INVESTIGATION ON STAND-ALONE SOLAR SYSTEM FOR RURAL ELECTRIFICATION

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INVESTIGATION ON STAND-ALONE SOLAR SYSTEM FOR RURAL ELECTRIFICATION

Abstract

Stand-alone photovoltaic systems along with a battery storage system play a significant role in providing electricity to remote off-grid communities. The main objective of this research project is to understand the design and operation principles of a stand-alone PV system.

The procedures for the design and sizing of a small stand-alone PV electricity system suitable for small off grid household has been reviewed. Subsequently, a manual sizing guideline is implemented in Excel sheet and compared with commercial software PVsyst.

To further understand the operation of the stand-alone PV system, simulation model has been developed in MATLAB/SIMULINK environment. Operations of the stand-alone PV system with PWM charge controller were studied under varying conditions. From the simulation, it was found that the matching of PV and battery voltage is important to ensure good energy yield in the system. Overall the project has provided good understanding on the various components and their operation concepts in stand-alone PV system.

Abstrak

Sistem photovoltaic berdiri-sendiri bersama-sama dengan sistem penyimpanan bateri memainkan peranan penting dalam membekalkan tenaga elektrik kepada masyarakat luar grid. Objektif utama projek penyelidikan ini adalah untuk memahami reka bentuk dan operasi prinsip-prinsip sistem PV yang berdiri sendiri.

Untuk lebih memahami operasi system PV yang berdiri sendiri, suatu model simulasi telah dibangunkan dalam persekitaran MATLAB/SIMULINK. Operasi sistem PV yang berdiri sendiri dengan pengawal caj PWM telah dikaji di bawah senario yang berbeza-beza. Daripada keputusan simulasi, adalah didapati bahawa pemadanan voltan PV dan bateri adalah penting untuk memastikan penghasilan tenaga yang baik dalam system solar tersebut. Keseluruhan projek ini telah memberikan pemahaman yang baik mengenai operasi dan konsep-konsep pelbagai komponen di dalam sistem PV berdiri sendiri.

Acknowledgements

First and foremost, I would like to give thanks to the ALLAH (Almighty) who has walked with me throughout this journey. I would also like to express my gratitude to my father, my mother and my sisters for their continued blessing and support.

I would like to express my deepest appreciation and gratitude to my supervisor Dr. Che to propose it in the midst of the work of my project. He encouraged me to continue to focus on achieving my goal. His observations and comments helped me identify the general direction and proceed with the investigation through and through it. He helped me in an unimaginable way and was a source of knowledge.

Special thanks to all faculty in in Energy Laboratory, UMPEDAC and the Faculty of Engineering in helping me and for proposal, thoughts, discussions and advice on finishing this research work My sincere thanks also goes to everyone who has furnished me with kind words, new thoughts, a welcome ear, helpful feedback, or their significant time, I am truly indebted

Lastly, I might want to thank our colleagues and all the staff individuals in Department who have directly or indirectly way added to the venture.

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D : duty cycle

G: Irradiance intensity (kw⁄m2)

Gref: Reference irradiance intensity 1000

I: Cell output current (A)

Isc: Cell reverse saturation current (A)

I_{sc_ref}: Reference cell reverse saturation current at (A)

I_{mp}: the optimum current for MPP for specific irradiance G

I_{sh}: Shunt current (A)

K: Boltzmann constant

P_{PV}: PV array power

q: Charge of electron = C

Rsh: Parallel resistance (Ω)

Rs: Series resistance (Ω)

T: Solar cell temperature (°C)

T: Ambient temperature (°C)

V_{oc}: PV open circuit voltage for specific irradiance G

V_{PV}: PV array voltage

V_c : Cell output voltage (V)

List of Abbreviations

AC Alternating Current

Ah: Ampere Hour

ARV: Array Reconnect Voltage

BHS: Battery Home System

CCCV: The constant current-constant voltage

CC: constant current

DC: Direct Current

DOD: Depth of Discharge

FF: Fill Factor

GDP: Gross domestic product

HVD: High Voltage Disconnect

IDCOL: Infrastructure Development Company Limited

IEA: International Energy Agency

LVD: Load Disconnect Voltage

LVR: Load Reconnect Voltage

MPPT: Maximum power point

NOCT: Nominal Operating Cell Temperature

PV: Photovoltaic

PWM: Pulse width modulation

RES: Renewable Energy resources

SHS: Solar Home System

SOC: Stat of charge

STC: Standard Test Condition

VR: Voltage Regulation

VRR: Voltage Regulation Reconnect

CHAPTER 1: INTRODUCTION

1.1 Introduction

The development of modern electrical energy delivery systems for developing countries, particularly among rural communities, is still a challenging issue in the world due to the high cost of power transmission infrastructure. As a result, many remote communities have to rely on on-site power generation based on diesel or gasoline generator. However, the utilization of diesel generators as the main power supply in rural areas has become burdensome to the communities due to the following reasons: firstly, diesel generators require daily fuel supply and periodic maintenance; secondly, the limited source of fossil fuels and the difficulty in accessing them remain a big challenge for most off-grid societies. Meanwhile the exploration of modern technologies based on sustainable energy systems has given hope in providing more cost effective and convenient means of electrifying the underdeveloped off-grid communities.

1.2 Motivation

"I'd *put my money on the sun and solar energy, what a source of power! Hope we don't have to wait until oil and coal run out before we tackle that "(Taylor, Daniel et al. 2015)*

[Thomas Edison, 1931]

Among the various renewable energy source, solar photovoltaic energy has received plenty of attention in the past few decades. The main reasons for this great interest are; **(1)** Increased efficiency of solar cells. **(2)** Modern technological improvements**. (3)** Green and environmental friendship. Practical applications of solar energy are the provision of residential loads and remote electrical installations.

It also has a major role in distribution network. The efficiency of solar cells is currently relatively low 12-20%, which means that the PV panel can reap a small amount of solar energy (conventional solar panels of 33.9% recently announced by Siemens and American company Cimpros). The photovoltaic business is developing internationally as fast as 30%, where China is a leading manufacturer of solar photovoltaic (PV) panels. As seen in figure 1.1, in 2016, China shipped solar panels totaling 34.54 MW regarding useable power(Brunisholz 2015). In 2016, a china only has 75% of the global solar transections (Cao and Groba 2013). Due to the high utilization of PV modules, several national and global companies are merged each year. With increasing competition in the market, the prices of photovoltaic units are decreasing over time (Feldman 2012).

In recent surveys, the average cost of PV panels per unit of power, has reduced from $ 1.61 to $0.8 as a contrast to the electricity prices which has risen steadily during the same period (Gambhir, Gross et al. 2014).This has further reduced the entry barrier for the adoption of solar PV energy in grid electrification.

The encouraging development in field of solar PV has made PV systems more accessible to the public, not just in terms of technology, but also in terms of cost. While there have been lots of effort in implementing grid connected PV farms to cut down reliance on fossil fuel, one significant potential of PV technology is in providing electricity to the remote off-grid communities. This is particularly true for areas around the tropical zones where the amount of sunlight is generally available to meet the request for electricity production. This sort of project is not new but if successfully carried out in large scale, it can bring revolutionary changes to the lifestyle and social welfare of the off-grid communities.

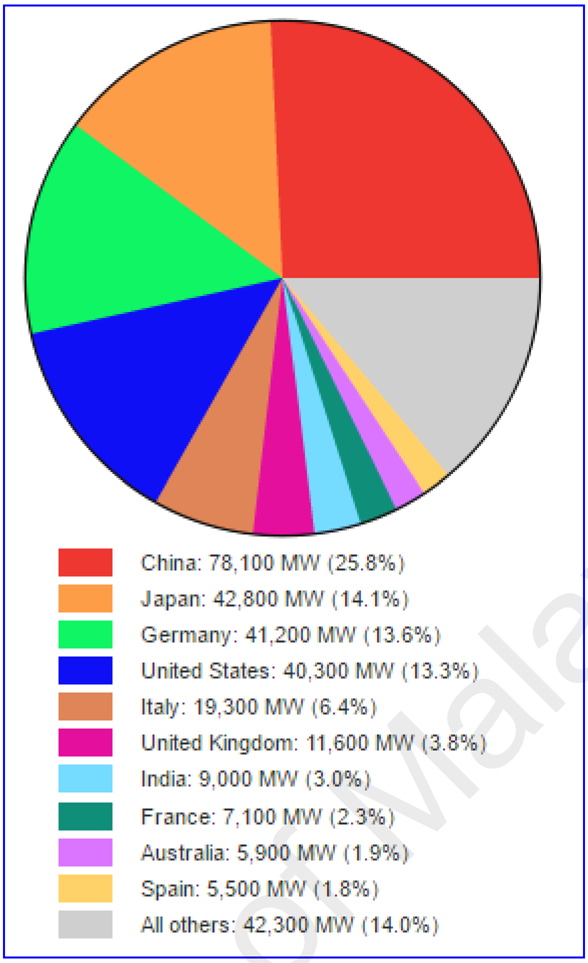

Figure 1.1: Top 10 countries in 2016 based on total PV installed

Malaysia is one of the tropical countries that can greatly benefit from the vast solar energy potential readily available to the nation. Due to the geographical factor of Malaysia, where it is located near the equator between 1° N and 7° N, 100° E and 119° E, the country receives approximately 6 hours of sunlight per day. It is hence very convenient to capture as much potential as solar energy for electricity use in the rural area. In Malaysia there are a lot of sectors joining hands in sponsoring PV systems including government and the private sector. This shows that solar energy has become one of the most desirable energy sources in Malaysia.

As seen from figure 1.2, solar radiation from Peninsular Malaysia declines towards the southern direction, with the state of Perlis enjoying the highest irradiance level.

For East Malaysia, Sabah gets the highest amount of solar radiation than Sarawak. The average daily sun peak hours in Malaysia range from 4-6 hours per day, giving approximately 5.1 to 5.5 kW/m^2.(Mekhilef, Safari et al. 2012)

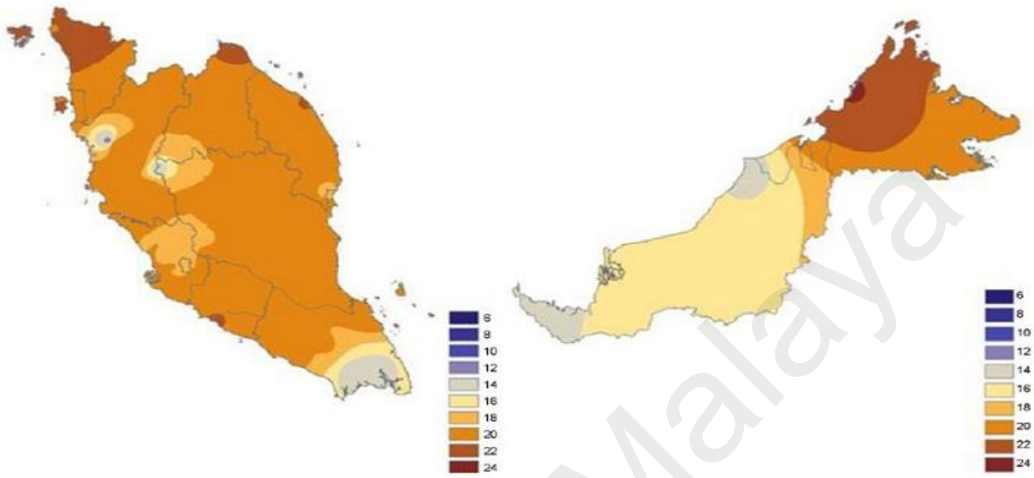

Figure 1.2: Average daily solar radiation in Malaysia

1.3 Problem statement of research

Currently, photovoltaic system is considered the one of the most cost-effective and convenient solution to be used for local generation in remote areas, since it does not use any rotating parts or requires complicated supporting civil structure. Nevertheless, it is well known that photovoltaic power cannot fully control to meet the energy demand due to intermittent weather conditions of solar energy. As a result, energy storage systems, usually batteries, need to be used in stand-alone PV system, which increases the cost and complexity of the system. The sizing of the solar panels and batteries, as well as the selection of suitable charge controller is detrimental in deciding the performance of the system. Hence, it is important to understanding the underlying principles for PV system design and sizing, as well as the effect on the choice of components in the system.

This project intends to study the practical operating principles of the various commercially available stand-alone solar system, in order to provide recommendations on how to sizing and/or improve the overall system performance.

1.4 Thesis objectives and contributions

1.4.1 Objectives

The objectives of this project are as follows:

1. To study the operating principles of the component equipment in a commercial stand-alone solar system.
2. To study the sizing principles for the components in a stand-alone PV system
3. To verify the operation of a stand-alone solar system using MATLAB simulation, highlighting the importance of matching the solar panel with the system voltage.

1.4.2 Contributions of the thesis

The primary aim of this work is to model, analyze and control a stand-alone PV system. Some of the notable points achieved in this thesis are:

1. The characteristics of a typical solar photovoltaic panel have been investigated, where the effect of temperature and irradiation changes on the output properties of the PV solar array was studied.
2. The structure and operating principles of the component equipment, particularly the charge controller, in a stand-alone PV system have been studied.
3. A set of a design principle for stand-alone PV system has been identified and compared with commercial design software, i.e. PVsyst.
4. A simulation model has been constructed to allow the evaluation of a stand-alone PV system based on PWM charge controller.

5. The effect of solar panel selection in terms of energy yield has been investigated using the constructed Matlab simulation model for the case when low cost PWM charge controller is used.

1.5 Outline of thesis

The outcomes of this project have been reported in five chapters, as follows:

Chapter 1: Provides an introduction to the project, giving the background, problem statement, objectives, scope of the project, and the thesis outline.

Chapter 2: Reviews literature related to the scope of this project based on journals and other references. It explains the operation principles of various components in a stand-alone photovoltaic system

Chapter 3: Focuses on the design and sizing principles of a stand-alone PV system. From the first principles, an Excel sheet has been prepared to allow manual sizing of the PV system. The results obtained are found to be comparable with those obtained from commercial software.

Chapter 4: Shows the complete modeling, simulation, and validation of the proposed system. The effect of weather condition, temperature of the panel as well as the issue of PV and battery voltage matching has been simulated and discussed in this chapter.

Chapter 5: Concludes the overall findings obtained from this project and provides some recommendations for future works.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In the previous chapter, the purpose of the project has been briefly explained. In this chapter, literature review will be presented to provide some background knowledge on various important aspects of a standalone PV system for rural community.

2.2 PV systems

Photovoltaic systems operate primarily in three modes, namely stand-alone mode, grid-tied mode, and hybrid mode (Goel et al, 2017). While grid-tied PV is common nowadays due to Feed-in-Tariff, stand-alone PV systems are important in remote and rural areas where electrical grids are not available. In 1968, a 48 Wp PV system was utilized to power an academic TV for a faculty in Niger (In 2014). It was the first formally reported photovoltaic application in rural electrification. Since then, more PV installations had been established, ranging from small-powered street-lighting or solar pump to large-scale solar home systems.

Since solar energy is intermittent and time dependent, it is to critical include a storage device, usually battery, in a stand-alone PV system to ensure the load demand can be met at all times. On the other hand, a storage device is not an important component of grid-connected PV systems, although it can sometimes be used to minimize voltage fluctuations, and emergency power supplies (Gambhir, Gross et al. 2014) For solar PV system operate in hybrid mode, the system is usually connected to the grid in normal operation and can transit into stand-alone mode when necessary, such as during grid outages. Since focus of this project is on stand-alone PV system, the literature review presented in subsequent parts of this chapter will focuses on stand-alone system only.

2.2.1 Configurations of stand-alone pv system

Stand-alone PV systems are designed to work independent of the electrical tie grid and are generally designed and sized for feeding some DC and / or AC electrical loads. Depending in their configurations, the systems may differ in terms of their structure and components. There are generally three main configurations: direct-coupled stand-alone PV system, stand-alone PV system with battery and stand-alone PV hybrid system.

The simplest configuration of stand-alone PV system is the direct-coupled system, where the PV module is directly connected to the load as shown in figure 2.1. Since there is no energy storage devices (batteries) within the direct-coupled systems, loading works solely throughout the daytime, creating these styles appropriate for common applications like ventilation fans, water pumps, and utilization pumps for solar thermal heating systems. Matching the resistance of the electrical load to the maximum power output of the PV array is an important issue in direct-coupled system. for a few loads like positive water displacement pumps, a DC-DC converter, referred to as Maximum Power Point Tracker (MPPT), is employed between the array and load to assist higher utilize the available array maximum power output (Bhatia 2014).

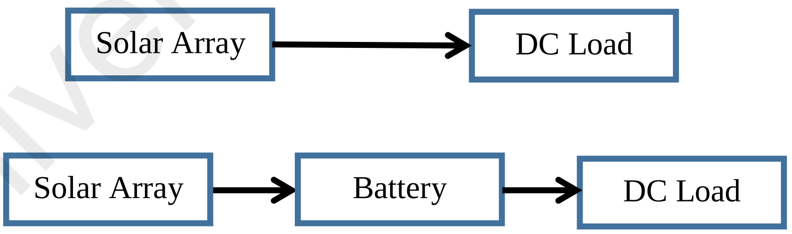

Figure 2. 1: Direct-coupled PV system.

In most applications, electrical power is needed not just during the day, but also during the night or when the solar irradiance is not good due to cloudy or rainy weathers. In such applications, the use of energy storage devices, particularly battery, become important for the standalone PV system. A charge controller is usually used to interface between the PV panel, the battery and the load, to protect the battery from overcharging and voltage fluctuation. (Manju, Ramaprabha et al. 2011) figure 2.2 shows a diagram of a typical stand-alone PV system with battery, driving DC and AC loads.

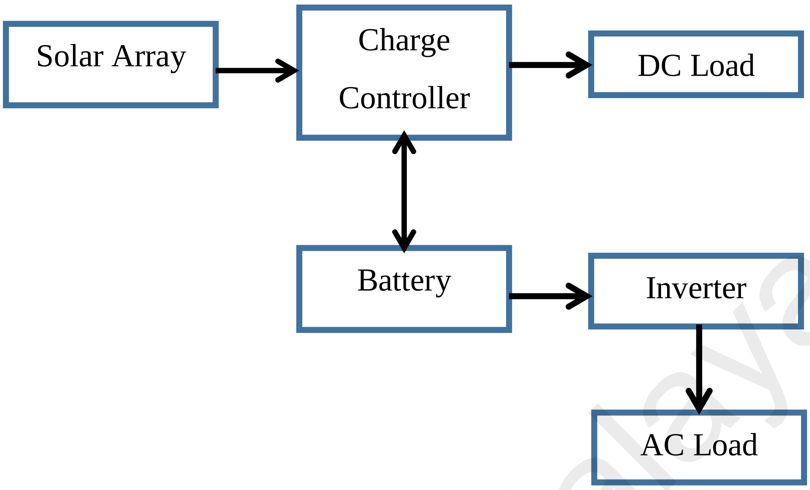

Figure 2. 2: Diagram of a stand-alone PV system with battery storage.

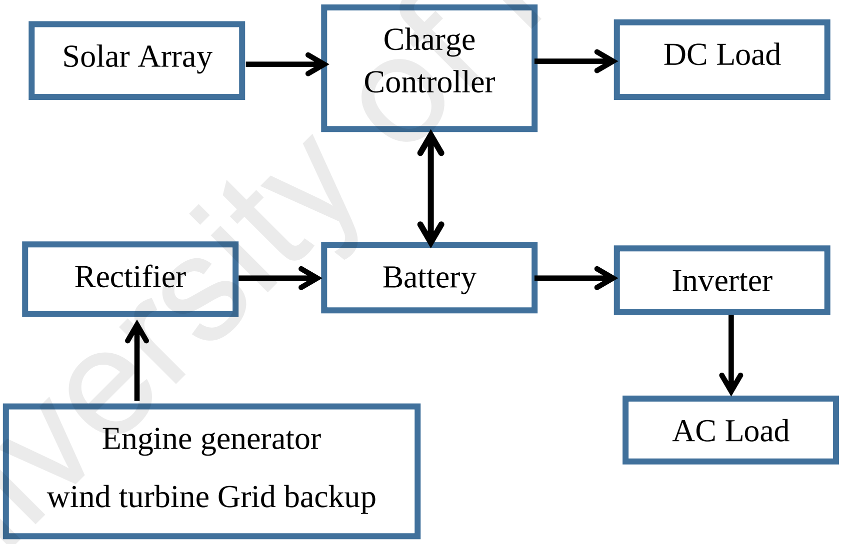

Figure 2.3: Diagram of the stand-alone PV hybrid system.

In stand-alone PV system with battery storage, the correct sizing of battery is important to ensure that the system can continue in providing power in the absence of power from PV. To reduce the dependency on battery, stand-alone PV hybrid system can be used, where alternative energy sources, such as engine generator or wind turbine, are used as backup energy to the PV. figure 2.3 above shows the composition of the stand-alone PV hybrid system.

Among the three configurations, stand-alone PV system with battery is most suitable for small scale rural electrification. Compared to the direct-couple configuration, the use of battery ensures power continuity for the user; while compared to the PV hybrid system, the cost and complexity of the PV-battery system is much favourable.

2.3 Components of stand-alone pv system with battery

The PV system includes various elements that need to be chosen based on the kind of PV system, its location, and the intended applications. Its components must be connected and balanced to form an energy system that is functionally capable of providing electrical energy. These components are PV panels, battery, charge controller, inverter, load and wiring etc. (Pal, Das et al. 2015)

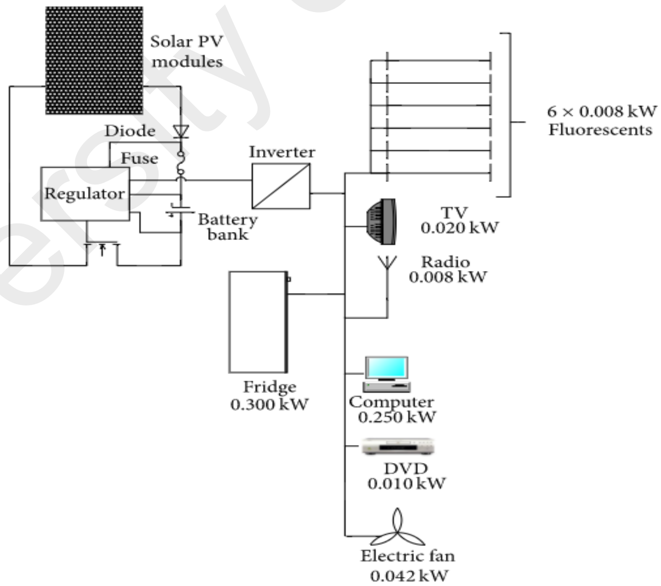

Figure 2.4:Typical of stand-alone PV System (Kanteh Sakiliba, Sani Hassan et al. 2015)

2.3.1 PV panels

2.3.1.1 Solar Photovoltaic Cells

A PV panel essential is made up from multiple solar photovoltaic cells connected in parallel and/or series. Hence understanding the operation principles of photovoltaic cells is detrimental in understanding the operation of a PV panel.

Photovoltaic cells are semiconductors that used to produce electricity by converting light vie effect of the optical photon. If the optical photon energy is larger than the band gap, the electron emits and the flow of electrons creates the current. Photovoltaic cells are completely different from the photodiode as shown in figure 2.5 (Nithiyananthan,2017); The light is converted to a photovoltaic stream on the N-channel from the semiconductor to the current or voltage signal, however, photovoltaic cells are often biased forward.

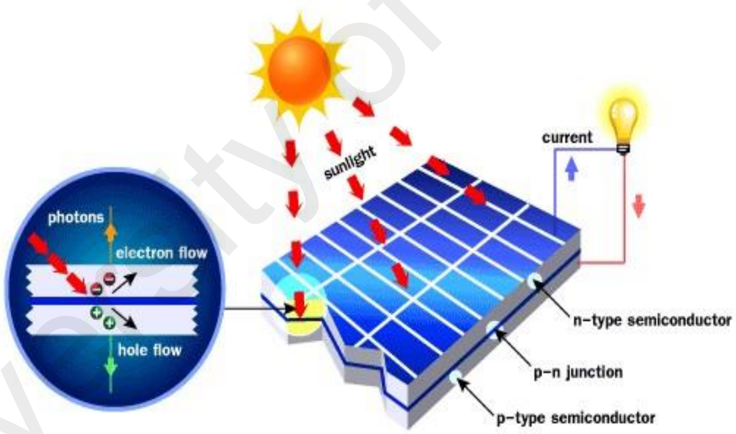

Figure 2.5: The Basic operating principle of a solar cell

Photovoltaic (PV) technology utilizes semiconductor (chip) cells, typically several centimeters square. The cell is largely a p-n diode with a link positioned near the top surface. A diverse cell area unit is assembled into a very module to generate the required power.

In the solar power generation system, a set of solar cells is needed to supply high power so that it is connected to a type of solar module or solar panels and to formulate the higher array capacity as shown in figure 2.6.

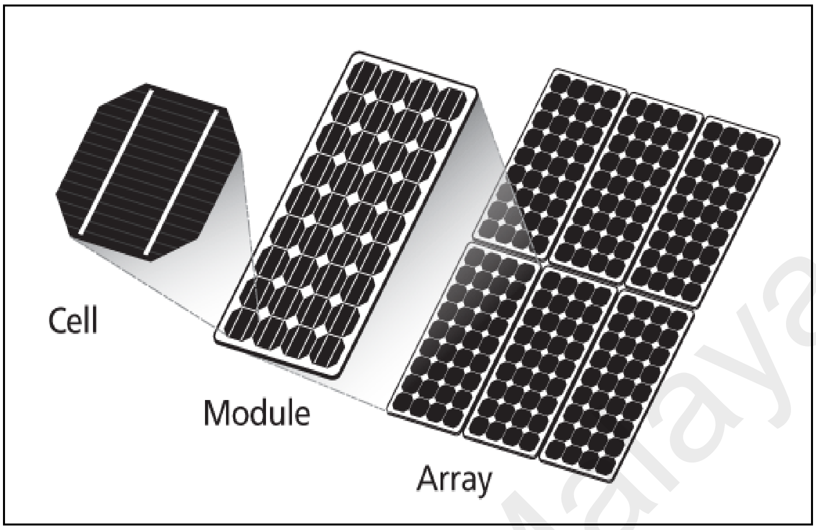

Figure 2. 6: Solar Module and solar PV Array

There are three main types of solar cells commercially available in the market:

(1) Polycrystalline cell is more efficient than thin-film solar cell but that is more expensive to produce. They are most commonly uses in large to medium electric applications like grid connected PV power generation

(2) Monocrystalline cell is manufactured by pure semi-conducting materials so it has higher efficiency (above 17% in industrial production and 24% in research laboratories (Bruton, Mason et al. 2003). Poly-crystalline solar cell is slightly less efficient than Mono-crystalline but less in cost.

(3) Thin film cell very thin layers of semiconducting materials are uses so they can be produces in large quantity at lower cost but it efficiency is less. This technology is uses in calculators, watches and toys etc. There are too many other PV technologies available like Organic cells, Hybrid PV cells combination of both mono crystalline and thin film silicon etc.

Table 2.1: Comparative capital required for solar panel

Type Panels	Mono-crystalline 	Poly-crystalline 	Thin Film 
Efficiency	14 % -18 %	12 % -14 %	5 % -6 %
Temperature	0 % - +5 %	-5 % -+5 %	-3 %- +3 %
Life time	25-30 years	20-25 years	10-20 years
Durability	25y warranty	25y warranty	25y warranty
Cost per watt	0.79 $	0.73 $	0.73 $

2.3.1.2 Photovoltaic cell mathematical model

There are completely different mathematical models in typical photoreceptor models that offer a near-linear behavior of solar cells. The accuracy of each model is categorized in line with the number of internal phenomena that are thought of. A typical solar cell is usually drawn by a p-n diode connected to an existing source (Aashoor, 2015), with its equivalent circuit as depicted in figure 2.7 The fundamental model doesn't provide a high vary of accuracy however it shows the fundamental behavior of the cell.

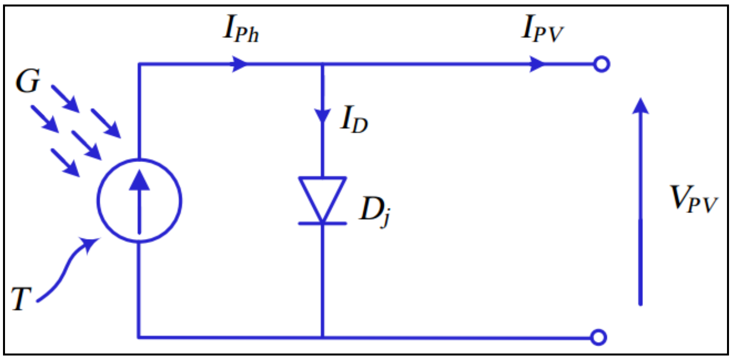

Figure 2.7: Simple model of photovoltaic cell

The current supply represents the photocurrent made by daylight and also the diode obtains the current-voltage properties of the cell. The current-voltage properties will be obtained by applying Kirchhoff's law of current as in the which provides equation

$$I_{pv} = I_{ph} - I_D \tag{2.1}$$

As shown in Figure 2.7, the D_J is the ideal diode p-n and outlined the diode internal diffusion current and I_{Ph} the photocurrent, is proportional to the radiation and surface temperature. Illustration of this voltage and current solar cell by V_{PV} and I_{PV}, respectively. The diode internal diffusion current is expressed by Equation 2.2

$$I_D = I_S\left[\exp\left(\frac{qVpv}{AKT_c}\right) - 1\right] \tag{2.2}$$

where q is electron charge, 1.6 × 10-19 C, A is diode ideality factor takes the value between 1 and 2, k is Boltzmann constant, 1.38 × 10-23 J / K, and Tc is the operation temperature of a cell in Kelvin. the varies of dark cell saturation, IS, affected by the operation temperature according to equation 2.2. The photovoltaic current, I_{Ph}, is related to solar intensity and cell operating temperatures as shown in Equation 2.3.

$$I_{ph} = \left[I_{sc} + k_i\left(T_c - T_{ref}\right)\right] \cdot \frac{G}{G_r} \tag{2.3}$$

where

K_I = temperature coefficient of the cell's short circuit given in A/K,

T_{ref} = reference temperature of the cell in K, which is 298 K (25°C) by default,

G = the solar insolation in W/m^2, with reference value being Gr = 1kW/m^2.

I_{SC} = short-circuit current, which is measured under standard test of 25°C and 1kW / m^2

The value of I_s can be obtained as

$$I_S = I_{RS}\left(\frac{T_c}{T_{ref}}\right)^{\left(\frac{3}{A}\right)} \cdot \exp\left[\frac{q \cdot E_{gap}}{A \cdot k}\left(\frac{1}{T_{ref}} - \frac{1}{T_c}\right)\right] \qquad (2.4)$$

where E_{gap} is the band gap energy of the semiconductor used in the cell. I_{RS} is the cell's reverse saturation current in Ampere at T_{Ref}, and solar radiation 1kW / m^2 which can be obtained by Equation 2.5

$$I_{RS} = \frac{I_{sc}}{\exp\left(\frac{q \cdot V_{oc}}{AkT_{ref}}\right) - 1} \qquad (2.5)$$

where V_{OC} is the open-circuit voltage at a reference temperature.

While the model in figure 2.7 is sufficient to gives the characteristics of a PV cell, in some applications, more detailed models including the parasitic series and shunt resistances is need figure 2.8 shows a more accurate model that includes parasitic parts, i.e. the shunt resistance R_{Sh} , series resistance R_S . Using this model, I_{PV} cell current PV cells is given as.

$$I_{pv} = I_{ph} - I_S\left[\exp\left(\frac{q \cdot (V_{pv} + I_{pv} \cdot R_S)}{A \cdot k \cdot T_c}\right) - 1\right] - \left(\frac{V_{pv} + I_{pv} \cdot R}{R_{sh}}\right) \qquad (2.6)$$

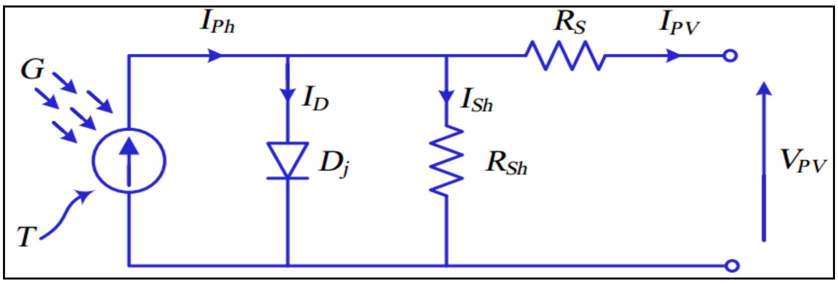

Figure 2.8: Complete general model of photovoltaic cell

2.3.1.3 Characteristics of pv cells

Through series or parallel connection, PV cells form PV modules, which can then be further connected in strings to provide the desired voltage, current and power. To explain the characteristics of a PV module, current-voltage (I-V) curve is the way to show the performance of the PV module, and through it, some vital parameters of a PV module will be obtained. (Wang 2011)

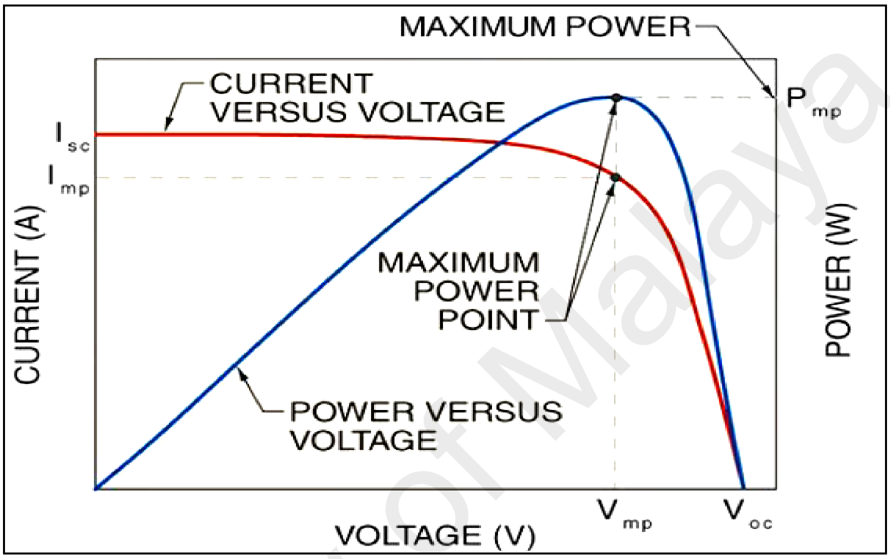

Figure 2.9: I-V properties of PV modules

Figure 2.9 shows a basic I-V curve for PV module, highlighting key parameters such as short-circuit current (I_{sc}), maximum power current (Imp), open-circuit voltage (Voc), maximum power voltage (Vmp), and maximum power point (MPP). All these parameters may vary depending on the irradiance and temperature of the PV module. Within the I-V curve figure, the maximum power point is that the module operational point at which the module produces maximum power; the corresponding current and voltage are known as maximum power current and maximum power voltage respectively. This value is used to evaluate the performance of photovoltaic units under standard test conditions or other conditions. (Villalva,2009), (Aashoor 2015)

It is well known that the output power of a PV cell varies with the solar irradiance. Generally, the variation in solar irradiance has a small influence on voltage but the bigger influence on current, where the current approximately changes linearly with irradiance.(Villalva, Gazoli et al. 2009) These characteristics are as shown figure 2.10

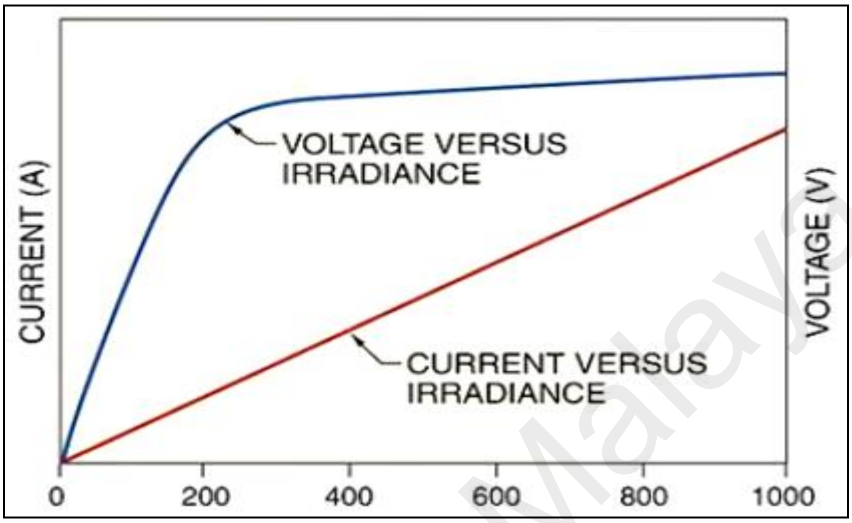

Figure 2. 10: Solar irradiance response

Apart from irradiance, temperature also affect the cell performance. The rise of temperature will cause a dramatic fall of voltage but only a little increase of current, thus higher operation temperature reduces power output and module efficiency. Long duration high temperature environment also leads to damage of PV modules. So, it is desired to install modules in a place where is cool enough. Temperature affection on modules is shown in the figure 2.11 below. (Wang 2011)

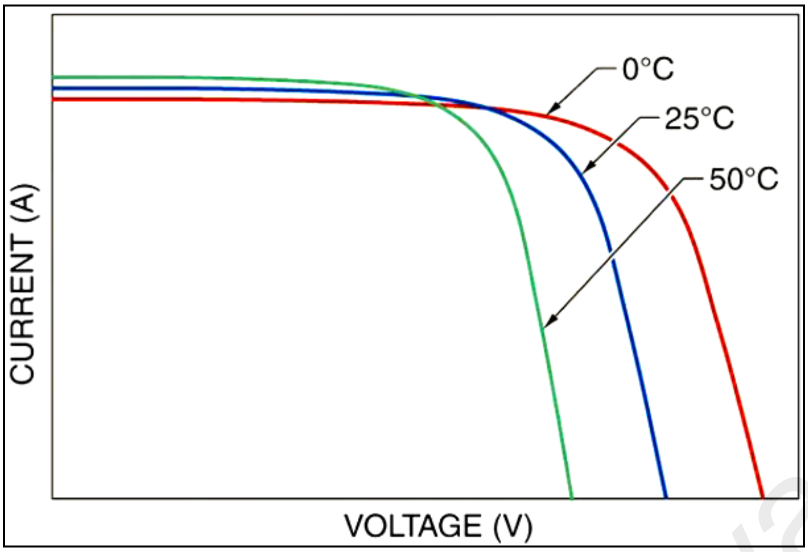

Figure 2.11: Voltage will drop due to temperature increase

2.3.1.4 Fill Factor (FF)

The photovoltaic fill factor is the ratio of the maximum output power (MPP) to the product of the open circuit voltage and short circuit current, as follows

$$FF = \frac{I_{MPP} \cdot V_{MPP}}{I_{SC} \cdot V_{OC}} = \frac{Green\ Area}{\text{Blue Area}} \tag{2.11}$$

It determines the form of PV module characteristics as shown in figure 2.12. Fill factor plays a vital role in differentiating photovoltaic cells performance, where a high fill factor indicates high-performance cell with minimum internal losses.

After a simple multiplication results the following equation

$$I_{SC} \cdot V_{OC} FF = I_{MPP} \cdot V_{MPP} = P_{\max} \tag{2.12}$$

where V_{MPP} is voltage in MPP and I_{MPP} is current in MPP. The ranges of fill factor varies depending on material and it is invariably < 1, with a common fill factor being around 0.6-0.8.

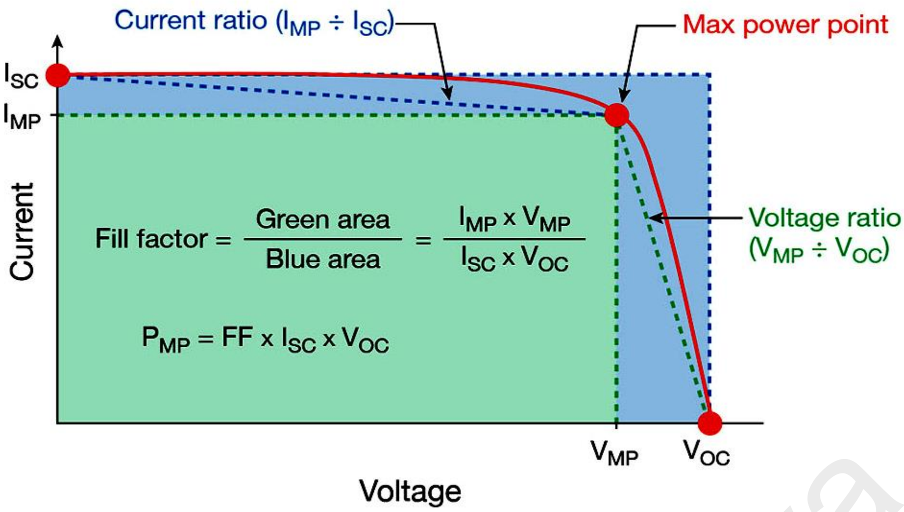

Figure 2.12: Photovoltaic module characteristics showing the fill factor

2.3.1.5 PV module configurations

Usually a typical output power of solar cells is very low. They're sometimes below 2W at 0.5V. Hence, the photovoltaic cells are connected specifically configurations thus as to form an array that is named a photovoltaic module. Generally, the modules are unit created from a set of cells connected parallel and serial to produce the required output power and voltage as shown in figure 2.13 additionally to the PV system, a set of PV modules is connected in series and parallel in kind of PV array to get the specified voltage and current values. Once two or additional solar panels are linked in series, the same current flows through every panel furthermore the output voltage is the total voltages produced by every panel. Thus, Equation (2.6) may be written as

$$I_{PV} = N_P I_{ph} - N_P I_S \left[\exp\left(\frac{q}{A \cdot K \cdot T_C} \left(\frac{V_{PV}}{N_S} + I_{PV} \cdot \frac{R_S}{N_P} \right) \right) - 1 \right] \qquad (2.13)$$

On the opposite hand, once the solar panels are connected in parallel, the output voltage remains identical. Therefore, the output current becomes the total of the currents of every panel,

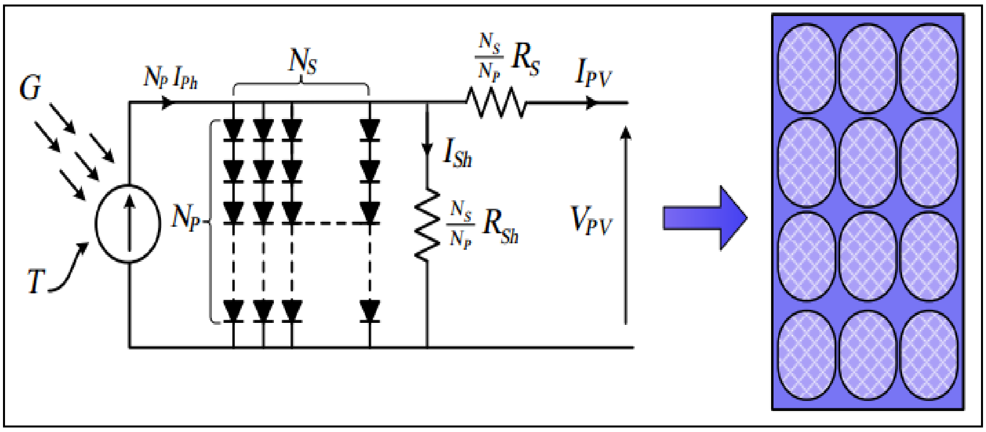

Figure 2.13: Solar model in parallel and series branches.

2.3.1.5.1 Series connection

Figure 2.14 series connection for PV cells and modules. Series connection allows that voltage of all the connected cell/modules to stack up to form higher voltage, but the current is restricted to the lowest among the connected cell/module.

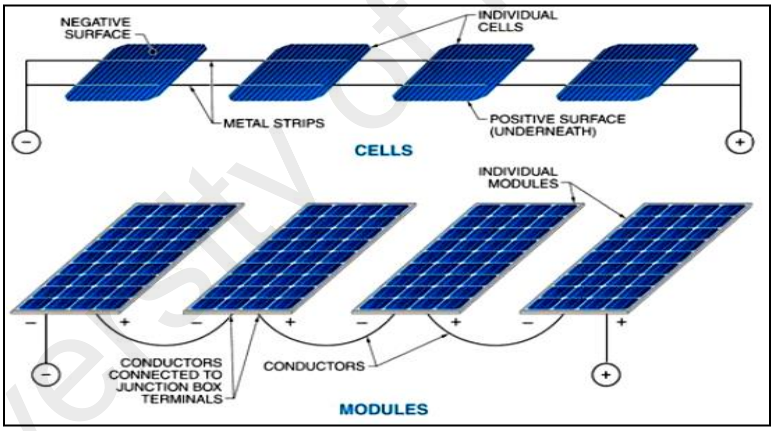

Figure 2.14: Series connection PV module and array

As show figure 2.15 below, if modules with a different I-V curves are connected together power loss will occur, because only the lowest current can be the output of the entire module. However, modules with different voltages can be connected in series if their output currents are the same. In this case it will not have power loss. (Wang 2011)

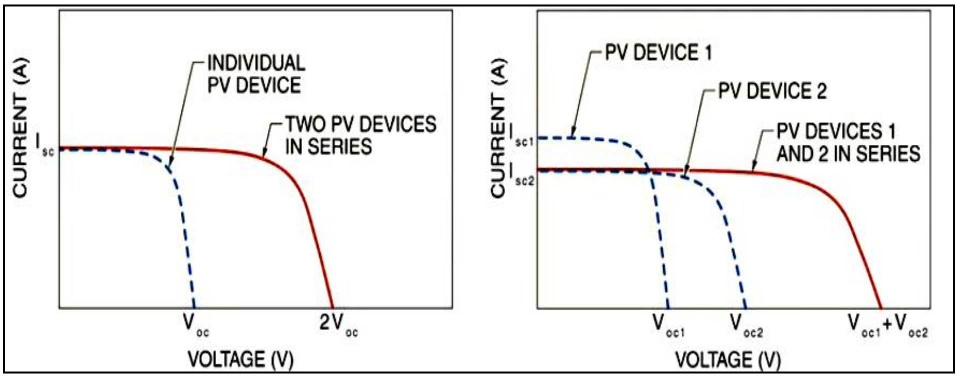

Figure 2.15: V-I outputs for similar module and dissimilar module

2.3.1.5.2 Parallel connections

When PV cells or modules are connected in parallel as shown in figure 2.16, the total output current is the addition of every branch's current and voltage is the same for all cell or module string.

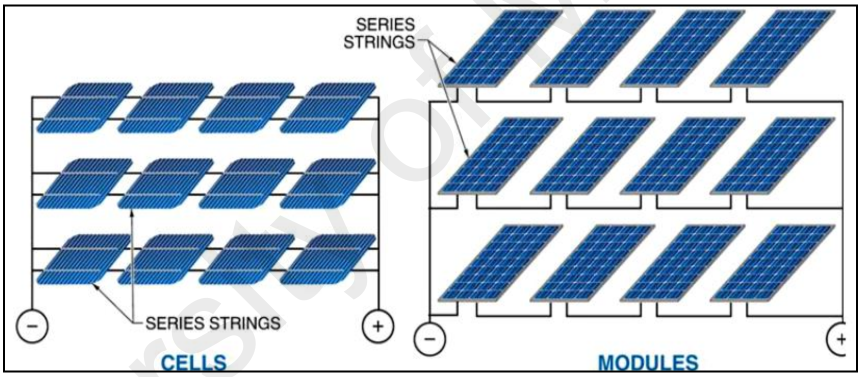

Figure 2.16 :Parallel connection PV module and array

If two different modules are connected in parallel the voltage is the average value between the two voltages.

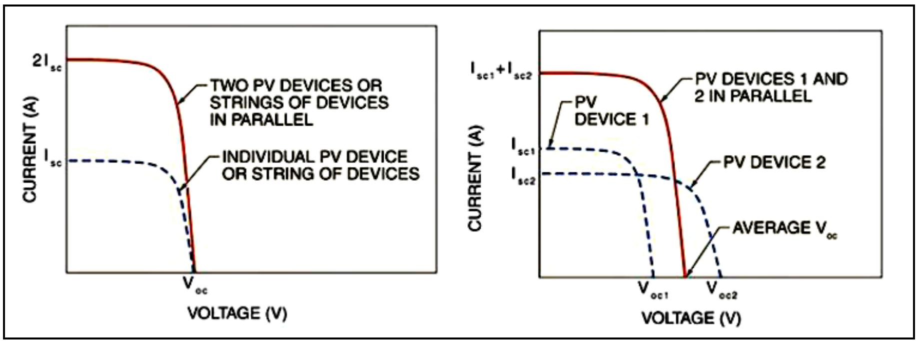

Figure 2.17: V-I outputs for similar module and dissimilar module

2.3.1.6 Bypass diodes

Sometimes PV modules will experience reverse-bias situations where a negative voltage will be generated instead of normal positive voltage. In some other cases, the cell/module maybe open-circuit or broken. Such conditions maybe reduce the cell/module string where the faulty cell is located, and in worst case (such as if the cell is open-circuited) will cause the whole strong to cease function.

A bypass diode is usually used to prevent these phenomena. It is connected in parallel with PV cells. In normal conditions the current will flow through cells and in the case of a broken/damaged cell, current can still pass through bypass diode to charge the battery. Without bypass diode the reverse voltage will reach breakdown voltage and finally damage the modules. Usually a bypass diode will limit the breakdown voltage to 0.7 V

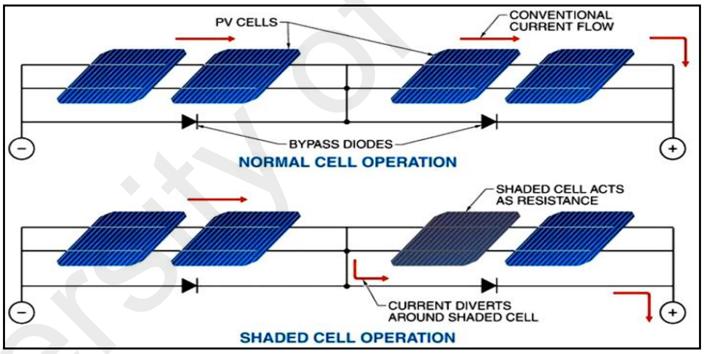

Figure 2.18: Bypass Diodes in Photovoltaic Cell

The most popular solar photovoltaic panel for solar charging applications consist of 36-cell module which gives around 21.6 volts. a peak cell voltage of 0.6 volts reduced to regarding 16.5 volts under full load conditions. Figure 2.16 &figure 2.20 .36cells solar panels are higher for very popular climates so as to offset power output loss from the upper operative temperatures.(Yongji and Deheng 1992)

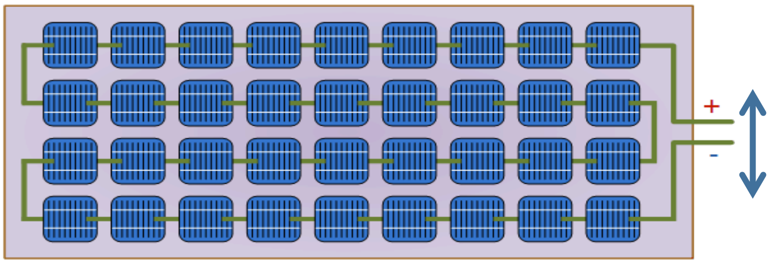

Figure 2.19: Typical 36 Cell Photovoltaic Panel

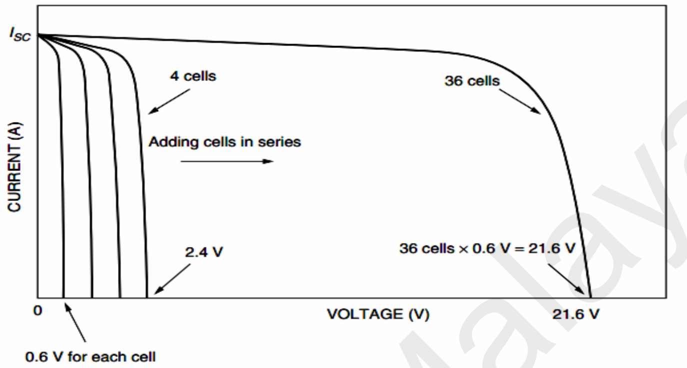

Figure 2.20: 36cells wired in series, parallel (Masters 2013)

2.3.1.7 Importance of PV module size

PV modules are the ones supplying energy to the system. Without the idea of how the rated power should is used will cause trouble to the system. If PV modules are oversized, there will be an additional expense to the total cost of the system. Performance is also affected. One scenario is that the PV module will charge the battery faster in a day. This may sound good but the truth is the energy that the PV module can give is not totally used, especially from a stand-alone system because the energy that it can give after charging the battery at full charge is just thrown away. On the contrary, undersized PV modules may require longer charging hours or in the worst case is that it will reach two or more days to fully charge the battery. Therefore, correct sizing of PV module is necessary in order to optimize the system.

2.3.1.8 Simple panel load matching

One of the best techniques used for high performance by matched panel load technique to running a PV array close to the maximum power point. in this technique, the optimum in operation point of a photovoltaic array is determined is set either by a series of measurements under common operating conditions

The load is selected to obtain the values of voltage and current like the MPP. It's widely used worldwide in PV solar charger systems that involves selecting the common battery voltage close to the common V_{MPP} solar panels. It has the advantages of simplicity and no further electronic equipment is employed, consequently, the power loss among the panel and battery is reduced and therefore the hazard of component failure is saved low for the whole system. However, the system doesn't take into consideration changes in radiation or temperature (Walker 2001)

The load resistance value is given by:

$$R_{MPP} = \frac{V_{MPP}}{I_{MPP}} \tag{2.14}$$

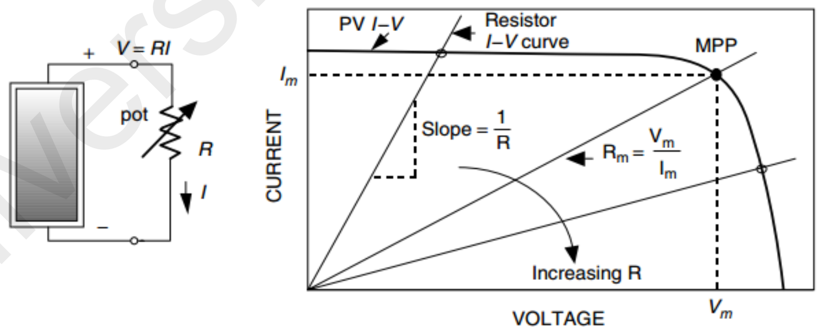

Figure 2.21: Matched to the maximum load demand. (Masters 2013)

As a solar panel output power, maximum power changes are generated with climatic conditions (solar radiation and temperature) and also the electrical properties of the load. Thus, the interior PV resistance varies seldom matches the load resistance. It's important to perform the photovoltaic generating system at the MPP or near it to confirm best solar use accessibly

In figure 2.22 the power of the photovoltaic module can be reduced with a constant resistance load designed for sunlight conditions with varying radiation. The solid maximum power point (MPP) dots show the operating points that may result in maximum PV power

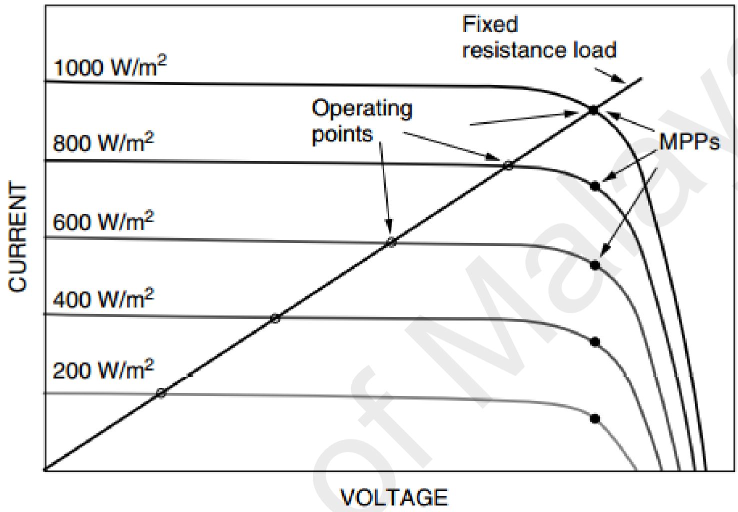

Figure 2. 22: Operating points of a PV module with load

Finally, the tilt angle of PV panel is also important in determining the amount of sun light it will capture. In (Khasawneh, Damra et al. 2015), the authors highlighted that the incline angle of the solar panel impacts the output of the photovoltaic array because it changes the amount of solar radiation incident on the panel. For that reason, the installation of PV panels at an optimum angle helps to reduce the cost of electricity (LCE) by increasing the energy production of the same PV system installation.

2.3.2 Battery

For stand-alone PV system, battery is critical due to the irregular nature of the solar energy. There are various types of batteries that can be used for standalone PV system, such as lead acid, nickel- cadmium (Ni-Cd) and lithium battery.

For rural application, lead acid is still the most commonly used battery (Copetti, Lorenzo et al. 1993) due to the lower cost and better availability and safety compared to Ni-Cd and Lithium batteries. In most PV systems, the batteries used are valve regulated lead acid (VRLA) that contains two sub-types: GEL cell and AGM. (Dunlop and Farhi 2001)

2.3.2.1 Battery capacity

Capacity measures energy storage capability of batteries and is expressed as Ampere hour (Ah). Capacity can be influenced by several parameters including temperature, charge and discharge and age. Usually batteries will have better capacity under higher temperature than cold conditions, but excessive high temperature also reduces the battery life. The manufacturer usually defines battery capacity in terms of discharge rate as well as main parameters as Voltage, and Amp-hour capacity. For example, for a 100 Ah battery being discharged continuously at a constant current of 5A, the battery will be fully discharged in 20 hours, or in terms of the Crate or C/rate will be C20 or C/20.

The discharge characteristics of a battery depends on the discharge current as well. Figure 2.23 provides discharge curves of the TR1.3-12V sealed lead acid battery

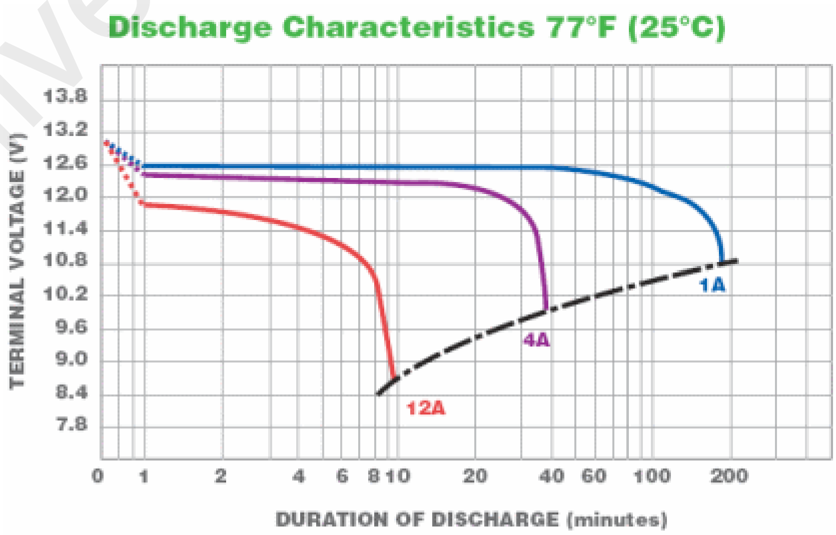

Figure 2.23: Discharge characteristics of the TR1.3-12V

As seen from the figure, the operating voltage for the 12 V battery ranges between 10.5 to 14 V.

➢ **The depth of discharge (DOD)**

The DOD is used to determine the extent in which the amount of charge in the battery has been used up. The battery cycle life, i.e. the number of times the battery can be discharged and fully charged back, depends on the DOD. The relationship between the cycle life and depth of discharge demonstrate a logarithmic nature as shown in figure 2.14.

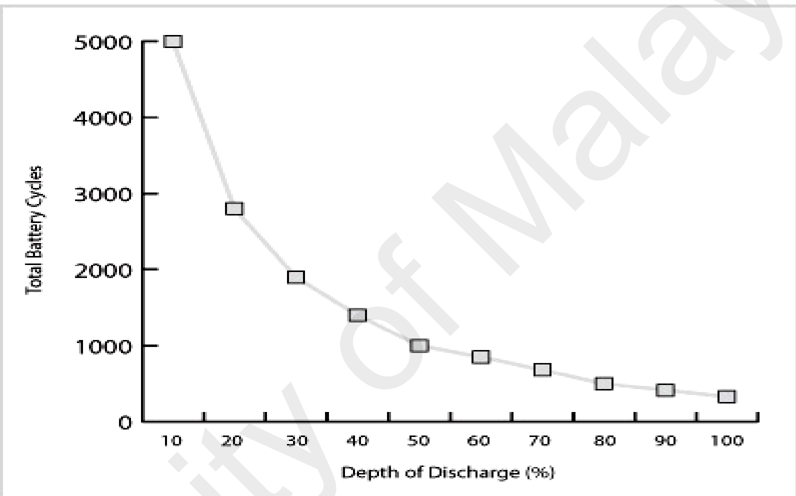

Figure 2.24 : Depth of Discharge vs Cycle Life

In sizing the battery, the maximum allowable DOD is important: lowering DOD will increase cycle life of the battery but does not operate the battery at its full potential which lead to over sizing. Therefore, when installing a PV system, the installer must choose the right DOD to avoid oversize or under size batteries. Generally, the right DOD is set to 50% to 75%. (Dunlop 1997)

➢ **State of Charge (SOC)**

Contrast to DOD, SOC is the amount of stored energy remaining in the battery. A 100% SOC indicates that the battery is fully charged, 75% of SOC indicates that three quarters of storage capacity remains and so on. The SOC can be estimated from the battery voltage, but not to a very accurate level. The relation between SOC and DOD for a 12 V battery is as shown in figure 2.25.

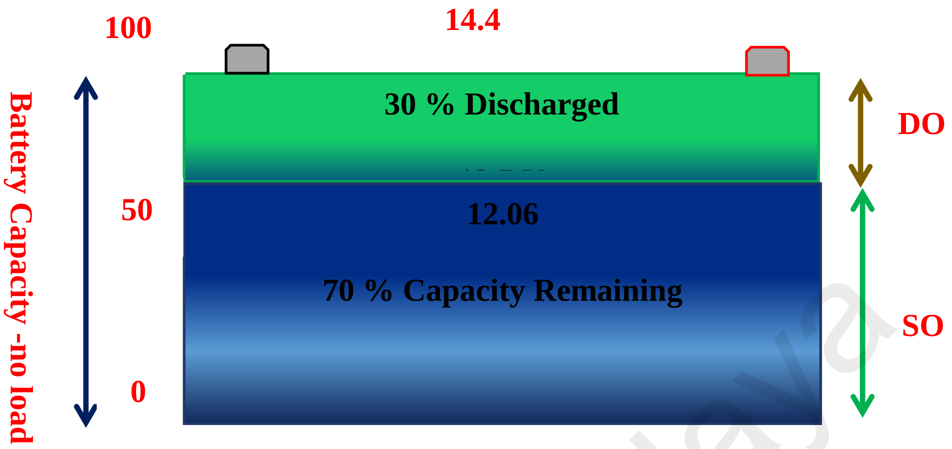

Figure 2.25 :SOC level of 12 V Battery

2.3.2.2 Choice of battery voltage

In a stand-alone PV system with a direct connection to DC load (without inverter), the battery voltage determines the distribution voltage directly. The selection of the battery voltage, hence the system distribution voltage, depends largely on the voltage requirement of the equipment.

For stand-alone PV systems with AC load, inverter is used to converter the battery voltage to higher AC voltages. In such case, the choice of the distribution voltage depends various factors such as the power (current) handling capability of the components, wiring sizes, future plan for the extension of the systems, etc. Taking into account the fact that commercial batteries are in the multiple of 12Vs, the commonly used voltage levels are 12V, 24V and 48V.

This decision ought to be created in the first part of installation since the present appliance voltage sometimes cannot be modified, and voltage regulators are going to be costly and not economical. The rated distribution voltage can be chosen in line with the subsequent criteria

12V: Small systems for lighting and TV:

Max power for load	< 300 W
Maximum current	25 A
Recommended inverter power	< 1 kW

24V: Medium household with refrigerator and some small appliances, or wiring extension more than 10 m.

Max power for load	< 1000 W
Maximum current	42 A
Recommended inverter power	< 5 kW

48V: Special applications for industrial or agricultural purposes

Max power for load	< 3000 W
Maximum current	62 A
Recommended inverter power	< 15 kW

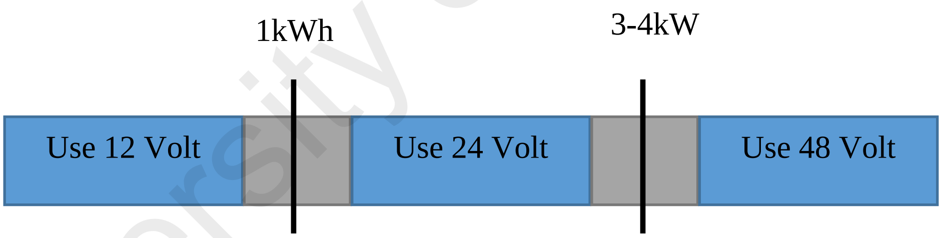

Figure 2.26 : Selection of the voltage level

According to standard off grid PV power systems design guidelines developed by the Sustainable Energy Industry Association of the Pacific Islands in Collaboration with the Pacific Power Association, the selection of the voltage level can be done based on the power level required, as shown in figure 2.26

2.3.3 Charge controller

While the solar PV panels and batteries are definitely indispensable components in a stand-alone PV system, a controller which is able to coordinate the operation of various parts of the system is also very important (Soni, Yadav et al. 2016). In (Bin and Yundong 2012) presented control methods and power management strategies for a stand-alone PV system, where satisfactory experimental results were shown. Instead of using complex and costly controller, the control of the PV panel, battery and load in small stand-alone system for off-grid household is usually done using a simple charger controller. The charge controller is very important in determining the proper operation of the whole system. As a matter of fact, in (Salas, Manzanas et al. 2002) , the authors stressed that the charge controller is one of the core components of the stand-alone PV system, which is strategically used to control the flow of energy from a photovoltaic array to batteries. In(Sani, Yahya et al. 2014) and(Shoaib and Nagaraj 2013) the authors pointed out the importance of PWM as a major advancement in the areas of solar battery charging. PWM solar charging technology uses similar to other modern high-grade battery chargers. When the battery voltage reaches the regulation set point, the PWM algorithm slightly reduce the charging current until specified point to avoid heating and gassing for the battery, but still charging to return as much power as possible to the battery in the shortest time. The results are a fully functional battery, highest charging efficiency, and rapid recharging. In the work by (Huang & Lin, 1993) the authors showed the importance of MPPT technique in optimizing power extraction from PV panel. Compared to just PWM control, controller equipped with MPPT control will allow better power extraction but at the cost of higher initial investment (Yaden, Melhaoui et al. 2013).

However,(Sumathi, Kumar et al. 2015)has suggested that there are special circumstances that may not need a charge controller: for example, when a low voltage (self-regulating unit) is used in the appropriate climate; or when the battery is too large compared to the array. The authors claimed that by eliminating the need for a sensitive electronic charging control module, the design is simplified, cost is reduced and reliability can be improved. Nevertheless, it is expected that a system without charge controller will not be able to operate with maximized energy yield and may even reduce the life time of the components if sizing is not done properly.

The main function of the charge controller in a PV system is to operate the battery within the allowable SOC, while protecting it from overcharge by the array or over-discharge by the loads (Dunlop 1997).The battery control algorithm or control strategy determines the efficiency of battery charging and the use of a PV array, and ultimately the system's ability to meet load requirements. Extra options like temperature compensation, alarms, metering and voltages by voltage standards, and special algorithms will enhance the capability of the charge controller to take care of the validity and extend the battery life.

Important functions of battery charge controllers and system controls are:

- **Avoid Overcharging:** To reduce the power provided to the battery by the PV array once the battery becomes absolutely charged.
- **Avoid Over-discharging:** to disconnect the battery from electrical loads once the battery reaches a low state of charge.
- **Control Loads:** to connect and disconnect an electrical load at predefined durations, for instance turn on the lights after sunset to sunrise. (Salas, Manzanas et al. 2002)

2.3.3.1 Charge controller configurations

In general, the charge controller can be classified as series or shunt type depending on how the connection between PV panels and battery are established using the switching device in the controller. (Suponthana, Ketjoy et al. 2007)

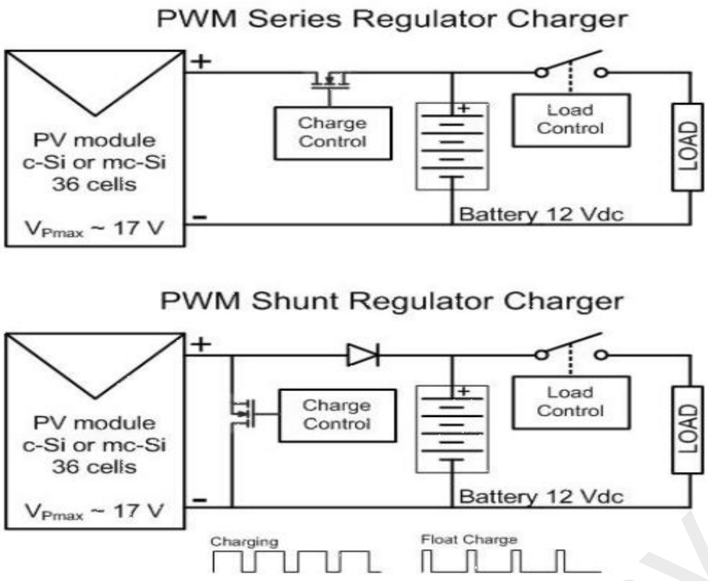

Figure 2.27: PWM series and shunt charger

The series charge controller uses switching device which is connected in a series between the PV array and the battery. This type of solar charger is widely used in small-scale photovoltaic systems and can also be used for larger systems due to the current limitations of shunt controls. The shunt charge controller has a shunt switching device that switches the battery charge from the PV array. This type of charging controller is used mainly to regulate the voltage (or current) to avoid batteries from overcharging and deep discharging that can severely damage the battery.

Regardless whether the charge controller is series or shunt type, the operation mechanism can be further classified into ON/OFF type or constant voltage charging. ON/OFF type is not very good as the voltage supplied to the battery cannot be controlled. For constant voltage charging, there are three main methods being used, namely linear, pulse width modulation (PWM) and maximum power point tracking (MPPT). (Enric and Michael 1998). Figure 2.28 gives a brief summary of the classification of charge controller

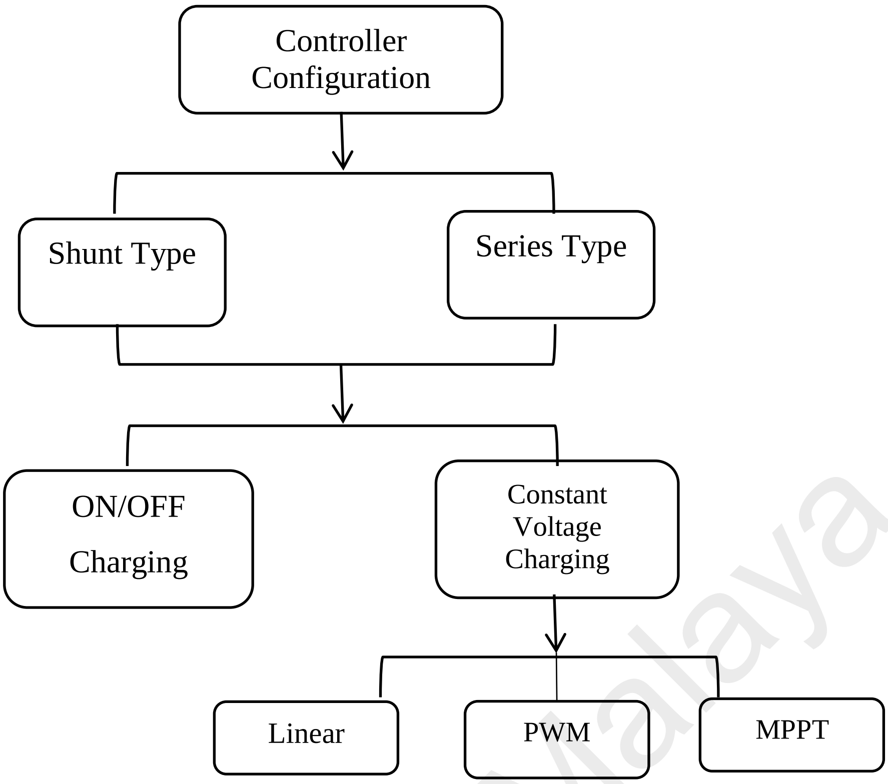

Figure 2.28 : Common Controller Typologies for Battery Charging

Among the different types of charge controller, the PWM and MPPT charge controllers are the two most common ones found in the market.

2.3.3.2 Comparison between MPPT and PWM charge controller

There are many sorts of charger controller designed to use with PV power grid within the market. consistent with the charge controller survey by Photon Energy magazine among 38 manufactures and over 260 charge control models, only three types of algorithms are used in the PWM and MPPT charger controller(Suponthana, Ketjoy et al. 2007)

If the maximum charge capacity is the only factor for charger selection, the MPPT controller will be the better choice over PWM controller. However, these are two completely different technologies, each with its own advantages. Selection depends on site conditions, system parts, array size, load consumption and the price value of the specified solar panel system. The selection between a PWM and MPPT controller can be made base on the following considerations:

❶ **Temperature conditions** MPPT controller is more suitable for cooler weather conditions. The MPPT controller is capable of capturing the overvoltage module to charge the batteries. It produces up to 20 -25% charging of the PWM controller. PWM type is unable to capture the over-voltage due to changes in PWM technology in constant voltage as a battery. But once solar panels are deployed in hot climates, there is no extra effort to convert them to make the MPPT redundant and eliminates its advantage on PWM. (Osaretin and Edeko 2015)

❷ **Array Voltages** PV array and battery voltages ought to match for PWM charger, however, PV array voltage may be on the highest battery voltage for MPPT.

❸**Battery voltage:** PWM works with battery voltage, so it works fine at a warm temperature and once the battery is fully charged while the MPPT is higher than the battery voltage, it will be "enhanced" in cold temperatures and once the battery is low.

❹ **System Size** PWM is usually used in smaller systems where the additional benefit from using MPPT charger marginal; On the other hand, MPPT is generally recommended for systems with larger sizes.

❺ **Cost:** MPPT controllers is usually much more expensive than PWM controllers. However, they are more efficient under certain conditions, which gives better energy yield compared to similar system using PWM controller.

2.3.3.3 Charge controller design and operation

The PV control current will change in two stages immediately with increased battery voltage, once the load is pulled down. The other control stages remain at a low level of charging until the battery voltage drops within between 12.5 to 12.8 volts (Dunlop and Farhi 2001), before the purpose, PV module the current to resume.

In giant SHS with 45-150 wp, the PV module produces an oversized quantity of energy and loads are connected to the battery rather than the PV panel directly as shown in figure 2.27

In the nominal 12-volt battery system, the voltage varies between 11.5 and 14.4V V, relying factors are SOC, current charge, discharge current, sort and battery life. once the battery is absolutely charged with no charging, discharging the current flowing into the loads then the battery voltage reaches concerning 12.4 to 12.7 V. throughout solar energy generation, charging current flows to battery voltage jumps to around 13.7 V (depending on charging current), currently if the loads are connected to the switch (LVD = on) the dip all the way down to 12.0 to 11.8 V (depending on the system).

If the control (PWM) permits, the current then flows into the battery until the voltage level will increase up to 14.4 volts. By means that for overcharge protection, by 14.4 volts the charge controller is switched off PWM. At this stage permits loads to connect with the system (LVD = ON); and therefore, the loads will consume power, discharge the battery, until below 11.5 volts. If the battery voltage is a smaller amount than 11.5 volts (control = off) through PWM for a minimum of 30 sec, and also all loads from the system (LVD = off). Even the battery voltage goes up to 12.5 volts, the loads are reconnected back (LVD = ON). Within the PWM charge controller, the power dissipation is smaller than different charge controllers like series and shunt charge controller gift in below figure 2.27

The PWM algorithmic program which will be a PWM series or PWM shunt regulation uses the electronics control switch solely to turn on and off the variable frequency control switch, 500 Hz to 1 kHz or higher with a variable duty cycle to stay battery voltage charging near the point range (Suponthana, Ketjoy et al. 2007)

The simple diagram of the PWM charger is shown in figure 2.30. that PWM algorithmic program permits the battery to be charged within the close to the state to totally charge the correct voltage and produces less heat. PWM features benefits such as:

1. High charging efficiency
2. Longer battery life
3. The battery temperature is low
4. Reduces battery pressure

2.3.3.4 PWM solar charge system design

Figure 2.29 shows the schematic of a typical series PWM charge controller. While logic circuits can be used to perform the PWM control in the charge controller, most of the modern PWM charge controller has embedded microcontroller for data processing and decision making.

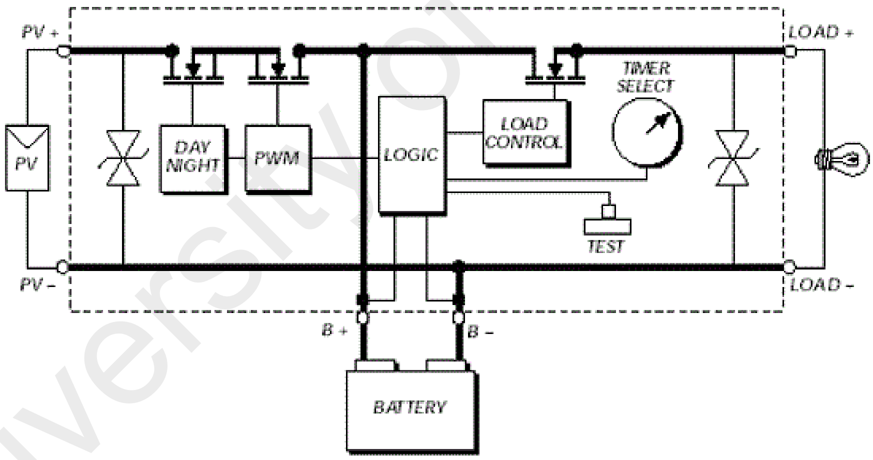

Figure 2.29: Diagram of the assembled components

The microcontroller is responsible for:

- ✧ Measures the photovoltaic cell voltage.
- ✧ Measures battery voltage.
- ✧ Decide when to start charging the battery.
- ✧ Decides when to prevent battery charging.

- ✧ Specifies when to run the load.
- ✧ Specifies when to turn off the load.

The typical control logic for a charge controller operating with a 12V is as follows:

I. If battery voltage is a smaller amount than 5.5V, the controller determines it a brief circuit condition and load is disconnected instantly.

ii. If battery voltage is a smaller amount than 10V, the controller activates the battery charging and a load is disconnected from the battery (for 12V load).

iii. If battery voltage is bigger than 15V, the controller turns off the battery charging.

iv. If battery voltage is bigger than and equal 12V, a load will be connected with battery usually (for 12V load)

Figure 2.30 shows the control flow chart of charge controller (Karim, Siam et al. 2013)

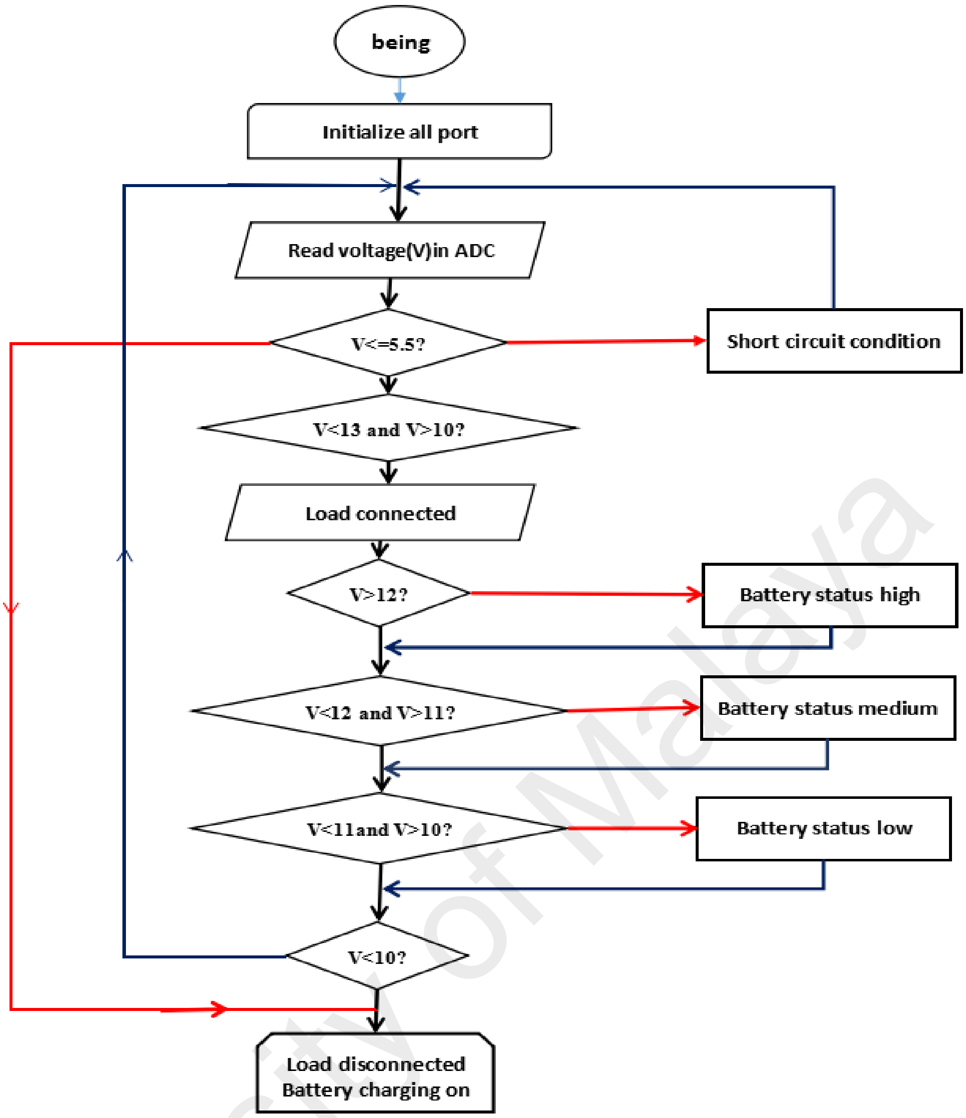

Figure 2.30: Flowchart of Charge Controller

2.3.3.5 Charge cycle of a charge controller

To ensure better battery health and cycle life, multi-stage charging methods can be implemented on the charge controller. A common three-stage charging method for battery will involve the following steps:

1. **Bulk charging** (**constant-current charge**)

   During the bulk phase of the charging cycle, the voltages slightly rise to the overall level (typically 14.4 to 14.6 volts) while the batteries pull out the maximum current that remains constant at this stage. Here, during this project, we tend to think of 14.4 volts as a voltage at the bulk level and that we charge the battery at 14.6 volts. Once the total voltage level reaches the absorption, the stage begins

2. **Absorption (Constant voltage charging)**

   During this phase, the voltage is maintained at the bulk voltage level for a certain period (usually in an hour), while this current gradually tapers off when the batteries are charged. Once the battery reaches the charged voltages, PWM starts to carry the constant voltage (14.4 volts) to avoid overheating and over-gassing the batter

3. **Float charge**

   After the absorption time the voltage is reduced to float level (usually14.4-13.7 volts) and therefore the batteries draw a little maintenance current until next cycle. This can be ideal charge procedure. We get 13.5 volts or float level in our project. A load is disconnected once the battery voltage decreases below usually 10.5Volts. It’s sensible to vary the voltage levels with battery temperature because the voltage values have major temperature characteristics, it's safe to charge most of the lead-acid batteries by currents up to C/10h, wherever C is that the battery capacity in Ah. The relationship between current and voltage throughout the three phases of the charge cycle is as shown in figure 2.31

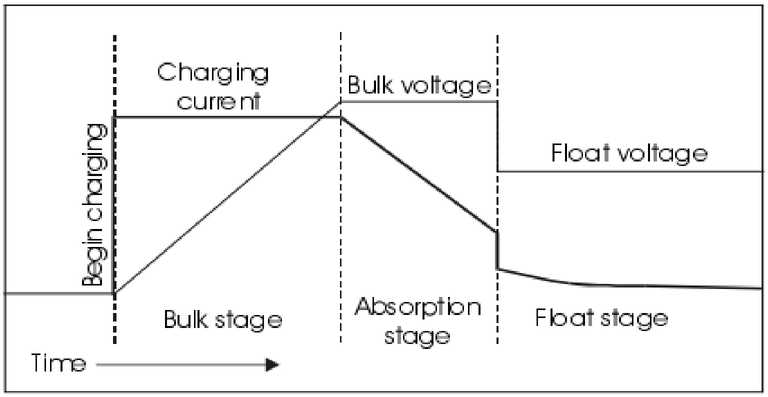

Figure 2.31: The diagram of charging stages of lead-acid battery

2.3.4 Single phase inverter

For stand-alone PV system driving AC load, an inverter will be necessary to converter the DC voltage from PV and battery into AC power usable by the appliances. There are two ways in which inverters modify DC current to AC: modified sine wave signals and pure sine wave signals. Modified sine wave inverter generates quasi-sine waves which are either square wave or pulses in nature; while pure sine wave inverters produce more sinusoidal voltage output just like the one in utility grid. Modified sine wave inverters are typically cheaper; however, some electrical appliances do not operate well with modified sine wave inverters and can produce a buzzing noise.

The main electrical inverter characteristics that needs to be taken into consideration when selecting the device are:

- ✓ Voltage and Current inputs and outputs. -
- ✓ Waveform type: Square, modified or sinusoidal.
- ✓ Voltage limit at the input.
- ✓ Total Harmonic Distortion (THD), which measured the purity of the output.
- ✓ Output power.

2.4 Summary

This chapter provides a summary of literature within the proposed research area focusing on stand-alone PV system. The main components of a stand-alone PV system have been discussed in details and their functions explained. It is worth noting that the charge controller is one of the most important component in a typical stand-alone PV system, without which the system will not be able to operate properly. While the MPPT charge controller is better in terms of energy yield, it is costlier and usually not used in low cost stand-alone systems for rural electrifications. Instead PWM charge controller is usually preferred in such applications. Good understanding on the operation performance and selection concerns of PWM charge controller together with other parts of the stand-alone PV system is hence important for a good system design.

Subsequently, this project studies the design procedure for a stand-alone PV system and investigate the performance of a standalone PV system with PWM charge controller.

CHAPTER 3: METHODOLOGY

3.1Concept of design

The renewable energy system for sustainable development described in figure 2.4 for energy production varies depending on the following data

- Peak power (Wp)
- Energy storage capacity of system
- Consumption of load characteristics

3.2 Methodology of sizing design by PVsyst

PVsyst is a PC software package for the study, size and analysing information from complete PV systems. It deals with stand-alone, grid-connected, pumping and DC-grid (public transport) photovoltaic systems, and includes meteorological and PV Systems elements databases, additionally as general solar energy tools. The simulation procedure was achieved as shown in figure 3.1 (Kanteh Sakiliba, Sani Hassan et al. 2015)

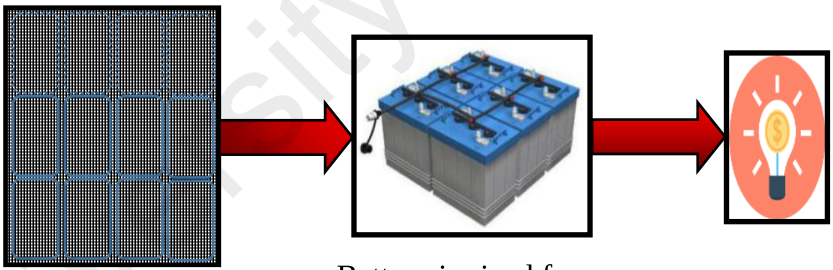

Figure 3.1: Selection and-sized components.

3.2.1 Stand-alone PV system

The total electrical power generated is determined by the PV array that is provided for the load and different types of energy loss. The result was the optimal size for the SHS configuration. Besides, the total energy flow is calculated through the entire system. With the PVsyst program, you can determine the expected power provided to the load for the entire year.

The tactic was want to design and size a stand-alone system that may be economically competitive in comparison to buying electricity from the utility grid and choosing the right size elements was critical because it had an impact on life and reliability of initial prices.

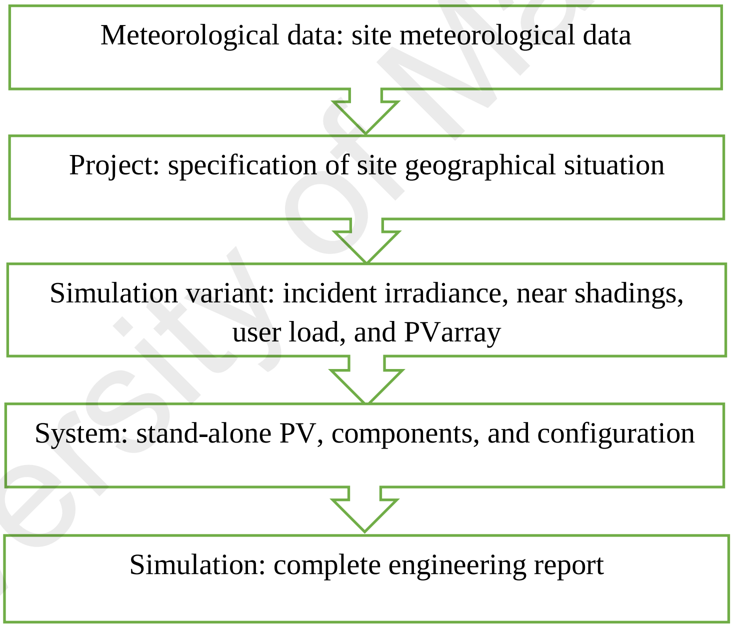

Figure 3.2: Outline of the simulation process

The design criteria for SHS stand-alone PV system were calculated using a minimum of average radiation within a month to determine the size of the photovoltaic cell array and the battery bank and work by meeting the daily requirements to achieve the sizes.

3.3 The site coordinates and meteorological data

The process is started with the site screening. It means it must be located in a place where there is enough sunlight. So, this part very important. Because the price of the whole system depends on it.

Expected performance of the photovoltaic system at the location, it's necessary to gather meteoric and environmental information for the location into account. The Photovoltaic Geographical Information System (GIS) could be a sensible supply of information. the typical incident shows daily radiation information for each the horizontal and air temperature of the site in figure 3.3 it's clear from the figure that the solar incident within the site considering wherever it exceeds 4 and 5 kilowatts / month on the horizontal

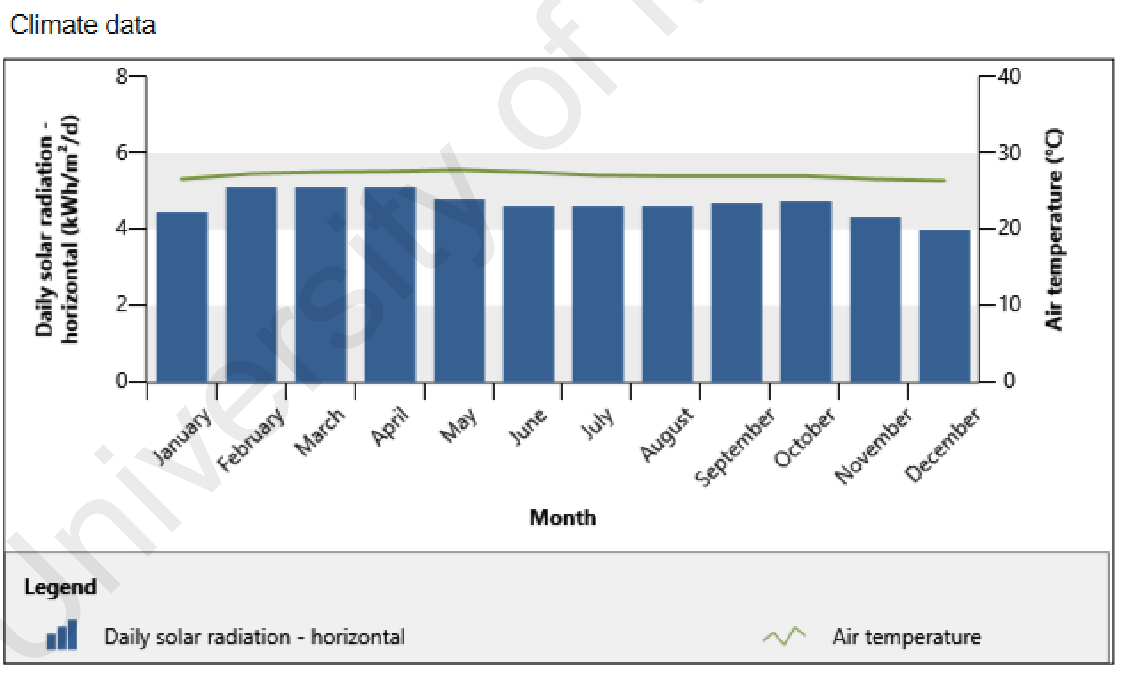

Figure 3.3 : Daily radiation and air temperature of the site

3.4 Methodology of sizing design by (excel worksheet)

When sizing the photovoltaic system, the logical first step is to consider the energy demand. Thus, a primarily stand-alone PV system sizing begins at the load side and proceeds backward to the PV arrays as shown in figure 3.4 .(Ovali 2016).

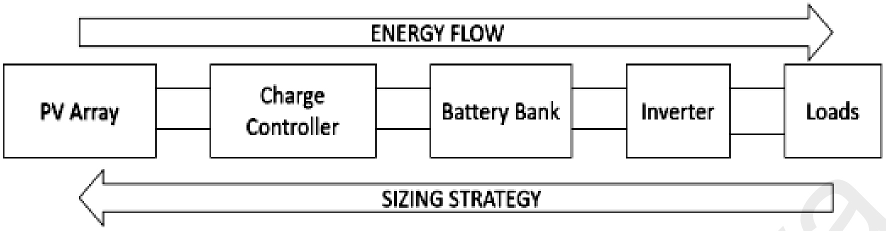

Figure 3.4: Sizing strategy for stand-alone system

The purpose is to first decide the system load necessary and then to determine the PV module size, charge controller, and battery required to meet the energy demand of the load side.

3.5 Sizing calculation

The sizing stand-alone PV system is based on four basic calculations. First, load analysis determines the demand for energy on the load side. Second, monthly load requirements are compared to the insolation of the availability city data to determine the critical month design. Then, the size of the battery bank should be an appropriate size to produce sufficient power to a load for a certain period of time such as if PV arrays reduce output during cloudy days. Finally, PV-sized arrays must be generating enough power for both load and battery requirements.

3.5.1 Residence load profile

The appliances in the remote area assumed, does not require giant quantities of power. It's assumed this load is constant around the year. There are two types of loads that are classified according to the type of feed source (DC load or AC load). During the design stage, the type of load is considered either resistive or inductive. Resistant loads do not have any high pull of current for operating purpose. And the equipment classified as resistive loads are light- bulbs. In contrast, the inductive load like electrical heaters. Inductive loads reverse resistive loads, where the first pulls a large amount of current (inrush), at the start of operation, examples such as transformers, electric motors, and coils. Each of the system loadings has two important design features for SHS and BHS, duration of consumption (hours) and peak power (watts) per load. These loads are different electrical devices that power consumes the battery either directly or indirectly. Because of the minimum power requirements for the system, which is 12V dc devices, such as TV. DC supply, mobile charger, ceiling fan, and CFL, LED, are connected directly to the system. Three different types are classified according to power per day: giant SHS system, normal SHS size and BHS load consumption represent in the Table 3.1, Table 3.2and Table 3.3severally.

Table 3.1: Typical giant size load consumption

Appliance	Power Rate	Time (h)	Total energy	Energy consumption
LED Light (4)	7 W	8	56	224
Table Fan (3)	10 W	8	80	240
M. Charger (2)	5 W	3	15	30
Refrigerator (1)	100 W	12	1200	1200
TV (19") (1)	40 W	6	240	240
Total energy (kWh/day)				1.934

Table 3. 2: Typical normal size load consumption

Appliance	Power rate	Time (h)	Total energy	Energy consumption
LED Light (3)	7 W	5	35	105
Table Fan (2)	10 W	8	80	160
M. Charger (1)	5 W	3	15	15
Refrigerator (1)	100 W	12	1200	1200
TV (19") (1)	40	4	160	160
Total energy (kWh/day)				1.640

Table 3.3 : Typical BHS load consumption

Appliance	Power Rate	Time (h)	Total energy	Energy consumption
LED Light (2)	7 W	5	35	70
Table Fan (1)	10 W	6	60	60
M. Charger (1)	5 W	3	15	15
Refrigerator (1)	20 W	12	240	240
Total energy (kWh/day)				0.385

The corresponding load profile for a typical day is indicated in the figure 3.5. The daily electrical demand is shown in Table 3.1. the typical daily load demands EL will be calculated to be 1.934 Wh/day.

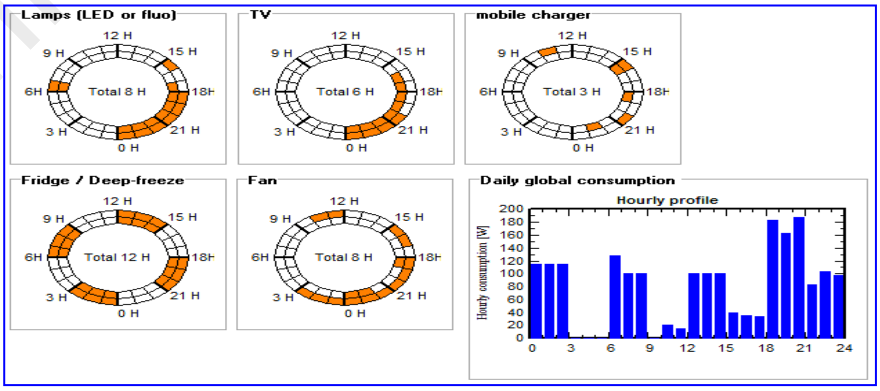

Figure 3.5: The load profile of the household. (PVsyst6.34)

3.5.2 Determining the size of the PV panel

A photovoltaic array is an interconnected set of solar modules. The power that one module will manufacture is never enough to fulfil the necessities of residential power, to create solar panels need to be connected along several PV modules. In order to obtain the desired voltage, the photovoltaic modules are connected in a series while connecting the PV modules in parallel can obtain the required current as you wish. the subsequent info ought to be specified before changing the particular size of the PV, (Guda and Aliyu 2015)

- The dc voltage of the system (Vdc)
- The average sun peak hours per day (T_{sh})
- The daily average energy demand in watt-hours (E_d)

To size the array, firstly it is necessary to estimate the average daily energy demand (E_{rd}), taking into account the efficiencies of the component devices. This can be obtained using the following equation:

$$E_{rd} = \frac{\text{daily average energy consumption}}{\text{product of componenet's efficiencies}} = \frac{Ed}{\eta_{bat}\eta_{inv}\eta_C} = \frac{Ed}{\eta_{overall}} \qquad (3.1)$$

where:

η_{bat} =battery efficiency

η_{inv} =inverter efficiency

η_C =charge controller efficiency

The average peak power (P_p) is then obtained by dividing the specified daily average energy demand by the typical daytime peak sun hours of the location (T_{sh}) as in equation

$$P_p = \frac{\text{daily energy requirement}}{\text{minimum peak sun\_hour/day}} = \frac{E_{rd}}{T_{sh}} \tag{3.2}$$

To calculate dc current of the system (I_{DC}) by dividing the average peak power by the dc voltage of the system as in equation 3.3.

$$I_{DC} = \frac{\text{peak power}}{\text{sysytem DC voltage}} = \frac{P_p}{V_{DC}} \tag{3.3}$$

The solar panels shall be connected to the parallel and series consistent with the requirement to satisfy the system's needed current and, voltage calculated as follows:

The number of modules in series (N_{Sm}) can be obtained by dividing the system dc voltage by the rated voltage of each module (V_{rm}) as expressed in equation

$$N_{Sm} = \frac{\text{system DC voltage}}{\text{module rated voltage}} = \frac{V_{DC}}{V_{rm}} \tag{3.4}$$

Next the number of the module in parallel (N_{Pm}) by dividing the total dc current of the system by the rated current of one module(Irm) as in equation.

$$Npm = \frac{\text{System dc current}}{\text{Module rated current}} = \frac{Idc}{Irm} \tag{3.5}$$

Finally determined the total number of the array (N_{tm}) by multiplying the series number of modules by the parallel number of modules, then array size giving in equation

$$N_{tm} = N_{sm} \times N_{pm} \tag{3.6}$$

At Last, step we selected specifications of modules at standard test conditions (i.e., 1000 W/m2 and 25 ˚C):

3.5.3 Determining the size of the battery

The battery select size starts by determining the first estimated energy storage (E_{est}) needed that is equal to the product of the daily average energy request and the number of autonomy days (D_{aut}) as in equation

$$E_{est} = E_d \times D_{aut} \tag{3.7}$$

For safety storage, the result obtained is divided into the maximum allowable depth of discharge (M_{dod}) as given by equation.

$$\mathrm{E_{safe}} = \frac{\text{energy storage required}}{\text{maximum depth of discharge}} = \frac{E_{est}}{M_{dod}} \tag{3.8}$$

Then determined the total capacity of the battery bank in ampere-hours (C_{tb}) by dividing the safe energy storage by the rated dc voltage of one battery (V_b) as in equation.

$$\mathrm{C_{tb}} = \frac{\mathrm{E_{safe}}}{\mathrm{V_b}} \tag{3.9}$$

After that to find a total number of batteries (N_{tb}) can be obtained by dividing the total capacity of the battery bank (C_{tb}) in ampere-hours by the capacity of one of the selected batteries in ampere-hours (C_b) as given by equation.

$$N_{tb} = \frac{C_{tb}}{C_b} \tag{3.10}$$

By dividing the V_{dc} voltage system by the rated dc voltage of one battery (V_b) will get the number of series batteries (N_{sb}) as in equation

$$N_{sb} = \frac{V_{dc}}{V_b} \tag{3.11}$$

Also, to calculate the number of parallel battery strings (N_{pb}) as in equation (3.12).

$$N_{pb} = \frac{N_{tb}}{N_{sb}} \tag{3.12}$$

Finally, by knowing how many batteries are connected to the series and connected in parallel, the total number of batteries can be determined $N_{tb} = N_{sb} \times N_{pb}$ batteries.

From the list of databases manufactures we selected Model: 8A4DLTP 12V 100Ah Valve Regulated Absorbed Glass Mat Technology, specifications at standard test conditions

3.5.4 Determining the size of solar charge controller

The key parameters for sizing the charge controller are the voltage and the current ratings. In terms of voltage, it should be selected to match the system voltage, with the maximum operating voltage of the charge controller being higher than the Voc of the PV panel to avoid damage. In terms of current, the charge controller is usually oversized, such that it will be able to withstand the array current and the total load current with some safety margins.

The standard to size the charge controller is to confirm it’s able to withstand the whole short circuit current of the array with a definite safe factor (F_{safe}). The safety factor is important so as to permit for an inexpensive system enlargement. Thus, the required charge controller current (I_{cc}) is as follows

$$I_{cc} = I_{sc}^{M} \times N_{pm} \times F_{safe} \tag{3.13}$$

Where the I_{cc} = short circuit current pv array

The number of chargers required is equal to the charge controller current regulator divided by current for each charger as given by equation.

$$N_{controller} = \frac{I_{cc}}{\text{Amps each controller}} = \frac{I_{cc}}{I_{c\_mps}} \tag{3.14}$$

In order to determine the proper input of the regulator, the temperature changes leading to the displacement of the solar panel point of action from the point of maximum power should be considered. This changes the voltage value of V_m to the panel. Therefore, we take into account the temperature coefficient and determine the voltage of the PV array,

$$V_{pv} = 0.95 \times V_{mp} \times N_{sm} \tag{3.15}$$

Energy losses should be considered along with the wiring that connects the solar panels to the storage system via the charger. The wire yields are given in the stand-alone PV systems and η_{cable} the losses are typically 5%, thus the efficiency is 95% The minimum voltage array

$$V'_{pv} = \frac{V_{cc}}{\eta_{cable}} \tag{3.16}$$

Where the voltage of the charger controller. η_{cable} Cable efficiency

3.5.5 Determining the capacity of the inverter

In sizing the inverter, selection of the voltage and power ratings is important. The voltage should be determined by the nominal voltage as the battery bank, while the power rating is determined by the expected load with some safety margins. In practice, the capacity of the inverter can be calculating as the total power of all the loads running at the same time and 3 times the total power of all inductive loads with giant surge currents. Furthermore, a factor of 1.25 should be included to have 25% reserved capacity for system expansion (Birajdar, Bammani et al. 2013). Hence, the inverter power is obtained as:

$$P_{inv} = 1.25\left(P_{sum} + 3P_{ind}\right) \quad (3.17)$$

Where:

P_{inv} = Power of the inverter

P_{sum}= Power of all loads running at the same time

P_{ind}= inductive loads power with large surge currents

The apparent power of the inverter can be divided by the PF power factor of the inverter, the typically PF value is taken 0.8

$$S_{inv} = \frac{P_{inv}}{pf} \quad (3.18)$$

The inverter current shall be:

$$I_{inv} = \frac{S_{inv}}{V_{sys} \times \eta_{inv}} \quad (3.19)$$

The number of inverters required is equal to:

$$N_{inverter} = \frac{\text{input power inverter}}{\text{maximum power inverter}} = \frac{P_{inv}}{P_{max\_inv}} \quad (3.20)$$

3.3.6 Sizing of system cables

After sizing and selecting the major components, the interconnections wires are next selection of appropriate wire size and type enhances the reliability and performance of the photovoltaic system. The size of wire must be able to carry the current at operating temperature without undue losses

3.5.6.1 Sizing of cable between charge controller & battery

The cables connected between the solar charge control and the battery must be of the correct size to ensure that the safe handling of the cable is not exceeded and the voltage drops in the cable are minimized. Low voltage is given in the cable as follows:

$$V_{drop\_DC} = V'_{pv} \times 5\% = \frac{V_{cc}}{\eta_{cable}} \times 5\% \qquad (3.21)$$

The design of pv solar system, the voltage drop in a cable 5% that maximum allowable drop in PV connected systems.

The maximum current produces by the PV panels is given by the equation:

$$\mathrm{I_{dc\_cable}} = \mathrm{I_{cc}} = \mathrm{I_{sc}^{M}} \times \mathrm{N_{pm}} \times \mathrm{F_{safe}} \qquad (3.22)$$

The cross section that would be adequate for this current would be given by the equation:

$$A_{DC\_cable} = \frac{2 \times L_{DC\_cable} \times I_{DC\_cable} \times \rho}{V_{drop\_DC}} \qquad (3.23)$$

Where:

$\boldsymbol{A_{DC\_cable}}$ is area cross-sectional (CSA) in mm2

$\boldsymbol{L_{DC\_cable}}$ the length of cables in meters,

$\boldsymbol{\rho}$ is copper resistivity which is normally taken to be 0.0183 mm2/Ω multiple by 2 for total wire length.

3.5.6.2 Sizing of cable between inverter and battery bank:

The area cross section of cable based on the maximum length of cable and current supply

The maximum current from the battery at full load supply is given by:

$$I_{inv} = \frac{S_{inv}}{V_{DC} \times \eta_{inv}} \tag{3.24}$$

To calculate the voltage, drop on the wire

$$V_{drop} = V_{DC} \times 5\% \tag{3.25}$$

Thus, area cross-sectional of cable used for the wiring between battery bank and inverter given by the equation:

$$A_{inv\_cable} = \frac{2 \times L_{inv\_cable} \times I_{inv} \times \rho}{V_D} \tag{3.26}$$

Where: L_{inv_cable} the length of the wire required is determined.

3.5.6.3 Sizing of cable between inverter and load:

The ac-cable wiring the inverter to loads of the residence must withstand the maximum current that produces at full load. At an ac-voltage rate 220 V can obtain the current by the following the formula

$$\mathrm{I_{inv}} = \frac{\mathrm{S_{inv}}}{\mathrm{V_{ac}} \times \mathrm{pf}} \tag{3.27}$$

Where, pf = power factor = 0.8

The system connection improves the performance and reliability of PV systems. To increase reliability and safety, the results are compared with the outgoing system

3.6 Economic analysis of PV system

Economic analysis is performed using USD dollar, ($). The viability of proposed system can be determined by using economic analysis. The designer knows whether the investment is handy or not.

3.6.1 Life cycle cost analysis

In this part, the life-cycle cost (LCC) estimation of the designed stand-alone PV system is discussed. The LCC of an item consists of the full prices of owning and operative an item over its lifetime, expressed in today's cash. The cost of a stand-alone PV system includes acquisition cost, operative cost, maintenance cost, and replacement cost.

All these prices have the following specifications (Birajdar et al ,013).:

- The initial cost of the system is high.
- No fuel costs.
- Low maintenance costs
- Low replacement costs (mainly for batteries).

The LCC of the PV system includes the sum of all the present worth's (PWs) of the prices of the PV modules, storage batteries, battery charger, inverter, the price of the installation, and the maintenance and operation cost (M&O) of the system. The main points of the used cost information all items are shown in Table 3.4

The period N of all the things is taken into account to be 20 years, except that of the battery that is taken into account to be five years. Thus, extra three groups of batteries (each of 6 batteries) have to be purchased, after five years, ten years, and fifteen years, assuming an inflation rate I of 3% and a discount or interest rate d of 10%. Therefore, the PWs of all the items are often calculated as follows

- the price of a PV array panels is given as follows:

$$C_{pv} = \left(0.8\frac{\$}{W}\right) \cdot PV_{peakpower} \cdot N_p \tag{3.28}$$

- The initial price of batteries is given in the following relation:

$$C_{bat} = \left(1.65\frac{\$}{Ah}\right) \cdot Ah_{tot} \tag{3.29}$$

Where

Ah_{tot} Amps-hour required from the batteries is calculated from the equation

- The rate price of the solar charge controller is given by:

$$C_c = \left(3\frac{\$}{A}\right) \cdot I_{controller} \cdot N_{controller} \tag{3.30}$$

- The price of the AC inverter is given:

$$C_{inv} = \left(0.4\frac{\$}{W}\right) \cdot P_{rat,inv} \tag{3.31}$$

Table 3.4: The cost of using all elements.

Component	PV panel	Battery	Charge Controller	Inverter	Installation	M&O/Y
Cost	0.8 $/W	1.65 $/Ah	3$/A	0.4 $/W	10% cost PV	20% cost PV

The PW of the maintenance price CMPW can be calculated to be, using the maintenance price per year (M/yr.) and the period of the system (N = 20 years), from (Birajdar et al,2013)

$$C_{MPW} = (M/yr)\times\left(\frac{1+i}{1+d}\right)\times\frac{1-\left(\frac{1+i}{1+d}\right)^{N}}{1-\left(\frac{1+i}{1+d}\right)},........\quad \{C_{mant} = 20\%C_{pv}\ ,\} \qquad (3.32)$$

Assuming that annual maintenance costs (M/yr.) account for 2% of the cost of solar panels.

- Installation cost

$$C_{Ins} = 10\%\times C_{pv} \qquad (3.33)$$

The additional CBnPW batteries that will be purchased will be calculated by calculating the present value of group n after N years of the following relationship:

$$C_{BnPW} = C_{B}\left(\frac{1+i}{1+d}\right)^{N} \qquad N = 5,10,15 \text{ year} \qquad (3.34)$$

The cost of wiring is calculated as follows:

- cable PV Module through Charge Controller to Battery:

$$C_{DC\_cable} = \left(0.15\frac{\$}{m\times mm^{2}}\right)\cdot \text{area of the wire}\times L_{cable} \qquad (3.35)$$

- the cable between inverter and battery bank

$$C_{inv\_cable} = \left(0.15\frac{\$}{m\times mm^{2}}\right)\cdot \text{area of the wire}\times L_{cable} \qquad (3.36)$$

➢ The total cost of wiring

$$C_{wiring} = C_{DC\_cable} + C_{inv\_cable} \tag{3.37}$$

❶ initial cost of investing the solar system can be calculated as follows

The initial cost of the solar system investment (II)= cost of the PV panels + cost of batteries + cost of the solar charger + cost of the AC inverter + additional costs.

$$II = C_{pv} + C_{bat} + C_{c} + C_{inv} + C_{wiring} \tag{3.38}$$

❷the total cost of the system is calculated by combining all the above costs

Solar system life cycle cost = cost of initial investment solar system (II)+ cost of second, third and fourth battery packs + system installation cost + maintenance and operation cost.

$$LCC = II + C_{B1PW} + C_{B2PW} + C_{B3PW} + C_{ins} + C_{MPW} \tag{3.39}$$

The Stand-alone system operates without any power failure or breakdown. (probability of loss) LLP = 0

It is occasionally helpful to estimate the total cost of the LCC system on an annual basis. The annual LCC cost of the solar power system (ALCC) according to current US dollar prices obtained by

$$ALCC = LCC\left[\frac{[(1-(1+i/1+d))]}{(1-(1+i/1+d)^{N})}\right] \tag{3.40}$$

- The unit cost of1 kWh is equal

$$\frac{ALCC}{365E_L} \tag{3.41}$$

As a result, the price of solar power production is higher than traditional methods, it is expected this price will decline significantly in the future as a result of the lower initial cost of producing solar panels. Simultaneously, we note the high price of electricity production from traditional methods due to the rapid increase in the price of conventional fuels. The generation of electric power from electrochemical systems will be promising to feed domestic loads in the future, particularly with the steady decline in the price value and enhance the efficiency of solar units and their generation of clean, environmentally friendly energy as compared with conventional electricity generation in public electricity networks.

3.7 Economic viability using simple payback analysis

Cost recovery period n is the period needed to recover the Initial capital to build system, usually it estimated in years, and the knowledge calculates the estimated revenue and economic benefits. In general, the (n) value is not an integer, calculated by the simple relationship

$$\text{simple payback period} = \frac{\text{initial investment (II)}}{\text{Cost of the system(Kwh)} \times \text{Annual production of energy(CF)}} \tag{3.42}$$

It can be calculated according to the precise equation to load the engineering economy

$$\sum_{n=1}^{n} \frac{CF_n}{(1+d)^n} - II = 0 \tag{3.43}$$

Where: initial cost of investment (II) the initial cost of the establishment of the system, (CF) Annual production of the system, (d) Interest rate.

Thus, the recovery time calculated from the previous equation is equal to:

$$n = In\left(\frac{1}{1-\frac{II \cdot d}{CF}}\right) \div In(1+d) \tag{3.44}$$

It is calculated CF as follows:

$$\mathrm{CF} = \mathrm{E_L} \times \text{price of KWh} \times 365 \tag{3.45}$$

3.8 Installation of PV systems in buildings:

The areas where PV panels can be installed are:

- Roofs of buildings.
- Roofs of car parking.
- Any other open area.

In the studied system can be installed solar panels on the roof of the residential unit towards the south and at a tilt angle of the board with the horizon, to calculate the space occupied by the panels, the distance between the rows of the solar panels should be determined so that no shading of the panels occurs as they are installed behind each other. The shadow is not in one direction only while relying on the other, the tilt angle of the sun to the east or west at the beginning of the day or the end and are identical in both cases

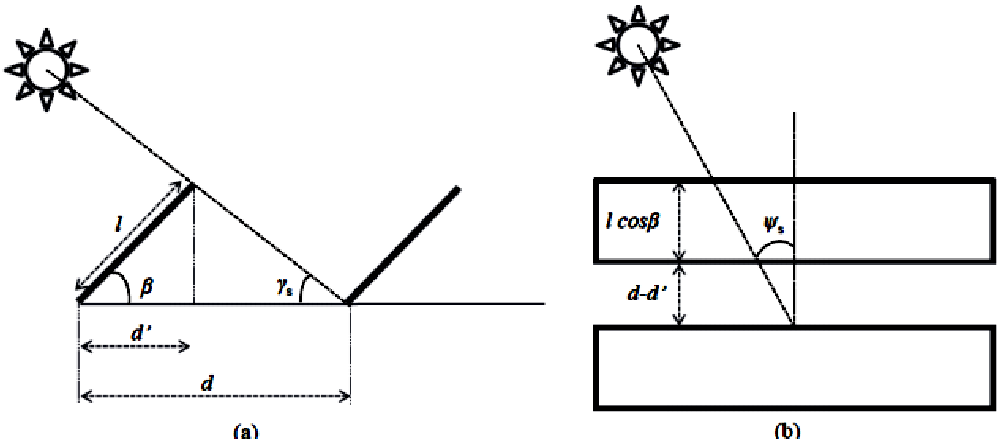

Figure 3. 6: The distance between panels (shadow length 'd-d)

The distance between panels can be calculated according to the following relationship (Martín-Chivelet 2016)

$$d = l\cos\beta + \frac{l\sin\beta}{\tan\gamma_s}\cos(180-\psi_s) \tag{3.46}$$

Where: l solar panel length m, γ_s =63.9 ψ_s 201. The angle of inclination of the sun

Figure 3.7: Solar Position for site

(https://www.esrl.noaa.gov/gmd/grad/solcalc/index.html)

The length of the panels connected to the parallel,

$$L_P = d \times (N_P - 1) + l \cos\beta \qquad (3.47)$$

The length of the panels connected to the series,

$$L_S = K \times N_S \qquad (3.48)$$

Where K solar panel width m Thus, the area occupied by the panels

$$A_{PV} = L_P \times L_S \qquad (3.49)$$

The excel worksheet is designed to calculations and determine the components of the solar system Table 3.5, in which we can identify all components of photovoltaic systems after selected required design parameters mentioned in the previous steps

Table 3.5:List of PV system components and cost estimate

Appliance	Quantity	Power (Watt)	Hours per Day	Energy per Day					
					Inverter efficiency	=	94%	PVmodule cost $	1350
					Charge efficiency	=	94%	Battery cost $	498.3
TV	1	40	6	240	Battery efficiency	=	95%	Solar charge cost	225
Recivier	0	25	6	0	sun hours (Tsh)	=	4	Inverter cost	2000
fridge	1	100	12	1200	System Voltage Vsys	=	12	wire cost (PV-Bat)	85.5
computer	0	65	4	0	PV power rate	:	135	wire cost(Bat-Inv)	1.5
Printer	0	700	0.5	0	PV module Vmp	:	18.5	Interest rate (d)	0.1
Iron	0	1000	0.4	0	PV module (Imp)	:	7.29	Inflation rate (i)	0.03
Washing	0	200	1	0	PV module(Isc)	:	8.54	Installation area	
CFL	4	7	8	224	depth of discharge	:	80%	PV module lenght	1.64
Phone	2	5	3	30	battery capacity (Ah)	=	100	PV module width	0.992
Rech lamp	0	10	5	0	battery voltage (Vb)	:	12	declination angle	60
Fan	3	10	8	240	Days of Autonomy	:	1.5	elevation angle	25
Shaver	0	15	0.4	0	charge control Vcc	=	12	Tilt angle	0
Total energy demand per day Ed				1934	charge control Icc	=	45	PV array Area(m.sq)	8.135
Cost KWh	Initial Cost		Total Cost		Inverter power Pi	:	5000	distance // panels d (m)	1.64
0.67	4160.3	$	5415.652	$	wire lenght(pv-bat)	:	15	PV parallel length Lp	8.2
stand alone PV system					wire lenght(bat-inv)		5	PV series length Ls	0.992
PV module		Batterry		No of Charge	Area of cable (pv-bat)		simple payback period		
series =	1	series =	1	1	38		year	13.19	
parallel =	5	parallel =	3	Inverter power	Area of cable (bat-inv)		precise payback period		
Total =	5	Total =	3	222.5	2		year	22.52	

Most solar panels have a rated service life of around 20 years, which means you essentially get 11.26 years of free energy after the payback period

CHAPTER 4: SIMULATION AND DISCUSSION

In order to understand the operation of a stand-alone PV system better, simulation using MATLAB simulation is done and presented in this chapter. This chapter deals with implemented MATLAB simulation to extract the parameters for numerous PV cells and modules the simulation results will measure each module, and will be presented the result discussion to determine the performance parameters and evaluate the validity and efficiency of the controller by certain special requirements for the standard test condition (STC)

4.1 Matlab simulation for individual components

This section present simulation model developed using (MATLAB/Simulink) environment to simulate the components in a stand-alone PV system. The model is an excellent tool to predict the effect of external conditions such as irradiance, shadow, and temperature on the generated power form the stand-alone PV system.

4.1.1 Simulation of PV module

This section describe the simulation of PV module based on MATLAB/Simulink. For the purpose of simulation, a Kyocera KC130GT. whose specific parameters are as listed in Table 4.1, is considered here.

Table 4.1: Electric specification of PV module used in simulations

Name	Kyocera KC130GT
peak power (Wp)	130.064 W
Voltage at maximum power point(Vmp)	17.9 V
Current at maximum power point (Imp)	7.39 A
Open circuit voltage module (VOC)	21.9 V
Short circuit current module (ISC)	8.02 A
Total number of cells in series (NS)	36
Total number of cells in parallel (NP)	1

Maximum system voltage	1000 V
Range of operation temperature	-40 °C to 80 °C

All electrical specifications are under standard test conditions of irradiance of 1 kW/m2, cell temperature of 25 °C and clear sky of 1.5 air masses

A) Simulation for Single PV Panel

Based on the parameter, it is known that Kyocera KC130GTPV consists of 36 cells. To simulate this PV panel in MATLAB, the PV model is modelled using 36 individual cells, as shown in figure 4.1.

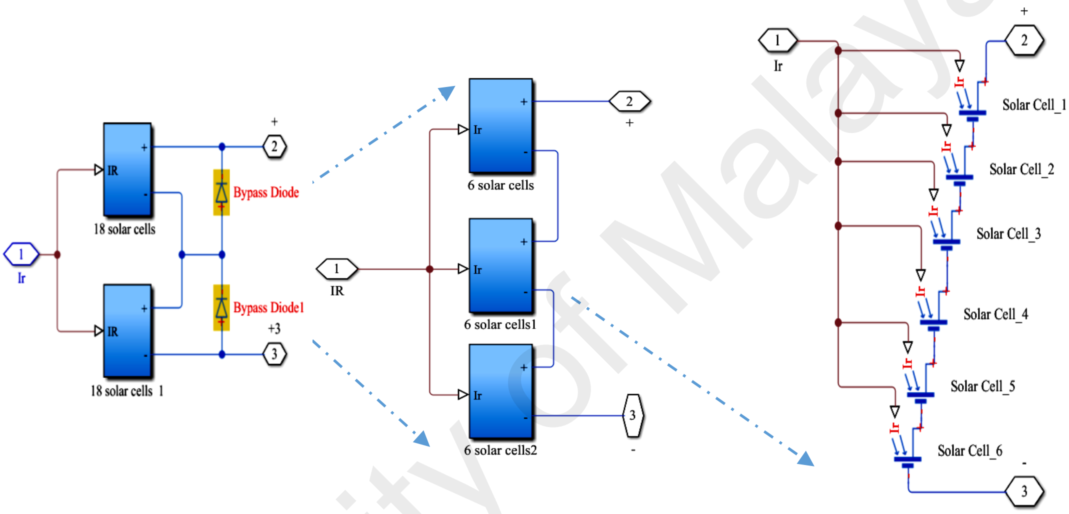

Figure 4.1: Model of solar cell module having 36 individual cells

In order to confirm the performance of the panel, it is necessary to obtain the I-V and P-V characteristics. This is done by varying the terminal voltages of the panel from zero to Voc and measuring the corresponding PV current output properties including the current photovoltaic, voltage, and power, as shown in figure 4.2.

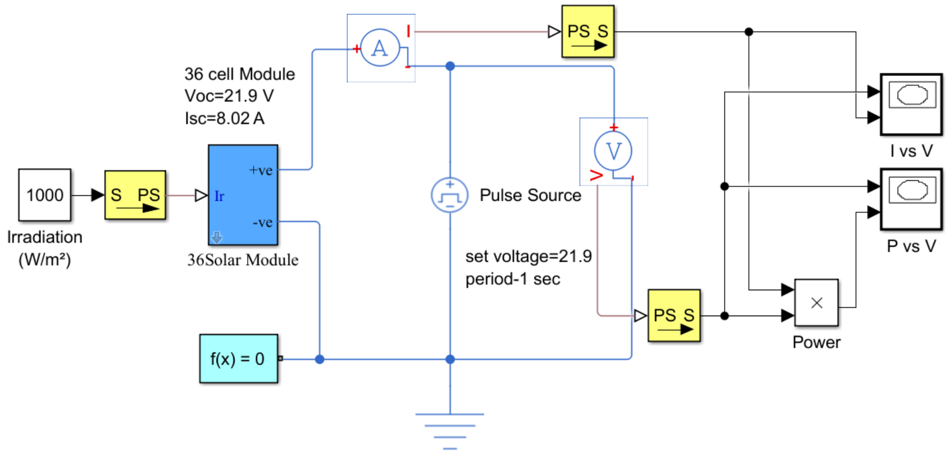

Figure 4.2: Model of Solar PV module to test output parameters

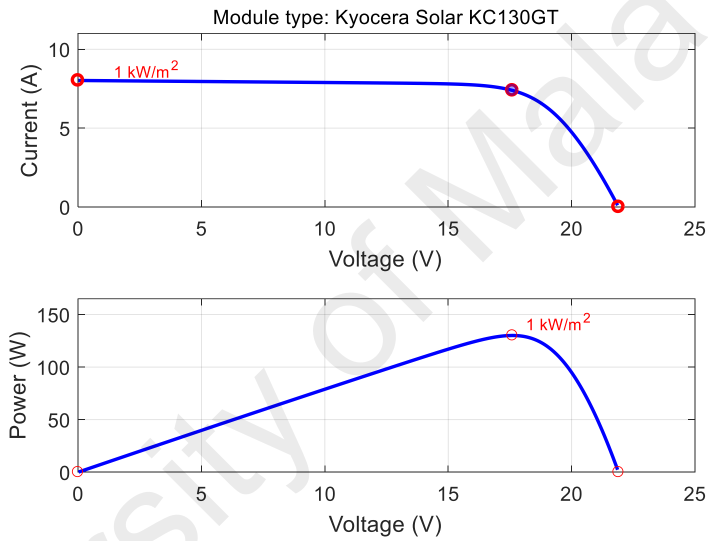

Figure 4.3: I-V characteristic and P-V characteristic with (STC)

B) Simulation of PV Array

If the output voltage of a single PV is not sufficient to meet load requirement, the PV modules may be connected in a parallel and series to achieve the required voltage and current. For example, the model of PV array in the figure 4.4 is formed by connecting two parallel branches of PV strings, with each string having three PV modules (Varshney, Chauhan et al. 2014)

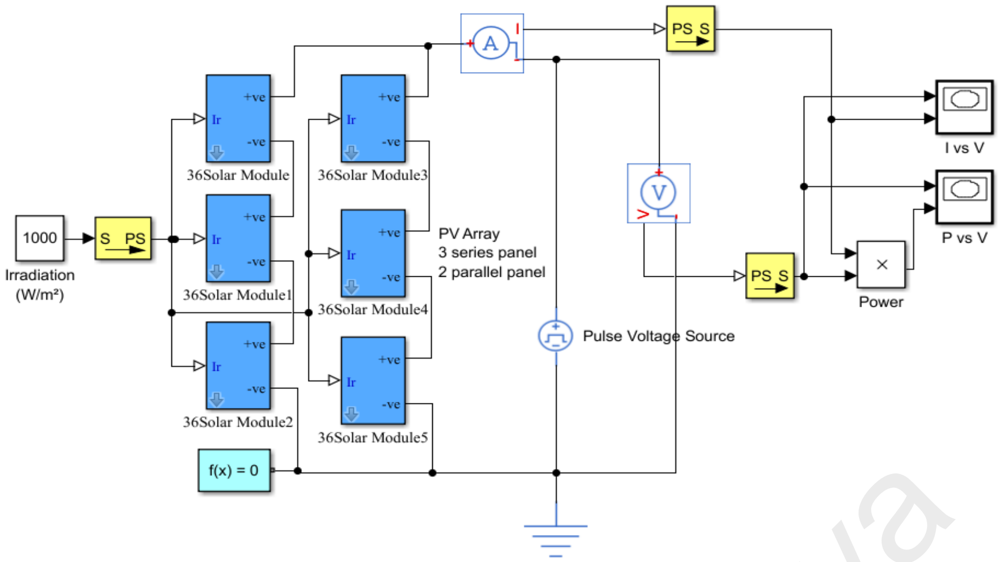

Figure 4.4: PV Array Model configuration

The I-V, P-V characteristics of the PV array are shown in figure 4.5 and Table 4.2 gives overall parameters of the solar array

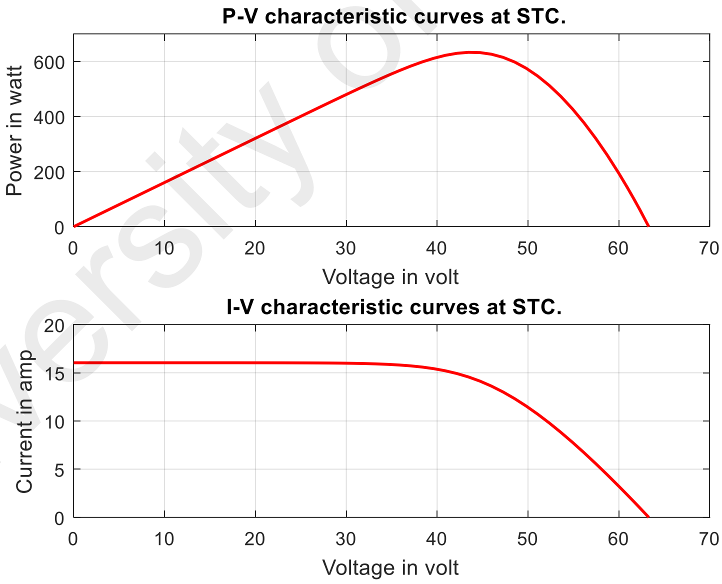

Figure 4.5: The I-V and P-V curve characteristics of PV array

Table 4.2:Overall parameters of the PV Array

Parameter	Value
Irradiance	Constant 1000W/m2
Pulse voltage source parameter	
Pulse Amplitude	$V_{oc} \times N_s = 21.9 \times 3 = 65.7v$
Pulse Rise Time	1 sec
Model Parameter	
No of series pv model	3 panel
No of parallel pv module	2 panel
Total no of pv array	6 panel
Total Array Output	$V_{oc} \times N_s = 21.9 \times 3 = 65.7v$
Total Open circuit voltage	$I_{sc} \times N_p = 8.02 \times 2 = 16.04$
Total Short circuit current	1.053KW
Peak power rate	
MPP power:	632.8883
MPP voltage:	43.4455
MPP current:	14.5674

The properties of the PV array are estimated as follows

(1) The properties of I-V and P-V are given under varying radiation with a constant temperature are shown in Figure 4.6. Here, the solar radiation varying by 200, 400, 600, 800 and 1000 W/m 2 whereas the temperature remains constant at 25 °C.

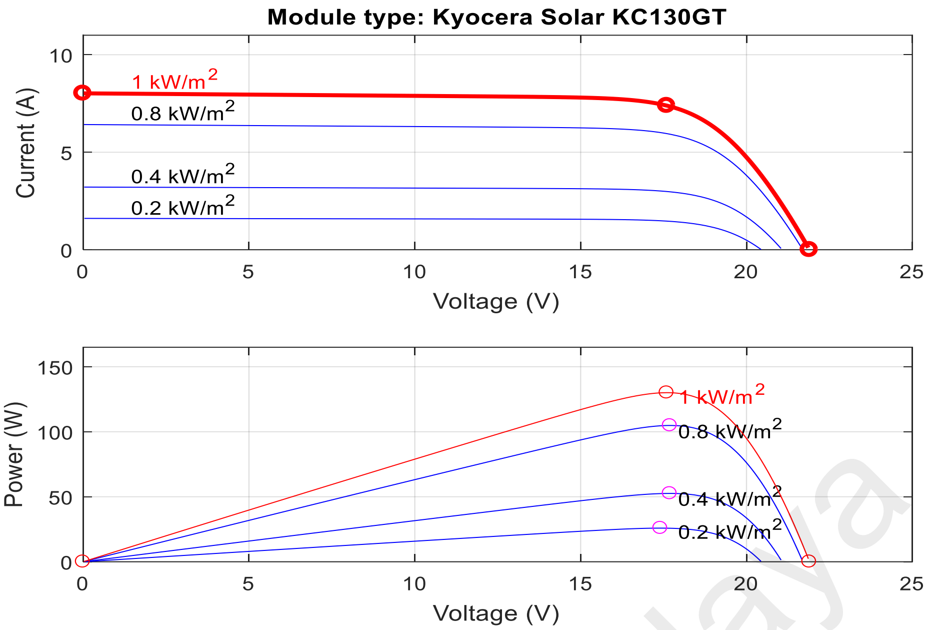

Figure 4.6: I-V&P-V properties at fixed temperature with varying irradiance.

(2) The properties of I-V and P-V are obtained by varying temperatures and constant irradiation in figure 4.7. Here, the temperature ranges from 25 to 45 respectively Whereas the irradiation level remains constant at 1000 watts / m ^{2}.

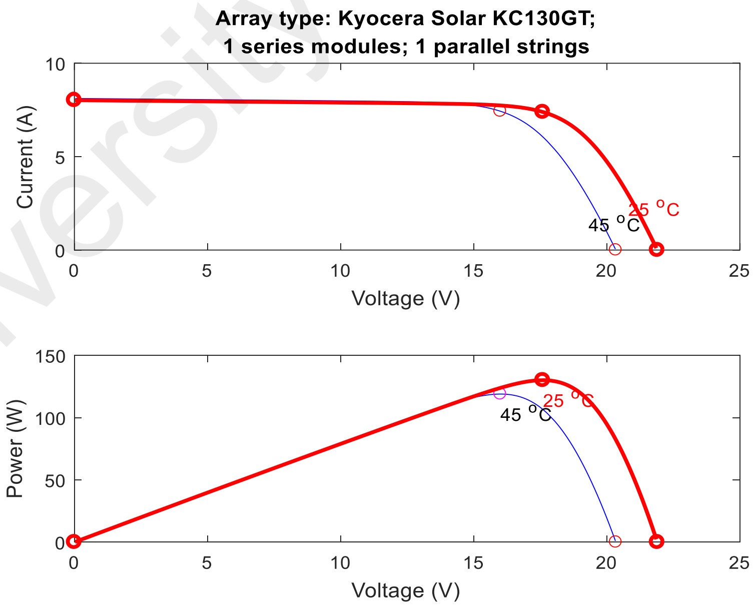

Figure 4.7:I-V&P-V properties at fixed irradiance with different temperature.

Figure 4.6 and figure 4.7 shows the resulted I-V and P-V characteristics due to ambient temperature changes under fixed solar irradiation. According to the graph, the peak output power is 130 watts at 25°C and 121 W at 45° C. Cell temperature depends on the photovoltaic material that is affected by V_{OC}. Most photovoltaic panels including multi-crystalline photovoltaic panels, the temperature set by ambient temperature (Ta°C), increased voltage by 0.12 V (Dubey, Sarvaiya et al. 2013). The experimental equations for photovoltaic voltage and cell efficiency can be expressed as

$$V_{oc} = K_v \times T_{STC} - T_A + V_{oc,ref} \tag{4.1}$$

$$\eta_c = \eta_{T,ref}\left[1 - K_V\left(T_C - T_{ref}\right)\right] \tag{4.2}$$

where:

V_{OC} is open circuit Voltage (V)

η_c is the cell efficiency

$\eta_{T,ref}$ is module electrical efficiency at a reference temperature (k)

KV is temperature Coefficient of open circuit voltage (V/℃)

TC is cell temperature (c)

Ta is ambient temperature

Tref is reference temperature (25 ℃)

The developed model has advantages in studying the effect of environmental conditions on the operation of such variable conditions of temperature, solar radiation, and the effect of shading in particular.

C) Simulation on the Effect of Shading

The effect of shading on the operation of the solar PV array's is assessed through the several cases based on (Nguyen and Nguyen 2015), as shown in Table 4.3. The same cases were considered and simulated as shown in figure 4.8

Table 4.3: cases of the simulation state

Cases	A description of the simulation state
1	No shading on PV panel (full irradiation on solar PV array): 1000 W/m^2
2	One PV panel shaded (receives irradiation of 500 W/m^2), others receive full irradiation of 1000 W/m^2
3	Two PV panels shaded equally (receive irradiation of 500 W/m^2), others receive full irradiation of 1000 W/m^2
4	Two PV panels unequally shaded (receive irradiation of 500 and 200 W/m^2), others receive irradiation of 1000 W/m^2

As seen from the results, shading of panels causes the P-V curves to deviate from its ideal condition. The lower the irradiance, the lower the peak power of the resultant curves. Furthermore, unlike normal case where there is only one MPP, panels with shadings have more than one MPP, which may cause complication in the controller, particularly when MPPT is used. This issue needs to be taken into consideration in design of the system.

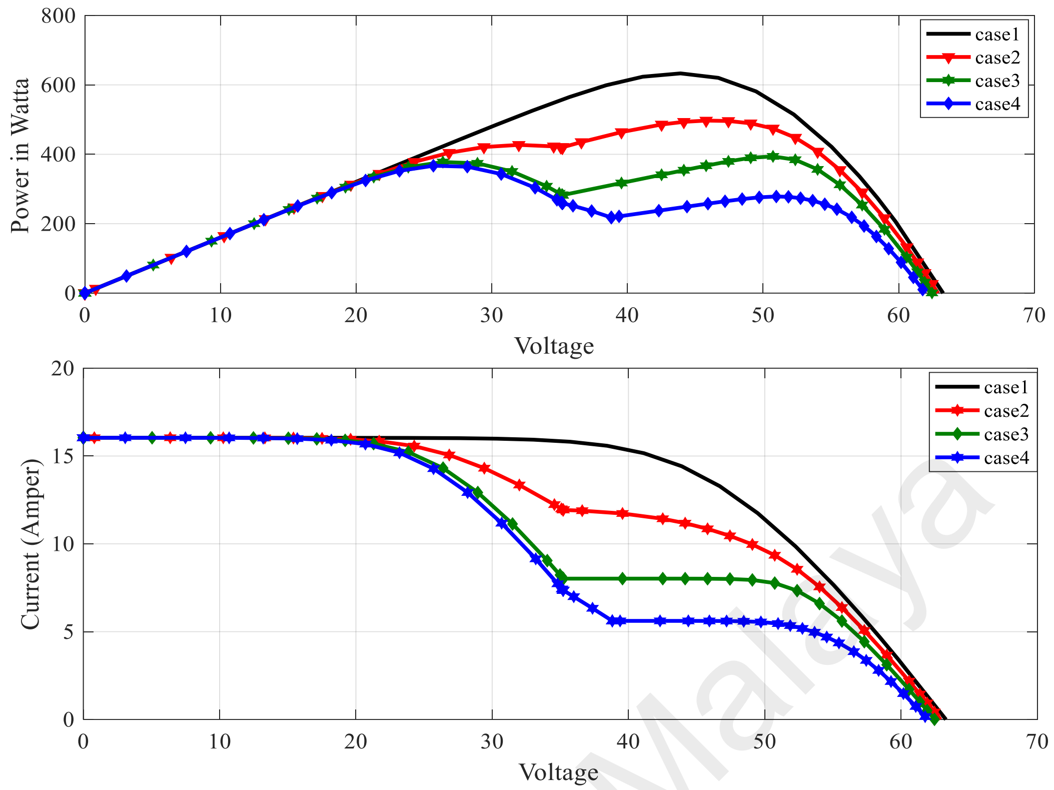

Figure 4.8 : I-V & P-V characteristic under partial shading condition

A) Simulation on the Effect of Changing Resistive Load

From characteristics of the PV modules under normal condition, it is obvious there is only one maximum power MPP, where the corresponding current is I_{MPP} and the voltage is V_{MPP}. The effective resistance at MPP, R_{MPP}, can be calculated from V_{MPP} and I_{MPP} values in the datasheet, which is

$$R_{MPP} = \frac{V_{MPP}}{I_{MPP}} = \frac{17.6}{7.39} = 2.381\Omega$$

In the simulation, the PV power module is connected to a DC resistor load, whose resistance is varied. as shown in figure 4.9. The simulation is done under standard test conditions with radiation (G) of 1000 W/m2 and unit temperature (Tc) of 25 ° C

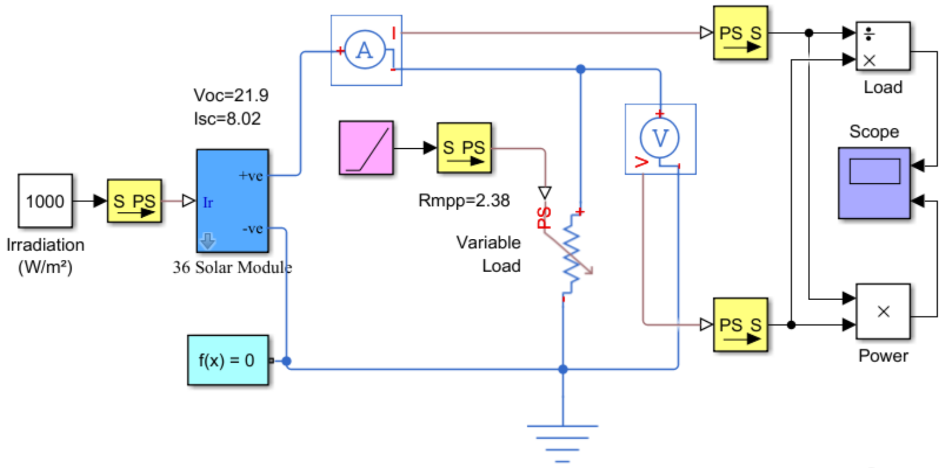

Figure 4.9: Simulink simulation of PV module for a DC load

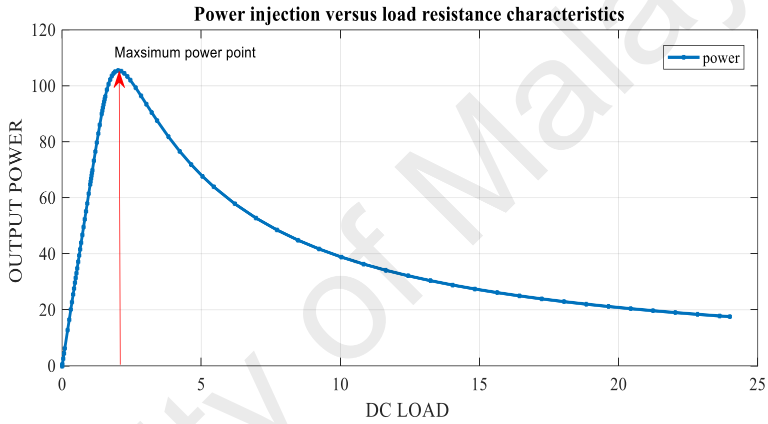

Figure 4.10:Effect of resistance varies for the power of PV panel

Figure 4.10 shows the output power which obtained from PV array under varying load. From the figure, it is clear that the output power is determined by the effective resistance connected to the solar panels. Maximum power can only be obtained when the effective resistance equals to R_{MPP}

4.1.2 Simulation of battery

As explained in earlier chapters, battery is an integral part of a stand-alone PV system. To understand the operation of a battery, simulation model using MATLAB has been constructed, as reported in the subsequent sections.

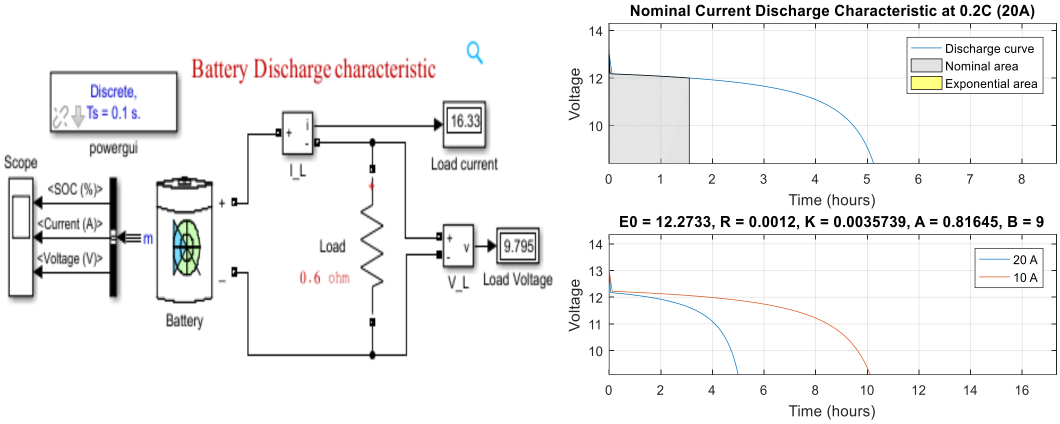

Figure 4.11: simulation discharge individual (VRLA) lead acid battery

The battery model is connected to a resistive load and the voltage as well as current for the battery is monitored. By changing the values of the resistors, the discharge currents (which also affect the discharge rate) for the battery will change. Figure 4.11 shows the battery discharges more rapidly when the discharge rate is increased

The discharge time obtained when the battery is discharging at a 0.2C rate is 5 hours. If the discharge rate was decreased to 0.1 C the expected discharge time would be10 hour (2 times more than 0.2 C rate), This characteristic means that the discharge time of a battery in great demand will decrease more rapidly than a battery powering a load at a low discharge rate. To increase the capacity, multiple batteries can be connected series and/or parallel connection, forming what is known as a battery bank.

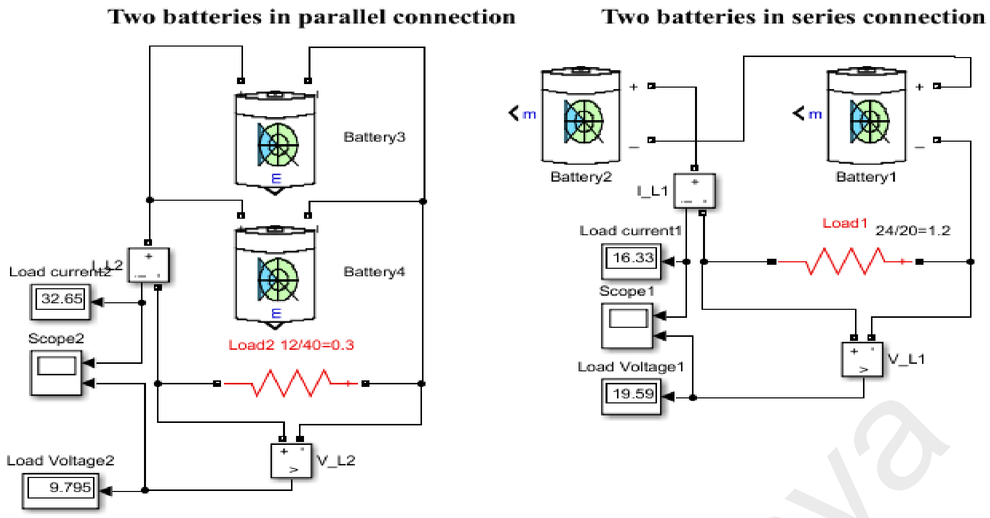

Figure 4.12: illustrated a combination battreis in Series / parallel connections

Figure 4.12 shows an example of parallel and series connected batteries. For parallel connection, the voltage will remain 12V only but the Ah capacity will be doubled. On the other hand, for series connection, voltage will be doubled while the effective Ah remains the same.

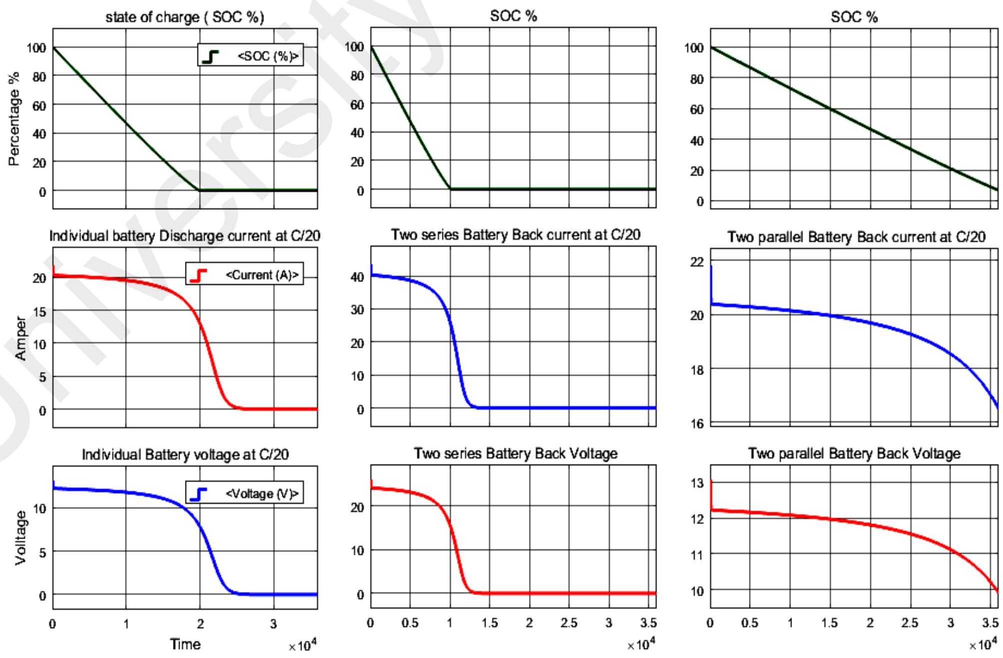

Figure 4.13: Typical discharge characteristics of Battery Bank.

The SOC, current and voltage of a single battery, two parallel batteries and two series batteries are shown in figure 4.13. For the same resistive load, the discharge current is higher for series connection because the voltage is doubled. Since for series connection, the capacity is the same as individual battery, but the discharge current is doubled, the discharges twice the speed to SOC=0. On the other hand, the discharge current remains the same as individual battery for parallel batteries. However, since the Ah is doubled, it takes double the time to discharge the battery fully.

4.1.3 Simulation of charge controller

The main function of the charging controller in the PV system is to control the charging and discharging of the battery. In excellent condition, the charge controller should keep battery charge within the range of 20% and 100% for a deep cycle lead acid. To investigate the effect of charge controller on stand-alone PV system, simulation in MATLAB is used.

To start with, the most common type of charge controller, i.e. the PWM charge controller is simulated, with the simulation model as shown in figure 4.14. In this case, a series charge controller is considered, where a series switch is present between the PV panel and the battery. The switch is controlled to turn ON and OFF at high speed, such that by controlling the duty cycle of the ON-time, i.e. the pulse-width of the switching signal, the voltage applied to (hence charging current of) the battery can be controlled.

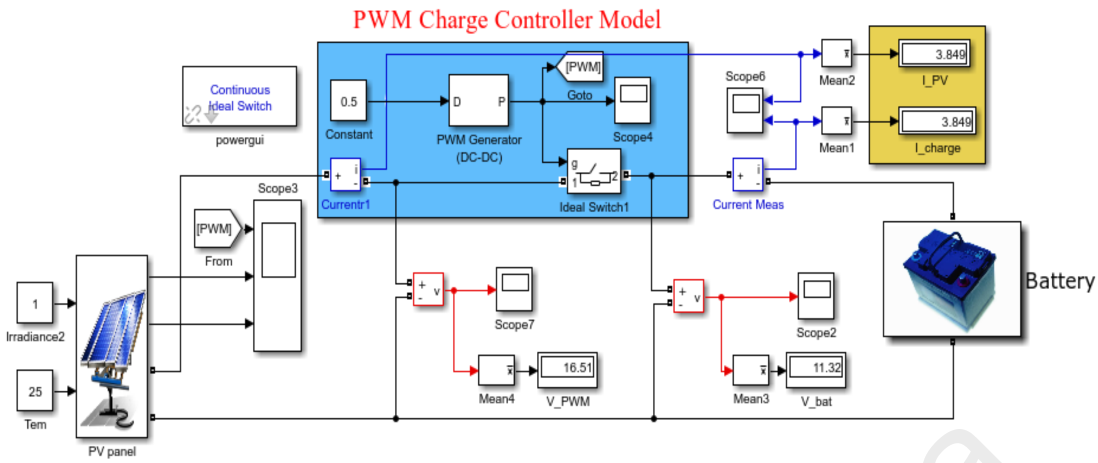

Figure 4.14: PWM Charge Control Model

Simulation is first done with a switching frequency of 5kHz, and the PV panel has a Voc =21.7 and Isc=8.02 A, under standard testing conditions. The PWM switch is controlled at a duty cycle of D=0.5 for 1 second.

The PV voltage and current, as well as the PWM signal for the switch are shown in Figure 4.15. As visible form the figure, the PV voltage and current behaves like pulsed signals, where V_{pv}=V_bat=11.32 V and I_bat= I_pv =3.845A during ON time; while V_pv=Voc =21.7 V and I_bat=I_pv=0 during OFF time.

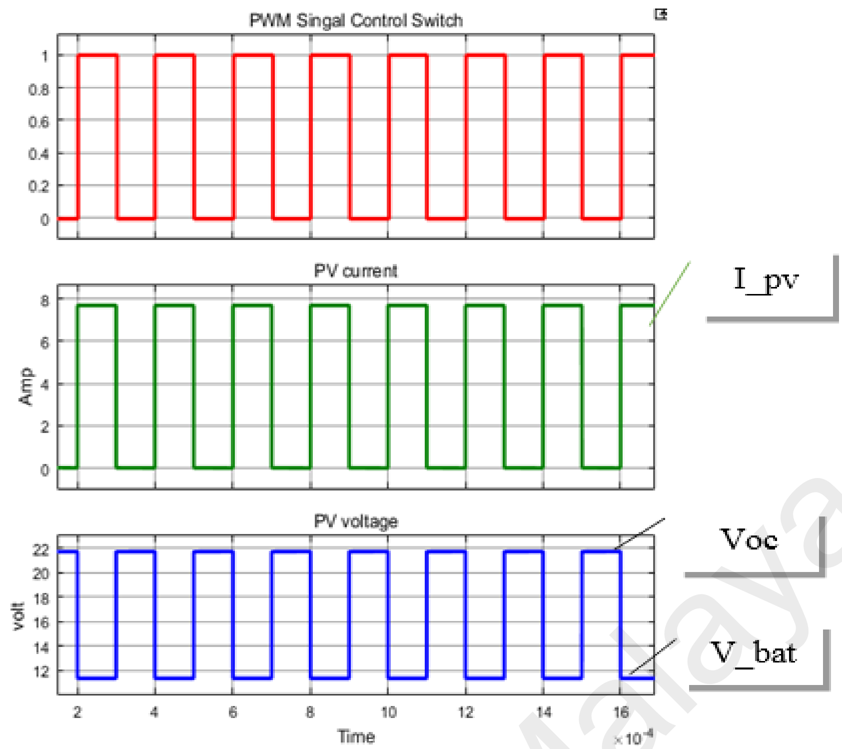

Figure 4.15: PV voltage and current, controlling by PWM signal

Due to the high switching frequency, it is difficult and time consuming to run such simulation for a full day (24 hours). To overcome this problem, an average model for the PWM charge controller needs to be developed to achieve satisfactory result by replacing high frequency pulse width modulation switch control at same duty cycle by product and voltage control source and current control source instead to PWM generator tools. The equivalent average model PWM charge controller is as shown in figure 4.16

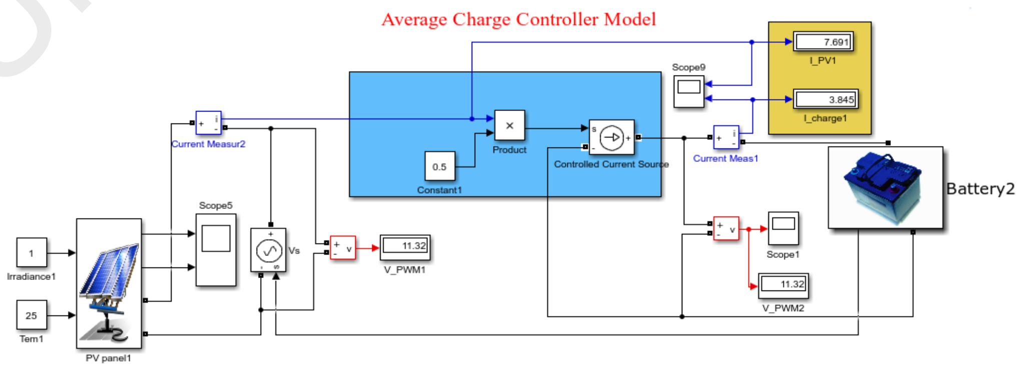

Figure 4.16: Average Charge Controller Model

To ensure that the average model is able to represent the detailed model, the two models were simulated under the exact same simulation conditions for 1s. The resulted battery SOC, voltage and currents are as shown in figure 4.17. As seen from the figure, the two models gives identical results, confirming the appropriateness of the average model.

Table 4.4: Verification of simulation results

Solar panel	**Duty cycle**	**PWM model**		**Average model**	
		Imp	**I_bat**	**Imp**	**I_bat**
Voc= 21.7	0.5	3.849	3.849	7.69	3.849
Isc=8.02	0.2	1.541	1.541	7.69	1.539

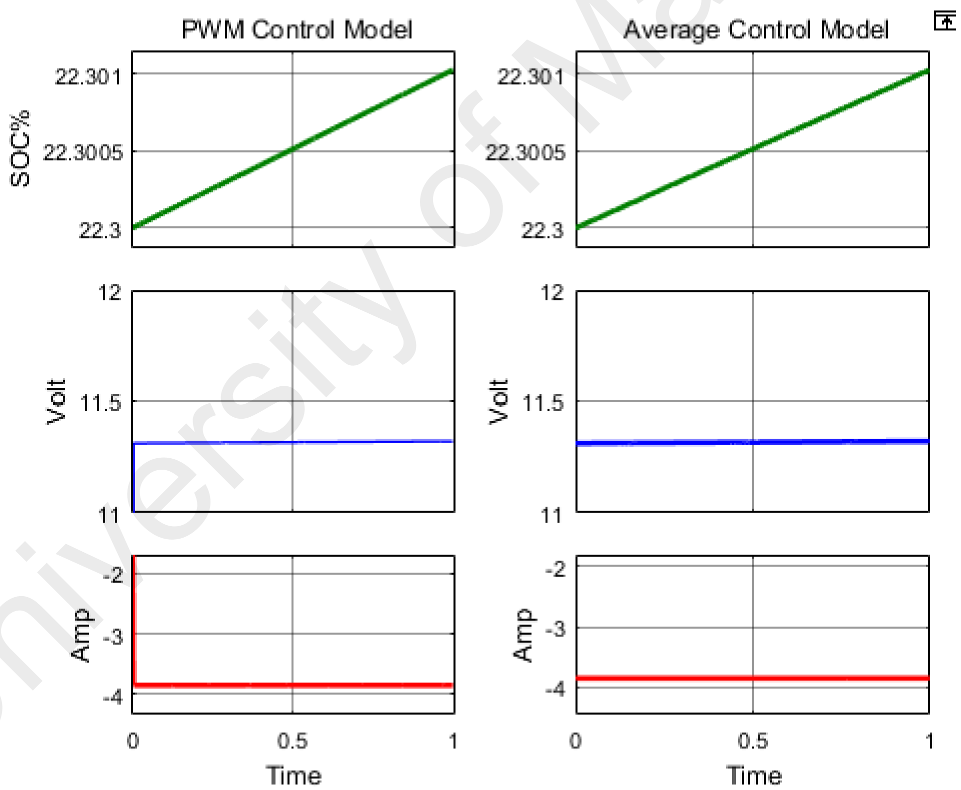

Figure 4.17 : Simulation results in SOC battery, voltage and currents

For actual implementation of the PWM charge controller, the duty cycle of the PWM is not fixed, but varied according to the battery voltage. The outputs of the charge controller are the switching signals for based on input are including actual battery voltage (Vbatt) as set point fully battery charge as illustrated in figure 4.18. It measures the excess current flowing in the battery from the solar panels and usually classifies the current battery and current that determine the current to charge the battery down. The output voltage control depends on the battery voltage and PV voltage If the controller is open or closed depending on the battery status in the system. To turn on through each switching system has its own operating state to control the state the switch control in this model is displayed in figure 4.18

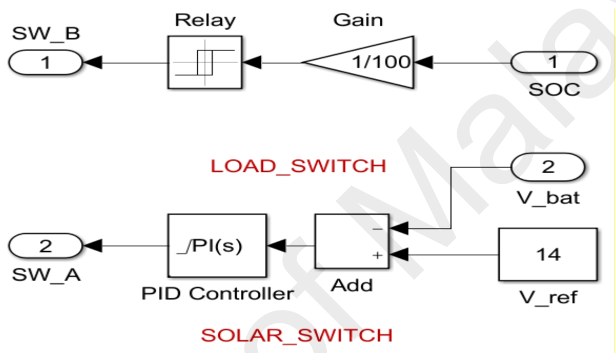

Figure 4.18: Switch control model

This model of PWM charge controller is used for subsequent simulation of the standalone PV system.

4.2 Matlab simulation of a standalone pv system

With simulation of the main components ready, the whole stand-alone PV system can be simulated in MATLAB to illustrate the operation of the system. To make the simulation results more realistic, it is necessary to use the metrological data for a specific site over a 24-hour. Solar irradiance data from Ayaer Keroh, Malacca 12 and 17 February 2018 were used for this case. The data for 12th February (figure 4.19) represents a good sun day, while 17th February (figure 4.20) illustrates the case with a bad sun day, so that the influence of weather conditions can be included.

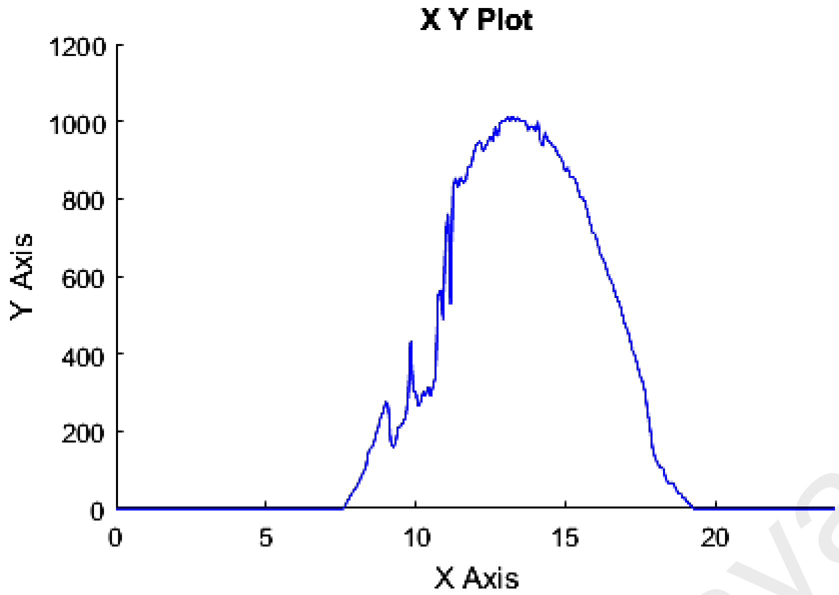

Figure 4.19: Irradiance vs. Time for sunny day simulation purposes

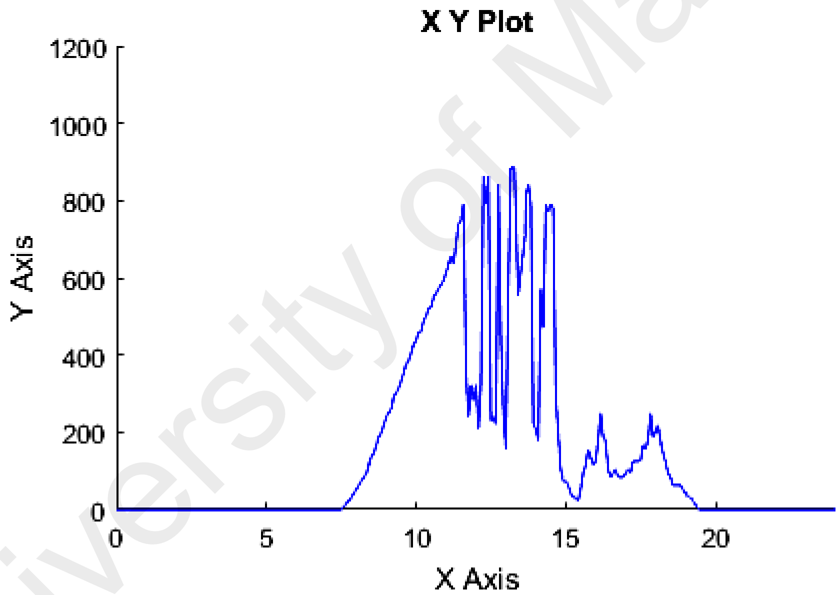

Figure 4.20: Irradiance vs. Time for running day simulation purposes

The proposed system site in the Malacca, Thus the system configures and sizing respect to the February month in this month, only 5 hours of sunlight are received per day shown in figure 3.3. In addition, during this month it is fairly common to see days without sunshine, because of cloud cover and to meet the requirement of 400Wh collected per day using Pvsyst (Appendix B)

Based on the system sizing obtained, a 135W PV is selected with 12V 100Ah battery. A resistor is used to represent the load with power consumption of 400 W/day. With a voltage of 12 volts and keeping the load constant throughout the day (24 hours), a parallel resistor of 8.64 Ohms is connected in parallel with the battery. For the purposes of this simulation, the initial state of the battery charge was set to be at 75%. The whole system model is as shown below:

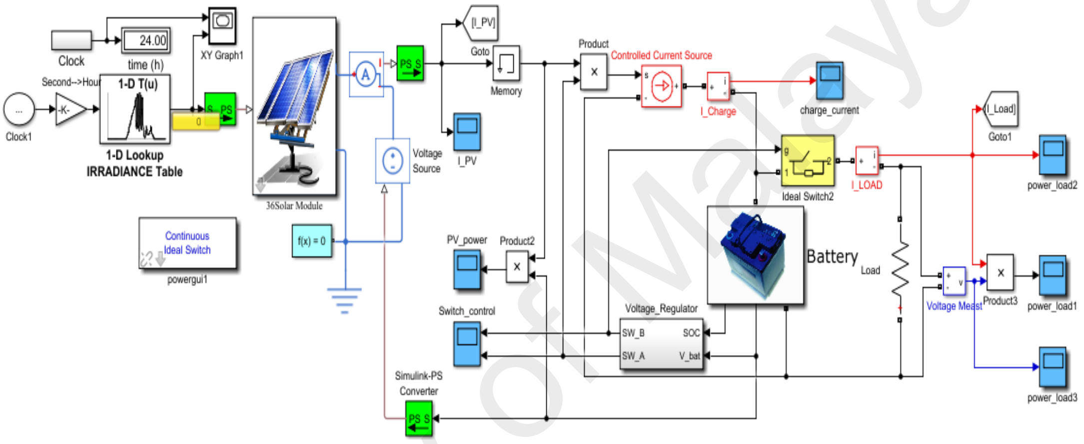

Figure 4.21: Simulink diagram DC load PV off-grid model

The results, the SOC battery increases during the sun peak hour in between 10:00 to 14:00 hours, and the initial SOC gradually increases above 75% as shown in figure 4.22 in order to achieve simulation which depending on the proposal with features characterized short circuit current 8.02A, open circuit voltage 21.7 V battery capacity between (SOC $\geq$ 20 %) and (SOC $\leq$ 95 %). During periods where the solar irradiance is high enough, power provided by the PV is consumed by load and with the surplus energy being stored in the battery. Once there is no sufficient PV power due to low sun, the load will draw power from the battery. Once the SOC is below 30% the load is disconnected from the battery.

The battery parameters (battery current, voltage, and SOC), in addition to the load current and array output current were recorded and plotted in graphs. The graphic plot that contains the battery voltage is useful in determining the effective performance of the charger and the whole system. The SOC will show the amount of battery capacity used per day.

4.2.1 Effect of different weather conditions

It is known that the performance of a stand-alone PV system will be dependent on the weather condition. To illustrate this, two different scenarios were tested using the developed model.

Case 1: Sunny day conditions and constant load resistance

For this case, the irradiance for 12th Feb is used with the load resistance being constant. The battery SOC, battery current and the battery voltage are represented in Figure 4.22, while the PV voltage, PV power, charging current, battery power, load current and load power are shown in figure 4.23.

As seen from the figure, the battery SOC was initially at 75% and continue to drop to around 55% as it supplies the power to the load. Around 4000s, which is equivalent to approximately 11:11 am, the PV panels started providing power. As the solar irradiance continued to increase, the PV panel was able to provide the load power, with surplus energy being stored in the battery. By the end of the sunny day, the battery SOC reached approximately 94% before decreasing again as the sun set, ending at 83%, which is 8% net increase in SOC over a day.

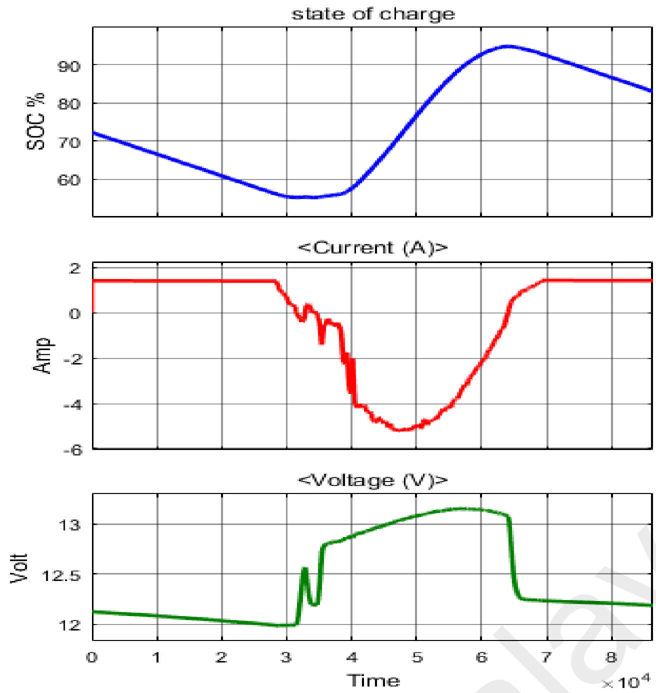

Figure 4.22: Case 1 simulation state of the battery during the sunny day

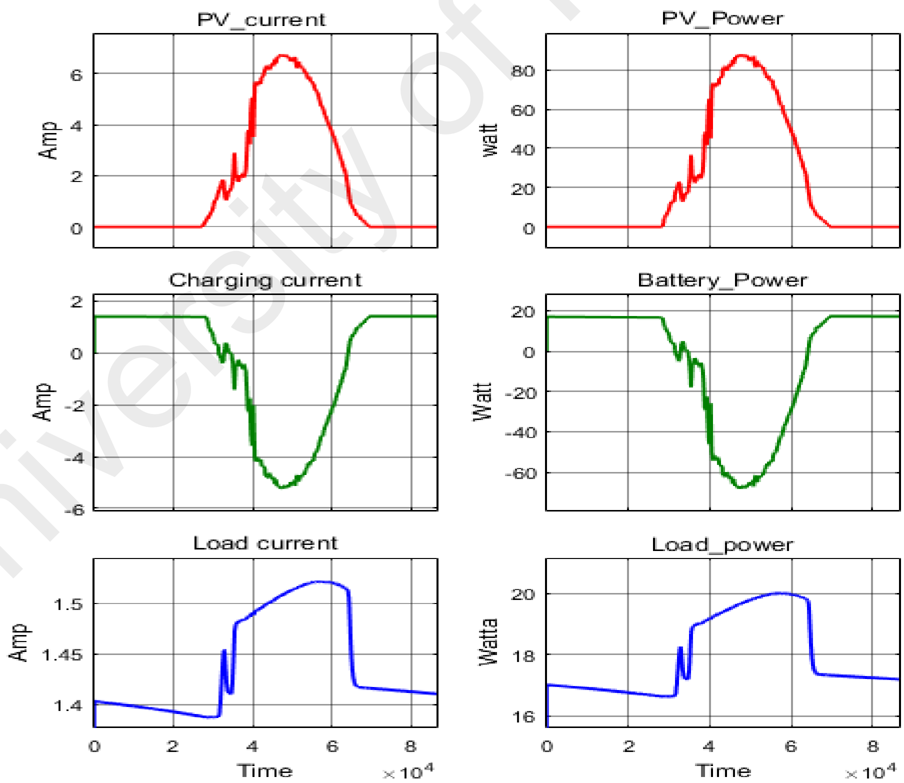

Figure 4.23: Case 1 simulation during a sunny day

Case 2: Cloudy conditions and constant load resistance

In this case, the solar irradiance for a cloudy day on 17th February is used for the simulation, while keeping the load resistance constant. The corresponding system variables are as shown in figure 4.24 and figure 4.25. Similar to the sunny day case, the battery SOC dropped from 75% to around 55% during the night, since the load was the same. During the day, the PV was not able to provide as much power as the sunny day, due to the intermittent and lower solar irradiance, as visible from the PV power graph. As a result, the battery was not able to charge well, rising up to a peak of 74% before dropping to around 58% by the end of the day. It is obvious that there is a net negative change in SOC.

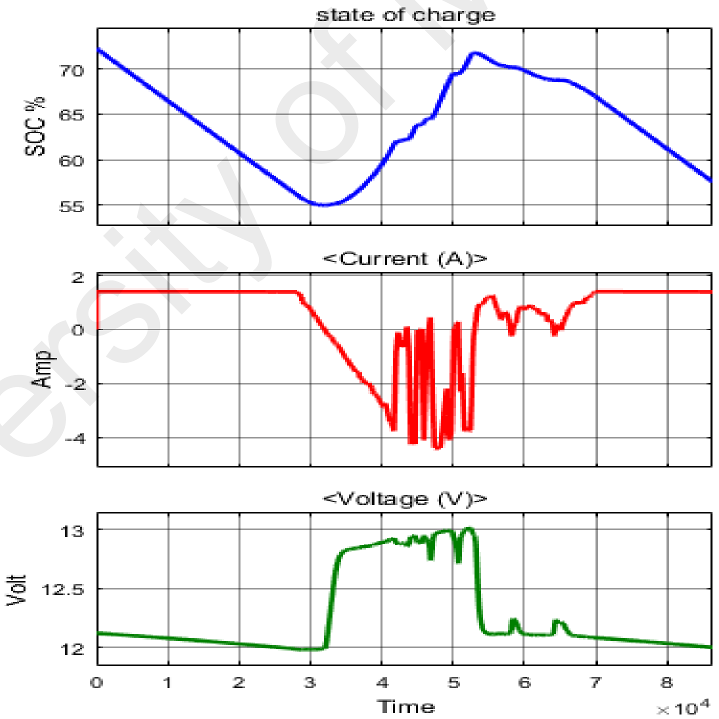

Figure 4.24: Case 2 simulation state of the battery during the cloudy day

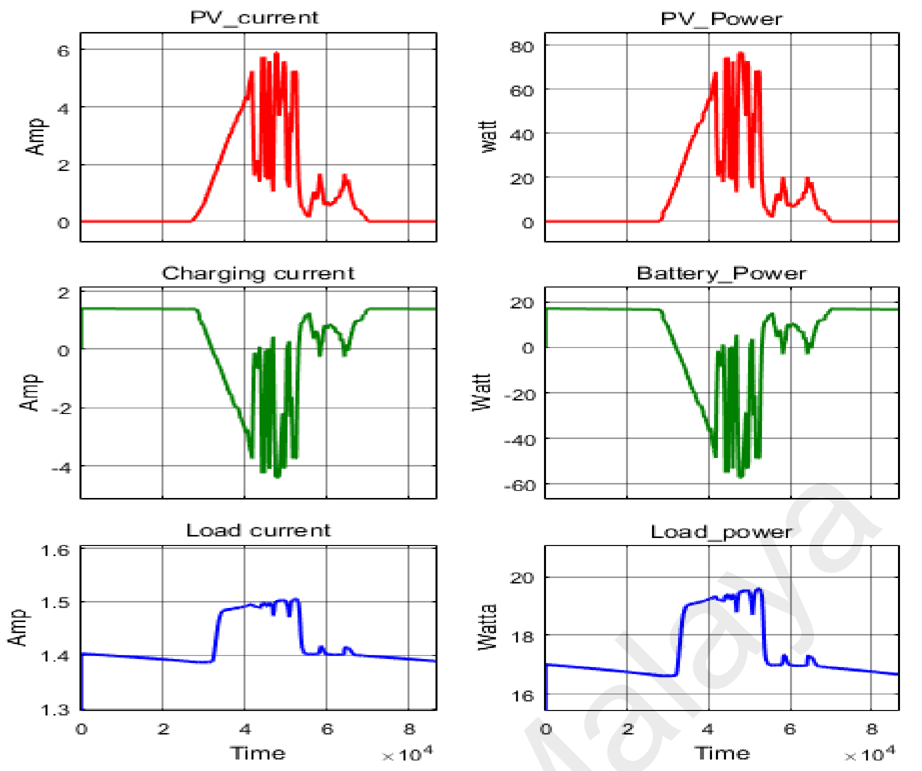

Figure 4.25: Case 2 simulations during a cloudy day

It is clear that the simulated system works much better under sunny conditions. Data obtained from the cloudy day battery status drop about 25%, indicating that the maximum two consecutive clouds cannot be handled by the system.

If the bad weather persists, it is expected that the system will become unsustainable. Once the battery doesn't store enough energy to meet the demand, the system will no longer be able to provide constant output power through the day.

4.2.2 Effect of PV module and battery voltage matching

For stand-alone PV system with PWM charge controller, it is important to match the PV panel voltage with the battery voltage in the system. For example, for a 12V systems, the panel should be slightly higher than 12V at MPP. This is because with the use of the PWM charge controller, the PV panle will be pulled to be equal to the battery voltage. If this operating voltage is far away from the MPP voltage, the power output from the panel will be far below the maximum. Since the full module capacity is not used to produce electricity whenever it operates away from the maximum power point, photovoltaic modules must be carefully matched to the system load and storage. Using a module with a maximum voltage which is much higher than nominal voltage should be avoided. Mismatch in PV and battery voltage can severely reduce the power output from the PV panel and affect the energy yield.

As already discussed in Chapter 3, usually only the power of the PV panel is being considered in the sizing of stand-alone PV system. However, there can be many panels of similar power rating, but different voltage and current specifications available in the market. Table 4.5 illustrate this by showing five commercially available PV panels of 135Wp, but with different voltage and current ratings. To improve the performance of the stand-alone PV system, a matching PV panel needs to be selected. To study the effect of PV and battery mismatch, the developed simulation in MATLAB is used.

Table 4.5: Specifications for selected commercial PV panels.

Manufacturers	Model No	Voc (V)	Isc (A)	Vmp (V)	Imp (A)
Heizmann	HSE-ES-135W-12	21.8	8.59	16.7	8.09
Canadian solar	CS6C - 135M	22.2	8.07	17.8	7.58
Axitec solar	AC-135M/156-40S	24.5	8.54	18.5	7.29
Mega slate	Mega Slate II Standard 135Wp	19.6	9.6	15.9	8.5
CP-Solar	CPS135 M27-135Wp	32.9	5.31	27.8	4.86

It is important to note that another factor that can affect the PV characteristics is the panel temperature. For example, the maximum power of the CP-Solar panel drops from 135W to approximately 115W as the temperature increases from 25 C to 45C, as shown in figure 4.26. This is also taken into consideration in the simulation.

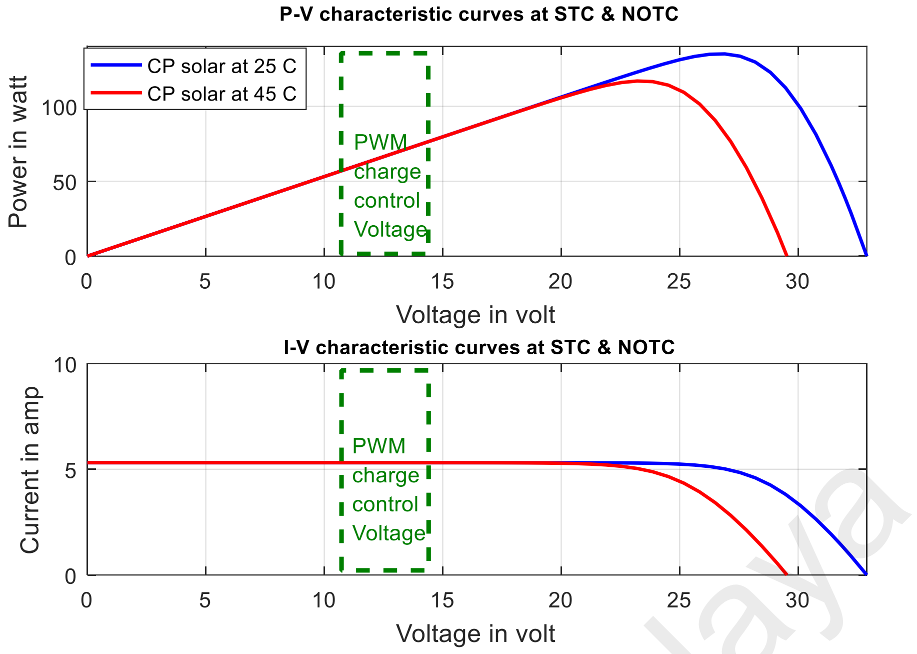

Figure 4.26: Photovoltaic module tested at a temperature

Figure 4.27 illustrate the P-V and I-V curves for the Axitec, Mega Slate and CP solar panels under 25°C and 45°C condition. These changes were due to the changes in the voltage and current characteristics, as detailed in Table 4.6. For stand-alone PV system operating with a nominal 12V battery and a PWM charge controller, the range of operating voltage for the PV panel is tied with the battery voltage, which is in the range of 11V to 14V, as highlighted in the figure.

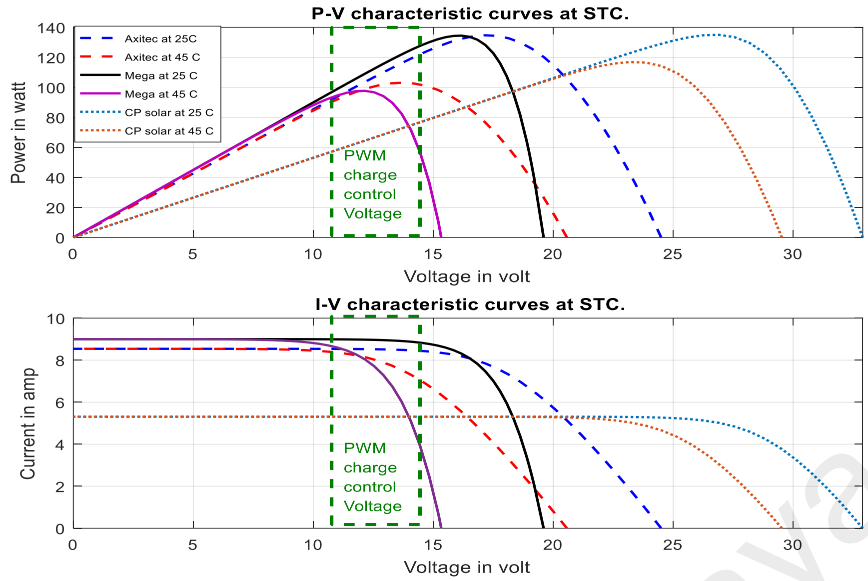

Figure 4.27: Photovoltaic modules are tested at a temperature

Table 4.6: performance typical PV module at a different temperature

Irradiance / Temp	Voc	Isc	Vmp		Imp		FF	
			25	**45**	**25**	**45**	**25**	**45**
Mega Slate II Standard 135Wp								
1000	19.6	9.6	15.25	11.37	8.87	8.5	0.719	0.518
800	19.6	9.6	15.32	11.37	7.05	6.77	0.57	0.41
400	19.6	9.6	14.84	10.97	3.5	3.37	0.28	0.197
200	19.6	9.6	14.39	10.19	1.76	1.71	0.135	0.0927
Axitec AC-135M/156-40S								
1000	24.5	8.54	17.17	13.72	7.8442	7.514	0.6437	0.4927
800	24.5	8.54	17.80	14.21	6.2599	6.034	0.5327	0.41
400	24.5	8.54	18.366	14.7	3.1919	3.0857	0.2802	0.216
200	24.5	8.54	18.33	14.7	1.6026	1.537	0.1404	0.1080
CPS135 M27-135Wp								
1000	32.9	5.31	26.91	23.20	5.016	5.037	0.772	0.669
800	32.9	5.31	27.07	23.22	4.025	4.059	0,6238	0.539
400	32.9	5.31	27.1	23.37	2.025	2.027	0.314	0.271
200	32.9	5.31	26.49	23.23	1.022	1.004	0.155	0.133

Firstly, the case where the panels are at 25°C panels is considered. From the graph, it can be observed that CP solar will give only 55-75W due to its high voltage rating, which is far away from the operating voltage of the battery.

On the other hand, Mega Slate and Axitec has quite similar performance, giving approximately 90-130W of power in the operating range. Between the two, Mega Slate has slightly higher power output because of its MPP voltage which is closer to the battery voltage. When the temperature increases to 45°C, the scenario becomes a bit different. As predicted, all the panel maximum power and V_{OC} reduces with the increased temperature.

For CP solar, the power generated is still around 55-75W, because this region of the P-V curve was not affected by the temperature. For Mega Slate and Axitec, the increase in temperature has different effects, where the power generated by Mega Slate drops more significantly than that of Axitec, reaching as low as around 60W compared to 90W of Mega Slate.

To illustrate the effect of PV and battery voltage mismatch, the three different types of solar panels are used to run the same simulation scenario and the resultant SOCs, which reflect the energy yield was recorded. These SOCs are shown in figure 4.28 and figure 4.29, for the cases of a cloudy day and a sunny day weather respectively. Varying solar irradiance from 12th and 17th February were again used to provide a more realistic simulation.

For the case of 25°C panels under cloudy weather, Mega Slate performed the best as expected, because of having an MPP voltage that is closer to the battery voltage. PC solar is the worst, with the lowest SOC by the end of the day.

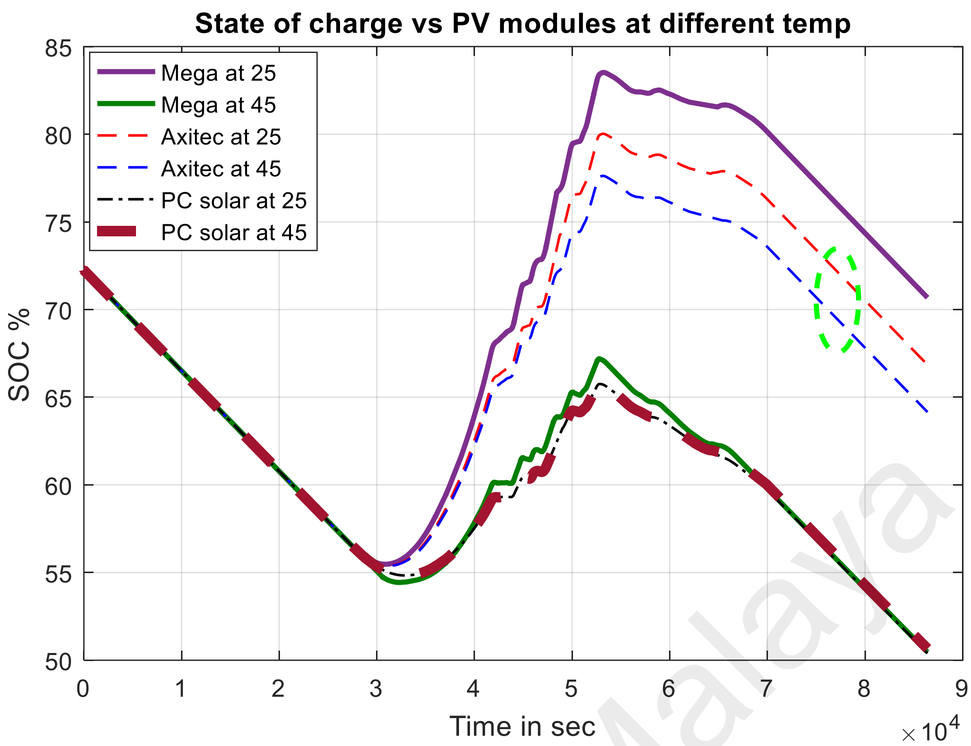

Figure 4. 28: State of charge vs. PV modules during a cloudy day

However, when 45°C panel temperature was considered, the energy yield from Mega Slate drop significantly, giving a result as poor as PC solar. Axitec, on the other hand, shown a slight drop in energy yield, but generally maintained quite consistent performance. The energy yield from PC solar is almost identical as in the case of 25°C, largely because of the fact that the temperature change has not affected the P-V characteristics around the region of the battery voltage.

For the case of 25°C panel on a sunny day, Mega Slate again was predicted to have the best performance, followed by Axitec and then PC solar. However, in the case considered, the battery was fully charged before sun set, so the SOC by the end of the day was similar for Mega Slate and Axitec.

The effect of increase temperature was again severe for Mega Slate, where the SOC of the battery was only 77% compared to 88% for the 25°C case. On the other hand, the effect of energy yield for Axitec and PC solar was quite marginal, due to the fact that their P-V curve around the battery voltage was not severely influence by the temperature change.

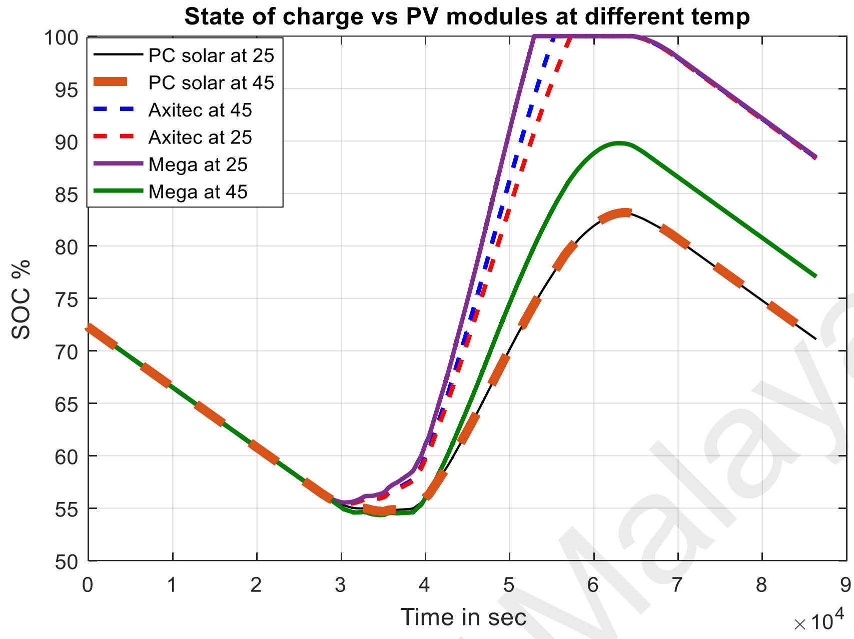

Figure 4.29: State of charge vs PV modules during sunny day

4.3 Summary:

In this chapter, modeling and simulation of a stand-alone PV system with its component devices in MATLAB/SIMULINK has been presented. The simulation is able to show the effect of the component selection and weather condition on the total energy yielded from the PV system.

One notable issue discussed here is the effect of PV module and battery voltage mismatch. It has been demonstrated that even though the panel power is the same, the PV panel voltage and current characteristics can have profound impact on the energy yield form the system when PWM charge controller is used. Ideally, the PV MPP voltage should be higher but close to the battery operating voltage. The effect of panel temperature should also be considered to ensure that the system perform well under all possible scenarios

CHAPTER 5: CONCLUSIOM AND FUTURE WORK

5.1 Conclusion

In this project, the design and implementation of small stand-alone PV system suitable for electrification of off-grid communities has been considered. The design and sizing principles for various components in the system has been reviewed and compared with existing commercial design software, i.e. PVsyst. Furthermore, a simulation model has been developed in MATLAB to allow the studying of various factors affecting the performance of a stand-alone PV system operating with PWM charge controller.

The purpose of this thesis was to study how this photovoltaic system was made and how it worked. From the simulations, it can be concluded that proper sizing of PV and battery capacity as well as the selection of power management are crucial to improve system efficiency

The life cycle cost analysis, it is found that he prices of stand-alone PV system in Malaysia is still higher than the grid electricity tariff. This is mainly due to the higher price of battery and panels which are the main cost components in the system. For small systems, such as the ones considered here in this project, the lack of economy of scale is also a factor of the higher cost. However, this price is predicted to diminish in the future, with the price of the PV panel and battery decreasing. Furthermore, it is expected that the grid electricity tariff will continue to grow in the future due to the increase in fuel prices. It can be expected that the use of stand-alone PV system will be more and more favorable in the future, and certainly better than using diesel generator for rural communities.

The designed worksheet enables us to easily scale the components of the PV system by simply inserting of the design parameters of the site and the applications, and can be handled simply because of its flexibility, accuracy and speed in displaying and showing design results. The manual system sizing and design made by the simulation engine had very accurate results, as the quantity of components required to supply power from the stand-alone PV system has all matched, except the number of solar panel (6 for the manual sizing and 5 from PVsyst).

From the simulation results, it is also concluded that the matching of PV panel and battery voltage is important to guarantee good energy yield from the system. As a rule of thumb, the PV panel MPP voltage should be selected to be close to the battery operating voltage. Furthermore, the effect of temperature should also be accounted, to ensure consistently good energy yield can be obtained. To allow more detail designed, P-V curves can be used to estimate the performance of the system under different temperature and conditions. It is worth noting that the voltage matching issue is only important when PWM charger controller is used. If the more advanced MPPT charge controller is present, the choice of PV panel voltage and battery voltage is expected to have less impacts.

5.2 Future scope of work

In the process of completing this project, various other interesting issues related to the designing and implementation of stand-alone PV system has been observed. Due to the limited time and scope for the project, these issues have not been studied in depth and are proposed here as potential future works for others.

In this project, the use of a low cost and simple PWM charge controller is consider. Future research can bring some other converters such as boost, Cuk, and buck-boost along with novel control techniques to improve flexibility in selection and configuration of PV connection range.

From the simulation conducted, it is clear that the use of PWM charge controller is not very good in optimizing the energy yield form the PV system. Due the the operation principle of the PWM charge controller, the PV operating voltage is restricted to be around the battery operating voltage, making the matching of PV and battery voltage an important issue, detrimental to the performance of the system. Future work can involve the study of MPPT charge controllers and its application in stand-alone PV system.

In this project, the study focuses on small stand-alone PV system, which is more suitable for single household application. In some rural community, larger centralised PV system with hybrid energy sources can be implemented to improve the reliability and availability of the power supply. The study of sizing and modelling of such system will be interesting.

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