evaporation measurement, JPS manual evaporation pan, automatic evaporation pan, automation & PLC and relevant studies on automatic evaporation pan.

2.1 Department of Irrigation and Drainage Malaysia (JPS)

JPS is the second biggest technical and engineering government agency of Malaysia after Public Works Department (JKR). Generally, JPS which has been established in 1932 is responsible for all works connected to drainage and irrigation in Malaysia. Its main functions and roles can be divided into 5 core businesses which are:

i) Malaysian entire river basin and coastal zone management

ii) Water resources management and hydrology

iii) Flood management

iv) Special projects management related to flood mitigation, river of life etc.

v) Eco-friendly drainage management

Out of these the field of hydrological instrumentation and hydrological activities which is related to this study will fall under the water resources management and hydrology category which is controlled and managed by Water Resources Management and Hydrology Division (BSAH) of JPS. Currently there are more than thousand hydrological stations nationwide maintained by the division besides running a lot of new stations development and existing stations upgrading. All the hydrological data such as rainfall, water level, evaporation, water quality, river discharge and a lot more are collected, processed, analysed, archived, disseminate and managed by the division. The division is also responsible in forecasting and providing early warnings of flood and drought event to the public. (Jabatan Pengairan dan Saliran, About Us: Our Background, 2018)

2.2 Hydrological Station

2.2.1 Hydrological Station Definition

Below is the definition of some terms related to the hydrological station according to the World Meteorological Organization (2006):

i) Hydrological observation: The direct measurement or evaluation of one or more hydrological elements, such as stage, discharge, water temperature, etc.

ii) Hydrological observation station: A place where hydrological observations or climatological observations for hydrological purposes are made.

iii) Hydrological Station for specific purposes: A hydrological station established for the observation of a specific element or elements, for the investigation of hydrological phenomena.

iv) Automatic station: A station at which instruments make and either transmit or record observations automatically, the conversion to code form, if required, being made either directly or at an editing station.

2.2.2 Hydrological Station Classification

According to the World Meteorological Organization (2006) also the hydrological observing stations could be classified to one or more than one of the following categories:

(a) Hydrometric stations

(b) Groundwater stations

(c) Climatological stations and precipitation stations for hydrological purposes

(d) Hydrological stations for specific purposes

'The hydrological stations for specific purposes' specifically on the other hand should include those stations the data of which are necessary or used for purposes such as:

(a) Determination of the water balance of catchments, lakes, reservoirs or glaciers

(b) Measurement of waves and currents on lakes and reservoirs

(c) Measurement of evaporation and evapotranspiration

(d) Measurement of soil moisture

(e) Determination of the physical and chemical properties of water.

Thus it can be clearly concluded that an automatic evaporation pan station falls under the 'hydrological stations for specific purposes' category.

2.2.3 Hydrological Station Components

Based on the definition and analysing various existing hydrological stations owned by JPS, a good and perfect hydrological station should consist of following components:

i) Hydrological instruments – It consist of various types of sensors to measure hydrological parameters such as water level, rainfall, river discharge, evaporation etc.

ii) Remote Terminal Unit (RTU) – Consist of data logger as well as processor to process measurement at site, perform data acquisition and transmit data to the server.

iii) Communication medium – Interface to perform transmission of the site data to the server such GSM modem, satellite modem, radio modem etc.

iv) Power supply system – To power up all the site components. Most of the hydrological stations are located at remote area, thus solar photovoltaic system is preferred for the station.

v) Enclosure – To store and house all the site components

vi) Electronic components such as surge protection device, relays, miniature circuit breakers etc. to provide electrical protection for the site components.

vii) Monitoring System – To publish / store all the data collected at server.

The Figure 2.1 shows the process flow of the system involved for a typical hydrological data collection process.

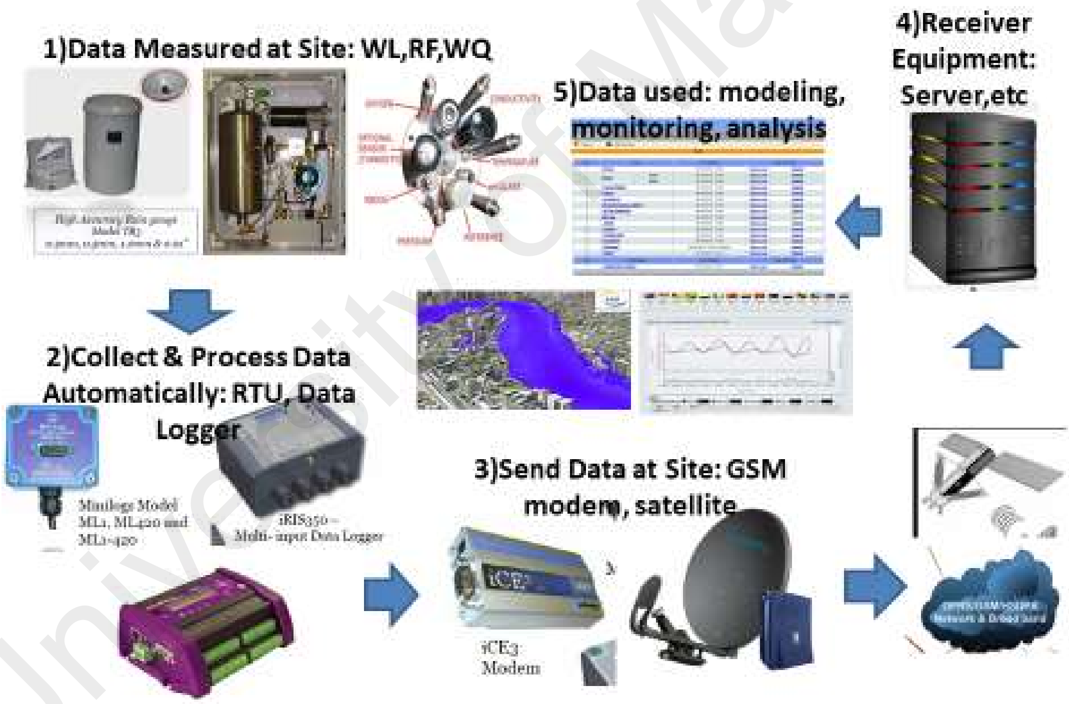

Figure 2.1: Typical process flow of hydrological data collection process

The hydrological site parameters such as water level (WL), rainfall (RF), water quality (WQ) etc. will be measured using the suitable sensor. The measured data will be collected and processed by the connected RTU or data logger. Then through the connected communication interface such GSM or satellite modem etc. the data will send via communication protocol to the destination server. At the server data received will be stored in an appropriate database and made available for the user. The data collected will be used for various uses such as real time monitoring, analysis, research, modelling etc.

2.3 Evaporation Measurement

2.3.1 Introduction

According to World Meteorological Organization (2006) evaporation is defined as a quantity of water evaporated from an open water surface or from the ground, whereas evapotranspiration is defined as a quantity of water vapour evaporated from the soil and plants when the ground is at its natural moisture content.

Evaporation from open water surfaces and evapotranspiration (ET) from vegetation are one of the major parameters in the hydrologic cycle. The percentage of most precipitation lost in the form of evaporation and ET varies from one place to another. It needs field observations data and other parameters in order to estimate evaporation and ET. Field measurement is a critical part of the evaporation estimation process. Errors occurred in the field due to the data collection and measurement will also causing errors in estimating evaporation and ET. (Abtew & Malesse, 2013)

2.3.2 Measurement Techniques

Direct measurements of evaporation or evapotranspiration from extended natural water or land surfaces are not practicable currently. However, there are 6 types of commonly used indirect techniques in measuring evaporation ranges from the evaporation pan to remote sensing techniques. Following are the 6 methods of measurement and brief description about the concept of its technique (Abtew & Malesse, 2013):

i) Evaporation pan

The evaporation pan is the most common method in measuring or estimation of open water evaporation. There are various types of pans used throughout the world such as:

a) United States (US) Class A evaporation pan. The common pan size is 120.7cm in diameter and 25cm in depth. Figure 2.2 shows 4 different setups of this type of pan.

b) Sunken Colorado pan. It is a (100x100) cm square pan with 50cm deep and buried underground in depth of 45cm.

The most common type of pan used will be the US Class A evaporation pan. Water level will be monitored using built in stilling well and hook gauge. Water is added or removed to maintain water level at 5cm from the top and the typical measurement resolution would be 1mm. The pan is accompanied with a rain gauge to factor out the contribution of rainfall to the depth of water in the pan.

The daily evaporation (E) shall be calculated based on the daily recorded measurement using following equation:

$E = H_t - H_{t-1} + R_f – L +/- e$

Where H_t is the current day water level height of the pan from bottom and H_{t-1} is the day before water level height; R_f is rainfall over the pan; L is other losses such as bird or animal consumption; and e is errors.

Figure 2.2: Various setups of US class A evaporation pan (Abtew & Malesse, 2013)

ii) Lysimeters

A field lysimeter which is one of the common methods in measuring evapotranspiration (ET) is a way of controlling a small section of the surrounding environment for water balance monitoring with little alteration to the physical and climatic conditions that prevail at the site. Evaporation or ET is derived from water balance. In most cases, the main part would be tank where soil is filled and vegetation is planted and devices to control and measure change in moisture are installed. There are two types of lysimeters: the weighing lysimeter and the water balance lysimeter.

iii) Eddy correlation

The evaporation (E) is calculated based on the correlation method of vertical wind speed and air moisture content fluctuation using following equation:

$$E = 1/N \sum_{i=1}^{N} (wi - w)(qi - q')$$

Where wi is vertical wind speed and qi is specific humidity at time i. The Eddy correlation instrumentation requires highly maintained fast responding sensors. Daily maintenance is required, and there is no guarantee of collecting continuous good quality data.

iv) Bowen ratio

The Bowen ratio (β) estimation requires temperature and vapor pressure measurements at two heights over the water surface using following equation that will be further analysed to calculate the evaporation:

$$\beta = \frac{H}{\lambda E} = \gamma \Delta T / \Delta e$$

Where λE is latent heat flux; H is sensible heat; γ is psychrometer constant; ΔT is change in temperature; and Δe is change in vapor pressure.

v) Lidar

Lidar which stands for light detection and ranging method makes three-dimensional measurements of water vapour concentration over a surface using the Monin–Obukhov similarity theory. It samples the local time-average vertical gradient of water vapour. Local evaporation flux is calculated from this using similarity theory and supplementary measurements of friction velocity and atmospheric stability.

vi) Satellite-based model

Satellite-based model is the latest technology using satellite and remote sensing technique in order to calculate the rate of evaporation.

2.4 JPS Manual Evaporation Pan

In order to standardize the evaporation pan design and measurement used in JPS hydrological station, JPS has developed "Hydrological Procedure (HP) No. 21: Evaporation Data Collection Using US Class 'A' Aluminium Pan" in 1981. The 2.4.1 and 2.4.2 parts of this section will summarize the important contents of the standard.

2.4.1 Components Involved

Basically an evaporation pan station shall consist of following equipment:

i) 1210mm internal diameter and 255mm height of evaporation pan made of no. 20 gauge aluminium plate.

ii) Fixed point gauge which comprises a pointed brass rod mounted with a 75 mm diameter size brass cylinder (called as stilling well) is placed about 300 mm from the north edge of the pan.

iii) Graduated measuring can for measuring purposes as in the Figure 2.3.

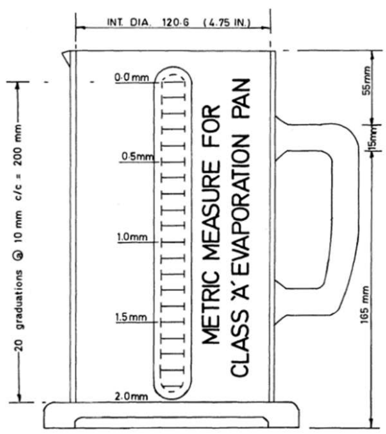

Figure 2.3: Dimension and design of the graduated measuring can (Jabatan Pengairan dan Saliran [JPS], 1981)

iv) Storage tank to supply water to replace the evaporated water at the station.

v) A standard daily rain gauge installed at least 1.5m away from the pan to measure the daily rainfall. According to JPS Hydrological Procedure HP32, a standard daily rain gauge is a non-recording type of rain gauges that has a 203mm diameter receiver on top to catch and funnel the rain into a can where the rainfall measurement is done by pouring the rainwater collected in the can into a measuring cylinder (JPS, 2018). Figure 2.4 shows the typical daily rain gauge at the JPS evaporation station. Tipping bucket automatic rain gauge which is much more accurate can also be used in the station for the purpose.

Figure 2.4: Daily rain gauge used in JPS station

Figure 2.5 shows the evaporation pan dimension and components obtained from the HP No. 21.

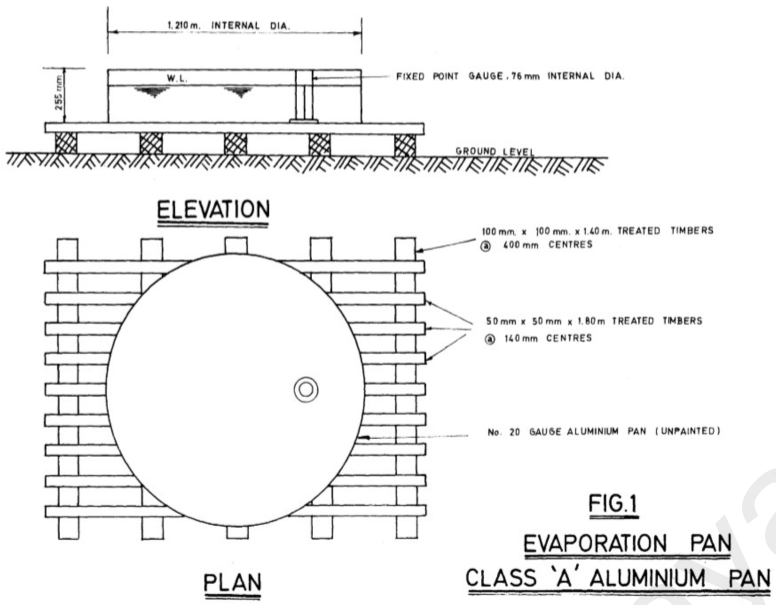

Figure 2.5: Evaporation pan dimension and components (JPS, 1981)

2.4.2 Manual Observation and Measurement Procedures

Following are steps and procedures involved in measuring the evaporation according to the standard:

1) The evaporation pan should be filled with fresh water up to the level of the tip of the fixed point gauge which is 191mm from the bottom of the tank or 64mm below the top rim of the tank.
2) The daily measurement and observation is carried the following day at 8.00am.
3) The amount of rainfall during the past 24hours is measured using the rain gauge.
4) The rise or fall in water level in the evaporation pan must now be measured (as shown in the Figure 2.6 and 2.7). The graduated measuring can be used for the purpose.
5) If the level of the water in the pan is below the tip of the fixed point gauge, evaporation has been greater than rainfall and water must be added until the tip of the fixed point gauge coincides with the surface of the water in the well.

6) If the level is above the tip of the fixed point gauge, rainfall has been greater than evaporation and water must be removed to return the level to the tip of the fixed point gauge. As the water approaches the tip of the point gauge, pour slowly to prevent overfilling owing the time required for water to flow into the well. (Note: If the daily rainfall exceeds 38mm the evaporation measurement for the day is considered to be rejected)

7) Evaporation (E) is then calculated according to the equation below:

   E = daily rainfall (mm) + amount of water added (mm) – amount of water removed (mm)

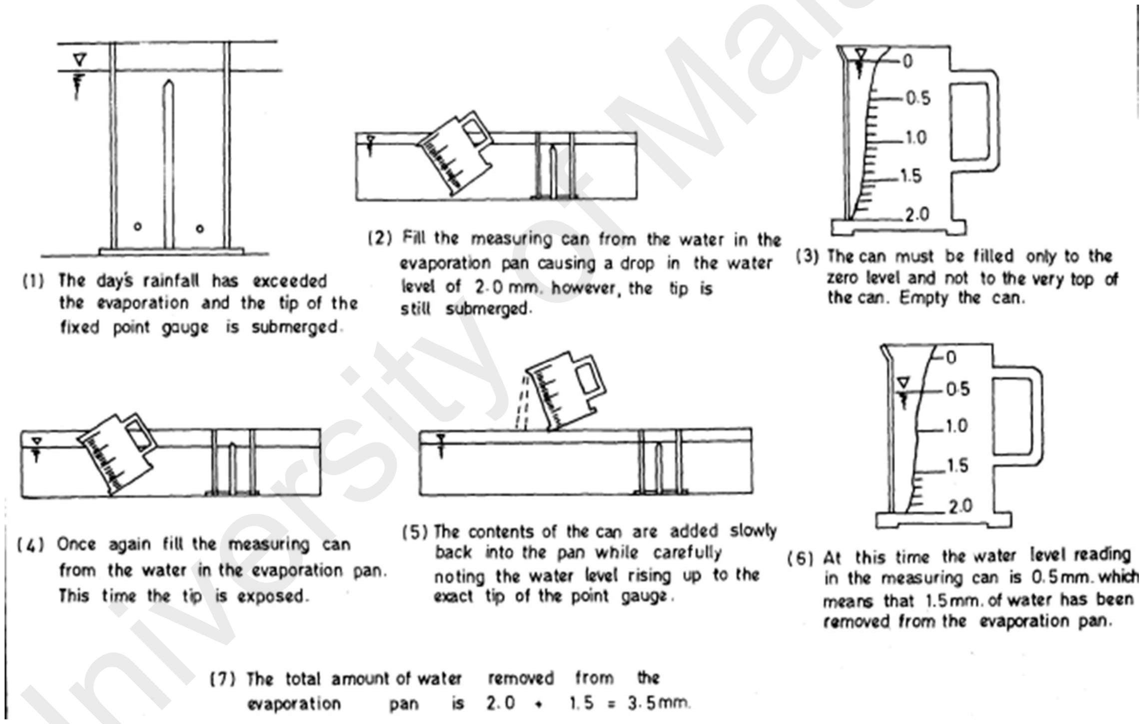

Figure 2.6: Measurement steps if the level above the tip (JPS, 1981)

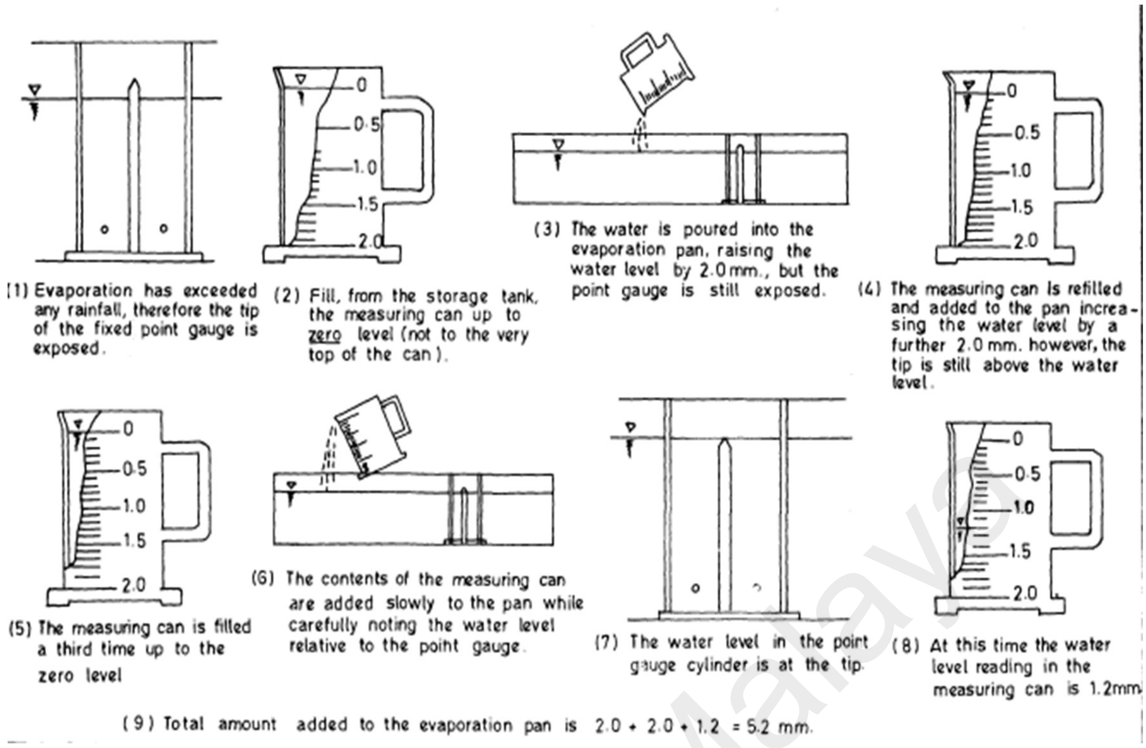

Figure 2.7: Measurement steps if the level below the tip (JPS, 1981)

2.5 Automatic Evaporation Pan

The evaporation pan system described in the sections 2.4.1 and 2.4.2 is the manual system in which the measurement and data collection are carried out manually. So far there are no any standard guidelines available for an automatic evaporation system in which the measurement and data collection are done automatically.

In 2016 JPS through the JPS/IP/H/09/2014 Project has installed completely new automatic evaporation system with telemetry function at 4 selected evaporation hydrological stations as listed below:

a) JPS Ampang Test Station, Kuala Lumpur

b) Kuala Kubu Bharu Evaporation Station, Selangor

c) Sri Bandi Evaporation Station, Terengganu

d) Benut Evaporation Station, Johor.

The new system was installed at each location without disrupting the existing manual evaporation pan system. The entire system design and components involved will be reviewed in this section.

In order to obtain the overall detail design of the system installed following methods has been employed:

- Site visit
- Reviewing the document contract, user manual, testing & commissioning report of the project.

Site visit has been carried out at Kuala Kubu Bharu Evaporation Station in Selangor and at JPS Ampang Test Station, Kuala Lumpur on the 18thSeptember 2018 and 5th October 2018 respectively. Besides performing site reconnaissance in order to get information and to understand about the installed system, the purpose of the site visit is also to check on the functionality and condition of the system and components installed at site after 2 years commissioning of the project.

Figure 2.8 shows the Kuala Kubu Bharu Evaporation Station which is located inside the compound of the Kuala Kubu Bharu Water Treatment Plant.

Figure 2.8: Kuala Kubu Bharu Evaporation Station

The project's documents that have been reviewed under this process are as follows:

a) Technical Specification of the project

b) Brochures and Catalogues of the product installed

c) Instruments Installation Reports

d) Testing and Commissioning Reports

e) User Manual

2.5.1 Overall System Diagram

Figures 2.9, 2.10, 2.11 and 2.12 show overall concept of the components and the wiring diagram of the evaporation pan and the rainfall gauge of the system installed at site obtained from the User Guide for Evaporation & Rainfall for JPS/IP/H/09/2014 Project.

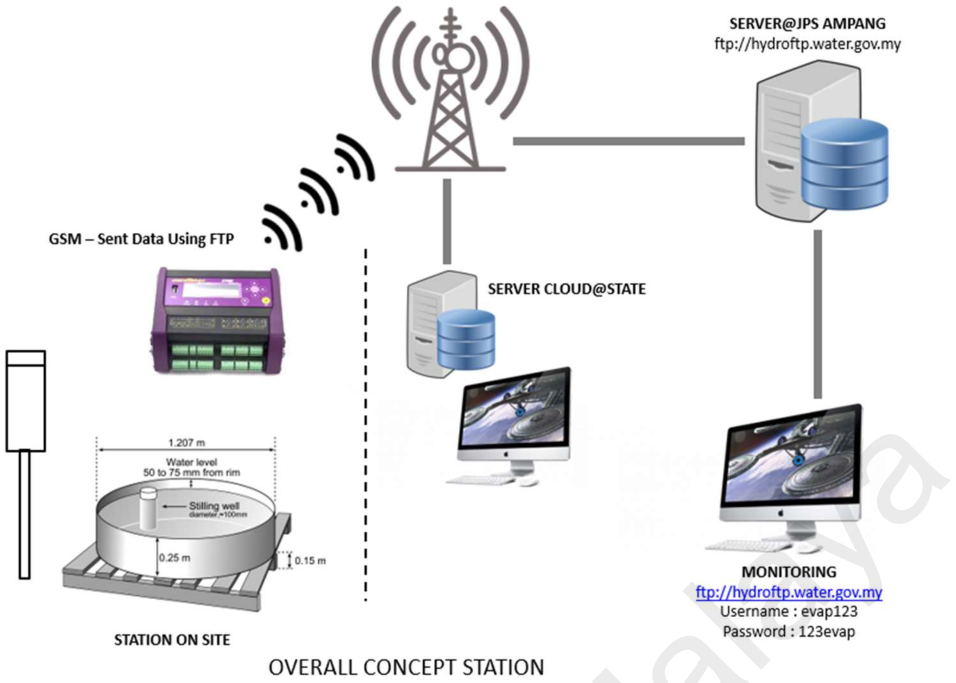

Figure 2.9: Overall system architecture (Hydroaxis Sdn Bhd, 2016)

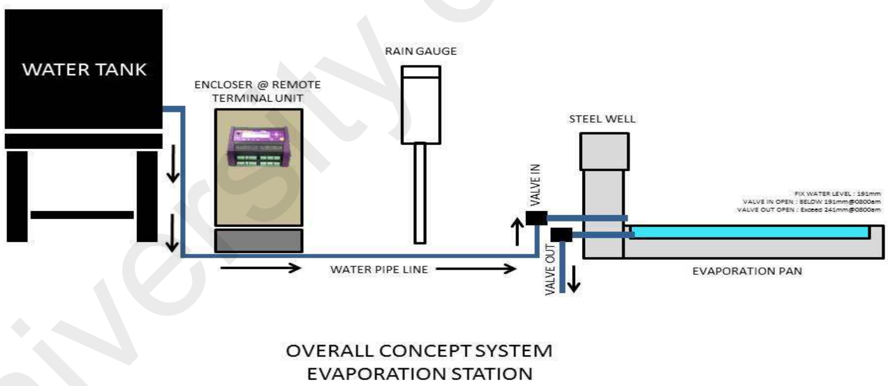

Figure 2.10: Overall concept diagram at site (Hydroaxis Sdn Bhd, 2016)

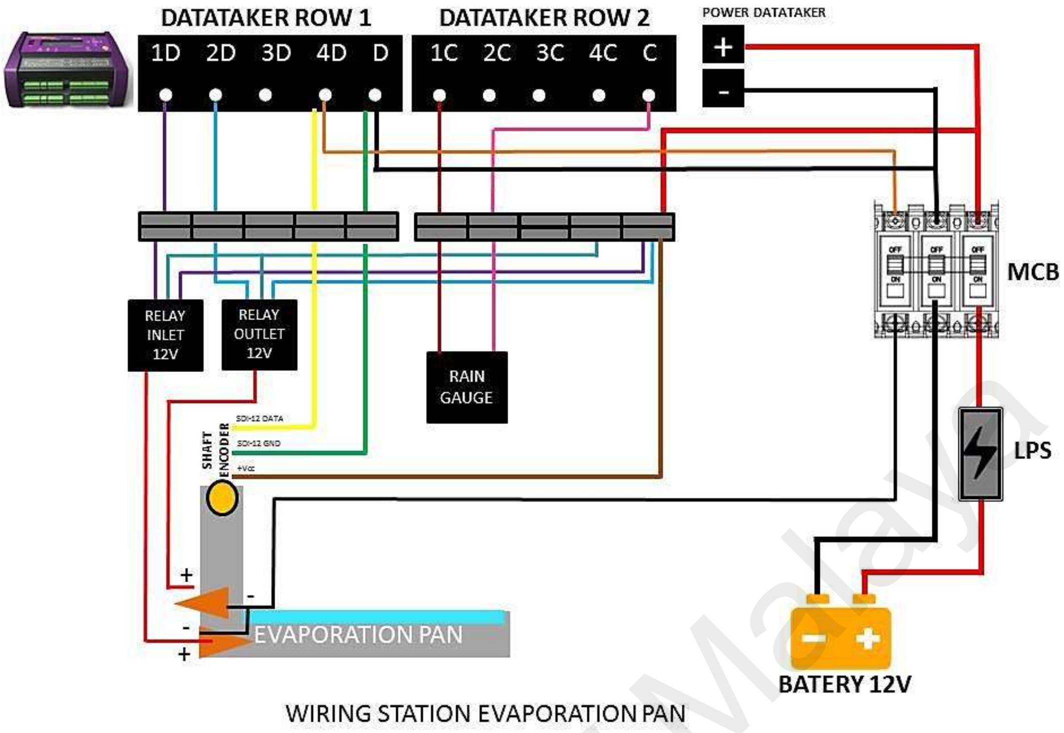

Figure 2.11: Electrical wiring diagram at site (Hydroaxis Sdn Bhd, 2016)

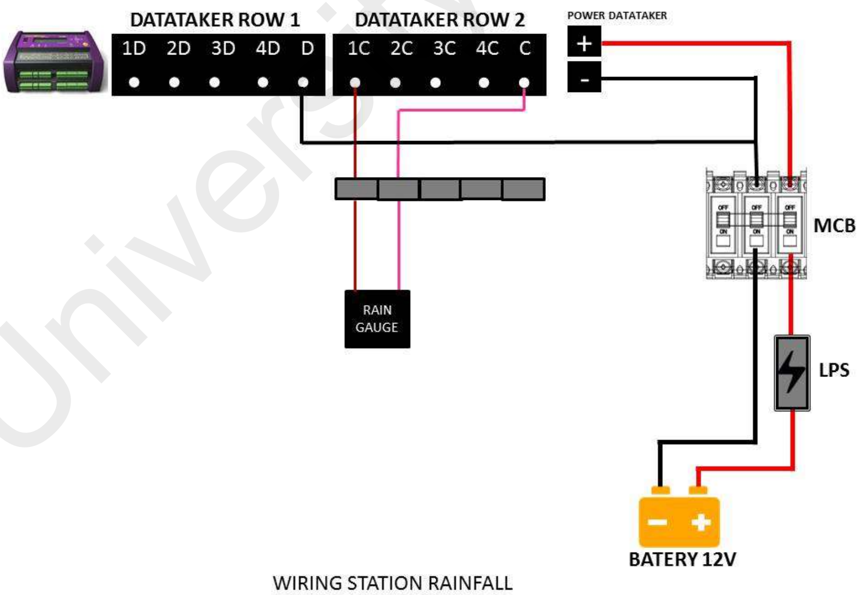

Figure 2.12: Wiring diagram of the rainfall gauge (Hydroaxis Sdn Bhd, 2016)

Basically 3 major components of the system are connected with the Remote Terminal Unit (RTU) which are:

i) The float-operated shaft encoder water level sensor. The sensor is installed inside the stilling well to measure the actual evaporation pan water height.

ii) Rainfall gauge that measures the actual rainfall.

iii) Two 12VDC relays which are connected to the respective normally closed inlet and outlet valve. The inlet valve is also connected with the water pipe from the water tank. It will release the water into the evaporation pan when the connected relay is energized. On the other hand, the outlet valve will release the water from the evaporation pan when its relay is energized.

The actual water level of the evaporation pan and the cumulative rainfall reading will be logged daily at 8.00am in the RTU. The logged data will be sent telemetrically using GSM communication to server at JPS Ampang daily once at 8.00am.

2.5.2 The Evaporation Pan Installed

The evaporation pan installed at site is basically the same as the one used for the manual operation in terms of dimension and material except that it has some elements and components added to the typical evaporation pan. The figure 2.13 shows the evaporation pan used for the project.

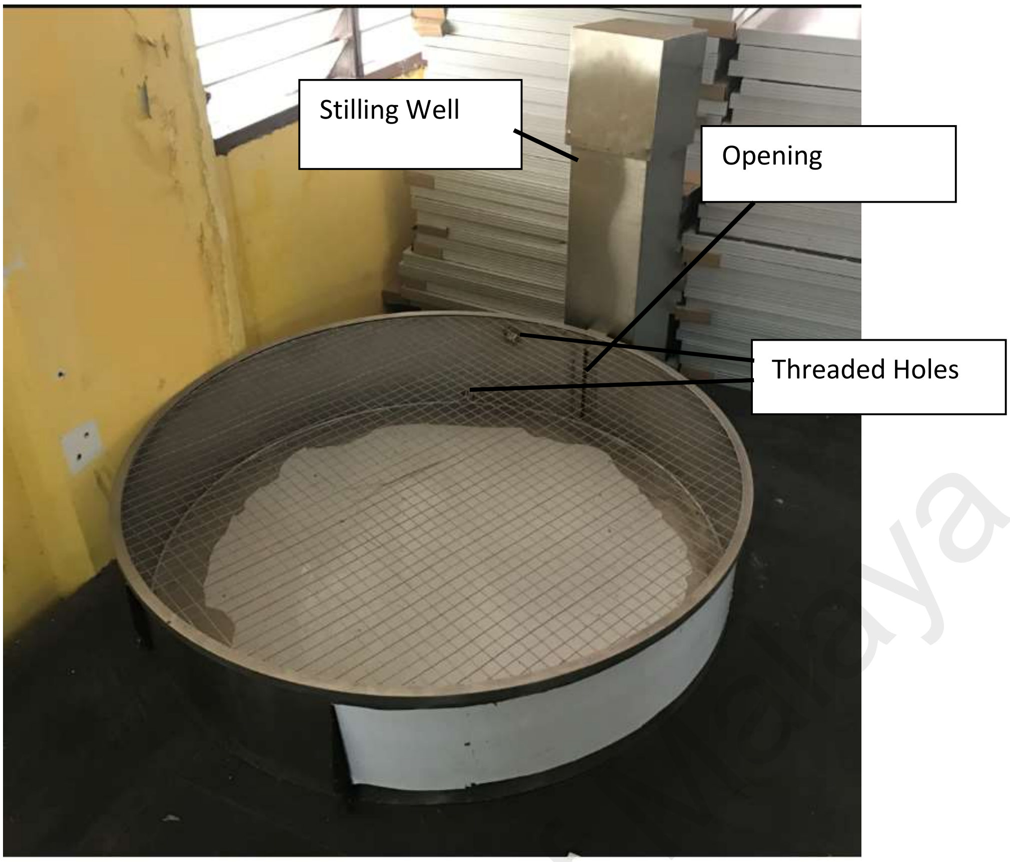

Figure 2.13: Evaporation pan used for the project

The pan is not an off the shelf product but a custom made with some special features, added elements and modifications that ensuring the measurement could be done automatically. The thickness of the pan is 3.5 mm and other dimensions of the pan which are the 1210 mm internal diameter and the 255 mm internal height are complied with the standard US Class "A" Aluminium Pan.

The features of the pan are detailed out as follows:

a) An aluminium box which is so called stilling well with the size (200x200x900) mm is welded and connected with evaporation pan. The stilling well will be mounted with the float-operated shaft encoder water level sensor as shown in the Figure 2.14 to measure the actual water level of the pan.

Figure 2.14: The shaft encoder water level sensor on top of the stilling well

b) There is an opening between the pan and the stilling well to ensure water inside the evaporation fill up the stilling well without any restriction. Therefore, the height of the water inside the pan and the stilling well will be equal.

c) 2 nos. of 30 mm threaded holes with welded flange at the upper and lower part of the pan. These holes are designed for the connection with the inlet and the outlet valve. The inlet valve which will carry the water supply from the water tank will be connected at the upper hole while the outlet valve will be discharging water from the pan will be connected to the bottom hole.

2.5.3 The Float Operated Water Level Sensor

The sensor used to measure the water level of the evaporation pan would be from the float-operated shaft encoder type. The sensor which adopts the measurement principle of float gauge and shaft encoder is easily mounted on top of the stilling well and measure the water level inside the well. According to WMO Technical Regulations float gauge is a gauge consisting essentially of a float which rides on the water surface and rises or falls with it, its movement being transmitted to a recording or indicating device. While a shaft encoder is a device that will convert the angular position of a shaft to analog signal. Figure 2.15 shows the picture of the sensor.

Figure 2.15: Ott SE 200 sensor

The sensor will be connected via the SDI-12 / 4-20mA interface with the RTU. Hence the calculated measurement of the sensor could be monitored and stored in the RTU. The wiring of sensor is connected to the RTU and the battery according to the wiring diagram as in the Figure 2.11. Following are some technical details of the sensor installed for the project:

Brand: Ott Hydromet

Model: Ott SE 200 float-operated shaft encoder water level sensor

Measurement range: +/-30mm

Interface: SDI-12 or 4-20mA

Resolution: 0.001m or 1mm

Accuracy: 0.03% Full Scale +/-1digit

Power supply: 9 – 30VDC

Protection Class: IP54

2.5.4 The Rainfall Gauge

The rainfall gauge is also installed at the evaporation pan station separately but it is connected with the same RTU. The rainfall gauge tipping bucket type installed will measure the rainfall at the location and the daily rainfall data will be used to calculate the amount of the evaporation.

Below are some technical details of the tipping bucket installed for the project and the Figure 2.16 shows the tipping bucket model.

Figure 2.16: Tipping Bucket TB3 Model

Brand: HyQuest Solution

Model: Tipping Bucket Rain Gauge Model TB3

Resolution: one tip at 0.5mm of rainfall

Calibration accuracy: +/-2% for 250mm/hr intensity

Contact system: Dual reed switches encapsulated with varister protection

When the capacity of the bucket which is 0.5mm is full with the water as the rainfall flow from the funnel into the bucket, the bucket will be tipped and the contained water will be emptied. The process will activate the reed switch which will send an electrical pulse to the connected RTU. Each pulse is programmed to be counted as 0.5mm rainfall, so the cumulative daily rainfall could be calculated.

2.5.5 RTU Program and Automation System

The system at site is controlled and monitored using the remote terminal unit brand Data Taker and model DT80. The RTU has been programmed to do the scheduled measurement, data acquisition, automation and transmitting the data to server. The Figure 2.17 shows inside component of the enclosure installed at site.

Figure 2.17: Datataker RTU inside the enclosure

The automation of the evaporation pan automatic operation is realized using 2 major components as follows:

a) 2 nos. of 12VDC Normally Closed Solenoid Valves to allow water flow at the inlet and outlet of the evaporation pan.

b) 2 nos. of 12V/30A Relays connected to each solenoid valve respectively for extra protection of the connected RTU.

The Figures 2.18 and 2.19 show the solenoid valve and relays installed JPS Evaporation Station.

Figure 2.18: Solenoid valve installed at site

Figure 2.19: The connected 12V relays inside the enclosure

The RTU is programmed using the built-in dEX Data Taker software to configure the connected water level sensor and tipping bucket in real time, to perform data acquisition, to do the automation process, to calculate the evaporation rate and lastly to send the data according to pre-programmed format to FTP Server at JPS Ampang Control Centre using GSM Communication daily at 8.00am.

The Figure 2.20 shows some of the essential part of the program coding installed inside the RTU.

```
</measurement>
<measurement username="Too High at 8" type="MANUAL" species="" scheduleid="A" cv="1002" rid="6">
  <raw><![CDATA[IF(1CV>192)AND IF(T><08:01:00,08:02:00)"WL too high at 8 am^M^J"{2CV=1;11CV=1;21CV=0}]]></raw>
</measurement>
<measurement username="Too High Other" type="MANUAL" species="" scheduleid="A" cv="1003" rid="8">
  <raw><![CDATA[IF(1CV>241)AND IF(T<>07:59:00,08:01:00)"WL too high at other time^M^J"{2CV=1;11CV=1;21CV=0}]]></raw>
</measurement>
<measurement username="Too Low at 8" type="MANUAL" species="" scheduleid="A" cv="1004" rid="9">
  <raw><![CDATA[IF(1CV<190)AND IF(T><08:01:00,08:02:00)"WL too low at 8 am^M^J"{2CV=0;11CV=1;21CV=0}]]></raw>
</measurement>
<measurement username="WL Reference" type="MANUAL" species="" scheduleid="A" cv="1005" rid="9">
  <raw><![CDATA[IF(T><08:04:00,08:05:00){35CV("Old WL Reference",W)=1CV}]]></raw>
</measurement>
<measurement username="WL Today" type="MANUAL" species="" scheduleid="A" cv="1006" rid="10">
  <raw><![CDATA[IF(T><07:59:00,08:00:00){36CV("WL at 8",W)=1CV}]]></raw>
</measurement>
```

Figure 2.20: Snapshot of some part of the coding installed inside RTU

The process involved and programmed are explain as follows:

a) At 8.00am daily the current water level of the evaporation pan will be measured.

b) If the water level is above 191mm then the exceed water level will be discharged.

c) The outlet valve will be triggered to release water and stop when the water level reaches 191mm.

d) If the water level is below 191mm then the shortage will be filled up.

e) The inlet valve will be triggered to release water and stop when the water level reaches 191mm.

f) The daily evaporation will be calculated using following formula:

(evaporation = yesterday water Level – current water level + cumulative daily rainfall)

g) The data will be sent to the JPS Ampang FTP Server using comma separated values (CSV) format as follows:

(date (in dd:mm:yyyy), time (in hh:mm:ss), yesterday water level after the water release / fill up after 8.00am (in mm), today water level at 8.00am (in mm), cumulative rainfall from 8.00am yesterday until 8.00am today (in mm), calculated evaporation (in mm))

The table in the Figure 2.21 shows the excel file of the imported csv file from the server for better understanding.

DATE	TIME	YESTERDAY	TODAY	RF	EVAP
1/11/2015	8:00:02 AM	191	191	42	42
2/11/2015	8:00:02 AM	191	193	11.5	9.5
3/11/2015	8:00:02 AM	191	191	39	39

Figure 2.21: The exported csv file in excel

2.5.6 Solar Power Supply System

The entire evaporation pan system uses solar photovoltaic system to power up all the components at site. The solar power supply installed at site consists of solar panel, solar charge controller and sealed lead acid battery which is wired based on the concept diagram as shown in the Figure 2.22.

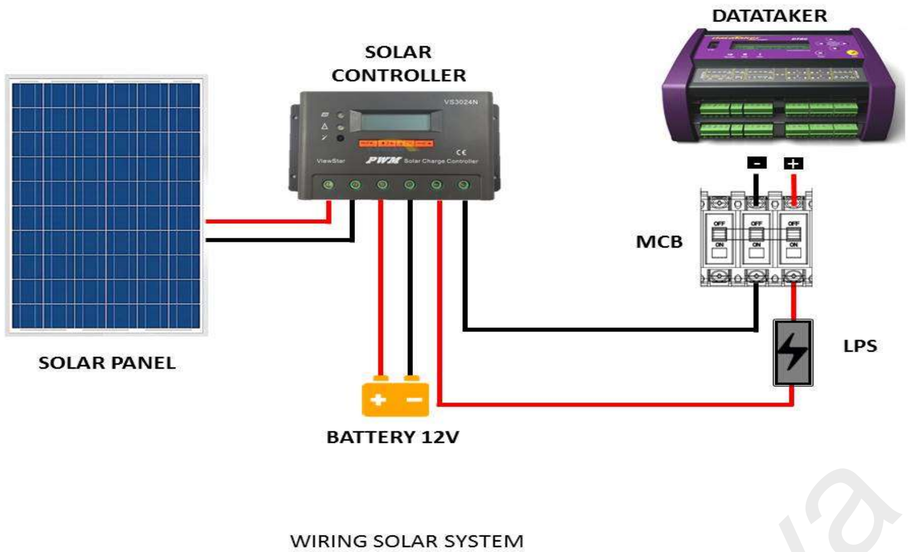

Figure 2.22: Photovoltaic solar system wiring at site

Besides the 3 major components surge protection device (SPD) is also installed at site which can be identified from the Figure 2.22 as LPS. The device is meant for electronic components inside the enclosure against transient surge conditions such as lightning which is very common risk occurred at site. Figures 2.23, 2.24 and 2.25 show the solar components installed at Kuala Kubu Bharu Evaporation Station.

Figure 2.23: Solar panel

Figure 2.24: Surge protection device

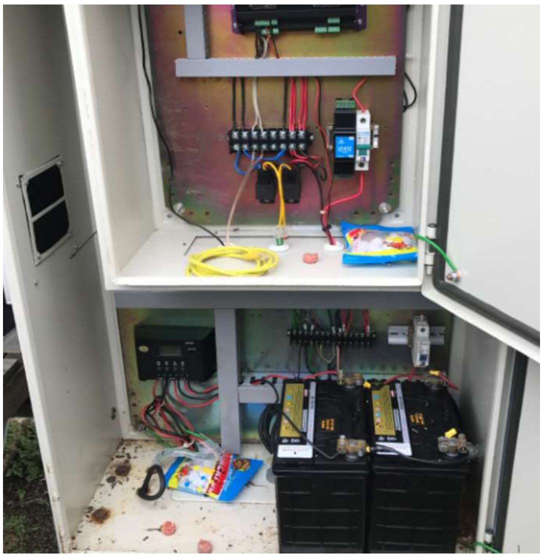

Figure 2.25: Battery and solar charge controller

Below are some of the technical details of the solar components used for the project:

a) Solar Panel

Nominal output voltage: 12V DC

Output Power: 40W

Quantity used: 1

b) Solar Charge Controller

Brand & Model: EP Solar VS3024N

Maximum Current: 30A

Quantity used: 1

c) Battery

Type: Maintenance Free Sealed Lead Acid

Nominal Voltage: 12VDC

Capacity: 40AH or 100AH

Quantity: 1 for 100AH and 2 for 40AH

2.6 Automation & PLC

Automation or automatic control is the technology by which a process or procedure is performed without human assistance (Groover, 2014). It uses various control systems for operating equipment such as machinery, processes in factories, boilers and a lot more applications with minimal human intervention or completely automated. Depending on exact function of the automatic system, following one of several different tools may be responsible for an automated system (Plant Automation Technology, 2018):

a) Artificial neural network

b) Distributed control system

c) Human machine interface

d) Supervisory control and data acquisition (SCADA)

e) Programmable logic controller (PLC)

PLC which is one of the common interfaces used for industrial automation system is a ruggedized industrial computer that can be used for the control of production processes, such as robotic application, assembly lines or any activity that needs high reliability of control, programming and fault diagnosis process.

PLC programming is normally carried out using ladder logic diagram. Each PLC brand and model available in the market can be programmed using its own or compatible plc software. For an example the famous CX-Programmer PLC software is compatible for all

PLC brand OMRON. Other type of languages such as Sequential Function Chart, Structured Text, Functional Block Diagram etc. can also be used for PLC programming.

A PLC will consist of 4 main components which are:

i) Power supply unit – Can either be built in or be an external unit.

ii) Central Processing Unit (CPU) – This is a computer where ladder logic program is stored and processed.

iii) Input / Output (I/O) Terminals – Where all the external I/O is connected to the PLC.

iv) Indicator Lights.

PLC can be packaged into several configurations from largest to smallest configurations as shown in the Figure 2.26. The smallest one would be Micro PLC type which normally has fixed quantities of I/O and lower price.

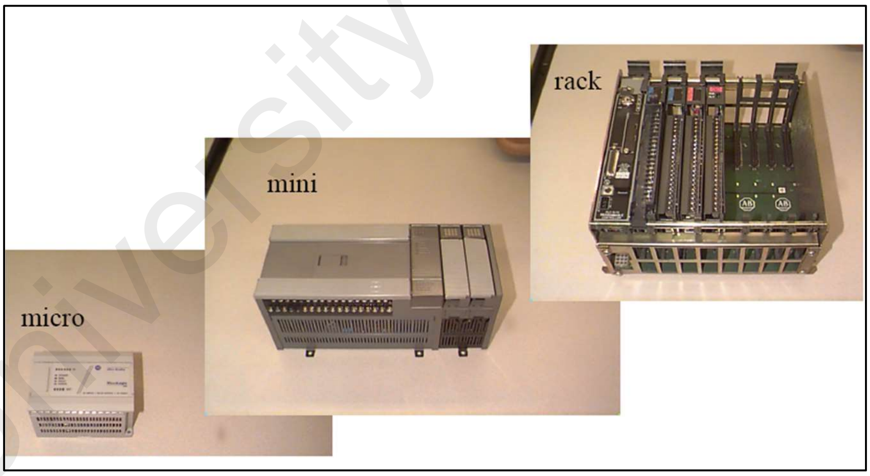

Figure 2.26: Some PLC types (Jack, 2007)

2.7 Relevant Studies on Automatic Evaporation Pan

Caissie (2011) has designed and tested new device to automate a Class A evaporation pan. The new device designed consists of an overflow apparatus mounted at the bottom of a pan and a stilling well which is connected through pipe to the overflow apparatus from outside. Apart from that a pressure level sensor and a water pump are also included as part of the whole automatic evaporation pan system. As seen in the Figures 2.27 and 2.28 at the time of evaporation measurement cycle when the level inside the stilling is lower than reference level pump will be activated to pump water from the well to the pan until excess water from the apparatus flows back to the stilling well. The evaporation will be calculated from the quotient of the height difference inside the well and the amplification factor of the area of the pan to the stilling well area. The entire design has been prototyped and tested in laboratory. The results showed very good performances with errors typically less than 0.1mm.

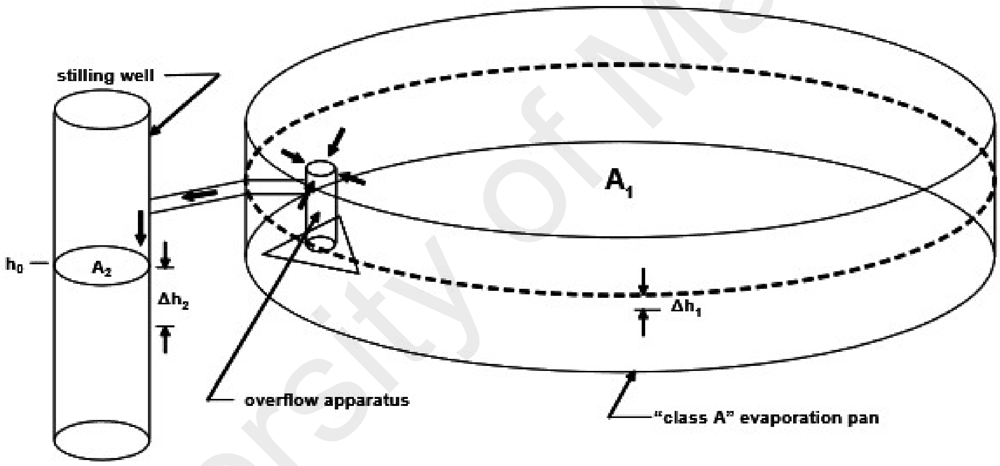

Figure 2.27: New overflow apparatus and stilling well (Caissie, 2011)

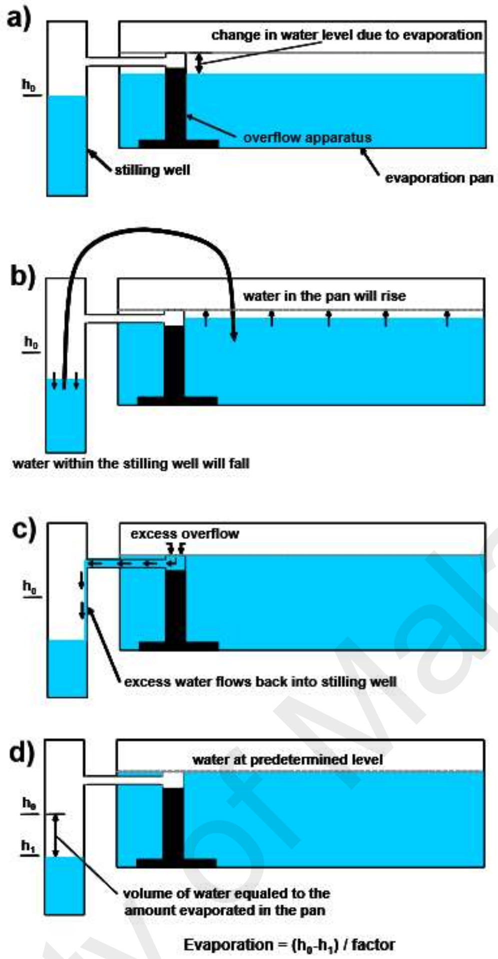

Figure 2.28: Automation process during measurement (Caissie, 2011)

Bruton, Hoogenboom and McClendon (2000) have conducted comparison study between automatic and manual evaporation data at two locations in Georgia from1991 to 1997. The automatic data at Griffin location and Watkinsville location are obtained from Georgia Automated Environmental Monitoring Network (AEMN) while the respective manual data for the location are from the National Weather Service (NWS). The average total annual evaporation rate from manual stations showed 537 mm for Griffin and 1051 mm for Watkinsville. The corresponding automatic data were 414 mm and 676 mm respectively. It has been concluded that mechanical problems with the sensor used in the automated evaporation system were responsible for much of the difference between the two obtained data.

In order to get an accurate measurement of water level height for automation of evaporation pan Fasinmirin and Oguntunde (2009) have developed a digital water level sensor for the purpose. A circuit built is connected to a digital device ICL7106 in order to generate a stable reference voltage for the sensor. The ICL7106 converts the voltage generated from the electrical impulse as the level of the pan changes to a digital display. Results showed that the sensor readings are almost linear with the manual observations with the correlation coefficients, R greater than 0.97.

Recently Ashrafzadeh, Malik, Jothiprakash, Ghorbani and Biazar (2018) have developed an efficient neural network artificial intelligence model using the firefly algorithm (FA) capable of estimating daily pan evaporation at two weather stations in northern Iran. The raw metrological dataset of the two weather stations such as temperature, relative humidity, precipitation, wind speed etc. have been used to develop different types of artificial neural network models. Based on the simulation carried out there were no significant difference can be seen between the observed and the predicted results. From the various hybrid artificial neural network models simulation test, the integration of the FA and the multilayer perceptron networks showed the highest accuracy in estimating daily pan evaporation in terms of root mean square error.

From the studies it shows that there were many different techniques and methods have been adopted to automate an evaporation pan. Moreover, the accuracy, reliability and durability of the sensor and other components used also play an important role to ensure the quality of the measurement, automation and data collected. Lastly with the available other relevant raw data it is also possible to estimate the evaporation rate using artificial intelligence techniques which is also could be used as a benchmark for references.

CHAPTER 3

3. METHODOLOGY

3.1 Introduction

Altogether there will be 5 methods used for this research in order to achieve the overall objectives of the study. The first 2 methods belong to the first phase of the research which is the evaluation study on the existing automatic evaporation pan system installed for JPS/IP/H/09/2014 Project while the remaining 3 methods belong to the second phase which is the development of the PLC Controller for automatic evaporation pan system. The methods and procedures involved for this study will be carried out according to the following manner as in the Figure 3.1.

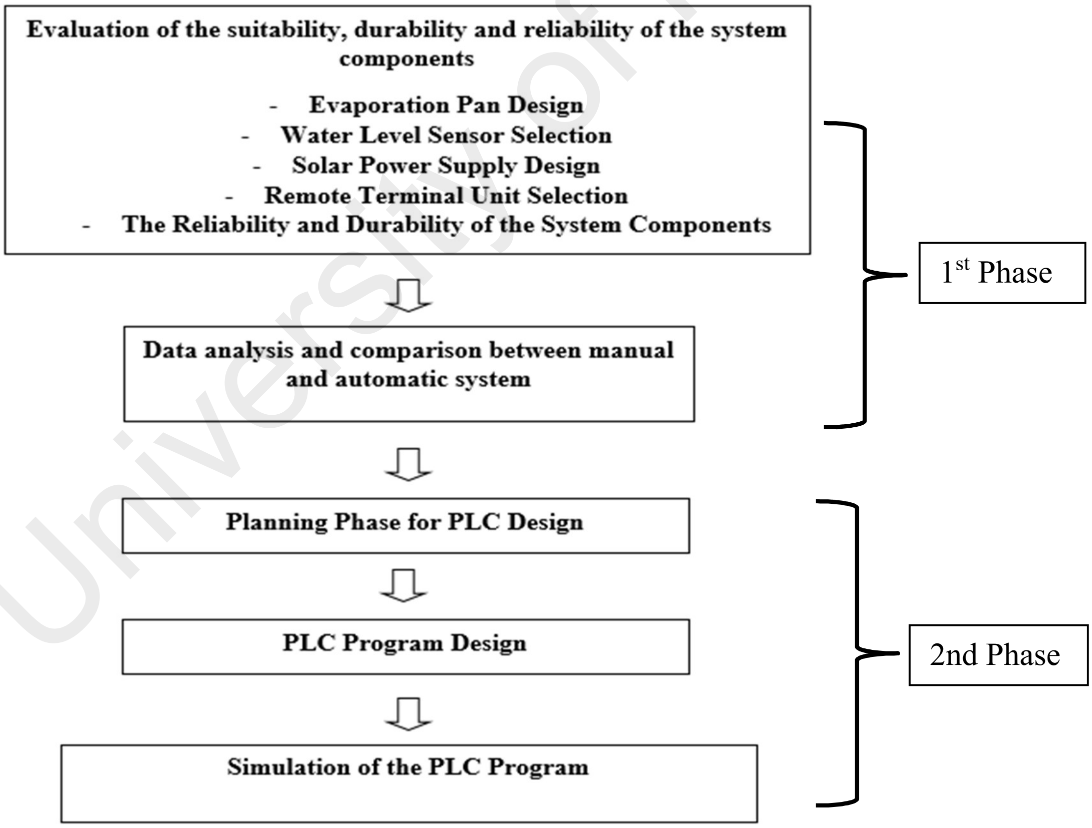

Figure 3.1: Flow diagram of the methodology

3.2 Evaluation of the Suitability, Durability and Reliability of the System Components

Under this topic the suitability, durability and reliability of the major components installed at site for the existing automatic evaporation system installed in JPS will be reviewed. For the suitability part the evaporation pan design, the selection of the water level sensor, the existing solar power supply design and the RTU installed will be discussed deeper and the possible better solution will be compared for design improvement and optimization.

While for the durability and the reliability part the findings from the site visit carried out and the review of any issues related to the system will be used to evaluate the existing system.

3.2.1 Evaporation Pan Design

The existing evaporation pan design used in the project basically has been designed to include the stilling well part to cater for water level measurement using float-operated shaft encoder water level sensor as shown in the Figure 3.6. The dimension and the size of the evaporation pan comply with the International Standard and the same as the manual evaporation pan. But as the new evaporation pan comprises welded stilling well and act as a one system the volume of the water contained in the entire system differs from the manual one.

Figure 3.2 shows the both evaporation pans sit beside each other at Kuala Kubu Bharu Evaporation Station and Figure 3.3 on the other hand shows conceptual drawing containing the dimension of the automatic evaporation pan installed at JPS site. The material used is aluminium sheet with the thickness of 3.5 mm for the entire components.

The evaporation pan is exposed to the open air while the connected stilling well is covered at the top.

From the Figure 3.3 we can calculate that the volume of the water contained in the evaporation pan from the reference 191 mm water level used to measure the evaporation is calculated as follow:

Volume of water = Volume of evaporation pan + Volume of stilling well

$$= ((\pi \times 605^2) \times 191) + (200 \times 200 \times 191)$$

$$= 219,631,177mm^3 + 7,640,000mm^3$$

$$= 219,631cm^3 + 7640cm^3$$

$$= 227,271cm^3$$

Hence the volume of water used in the automatic evaporation pan to measure the daily evaporation rate is 7640cm^3 greater than the manual evaporation pan which is almost 3.5%.

Although the rate is small but as the daily evaporation rate is also very small, thus the difference is really matters for obtaining an accurate and effective measurement.

Figure 3.2: Manual (on the left) and automatic evaporation pans at Kuala Kubu Bharu

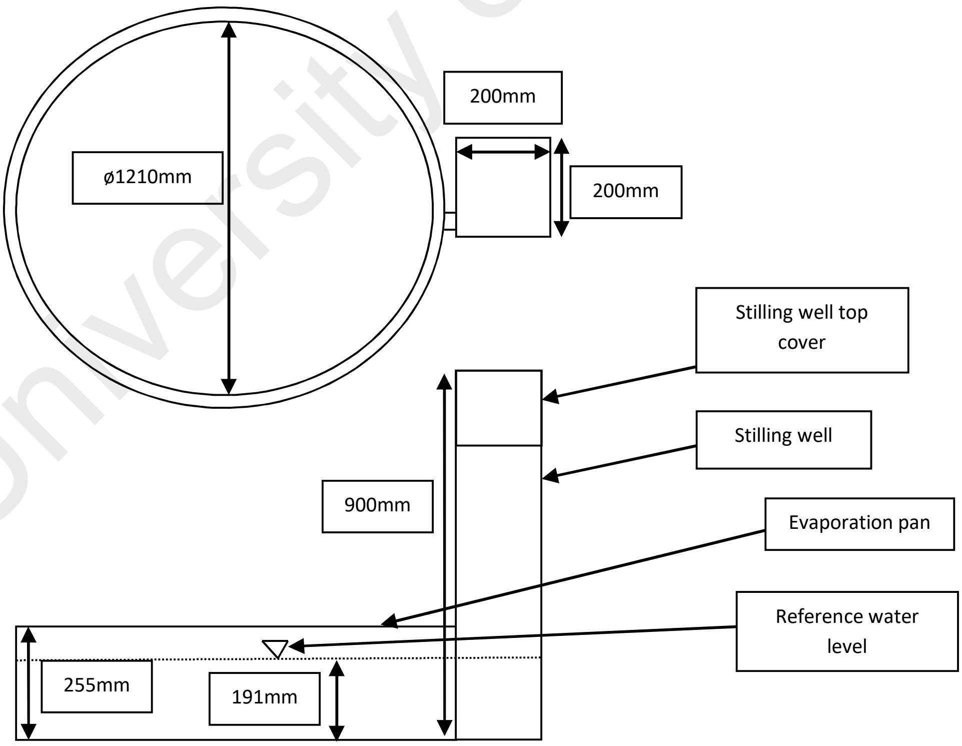

Figure 3.3: Dimension of the existing automatic evaporation pan

3.2.2 Water Level Sensor Selection

According to "JPS Hydrological Standard for Water Level Station Instrumentation" commonly there are 4 types of water level sensor which are air bubbler, radar, ultrasonic and submersible pressure transducer installed at JPS River Stations to measure water level. Each of them adopts different measurement techniques and is suitable for different site conditions and to measure river level range. Besides these 4 types of water level sensor the float-operated shaft encoder water level sensor is also has been used in some older river stations which has been constructed with stilling well structure exactly beside the river. The water level inside the stilling well will be the same as the river level as it is freely connected with the river. The float-operated will be installed inside the stilling well.

The Figures 3.4 until 3.7 showing some types of water level sensor installed at JPS River Station.

The Table 3.1 shows the comparison between the 5 types of water level sensor in terms of application and measuring range.

Figure 3.4: Ultrasonic water level sensor

Figure 3.5: Stilling well

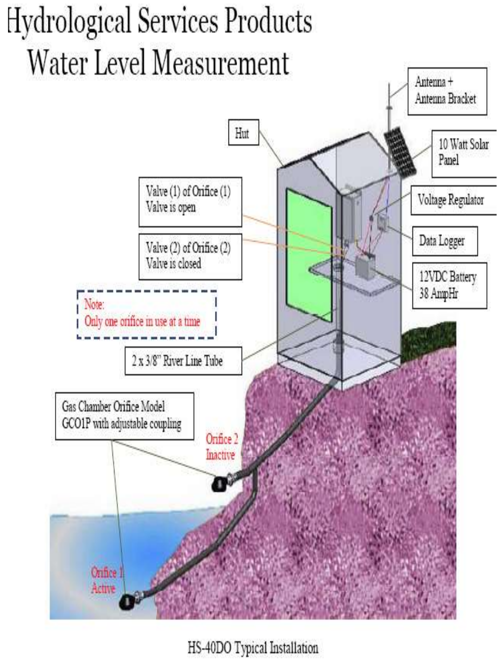

Figure 3.6 Air bubbler principle

Figure 3.7: Radar water level sensor concept

Table 3.1: Comparison between different types of water level sensor in JPS

Type	Application	Measuring Range
Air Bubbler	River with deep slope elevation	0-35m
Ultrasonic	Site nearby bridge	0-15m
Radar	Site nearby bridge	0-35m
Submersible Pressure Transducer	River with deep slope elevation with less sediments	0-20m
Float-Operated Shaft Encoder	Site with stilling well structure	0-30m

From the comparison table it is clearly can be seen that none of the sensors is specifically meant for low level measurement which is relevant to the evaporation pan level. Some requirements that shall be considered in choosing the water level sensor for evaporation pan are detailed out as following:

i) Measuring range: 0 – 255mm

ii) Measurement is also has been carried out less than 5 times daily

iii) Can produce 4-20mA or SDI12 output signal

The one is currently used for the automatic evaporation pan system is the float-operated shaft encoder water level sensor which might be chosen due to the following reasons compared with the other common water level sensors:

a) The sensor could do the measurement without the need to install any structures or object that will obstruct the evaporation pan.

b) Easy to install and can do the measurement within the evaporation pan range although with less accuracy.

c) It is durable and easy to install.

Although the sensor is the best available sensor to be chosen comparing with the other 4 types, it is also shows some following disadvantages that need to be improved in order to get a better measurement:

i) The accuracy of the sensor which is 0.03% of the Full Scale 30m is around 0.9mm seems to be relatively high for 255mm measuring range of the evaporation pan. The daily average evaporation rate in Malaysia would be around 0 to 10 mm. So if the accuracy of the sensor is 0.9mm, then the accuracy of the measurement obtained would be about 10% which is very high.

ii) Evaporation pan design shall include the stilling well structure as discussed in the section 3.2.1 which is also affecting the reliability of the measurement obtained compared with the International Standard.

As a result, possibility of implementing other types of water level sensor shall be discussed in order to overcome these deficiencies. One of the sensors that could be taken into consideration would be Micro-Electro-Mechanical-System (MEMS) pressure sensor.

A lot of study has been carried out that showing the sensor ability to give better accuracy, higher sensitivity and better sensor characteristics. Some of the studies are summarized as follows:

i) A. Nallathambi et al. (2016) have carried out a study to design and analyse the MEMS based piezoresistive pressure sensor for sensitivity enhancement.

ii) Sarath T M et al. (2013) on the other hand carried out an experiment using MEMS pressure sensor that proved that the low level measurement of water level for the range 0 to 24cm could be achieved using MEMS pressure sensor.

iii) S. Santosh Kumar et al. (2013) have published their works on the design and simulation of MEMS silicon piezoresistive pressure sensor for barometric application which could be used using the same concept with the different design parameters and pressure range in designing for water level measurement application as the pressure is also increases when the water level depth rises.

3.2.3 Solar Power Supply Design

It is known that from the site visit carried out the solar power supply system installed of the 4 automatic evaporation pan system installed under the JPS/IP/H/09/2014 Project which consist of solar panel, solar charge controller and seal lead acid (SLA) battery have different capacity and quantity of battery. For example, JPS Ampang Test Station installed with 1 no. of 100AH SLA Battery with 40W Solar Panel whereas Kuala Kubu Bharu Evaporation Station on the other hand used 2 nos. of parallel connected 40AH SLA

Battery and 40W Solar Panel. Although both stations share same components, usage and system but not standardly installed with same or correct size.

Hence the required solar power design of the system for 14 days of operation without sunshine which is the standard norm used in JPS will be calculated roughly under this procedure. (Calculation carried out is based on the Leonics Company Limited Solar PV System Design Manual)

a) Firstly the required watt-hours per day of all of the components (as shown in the Table 3.2) need to be calculated. The required power consumption of the components is obtained from the product brochures.

b) Based on the Table 3.2 calculation the daily required watt-hours need to be multiplied with 1.3 (the energy lost in the system) in order to get total Watt-hours per day which must be provided by the Solar Panel.

So total watt-hours required = 16.3Wh x 1.3 = 21.2Wh

Therefore, the required calculation for solar panel would be as follows:

i) Average daily sunshine hours = 6h

ii) Required solar panel size = 21.2Wh / 6h = 3.5W

iii) Hence if we use 10W solar panel, it will provide 10W/3.5W = 2.85 safety factor.

iv) Likewise, if we use 20W solar panel, it will provide 20W/3.5W = 5.71 safety factor.

Table 3.2: The daily watt-hours used by the entire system at site

No	Component	Current Required (A)	Daily usage in hours (h)	Capacity (Ah)	Volt (V)	Daily Watt-hours required (Wh)
1	Solar Charge Controller	0.0125A	24h	0.3Ah	12	3.6Wh
2	Float Operated Shaft Encoder Water Level Sensor (active mode)	2mA	0.08h (5min)	0.16mAh	12	1.92mWh
3	Float Operated Shaft Encoder Water Level Sensor (sleep mode)	400μA	24h	9.6mAh	12	0.12Wh
3	30W Solenoid Valve for Inlet	2.5A	0.08h (5min)	0.2Ah	12	2.4Wh
4	30W Solenoid Valve for Outlet	2.5A	0.08h (5min)	0.2Ah	12	2.4Wh
3	3G/GPRS/GSM Modem	0.021A	24h	0.504Ah	12	6.05Wh
5	RTU (Datataker DT80)	0.006A	24h	0.144Ah	12	1.73Wh
Total				**1.36Ah**		**16.3Wh**

c) The next step would be from the total capacity 1.36Ah the required battery size to cater for 14days non sunny day could be calculated:

Minimum capacity requirement for 14 non sunny days

= (14 x 1.36Ah)/ (0.85* x 0.6*) = 37.33 Ah

(* 0.85 and 0.6 are the constant used for battery loss and depth of discharge respectively)

Hence the required battery size for 14 non sunny days of operation would be 40Ah which is the nearest to the minimum capacity requirement 37.33Ah.

3.2.4 Remote Terminal Unit Selection

The Remote Terminal Unit (RTU) used for the existing automatic evaporation pan system is Datataker Model DT80 (as shown in the Figure 3.8).

Figure 3.8: RTU Datataker DT80

This RTU has been used for the project because it can provide one stop solution for all kind of functions required for the automatic evaporation pan system at site. The RTU could do the data processing and data logging of the sensor's data at site, data storing, be programmed to do the automation process and has a built-in GSM Modem to perform communication process. Simply to say the RTU could carry out the normal function like the common RTUs available in the market plus with the built-in Controller and GSM Modem.

Despite that the RTU installed at site still faces a lot of issues and shows some critical disadvantages that are highlighted as follows:

a) Expensive price

b) The automation program built-in inside is not a standard Automation Program such as Ladder Diagram etc. Therefore, IT personnel are needed when it comes to adjustment and troubleshooting.

c) The RTU is not simply could be replaced with other types of RTUs available in JPS. JPS has more than 1000 other hydrological stations such as Water Level and Rainfall which are also installed with RTU but without built-in controller function. Thus when it comes to emergency cases the exact type of RTU is required for replacement.

As a result, possibility of using other standard PLC Controller coupled with the normal RTU as another option will be studied as a part of this research to overcome those problems. The possibilities of implementation and the methods required will be discussed in the sections 3.4, 3.5 and 3.6.

3.3 The Reliability and Durability of the System Components

Under this procedure the components installed at site after 2 years of the installation will be checked in terms of the reliability and the durability. The first method adopted in carrying out the verification process is by performing functionality testing and visual observation during site visit at the station. 2 site visits at JPS Ampang Test Station and Kuala Kubu Bharu Evaporation Station have been carried out on the 18th September 2018 and the 5th October 2018 respectively for the purpose.

Following are some of the important findings from the site visits:

i) Most of the evaporation pan installed at site corroded badly although the material used is aluminium which is supposedly difficult to corrode. Figures 3.9 and 3.10 show some of the findings.

ii) As shown in the figure 3.11 the base used to place the evaporation pan that supposed to be hardwood according to the standard was installed with normal wood pallet. The pallet damaged badly that made the pan position becoming very unstable and unlevelled.

Figure 3.10: Corroded pan at different angle

Figure 3.9: Corroded pan

Figure 3.11: The wood pallet damaged badly

Second method used would be reviewing all the documentation regarding issues as well as operation and maintenance (O&M) reports about the installed system after the installation period until present.

Altogether there were 2 reports has been reviewed for the purpose which are testing & commissioning report during handover of the project and operation & maintenance report for the maintenance carried in September 2018. The findings from the review could be seen from the Figures 3.12, 3.13 and 3.14.

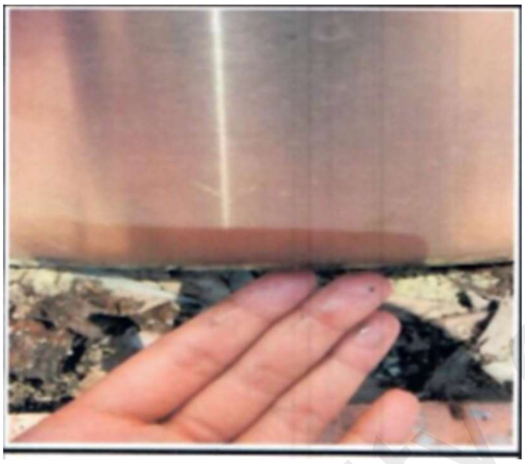

Figure 3.12: Evaporation pan leaking

Figure 3.13: Defective valve

Figure 3.14: Leaking at the valve joint

3.4 Data Analysis and Comparison Between Manual and Automatic System

Although the automatic evaporation pan system has been installed at the 4 evaporation stations under the JPS/IP/H/09/2014 Project, the manual evaporation pan operation and measurement at that stations were not disrupted and the daily data collection is still running.

So in this section the manual data collected at station will be compared with the automatic evaporation data stored in the server. The data from January and February 2018 from the Kuala Kubu Bharu Station will be used for the analysis. The period is chosen because during that time the automatic system was in the best condition and well maintained.

Furthermore, the efficiency of the automation process could also be calculated from the data as the system at site take the water level measurement each time just after it releases or fill up the water up to the reference level which is 191mm and the measurement will be sent the next day at 8.00am to the server together with the actual water level at 8.00am.

The Tables 3.3 and 3.4 show the automatic evaporation pan system data at Kuala Kubu Bharu Station for January 2017 and February 2017 respectively retrieved from the JPS server. While the Tables 3.5 and 3.6 on the other hand show the manually collected data for the same period of time from the manual evaporation pan system at the same station obtained from JPS Selangor.

Table 3.3: Automatic evaporation data for Kuala Kubu Bharu Station January 2017

Date	Time	Yesterday WL (mm)	Today WL (mm)	Rainfall (mm)	Evaporation (mm)
1/1/2017	8:00:02 AM	191	189	0	2
2/1/2017	8:00:02 AM	191	218	29	2
3/1/2017	8:00:02 AM	191	189	0.5	2.5
4/1/2017	8:00:02 AM	191	191	0	0
5/1/2017	8:00:02 AM	191	190	0	1
6/1/2017	8:00:02 AM	190	189	0	1
7/1/2017	8:00:02 AM	191	192	1	0
8/1/2017	8:00:02 AM	191	189	0	2
9/1/2017	8:00:02 AM	192	192	0	0
10/1/2017	8:00:02 AM	191	190	0	1
11/1/2017	8:00:02 AM	190	189	0	1
12/1/2017	8:00:02 AM	192	191	0	1
13/1/2017	8:00:02 AM	191	189	0	2
14/1/2017	8:00:02 AM	190	218	34.5	6.5
15/1/2017	8:00:02 AM	191	216	35	10
16/1/2017	8:00:02 AM	191	201	22	12
17/1/2017	8:00:02 AM	191	193	12.5	10.5
18/1/2017	8:00:02 AM	191	190	4.5	5.5
19/1/2017	8:00:02 AM	190	190	0	0
20/1/2017	8:00:02 AM	190	198	15.5	7.5
21/1/2017	8:00:02 AM	191	190	0	1
22/1/2017	8:00:02 AM	190	189	0	1
23/1/2017	8:00:02 AM	191	207	18.5	2.5
24/1/2017	8:00:02 AM	191	216	33	8
25/1/2017	8:00:02 AM	191	209	31	13
26/1/2017	8:00:02 AM	191	192	9	8
27/1/2017	8:00:02 AM	191	190	0	1
28/1/2017	8:00:02 AM	190	189	0	1
29/1/2017	8:00:02 AM	190	199	14	5
30/1/2017	8:00:02 AM	191	190	0	1
31/1/2017	8:00:02 AM	190	189	0.5	1.5
Total				260.5	110.5

Table 3.4: Automatic evaporation data for Kuala Kubu Bharu Station February 2017

Date	Time	Yesterday WL (mm)	Today WL (mm)	Rainfall (mm)	Evaporation (mm)
1/2/2017	8:00:02 AM	191	191	0	0
2/2/2017	8:00:02 AM	191	191	0	0
3/2/2017	8:00:02 AM	191	190	0	1
4/2/2017	8:00:02 AM	190	189	0	1
5/2/2017	8:00:02 AM	191	191	3	3
6/2/2017	8:00:02 AM	192	190	0	2
7/2/2017	8:00:02 AM	190	190	2	2
8/2/2017	8:00:02 AM	190	190	0	0
9/2/2017	8:00:02 AM	190	184	0	6
10/2/2017	8:00:02 AM	190	190	0	0
11/2/2017	8:00:02 AM	190	189	0	1
12/2/2017	8:00:02 AM	190	189	0	1
13/2/2017	8:00:02 AM	191	190	0	1
14/2/2017	8:00:02 AM	190	189	0	1
15/2/2017	8:00:02 AM	191	189	0	2
16/2/2017	8:00:02 AM	191	189	0	2
17/2/2017	8:00:02 AM	191	190	0	1
18/2/2017	8:00:02 AM	190	189	0	1
19/2/2017	8:00:02 AM	191	191	0	0
20/2/2017	8:00:02 AM	191	189	0	2
21/2/2017	8:00:02 AM	191	191	0	0
22/2/2017	8:00:02 AM	191	190	0.5	1.5
23/2/2017	8:00:02 AM	190	189	0	1
24/2/2017	8:00:02 AM	191	200	13.5	4.5
25/2/2017	8:00:02 AM	191	190	0	1
26/2/2017	8:00:02 AM	190	189	7	8
27/2/2017	8:00:02 AM	191	192	4	3
28/2/2017	8:00:02 AM	190	190	6.5	5.5
Total				**36.5**	**51.5**

Table 3.5: Manual evaporation data for Kuala Kubu Bharu Station January 2017

BAHAGIAN PENGURUSAN SUMBER AIR DAN HIDROLOGI

BSAH-DK-PSB

DOKUMEN KUALITI

PENYATA SEJATAN BULANAN (PSB)

NO. KELUARAN : 6

NO. PINDAAN : 0

TARIKH KUATKUASA : 01.10.2015

MUKA SURAT : 1 drpd. 1

PSB

Tempat : LOGI AIR K.K.BHARU

Rujuk Grid : VK 080956

No. Stesen: 3 5 1 6 3 2 2

Tahun: 2 0 1 7

Bulan: 0 1 (Tulis Angka sahaja)

Haribulan	Masa	Hujan (mm)	Aras Tambah (mm)	Air Buang (mm)	Sejatan (mm)	Catatan
1.	0800HRS	0.0	2.0	0.0	2.0	
2.	0800HRS	33.5	0.0	22.0		Rekod dibatalkan
3.	0800HRS	0.5	1.5	0.0	2.0	
4.	0800HRS	0.0	3.0	0.0	3.0	
5.	0800HRS	0.0	2.5	0.0	2.5	
6.	0800HRS	0.0	2.5	0.0	2.5	
7.	0800HRS	1.5	0.5	0.0	2.0	
8.	0800HRS	0.0	4.0	0.0	4.0	
9.	0800HRS	0.0	4.0	0.0	4.0	
10.	0800HRS	0.0	4.0	0.0	4.0	
11.	0800HRS	0.0	3.0	0.0	3.0	
12.	0800HRS	0.0	5.0	0.0	5.0	
13.	0800HRS	0.0	2.0	0.0	2.0	
14.	0800HRS	37.0	0.0	25.0		Rekod dibatalkan
15.	0800HRS	41.5	0.0	28.0		Rekod dibatalkan
16.	0800HRS	26.0	0.0	16.0	10.0	
17.	0800HRS	13.5	0.0	8.0	5.5	
18.	0800HRS	6.0	0.0	2.0	4.0	
19.	0800HRS	0.0	2.0	0.0	2.0	
20.	0800HRS	18.0	0.0	11.0	7.0	
21.	0800HRS	0.0	1.0	0.0	1.0	
22.	0800HRS	0.0	3.0	0.0	3.0	
23.	0800HRS	22.0	0.0	15.5	6.5	
24.	0800HRS	39.0	0.0	30.0	9.0	
25.	0800HRS	33.5	0.0	23.5	10.0	Sejatan = 115.0 x 31/28
26.	0800HRS	10.5	0.0	6.0	4.5	= 127.32 mm
27.	0800HRS	0.0	2.0	0.0	2.0	
28.	0800HRS	0.0	2.5	0.0	2.5	
29.	0800HRS	17.5	0.0	11.0	6.5	
30.	0800HRS	1.0	2.5	0.0	3.5	
31.	0800HRS	0.0	2.0	0.0	2.0	

Disukat oleh : ABDUL HALIM B. MD. RAHMAN

Tandatangan :

Tarikh : 1/2/17

Sejatan dihitung oleh :

Tandatangan :

Tarikh : 1/2/2017

MOHD ILHAM BIN MOHD ZAINUDDIN
Penolong Jurutera JA29
Bahagian Pengurusan Sumber Air & Hidrologi
JPS Negeri Selangor

Hitungan disemak :

Tandatangan :

Tarikh :

NOOR AZIAH BINTI DAUD
Pegawai Hidrologi Negeri
Bahagian Sumber Air Dan Hidrologi
Jabatan Pengairan Dan Saliran
Negeri Selangor Darul Ehsan

Table 3.6: Manual evaporation data for Kuala Kubu Bharu Station February 2017

BAHAGIAN PENGURUSAN SUMBER AIR DAN HIDROLOGI

BSAH-DK-PSB

DOKUMEN KUALITI

PENYATA SEJATAN BULANAN (PSB)

NO. KELUARAN : 6

NO. PINDAAN : 0

TARIKH KUATKUASA : 01.10.2015

MUKA SURAT : 1 drpd. 1

PSB

Tempat : **LOGI AIR K.K.BHARU**

Rujuk Grid : **VK 080956**

No. Stesen: 3 5 1 6 3 2 2

Tahun: 2 0 1 7

Bulan: 0 2 (Tulis Angka sahaja)

Haribulan	Masa	Hujan (mm)	Aras Tambah (mm)	Air Buang (mm)	Sejatan (mm)	Catatan
1.	0800HRS	0.0	2.0	0.0	2.0	
2.	0800HRS	0.0	1.0	0.0	1.0	
3.	0800HRS	0.0	3.0	0.0	3.0	
4.	0800HRS				Tiada Rekod	Rekod dibatalkan
5.	0800HRS	44.0	3.5	0.0		
6.	0800HRS	0.0	2.5	0.0	2.5	
7.	0800HRS	2.5	2.0	0.0	4.5	
8.	0800HRS	0.0	2.0	0.0	2.0	
9.	0800HRS	0.0	4.0	0.0	4.0	
10.	0800HRS	0.0	4.5	0.0	4.5	
11.	0800HRS	0.0	5.5	0.0	5.5	
12.	0800HRS	0.0	4.0	0.0	4.0	
13.	0800HRS	0.0	3.0	0.0	3.0	
14.	0800HRS	0.0	5.0	0.0	5.0	
15.	0800HRS	0.0	6.0	0.0	6.0	
16.	0800HRS	0.0	6.0	0.0	6.0	
17.	0800HRS	0.0	5.5	0.0	5.5	
18.	0800HRS	0.0	4.5	0.0	4.5	
19.	0800HRS	0.0	4.5	0.0	4.5	
20.	0800HRS	0.5	4.0	0.0	4.5	
21.	0800HRS	0.0	3.0	0.0	3.0	
22.	0800HRS	0.0	2.5	0.0	2.5	
23.	0800HRS	0.5	2.0	0.0	2.5	
24.	0800HRS	14.5	0.0	9.5	5.0	
25.	0800HRS	0.0	3.5	0.0	3.5	Sejatan = 103.5 x 28
26.	0800HRS	11.5	0.0	5.0	6.5	27
27.	0800HRS	2.0	0.5	0.0	2.5	= 107.33 mm
28.	0800HRS	12.0	0.0	6.0	6.0	

Disukat oleh : Abd. Hakim

Tandatangan :

Tarikh : 1/3/2017

Sejatan dihitung oleh :

Tandatangan :

MOHD ILHAM BIN MOHD ZAINUDDIN
Penolong Jurutera JA29
Bahagian Pengurusan Sumber Air & Hidrologi
JPS Negeri Selangor

Tarikh 10/3/17

Hitungan disemak :

Tandatangan :

Tarikh

NOOR AZIAH BINTI DAUD
Pegawai Hidrologi Negeri
Bahagian Sumber Air Dan Hidrologi
Jabatan Pengairan Dan Saliran
Negeri Selangor Darul Ehsan

13/3/17

3.5 Planning Phase for PLC Design

In order to design a good PLC Program a proper process flow and planning shall be followed. After understanding the process description involved the program shall be planned systematically. There are a lot of standard planning program commonly been used in PLC design such as Boolean Logic Design, Karnaugh Maps, Structured Logic Design, State Based Design etc. Each of them suits for different kind of process steps. For this design the Flowchart Based Design will be adopted as the process involved in the program has sequential process and some simple decision steps.

The chart below described how the entire PLC Program will be carried out sequentially for this study.

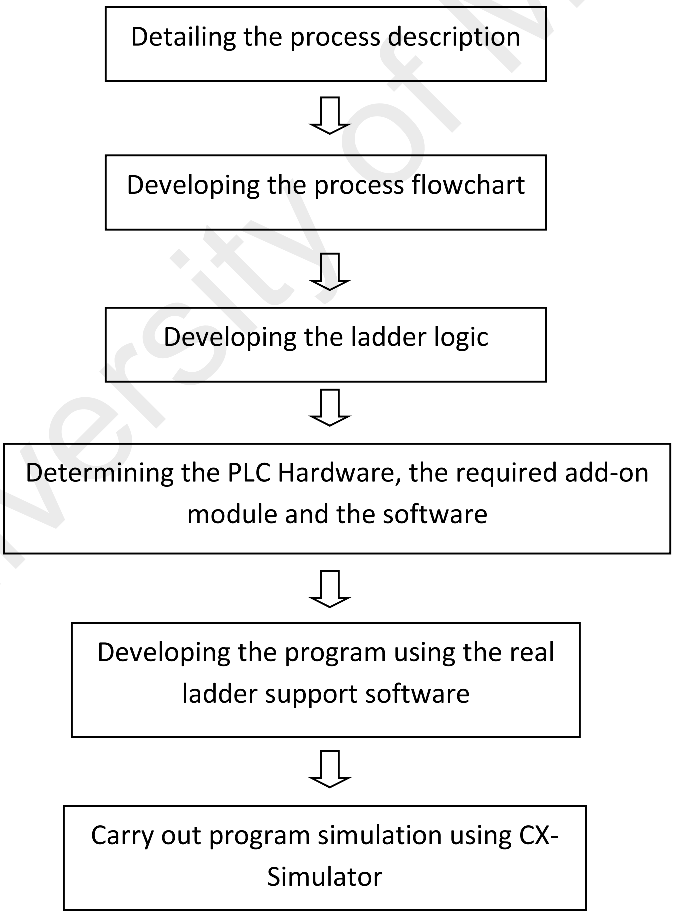

Figure 3.15: The overall process flow of the PLC Program

The overall automation process involved for the PLC Design has been described in detail in the section 2.5.5 of this report. From the description the related flowchart will be developed. The developed flowchart based on the process involved for this program is shown in the Figure 3.16.

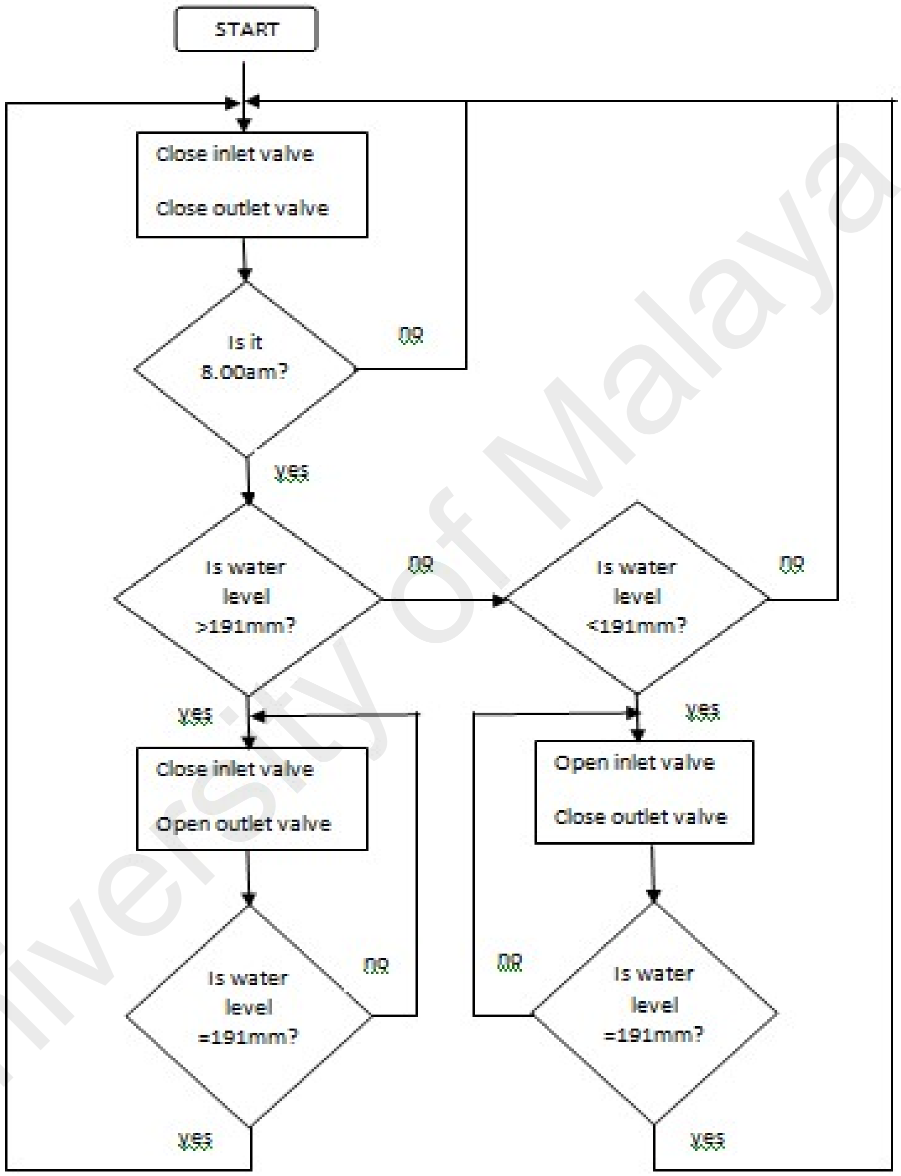

Figure 3.16: Flowchart for the PLC process

The developed flowchart as in the Figure 3.16 will be transformed into the ladder logic diagram. The corresponding ladder logic program for the flowchart is shown in the Figure 3.17.

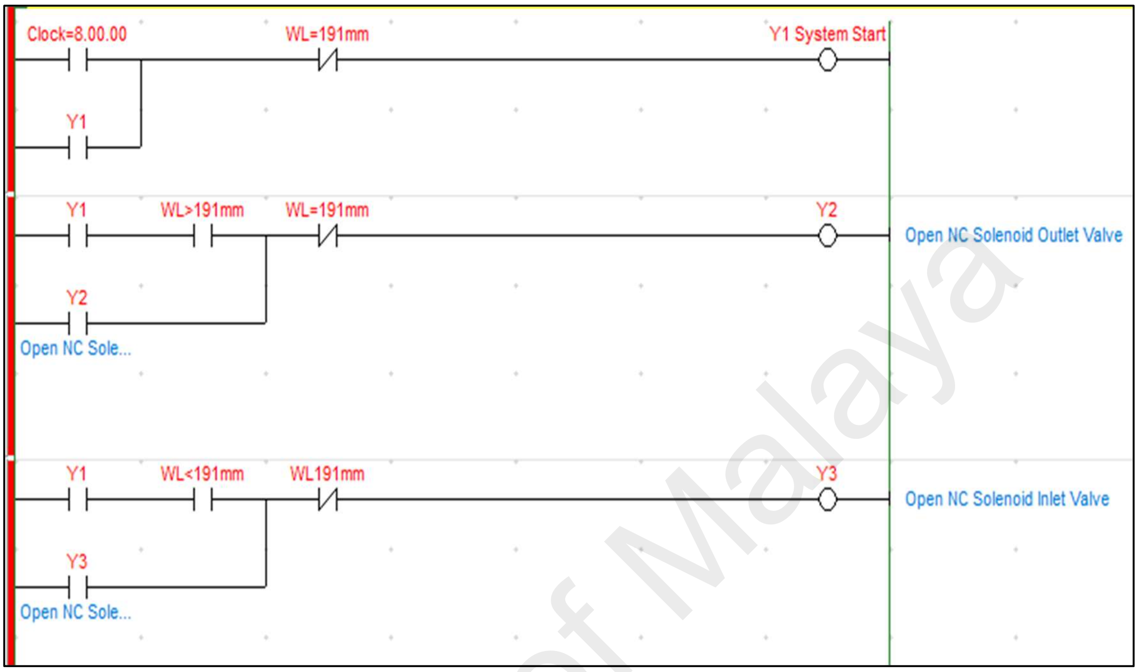

Figure 3.17: Corresponding ladder logic of the flowchart

3.6 PLC Program Design

In order to design the real PLC Controller, the PLC Program shall be programmed in the compatible Software for the controller. For this study the CX-Programmer software that compatible for all type of PLC brand Omron will be used.

Before designing the PLC Program some information regarding the inputs and outputs voltages, and signal types shall be gathered to ensure the appropriate PLC model and add-on module could be chosen.

The Table 3.7 shows the inputs and outputs characteristics for the program.

Table 3.7: Input and output properties of the program

No	Hardware	Input / Output	Voltage Supply	Signal Type
1	Water Level Sensor	Input	10-30VDC	Analog 4-20mA
2	Normally Closed Inlet Solenoid Valve	Output	12VDC	Digital output
3	Normally Closed Output Solenoid Valve	Output	12VDC	Digital output

From the Table 3.7 the required PLC shall cater for the minimum 1 analog input and 2 digital outputs with 24VDC power supply unit as the system and all the components will use the DC Voltage supply.

For the programming part of the ladder diagram in the CX-Programmer, the 2 solenoid valve outputs could be represented with the standard coil function while the 4-20mA analog input signal from the water level sensor needs to be scaled using the appropriate scaling function in order to successfully run the program.

Apart from that there is also another 1 internal input which is the clock function required for the program. The function could be realised using the Real Time Clock (RTC) function of the CX-Programmer.

3.6.1 Major Instructions

Some important instructions used in the ladder diagram design of the program would be as follows:

i) Date Comparison Instruction

The instruction is used to compare the present time with the comparison time data which has been programmed at 8:00:00 am. As could be seen in the Figure 3.18 the "=DT(341)" instruction will compare the "A351"data which is the PLC Internal Clock with the programmed time which is 8.00.00am in the D100 PLC Memory. If the present time equals to 8.00.00am the Holding Relay 100.10 which indicating System Start is turned on.

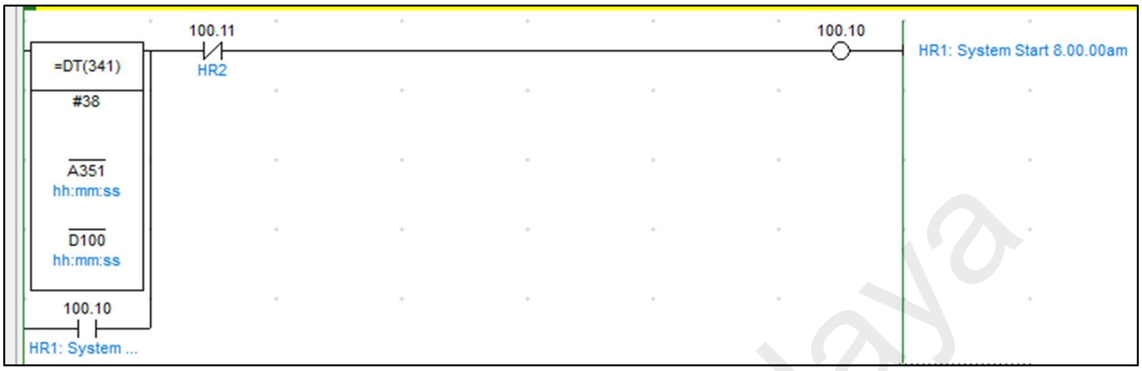

Figure 3.18: Date Comparison instruction used in the program

ii) Scaling Instruction

As the water level sensor used in the system gives 4-20mA current signal to indicate the current water height of the evaporation pan, thus the signal converted to the digital format needs to be scaled appropriately using SCL3 scaling instruction. As shown in the Figure 3.19 the analog input in the D10 PLC Memory will be scaled in the D200 PLC Memory and the result is output Common Input Output (CIO) 201 of the PLC Memory.

Figure 3.19: Scaling instruction used in the ladder diagram

The Figure 3.20 on the other hand shows the programmed scaling instruction in the D200 PLC Memory.

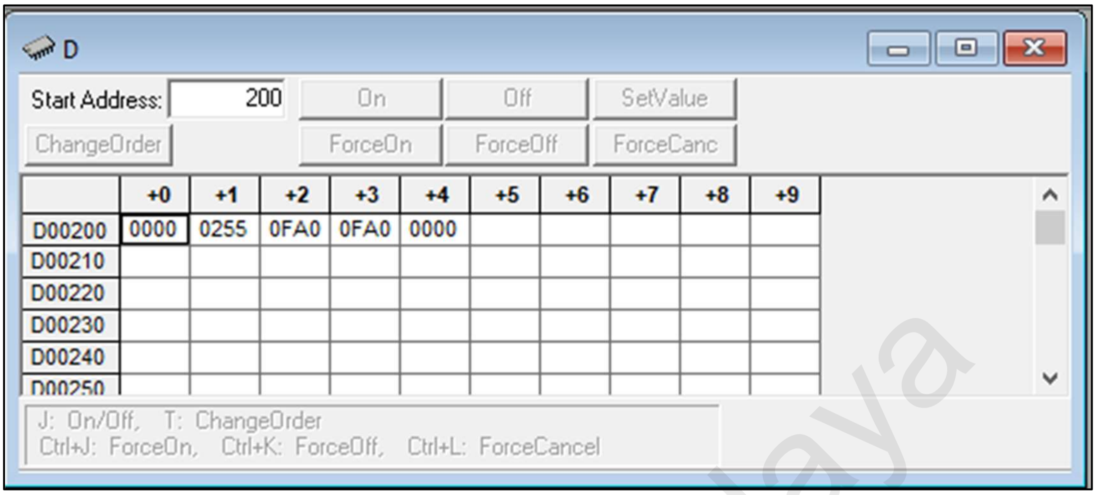

Figure 3.20: D200 values written in the PLC memory

The content of each value written in the D200 until D204 of the PLC memory is described as follows:

a) D200: 0000 value – represent offset value which is zero.
b) D201: 0255 value – represent total range of the evaporation level 255mm.
c) D202: 0FA0 value – represent hex value of the 4000 decimal value of the scaling range for the PLC analog input.
d) D203: 0FA0 value – represent the maximum conversion.
e) D204: 0000 value – represent the minimum conversion.

So when an analog sensor is connected to the D10 point the digital hex value of the current water level height can be calculated using equation as in the Figure 3.21.

$$R = \frac{\Delta Y}{\text{Binary conversion of } \Delta X} \times ((\text{Binary conversion of S})+(\text{Offset}))$$

Figure 3.21: Equation for digital value of the analog input

For example, the corresponding R hexadecimal value (hex) for the 191mm water level reference point used in the evaporation pan would be:

R = (4000/255) x (191 + 0) = 2996 decimal value = BB4 hexadecimal value

But in reality this value need to be tested and verified with the connected sensor at site.

iii) Input Comparison Instruction

As could be seen in the Figure 3.22 the Input Comparison functions "=(300)", "<(310)" & ">(320)" are used to compare the analog input from the sensor with hex value BB4 that equivalent to 191mm reference level of the evaporation pan.

If the input value complies with the respective commands (equal to, lower than or greater than) the corresponding holding relay will be turned on.

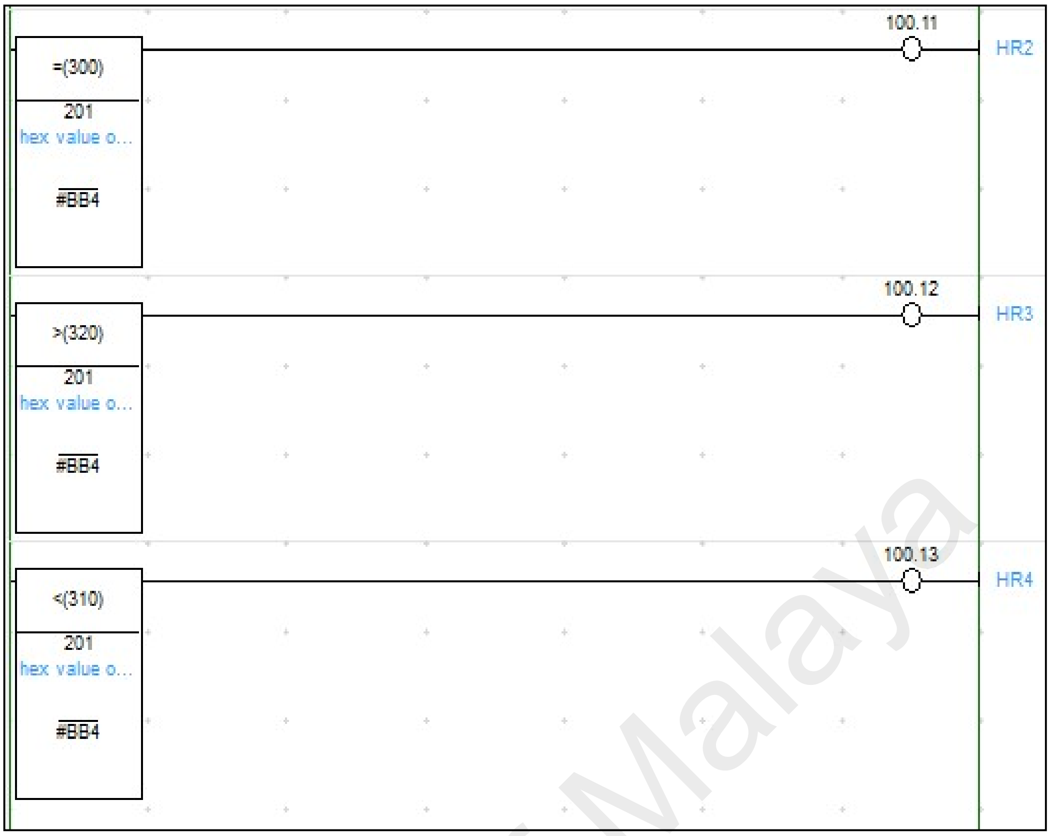

Figure 3.22: Input comparison functions used for the program

3.6.2 The Ladder Diagram

Figure 3.23 shows the complete ladder diagram developed in CX-Programmer for PLC Control.

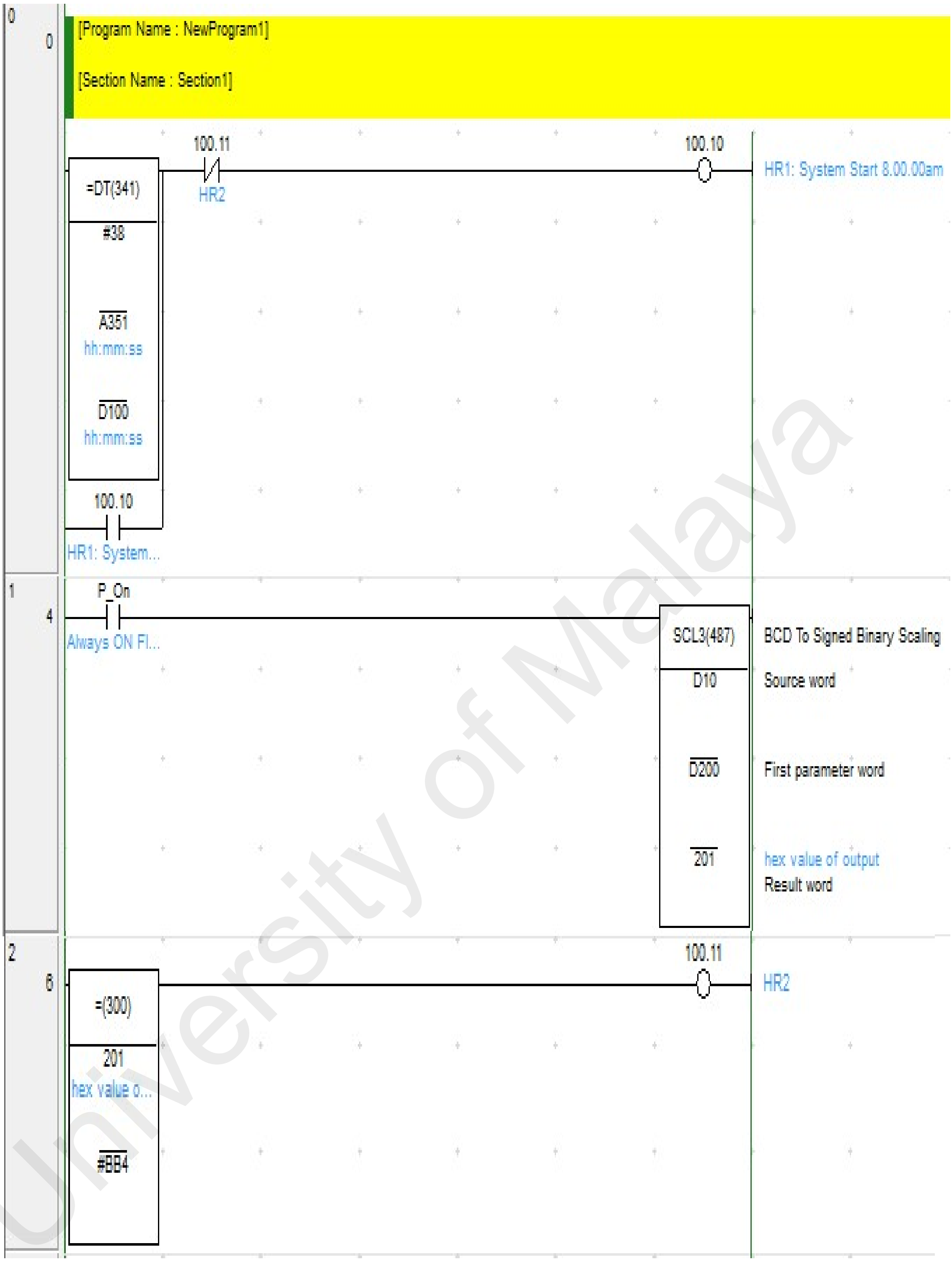

Figure 3.23: Ladder diagram developed in CX-Programmer

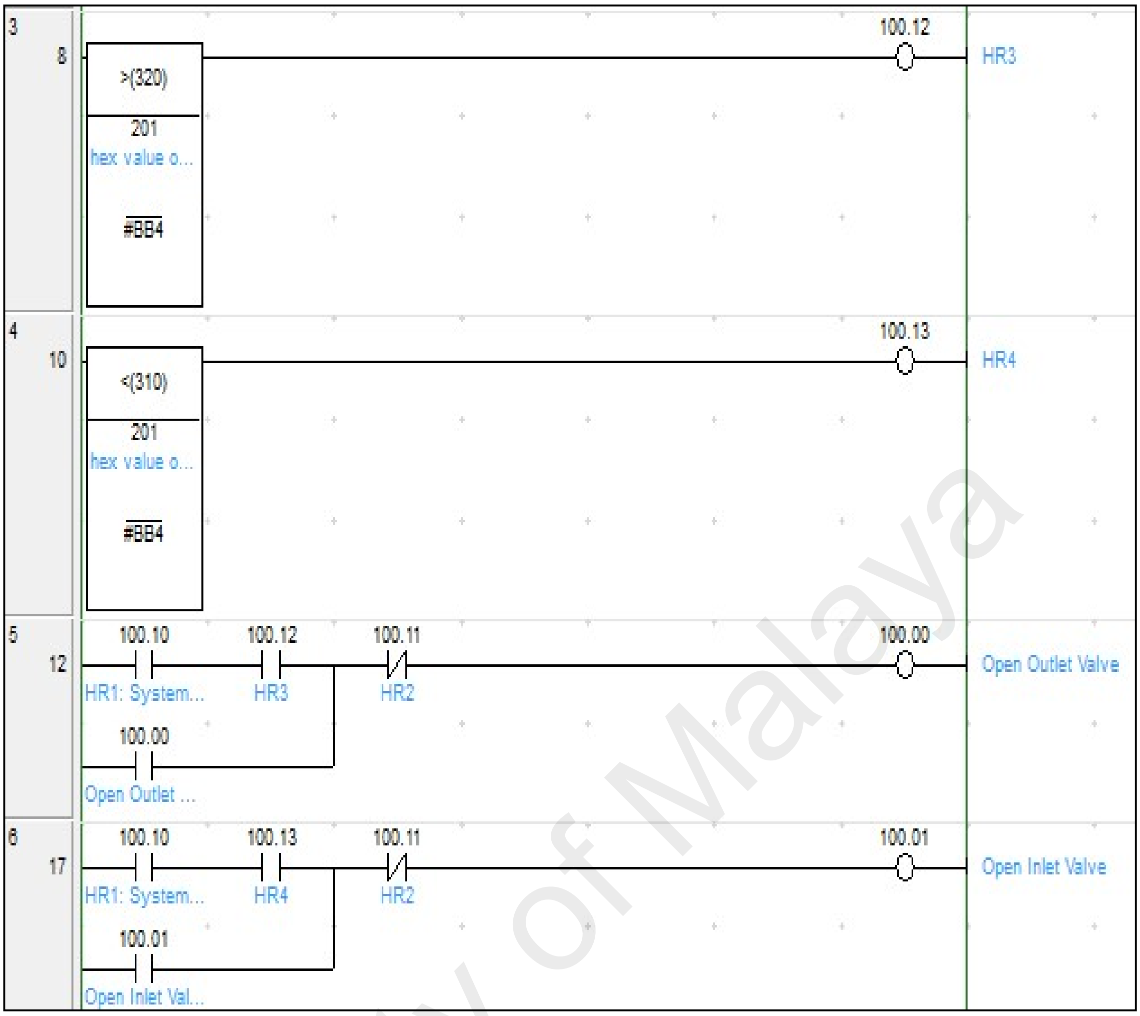

Figure 3.23: Ladder diagram developed in CX-Programmer (continued)

Operation carried out in each rung is explained as follows:

a) Rung 0:

The system will energize the System Start Holding Relay 1 (HR1) when PLC time equals to pre-programmed 8.00.00am. The system will remain on and only will be deactivated when the HR2 is turned on.

b) Rung 1:

The connected sensor analog signal will be continuously scaled and the resulted output will be kept in the CIO 201.

c) Rung 2:

Instruction to turn on HR2 when the CIO201 equals to BB4 hex value.

d) Rung 3:

Instruction to turn on HR3 when the CIO201 greater than BB4 hex value.

e) Rung 4:

Instruction to turn on HR4 when the CIO201 lower than BB4 hex value.

f) Rung 5:

Outlet valve will be opened as the 100.00 Output Relay is energized when HR1 and HR3 are energized. It will remain on until is deactivated by HR2.

g) Rung 6:

Inlet valve will be opened as the 100.01 Output Relay is energized when HR1 and HR4 are energized. It will remain on until is deactivated by HR2.

3.7 Simulation of the PLC Program

In order to check the functionality of the developed PLC Program, the program will be tested and simulated using the CX-Simulator application that has been embedded in the CX-Programmer program. Several following simulations will be carried out:

i) PLC clock is set to 7:59:45am and when the actual time reaches 8:00:00am the changes is observed.

ii) Digital value of the sensor is set to a decimal value greater than 2996 which corresponds to the water level reading above than 191mm.

iii) Digital value of the sensor is set to a decimal value below than 2996 which corresponds to the water level reading less than 191mm.

iv) Digital value of the sensor is set to a decimal value equal to 2996 which corresponds to the water level equal to 191mm.

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Introduction

Altogether there will be 5 components will be interpreted and discussed under this chapter which are:

i) Analysis on evaporation pan design

ii) Optimum solar power design

iii) Components reliability analysis

iv) Manual and automatic system data analysis

v) Simulation of the PLC program

4.2 Analysis on Evaporation Pan Design

As elaborated in the section 3.2.1 the evaporation pan design used for the existing automatic system comprises 2 components (stilling well and pan) connected as a one system. Whereas the manual version of the evaporation pan has no other component connected to it. Table 4.1 shows some comparison between two systems.

Table 4.1: Comparison between automatic and manual pan

No.	Characteristics	Manual System	Automatic System
1	Components	Pan only	Pan and Stilling Well
2	Pan size (mm)	1210mm diameter & 255mm height	1210mm diameter & 255mm height
3	Area exposed to air	$1.1499m^2$	$1.1499m^2$
4	Volume used	$219{,}631cm^3$ = 219.6l	$227{,}271cm^3$ = 227,3l
5	Volume to reduce for 1mm Evaporation	$1150cm^3$ = 1.15l	$1190cm^3$ = 1.19l

From the comparison made, it can be concluded that the automatic evaporation pan required an extra 40ml of water in order to reduce 1mm of water as compared with the manual system although the exposed area to the air and the pan size for both systems are same. In terms of percentage likewise an approximately 3.5% of extra water will be required.

Although the percentage is just 3.5% but as the average evaporation rate is just in the range of 0 to 10mm, the difference could not be taken for granted. Evaporation pan design optimization need to be considered for further enhancement of the automatic evaporation pan measurement.

4.3 Optimum Solar Power Design

From the calculation carried out in the section 3.2.3 the minimum requirement for the sealed lead acid battery would be 37.33Ah to cater for 14 days of operation without any sunshine. Hence the best available capacity in the market would be 40Ah.

It is recommended to use 2 nos. of parallel connected 40Ah battery instead of one. This is to provide an extra protection for site components based on the following reasons and factors during worst case scenario situation:

i) Most of the hydrological stations are situated in remote area.

ii) Difficulty to find a replacement battery in short period of time.

iii) Data losses due to power supply failure could not be acceptable.

iv) Lack of maintenance budget.

v) In actual situation both of the battery will not be depleted at the same time.

While for the solar panel it is suggested to use a minimum size of 20W solar panel for automatic evaporation pan system as it will give an extra 5.7 safety margin.

4.4 Components Reliability Analysis

The Table 4.2 shows analysis of the components reliability review carried out from the procedure in the Section 3.3.

Table 4.2: Analysis of the components reliability

No.	Findings	Causes	Action taken	Future Recommendation
1	Evaporation pan corroded badly	Low quality of aluminium is used	The pan cleaned and washed.	The high quality of aluminium is used for fabrication. The material used shall be tested before the fabrication.
2	Evaporation pan leaking	Low mechanical finishing and machining quality.	The leaking part sealed.	The pan shall be manufactured according to the design. The welding finishing shall be inspected and tested in detail.
3	Wood pallet damaged badly.	Tear and wear process.	Replace new pallet.	Using hardwood pallet instead of normal wood.
4	Leaking at the valve joint	Material and the seal at the joint experienced tear and wear process.	The leaking part sealed.	Using high quality and durable type of pipes and joints.
5	Defective valve	Poor regular maintenance	The valve replaced	Using high quality and durable type of pipes and joints and performing regular maintenance.

Based on the analysis it is important to choose very high quality and durable components that are suitable for outdoor application and can withstand Malaysian climate condition. Otherwise frequent maintenance and replacement will be required that will be costly.

4.5 Manual and Automatic System Data Analysis

4.5.1 Graph Comparison and General Analysis

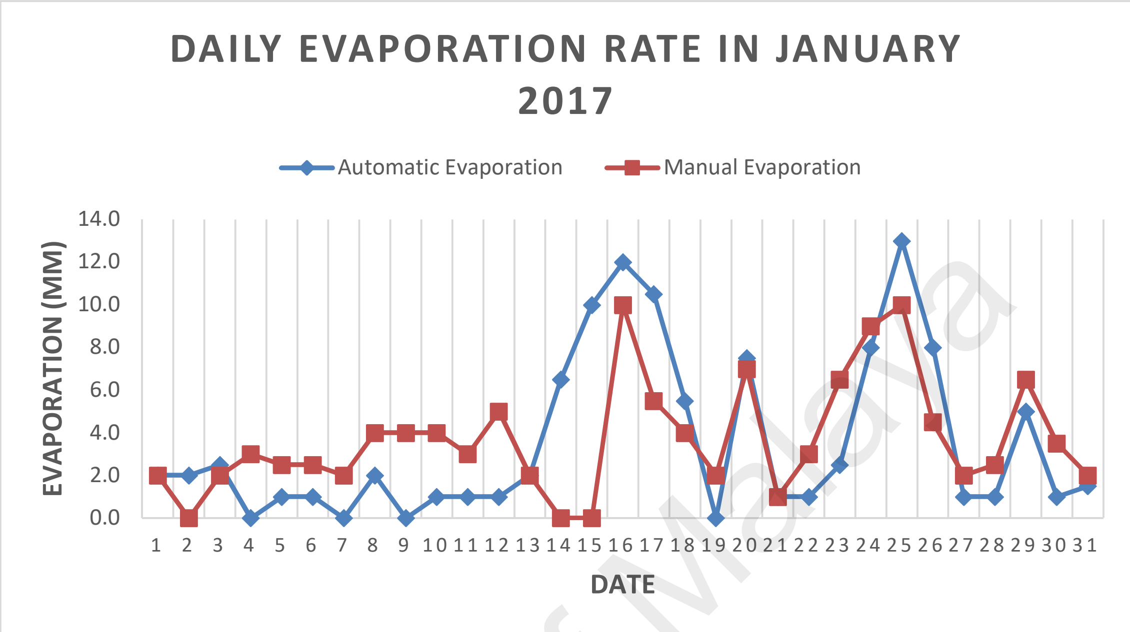

Figure 4.1: Evaporation rate trending in January 2017

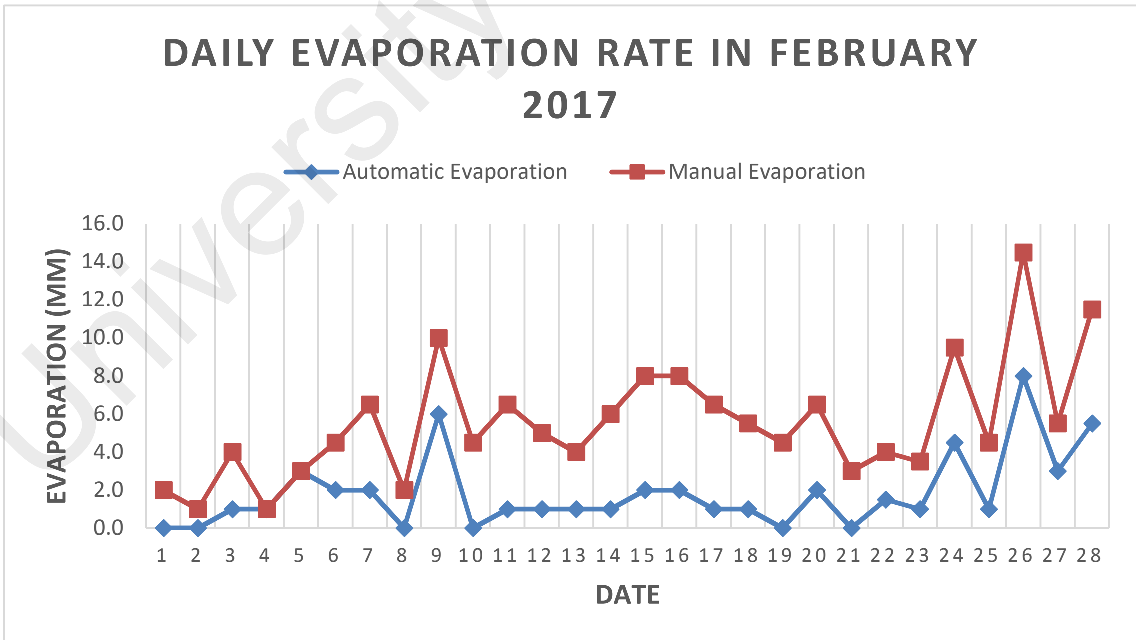

Figure 4.2: Evaporation rate trending in February 2017

Figures 4.1 and 4.2 show the graphs of the daily evaporation rate trending between automatic and manual evaporation system in January and February 2017. Both graphs show similar evaporation trending between the automatic and manual system.

The monthly evaporation for January and February between automatic and manual measurement is shown in the Table 4.3.

Table 4.3: Comparison of monthly evaporation for manual and automatic system

	Automatic System			**Manual System**		
	Total Evaporation (mm)	Days counted	Average Evaporation (mm)	Total Evaporation (mm)	Days counted	Average Evaporation (mm)
January 2017	110.5	31	110.5	115.0	28	127.3
February 2017	51.5	28	51.5	103.5	26	111.5

The average evaporation is obtained from the total evaporation divide by the total days of the measurement taken excluding the rejected measurement. Both systems show quite an equal average evaporation rate in January with the manual measurement has 15.2% of higher average evaporation.

But the February 2018 measurement on the other hand shows a different scenario. The average evaporation of the manual system is more than 2 times greater than the automatic evaporation rate.

4.5.2 Detail Analysis of Both Measurements

i) Irregularities findings in manual measurement

a) First finding shows that 3 measurements on the 2nd, 14th and 15th January 2017 and 2 measurements on the 4th and 5th February 2017 have been rejected. It is clear that the measurement on the 15th and 5th February 2017 are rejected due to rainfall rate 41.5mm and 44.00mm which are higher than 38mm, since according to HP 21 evaporation is not taken when the daily rainfall exceeds 38mm. The rainfall measurement for the automatic system on the 15th January 2017 shows 35mm which is 3.5mm lower than the manual and shockingly the recorded automatic rainfall for the 5th February was just 3mm.

But for the 2nd and 14th January the measurements the reason for rejection is not clear because the rainfall rate on that dates are lower than 38mm. Also there are no measurement recorded on the 4th February.

b) It is also found that the measurement on the 24th January is still taken into consideration although the rainfall is 39mm which is higher 38mm.

c) If the measurements of 12th, 14th and 15th January are excluded for both automatic and manual measurements, the average measurement for January 2017 would be:

Manual average evaporation: 115 x (31/28) days =127.3mm

Automatic average evaporation: 92mm x (31/28) days = 101.86mm

The total difference for manual evaporation is 25.6mm or 24.9% higher than automatic measurement.

ii) Sources of errors

a) Introduction

According to Abtew and Malesse (2013) errors in metrological parameters can be classified into three categories: systematic, random, and process errors.

Systematic errors are caused by sensor manufacturing defects or calibration error putting constant upward or downward drift in observations. Once these types of errors are identified, correction can be made to the sensor. Some data can be salvaged through application of correction factors.

Random errors are errors whose sources may not be known and occur in both increasing and decreasing direction without reasonable pattern. Sources of errors are instrument malfunction, instrument limitations, instrument calibration and programming, environmental factors, data recording and transfer, data processing, and storage.

Process errors are those incurred through data recording, processing, transfer, and storage.

b) Possible errors

In manual measurement the process errors occurred generally are very high since the worker needs to fill up water up to the fixed point level if the pan level has dropped or to take out the extra water until the level reaches fixed point level if the water level has increased based on his observation daily for measuring the pan water level. Additionally, the daily rain gauge used in manual system is also exposed to high process error.

Whereas for the automatic measurement the possible process errors occurred during the measurement are generally can be neglected if the automatic operation runs smoothly without any failure. There could be possible systematic and random errors occurring due to sensor malfunction and lack of maintenance but these errors could be assumed to be negligible since the period chosen for the comparison is during the automatic system was in the best condition and well maintained.

iii) Accuracy of the measurement

In manual measurement no measurement accuracy could not be confirmed since all the evaporation level and rainfall measurement are obtained through observation and manual measuring process.

On the other hand, for the automatic measurement the accuracy of tipping bucket HS TB3 and OTT SE200 Float Operated Water Level Sensor used are guaranteed by the manufacturers to give measurement accuracy of 3% and 0.9mm respectively.

vi) Efficiency of automation

Moreover, the automatic evaporation measurement is efficiently automated using the RTU program. As the water level measurement immediately after the automation process to fill up or release water up to or until 191mm level is recorded, thus the percentage difference between the actual measurement and the 191mm reference level can be used as a guideline in order to calculate the efficiency of the automation. The recorded level for the day before (Yesterday WL) will be sent together with the current water level before the automation process to the server.

The average recorded "Yesterday WL" for January, February 2017 and both months are shown below:

i) Average January "Yesterday WL" = 5914/31 = 190.774mm

ii) Average February "Yesterday WL" = 5337/28 = 190.607mm

iii) Total average "Yesterday WL" for both = (190.774 + 190.607)/2 = 190.691mm

Hence the efficiency of the automation would be:

= (190.691/191) x 100 = 99.84%

4.5.3 Conclusion

Based on the comparison and the detail analysis conducted it can be concluded that the automatic measurement of evaporation is much more reliable and accurate compared to the manual system provided that the system is regularly maintained and no any instrument malfunction occurred, due to the following reasons:

i) Relatively very high and frequent process errors occurred in the manual system due to the manual measurement and human errors.

ii) High accuracy of automatic measurement of the rainfall tipping bucket and water level sensor in the automatic system which are 3% and 0.9mm respectively are guaranteed by manufacturer. On the other hand, no accuracy check could be measured and guaranteed for the manual measurement.

iii) The automation process of the automatic system has been proven to be very efficient and reliable with the calculated efficiency rate to be 99.84% for January and February 2017 measurement.

4.6 Simulation of the PLC Program

Several tests and simulations have been carried out to test the program using CX-Simulator. Each test that has been carried out and the respective observed result is detailed out as follows:

i) Test Procedure 1: PLC clock is to 7:59:30am and the PLC program is set in run mode. The ladder diagram program is monitored before and after 8:00:00am. The digital value is set to decimal value of 2996 which is correspond to 191mm water level after the Holding Relay 1 is triggered.

Observation: Before 8:00:00am the Output 100.10 remained off but exactly at 8:00:00am the 100.10 Holding Relay is turned on (as shown in the Figure 4.3) and it remained on as the output has been latched. The output is turned off immediately after the digital value is set to 2996 decimal value that resulted the normally closed Holding Relay 100.11 disconnected the circuit.

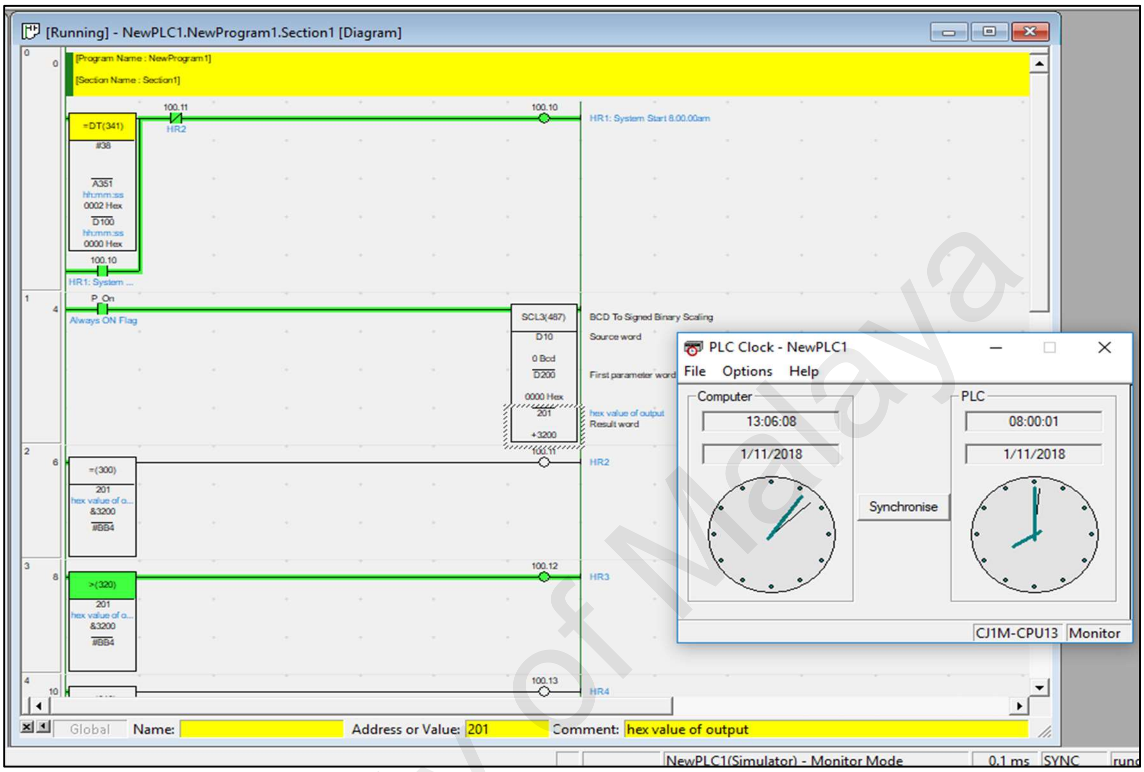

Figure 4.3: System start at 8:00:00am simulation

ii) Test Procedure 2: The PLC Clock is set again at 8:00:00am to start the system and the digital value is set to decimal value of 2900 which is correspond to water level below 191mm.

Observation: Both normally opened Input Relay 100.00 and 100.13 are turned as can be seen in the Figure 4.4. Both outputs remained on due to the latching of the Output O:100.00.

The output is turned off immediately after the digital value is set to 2996 decimal value that resulted the normally closed Holding Relay 100.11 disconnected the circuit as shown in the Figure 4.5.

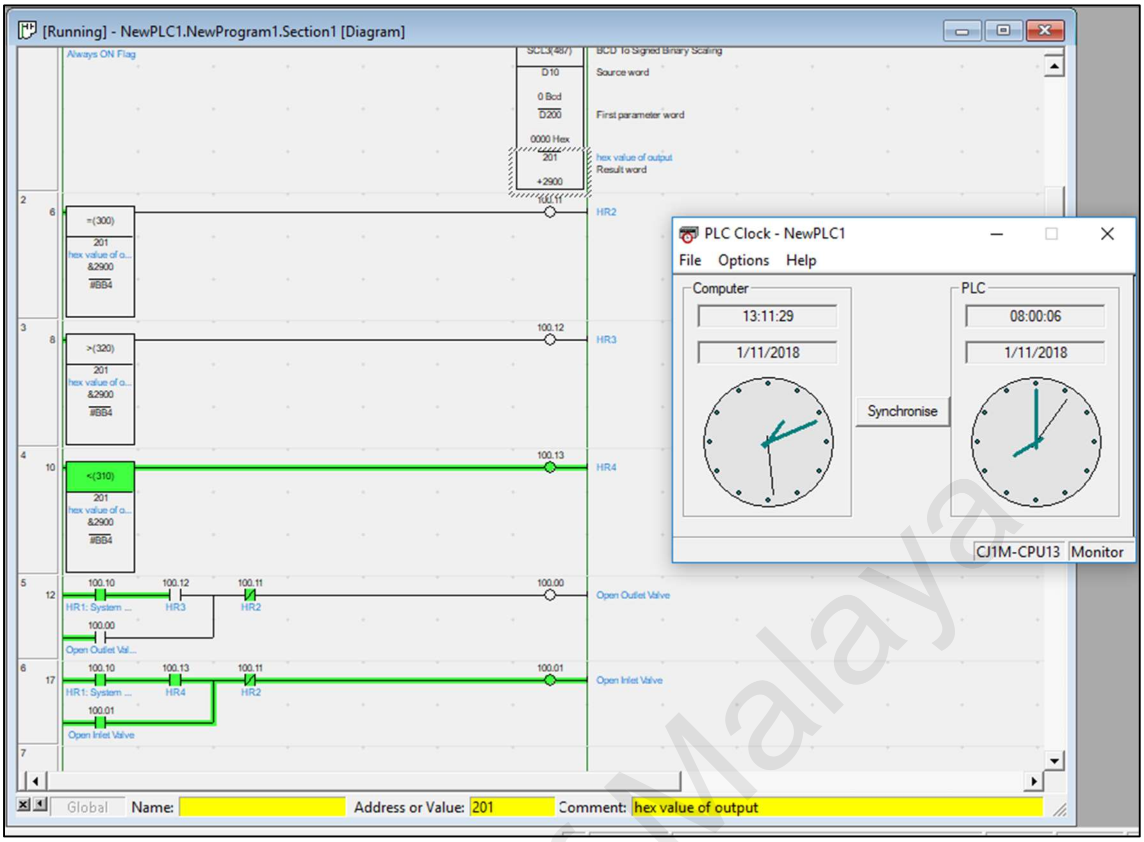

Figure 4.4: Water level below 191mm reference level simulation

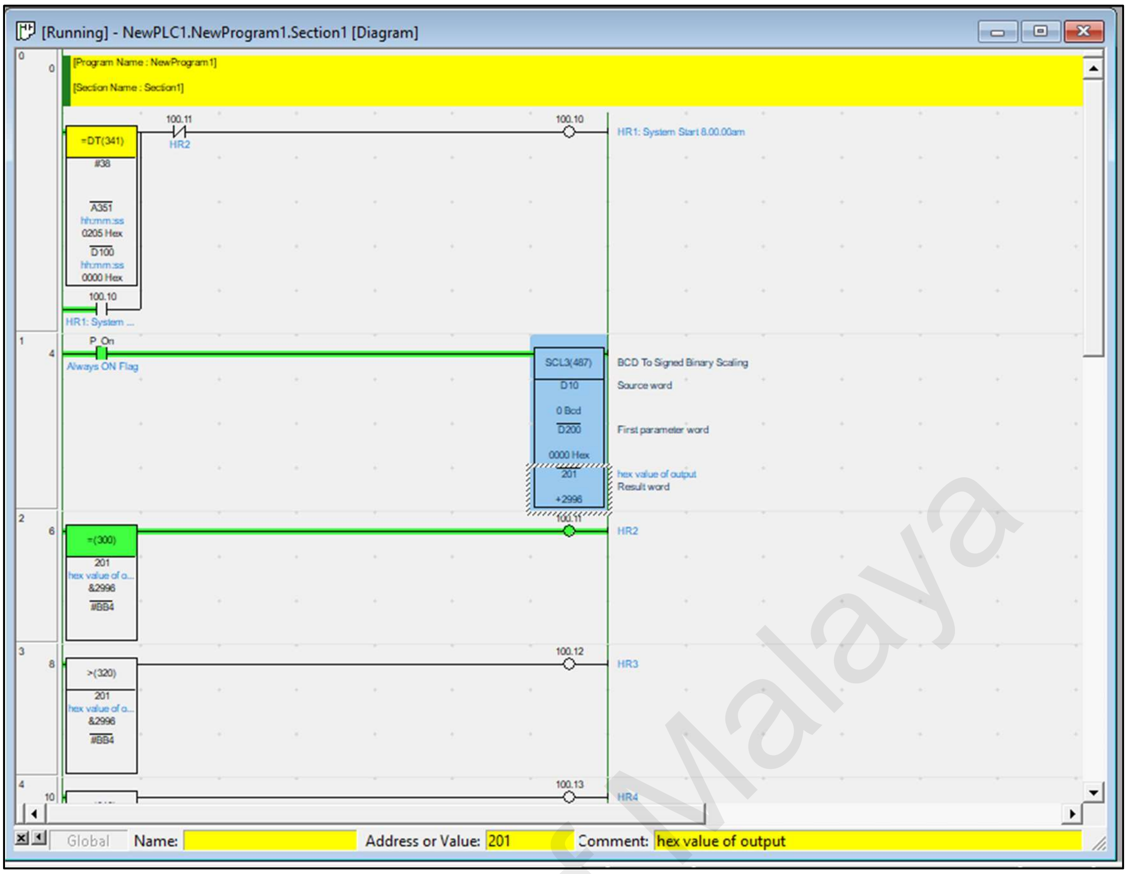

Figure 4.5: Water level equals to 191mm simulation

iii) Test Procedure 3: The PLC Clock is set again at 8:00:00am to start the system and the digital value is set to decimal value of 3200 which is correspond to water level above 191mm.

Observation: Both normally opened Input Relay 100.00 and 100.12 are turned as can be seen in the Figure 4.6. Both outputs remained on due to the latching of the Output O:100.00.

Likewise, the output is turned off immediately after the digital value is set to 2996 decimal value that resulted the normally closed Holding Relay 100.11 disconnected the circuit.

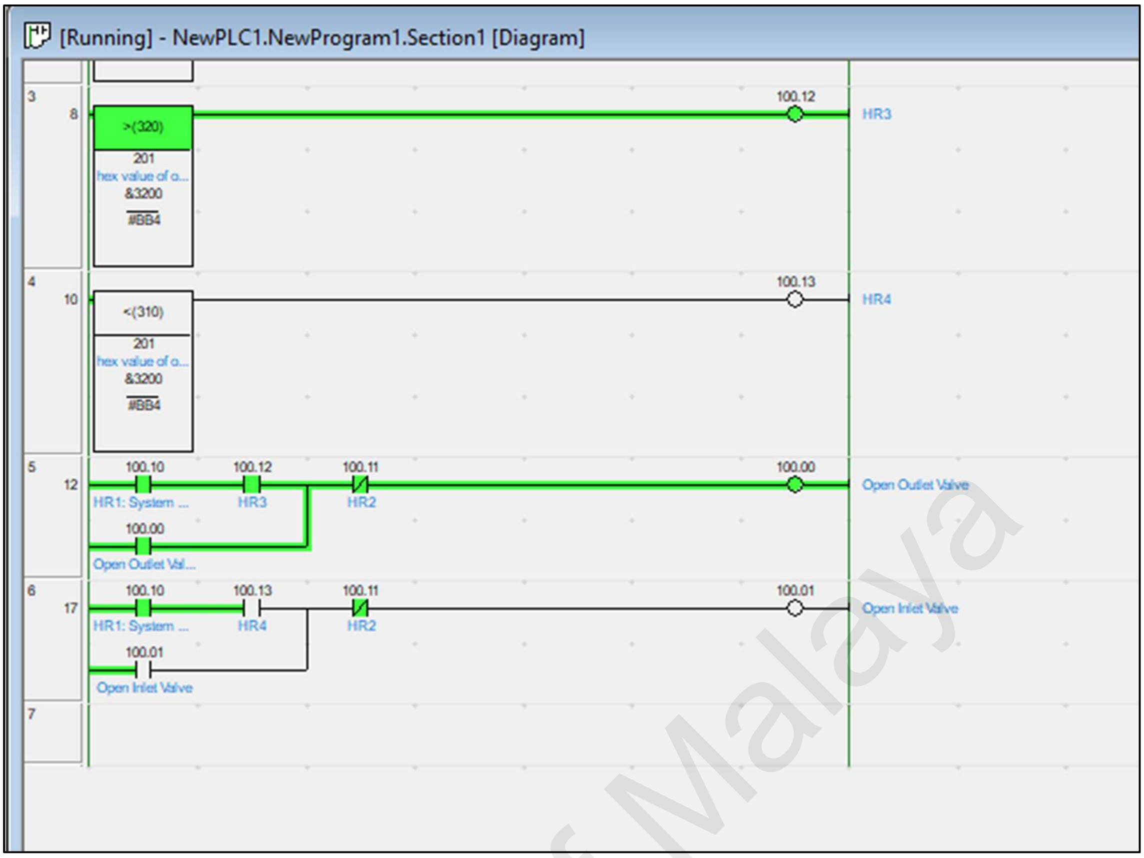

Figure 4.6: Water level above 191mm reference level simulation

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The existing automatic evaporation pan system installed in JPS hydrological station which adopt its own design in order to operate automatically based on the JPS standard has been reviewed and evaluated thoroughly. The evaporation pan design which has been suited with the best available water level sensor typically used in hydrological station shows 3.5% of higher water volume compared with the standard manual pan which is not connected to any parts.

The optimum solar panel and battery sizing according to the system requirement have been calculated and it is recommended to use 2 units of parallel connected battery instead of installing only one in order to provide better power backup protection during worst case scenario situation.

Components reliability and durability also play an important role in design and development of automatic evaporation pan system. All the components installed outdoors in the Malaysian tropical climate exposed to high tear and wear process. Thus, best quality and highly durable components and workmanships are required to increase the lifespan of the equipment and quality of the evaporation measurement despite regular maintenance.

The collected data of the automatic evaporation pan system also has been compared with the manual system at the same location. In overall both data show the same trending and it has been concluded that the automatic system data to be much more reliable and accurate than the manual one if the system has been maintained well due to higher accuracy of the measurement, high automation efficiency and less process errors.

Lastly PLC program has been designed and simulated using the CX-Programmer software and CX-Simulator application. The automation of evaporation pan has been made possible using the real-time clock function, the instructions such as scaling and value comparison of the PLC.

5.2 Recommendation

5.2.1 Possibility of Using MEMS Water Level Sensor

As discussed in the section 3.2.2 the float-operated shaft encoder water level sensor used for the evaporation system is the best available option among the 5 types of water level sensor commonly used in JPS for hydrological stations. But through the further analysis, there are some disadvantages and deficiencies that need to be overcomed in order to optimize the measurement. As a result, possibility of using MEMS based pressure sensor for water level measurement will be discussed here briefly.

Sarath T. M. et al. (2013) have carried out an experimental study in comparing capacitive and MEMS pressure for 0 to 60cm range of water level measurement. The Motorola MEMS piezoresistive transducer model MPXV5004GP has been used together with the LT1763 voltage regulator and low noise capacitors in setting up a small MEMS pressure sensor for water level measurement as shown in the Figure 5.1.

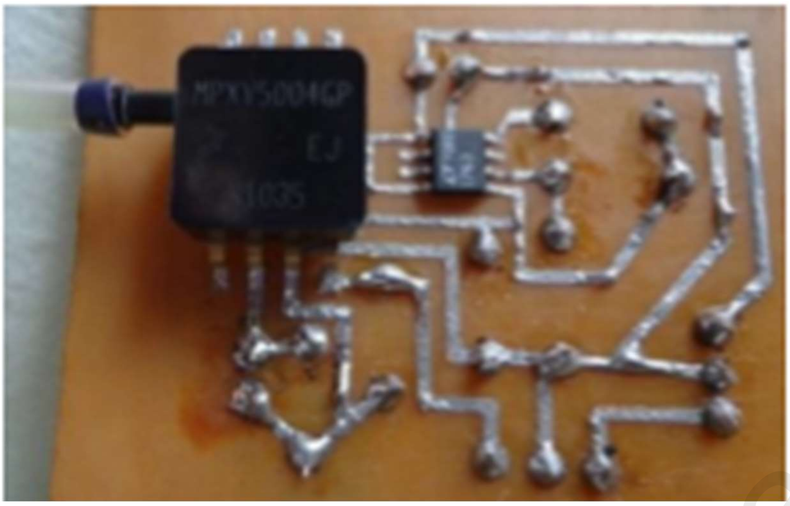

Figure 5.1: The built-up MEMS pressure sensor (Sarath T. M. et al., 2013)

The water level for different level of the water tank size (25 x 25 x 50) cm as shown in the Figure 5.2 will be measured using both MEMS and capacitive level sensors. The MEMS sensor is placed on top of the tank and is connected with an open ended tube which is submerged in the tank. The pressure exerted by the trapped air in the tube which is equivalent to the voltage produce is measured by the sensor.

Figure 5.2: Test rig used in the experiment (Sarath T. M. et al., 2013)

From the study it is found that the capacitive level sensor does not show a perfect linear behaviour from 0 to 24cm level measurement. Whereas the MEMS based pressure sensor shows a very good linearity for that range which could be seen in the graph of the Figure 5.3.

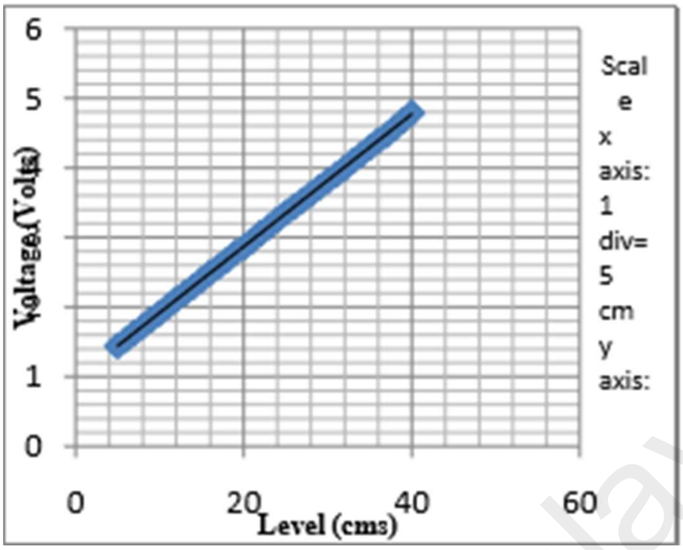

Figure 5.3: Graph of voltage against water level for MEMS sensor (Sarath T. M. et al., 2013)

Therefore, it can be concluded that MEMS pressure is much suitable for low level measurement particularly in the range 0 to 40cm which is the required for the evaporation pan water level.

Additionally, with the implementation of MEMS Pressure Sensor for evaporation pan the requirement to have a stilling well component which has further affected the efficiency of the measurement can be overcome.

Further study and test need to be conducted to find out the practicality of implementing the sensor for automatic evaporation pan system. The reliability, durability, outdoor environmental, accuracy and other factors need to be reviewed in order to make a final conclusion.

5.2.2 Real Implementation of PLC Controller

In order to implement the PLC controller for the existing automatic evaporation system, the controller needs to be coupled with a standard RTU. The RTU will be functioning in order to do the water level sensor schedule measurement, data collection, data processing and data sending through communication interface usually GSM modem to the server, while the PLC will be performing the automation operation.

A micro or mini PLC with real time clock function and at least 1 analog input and 2 digital outputs would be sufficient to be chosen for the system. For example, the mini PLC of the brand Controllino model Mini 100-000-00 (Figure 5.4) and any typical RTU used for telemetric function at JPS hydrological station such as RTCU DX4 Pro (Figure 5.5) can be combined together as an integrated system to control and monitor the entire process.

Apart from that, 4 to 20mA signal splitter (as shown in the Figure 5.6) will be required as well to split the water level sensor reading into RTU and PLC simultaneously.

Figure 5.4: Controllino Mini PLC

Figure 5.5: RTCU DX4 pro

Figure 5.6: 4 to 20 mA signal splitter

In terms of the costing, this PLC controller integrated system could be obtained with less than RM3,000.00, since the mini PLC costs less than RM600 and the RTU could be bought with less than RM2,000.00.

Hence as a comparison with the existing RTU with a built in controller function used in the JPS automatic evaporation stations which is more than RM7,000.00, the solution provides a cheaper option. It is recommended that the use of PLC integrated system could be tested and implemented to provide another option for the automatic evaporation system which is much cheaper

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