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UNIVERSITI TEKNOLOGI PETRONAS

INTEGRATED PV PERFORMANCE MONITORING SYSTEM

by

NUR SYAHIDAH BINTI HUSAIN

The undersigned certify that they have read, and recommend to the Postgraduate Studies Programme for acceptance this thesis for the fulfillment of the requirements for the degree stated.

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INTEGRATED PV PERFORMANCE MONITORING SYSTEM

by

NUR SYAHIDAH BINTI HUSAIN

A Thesis
Submitted to the Postgraduate Studies Programme
as a Requirement for the Degree of

MASTER OF SCIENCE
ELECTRICAL AND ELECTRONIC ENGINEERING DEPARTMENT
UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR

MAY 2013

DECLARATION OF THESIS

Title of thesis: Integrated PV Performance Monitoring System

I NUR SYAHIDAH BINTI HUSAIN
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hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTP or other institutions.

Witnessed by

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ABSTRACT

The main aim of this research work is to design an accurate and reliable monitoring system to be integrated with solar electricity generating system. The amount of solar energy received on the surface of the earth varies due to meteorological conditions and apparent trajectory of the sun. Due to this, the availability of sunlight is an average of 5-6 hours per day throughout the year in Malaysia. The performance monitoring system is required to ensure that the PV based solar electricity generating system is operating at an optimum level. The PV monitoring system is able to measure all the important parameters that determine an optimum performance. The measured values are recorded continuously, as the data acquisition system is connected to a computer, and data is stored at fixed intervals. The hardware is fully supported by software designed to give full flexibility in terms of data retrieval and processing. The data can be locally used and can be transmitted via internet for monitoring purposes. The data that appears directly on the local monitoring system is displayed via graphical user interface that was created by using Visualbasic.net. The Apache software was used to retrieve data from the internet. The transmitted data received by the remote terminal can be viewed by using any internet browser.

The accuracy and reliability of the developed monitoring system was tested against the data that captured simultaneously by using a standard power quality analyzer device. The analysis between the data captured by the developed monitoring system and by using the standard power quality analyzer device shows that there is 97 % correlation between them. The high correlation value indicates the level of accuracy of the monitoring system. The aim of leveraging on a system for continuous monitoring system is achieved, both locally, and can be viewed simultaneously at a remote system. This will allow for the monitoring of distributed PV based solar electricity generating systems.

ABSTRAK

Objektif utama penyelidikan ini dilakukan adalah untuk mencipta satu sistem pemantauan yang tepat bagi diintegrasikan dengan sistem penjanaan tenaga solar. Jumlah tenaga solar yang diterima pada permukaan bumi berubah mengikut keadaan meteorologi dan kedudukan semasa matahari. Oleh sebab itu, purata sinaran matahari di Malaysia adalah 5-6 jam sehari untuk sepanjang tahun. Sistem pemantauan ini diperlukan untuk memastikan bahawa penjanaan tenaga solar berdasarkan PV beroperasi pada tahap yang optimum. Sistem pemantauan PV ini berupaya untuk mengukur parameter-parameter penting yang menentukan prestasi yang optimum. Nilai-nilai yang diukur direkodkan secara berterusan, di mana sistem pengumpulan data disambungkan kepada sebuah komputer dan data disimpan pada selang masa yang telah ditetapkan. Alatan ini dibantu oleh perisian yang direka untuk memberi fleksibiliti dari segi dapatan semula dan pemprosesan data. Data ini boleh digunakan secara terus pada sistem ini dan boleh dihantar melalui internet untuk tujuan pemantauan. Data yang muncul secara langsung pada sistem pemantauan ini dipaparkan oleh paparan grafik yang direka menggunakan Visualbasic.net. Perisian Apache pula digunakan untuk mendapatkan semula data dari internet. Data yang dihantar diterima oleh terminal kawalan jauh yang dapat dipaparkan melalui pelayar internet.

Ketepatan dan daya harap sistem pemantauan yang dibangunkan ini telah diuji dengan data yang diambil secara berterusan menggunakan alat analisis kualiti kuasa yang biasa. Analisa antara data yang diambil menggunakan sistem pemantauan ini dan data yang diambil menggunakan alat analisa kualiti kuasa yang biasa menunjukkan terdapatnya 97 % kolerasi di antara mereka. Nilai kolerasi yang tinggi ini menunjukkan tahap ketepatan sistem pemantauan ini. Tujuan untuk meggunakan sistem pemantauan ini secara berterusan melalui kedua-dua alat sistem pemantauan itu sendiri dan melalui sistem pemantauan jarak jauh berjaya dicapai. Ini telah membolehkan pemantauan dibuat pada sistem penjanaan solar berdasarkan system PV.

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ABBREVIATIONS & SYMBOLS

Abbreviations

a-Si	Armophous Silicon
ADC	Analog Digital Conversion
BIPV	Building Integrated Photovoltaic
CdTe	Cadmium Telluride
CIGS	Copper Indium Gallium Selenide
CIS	Copper Indium Selenide
D/A	Digital to Analog Converter
DAQ	Data acquisition
DAS	Data Acquisition System
DCS	Distributed Control System
DIO	Digital Input/Output
DSSC	Dye-Sensitized Solar Cells
FiT	Feed-in Tariff
GaAs	Gallium Arsenides
GUI	Graphical User Interface
GPIS	General Purpose Interface Bus
HMI	Human Machine Interface
I/O	Input/Output
MBIPV	Malaysian Building Integrated Photovoltaic
MTU	Master Terminal Unit
MESITA	Malaysia Electricity Supply Industry Trust Account
PC	Personal Computer
MEC	Malaysia Energy Centre
PV	Photovoltaic
PVEGS	Photovoltaic based Solar Electricity Generating System
RES	Renewable Energy System
RTU	Remote Terminal Unit
R/W	Read/Write
SCADA	Supervisory Control and Data Acquisition System
SEGS	Solar Electricity Generating System

SEDA	Sustainable Energy Development Authority
SREP	Small Renewable Energy Power
STC	Standard Test Conditions
TNB	Tenaga Nasional Berhad
TCP/IP	Transmission Control Protocol / Internet Protocol
TiO2	Titanium Oxide
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver Transmitter
UNITEN	Universiti Tenaga Nasional
USB	Universal Serial Bus
VB	Visual Basic

Symbols

γ	azimuth angle
δ	declination angle
I_D	diffuse radiation
I_B	direct radiation
I_G	global radiation
$I_{incident}$	incident solar radiation
$\beta_{optimum}$	optimum tilt angle
Voc	open-circuit voltage
Isc	short-circuit voltage
ω	solar hour angle
θ	solar incident angle
I_{module}	solar irradiance received by PV module
β	tilt angle
t_{hr}	time in hour
t_{min}	time in minutes
$\theta_{z,}$	zenith angle

CHAPTER 1

INRODUCTION

1.1 Energy Perspective

Global energy demand is increasing due to the increasing population. The world cannot depend on fossil fuels as the only source of energy, as its population has increased much faster than the oil and gas production and supply rate. The need to look for alternatives is now mandatory, and renewable energy resources can be viewed as promising solutions. The identified alternatives based on renewable resources such as solar, wind and biomass are considered viable. These alternatives can be utilized for generation of electricity, but like most of the developing nations, Malaysia is facing difficulties in exploring the full potential of these so-called “green” resources.

In year 1980, Malaysia’s main energy sources were crude oil, natural gas, coal and hydropower [1]. The government initiated the four fuel diversification strategy in Malaysia through the National Energy Policy to avoid energy crisis, similar to the 1973 and 1979 crisis [1, 2]. The energy mix as shown in Figure 1.1 proved to be a good decision for power generation system in Malaysia. Starting from 1995 to 2009, energy mix indicates that major supplier for electricity generation is coming from natural gas. The usage of crude oil is decreasing which in 1995 shows the contribution is 11 % and it reduced to 1.1 % by year 2009 due to its fast depleting supply. The energy demand in Malaysia keeps increasing yearly as shown in Figure 1.2. It can be seen that from the year 1999 to 2002, the energy demand increased by almost 20 % and by year 2010 the energy demand in Malaysia was up to 18,000 MW.

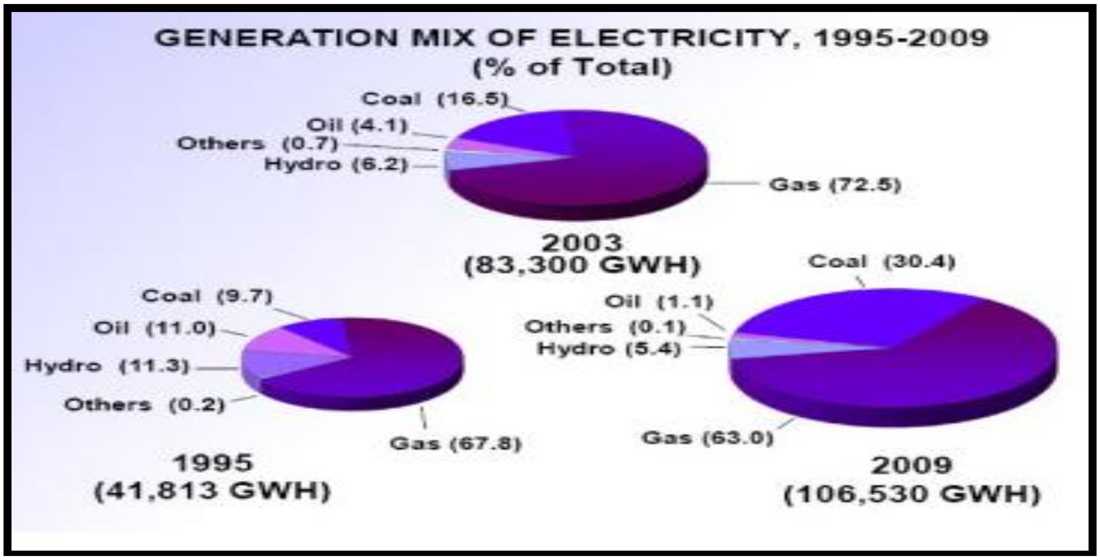

Figure 1.1 : Generation Mix of Electricity [3]

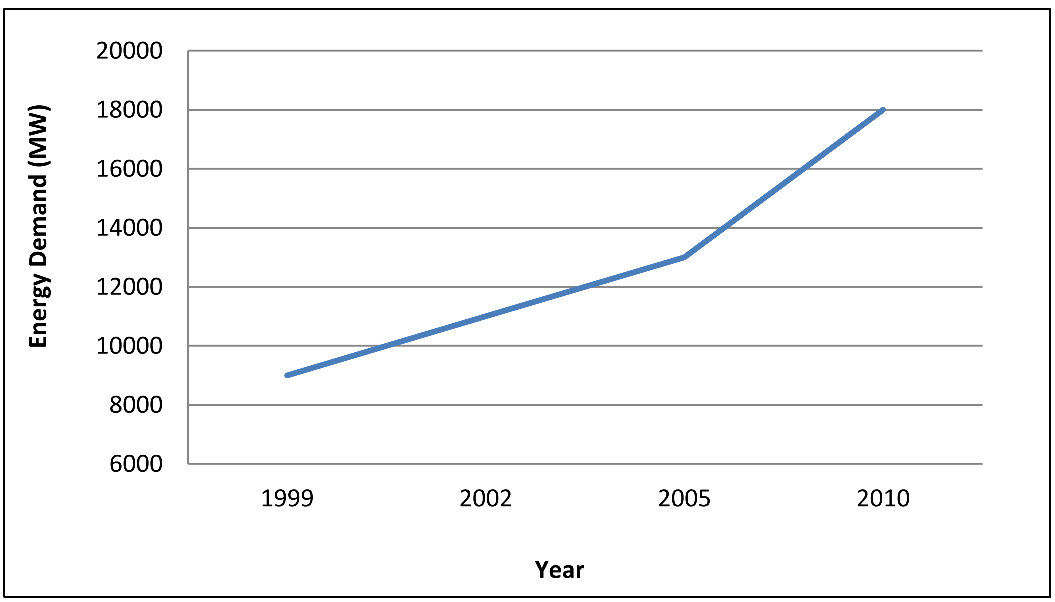

Figure 1.2 : Energy demand in Malaysia [4].

The sectors that are involved in the energy usage are the transportation, industrial, residential, commercial and agriculture sectors. In 2008, the energy consumption study shows that huge portion of energy is consumed in the industrial sector (43 %) and followed by transportation sector (36 %). Each sector has developed rapidly ever since, and the need for electrical power has also increased by many fields. The energy demand is increasing at a rate of 5-7 % annually, starting from 2004 and assumed to reach 23,092 MW by year 2030 [5, 6]. Malaysia has to find other alternatives source of energy rather than depending on existing energy sources such as coal, oil and natural gas which may be totally exhausted in the future. Besides that, the price of conventional fossil fuel fluctuates due to the imbalance between supply and demand, and the government has to find new solution to ensure long-term reliability, sustainability and security of energy supply. The renewable energy can be seen as one of the viable solutions that will also minimize the negative impact to the environment.

The renewable energy resources are known to be less competitive as compared to the conventional energy resources due to their intermittency and the relatively high maintenance cost. However, it has several advantages such as being renewable and environmental friendly. Renewable energy source produce minimal environmental impact compared and does not pollute [7]. In certain aspect, the renewable energy resources might be more beneficial compared to the conventional energy, but on the issue of the cost, the conventional energy would likely have considerable advantage over the renewable energy resource. The cost of implementing the renewable energy as the alternative energy might be high but the benefits reaped once the system can be fully utilized which are more than the conventional systems. The journey in replacing the current energy system with the new renewable energy system is long but should be able to meet the ever increasing energy demand. New technologies that used renewable energy sources must be developed and proper planning and monitoring strategies must also be put in place.

1.2 Renewable Energy in Malaysia

Malaysian government is fully supportive of the development and implementation of renewable energy based energy systems, and the commitment is clearly visible in the 10^{th} Malaysia Plan. Previously, in the Ninth Malaysia Plan, the need to reduce the dependency on petroleum products by increasing the use of alternatives fuel and promote the greater use of renewable energy for power generation and by industries was clearly stated. The renewable energy sector is targeted to achieve a production of 350 MW of grid connected electricity from renewable sources by the year 2009. However, by the end of the year 2009, only 53 MW was achieved which contribute to 15 % of the targeted capacity[8]. Thus, in the 10th Malaysia Plan, the importance of using the renewable was reiterated the new target for the next few years is aggressively re-emphasized. The relevant energy sectors are urged to promote the greater use of renewable energy for electrical power generation. The renewable energy based electricity production systems are expected to contribute about 6 % of the Malaysia's electricity production mix in the next few years and will reach up to 11 % by the year 2020 [8].

The implementation of various programmes have been launched to increase the awareness of the important of renewable energy system. The government came up with a plan of fuel mix in electricity generation in year 1999, known as Five-Fuel Diversification Strategy. The energy sources that contribute to energy mix are natural gas, coal, oil, hydro and renewable energy. In 2001, the Small Renewable Energy Power Programme (SREP) was initiated where the objective was to encourage and intensify the utilization of renewable energy in electrical power generation. Any small power generating plants that utilize renewable energy as the energy sources are encouraged to collaborate with Tenaga Nasional Berhad (TNB). The program has proven to be successful as the total electricity generated is 241.65 MW and approximately 43.5 MW is connected to the national grid [6]. In 2005, another project named Malaysian Building Integrated Photovoltaic technology application project (MBIPV) was launched to create awareness on solar energy for power generation. All of the programmes that utilize the renewable energy sources is initiated by the government to improve energy security and environmental performance of Malaysia in the future.

Feed-in Tariff (FiT) is one of the incentives create by the government to promote the development of renewable energy in Malaysia. The programme is managed by Sustainable Energy Development Authority of Malaysia (SEDA). SEDA was formed under the Sustainable Energy Development Authority Act 2011 which functions to manage the implementation of the FiT mechanism [9]. The FiT has been established in some other countries and at least 50 countries adopting the FiT policy show positive result [10]. Under this mechanism, the electricity produced by the renewable energy sources must be from within Malaysia and can be sold to the national utility companies at a fixed payment for every kilowatt hour (kWh).The implementation of FiT mechanism is intended to attract the consumer to invest more in the development of renewable energy. Malaysia Energy Center (MEC) also proposed another project for FiT under the Renewable Energy Fund to support the development of renewable energy based electricity generation. The project involves the contribution of 2 % of consumer's bill towards the fund if the electricity usage has exceeded a certain minimum point set [4, 11, 12].

The prospect of meeting the nation's increasing energy demand by utilizing the renewable energy resources for electricity generation is promising. One of the renewable energy sources that can be harnessed for electricity generation is solar energy. Since Malaysia is situated in the equatorial region with an average radiation of 4 500 KWh/m^2, it is an ideal location for large scale solar power installation. Considering the fact Malaysia is blessed with over 250 days of sunshine yearly, the potential for solar power generation is very high. By developing the renewable energy sector, it will reduce the dependency and consumption of fossil fuels as much as possible and hence provide economical, environmental and social sustainability. Energy security is also one of the key issues that are currently being deliberated, and the reliability and sustainability aspects of renewable energy based electricity systems must be carefully dealt with so that it can be viable option for future utilization.

1.3 Research Goals

1.3.1 Problem Statement

The solar electricity generating system (SEGS) uses photovoltaic modules to convert sunlight into electricity to power up the load. However, the limited access of sunlight throughout the day affects the conversion of solar energy to electricity. The fluctuation in solar radiation received at the surface of the earth is shown in Figure 1.3. Since solar radiation is the important input energy to be harnessed, the output from photovoltaic (PV) also fluctuates which can cause instability to the output power. Hence, the fluctuation needs to be monitored for optimization purposes.

The development of monitoring system for SEGS is to ensure that all the devices connected to the system functions properly. The setup for SEGS is rather expensive and complex, parameters such as PV array power output, PV array current, and battery voltage are useful to track the performance of the system. A failure or unstable output in any one of these parameters must be detected early so that the output power of SEGS can be optimized. Besides, most of the SEGS is installed in the inaccessible area where the access to the SEGS is limited. In residential area, it is difficult to access the PV arrays which are usually mounted parallel to the roof. Therefore, it is required to have a remote monitoring system that is capable of transmitting the measured data related to the performance of the SEGS to the owner of SEGS.

The PV monitoring system available in the market are specifically designed for certain region and as the performance of solar energy based systems depends on location, time of day, time of year, and weather conditions, the flexibility is rather limited. The cost related to the PV monitoring systems that are available in the market is relatively high and requires additional installations. In order to fulfill the entire requirements, the need to have a suitable remote monitoring system, a low-cost yet reliable system must be developed for centralized observation. The system must be developed using the currently available computer systems in order to monitor the performances of solar electricity generating system.

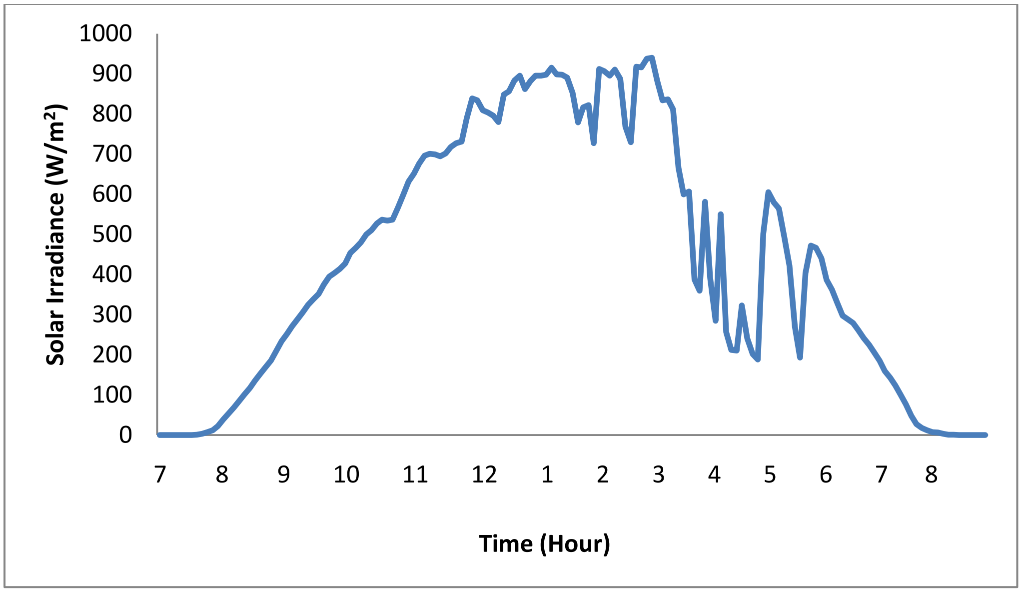

Figure 1.3: Solar irradiance measured in UTP on 22 January 2011

1.3.2 Scope of study

The thesis focuses on the development of PV monitoring system to track the performance of SEGS. The study is divided into three sections. In the first section, theoretical study on properties of solar energy includes the thorough review of solar radiation, solar geometry, solar electricity generating system and the previous research done on the PV monitoring system. Study was carried out on the basic structure of SEGS and also on the characteristics of solar energy, before proceeding to the design stage. The criteria to develop a reliable PV monitoring system were explored and a prototype was designed and implemented.

The second section of this research concentrates more on design and development of the PV monitoring system. Basically the structure of the system is divided into three parts, the first part is on displaying the data captured on the LCD, the second part is displaying the data on computer and the third part is displaying data through the web based system. In the first and the second part, the study focuses on development of the data acquisition system which allows the system to convert the input signal to sensible data reading. In the third part, the study focus on transmitting the data measured through internet connection for remote monitoring purposes. There are three software used in this project which are the C programming, Visual Basic (VB) software and Apache Server 2.2.15. The C programming software is used in the first part to programme the microcontroller connections. In the second part, the Visual Basic software is used to manipulate input from the user interfaces and display data on the computer while for the third part, the Apache Server 2.2.15 software is used to retrieve data from the internet.

The last section of the project is the analysis of the results that were obtained from the experimental work. The experimental work can be divided into three parts. The first part is aimed to investigate the effect of meteorological conditions on the performance of the SEGS. The second part is prototype testing on SEGS and the third part is verification performance of monitoring system developed for accuracy testing.

1.3.3 Objectives

The main objective of this research work is to develop the SEGS based performance monitoring system. Although the commercially available monitoring system can monitor the performance of SEGS and provide reliable data, the cost and design flexibility are areas that can be explored. Thus the designed monitoring system should be cost-effective and have the capability to transmit the analyzed data to the user for monitoring purposes including via internet. Based on that, the objectives of this research can be divided into three which are:

- To develop remote monitoring system to gauge the performance of solar electricity generating system
- To analyze the performance of solar electricity generating system for optimization of electricity generation.
- To carry out experiments to verify the accuracy of the PV monitoring system locally and also remotely, through the internet.

1.4 Outline of Thesis

This thesis is arranged into 6 chapters where the first chapter gives an introduction to the thesis by describing the background of the study, problems statement, objectives and scope of study as well as the outline of the thesis.

Chapter 2 describes the solar energy utilization, especially in Malaysia. This chapter will explain the characteristics and applications of solar energy related systems which includes the solar radiation, SEGS and the PV monitoring system. The advantages and disadvantages of various monitoring systems that are commercially available will also be outlined.

Chapter 3 describes the research methodology of the project. The steps involved in developing the monitoring system, the overall monitoring system design and the performance verifications of monitoring system developed are discussed. The experimentation setup and conditions for each experiment together with the hardware and software involved in this project are also discussed.

Chapter 4 presents the development of monitoring system in detail. The development of monitoring system is focused on the data acquisition system, the web based system and the final prototype. The detail design and connection of hardware and software related to the system is explained.

Chapter 5 presents detailed evaluation and analysis of results obtained through experimentation. The experimental work described in this chapter can be divided into three sections where the first one is the performance of PV system, the second part is prototype testing and the third part is performance verification on monitoring system.

Chapter 6 summarizes the whole research work for this project. This chapter also presented some possible future research directions that can further improve the PV monitoring system that was developed in this project.

The list of publications related to this research work is given in Appendix A.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter begins with the study on solar energy, focusing on solar radiation and solar geometry for optimizing the design of PV based solar electricity generating system (PVSEGS). The need for monitoring the PVSEGS will be highlighted as well together with the details of the PV monitoring system design.

2.2 Solar Energy

Solar energy has always been one of the main sources of renewable energy as compared to wind, biomass, wave and tidal energies. Solar energy which is clean and considered as environmental friendly has the potential of reducing the dependency on fossil fuel as the main source of electrical power generation. Solar energy is an essential inexhaustible source potentially capable of meeting a significant portion of the nation's future energy [4, 13]. The average solar radiation reaching the earth's surface per year can provide up to 10 000 times of the world's energy need. Although, the Sun radiates energy at 3.9×10^{26} W, but energy received at the outer atmosphere of Earth is 1353 W/m^2 [14].

2.2.1 Solar Energy Availability in Malaysia

Malaysia's potential for utilizing renewable energy for power generation is substantial, especially solar energy. Malaysia gets an average of 4.5 hours to 8 hours of sunshine every day [15],[16]. Malaysia is situated in the equatorial region, between 1.0ºN and

6.0ºN with an average radiation of 4 500 KWh/m^2, which can be seen as an ideal location for implementation of PVSEGS. The annual average daily solar radiation data for various places in Malaysia is shown in Table 2.1. The averaged solar irradiance data shows that Kuching, Kuala Lumpur and Bangi has the lowest irradiance value as compared to Georgetown, Bayan Lepas and Kota Kinabalu [17]. The solar energy resource has great potential to be optimally utilized for implementation of electricity power generation.

Table 2.1: Avarge value of solar radiation in Malaysia [18]

Locations	**Yearly Average Value (kWh/m^2)**
Kuching	1470
Bandar Baru Bangi	1487
Kuala Lumpur	1571
Petaling Jaya	1571
Seremban	1572
Kuantan	1601
Johor Bharu	1625
Senai	1629
Kota Bharu	1705
Kuala Terengganu	1714
Ipoh	1739
Taiping	1768
George Town	1785
Bayan Lepas	1809
Kota Kinabalu	1900

2.2.2 Solar Electricity Generation Policy

The development of solar energy in Malaysia has not been fully utilized although available in abundance. The cost of implementing PVSEGS system is relatively high. Figure 2.1 shows that the installations of PV system in residential areas are mostly concentrated in the west side of Peninsular Malaysia only, including Selangor, Federal Territory, Negeri Sembilan and Melaka. The installation cost of PV arrays may vary from $6.00 to $10.00 per watt[19]. The average residential household need to install at least a 5kWh system with a capital costs of RM35 000.

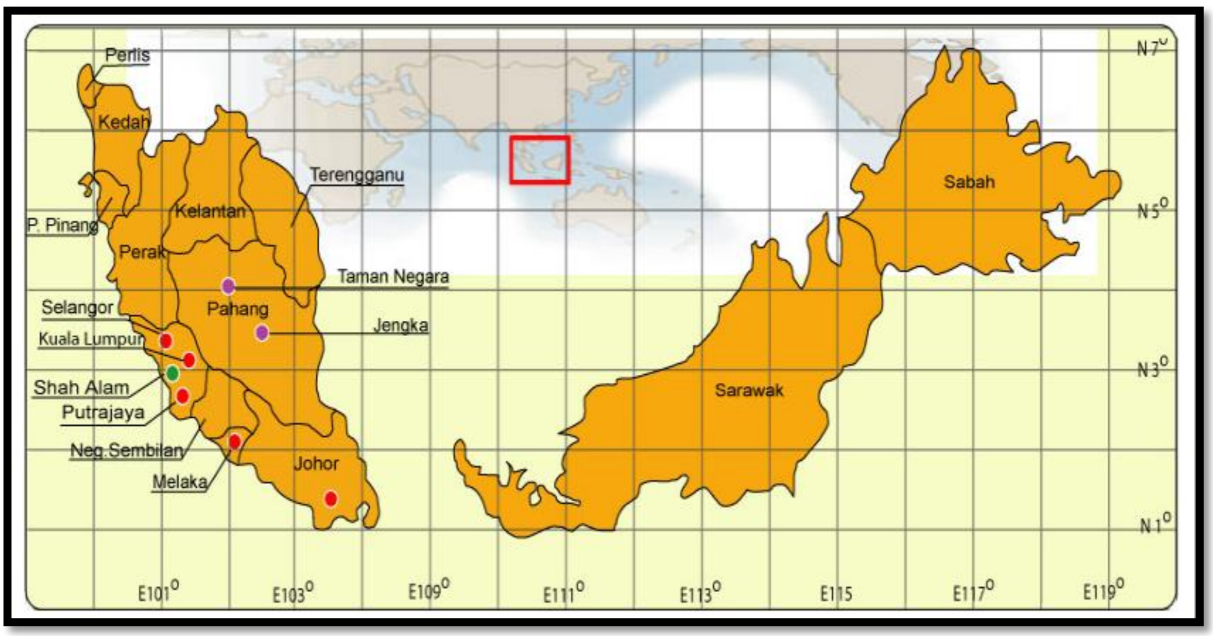

Figure 2.1: PV Installed area on residential building in Malaysia [20]

The lack of awareness and understanding of PV technologies are some of factors that restrict the deployment of PV system. Therefore, the government, under MEC created an initiative to reduce the cost of PV system by launching the project named Malaysia Building Integrated Photovoltaic also known as MBIPV. The objective of MBIPV is to induce the long term-cost reduction in development of PV by integrating the PV technology within building designs and envelopes. The three main programs offered under MBIPV in order to enhance penetration of PV in local market includes the Showcase, Demonstration and SURIA 1000, as shown in Table 2.2. The showcase and demonstration programs are created basically to give awareness, understanding of PV technologies and PV implementation for industry or residential areas. SURIA 1000 program offered capital incentives to install Building Integrated Photovoltaic system (BIPV) at residential and commercial properties in order to provide direct opportunities to the public and industry to be involved in renewable energy initiatives. Under this programme, public can bid for price rebates for the total BIPV equipment and installation cost. For the first round of bidding, out of 39 applicants, only 14 applicants were successful to receive 50 % discount of their PV system [6, 21]. On 31 December 2009, the total capacity installed for BIPV system is 1084 kWp.

At present, the FiT programme which was recently announced in the 10th Malaysia Plan was proposed under the Renewable Energy Act bill. The FiT programme is managed by SEDA to support the development of renewable energy based electricity generation. SEDA was assigned to be in charge of promoting, stimulating and facilitating any programme and actions regarding the development of sustainable energy in Malaysia. For solar PV, the internal rate of returns by implementing FiT are 5.1 % for BIPV, 8.7 % for PV on commercial roof-tops, and 10.9 % for PV solar farms [4]. It is estimated that the FiT programme would add 2 % to the average electricity tariff in the country. The FiT programme is almost definite to change the solar energy market and development in Malaysia.

Beside the MBIPV project and FiT programme, the government also emphasized on the future development of solar energy in Malaysia together with other renewable energy through the Economic Transformation Programme. Under the energy Entry Point Programme, it stated that Malaysia aims to build solar power capacity up to 1.25GW by the year 2020 [22]. In order to achieve the target, TNB as the primary electricity supplier in Malaysia has also promoted the development towards utilizing the green technologies. TNB’s upcoming project which is developing Malaysia’s first solar power plant in Putrajaya is expecting to be completed within 12 month, starting from February 2011 [22]. The main reason behind this project is more to create awareness and for learning process purposes rather than expecting profit or make any economic return. There are more upcoming projects involving solar energy that has potential of being one of the alternatives for future electrical power generation.

Table 2.2: Status of Programs offered under MBIPV project [6]

MBIPV program	Target Capacity (kWp)	Awarded Capacity (kWp)	Commissioned Capacity (kWp)
Showcase	125	140	140
Demonstration	205	214	197
SURIA 1000	1215	885	146
TOTAL	1545	1239	483

2.3 Solar Radiation

Solar radiation is the radiant energy emitted by the sun. Irradiation received on earth's surface is defined as the energy density of sunlight and is measured as kWh/m^2**.** Irradiance is the radiant power incident on per unit area of surface, given in W/m^2 [23, 24]. The intensity of solar radiation outside the earth's atmosphere varies throughout the year as the earth travels through its orbit. The rotation of the earth on its axis and around the sun causes the apparent movement of the sun daily and throughout the year. Thus, the amount of solar energy captured on the surface of PV array is influenced by the transient nature and trajectory of the sun.

2.3.1 Diffuse and Beam Radiation

The solar radiation received at earth's surface too varies due to atmospheric effect such as scattering, absorption and reflection as shown in Figure 2.2. The solar radiation that enters the atmosphere is absorbed, scattered and reflected by molecules such as air, water vapour and pollutants before reaching earth's surface [25]. The radiation that is coming straight from the sun and reaching the earth's surface without changing direction is called direct radiation, also known as the beam radiation. The radiation that is scattered also known as diffuse radiation whereas the radiation reflected from the ground is called reflected radiation. The global radiation, I_G, is the sum of the direct radiation, I_B, multiplied by cosine of the incidence angle, θ , and diffuse radiation, I_D, as shown in Equation 2.1 where θ is the angle formed between the solar disk and the normal to a horizontal surface [26, 27] as shown in Figure 2.3.

$$I_G = I_B \cos\theta + I_D \tag{2.1}$$

For a solar radiation striking on a surface at angle 90º, the angle θ between the ray and surface normal is 0º, where the cosine will be 1. The solar incident angle is not perpendicular to horizontal at all times due to the apparent movement of the sun. More solar energy can be harvested by using 2-axis tracking system, where angle θ is kept at 0º and the cosine will be 1.

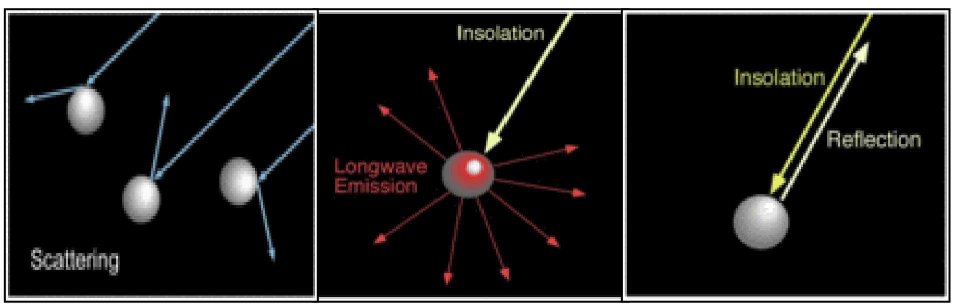

Figure 2.2: The atmospheric effect including scattering, absorption and reflection [28]

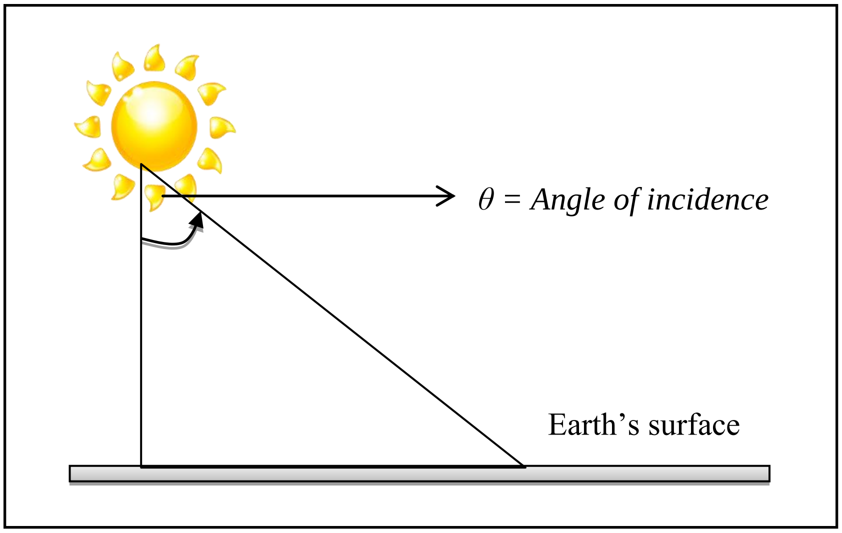

Figure 2.3: Solar incident angle, *θ* [26]

The modification of the incoming solar radiation by atmospheric and surface processes for the whole Earth is as shown in Figure 2.4. From the incoming solar radiation, after being scattered and absorbed, the remaining available solar radiation available at the earth’s surface is 51 %. Out of the balance 49 %, 4 % is reflected back to atmosphere by the earth’s surface, 6 % is reflected by atmospheric particles, 20 % is reflected by the clouds and 19 % is being absorbed by atmosphere and clouds. Therefore, the maximum radiation is received on the earth’s surface under the cloudless sky condition [29].

The measurement of solar radiation can be taken either by pyranometer, pyrheliometer or sunshine recorder. A pyranometer as shown in Figure 2.5 is used to measure the global radiation throughout the day [24]. The pyranometer can also be used for the measurement of diffuse radiation. This is done by using a shade ring to shield a pyranometer from direct solar radiation. A general analysis is developed to relate shade-ring corrections to the radiance distribution of diffuse radiation [30]. A pyrheliometer as shown in Figure 2.5 was used to measure solar radiation (beam) at UTP.

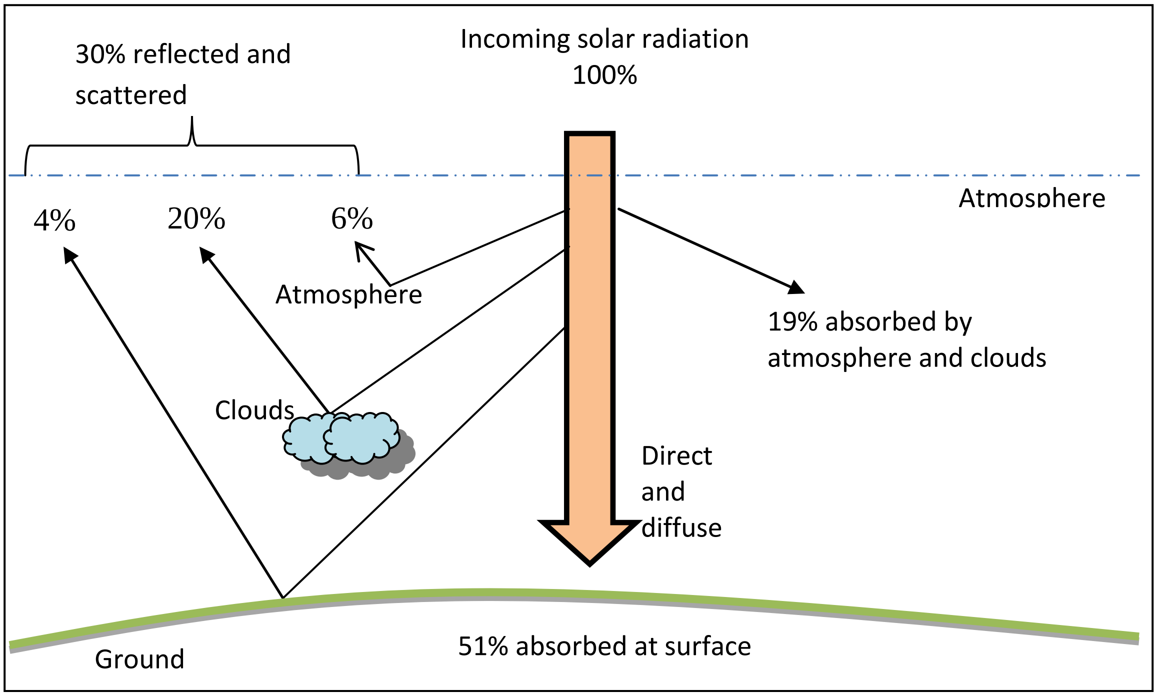

Figure 2.4: Modification of Incoming Radiation [29]

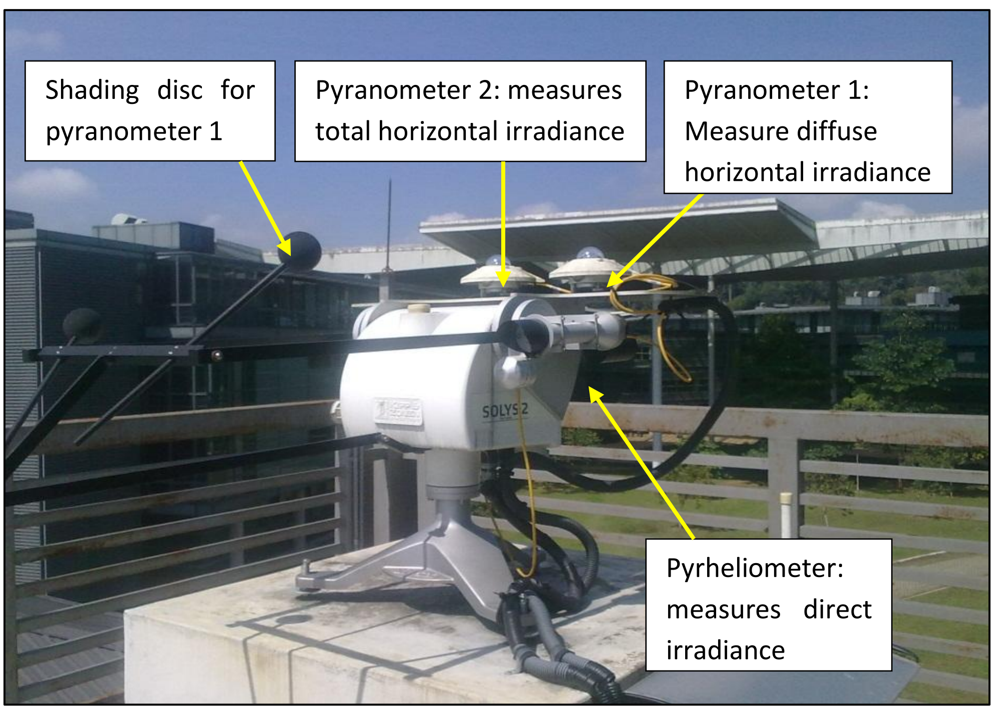

Figure 2.5: Solar radiation instruments at solar tower UTP

The solar radiation measurement includes the reading of global, direct and diffuse radiation captured from the sunlight. Figure 2.6 shows an example of solar radiation measurement at UTP.

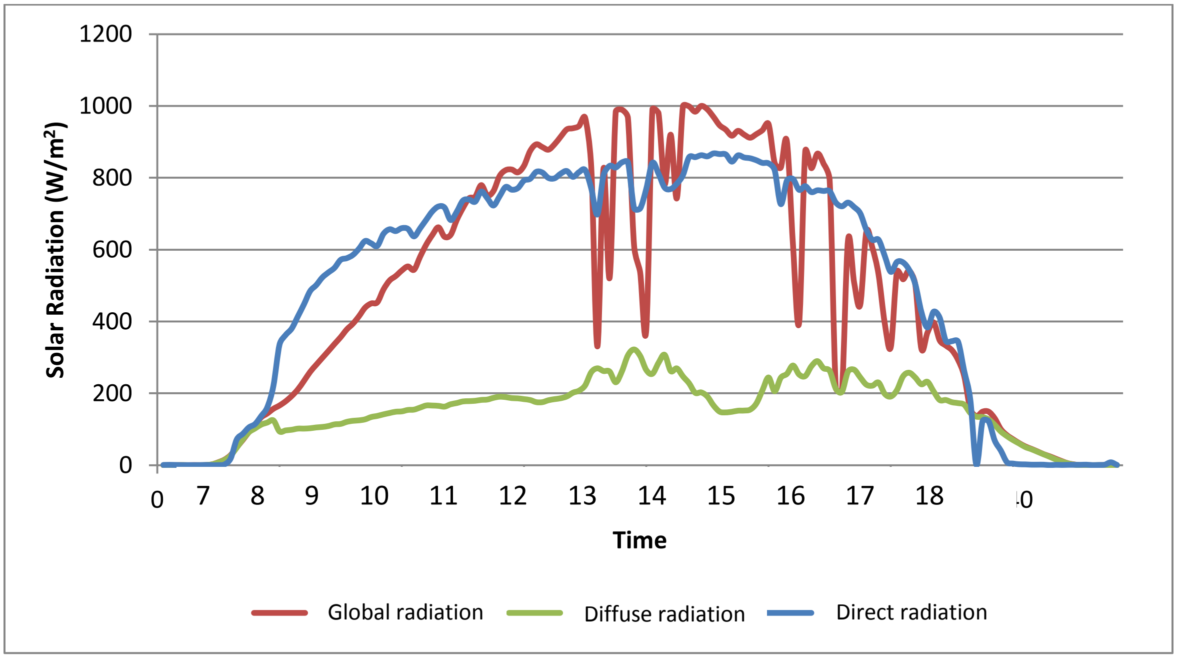

Figure 2.6: Solar radiation measurement in UTP on 2nd May 2011

2.3.2 Solar Geometry

In designing any kind of system that is related to the utilization of solar energy, it is important to consider the position of the sun to make sure that the site has proper solar access. Therefore, in order to have maximum solar energy converted into electricity, it is valuable to incorporate a system with an optimum tilt angle and orientation that can adjust to the position of the sun.

The rotation of the earth on its axis and around the sun causes the apparent movement of the sun. A PV module must be tilted towards the direction that captures the most sun in order to get the optimum solar radiation. Maximum solar gain for a given intensity of sunlight is achieved when the sun is positioned directly overhead or 90° from the horizontal compare to when the Sun is at 45° above the horizontal. Figure 2.7 models the effect of changing the angle of incidence from 90° to 45° which shows the lower angle covered more surface area, approximately 40 % greater compared to the higher angle but the intensity of the incoming solar radiation is getting lower approximately by 30 % [32].

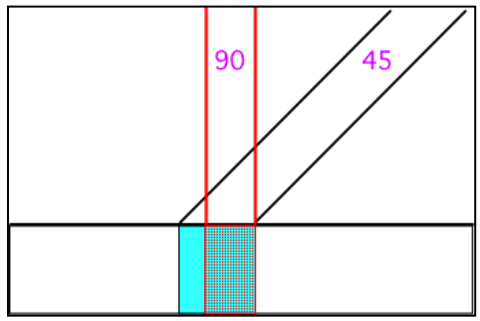

Figure 2.7: The effect of angle on the area that intercepts an incoming beam of radiation

The tilt angle and the orientation of the PV array would have to change to accommodate for direct incident irradiance on the array. Therefore, the orientation of PV module needs to be considered to allow for differences in latitude which can be done by using tracking system. The tracking system which can track the sun's trajectory throughout the day and around the year is actually expensive and requires high maintenance cost. Hence, it is necessary to carry out studies to determine the proper tilt angle and orientation of PV array prior to the setting up the SEGS.

The position of PV module is defined by the tilt angle, β and orientation is expressed by the azimuth angle, γ as shown in Figure 2.8. The tilt angle is the angle between PV tilted surfaced and the horizontal [33]. The azimuth angle is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, due south [33]. The optimum orientation of the PV array is towards the equator and the optimum tilt angle depends only on the latitude [34]. In most cases the optimal orientation is facing true south in the northern hemisphere and for southern hemisphere countries, it should face the true north [35]. In order to maximize the amount of solar radiation incident on PV module, the optimum tilt angle, $\beta_{optimum}$ for the PV module is found to be (ϕ-δ) which is equal to zenith angle, $\theta_{z,}$ at solar noon as shown in Figure 2.9 [36].

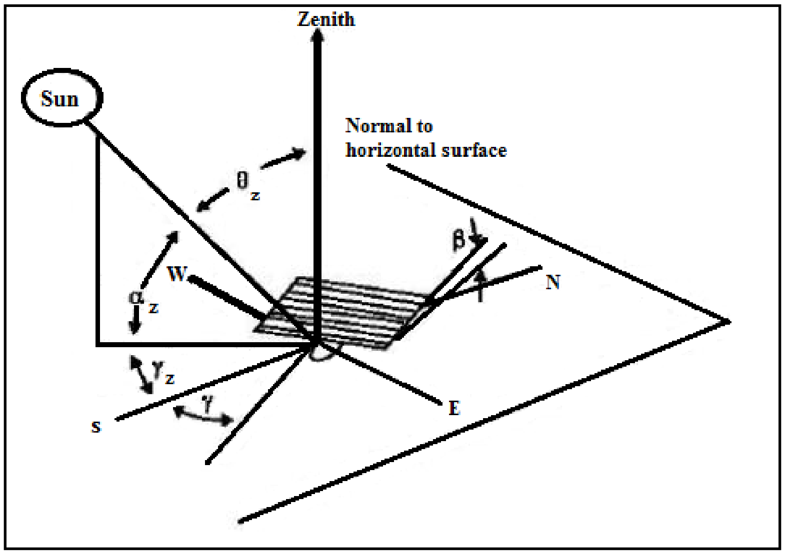

Figure 2.8 : PV module tilted at angle β [33]

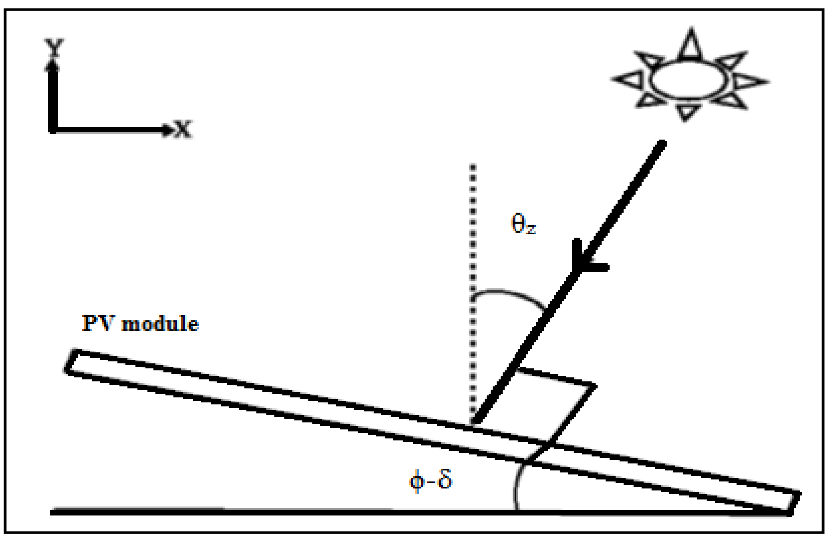

Figure 2.9: PV Module with $\beta_{optimum}$ at solar noon.

The zenith angle, θ_z is the angular displacement between the lines of the sun's rays to the vertical and is given by Equation (2.2) where δ is the declination angle, θ is the angle of incidence and ω is the solar hour angle. The latitude angle, ϕ is the angular location north or south of the equator.

$$\theta_z = \cos^{-1}(\cos\delta\cos\phi\cos\omega + \sin\delta\sin\phi) \tag{2.2}$$

The angle of declination, δ is the angle position of the sun at solar noon which varies between -23.45º to 23.45º throughout the year and can be determined by using Equation (2.3), where m is the day of the year.

$$\delta = 23.45 \sin \frac{360\,(248 + m)}{365} \qquad (2.3)$$

The solar hour angle, ω is the angular displacement of the sun to the east or west of the local meridian due to the rotation of the earth on its axis. The solar hour is estimated by using Equation (2.4) where t_{hr} is for the hour t_{min} for the minute.

$$\omega = \left(0.25 t_{\min} + 15 t_{hr} - 180\,^{\circ}\right) \qquad (2.4)$$

Once the right tilt angle and orientation of PV module have been determined, the solar irradiance that strikes onto PV module can be calculated by using Equation (2.5)

$$I_{module} = I_{incident} \cos\theta \qquad (2.5)$$

I_{module} is the solar irradiance received by PV module and $I_{incident}$ is the incident solar radiation which can be either solar beam radiation or solar direct radiation. The angle of incident, θ can be determined by using Equation (2.6) where ∂ is the angular position of the sun at solar noon, ϕ is the latitude, β is the slope angle, γ is the surface azimuth and ω is the hour angle[37].

$$\theta = \cos^{-1}\begin{bmatrix} (\sin\partial \sin\phi \cos\beta) - (\sin\partial \cos\phi \sin\beta \cos\gamma) + \\ (\cos\partial \cos\phi \cos\beta \cos\omega) + (\cos\partial \sin\phi \sin\beta \cos\gamma \cos\omega) + \\ (\cos\partial \sin\beta \sin\gamma \sin\omega) \end{bmatrix} \qquad (2.6)$$

2.4 PV Monitoring System

The transient nature of solar energy affects the performance of the PVSEGS and as a result, there is a need for efficient performance monitoring system. The installation of monitoring system is desirable in order to keep track the performance of PVSEGS and to ensure that the system is functions properly.

Monitoring system is designed to give an effective performance feedback in order to make sure that a system is reliable and functions at the optimum level. The hierarchy of designing a system or a project must start with planning, then implementation of the project, and the last step is evaluation of the project. The monitoring part includes in the evaluation process to obtain maximum possible output. By installing the monitoring system, all the parameters can be checked and analyze to make sure that the system is in good condition. The benefits of installing the monitoring system are actually providing an early detection of device failure and give prediction of possible breakdowns. Most of the monitoring system used closed-loop structure where the feedback controllers are integrated together into the structure to control detected problems. Some systems used open-loop structure where there is no feedback included in the system. In power generation industry based on renewable energy sources, there is a need for monitoring system to be integrated into PVSEGS to maintain the system's performance and to maximize the output power from the PV array. There are several types of monitoring system that are commercially available. Table 2.3 reviews some of the PV monitoring system design. The monitoring system design discussed here are the Supervisory Control and Data Acquisition System (SCADA) and Distributed Control System (DCS). The selected design is DSC where the structure is more simple and suitable to be applied for this project.

Table 2.3: Comparisons of PV monitoring system design

Monitoring System Design	Advantages	Disadvantages
SCADA	• Close-loop structure	• Design for industrial level • Complex system • High cost
DCS	• Design for small area (Residential area) • Suitable for Stand-alone SEGS • Reasonable Price • Required only one database	• Open-loop structure

2.4.1 Supervisory Control and Data Acqusition System (SCADA)

SCADA is an example of monitoring system designed for large scale control system which is widely used by TNB. The early version of SCADA operates manually where no data logging is involved and there is need to monitor the devices 24 hours a day. The modern system of SCADA nowadays uses a data acquisition system where the data will be sent, stored and analyzed at the main control room. The system operates to monitor and control operations from one main measurement station named Master Terminal Unit (MTU). The MTU will be able to receive data from various remote locations and send the feedback analysis. This reduces the requirement for maintenance people to visit the site as the information needed can be view directly from the control room [38].

The SCADA system uses a computer unit to monitor and store the data from all equipment related to the system while a communication system is required to connect between the transmitter and the programmable logic control (PLC) [39],[40]. A PLC is used to receive data and to be sent to MTU. The SCADA system also uses the human-machine interface function (HMI) to receive data from Input/Output (I/O) devices by using remote terminal unit (RTU) and provide graphical user interface (GUI) function

[41]. The HMI will be able to show the connection process to the operator and it is programmed to adjust the RTU controls. The RTU is a small computerized unit that works as local point for input/output (I/O) devices. It will collect the data locally before transferring the data to the MTU. The new system of SCADA allows the RTU to control the operation within its range through the closed loop feedback systems. This system has been applied at Murdoch University in Western Australia by RESLab, an Australian National Renewable Energy Systems and Components Test facility. Basically the company provides facilities and services for renewable energy industries such as designing, product development and including testing. SCADA has been included as testing facility to monitor and control the renewable energy system and its components[42].

2.4.2 Distributed Control System (DCS)

The DCS is another example of the monitoring system and has similar structure as SCADA. DSC is designed for a small area and has one database for the complete system as compared to the SCADA. In DCS system, all the I/O devices are connected to the local connector and data is sent to the controller by using fieldbus communication. The high speed Ethernet is used to transfer the data from the controller to the main measurement station. At the main measurement station, there are operator station and engineering station. The operator station works as process visualization while the engineering station is used for the configuration of the processes[43]. The DCS is always connected to its data source so that it can directly access the data from the I/O field in order to get response for any control operation.

2.4.3 Structure of PV Monitoring System

In developing the PV monitoring system for this project, the most suitable design chosen is DCS system. The PV system developed is usually designed for small area, therefore using the SCADA structure instead of DCS is not really suitable and will increase the cost as well. PV monitoring system is designed using the distributed control system based on the Client/ Server architecture as shown in Figure 2.10. Based on this structure, all the devices will be connected to a measuring station, which operates as a main server. The data from each device can be access by using data acquisition system (DAS) before transmitting it to the main server. Adding to the DCS system, the data information is also available through the internet. Any data can be accessed anywhere besides the main control station as long as the internet connection is available [44, 45]. The function of the system is similar to the SCADA and DCS which is to monitor the entire system to ensure it is functioning properly and maintaining a good performance. If any function falls outside of the specified parameters, the notification process will give reports so that any action that is required can be taken as soon as possible.

The PV monitoring system is divided into three sub systems which are:

a) The PV based solar electricity generating system which consists of PV panel, battery, charge controller and inverter.

b) The data acquisition system which will be used to measure the variables in order to evaluate the PV system performance.

c) The transmission system which will be used to transmit data for verification.

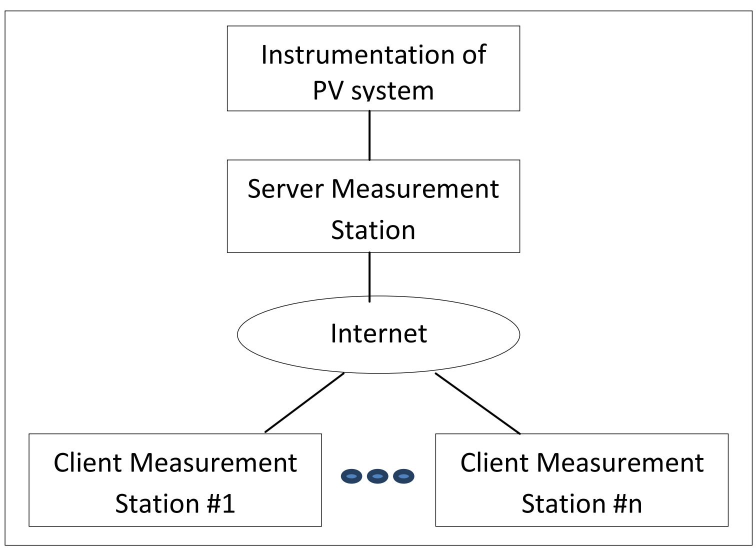

Figure 2.10: Distributed Measurement System Based on Server/Client Architecture

2.4.4 PV Based Solar Electricity Generating System

The basic design of PVSEGS consists of PV panel, charge controller, battery and inverter. The PV arrays convert solar irradiance directly into electricity. The PV array is sized to meet the load requirement during the month with the lowest solar irradiation[46]. The PV panel is connected to the charge controller where during on-peak demand, the solar PV provides electricity directly to the DC load through charge controller. The charge controller manages the charging of the battery. The battery is used as backup power supply to cater for the demand at night due to the availability of sunlight that is limited to 6-8 hours per day. The battery functions to store excess electricity generated by PV array and to supply electricity when PV panel supply less power than the demand[47]. The inverter is used to convert the DC to AC electricity to supply power to the AC load. Basically there are two options in designing the PV based system with back up supply, namely standalone PV based system and Grid-Connected PV system. The configuration and design for PV standalone is more simple compare to Grid-Connected PV system.

2.4.4.1 Standalone PV system

The standalone PV system as shown in Figure 2.11, usually produces power independently. These systems are ideal for remote locations where the grid cannot penetrate. In 2003, Malaysia built the first solar power station in Kampung Denai, on the eastern coast of Peninsular Malaysia [48]. The installation of SEGS at that time was done mainly in rural area where setting up grid was difficult. As the system is off-grid, it needs the battery for storage of electricity produced during off-peak demand periods, leading to extra cost on battery or else the excess power generated will be wasted [3]. The focus in designing the stand alone PV system is on the optimal size of PV panel and the capability of battery to meet load demand. There is example of PV standalone system in Arab Saudi, that is powered by 350 kW of concentrating PV power system to provide electricity to three remote villages [49]. Malaysia has also invested in the development of

PV standalone system and one of the projects is in Langkawi, Kedah where they implemented the PV system for a cable car station.

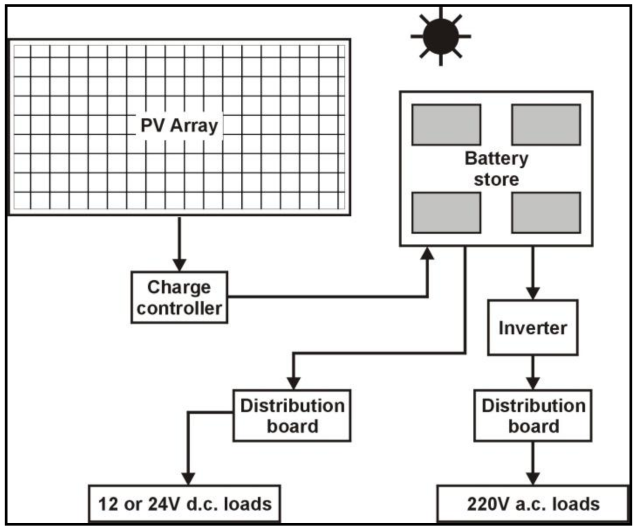

Figure 2.11: Standalone PV System

2.4.4.2 Grid-Connected PV system

In Grid-Connected PV system, it is connected to the local solar electricity network for power generation, transmission and distribution. During the day, the solar electricity generated by PVSEGS can be used for supplying electricity to the load while at night, power can be bought back from the network. The grid acts like a battery with unlimited storage capacity. Most of the components are similar to the stand alone PV system where the only differences are the grid connected PV system which consists of main fuse box that is interconnected with the utility power and the connection to the breaker panel to allow the auxiliary electricity supply whenever needed. The battery can also be included in the system just in case of the electricity breakdown. The grid-connected PV system and its components is shown in Figure 2.12.

The first grid-connected system in Malaysia was installed in Universiti Tenaga Nasional(UNITEN) in the year 1998. It was funded by the Malaysia Electricity Supply Industry Trust Account (MESITA) together with the TNB itself. The PVSEGS was designed to provide up to 3.15kWp of 3-phase electricity to one of the UNITEN buildings. One of the ongoing projects related to this system is the MBIPV project under MEC which has been discussed in section 2.2.

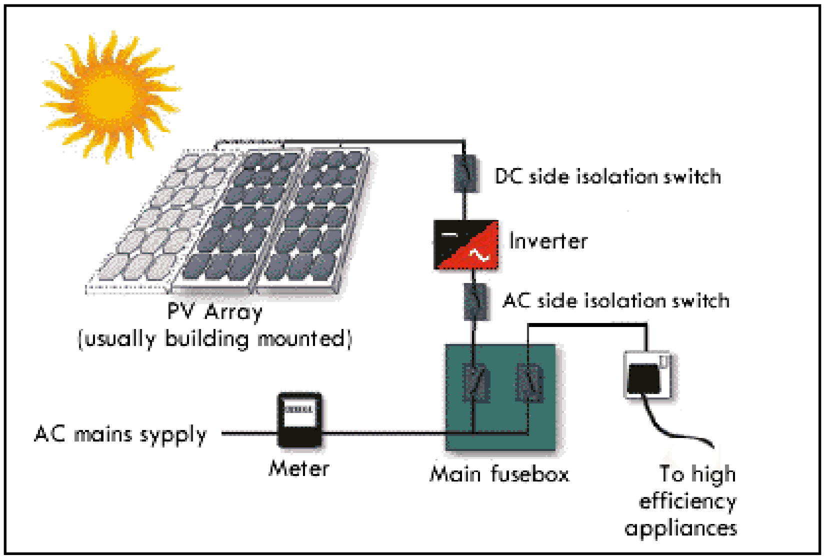

Figure 2.12: Grid-Connected PV system

2.4.4.3 Photovoltaic

In PVSEGS, photovoltaics play the important role as it converts the sunlight into electricity. Photovoltaic cell is made by using semiconductor materials. The conversion process from solar energy to electricity starts when the sunlight strikes the PV cell. The incoming solar radiation consists of photons that will be absorbed by the semiconductor materials. The absorption of photon generates an electron-hole pair, where electrons are removed from the atoms of the cell. This causes the separation between the holes and electron, which makes the electrons to be on the negative terminal and holes to be on the positive terminal, thus creating the potential difference [50].

The photovoltaic cells are grouped together to deliver the desired amount of power. The PV modules needs to be connected in an electrical circuit together with other PV modules to form arrays so that more powered can be generated[35]. PV modules and arrays performance are generally evaluated under Standard Test Conditions (STC) at a cell temperature of 25°C, solar irradiance level of 1000W/m^2 and solar spectrum under 1.5 Air Mass [51]. The modules and panels will be tested under STC to pass the listed criteria and then it will be certified by IEC 61215/IEC 61646. The criteria includes the level of degradation that must not exceed 5 % of each test or 8 % after each test sequence, the outer side of the PV module must not having major defect and the insulation test requirements are met [52].

2.4.4.4 Types of PV Cell Materials

The development of PV cells can be classified into three different generations. The first generations of photovoltaic cells are the monocrystalline and polycrystalline types. *Monocystalline* is the oldest in this generation and can produce the most efficient sunlight conversion technology, which is around 15-20 %. It has a uniform molecular structure with practically zero defects or impurities. The process to produce monocrystalline is complicated which makes it the most expensive as compared to other modules. Polycrystalline PV operates in a similar manner as the monocrystalline PV. It has lower efficiency if compared to the monocrystalline type which is around 9-12 %. This is because it uses small-grains of single-crystal which is low cost silicon[53]. The advantage of polycrystalline silicon is the material shows greater stability under electric field and light-induced stress. Figure 2.13 shows an example of monocrystalline silicon and polycrystalline silicon module. The characteristics for monocrystalline and polycrystalline are summarized in Table 2.4.

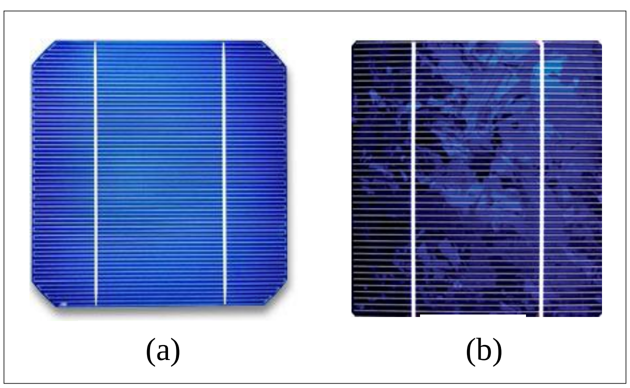

Figure 2.13: Type of PV cells materials a) Monocrystalline silicon cells and b) Polycrystalline silicon cells

Table 2.4: The characteristic of Mono-crystalline Silicon and Poly-crystalline Silicon

Type of PV cell	Conversion Efficiency (%)	Average Life Time (Years)
Mono-crystalline	15-20	25-30
Poly-crystalline	11-14	10-25

The second generation of PV cells are produced by using thin layers of semiconductor material made of Armophous Silicon (a-Si), Gallium Arsenides (GaAs), Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS) or Copper Indium Selenide (CIS). The advantages of using thin layers of silicon are that the PV panel is more flexible and significantly cheaper to produce than first generation cells. In terms of conversion efficiency, it is lower as compared to monocrystalline and polycrystalline where the efficicency of armophous silicon PV is around 6-8 % efficiency. Table 2.5 shows the comparison of conversion efficiency for several types of PV cells in second generation category.

Table 2.5: Conversion Efficiency of Second Generation Type PV Cells.

Type	Standard Product	Commercial Maximum Laboratory Efficiency	Maximum Recorded
Amorphous Silicon	6-8 %	8.3 %	15.4 % (Triple junction)
Cadmium Telluride	8-10 %	10.9 %	16.5 %
Copper Indium Gallium Selenide	10-12 %	12.2 %	19.0 %

The third generations of PV cells consist of hybrid solar cell, full organic solar cell and dye sensitized solar cell (DSSC) which are being produced from variety of materials besides silicon. In this generation, the focus is on producing PV cells that are cheaper, as compared to the silicon-based PVs [54]. Currently conversion efficiency of the third generation cells are still improving where the DSSC has recorded efficiency of 11.1 % [55].

2.4.5 Data Acquisition System

DAS is widely used in renewable energy system for monitoring and controlling PVSEGS. In 1999, Mukaro and Carelse developed a microcrontroller-based data acquisition system for monitoring the PV system and the environment as well [56]. DAS is developed to receive the information from the different devices in PVSEGS. It acquires all the necessary data for monitoring and analysis including the DC current and voltage, the AC current and voltage, solar radiation, ambient temperature or any other related variables depending on the selection of the signals to be displayed [57]. The data obtained will be sent to the main server station to evaluate the PVSEGS in terms of the performance, efficiency and reliability[56].

As technology progressed, the DAS has been simplified and made more accurate, and reliable through electronic equipment. Basically, different system will be using different data acquisition units to interpret the signal and obtain the desired information. There are several terms used in the data acquisition system including analog digital conversion (ADC), digital-to-analog converter (D/A), digital input/output (DIO), differential input, general purpose interface bus (GPIS), resolution, RS232, RS485, sample rate and single ended input. Common data acquisition units used for microcontroller-based data acquisition system are ADC and RS232. The microcontroller converts the analog signal to digital signal and is transferred to the computer by using RS232 serial interface [58, 59].

2.4.5.1 Types of Data Acquisition

In order to use the data acquisition units, a suitable type of data acquisition system is required to be used as a connection to transmit the data to the computer. There are several type of data acquisition such as:

a) **Serial Communication Data Acquisition Systems**

Serial communication data acquisition systems are usually used to communicate at a location that has short transmission distance from the computer. The RS232 can detect up to 15 meter only but RS485 can support until 1524 meter [60].

b) **Universal Serial Bus (USB) Data Acquisition Systems**

The USB is a device for connecting Personal computers (PC) to peripheral devices. It is most simple and universally available method of connection as most computers nowadays provide USB ports.

c) **Data Acquisition Plug-in Boards**

Data acquisition plug-in boards are connected directly to the computer which makes the data transmission faster as compared to the others. Each board installed in the computer is addressed at a unique I/O map location [60]. The data acquisition board is connected to I/O connector block by shielded cable and data is transmitted to the computer by using RS485 serial connection [61].

d) **Wireless Data Acquisition System**

These systems consist of one wireless transmitter unit and wireless receiver unit, for transmission of data. Wireless DAS can be divided into two categories, where the first one is using radio frequencies and the second one uses infrared signal [62]. The advantage of using this system is there is no need for wiring to be installed.

Data acquisition type that is commercially available is usually expensive, therefore there is a need to develop a specific data acquisition system which is cost-effective yet reliable.

2.4.5.2 Data Acquisition Units

Basically, different data acquisition system will be using different data acquisition units. Mostly in developing the PV monitoring system, they are using analog-to-digital converters (ADC) to convert the analog signal received from PV system to monitoring system. There are several terms that used in the data acquisition system that serve as the focal point in the system which shown in the Table 2.6.

Table 2.6: Type of data acquisition units

Type	Function
Analog-to-digital converter (ADC)	An electronic device that converts analog signals to an equivalent digital form.
Digital-to-Analog Converter (D/A)	An electronic component found in many data acquisition devices that convert the digital signal to analog signal.
Digital Input/output (DIO)	It refers to a type of data acquisition signal. Digital I/O is discrete signals which are either one of two states. These states may be on/off, high/low, 1/0 or 0/1.
Differential Input	Refers to the way a signal is wired to a data acquisition device. Differential inputs have a unique high and unique low connection for each channel. Data acquisition devices have either single-ended or differential inputs.
General Purpose Interface Bus (GPIS)	Synonymous with HPIB (for Hewlett-Packard), the standard bus used for controlling electronic instruments with a computer. Also called IEEE 488 in reference to defining ANSI/IEEE standards.
Resolution	The smallest signal increment that can be detected by a data acquisition system. Resolution can be expressed in bits, in proportions, or in percent of full scale.
RS232	A standard for serial communications found in many DAS. It is limited because it supports communication to one device connected to the bus at a time and it only supports transmission distances up to 50 feet.

RS485	A standard for serial communications found in many data acquisition systems. RS485 is not as popular as RS232, however, it is more flexible in that it supports communication to more than one device on the bus at a time and supports transmission distances of approximately 5,000 feet.

In PV monitoring system, there is an example of previous research work that is using ADC in the monitoring system which will be using in this project as well but in different approach. The next section will be explained more regarding the previous research work which used Data acquisition plug-in board in their system.

2.4.5.3 Implementation DAQ in PV Monitoring System

This section will be explained more on the example of previous project which are using one of DAQ System, Data acquisition Plug-In Boards in developed the PV monitoring system. Figure 2.14 is the DAQ Plug-In Boards which each of the components in this board has their own function. Each board installed in the computer is addressed at a unique Input/output map location. The I/O map in the computer provides the address locations the processor uses to gain access to the specific device as required by its program. For transmitting signal, the microcontroller will be connecting to the circuit to get the signal. Then by programming the board with the suitable code, the analog data will be converting into digital signal. The data collected by the microcontroller based DAQ and control unit are transmitted to a PC using an RS 485 serial connection in where the data are stored for displaying on the PC.

Figure 2.14: Data Acquisition Plug-in Boards

The connection for DAQ Plug-In board is made by installing the DAQ 6024E at the back of the PC. By using the special purpose shielded cable as shown in Figure 2.15, it can connect the I/O connector block to the DAQ card. Once the connection is made, there will be sub connection between the 68 pin assignments of I/O connectors. The input and output signal connections to the board are made by the I/O connector.

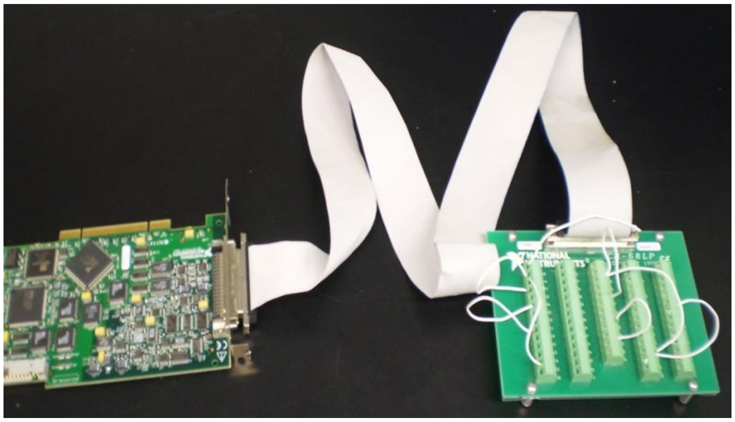

Figure 2.15: Connection between DAQ Boards with I/O Connector Block

The I/O connector for 6024E has 68 pins that you can connect to 68-pin accessories with the SH6868 shielded cable. Figure 2.16 shows the pin assignments for the 68-pin I/O connector on the 6024E.

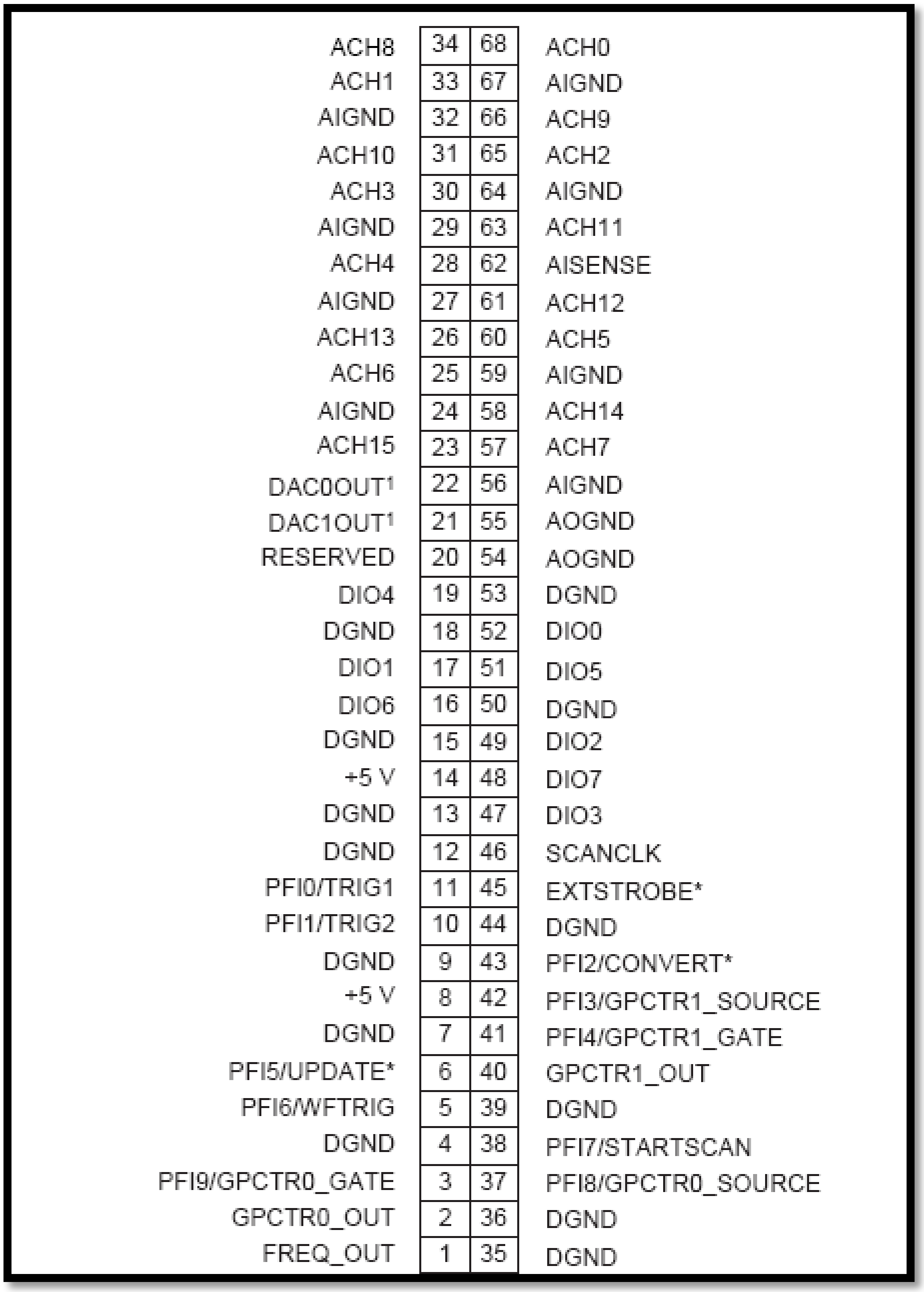

Figure 2.16: The Pin Assignments in I/O connectors.

The DAQ board is commercially used for transferring data in PV monitoring system but it is more expensive and it comes with the specific software in order to display the collected data in the computer. Therefore in this project, then main focus is to develop the low cost of DAQ which consists of PIC microcontroller and UART to USB converter. Refer Chapter 4 for more explanation regarding the DAQ system built for this project.

2.4.6 Transmission System

In building the complete DAQ system, there is a need for transmitting data to the computer. The data from PV system will be transferred to the computer to be monitored and saved for future used. Some of DAQ type required specific software in order to transmit the data. The DAQ Plug-In board comes together with Lab View software as complete DAQ system.

2.4.5.1 Lab View Software

Lab VIEW programs also known as the virtual Instrument, or VIs, as the appearance and operation same as the other physical instruments, such as oscilloscopes and millimeters. Every VI uses functions that manipulate input from the user interface or other sources and display that information or move it to other files or other computers . A VI contains the following three components:

a) Front panel –serves as the user interfaces.

b) Block diagram-contains the graphical source code of the VI that defines its functionality

c) Icon and connector panel – Identify the VI so that you can use the VI in another VI. A VI within another VI is called a subVI.

The connection between DAQ board and the Lab View software can be made by setting up a virtual channel. The Easy Counter VIs performs simple counting operations. Run these VIs from the front panel or use them as subVIs in basic applications. In addition, Easy Counter VIs automatically alerts if there any errors with a dialog box that will cause to stop the execution of the VI or to ignore the error.

Setting up the block diagram is important in running the Lab View Software. Figure 2.17 shows an example of block diagram for previous research work for PV monitoring. The analog input from the PV panel will be connecting to the *AI Config* which the functions is to configures an analog input operation for a specified set of channels. The channel that will be used is depends on the connection on the I/O connector block.The data from the *AI Config* will be sending to *AI Start* to starts a buffered analog input operation. This VI sets the scan rate, the number of scans to acquire, and the trigger conditions. Then it will be transfer to the *AI Read* so that it can reads data from a buffered data acquisition. The data will be displayed on the front panel as shown in Figure 2.18. From the front panel, data from PV system can be monitored to make sure that the system is in a good condition.

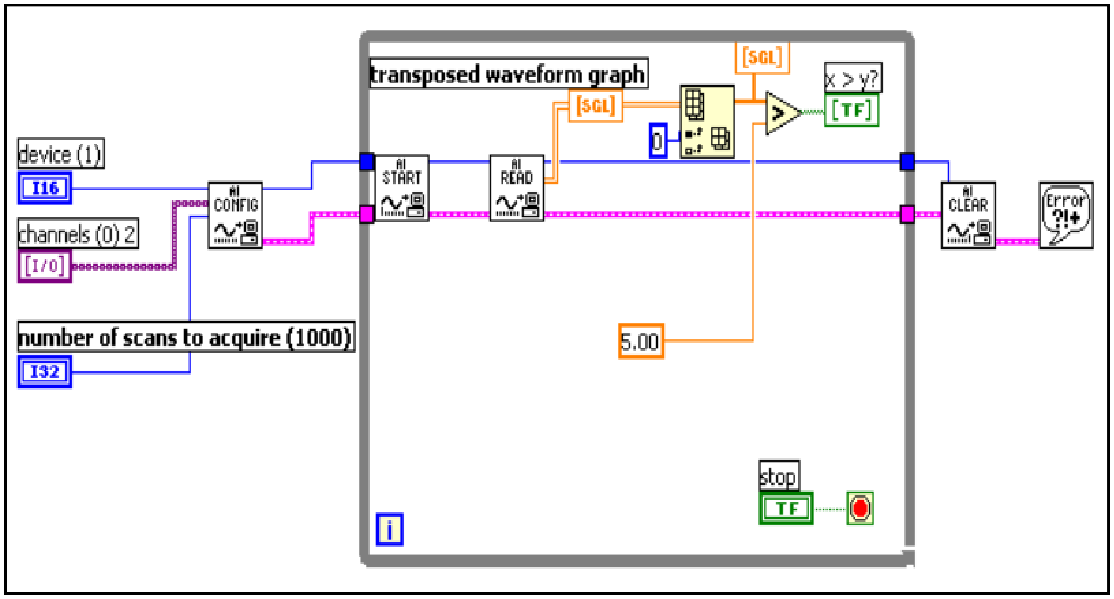

Figure 2.17: Block Diagram of Lab View Software

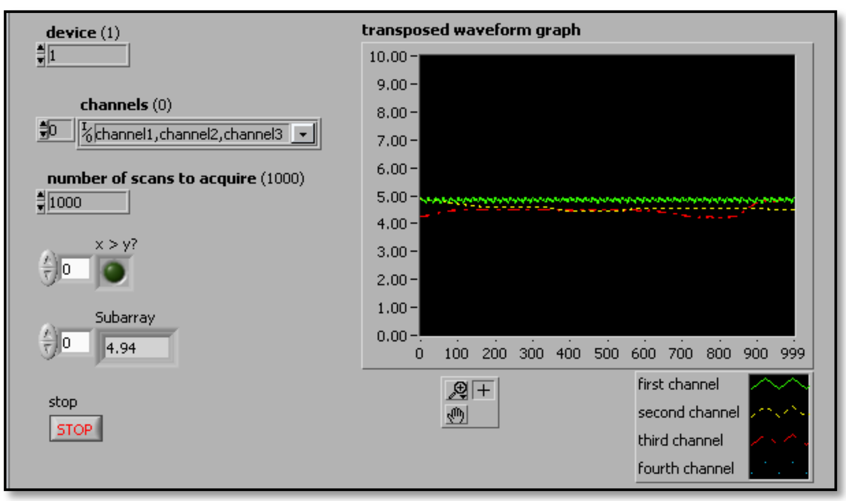

Figure 2.18: Front Panel of Lab View Software

The Lab View software is commercially used together with DAQ plug-in board. Therefore, the cost of using this software as part of PV monitoring system is much higher compare to the software used in this project. For this project, it used Visual Basic software for transmission data to display it on the computer. It is not required any specific DAQ to transmitting the data, hence reduce the cost. There is also software called RS232 communicator used for displaying data in the computer which will be discussed in the next section.

2.4.6.2 RS232 Communicator

The RS232 communicator is developed by using Embedded C, Visual Basic, PHP, Java Script and HTML. The RS232 communicator requires MAX 232 in order to interface data between PIC microcontroller and computer. In this previous research work, it shows that the system used PIC microcontroller and MAX 232 as part of the DAQ system. Figure 2.18 shows the block diagram of this project which includes RS232 as part of the system.

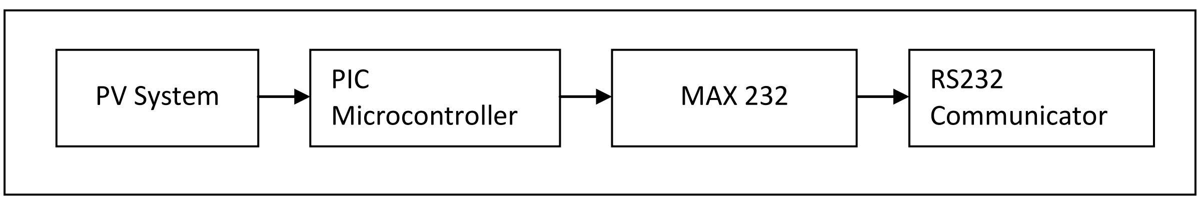

Figure 2.18: Block diagram of MAX232 and RS232 Communicator

MAX232 requires serial port connection in order to transmit data to RS232 communicator. Once the connection is established, the RS232 communicator file can be used to display data by pressing the connect button. The retrieved data will be displayed in the RS232 Communicator window as shown in the Figure 2.19. This software allowed the user to save the data for monitoring purpose. The stored data is saved in files with the extension **.csv** and can be manipulated to display data graphically as desired by users.

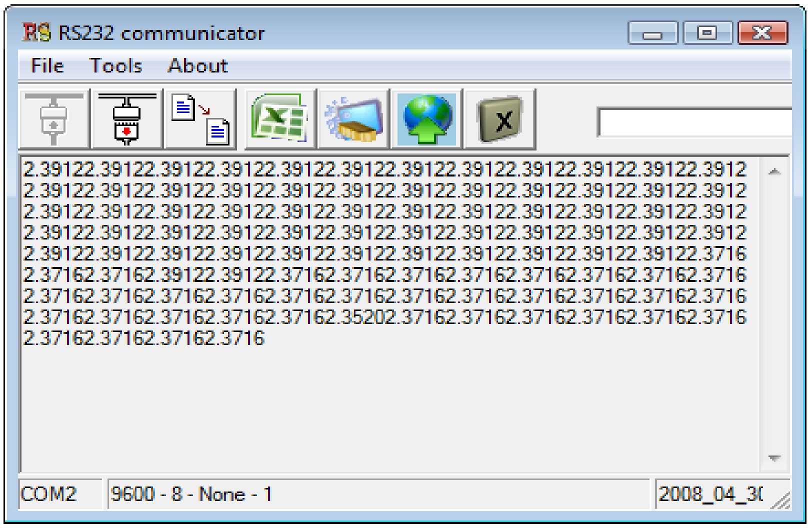

Figure 2.19: RS232 Communicator window

Same as Lab View software, the RS232 communicator also requires specific connection in order to retrieve data from the computer. It comes together with MAX232 as part of the connection and MAX232 required serial port connection in order to connect with the computer. In this project, instead of using MAX232 as part of the DAQ system, the UART to USB converter is used as it is more reliable and simple compare to the previous research work. Refer Chapter 4 for more explanation regarding the connection and advantage of using UART to USB converter.

2.5 Summary for Chapter 2

The background study on implementation of PVSEGS in Malaysia is described in this chapter. The comprehensive literature review study shows the importance of tilt angle and orientation of PV module for maximizing irradiation captured by PVSEGS. The concepts of PVSEGS have been explained in this chapter which consists of PV array, charge controller, battery, inverter and load. The functions and details about the PV monitoring system have also been outlined. Comparisons of previous research works on PV monitoring system were also presented. The literature review clearly shows the need for monitoring of PVSEGS for optimizing the PVSEGS system.

CHAPTER 3

METHODOLOGY

3.1 Overview

The chapter focuses on the research methodology of the project. The flow of the research work can be divided into four phases which are experimental work, design structure, prototyping and performance verification as shown in Figure 3.1. In experimental work *part*, investigations and studies on solar energy as the selected renewable energy sources for this project have been done to identify problems related to SEGS. Thus, experiments were carried out and it was found that the performance of solar electricity is not stable and there is need for a monitoring system. The research work continues with the design of a structure for PV monitoring system. The structure of PV monitoring system can be divided into three parts which are displaying data on the LCD, displaying data on the computer and displaying data on the Web based system. The designed structure was compared against a commercially available PV monitoring system.

The detailed description for PV monitoring system will be elaborated under prototyping section. The hardware and software used in developing the prototype are explained in this chapter. The process to develop the PV monitoring system starts with the development of data acquisition system, and the process continues with the transmission of data to the internet. The last part which is performance verification is divided into two parts which are the prototype testing and data analysis. The complete prototype was tested by monitoring the performance of SEGS. The prototype is verified by comparing the performance with the Fluke 43B power quality analyzer to gauge the reliability and accuracy of the developed system. The experiment setup for prototype testing is also discussed in this chapter. The result of the testing is analyzed by using the correlation analysis to determine the level of accuracy.

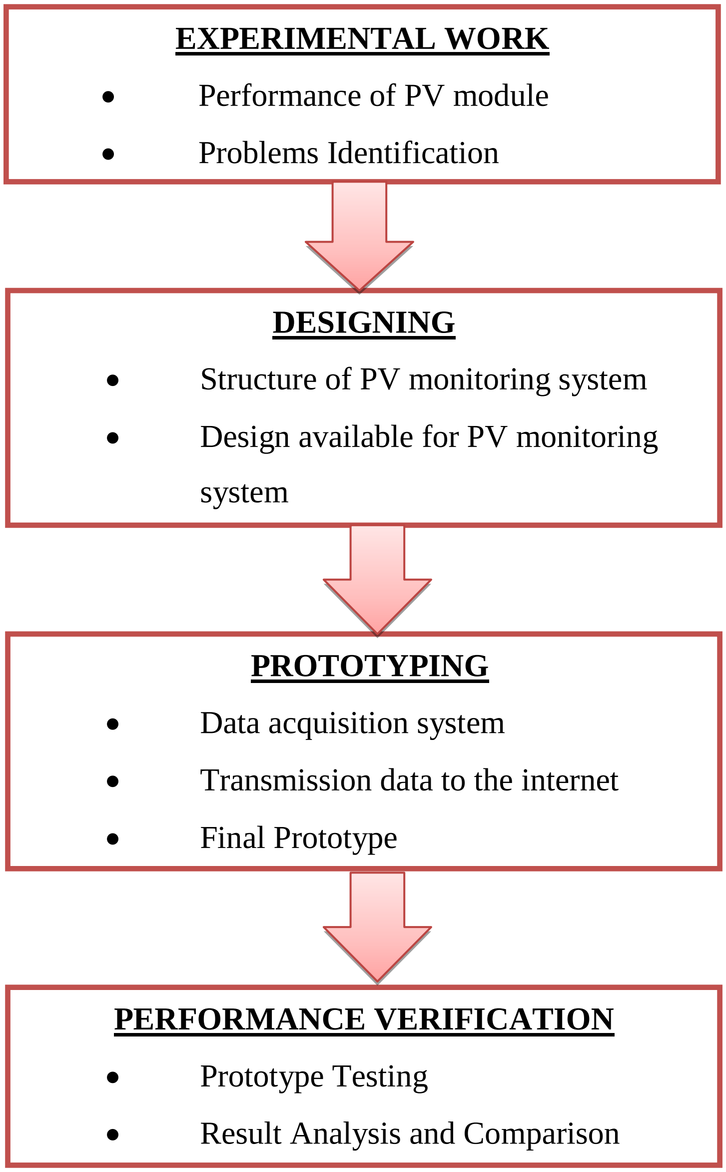

Figure 3.1: Flow Chart of Project Work

3.2 Experimental Work

The experiment part can be divided into two, where the first part is related to the performance of PV module under transient conditions and the second part was performed to investigate the performance of PV module under steady-state conditions. Data of the local meteorological conditions were investigated to learn the pattern of the solar irradiance since it is differ from one site to another. The effect of actual transient conditions on the PV module and steady-state were tested and analyzed. These experiments were conducted to investigate the difference between the PV module performance under controlled steady-state conditions with its performance when exposed to transient conditions. The result for both experiments will be discussed in Chapter 4.

3.2.1 PV Performance under Transient Conditions

It is important to consider the position of the sun, the weather condition, the tilt and orientation of panel and the efficiency of the panel when designing a solar energy related system. These factors can affect the stability of the electricity generated by using PVSEGS. The effects of the transient conditions on PV module performance were investigated by subjecting the PVSEGS to actual meteorological conditions.

The experiment was performed by using pyranometer to get the global solar irradiance data and the output of PV module was measured by using DAS. The open-circuit voltage and short-circuit current of the PV module was measured and logged by the sensors connected to the data acquisition system while the solar radiation data was acquired by using irradiance data logger, known as combilog. The measured data was analyzed to study the behavior of solar energy related system. The experiment setup is shown in Figure 3.2.

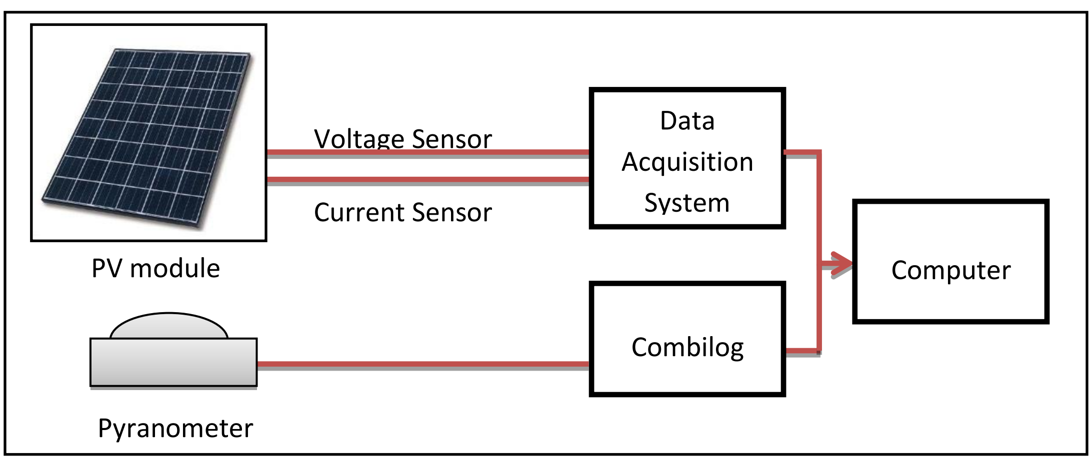

Figure 3.2: Experiment setup for PV performance on transient conditions

3.2.2 Performance of PV Module under Steady-State Conditions

Previous experiment shows that the performance of PV is not sustainable due to meteorological conditions, dust, clouds, shading and also high temperature. This experiment is conducted in order to observe the steady-state temperature and shading effect on PV performance. The experiment was held in the solar lab by using the solar simulator. The solar simulator uses a 2500 W Xenon arc lamp to simulate natural sunlight for accurate and repeatable indoor testing of the PV module. The light source is capable of producing irradiance up to 1000 W/m^2. In this experiment, the solar simulator was set to provide irradiance of 1000 W/m^2 and the irradiance level was verified by using the pyranometer. The experiments were divided into two parts, where the first one was conducted to observe the temperature effect and the second one is to observe the shading effect on PV module. In the first part, for temperature effect testing, the temperature is varied between 50ºC and 75ºC. The PV module is connected to the voltage sensor and current sensor for measurement of open-circuit voltage and short-circuits current. The experiment setup for temperature effect setting is described in Figure 3.3

In the second part, the experiment was performed to investigate the effect of shading on the PV module performance. The PV module was placed under solar simulator and the condition for shading was applied by using a translucent paper. The shading effect was divided into two conditions which are no shading and half shading. The PV was connected with voltage sensor and current sensor for open-circuit voltage and short-circuits current measurement.

The sensors for parameter measurement from both parts were connected to the DAS. The DAS is used to read the data and convert it to suitable form to be displayed on the PC. The software was used to capture data for analysis purposes. The result of the experiment shows that the temperature and shading can affect the performance of SEGS. Therefore a monitoring system needs to be integrated with PV system to make sure that there is no supply disruption which will caused interruptions of electricity power supply to the load. The analysis of the data captured in this experiment will be discussed in section 5.2.2.

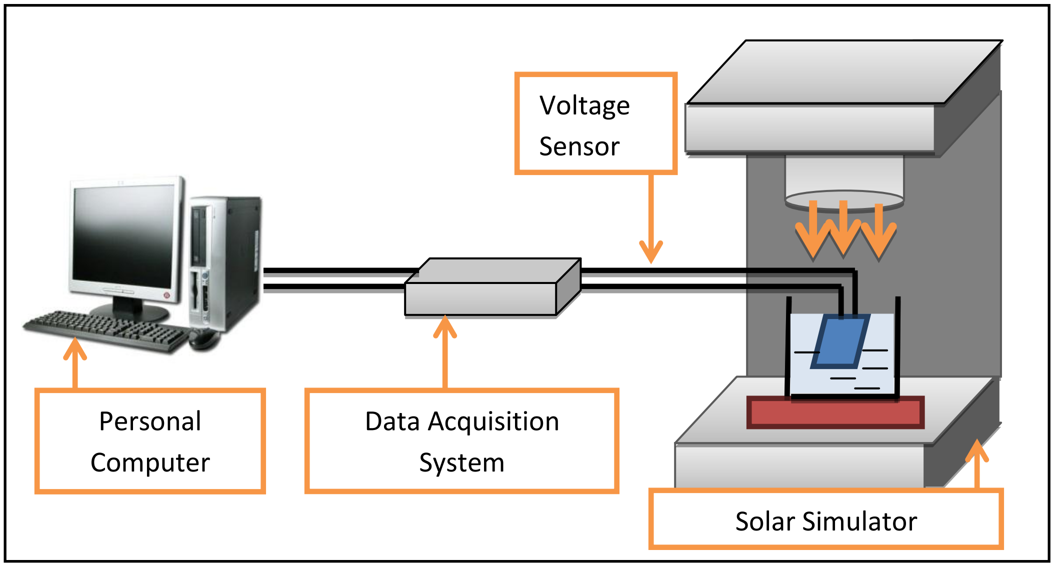

Figure 3.3: Experiment setup for temperature effect testing

3.3 Designing

The PVSEGS need to be integrated with a monitoring system to ensure that it is operating at optimum level. In this section, the first part involves the structure of PV monitoring system developed and the second part will provide some discussions on the availability of the latest PV monitoring system design.

3.3.1 Structure of PV monitoring system

The structure of the PVSEGS that interfaces with the monitoring system was designed according to the server-client architecture approach. The server – client architecture requires that all devices that need to be monitored, to be connected to one server measurement station that operates as a server. The acquired data from the measurement station will be available through a network. In this project, all the devices in PVSEGS will be connected to the developed monitoring system and measured data can be used by multiple users. The data can be remotely monitored via internet. The structure of the PV monitoring system is divided into three main parts. The first part is aimed to display the required data on the LCD display, the second part is to display and save the data on the computer while the last part is to display the data on the web based system. Each part uses different approaches and the specific details for software and hardware used will be explained in prototyping section. Figure 3.4 shows the structure for PV monitoring system.

Figure 3.4: The structure of the PV monitoring system

3.3.2 Design available for PV Monitoring System

In determining the best design to implement the monitoring system, research was carried out on commercially available system. Figure 3.5 shows the design available for PV monitoring system. Malaysia's main electricity supplier, TNB, has installed Supervisory Control Data Acquisition System, SCADA/DA programmed in the transmission network in stages from 1998 to 2004 [1]. SCADA is a system that can monitor and control the processes in a particular station. The focus of this project is on domestic sector where the SCADA system is found to be incompatible as it is designed to be used for industrial purposes. In residential area, small scale monitoring system is sufficient as the number of devices to be monitored is lesser as compared to the industrial sector.

DAQ board 6024E integrated with Lab View software is a monitoring system that can used in residential area. The connection of DAQ board 6024E involves signal connection to I/O connecter block and can receive up to 15 channel of analog input. The cost for implementing the system is quite high because it is bundled together with the specific software.

Microcontroller can be used as the basic structure for monitoring system because it has programmable I/O peripherals. The capability of saving information has made the microcontroller compatible as it has its own programmable memory. The microcontroller requires the serial communication to transfer the data to the computer. There are two options available for serial communication connection in microcontroller. The first option is by using MAX 232, a dual driver/receiver that functions to convert signal voltage level and adapt the RS-232 signal voltage levels to Transistor-Transistor Logic (TTL) logic. MAX232 requires the use of a serial port connection that must be integrated together with RS232 communicator software, in order to display the data via computer. There is another way to connect between MAX232 without using the serial port connector which is through USB to serial converter, but this requires more connection to be established.

The other option available for serial communication is Universal Asynchronous Receiver Transmitter (UART) to USB converter together with VB software which is the most suitable design for this monitoring system. This method is more reliable as USB port in computer is commonly used as compared to serial port and it is direct connection from microcontroller to the computer. More explanation regarding the design will be discussed in Chapter 4.

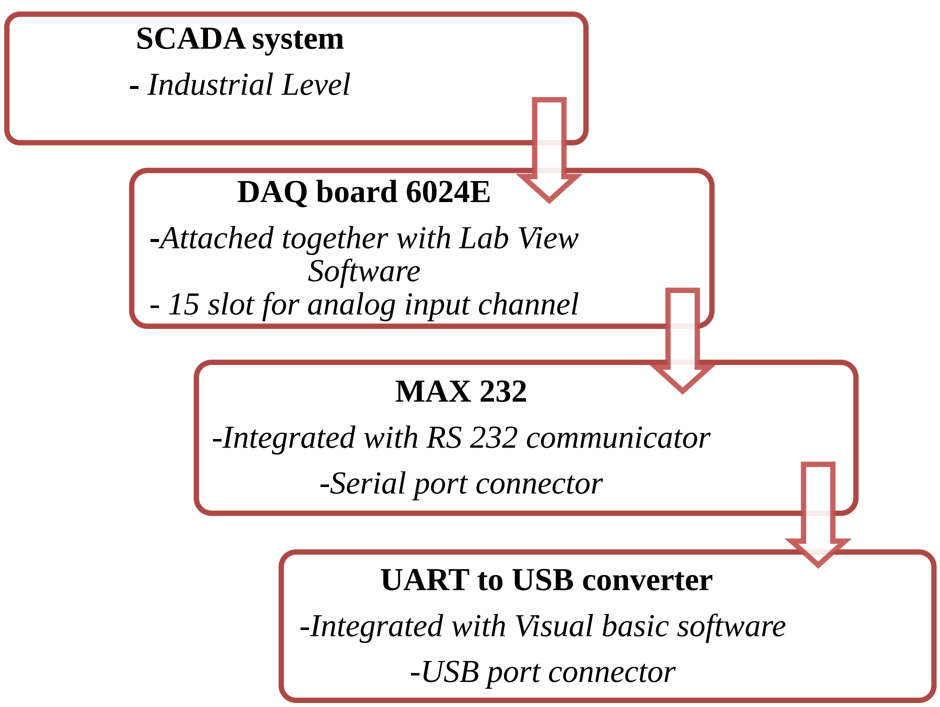

Figure 3.5: Design available in PV monitoring system

3.4 Prototyping

The prototyping section will provide detail discussion for each part of monitoring system. Two of the categories which are displaying data on LCD display and displaying data on the computer will be covered under the DAS part. For displaying data on web based system, the process will be elaborated under data transmission to the internet. The block diagram of the project will be explained under the final prototype part.

3.4.1 Data Acquisition System

The first part of the design of monitoring system design is to be able to display the readings on LCD. In DAS, the PIC 16F877 microcontroller is used for analog digital conversion from PV panel. In order to convert the input into a sensible readable data, a program was written and stored in microcontroller using C Programming software. The source codes of this programme can be viewed in Appendix B. The general configuration for PIC microcontroller involves reset button, oscillator, analog inputs, on/off switch and LCD display. More explanation regarding the connection of PIC16F877 will be discussed in Chapter 4. The second part is to display the data on local PC for data logging and recording purposes. The serial communication interface used for the handshaking process of the computer and the microcontroller is UART to USB converter. The USB to UART converter can offer direct interface between computer and microcontroller using low voltage supply from USB port. In this part, VB Software was installed and programmed in order to retrieve data and store the data before being analyzed. The results can be displayed in a table form and the data is saved as a spreadsheet.

3.4.2 Transmission Data to the Internet

The advantage of this system is that the data is allowed to be monitored remotely, as real-time values, via Internet. This completes the third part of the PV monitoring system which will allow data to be displayed on Web-based system. The software called Apache HTTP Server 2.2.15 is used in this project to retrieve data from the internet. The configuration setting must be done first and then the connection process can be started. In order to view the saved data, the IP address of the main computer with additional link of the subfolder will be required.

3.4.3 Final Prototype

Overall connection for the PV monitoring system structure including the hardware and software is as shown in Figure 3.6. The complete process of data transmission and data collection for monitoring purposes is given in this section. The process starts from the PV panel and it is divided into two channels. The first channel is connected to a charge controller which functions to charge battery during the day and supplies power to the household appliances at night in absence of the sun. The second channel is connected to the PV panel. The PV panel will send the data to the microcontroller to be displayed on the LCD and at the same time the data will be transferred through the UART to USB converter to be displayed on computer. The recorded data will be stored in the computer's hard disk and also in database on the developed website. The complete circuit for monitoring system device is implemented on a PCB board that was designed by using Eagle software. The schematic diagram of the circuit is as shown in Appendix B.

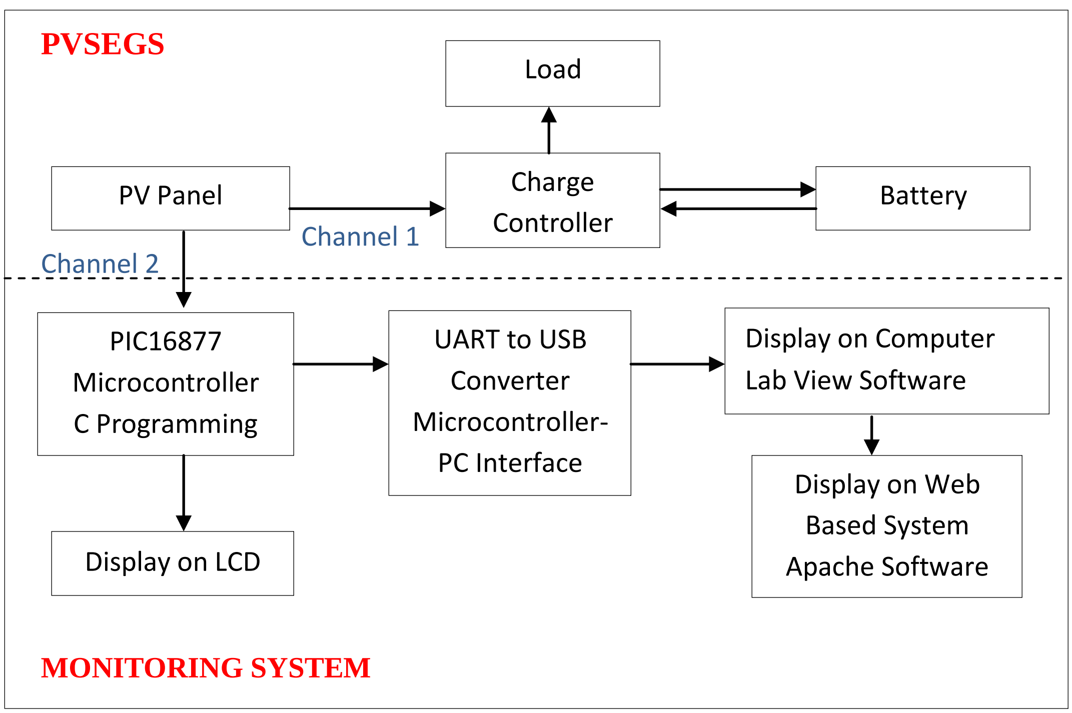

Figure 3.6: Block diagram of the project

3.5 Performace Verification

The performance verification is aimed to ensure that the developed monitoring system can function properly and it is reliable for measurement. The prototype is tested and the performance of the prototype is validated.

3.5.1 Prototype Testing

The prototype is tested against Fluke 43B Power Quality Analyzer (Fluke 43B). The Fluke 43B acts like multimeter and has the ability to record data. The Fluke 43B can be used for measurement of voltage, current, frequency, and power harmonics. Only two ports are available for measuring data although it consists of nine different functions. One ports are connected to voltage probe to measure voltage while the other port is connected to current probe to measure current. In order to do prototype testing, the sag and swells mode were used. The sag and swell functions are used for measuring short duration variations of voltage and current, and the graph of voltage and current will be plotted against time. The recorded time and plot interval is set before measurements are made. Figure 3.7 shows the connection of the developed DAS and the Fluke 43B for prototype testing.

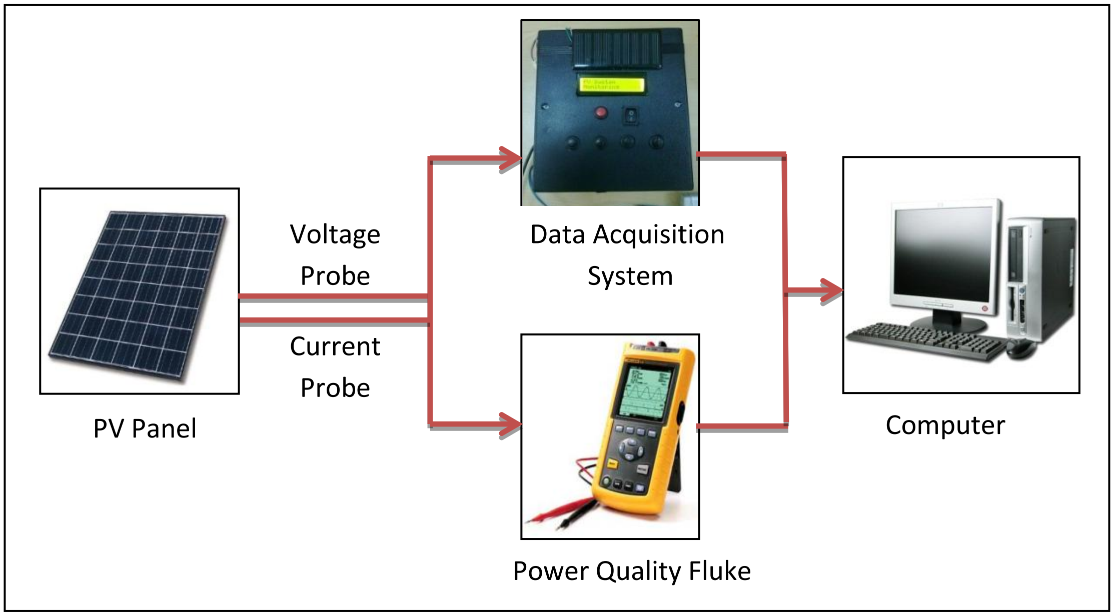

Figure 3.7: Experiment setup for prototype testing

Referring to the experiment setup as shown in Figure 3.7, all the parameters to be measured from the PV panel are connected to the voltage probe and current probe for open-circuit voltage and short-circuit current measurement. The DAS developed and Fluke 43B will measure the parameters by using the probe and sent the data to the computer. The computer is used for displaying the result and data is stored for analysis purposes.

3.5.2 Data Analysis and Comparison

The data captured using the monitoring system developed was compared with data captured by power quality analyzer device Fluke 43B. By using the correlation coefficient for data comparison, the accuracy of the developed system can be determined. The correlation coefficient indicates the strength and direction of linear relationship between two variables. A correlation of +1.00 shows good correlation which means that two variables move in the same direction at all times [63, 64]. The formula used to calculate the correlation coefficient is described in Equation 3.1 while the result for data comparison by using correlation analysis is discussed in Chapter 4.

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N})(\sum Y^2 - \frac{(\sum Y)^2}{N})}} \tag{3.1}$$

where ,

r = correlation coefficient

N = Number of values or elements

X = First Variable

Y = Second Variable

2.5 Summary for Chapter 3

The methodology used in this research work was elaborated in this chapter. The flow of the project comprises four phases which are experimentation, designing, prototyping and performance verification. Experimentation involved the performance of PV module and problem identification to show the importance of this project. The designing of the project is focusing more on finding the suitable design for PV monitoring system. A prototype was designed which consist of three important part which are displaying data on LCD, data acquisition system and transmission data to the internet. The prototype was tested and analyzed to verify the performance. The experiment result will be discussed in chapter 5.

CHAPTER 4

DEVELOPMENT OF PV MONITORING SYSTEM

4.1 Overview

The complete design, details of each components and software used in developing the monitoring system are discussed in this chapter. The process flow of developing the PV monitoring system and the relevant sections is shown in Figure 4.1

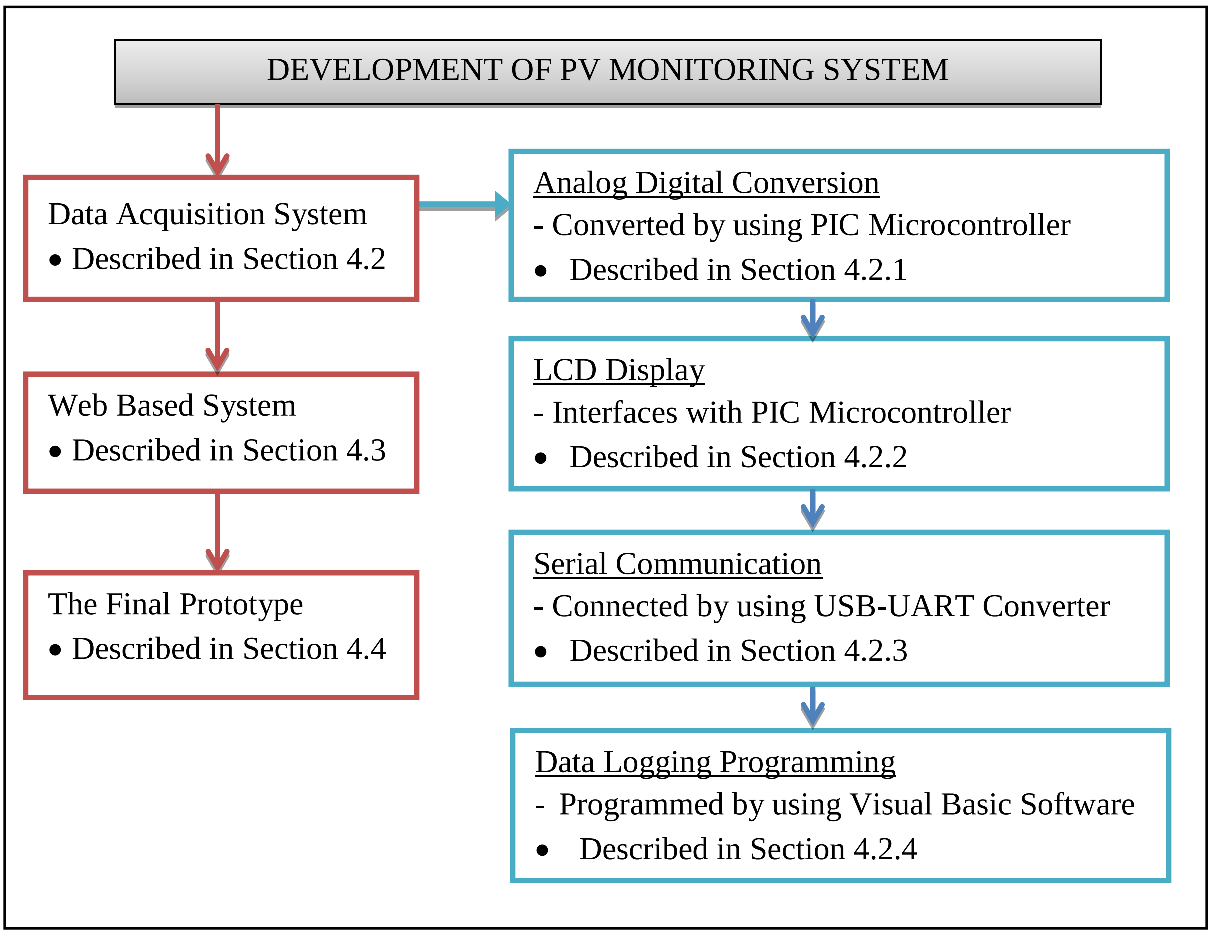

Figure 4.1 Process flow of PV monitoring system development

This chapter is divided into three sections, which are the description of DAS, the development of web based system and the final prototype. The DAS section consists of analog digital conversion, display of data, serial communication and data logging programming. The transmission of data from the monitoring device to the internet will be explained under the development of web based system section and the complete design of prototype is discussed in the last section.

4.2 Data Acquisition System Design

In designing PV based monitoring system, it requires the use of DAS to convert the data into the suitable form so that it can be monitored by the PC. The DAS consists of hardware and software that enable the supervision of local and remote systems. Data can be accessed, converted to desired form and information processed can be distributed for monitoring purposes [65]. The DAS used in this project is illustrated in the block diagram as shown in the Figure 4.2.

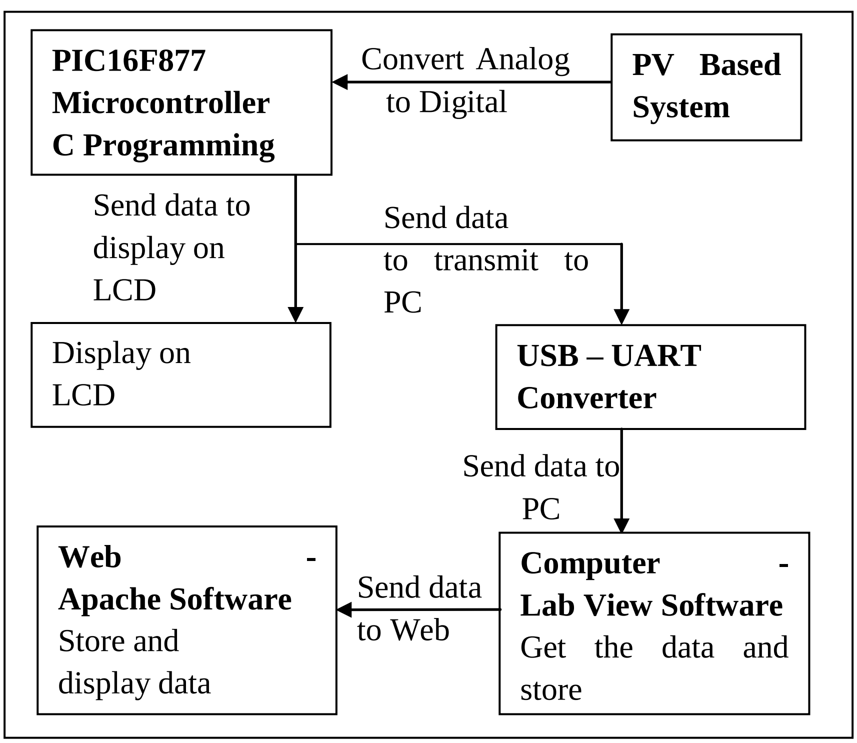

Figure 4.2: Block diagram of data acquisition system

The output from PV based system is converted to digital signal by using PIC16F877 microcontroller. The programme code used for analog digital conversion is written in C programming. The data retrieved can be displayed using LCD monitor for verification purposes, while the input to the computer will allow continuous monitoring of the system. The data can be captured and stored on the hard disk, so that it can be retrieved later, if necessary. The interface between the PIC and PC is achieved by using UART-USB converter. In order to capture and store data, VB software was used. The data captured via this software is automatically stored and displayed as real time values on a local PC or can be viewed over the Internet, by using a web-based system. The Apache software is used to display data via web-based system.

4.2.1 Analog Digital Conversion Configuration

In DAS, the data loggers or microcontrollers are used for measuring and receiving signals before transmitting the data to computer [56]. The microcontroller selected for this project is PIC16F877, which has the built-in ADC.

4.2.1.1 The Specification of PIC16F877

There are varieties of microcontrollers such as the 8-bit processors, 16-bit processors and 32-bit processors that can be used for ADC. The difference are in terms of the performance level, the cost and the size of memory chips which includes RAM, EEPROM and flash memory [66]. The 8-bit processors have limited RAM which tend to provide lower speed if compared to 16-bit processor and 32-bit processor. In terms of the cost, 16- bit processor is the cheapest and 32-bit processor is relatively expensive as it provides more addressable memory. The 16-bit microcontroller is suitable for this project as it has high performance level that is needed for high language programming. The specification of PIC16F877 includes 368 bytes of RAM space, 256 bytes of EEPROM and program flash up to 8k bytes. The pin diagram of PIC 16F877 is as shown in Figure 4.3.

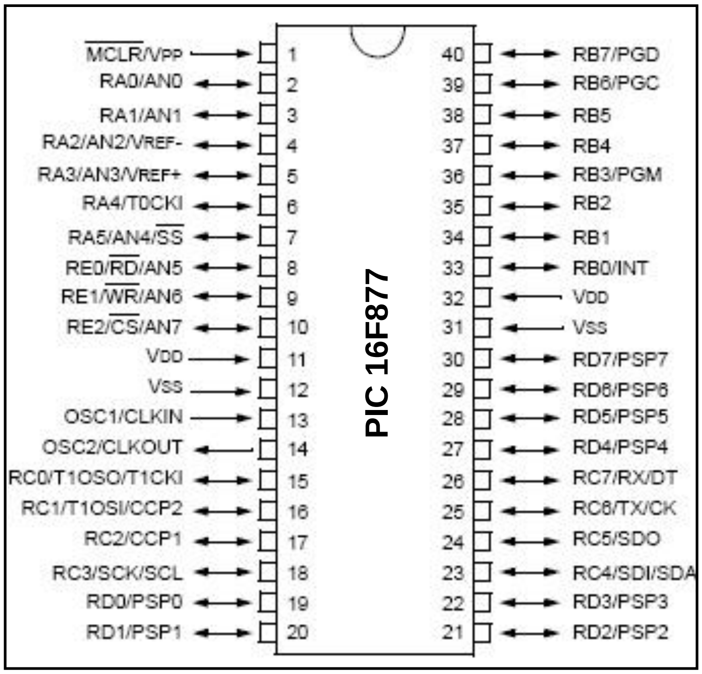

Figure 4.3: Pin diagram of PIC16F877

The general configuration for PIC16F877 involves the connection of the voltage supply, ground, reset and oscillator. The DC voltage supply and ground as shown in Figure 4.3 are represent by VDD and VSS. Microcontroller is reset by utilizing the simple circuit to pin 1 as shown in Figure 4.4.

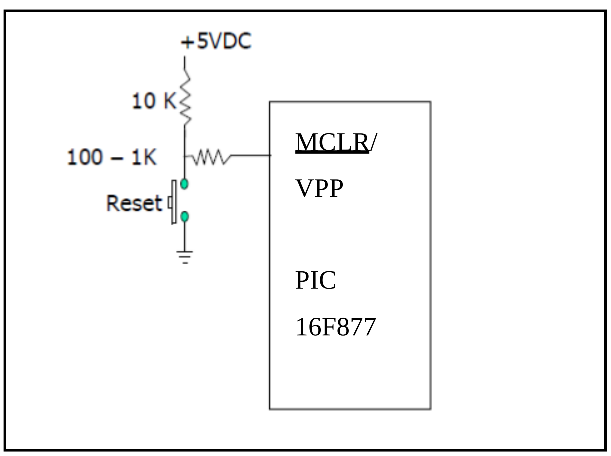

Figure 4.4: Reset circuit diagram for PIC16F877

Pin 13 and 14, OSC1 and OSC2 are representing the connections to the oscillator. The oscillator provides clock signal that is required for timing calculations. If microcontroller executes one instruction in four cycles, the oscillator will provide clock input to OCS1 which is divided into 4 clock quadrature at the same time to ensure that it is synchronous with internal digit circuit. The most common oscillator used is crystal and ceramic, known to provide more accurate clock. Usually the oscillator clock can have 2 pins or 4 pins. For this project, 4 pins oscillator clock is used and the connection is shown in Figure 4.5.

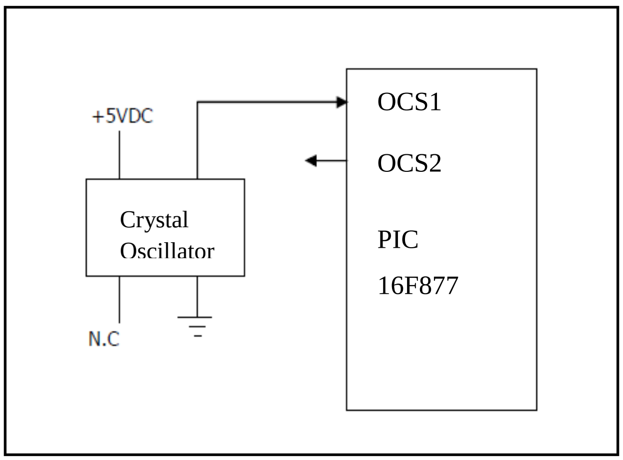

Figure 4.5: Oscillator circuit diagram for PIC 16F877

The other ports of PIC16F877 are arranged into five I/O ports which are listed in Table 4.1. The conversion of signal from analog to digital is assigned to port A and port E while port B and port C are used for the switch connection, the serial communication and for output to be displayed on LCD.

Table 4.1: I/0 ports of PIC16F877

Port Type	Specifications
Port A	• RA0 – RA5 (Digital Input / Output) • Analog to Digital Converter
Port B	• RB0 – RB7 (Digital Input / Output) • Associated to programming and interrupts
Port C	• RC0 – RC7 (Digital Input / Output) • Serial communication (USART/I2C/SPI) • Timer functions
Port D	• RD0 – RD8 • Parallel data transfer (PSP)
Port E	• RE0 – RE2 • Analog to Digital Conversion • PSP control bits

4.2.1.2 Programming Code for Analog Input

The input range of ADC for PIC16F877 refers to high and low voltage references. The high and low voltage references of microcontroller are DC supply and ground state. In order to get an accurate conversion, the analog input must be within the input range of the converter, otherwise the value of conversion will not be accurate.

Referring to the Figure 4.3, PIC 16F877 has a total of 8 analog inputs, represented by AN0 to AN7. All of the analog input is grouped under port A and port E. The programming codes for setting up the analog input are shown in Table 4.2. In order to setup all the ADC ports to analog input, the programme code in the C programming should be written as Programming (4.1). If there is only certain port of analog input required to be assigned, the code can be programmed as Programming (4.2) whereas only four ports, AN0, AN1, AN3 and AN4 are setup for the analog input. In order to read the value for a specific port, the programme code is shown as Programming (4.3) where 0 represents port AN0. Once the port has been assigned and setup correctly, the next step is to read the digital value from ADC. The programme code is written as Programming

(4.4) where *adcValue* is a variable that has to be declared first before being used. Since *read-adc( )* functions returns data in *int16* form, therefore the *adcValue* data has to be declared correctly with *int16* before assigning the port as mentioned in Programming (4.1) and (4.2) . The code for declaring the *int16* is described as Programming (4.5). The *read_adc( )*functions to return data either in 8-bit converter, 10-bit converter or 12-bit converter depending on the ADC setting. Therefore, the *read_adc( )* need to be mentioned earlier in the C programming code. The programming code is described as Programming (4.6) where in this project, 10-bit converter is used in PIC16F877.

Table 4.2: Programming code for analog input setup

Descriptions	Programming Code
Setup ADC port to analog input	*setup_adc_ports(ALL_ANALOG);* (4.1) *setup_adc_ports(AN0_AN1_AN3_AN4);* (4.2)
Assign port to read ADC value	*set_adc_channel(0);* (4.3)
Read value from ADC	*adcValue = read_adc( );* (4.4)
Declare function with int16	*unsigned int16 adcValue1*; (4.5)
Mention setting for ADC	*#device ADC = 10* (4.6)
Example of interpretation data	PVVoltage1 = (5.099 * *adcValue1*) /1023 (4.7)

The resolution of ADC input voltage ranges and output digital ranges can be varied between 8 bits, 10 bits and 12 bits. The resolution refers to the number of possible output states to represent the analog input. An 8-bit converter will have 255 maximum output states, a 10-bit converter will have 1023 maximum output states and 12-bit converter will have 4095 maximum output states. The equation for determining the possible output states are given as Equation (4.1) where n is number of bits.

$$V_{resolution} = \frac{V_{fullscale}}{2_n - 1} \qquad (4.1)$$

In order to interpret data, the *read_adc* function will read data from 0-1023, as shown in Table 4.3. Then, the data need to be converted back to the analog value, by multiplying with reference voltage (5.099) and dividing by 1023 [67]. In this project, PV voltage data was assigned in port AN0 and in order to get result of the PV voltage, the *read_adc* function is mentioned first, and then the programming code is written as Programming (4.7) where *adcValue1* is the value of PV voltage after ADC has read the data through *read_adc* function. After being scaled back, the *PVVoltage* 1 is the final value of PV voltage and the data will be displayed on the LCD.

Table 4.3: Value of *read_adc* for 10-bit converter

Analog Voltage (Decimal)	Digital Representation (Binary)	Value of *read_adc ( )* (Decimal)
0	0000 0000 0000 0000	0
0.0049	0000 0000 0000 0001	1
0.0098	0000 0000 0000 0010	2
0.0147	0000 0000 0000 0011	3
0.0196	0000 0000 0000 0100	4
0.0244	0000 0000 0000 0101	5
2.4438	0000 0001 1111 0100	500
2.4487	0000 0001 1111 0101	501
4.9902	0000 0011 1111 1101	1021
4.9951	0000 0011 1111 1110	1022
5.0000	0000 0011 1111 1111	1023

There is a need to add the delay function in the programming code for analog input data reading. The delay function is required to charge the capacitor on the input channel. The delay function determines the interval time of data reading. The programming for the delay function is given in Appendix C.

4.2.2 LCD Display

The microcontroller interfaces with the LCD display to show the status after ADC process. The LCD receives a feedback from the output of the power circuit and displays the data in two lines with a maximum of 16 characters on each line [68]. There is one port reserved for interfacing the LCD and microcontroller which is port B. The port need to be initialized first as an output port by setting the direction register, TRISB [67]. In order to set port B pin as an output, the TRISB bit must be set to zero. If TRISB bit is set to 1, it will set port B as the input port. Along the LCD display, there are 16 pins to enable the connection between LCD display and PIC microcontroller. The function of each pin assignment is listed in Table 4.4. The important pins that have been used are the voltage supply pin (Vdd), the ground pin (Vss), the contrast pin (Vo) and the busline pins (DB0-DB7). The data is presented to the display inputs by microcontroller and latched in by pulsing the enable input (E). The Read/Write (RW) is tied low, assigned to write mode as the LCD is only receiving data from microcontroller [69]. The connection of microcontroller and LCD display is shown in Appendix B.

The LCD display need to be declared first, at the beginning of the programming process, so that the output data can be displayed later. The code to mention the driver for LCD display is *"#include <lcd.c>".* The appearance on the LCD can be arranged according to the input value where there are four push button switches involved. The push button switches are basically assigned to control the data that will be appear on the LCD display. The four switches are connected with port C (RC2 and RC3) and port D (RD0 and RD1). RC2 is assigned for displaying value of PV voltage, RC3 is assigned to display value of PV current, and RD0 is assigned for displaying battery voltage value while RD1 is assigned for data logging. For this project, if there is no push button switch pressed, the general output display that will be appear on monitoring device is "PV System Monitoring", "Btn1:PV Voltage", "Btn2:PV Current","Btn3:Battery","Btn4:Data log". The programming code for general output display is given in Appendix C.

If one of the switches is pressed, the general display will be replaced with the assigned output display. In this case, if switch 1 is pressed, the value of PV voltage will appear on the LCD display. The example of the programming code for output display if switch 1 is pressed is given as Appendix C.

Table 4.4: Pin assignment for LCD 16X2

Pin No	Symbol	Function
1	Vss	GND
2	Vdd	+3V or +5V
3	Vo	Contrast Adjustment
4	RS	H/L Registered Select Signal
5	$R/\overline{W}$	H/L Read/Write Signal
6	E	H → L Enable Signal
7	DB0	H/L Data Bus Line
8	DB1	H/L Data Bus Line
9	DB2	H/L Data Bus Line
10	DB3	H/L Data Bus Line
11	DB4	H/L Data Bus Line
12	DB5	H/L Data Bus Line
13	DB6	H/L Data Bus Line
14	DB7	H/L Data Bus Line
15	A/Vee	+4.2V for LED/Negative Voltage Output
16	K	Power Supply for Backlight

4.2.3 Serial Communication

The common way to communicate between a microcontroller and computer is through serial communications. It is more reliable has lower cost, as compared to the parallel communication approach. This is because fewer conductors will be used in the serial communication system. The basic idea for serial communication is to load parallel data into shift register and then shift it out to produce a stream of serial data. The next step is to convert the serial data stream to a specific format such as RS232 and transmit it on a communication link. RS323 refers to a series of standards for serial binary data communication between data terminal equipment and data circuit-terminating equipment. There are two types of serial data communications for PIC, which are the synchronous communication and asynchronous communication. The synchronous communication requires common clock signal in order for two devices to communicate while asynchronous communication do not require common clock signal.

In PIC16F877, the UART is utilized for asynchronous serial communication. The UART implementation usually consists of two devices, which are the transmitter and the receiver. The most common protocol used for asynchronous communication in microcontroller is the RS232. In order to transmit data from microcontroller to computer, the serial port connector for port DB9 is used together with the MAX232. There is another way to connect MAX232 without using the serial port connector which is through USB to serial port converter. This method is more reliable as USB port in computer is commonly used if compared to serial port. However, in this project instead of using MAX232 and the converter/connector for interfacing between the computer and microcontroller, the connection is established through USB to UART converter. The progress made in the project for connection between microcontroller and computer is as shown in Figure 4.6. Figure 4.7 shows the components installed in the USB-UART converter and the description of each component is discussed in Table 4.5.

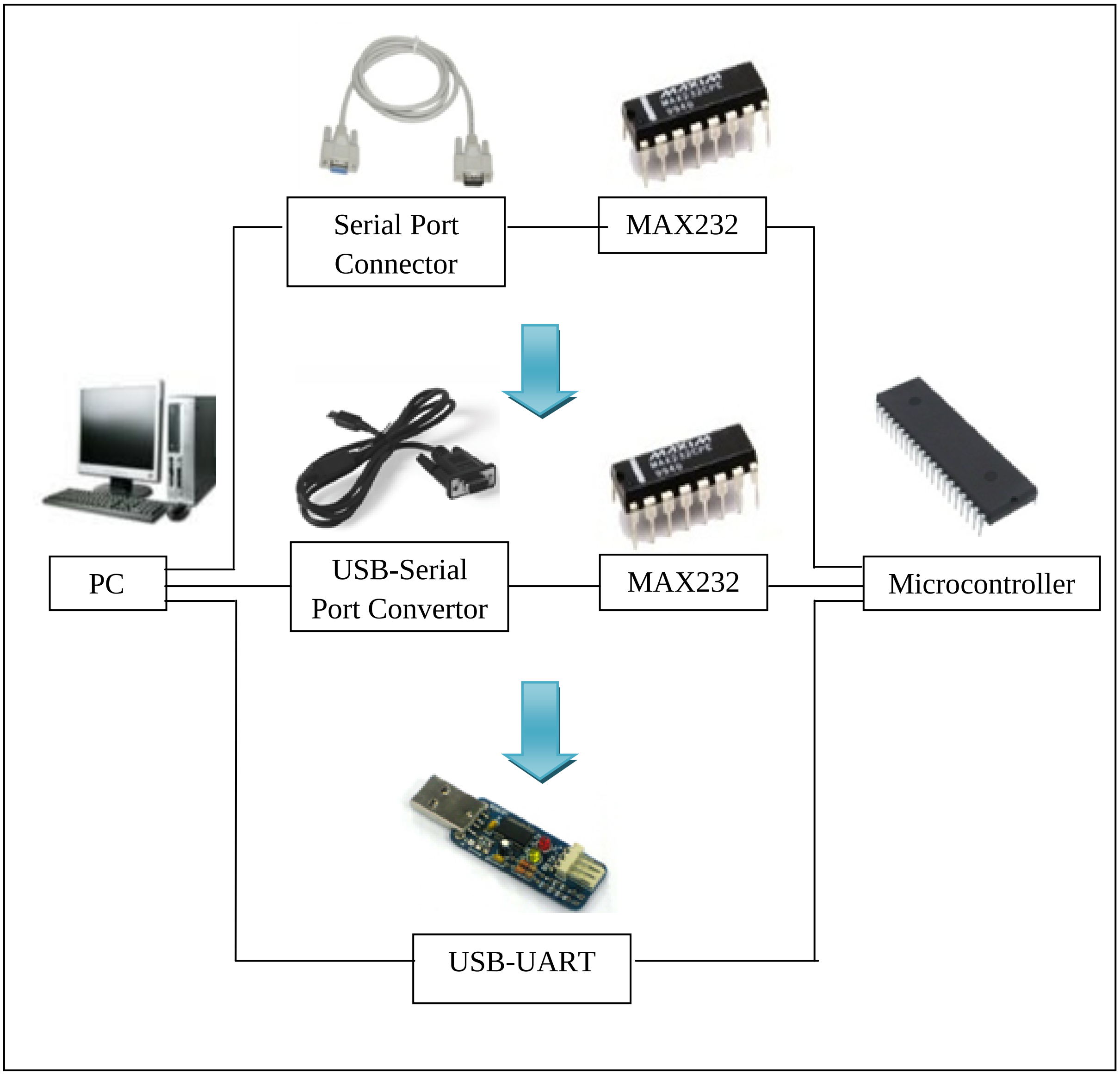

Figure 4.6: Connection between microcontroller and computer[70]

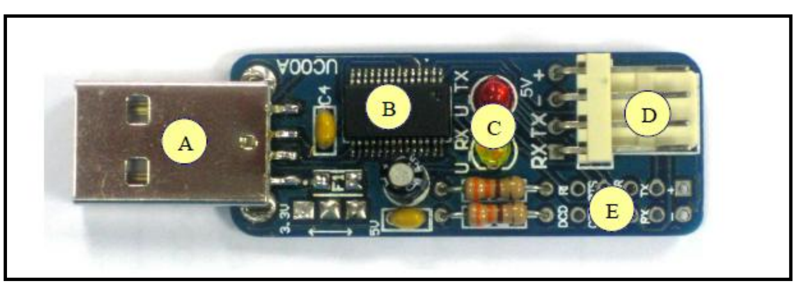

Figure 4.7: USB-UART Converter

Table 4.5: Description of USB-UART components

Label	Functions
A	USB connection type (male)
B	USB to UART converter chip
C	Two LED indicators for USB's transmitter and receiver status
D	4 ways header pin for interface to microcontroller
E	2x5 extension pad for extra COM Port Feature

In PIC16F877, for the hardware based RS232 port, the connection of USB to UART converter is through port C which consists of ports RC6 and RC7. Port RC6 is for transmitter connection (TX) while port RC7 is for receiver connection (RX). The TX pin and RX pin of USB to UART converter requires two more pins, which are the 5V and ground connections.

The RS232 also need to be initialized first before it can transmit data through the serial communication channel. In order to initialize the RS232 port, there are other options that should be considered including the stream, bits, parity, baud and xmit. The description of each option is described in Table 4.6. Once the options are determined, the programming code to define RS232 port can be written as "#USE RS232 (baud = 9600, parity = N, xmit = PIN_C6, rcv = PIN_C7, stream = stream_1, bits = 8) ".

Table 4.6: Description of RS232 Port Options

Option Format	Description
Baud = x	Set baud rate to x
XMIT = pin*	Set transmit pin as pin*
RCV = pin*	Set receive pin as pin*
PARITY = x	Set parity to none (x=N), even (x=E), or odd(x=0)
BITS = x	Set data bits to x
STREAM = stream_name	Associates a stream identifier to this RS232 port. The identifier may be used with functions such as *fputc( )*

4.2.4 Data Logging Programming

The programming is done by using VB software, so that the real-time data from PIC 16F877 to be displayed on the computer can be captured. The data will be displayed on the VB interface window and is updated every second. The programme is designed to save the data automatically after 15 minutes interval recording for monitoring purposes. The time interval can be changed, to be more than or less than 15 minutes. The stored data can be retrieved by using spreadsheet software. There are three main sections in the VB programming, which are the blank form, the project and the properties. The blank form windows are used to design the application's interface which will appear on the computer screen once the VB application starts. The project window displays the files that are created in the application, while the other window shows the properties of objects that are developed in the application.

In designing the application interface, there is a need to start with the interface drawing, setting up of the properties and also writing the codes. For the first step, the interface is designed as shown in Figure 4.8. The properties of every single item in the layout such as the size, the text font, the background colour, border style and other properties can be changed. As long as the properties box has the functions required, it can be modified according to the user's need.

Figure 4.8: Interface for PV monitoring system

The programming code is different for each item as it has specific function, and every programming code must start with command syntax code. Starting with the USB to

UART converter part, once the USB to UART is connected to the computer, the VB should be able to detect the connection port, so that the retrieved data can be sent to the computer. Once the port is detected, the port's name will appear at the interface of the monitoring system and the data can be retrieved if the connect button is clicked. The connect button will to allow the data to appear on the interface only if the button is clicked. If the detected port is similar with the assigned port, the programme will allow data to appear on the screen. When the data is being retrieved, the connect button is disabled while the disconnect button is enabled. The data retrieval process can be stopped by clicking on the disconnect button. The noticeable difference is the port specification will not be mentioned in the disconnect button programming code.

The developed system is designed to save data for monitoring purposes. The data can be stored in spreadsheets and can be viewed later if necessary. The location of folder to store all the data transferred can be determined later once the data logging is completed.

4.3 Web Based System

The software called Apache HTTP Server 2.2.15 is used in this project to retrieve data from the internet. The program connects to the server through Transmission Control Protocol/Internet Protocol (TCP/IP), which allows live communication. The TCP/IP protocol allows communication between computers even if they are from different manufactures or running different operating system[71]. Basically when a file is sent from a web server, TCP/IP will divide the file into small packets and sent over to the network. Although the packets have the same IP address, they can be routed differently or combined together to get them to the final destination [72]. At the end of the process, the TCP/IP needs to reassemble the individual packets into the form of original data before sending it to the destination. The benefit of using TCP/IP is that it has the ability for error checking and thus it increases the communication reliability [73].

In using Apache software for transferring data through internet connection, there are some setting that needs to be changed. After the software has been installed, the command for module status, fancy directory listings and language setting is modified as shown in Table 4.7. The hashtags have to be removed so that the folder's location link where the data is saved can be updated. The command can be viewed under the file named *"httpd.conf"*.

Table 4.7: Changes of command in Apache software

Descriptions / Status	Before	After
Module status	#LoadModulestatus_module modules/mod_status.so	LoadModulestatus_module modules/mod_status.so
Fancy directory listings	#Include conf/extra/httpd-autoindex.conf	Include conf/extra/httpd-autoindex.conf
Language settings	#Include conf/extra/httpd-languages.conf	Include conf/extra/httpd-languages.conf

As described in the block diagram of the project in Figure 3.6, once the data is saved in the computer by the programme, the data can be uploaded to the user via web based system. There is a specific folder assigned to locate all the saved data so that it can be viewed easily. In order to upload the data through the internet, the directory of this specific folder must be mentioned in the command given under apache software programming. In order to start using the Apache 2.2.15 software, the service monitor menu must be opened and start button must be clicked as shown in Figure 4.9. Then the web based system will update the data through local server before it can be displayed on the Web.

In order to view the saved data, there is a need to use an internet browser and IP address of the main computer, with an additional link to the subfolder. The web based system is programmed to update the data every five seconds. Any changes in the data received can be viewed by using the refresh button.

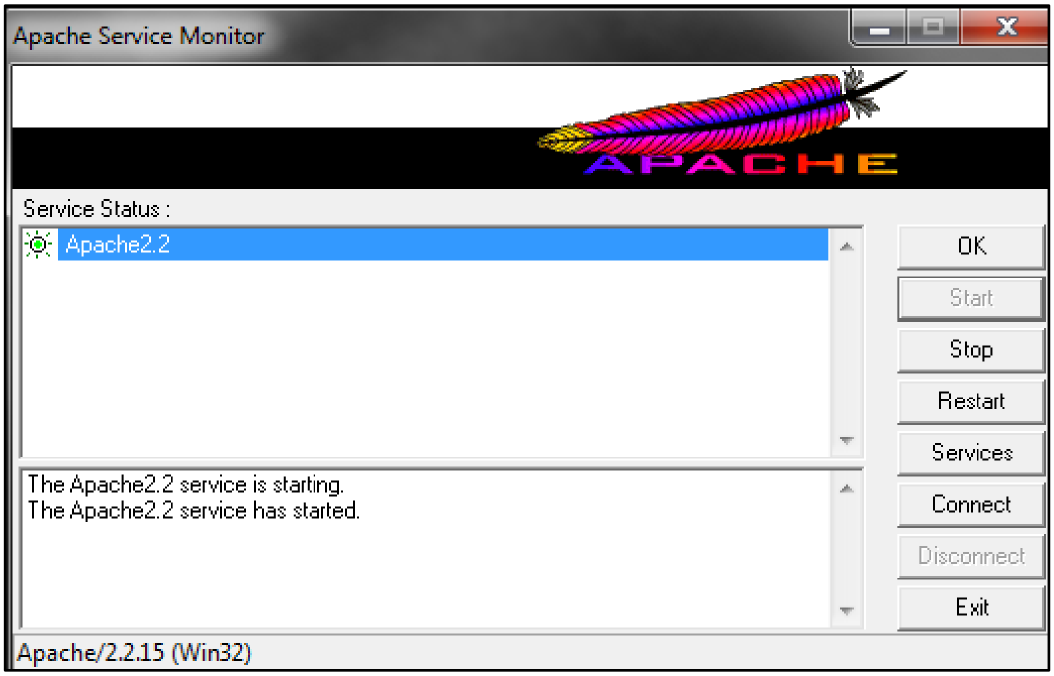

Figure 4.9 : Apache Software Monitor

4.4 The Complete Design of Monitoring System

The hardware part of the monitoring system is developed starting with the circuit design by using Eagle 5.1.0 software. The Eagle software is a program to design the PCB which consists of a schematic editor, a PCB editor and autorouter module [74]. The Eagle software was used to design the circuit diagram of DAS and the design was implemented on a PCB board. The complete connection of microcontroller for DAS which includes the reset diagram, oscillator, analog inputs, pushbutton switches, on/off switch, LCD display, and UART to USB converter is drawn in the schematic diagram as illustrated in Appendix B. In order to prepare the PCB board, the schematic diagram design is converted to the board diagram. The setting of each component is supposed to be synchronous with the diagram so that the process of placing the components later will be easier. Figure 4.10 shows the diagram of PCB board after it has been converted from the schematic diagram.

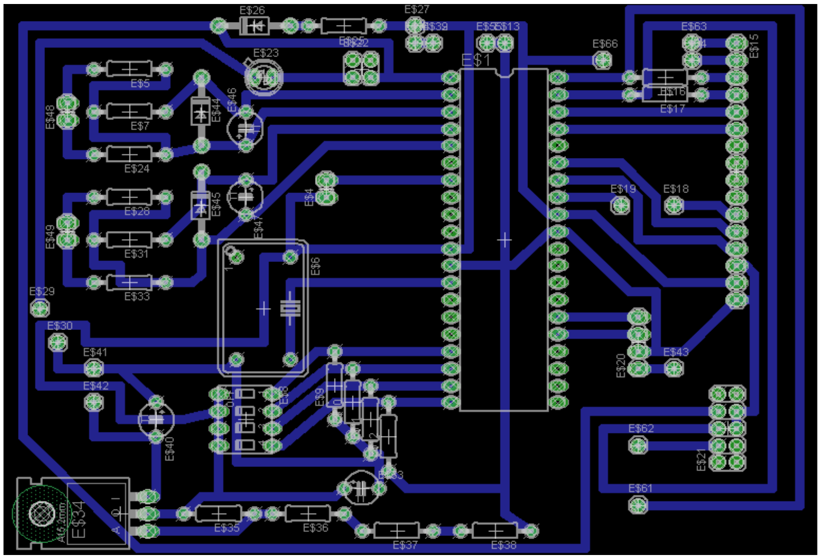

Figure 4.10: PCB circuit design

After implementing the data acquisition system on a PCB board, a casing was constructed to protect the hardware and to place the LCD display, reset switch, on/off switch, push buttons, and the serial port, as shown in Figure 4.11.

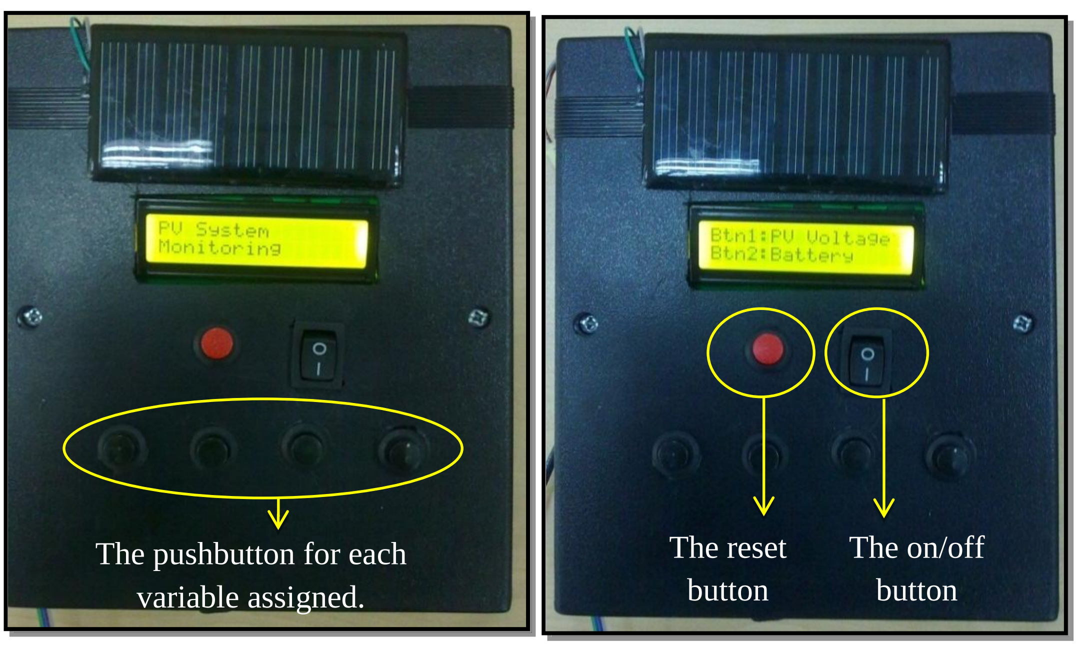

Figure 4.11: PV Monitoring System

4.5 Summary for Chapter 2

The design of prototype for PV monitoring system is explained in details in this chapter. The prototype consisted of data acquisition system and web based system. The data acquisition system divided into four main parts which are analog digital conversion, LCD display, serial communication and data logging programming. All four parts required in PV monitoring system in order to transmit data from PVSEGS to computer. The Web based system is designed to retrieve data from internet. Apache software is used in this project in order to transmit data via internet. The complete design of PV monitoring system is being tested and verified.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Overview

This chapter will be discussing the results from the experimental work. This chapter is organized into a three sections, which are the performance of PV module, prototype testing and performance verification. The process flow for the presentation of experimental work is shown in Figure 5.1.

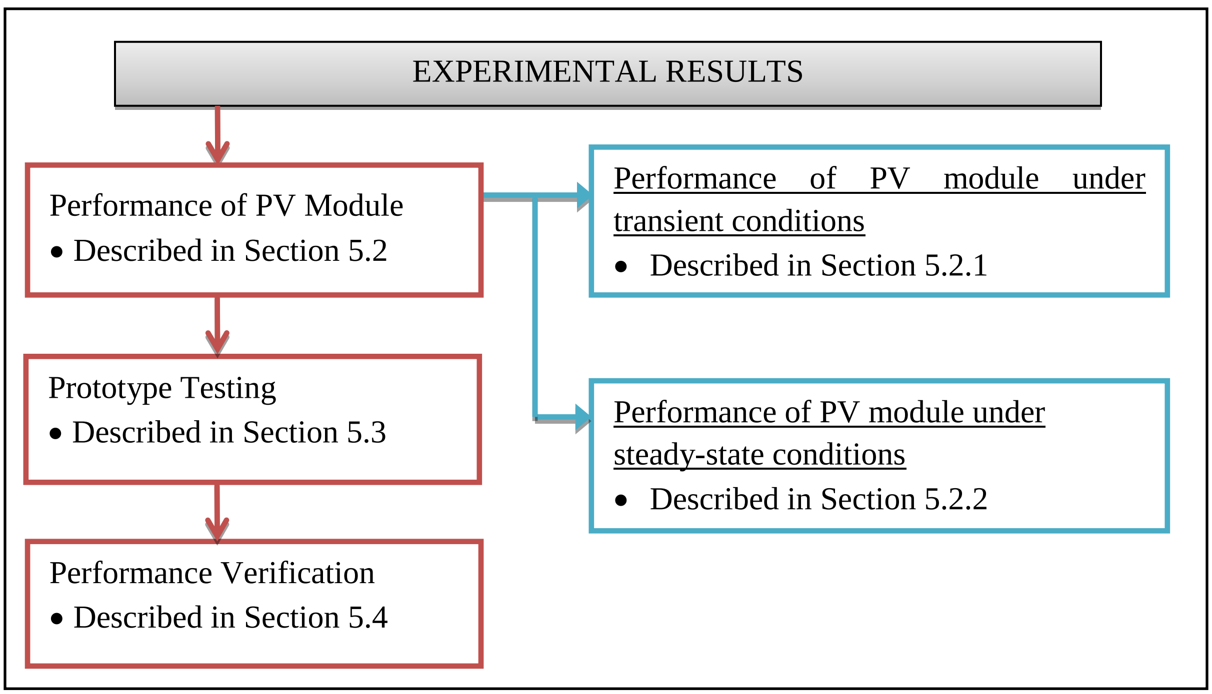

Figure 5.1: Process flow for reporting of experiment results

In the first section, the experimental work is divided into two parts where the first part is the performance of the PV module under transient conditions and the second part is the result of PV performance under steady-state conditions. The second section is prototype testing where the complete prototype was being tested to ensure that it is properly functioning. The third section is on the performance verification where the performance of prototype was compared with the standard reliable measuring device to ensure that the system is reliable.

5.2 PV Module Performances

The parameters of PV module are optimized at some reference condition, usually at standard test conditions (STC) of 1000 W/m^2 of irradiance, 25 ºC cell temperature and air mass 1.5 global spectrum [75]. PV modules are used as SEGS and subjected to actual outdoor conditions. Under this section, the performance of PV module is tested in both conditions. The first part of the experiment was performed to observe the effect of the solar irradiance on PV performance under transient conditions. Then the effect of steady state ambient temperature and shading on the PV module performance were tested and analyzed. The results from both experiments showed that the output from PV panel fluctuates due to the transient outdoor conditions.

5.2.1 Performance of PV Module under Transient Conditions.

The experiment was setup as shown in Figure 5.2 to measure solar irradiance data and the output of PV module. The average open-circuit voltage (*Voc*) and short circuit current (*Isc*) of PV module obtained in the experiment are 4.13V and 45.63mA. The result of solar irradiance measurement under transient conditions is shown in Figure 5.3 while the variations of *Voc* and *Isc* of a PV module are shown in Figure 5.4. The result shows that the fluctuation in solar irradiance affects the performance of PV module. When the solar irradiance value drops at a certain time, the *Voc* and *Isc* of PV module will drop as well. It is observed that the performances of PV module investigated under transient conditions is fluctuating throughout the day due to the solar irradiance input affected by meteorological conditions.

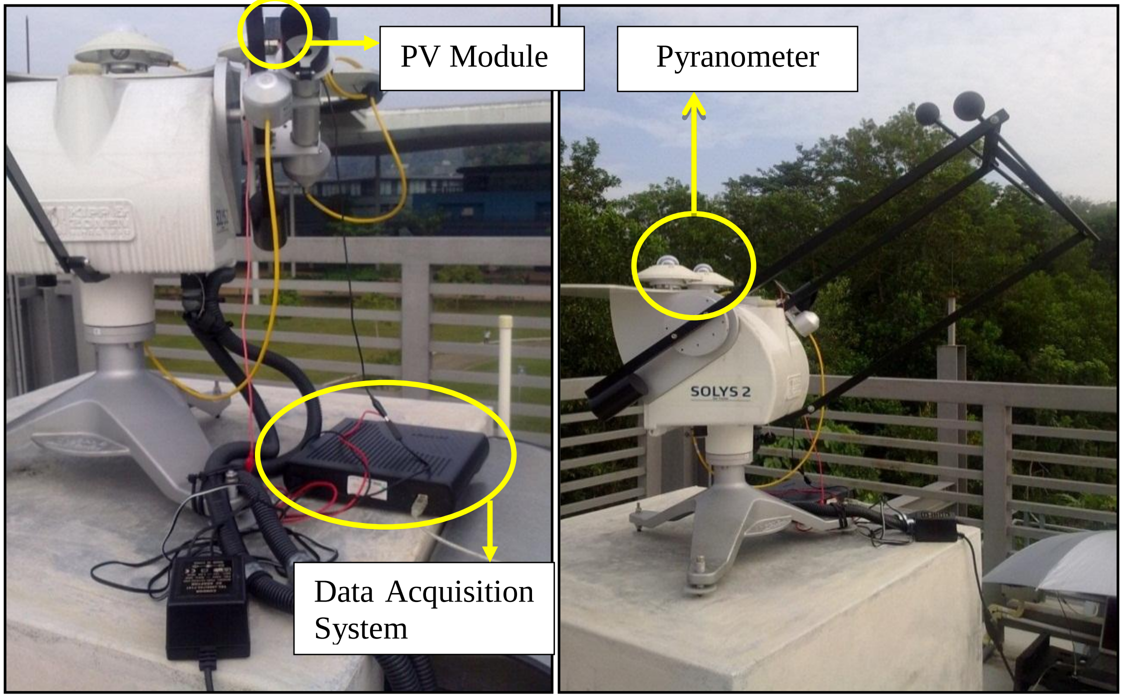

Figure 5.2: Experiment setup to measure solar irradiance and the output from PV module.

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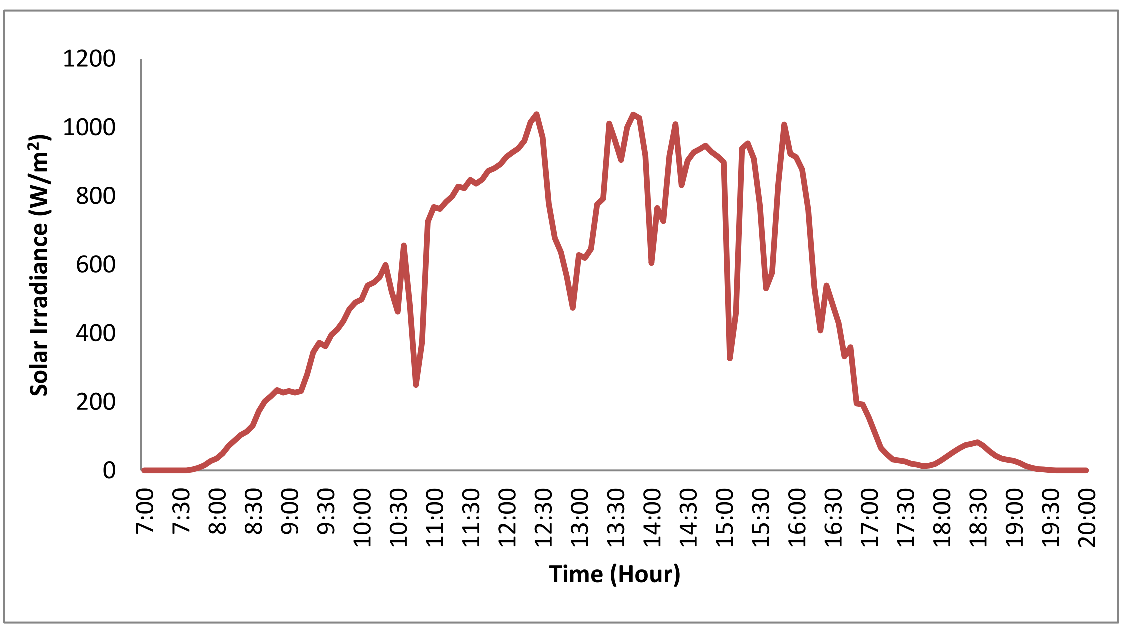


Figure 5.3: Average solar irradiance measured at Universiti Teknologi Petronas

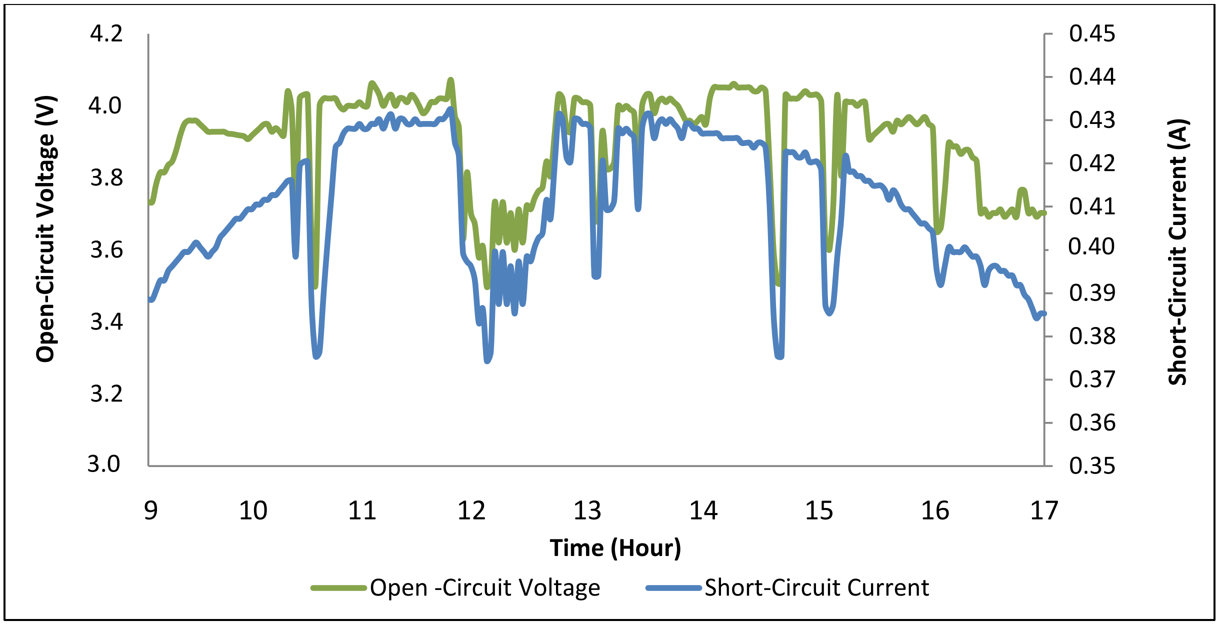


Figure 5.4: *Voc* and *Isc* of PV module

5.2.2 Performance of PV Module under Steady State Conditions

The fluctuations in the output of PV module are mainly due to the variation in solar radiation and also the transient meteorological and outdoor conditions. The shading effect by the clouds or dust on PV module will affect the PVSEGS. The change in operating temperature also influences the performance of PVSEGS. The effect of temperature and shading on the PV module performance were tested and analyzed under steady state conditions.

5.2.2.1 Effect of Temperature on PV Module

The effect of steady-state ambient temperature on PV performance was investigated. The *Voc* and *Isc* of PV module obtained in the experiment are 4.13V and 45.63mA, when subjected to irradiance of 1000W/m^2. The operating temperature of PV module was raised to 50ºC and 75ºC while the irradiance in the solar simulator was set to 1000 W/m^2. The result of PV performance for varying temperature is shown in Figure 5.5 while Table 5.1 shows the average value of PV performance on different temperature.

According to the Figure 5.5, the *Voc* is decreased with increasing temperature while the *Isc* increases with increasing temperature.

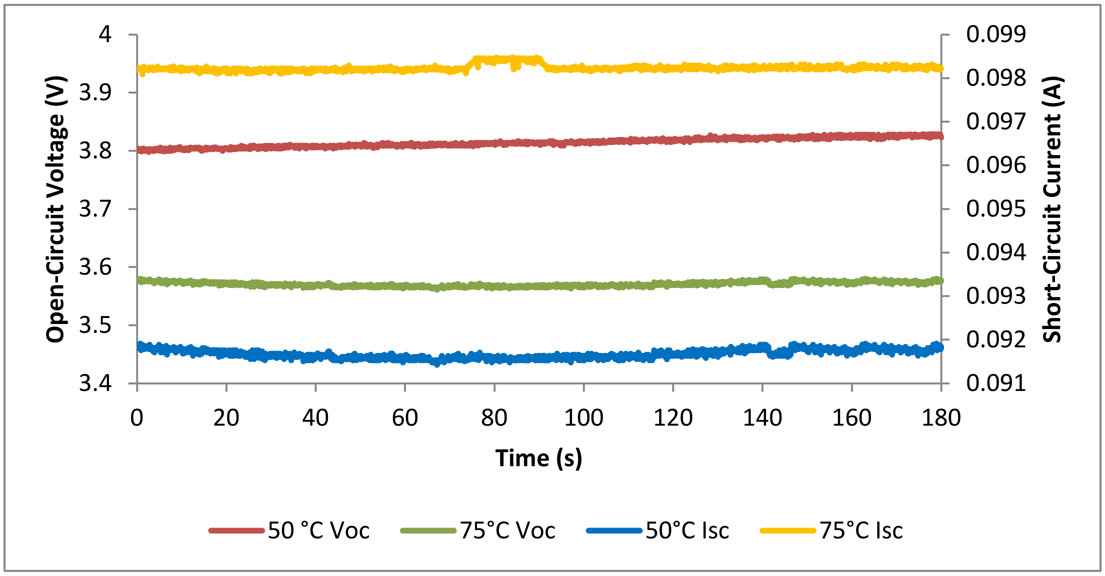


Figure 5.5: PV module's performance at varying temperatures

Table 5.1: Average value of PV module performance at different temperature

Average / Temperature	50 ºC	75 ºC
Open- circuit voltage (V)	3.816	3.569
Open-circuit Current (A)	0.092	0.098

5.2.2.2 Effect of Shading on PV Module

The experiment was performed to investigate the shading effect on the PV module performance. The experiment was done under steady-state conditions where the solar radiation is set at 1000W/m^2. The translucent paper was used to cover up the solar simulator's light in order to provide partial shading effect. Figure 5.6 and 5.7 shows the result of the *Isc* and *Voc* of PV module when there is no shading condition and partial shading condition was applied. The result of average value for voltage and current gain shows in Table 5.2. Referring to the graph, the value of *Isc* and *Voc* dropped when shading is applied to the PV module. The average value for *Isc* when there is no shading applied is 0.172A while it decreases to 0.110A when partial shading was tested on PV module. For the *Voc*, the average value of PV module performance when there is no shading condition applied is 4.662V and the value drops to 4.132V when the partial shading condition is applied to the PV module. The effect of shading on power output for PV panels can cause a large reduction even though the PV module is only partially shaded. Clearly, the output of PV module which is shaded will be reduced according to reduction of light intensity falling on it. Shading will generally result in a significant reduction in PV performance, therefore the best way is to avoid shade where possible [76].

The performance of the PV module under the solar simulator produced stable and consistent results due to the controlled conditions of the experiment setup. The PV module performance investigated under actual conditions was observed to be irregular and fluctuating throughout the day according to the solar irradiance and ambient temperature that it was exposed to. For monitoring performance of the PV module, the result transient condition is more reliable as it takes into consideration the actual condition.

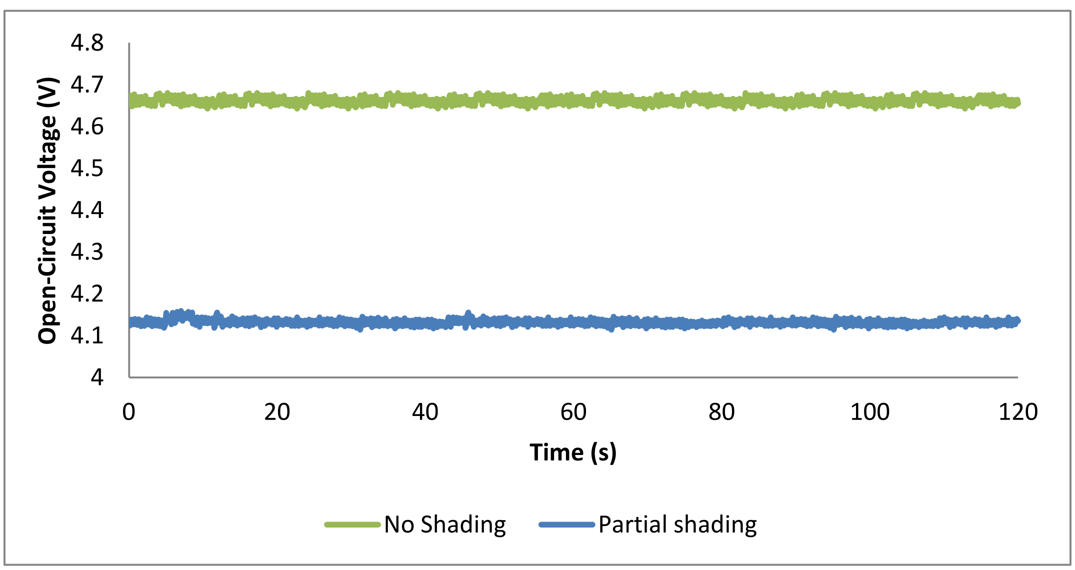


Figure 5.6: *Voc* response to partial shading condition

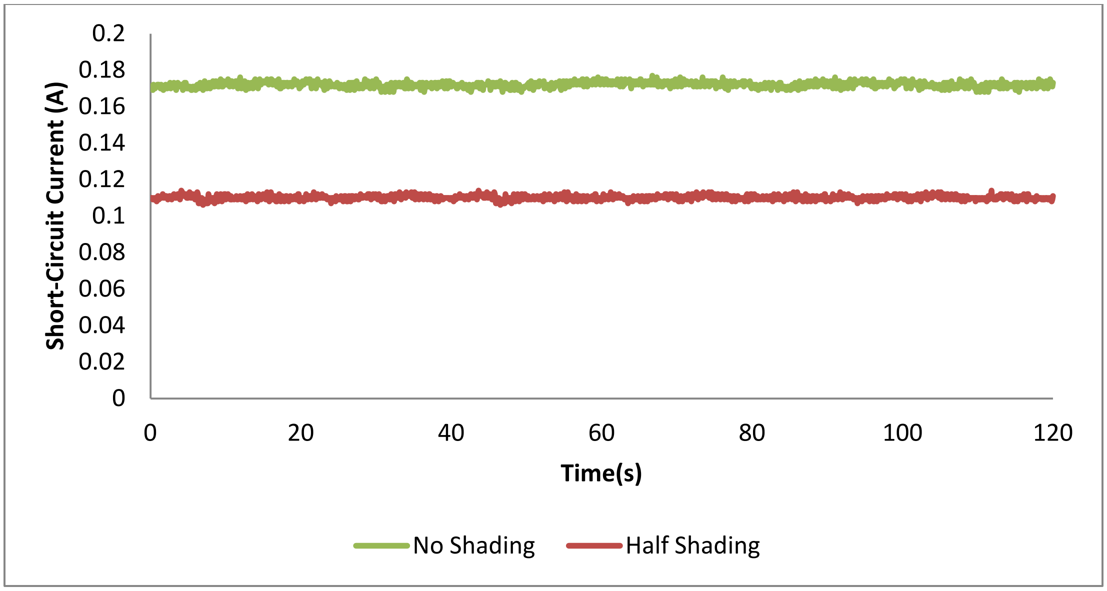


Figure 5.7: *Isc* response to partial shading condition

Table 5.2: Average value of *Voc* and *Isc* when subjected to different shading conditions

Measurement	No Shading	Partial Shading
Voc (V)	4.662	4.132
Isc (A)	0.172	0.110

5.3 Prototype Testing

It has been shown in the previous sections that the performance of the PV module fluctuates significantly, with the change in solar radiation and also other meteorological conditions. Therefore, it is essential to integrate a monitoring system with the SEGS. The monitoring system is needed to track the performance of SEGS so that it can provide the optimum output power and also to ensure that the system is in a good operating condition. This is achieved by monitoring the important parameters related to the SEGS especially the output from PV panel, charge controller, battery and inverter. A failure or unstable output from any one of these components must be immediately detected.

The prototype as discussed in Chapter 4 was tested to show that the developed monitoring system is able to monitor the performance of PVSEGS.

5.3.1 Performance Monitoring of PVSEGS

The performance monitoring system was tested by setting up the PVSEGS as shown in Figure 5.8. Experiments were performed by using the designed DAS to measure the output from PVSEGS. In this experiment, the parameters of PVSEGS that are being measured are PV voltage, PV current and battery voltage.

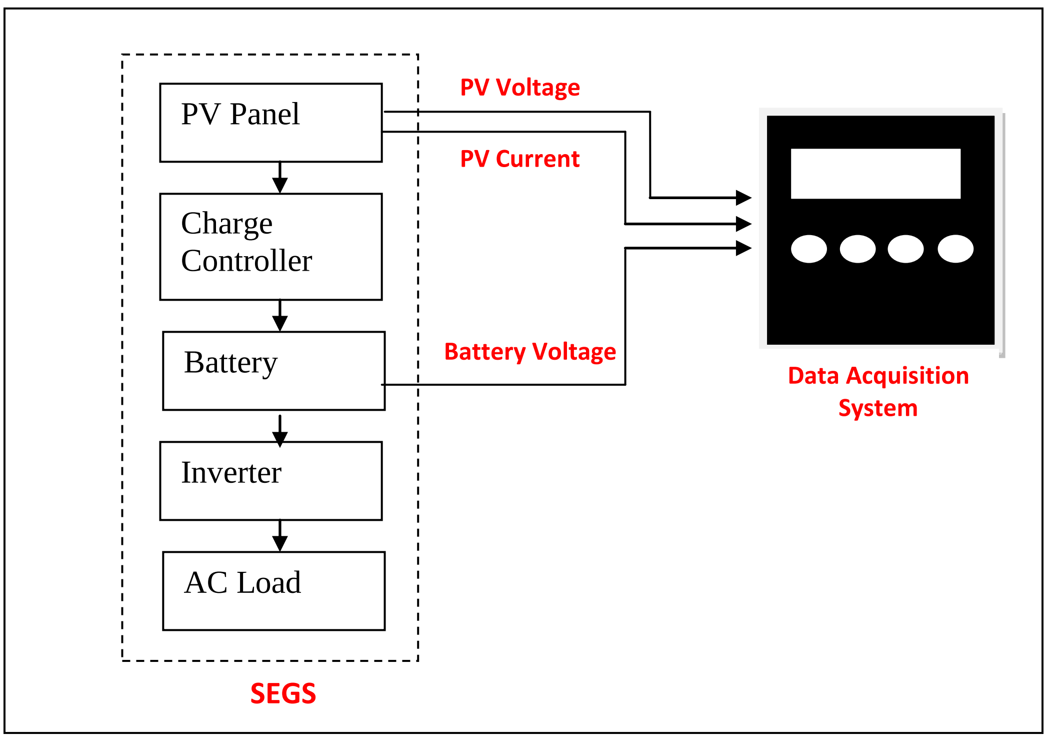


Figure 5.8: PVSEGS configuration for performance testing

The result of performance monitoring of PVSEGS is shown in Figure 5.9 and 5.10. Figure 5.9 shows the solar irradiance measurement and *Isc* of PV module while Figure 5.10 shows the measurement of PV voltage and battery voltage. According to the graph, the battery is charged when the value of PV voltage higher than the battery voltage. Once the battery is at 12V, the voltage starts to fluctuate. The fluctuation is due to the charge controller that regulates the voltage in order to avoid the battery from overcharging. The result shows that the designed DAS is able to monitor the performance of PVSEGS.

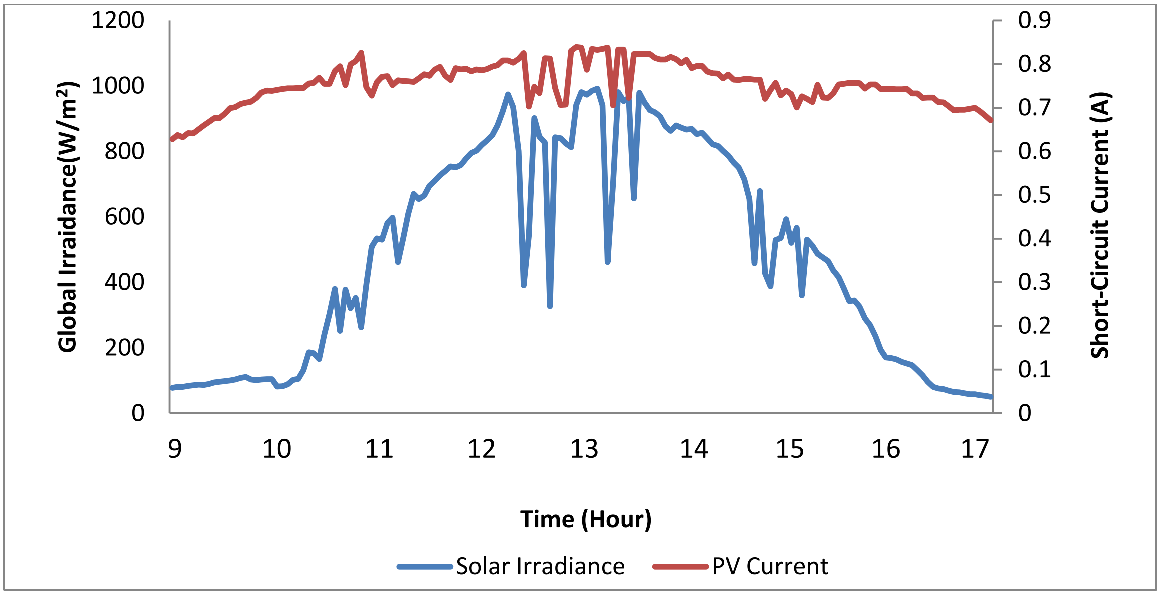


Figure 5.9 : Measurement of solar irradiance and PV current of PV panel

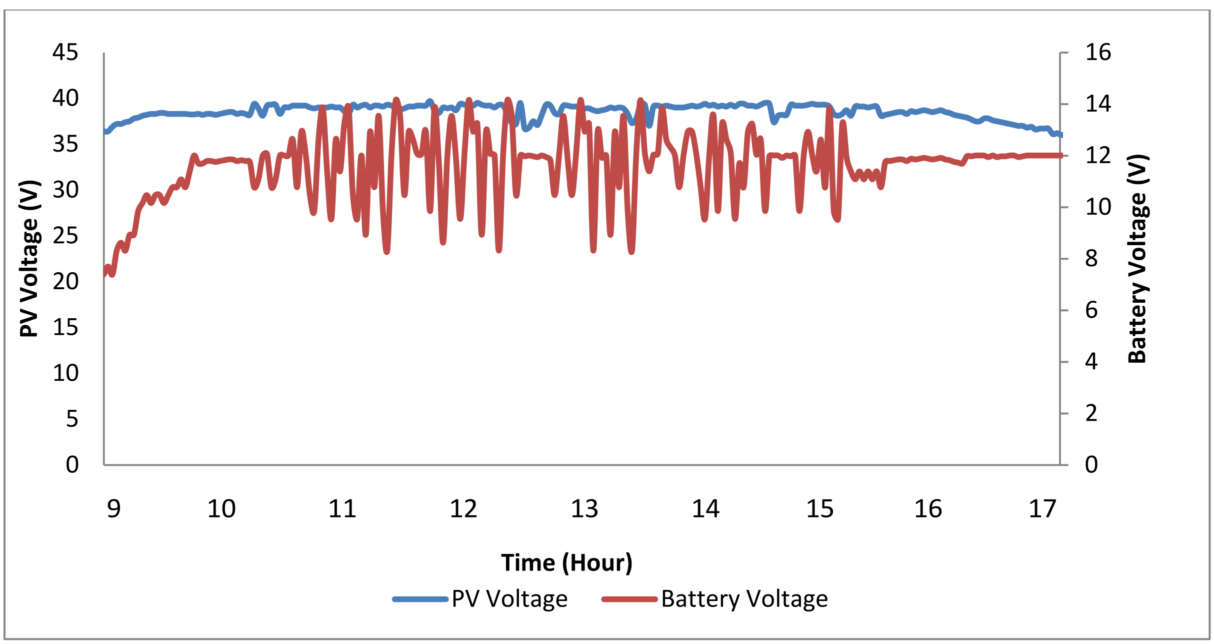


Figure 5.10: Measurement of PV voltage and battery voltage.

5.3.2 Performance Monitoring by Web Based System

The result from performance monitoring can also be viewed by using Web Based System. As discussed, the developed system has the ability to allow users to monitor their systems via the Internet. Once users are registered with the Web-provider, an account will be given as shown in Figure 5.11. Using this account, users can log in and monitor their system provided the Internet service is available. Figure 5.12 shows the graphical view of the eight hours record on 25th August 2010 at the local server. It is observed that the server displays accurately what is stored in the PC.

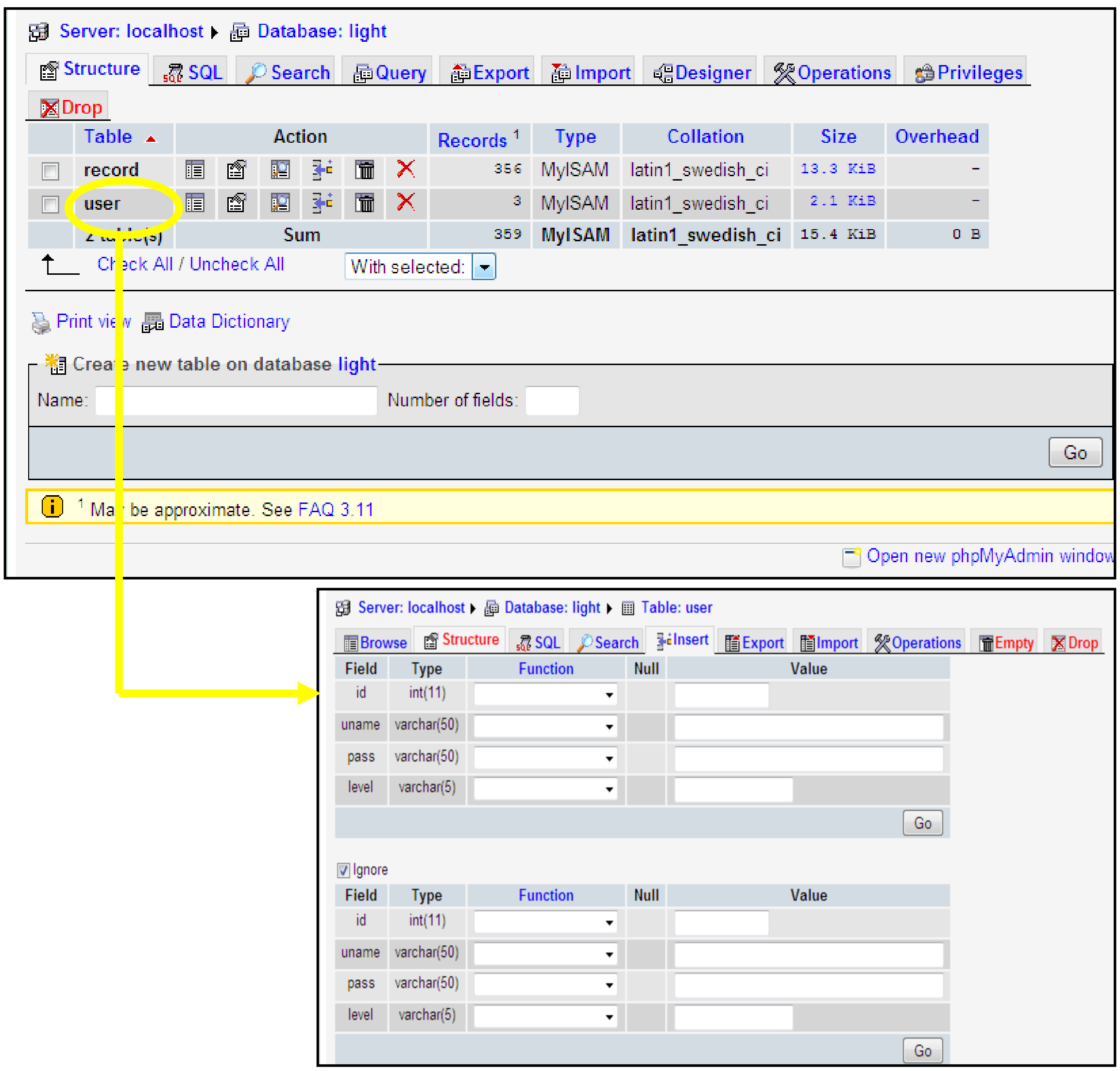


Figure 5.11: Register with Web Provider

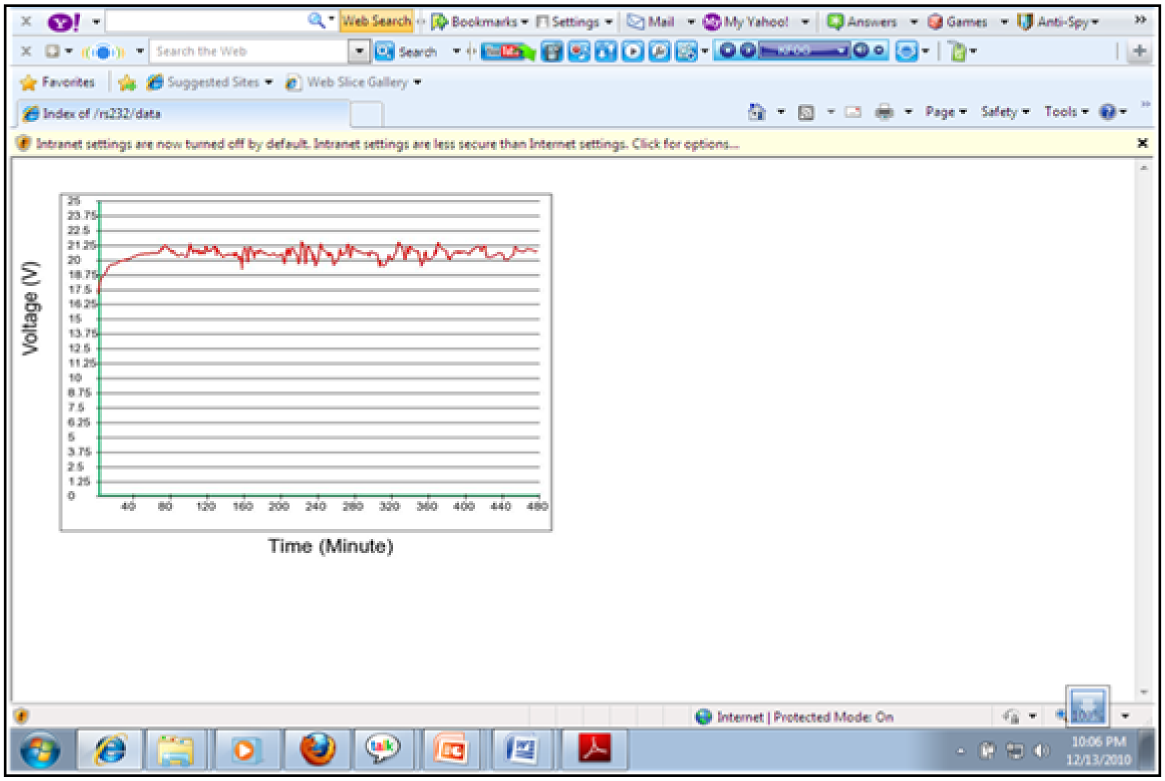
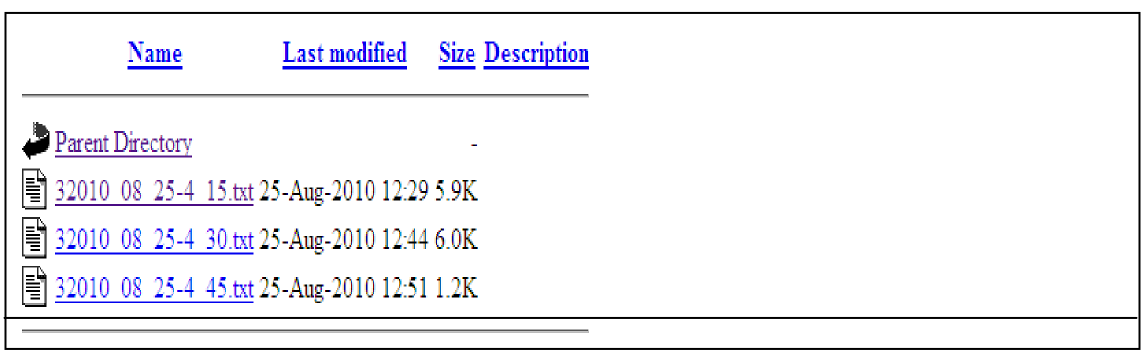


Figure 5.12: Monitoring Performance by Web Based System

The site is developed such that it is automatically refreshed. Any change in the solar radiation received at the panel surface will be recorded after each refresh. Figure 5.13 shows the examples of data files that are saved on the internet based server.



Name	Last modified	Size	Description
Parent Directory		-	
32010_08_25-4_15.txt	25-Aug-2010 12:29	5.9K	
32010_08_25-4_30.txt	25-Aug-2010 12:44	6.0K	
32010_08_25-4_45.txt	25-Aug-2010 12:51	1.2K	

Figure 5.13: Data collection on web server

5.4 Performance Verification

The experiment was conducted to verify the performance of the prototype and to ensure the realibilty of the monitoring system. The monitoring system developed is compared with the commercialized DAS to ensure that the system can function properly and will provide the accurate data as well. The result is compared based on the calculation of correlation analysis.

The experiment is setup at the solar lab tower in Universiti Teknologi Petronas. The connection for realibility testing experiment is discussed in Chapter 3 while Figure 5.14 shows the experiment setup during the day of data collection. The test was conducted for one month continuously starting from 1st December 2011 until 31st December 2011 and the data was recorded for 8 hours starting from 9 am to 5 pm. As December has the extreme weather conditions which usually occur during the monsoons, therefore it was a suitable month to compare the results in different conditions.

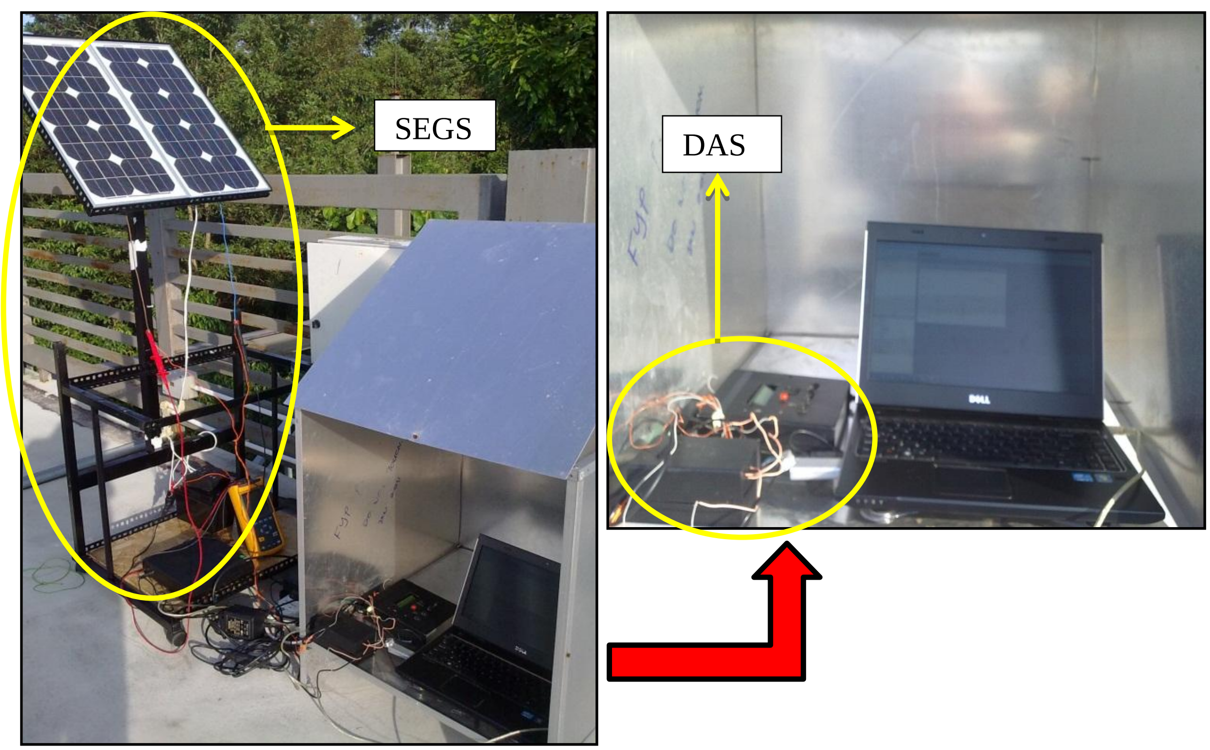


Figure 5.14: Experiment setup for reliability testing

5.4.1 Comparison between Designed DAS and Commercialized DAS

In this experiment, the comparison is focused only on the PV panel performance due to the limited input connection of commercially available DAS. The commercially available DAS allowed only two inputs connection for each measurement, therefore there are two parameters that will be measured from the PV panel connection, which are *Voc* and *Isc*. The specification of PV panel used in the experiment is described in Table 5.3. Two monocrystalline PV panels were used in the experiment and it is connected in series.

The result for the realibility testing includes the solar irradiance measurement and the measurement of PV panel performance by using designed DAS and also by using commercially available DAS. The solar irradiance measurement is captured by pyranometer to measure the input to the PV panel while the *Voc* and *Isc* measurements from both devices was compared to measure the output of PV panel. The accuracy of the designed DAS is determined by calculating the correlation factor as referring to the formula stated in 3.1.

Table 5.3: The specifications of PV panel

Desriptions	Unit
Type	Monocrystalline
Maximum Power (Pmax)	50Wp
Open-Circuit Voltage (*Voc*)	21.82V
Rated Voltage(Vmpp)	18.22V
Rated Current (Impp)	2.8A
Short-Circuit Current (*Isc*)	3.05A

Data collection on 14^{th} December 2011 is an example of weather conditions for sunny day. Figure 5.15 shows the solar irradiance measurement while Figures 5.16 and 5.17 described the performance of PV panel. For *Voc* data comparison, the correlation coefficient is 0.977109, while for the *Isc*, the correlation coefficient is 0.970655.

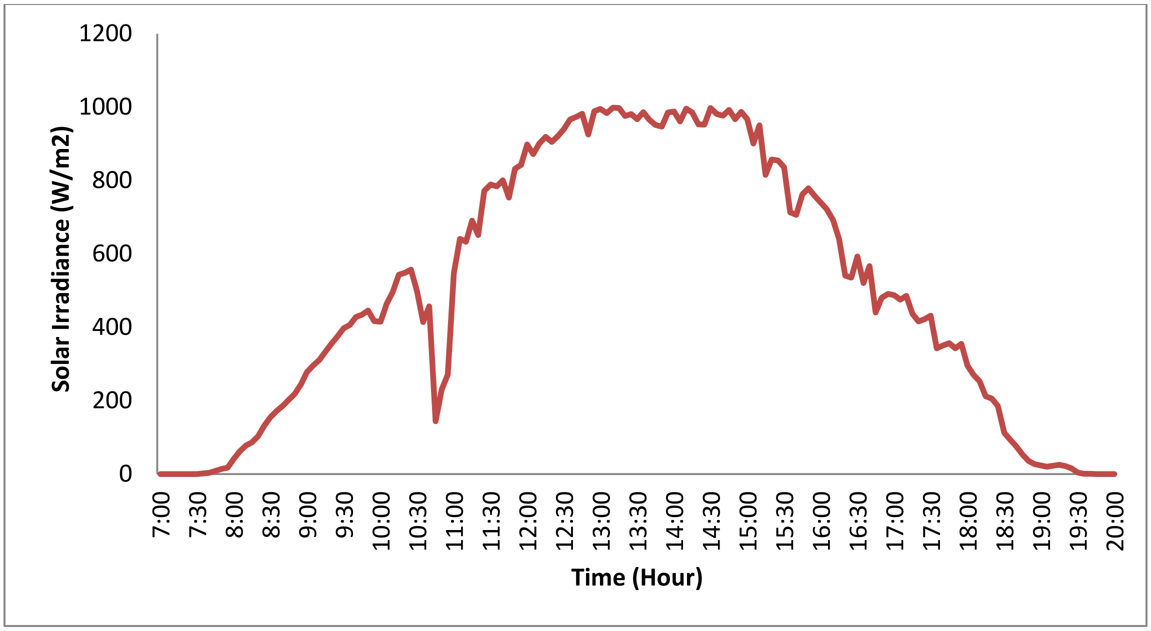


Figure 5.15: Solar irradiance measurement in UTP on 14th December 2011

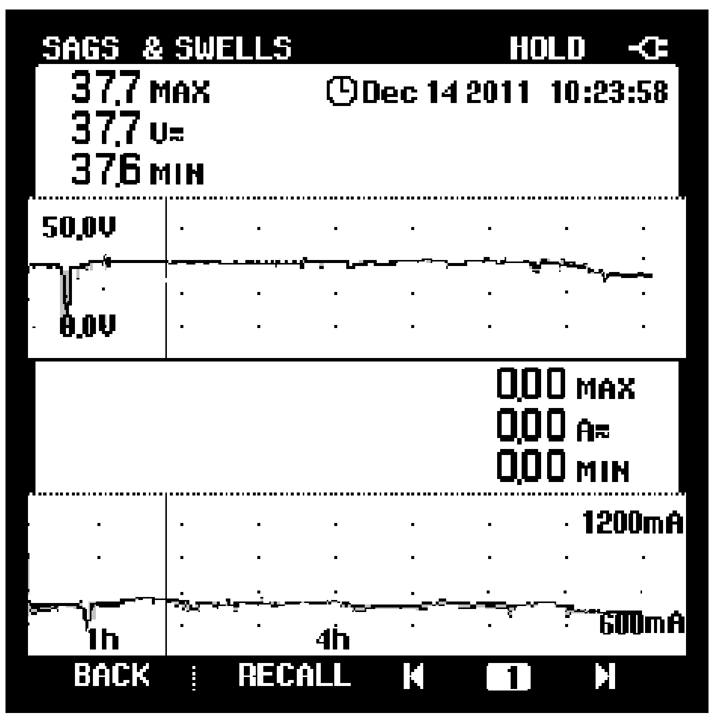


Figure 5.16: *Voc* and *Isc* of PV panel captured by using commercialized DAS on 14th December 2011

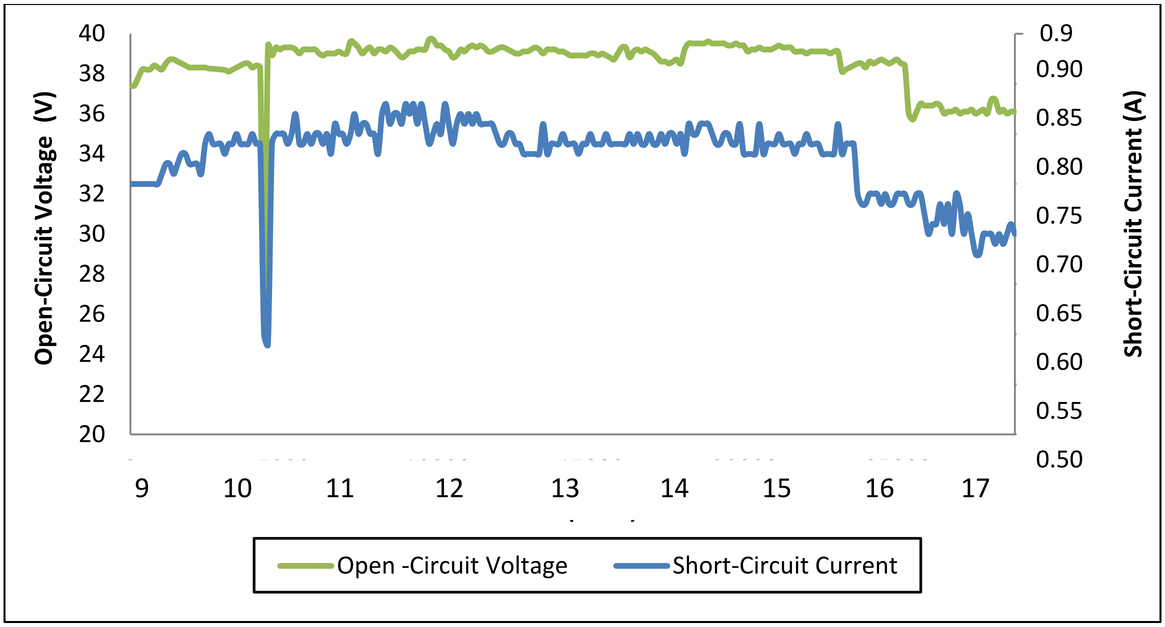


Figure 5.17: *Voc* and *Isc* of PV panel by designed DAS on 14th December 2011

An example of data collection for cloudy day is captured on 16th December 2011. The solar irradiance measurement is shown in Figure 5.18 while Figures 5.19 and 5.20 described the performance of PV panel. By using correlation analysis for comparison data of PV performance, *Voc* obtain 0.968950 while *Isc* gain 0.967844.

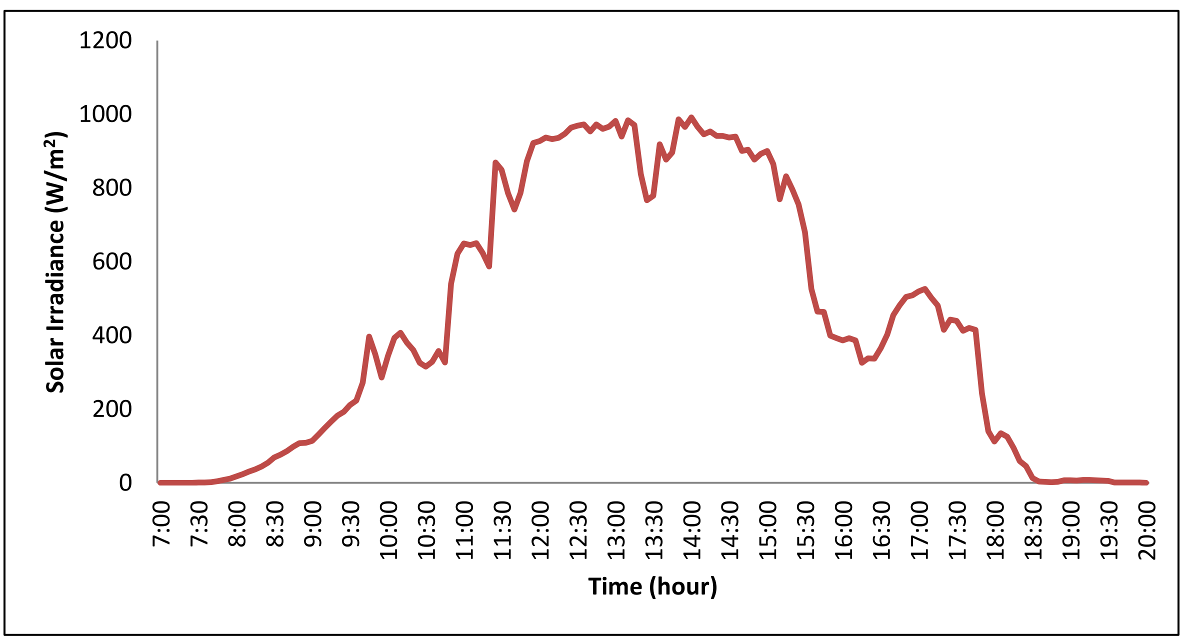


Figure 5.18: Solar irradiance measurement in UTP on 16th December 201

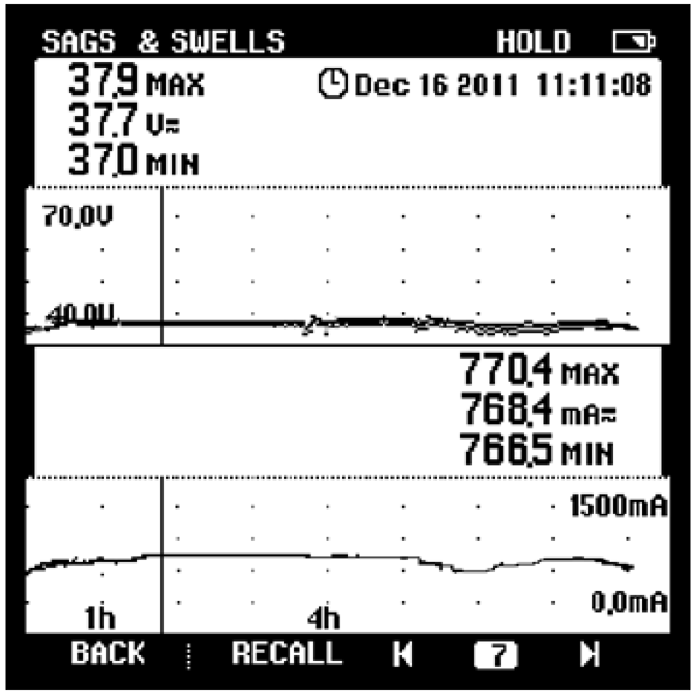


Figure 5.19: *Voc* and *Isc* of PV panel captured by using commercialized DAS on 16th December 2011

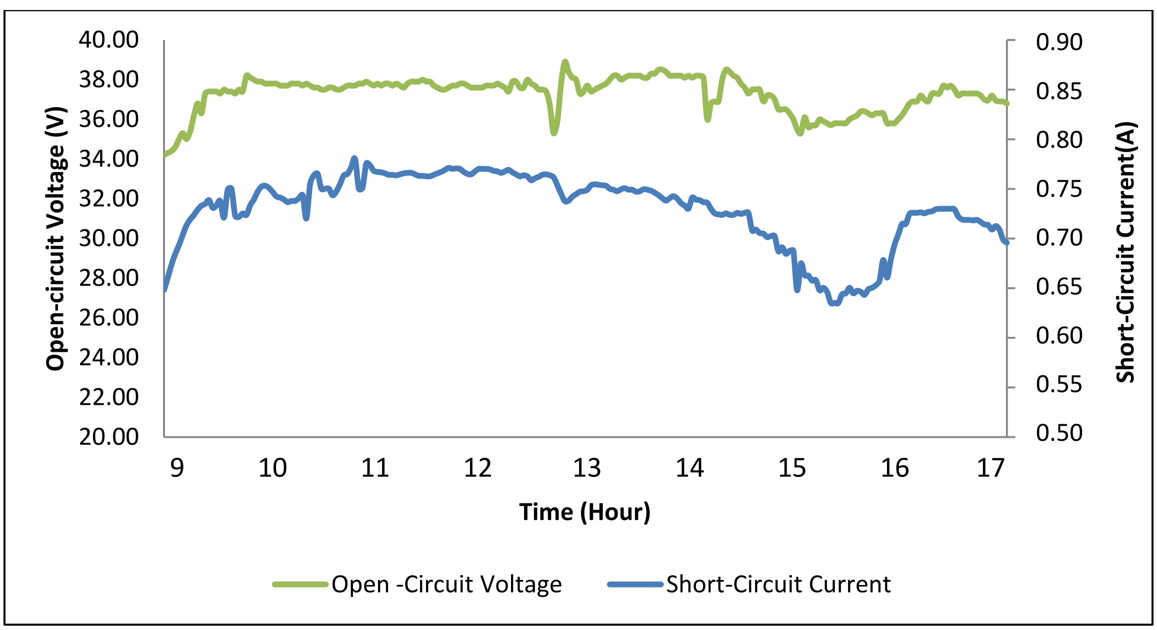


Figure 5.20: *Voc* and *Isc* of PV panel by designed DAS on 16th December 2011

An example of data collection of average day is captured on 21st December 2011. Figure 5.21 shows the measurement of solar irradiance with time while Figures 5.22 and 5.23 described the performance of PV panel. The data from both devices is compared by using correlation analysis and the result obtain for *Voc* is 0.986224, while for the *Isc* is 0.985783.

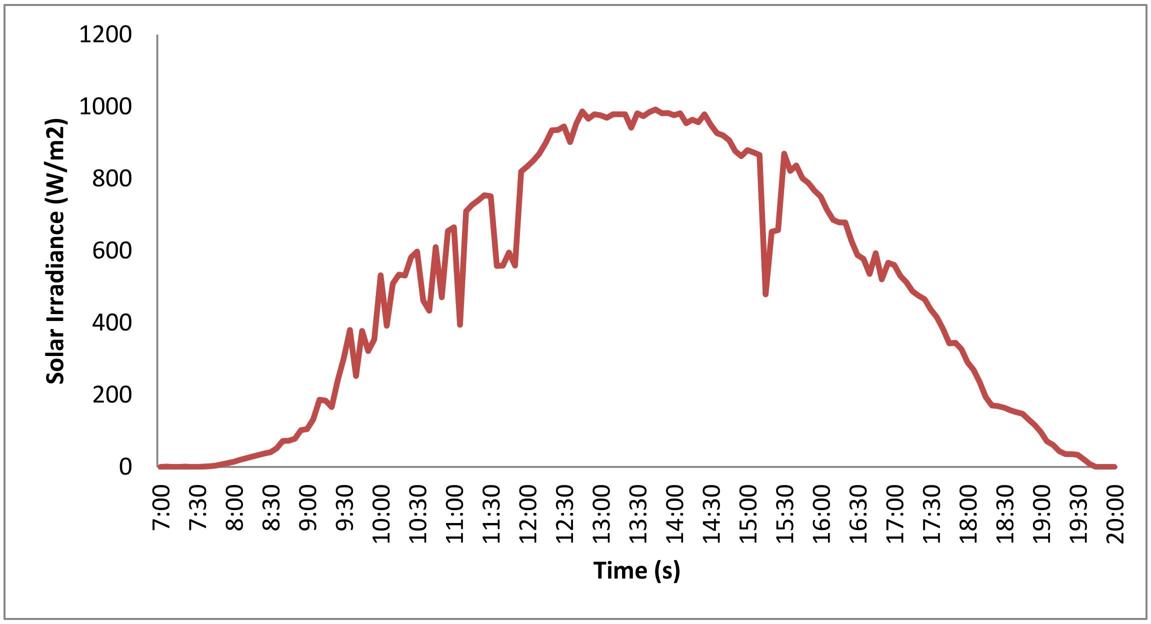


Figure 5.21: Solar irradiance measurement in UTP on 21st December 2011

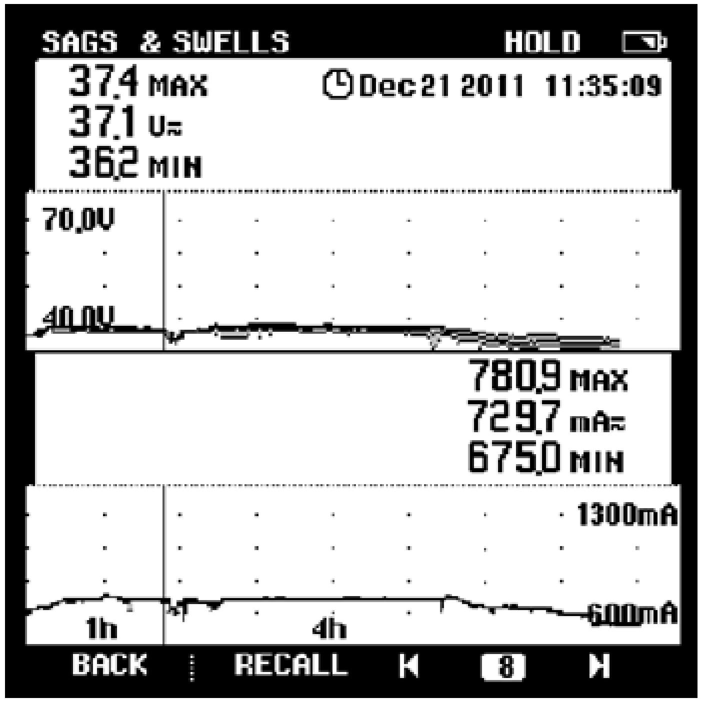


Figure 5.22: *Voc* and *Isc* of PV panel captured by using commercialized DAS on 21st December 2011

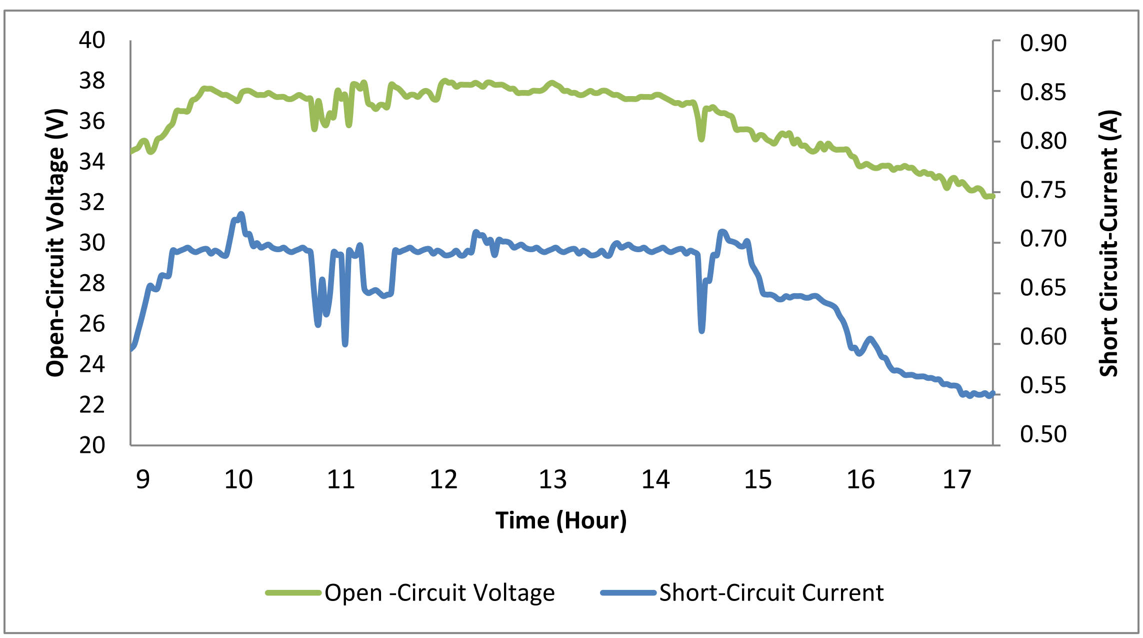


Figure 5.23: *Voc* and *Isc* of PV panel by designed DAS on 21st December 2011

Based on the result shown in Figure 5.15 until Figure 5.23, the fluctuations in solar irradiance with time affect the performance of PV panel. This is expected since there are factors affecting the amount of radiation incident on the panel surface such as cloud effects, sun path, and other meteorological effects. When the incoming solar radiation is low, the output from the PV panel including the *Voc* and *Isc* will provide low value as well. Therefore, integrating the monitoring system with the PVSEGS will be beneficial to ensure that the output and input of PV panel are measured correctly.

The monitoring system developed must undergo the realibilty testing in order to verify the performance of the devices. Thus, the data captured using the designed DAS was compared with data captured by commercialized DAS by using correlation coefficient analysis. The value of the coefficient correlation obtained for the 3 different weather conditions are displayed in Table 5.4. Based on the data analysis, the correlation coefficient for *Voc* is much higher compared to the *Isc* for each measurement. However, the value for the *Isc* is considered accurate as the lowest correlation is 96 %. The correlation of different weather conditions during data recording is within the 96-98 % accuracy. The monitoring system developed was operating to the required expectation. Thus, the system is proven to be reliable and can be used for monitoring PV performance.

Table 5.3: Correlation analysis of data collection

Date	Weather Conditions	Correlation Coefficient	
		Open-Circuit Voltage	Short-Circuit Current
14/12/2012	Sunny day	0.977109	0.970655
16/12/2012	Cloudy Day	0.968950	0.967844
21/12/2012	Average Day	0.986224	0.985783

5.5 Summary for Chapter 5

The experimental results presented compromise data of performance under steady-state conditions and performance of PV module under actual transient conditions. The results explained the need for monitoring system to be integrated with the PVSEGS. The prototype is tested against commercialized monitoring system and the result showed that the prototype is implemented successfully. The prototype performance was analyzed by using correlation factor and the result showed a reasonably good correlation and it is operated to the desired requirements.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This thesis represents the development of PV monitoring system. A reliable computerized data acquisition system for PV performance monitoring was developed. As the performance of PVSEGS fluctuates due to the intermittent nature of solar irradiation, there is a need for continuous monitoring to ensure the reliability and sustainability of implementing the PVSEGS. The commercially available monitoring system is relatively expensive and the flexibility is limited. A reliable monitoring system is designed to keep track all the parameters involved in PVSEGS and to ensure that the system is properly functions.

A PVSEGS prototype was implemented to be integrated with the designed monitoring system. The monitoring system was developed to be used for displaying data captured on the LCD, displaying and saving data in the computer and for transmission of data through the web based system. The data acquisition system used in this project allows the system to convert the input signal to sensible data reading. In this project, PIC16F877 microcontroller is used for measuring, receiving and converted the signals from the PVSEGS before transmitting the data to the computer. The serial communication, USB-UART converter is used for interfacing between the PIC microcontroller and PC for continuous monitoring through the computer. A Visual Basic (VB) 2005 software is programmed so that it can captured the real-time data from the PIC 16F877 to be displayed and stored in the computer. The measured data is stored in the real time data on the spreadsheet so it can be retrieved later, if necessary. The monitoring system is also designed to transmit data through the internet. Apache software is used to display data via web-based system. The data will be saved on the server and can be accessed if there is internet connection available.

PV monitoring system for this project is different from the previous research work. As compared to SCADA system which design for industrial level, this project is focusing more on small scale area. It is design for stand-alone SEGS and required only one database. The DAS used for this project is using PIC microcontroller and USB to UART converter instead of DAQ Plug-In board which is commercially used in PV monitoring system. The DAQ Plug-In board is more expensive as it is design to be used with specific software named Lab View Software. The transmission data from PVSEGS to the computer require both connections. Similar to PV monitoring system which used the RS232 communicator, it requires MAX232 and serial port connector in order to transmit data from PVSEGS to the computer. Hence this project is design to transmit data from PVSEGS to computer by using PIC microcontroller, USB to UART converter and Visual Basic software which is more simple and reliable.

The monitoring system designed in this project is tested and verified against the commercially available DAS for performance testing. The result shows that the designed monitoring system is approximately 97 % accurate. The calculation of accuracy is by using correlation factor between the commercially used DAS and designed DAS. Thus, the system is proved to be used for monitoring the performance of small scale PVSEGS or even for domestic installations. Through this project, an integrated monitoring system has been developed and tested. There is a need for continuous monitoring to ensure reliability and sustainability of implementing PVSEGS. This system will keep informed regarding on the performances of PVSEGS. The objectives achieved as all the data can be control by server and the performance of the PVSEGS can be access online from the computer.

6.2 Recommendation

In designing a PVSEGS, several factors need to be considered in order to generate maximum power output. The tilt angle and orientation of the PV panel is one of the important factors to be focused on in order to generate more electricity. The orientation of PV panel need to be perpendicular with the sun to captured the maximum amount of irradiance. For the future recommendation, the PVSEGS will provide an optimum result by upgrading the PVSEGS to the 2-axis tracking system and integrated together with the designed monitoring system. Compared to the single-axis tracking system, the 2-axis tracking system will provide more electricity as the amount of irradiation captured of the PV array is increased.

The implementation of monitoring system for online application can be improved by using the wireless connection. The transmission of data from PVSEGS to the computer would be easier and more reliable instead of using cable for data transmission. The research on wireless connection for monitoring system is a good improvement for PV monitoring system.

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APPENDICES

Appendix A: **List of Publication and Conference**

Publication:

1. Nur Syahidah Husain, Nur Athirah Zainal, Balbir Singh Mahinder Singh, Norani Muti Mohamed and Nur Syarizal Mohd Nor, "Integrated PV Based Solar Insolation Measurement and Performance Monitoring System,"

   DOI: 10.1109/CHUSER.2011.6163827
2. Prashantini Sunderan, Balbir Singh Mahinder Singh, Norani Muti Mohamed and Nur Syahidah Husain, "Sizing and Designing a Stand-alone Photovoltaic Electricity Generation System Using a Customized Simulation Program,"

   DOI: 10.1109/ICBEIA.2011.5994234
3. Prashantini Sunderan, Balbir Singh Mahinder Singh, Norani Muti Mohamed and Nur Syahidah Husain, "Techno-economic Analysis of An Off-Grid Photovoltaic Natural Gas Power System for a University,"

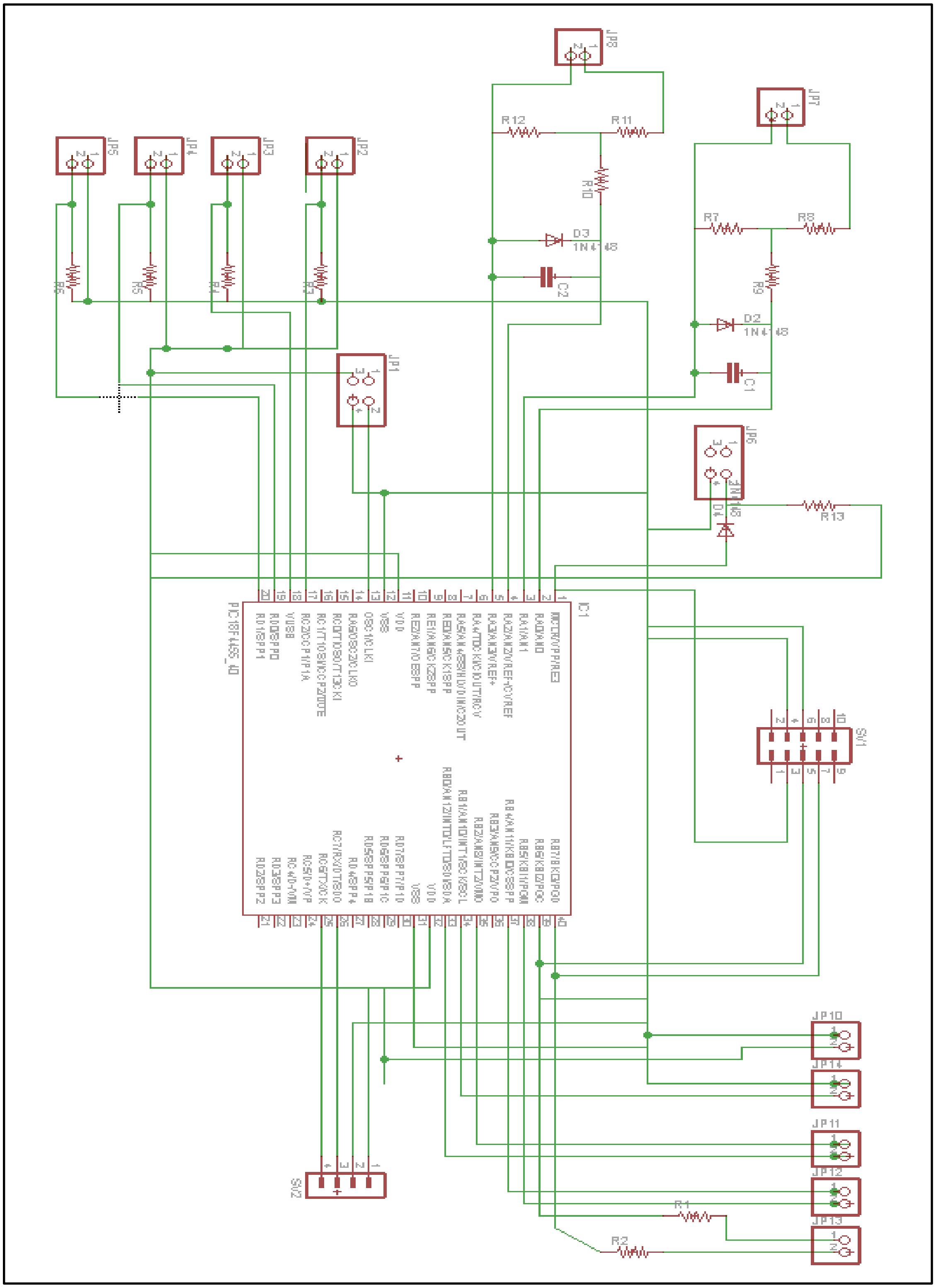
   DOI: 10.1109/ISESEE.2011.5977120

Conference:

1. N. S. Husain, N. A. Zainal, B. S. Mahinder Singh, N. M. Mohamed and N.S. Mohd Nor. Integrated PV Based Solar Insolation Measurement and Performance Monitoring System. Presented at Colloquium on Humanities, Science and Engineering (CHUSER). Pulau Pinang, Malaysia. 5-6 December 2011.
2. P. Sunderan, B. S. Mahinder Singh, N.M. Mohamed and N.S. Husain. Sizing and Designing a Stand-alone Photovoltaic Electricity Generation System Using a Customized Simulation Program. Presented at International Conference on Business, Engineering and Industrial Applications (ICBEIA). Kuala Lumpur, Malaysia. 5 - 7 June 2011.
3. N. S. Husain, B. S. Mahinder Singh, N.M. Mohamed. Remote Monitoring of Solar Electricity Generating System. Presented at International Conference on Fundamental &

Applied Sciences (ICFAS). Kuala Lumpur Convention Centre, Malaysia. 15 - 17 June 2010.

Appendix B: **Schematic Diagram for PIC16F877**



Appendix C: **Programmming code for PIC16F877**

```
#include <18f452.h>
#device ADC = 10
#fuses HS,NOWDT,BROWNOUT
#use delay(clock = 8000000)
#include <lcd.c> // include the driver for LCD display
#include <stdio.h>
#USE RS232 (baud = 9600, parity = N, xmit = PIN_C6, rcv = PIN_C7, stream =
stream_1, bits = 8)

unsigned int16adcValue1,adcValue2,adcValue3,totalvoltage1,totalvoltage2,totalvoltage3;
int i,j , K, t;
float PVVoltage1,PVVoltage2,PVCurrent,Battery ;

void main ( )
{
 set_tris_A(0xFF);// set port A as input
 set_tris_D(0xFF);// set port D as input

setup_adc_ports(ALL_ANALOG);
setup_adc(ADC_CLOCK_INTERNAL);
delay_ms(10);
lcd_init();

 while (true) {
  //PV voltage//
       totalvoltage1= 0;
       for (i = 0; i < 50; i ++)
        {
        set_adc_channel(0);//read from pin A0
        delay_us (200); // delay for sampling cap to charge
```

```
adcValue1 =read_adc();// get sampling ADC sampling
delay_us(200); // preset delay
     totalvoltage1 = adcValue1 + totalvoltage1;
     }
     adcValue1 = totalVoltage1/50;
     PVVoltage1    = ( 5.099 * adcValue1) /1023 ;//multiple voltage divider
```

//PV Current//

```
    totalvoltage2= 0;
    for (j = 0; j < 50; j ++)
     {
     set_adc_channel(1);//read from pin A2
     delay_us (200); // delay for sampling cap to charge
     adcValue2 =read_adc();// get sampling ADC sampling
     delay_us(200); // preset delay
     totalvoltage2 = adcValue2 + totalvoltage2;
     }
     adcValue2 = totalVoltage2/50;
     PVVoltage2  = ( 5.099 * adcValue2) /1023 ;//multiple voltage divider)
     PVCurrent  = (PVVoltage2/0.185);
```

//Batery Voltage//

```
    totalvoltage3= 0;
    for (K = 0; K < 50; K ++)
     {
     set_adc_channel(2);//read from pin A4
     delay_us (200); // delay for sampling cap to charge
     adcValue3 =read_adc();// get sampling ADC sampling
     delay_us(200); // preset delay
     totalvoltage3 = adcValue3 + totalvoltage3;
     }
```

```
        adcValue3 = totalvoltage3/50;
        Battery = (5.099 *adcValue3 /1023);

if (input (PIN_C2)&&~input(PIN_C3)&&~input(PIN_D0) && ~input(PIN_D1)
// if switch 1 is pressed
      {
        t= 0;
        lcd_gotoxy (1,1); // go to top left
        lcd_putc('\f'); // clear text from display
        printf(lcd_putc,"PV Voltage");
        lcd_putc('\n');
        printf(lcd_putc,"%f V ",PVVoltage1); // display PV voltage
        delay_ms(100); //delay
       }

else if (~input (PIN_C2)&&input(PIN_C3)&&~input(PIN_D0)&& ~input(PIN_D1))
// if switch 2 is pressed
     {  t=0;
        lcd_gotoxy (1,1); // go to top left
        lcd_putc('\f'); // clear text from display
        printf(lcd_putc,"PV Current");
        lcd_putc('\n'); //next line
        printf(lcd_putc,"%f A",PVCurrent); // PV Current
        delay_ms(200); //delay
      }

  else if (~input (PIN_C2)&&~input(PIN_C3)&&input(PIN_D0)&&~input(PIN_D1))
// if switch 3 is pressed
     {  t=0;
        lcd_gotoxy (1,1); // go to top left
        lcd_putc('\f'); // clear text from display
```

```
printf(lcd_putc,"Battery Voltage");
lcd_putc('\n'); //next line
printf(lcd_putc,"%f V",Battery); // Battery voltage
delay_ms(200); //delay
}

else if (input (PIN_C2)&&~input(PIN_C3)&&~input(PIN_D0) &&input(PIN_D1))
// if switch 1 and switch 4 are pressed
{
lcd_gotoxy (1,1); // go to top left
lcd_putc('\f'); // clear text from display
printf(lcd_putc,"PV Voltage");
lcd_putc('\n');
printf(lcd_putc,"%f V ",PVVoltage1); // display radiaition
delay_ms(200); //delay
printf ("        %i        %.2f        %.2f        %.2f
\n\r", t,PVVoltage1, PVCurrent, Battery);
delay_ms(5000);
t+=5;
}

else if (~input (PIN_C2)&&input (PIN_C3)&&~input(PIN_D0)&&input(PIN_D1))
// if switch 2 and switch 4  are pressed
{
lcd_gotoxy (1,1); // go to top left
lcd_putc('\f'); // clear text from display
printf(lcd_putc,"PV Current");
lcd_putc('\n');
printf(lcd_putc,"%f A ",PVCurrent); // display radiaition
delay_ms(200); //delay
```

```
printf ("            %i                  %.2f                  %.2f                %.2f
\n\r", t,PVVoltage1,PVCurrent, Battery);
        delay_ms(5000);
        t+=5;
        }

else if (~input (PIN_C2)&&~input(PIN_C3)&&input(PIN_D0) && input(PIN_D1))
```
// if switch 3 and 4 are pressed
```
      {
        lcd_gotoxy (1,1); // go to top left
        lcd_putc('\f'); // clear text from display
        printf(lcd_putc,"Battery Voltage");
        lcd_putc('\n'); //next line
        printf(lcd_putc,"%fV",Battery); // display tilt angle 2
        delay_ms(200); //delay
        printf ("            %i              %.2f                %.2f              %.2f
\n\r", t,PVVoltage1,PVCurrent,Battery);
        delay_ms(5000);
        t+=5;
      }

 else if (~input (PIN_C2)&&~input(PIN_C3)&&~input(PIN_D0)&& input(PIN_D1))
```
// if switch 4 is pressed
```
      {
        lcd_gotoxy (1,1); // go to top left
        lcd_putc('\f'); // clear text from display
        printf(lcd_putc,"Data Logging");
        delay_ms(200); //delay
        printf ("            %i              %.2f               %.2f             %.2f
\n\r", t,PVVoltage1,PVCurrent,Battery);
```

```
delay_ms(5000);
 t+=5;
    }

else if (~input (PIN_C2)&&~input(PIN_C3)&&~input(PIN_D0)&&~input(PIN_D1))
```

// if no switch is pressed

```
    {
    t=0;
      lcd_gotoxy (1,1); // go to top left
      lcd_putc('\f'); // clear text from display
      lcd_putc("PV System"); //
      lcd_putc('\n');
      lcd_putc("Monitoring "); //
      delay_ms(1000); //delay

      lcd_gotoxy (1,1); // go to top left
      lcd_putc('\f'); // clear text from display
      lcd_putc("Btn1:PV Voltage"); //
      lcd_putc('\n');
      lcd_putc("Btn2:PV Current"); //
      delay_ms(1000); //delay

      lcd_gotoxy (1,1); // go to top left
      lcd_putc('\f'); // clear text from display
      lcd_putc("Btn3:Battery"); //
      lcd_putc('\n');
      lcd_putc("Btn4:Data log"); //
      delay_ms(1000); //delay

      delay_ms(1000); //delay
```

```
 }
else
{
t=0;
  lcd_gotoxy (1,1); // go to top left
  lcd_putc('\f'); // clear text from display
  lcd_putc("Please check"); // wrong switch is pressed
  lcd_putc('\n');
  lcd_putc("the button again");
  delay_ms(200); //delay
}   }
}
```