DEVELOMENT OF PORTABLE SOLAR GENERATOR

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ABSTRACT

The increase of demand for energy, stimulated by developing countries and consequent decrease of power sources, is leading to an unsustainable future. These way renewable and clean energies are necessary to be used, particularly solar energy. It can produce heat or be directly converted into electricity, called photovoltaic (PV) energy. JX Crystals Inc is developing a class of compact portable solar generators using commercially available 32% efficient multifunction solar cells. Three different sized solar generators with nominal power ratings of 12 W, 36 W and 75 W are described. The high solar cell efficiency will allow all three units to be small, portable, and light weight. (For example, the 12 W generator will fit in a pocket.) The 36 W Charger is exemplary. The 36 W Charger in its stowed form will resemble a notebook computer case in size and form Deployed, its physical size is half that required for a traditional Silicon 16% solar cell Charger and one-quarter that for a 8% thin film solar cell Charger. A challenge for the use of these 32% efficient cells is their cost. This cost can be reduced ten fold through the use of linear Fresnel lenses as per the designs described herein. The challenge is to preserve simplicity of operation. By using bypass diodes in the cell circuits and by orienting the lens focal line and cell circuit East and West, the smaller 12 W and 36 W units can be easily aimed at the sun and they will then maintain output without adjustment for 2 hours in the middle of a sunny day. A simple 1-axis solar tracker is also proposed for the larger 75 W unit. It can fit within the stowed case where the case will fit within a backpack.

CONTENTS

LIST OF SYMBOL AND ABBREVIATIONS

UTHM	*UniversitiTun Hussein Onn Malaysia*
CPC	*Compound Parabolic Concentrator*
PV	*Photovoltaic's*
LED	*Light Emitting Diode*
Voc	*Open Circuit Voltage*
Isc	*Current Short Circuit*
VSHOT	*Visual Scanning Hartmann Optical Tester*
Wp	*Watt peak (measure of nominal power of a photovoltaicmodule under 1000 W/m2 light intensity*
FF	*Fill Factor*
DC	*Direct Current*
AC	*Alternating Current*
PSG	*Portable Solar Generator*
PCB	*Printed circuit Board*
TMY	*Total Metrology Year*
NOCT	*Nominal Operating Cell Temperature*
W	*Watt*
mm	*Millimeter*
PWM	*Pulse Width Modulation*
DIP	*Dual Inline Package*
MCLR	*Master Clear*
%	*Percentage*

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Energy resources have become an importance when we are out for outdoor activities. If it rains, camp fires will die out and torch light batteries usually do not last long. Besides that, hawkers from the night market also rely on generators to provide light. The world is full of alternative energies such as the heat from the sun, wind and hydro power. These energies can be harness to reduce relying totally on the supplied electricity. Moreover, some of the electrical devices and home lightings use only little power. Harnessing the natural energies can save money paid for the electricity and help to save our world. Hence the purpose of this project is to design a fully automated low cost power generation system that will harness solar energy and then convert it into electrical energy to power some of the electrical devices at home and for outdoor lighting. An additional feature is the solar tracking method of the panel which can maximize the energy harnessed.

The system will also include a backup battery which will store the extra charge giving the system to provide longer energy supply. The cost for the project will be emphasizing on low cost to produce so that it will be affordable to be installed for every home. Moreover, the design of the low cost mobile power generator will be convenient to be carried around to places where availability for electricity is an issue.

1.2 Problem Statement

In Malaysia now many people like having outdoor activities like camping, fishing, mounting climbing and other outdoor activities. So that activities sometime do at day and sometime do at night. Can we imagine what if happen the outdoor activities do at night without any energy supply. That will problem to do that activities or any emergency like loss power of cell phone to make the call or any equipment will problem without electrical supply

Based on the current situation described above is likely to people have problem to get the power supply when they are in jungle or some place without any source of electrical supply For that reason, the suitable solution is develop the new concept of generation and friendly user for everybody and any situation also easy to carry and light. This generator will use the renewable energy to produce the electricity. This generator also can generate the ac and dc supply. The best concept to solve this problem is develop the portable solar generator.

Hence this portable solar generator also can help the severely environment can not have the power supply using to have the some energy where it can help in emergency situation or critical situation

1.3 Objectives

The objective for the project is to produce a mobile generator system which is portable for many various uses such as outdoor activities and areas where there is a shortage of power supply. Besides that, it can also be used for residents in the rural area. The design of the project will also focus on low cost on producing the generator so that it is affordable. The low cost power generation system will be fully automated so that it will be easy to use. Solar power will be the power source option for the generator.. This project will help graduates be more competent in future as the experience gained in completing the project will be highly evaluated by the industry.

The overall objectives can then be summed as the main points below:

1. To propose a measurement technique and procedure in evaluating using simple measurement setup and tools
2. To design and build a portable generator system for small and easy to use
3. To evaluate and analyze the reliability of the constructed PSG

1.4 Scope of Project

This project will include working with both hardware and software. The hardware will include the materials such as the solar panel, acid lead battery, PIC microcontroller, printed circuit board (PCB), solar panel and so on. The hardware materials will be purchased either locally or pre order from companies from different states.

Not all of the hardware are designed but rather purchased to contribute as a part of the system such as lead acid battery and charge controller. The hardware will then be set up by connecting the system in a correct sequence. The mechanical design for the project will be studied such as the solar panel to the desired angle. Cooling the solar panel also the comprising the output. This will include the hardware and software implementation for the system. Software programming and hardware design will be deterministic for the overall outcome of the project.

After the materials are finally ready, the overall components and materials will be combined to work and function as a mobile energy generator. If there are problems that occur, troubleshooting will be done until the project works properly.

Figure 1.1: Portable Solar Generator

1.5 Thesis Outline

This thesis is divided into five chapters. First, chapter 1 is on the introduction to the project where problem statement, objectives and scope of project is presented on this chapter. Chapter 2 describes previous work, idea and concept which is related and a motivation for the work performed throughout this project. Chapter 3 describes the methodology used in the design of the experiment where flow of the project, experiment procedure and materials used is included in this chapter. While in chapter 4, it present the experiment results together with its analysis and discussion. Chapter 5 summarizes the main conclusion of the thesis and presents an outlook for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review is a study about the project and this chapter covers the fundamental concepts of Portable Solar Generator (PSG) and the fundamentals of PSG applied to concentration.

It involves all the aspect which can be linked to the project or research which is available in outside world. The research is not mainly focus directly to research which is already performed but also focused on fact research and references of studies. The source and information can be available from internet, library, and also from a person who has high knowledge about the research. This research is important because it resemble the starting point to creating, upgrade and producing a quality research which have trustable result obtained.

From past research that had been done, lot of knowledge can be obtained such as the equipment needs to be used, type of disadvantages can be expected, the basic knowledge need to master to run the experiment and the expected result to be obtained. This will help to reduce the time and cost used for performs of the research.

2.2 Solar Energy

Solar energy is the light and radiant heat from the Sun that influences Earth's climate and weather and sustains life. Solar power is sometimes used as a synonym for solar energy or more specifically to refer to electricity generated from solar radiation. Solar radiation is secondary resources like as wind and wave power, hydroelectricity and biomass account for most of the available flow of renewable energy on Earth. Solar energy technologies can provide electrical generation by heat engine or photovoltaic means, space heating and cooling in active and passive solar buildings, potable water via distillation and disinfection, day lighting, hot water, thermal energy for cooking, and high temperature process heat for industrial purposes.

Solar energy refers primarily to the use of solar radiation for practical ends. All other renewable energies other than geothermal derive their energy from energy received from the sun. Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps, and fans to convert sunlight into useful outputs.

Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.

2.2.1 Review of photovoltaic energy

A definition of a photovoltaic (PV) system is a system that converts directly solar radiation into electricity [4]. Since it was first found, in 1839 by Edmond Becquerel, and after improvements made in the almost 100 following years, the photovoltaic energy has raised a constantly growing interest all over the world. The possibility to generate electrical energy in practically any place in the world was extremely appealing. With the major drawback of the high cost of solar cells, the almost exclusive use of PV energy was made by space industry to fuel satellites, where no budget constraints were applied. The efficiency of solar cells more than double from 6% in 1954 to 13.5% [8], but still too expensive. Today the top efficiency of silicon cells is around 27.6% 2.2

Ironically, it was in offshore oilrigs and isolated on-shore gas and oil fields, among others, where PV systems were used, replacing the toxic and short-lived batteries [5]. Nowadays, total PV installed capacity is estimated to reach 50.9 GWp, representing a growth of 62.1% comparing to 2010 [8]. The continuously increasing price of oil, the global warming, the Kyoto Protocol, and the recent nuclear disaster that occurred in Fukushima, Japan, turns the attention of the world to renewable energies [4].

2.2.2 Functional Of Solar Energy

Photovoltaic energy is the conversion of sunlight into electricity. A photovoltaic cell, commonly called a solar cell or PV, is the technology used to convert solar energy directly into electrical power. [1]

Sunlight is composed of photons, or particles of solar energy. These photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a photovoltaic cell, they may be reflected, pass right through, or be absorbed. Only the absorbed photons provide energy to generate electricity.

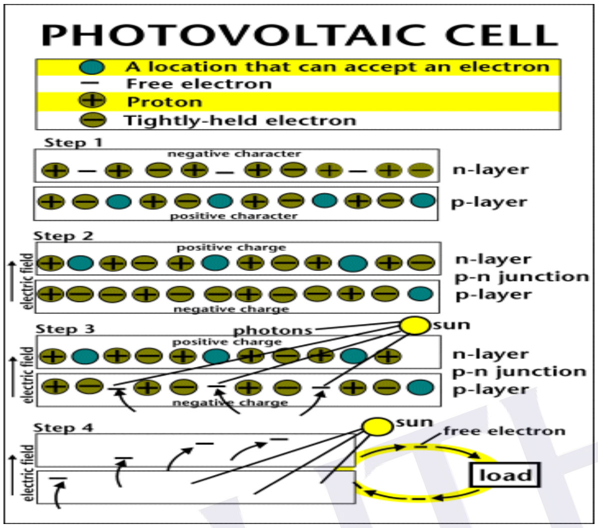

Figure 2.1: Photovoltaic Cell

When enough sunlight energy is absorbed by the material that is a semiconductor, electrons are come out from the material's atoms. Special treatment of the material surface during manufacturing makes the front surface of the cell more receptive to free electrons, so the electrons naturally migrate to the surface. When the electrons leave their position, holes are formed.

When many electrons, each carrying a negative charge, travel toward the front surface of the cell, the resulting imbalance of charge between the cell's front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When the two surfaces are connected through an external load, electricity flows. Photovoltaic cells, like batteries, generate direct current (DC) which is generally used for small loads like electronic equipment.

When DC from photovoltaic cells is used for commercial applications or sold to electric utilities using the electric grid, it must be converted to alternating current (AC) using inverters. Advantages of photovoltaic systems are:

1. Conversion from sunlight to electricity is direct, so that bulky mechanical generator systems are unnecessary.
2. PV arrays can be installed quickly and in any size required or allowed.
3. The environmental impact is minimal, requiring no water for system cooling and generating no by-products.

2.3 Solar Irradiance

Total solar irradiance is defined as the amount of radiant energy emitted by the Sun over all wavelengths that fall each second on 11 sq ft (1 sq m) outside the earth's atmosphere.

By way of further definition, irradiance is defined as the amount of electromagnetic energy incident on a surface per unit time per unit area. *Solar* refers to electromagnetic radiation in the spectral range of approximately 1-9 ft (0.30-3 m), where the shortest wavelengths are in the ultraviolet region of the spectrum, the intermediate wavelengths in the visible region, and the longer wavelengths are in the near infrared. *Total* means that the solar flux has been integrated over all wavelengths to include the contributions from ultraviolet, visible, and infrared radiation.

By convention, the surface features of the Sun are classified into three regions: the photosphere, the chromospheres, and the corona. The photosphere corresponds to the bright region normally visible to the naked eye. About 3,100 mi (5,000 km) above the photosphere lies the chromospheres, from which short-lived, needle-like projections may extend upward for several thousands of kilometers. The corona is the outermost layer of the Sun; this region extends into the region of the planets. Most of the surface features of the Sun lie within the photosphere, though a few extend into the chromospheres or even the corona.

The average amount of energy from the Sun per unit area that reaches the upper regions of the earth's atmosphere is known as the solar constant; its value is approximately 1,367 watts per square meter. As earth-based measurements of this quantity are of doubtful accuracy due to variations in the earth's atmosphere, scientists have come to rely on satellites to make these measurements.

Although referred to as the solar constant, this quantity actually has been found to vary since careful measurements started being made in 1978. In 1980, a satellite-based measurement yielded the value of 1,368.2 watts per square meter. Over the next few years, the value was found to decrease by about 0.04% per year. Such variations have now been linked to several physical processes known to occur in the Sun's interior, as will be described below.

From the earth, it is only possible to observe the radiant energy emitted by the Sun in the direction of our planet; this quantity is referred to as the solar irradiance. This radiant solar energy is known to influence the earth's weather and climate, although the exact relationships between solar irradiance and long-term climatologically changes, such as global warming, are not well understood.

The total radiant energy emitted from the Sun in all directions is a quantity known as solar luminosity. The luminosity of the Sun has been estimated to be 3.8478 x 10^{26} watts. Some scientists believe that long-term variations in the solar luminosity may be a better correlate to environmental conditions on Earth than solar irradiance, including global warming. Variations in solar luminosity are also of interest to scientists who wish to gain a better understanding of stellar rotation, convection, and magnetism.

Because short-term variations of certain regions of the solar spectrum may not accurately reflect changes in the true luminosity of the Sun, measurements of total solar irradiance, which by definition take into account the solar flux contributions over all wavelengths, provide a better representation of the total luminosity of the Sun.

Short-term variations in solar irradiation vary significantly with the position of the observer, so such variations may not provide a very accurate picture of changes in the solar luminosity. But the total solar irradiance at any given position gives a better representation because it includes contributions over the spectrum of wavelengths represented in the solar radiation.

Variations in the solar irradiance are at a level that can be detected by ground-based astronomical measurements of light. Such variations have been found to be about 0.1% of the average solar irradiance. Starting in 1978, space-based instruments aboard the *Nimbus 7, Solar Maximum Mission*, and other satellites began making the sort of measurements (reproducible to within a few parts per million each year) that allowed scientists to acquire a better understanding of variations in the total solar irradiance.

2.3.1 Solar Irradiance Data Sets

The most accurate measurements of solar radiation are obtained by a pyrometer placed at a location for a number of years, usually on the order of a decade or more, measuring the direct radiation every few minutes. However, the volume of data generated by this technique makes it impractical (and unnecessary) to provide the full data set for each location for PV system design. Instead, the data can be presented in several other formats.

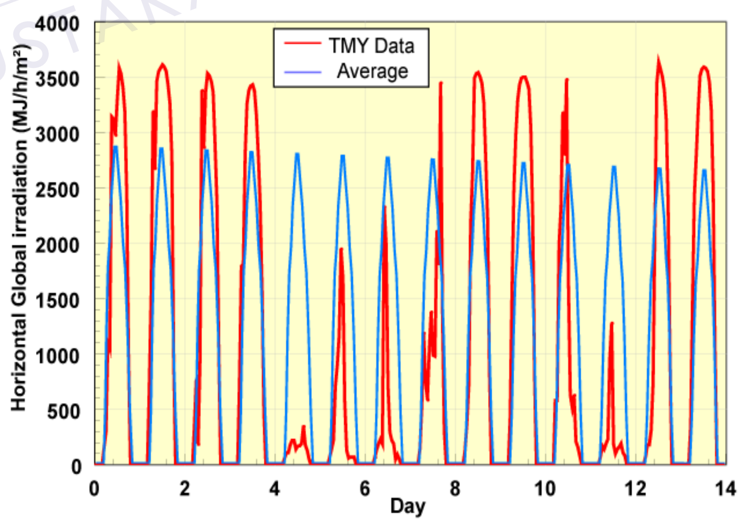

Figure 2.2 : Comparison of TMY and average solar radiation data

The most conceptually straight forward method of reducing the data set is to average the data over the measuring period. This form of data is called average daily, monthly or yearly radiation data. Although this data is useful for basic system design, the day-to-day variation in the solar radiation is lost. The loss of the day-to-day variation is critical since the design and performance of a system with, for example, 5 kWh/day nearly every day is quite different than one with 8 kWh/day on some days followed by several cloudy days with 2 kWh/day.

The most common format for solar radiation data is TMY data (or TMY2 data used by the National Renewable Energy Laboratories in the USA) which includes daily variability in the data. TMY data sets are described in the following page. However, average solar radiation data, particularly for each month of the year is also extensively used in rough estimates on the amount of PV panels required.

An additional useful, although less common data which can be determined from the full radiation data sets, is the probability of having a certain number of cloudy days which occur in a row, whereby the definition of a cloudy day is usually a day where less than 50% of the theoretically expected radiation is received.

For example, at a certain location, 4 cloudy days in a row may occur once a year and 5 cloudy days in a row may occur once every 5 years. This information is particularly useful in estimating storage sufficient requirements. However, this information is less commonly tabulated and, if used, must be determined from the original data sets.

2.4 PV Module Temperature

An unwanted side-effect of the encapsulation of solar cells into a PV module is that the encapsulation alters the heat flow into and out of the PV module, thereby increasing the operating temperature of the PV module. These increases in temperature have a major impact on the PV module by reducing its voltage, thereby lowering the output power. In addition, increases in temperature are implicated in several failure or degradation modes of PV modules, as elevated temperatures increase stresses associated with thermal expansion and also increase degradation rates by a factor of about two for each 10°C increase in temperature.

The operating temperature of a module is determined by the equilibrium between the heat produced by the PV module, the heat lost to the environment and the ambient operating temperature. The heat produced by the module depends on the operating point of the module, the optical properties of the module and solar cells, and the packing density of the solar cells in the PV module

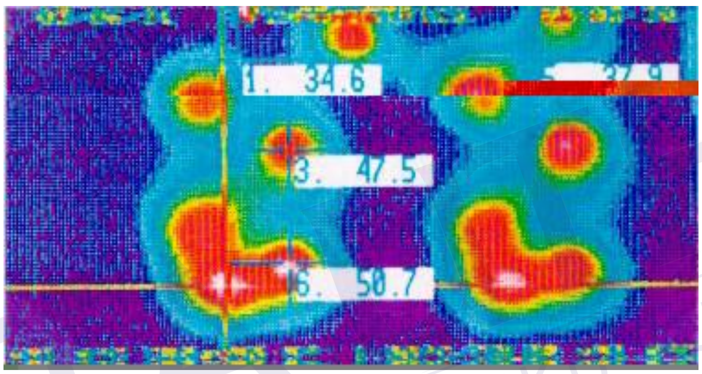

Figure 2.3 : Thermo graphic image of sixteen cell module with integral bypass diode cells under reverse bias conditions. Each color change corresponds to a 40^{o}C change in temperature.

The heat lost to the environment can proceed via one of three mechanisms; conduction, convection and radiation. These loss mechanisms depend on the thermal resistance of the module materials, the emissive properties of the PV module, and the ambient conditions (particularly wind speed) in which the module is mounted. These factors are discussed in the following pages.

2.4.1 Nominal Operating Cell Temperature

A PV module will be typically rated at 25 °C under 1 kW/m^2. However, when operating in the field, they typically operate at highest temperatures and at somewhat lower insulations conditions. In order to determine the power output of the solar cell, it is important to determine the expected operating temperature of the PV module.

The Nominal Operating Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module under the conditions as listed below:

1. Irradiance on cell surface = 800 W/m^2
2. Air Temperature = 20°C
3. Wind Velocity = 1 m/s
4. Mounting = open back side.

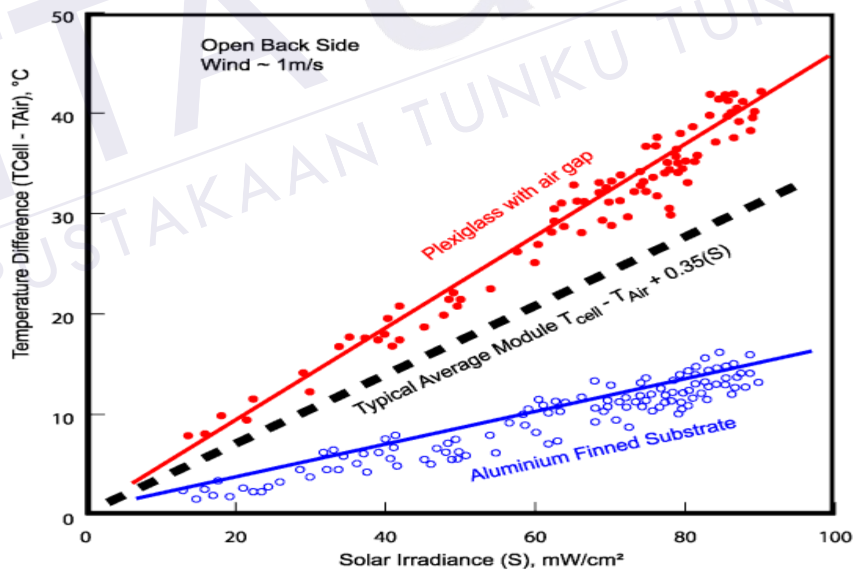

Figure 2.4: Temp Vs Irradiance

The equations for solar radiation and temperature difference between the module and air show that both conduction and convective losses are linear with incident solar insulations for a given wind speed, provided that the thermal resistance and heat transfer coefficient do not vary strongly with temperature. The NOCT for best case, worst case and average PV modules are shown below. The best case include aluminum fins at the rear of the module for cooling which reduces the thermal resistance and increases the surface area for convection.

Temperature increases, above ambient levels, with increasing solar irradiance for different module types [1]. The best module operated at a NOCT of 33°C, the worst at 58°C and the typical module at 48°C respectively. An approximate expression for calculating the cell temperature is given by [2]:

$$T_{cell} = T_{air} + [(NOCT - 20) / 80]S \quad (2.1)$$

where:

S = insulation in mW/cm^2. Module temperature will be lower than this when wind velocity is high, but highest under still conditions.

2.5 Air Mass

The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead). The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust. The Air Mass is defined as:

$$AM=1cos\theta \quad (2.2)$$

where θ is the angle from the vertical (zenith angle). When the sun is directly overhead, the Air Mass is 1.

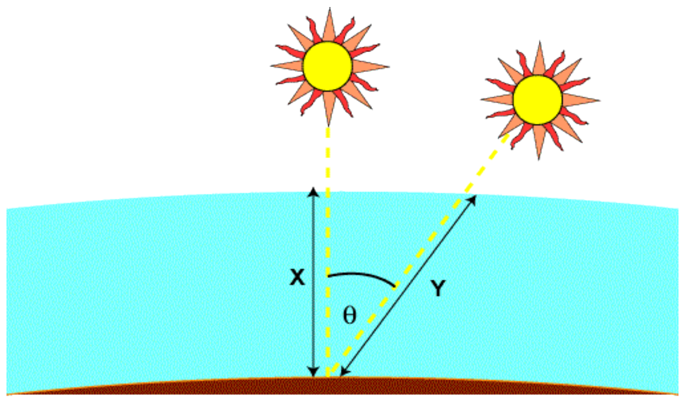

Figure 2.5: The air mass represents the proportion of atmosphere that the light must pass through before striking the Earth relative to its overhead path length, and is equal to Y/X.

A more detailed model showing the effect of air mass on the solar spectrum is available at the PV Lighthouse Solar Spectrum Calculator. An easy method to determine the air mass is from the shadow of a vertical pole.

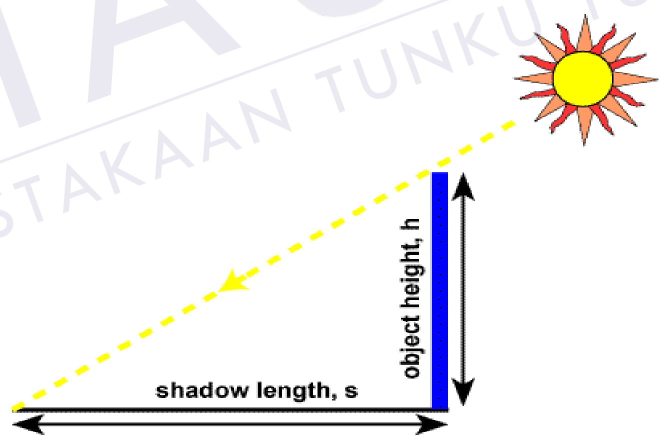

Figure 2.6: Hypotenuse Air Mass

Air mass is the length of the hypotenuse divided by the object height h, and from Pythagoras's theorem we get:

Air Mass = 1+sh2 **(2.3)**

The above calculation for air mass assumes that the atmosphere is a flat horizontal layer, but because of the curvature of the atmosphere, the air mass is not quite equal to the atmospheric path length when the sun is close to the horizon. At sunrise, the angle of the sun from the vertical position is 90° and the air mass is infinite, whereas the path length clearly is not. An equation which incorporates the curvature of the earth is[1]:

$$\textbf{Air Mass} = \mathbf{1\cos\theta+0.5057296.07995-\theta-1.6364} \qquad \textbf{(2.4)}$$

2.4.1 Standardized Solar Spectrum and Solar Irradiation

The efficiency of a solar cell is sensitive to variations in both the power and the spectrum of the incident light. To facilitate an accurate comparison between solar cells measured at different times and locations, a standard spectrum and power density has been defined for both radiation outside the Earth's atmosphere and at the Earth's surface.

The standard spectrum at the Earth's surface is called AM1.5G, (the G stands for global and includes both direct and diffuse radiation) or AM1.5D (which includes direct radiation only). The intensity of AM1.5D radiation can be approximated by reducing the AM0 spectrum by 28% (18% due to absorption and 10% to scattering). The global spectrum is 10% highest than the direct spectrum. These calculations give approximately 970 W/m^2 for AM1.5G. However, the standard AM1.5G spectrum has been normalized to give 1kW/m^2 due to the convenience of the round number and the fact that there are inherently variations in incident solar radiation. The standard spectrum is listed in the Appendix page.

The standard spectrum outside the Earth's atmosphere is called AM0, because at no stage does the light pass through the atmosphere. This spectrum is typically used to predict the expected performance of cells in space.

2.4.2 Intensity Calculations Based on the Air Mass

The intensity of the direct component of sunlight throughout each day can be determined as a function of air mass from the experimentally determined equation [2]:

$$\mathbf{I_D = 1.353 \cdot 0.7AM0.678} \qquad \mathbf{(2.5)}$$

Where $\mathbf{I_D}$ is the intensity on a plane perpendicular to the sun's rays in units of kW/m^2 and *AM* is the air mass. The value of 1.353 kW/m^2 is the solar constant and the number 0.7 arises from the fact that about 70% of the radiation incident on the atmosphere is transmitted to the Earth. The extra power term of 0.678 is an empirical fit to the observed data and takes into account the non-uniformities in the atmospheric layers.

Sunlight intensity increases with the height above sea level. The spectral content of sunlight also changes making the sky 'bluer' on high mountains. Much of the southwest of the United States is two kilometers above sea level, adding significantly to solar isolation. A simple empirical fit to observed data [3] and accurate to a few kilometers above sea level is given by:

$$\mathbf{I_D = 1.353 \cdot 1\text{-}ah0.7AM0.678\text{+}ah} \qquad \mathbf{(2.6)}$$

where a = 0.14 and h is the location height above sea level in kilometers.

Even on a clear day, the diffuse radiation is still about 10% of the direct component. Thus on a clear day the global irradiance on a module perpendicular to the sun's rays is:

$$\textbf{Irradiance Global } (\mathbf{I_G}) = \mathbf{1.1 \cdot I_D}$$

(2.7)

2.5 Fill Factor

The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}. Graphically, the FF is a measure of the "squareness" of the solar cell and is also the area of the largest rectangle which will fit in the IV curve. The FF is illustrated below. As FF is a measure of the squareness of the IV curve, a solar cell with a highest voltage has a larger possible FF since the "rounded" portion of the IV curve takes up less area.

The maximum theoretical FF from a solar cell can be determined by differentiating the power from a solar cell with respect to voltage and finding where this is equal to zero. Hence:

$$\frac{d(IV)}{dV} = 0 \qquad \textbf{(2.8)}$$

giving:

$$V_{MP} = V_{OC} - \frac{nkT}{q}\ln\left(\frac{V_{mp}}{nkT/q} + 1\right) \qquad \textbf{(2.9)}$$

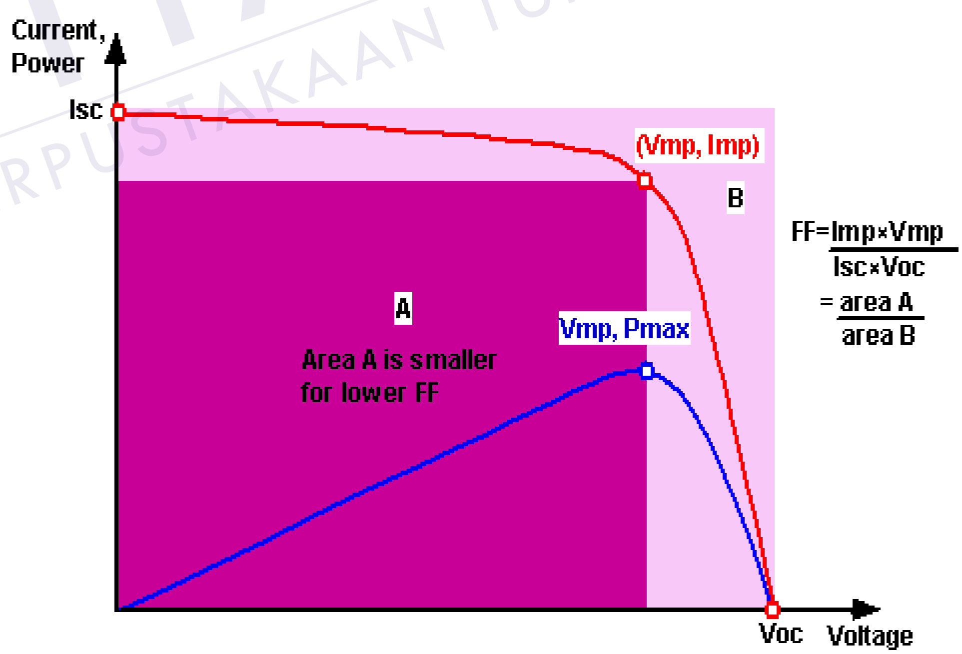

Figure 2.7 : Graph of cell output current (red line) and power (blue line) as function of voltage.

Also shown are the cell short-circuit current (I_{sc}) and open-circuit voltage (V_{oc}) points, as well as the maximum power point (V_{mp}, I_{mp}). However, the above technique does not yield a simple or closed form equation. The equation above only relates V_{oc} to V_{mp}, and extra equations are needed to find I_{mp} and FF. A more commonly used expression for the FF can be determined empirically as:[1]

$$FF = \frac{V_{OC} - \ln(V_{OC} + 0.72)}{V_{OC} + 1} \tag{2.10}$$

where v_{oc} is defined as a "normalized V_{oc}":

$$V_{OC} = \frac{q}{nkT} V_{OC} \tag{2.11}$$

The above equations show that a highest voltage will have a highest possible FF. However, large variations in open-circuit voltage within a given material system are relatively uncommon. For example, at one sun, the difference between the maximum open-circuit voltage measured for a silicon laboratory device and a typical commercial solar cell is about 120 mV, giving maximum FF's respectively of 0.85 and 0.83. However, the variation in maximum FF can be significant for solar cells made from different materials. For example, a GaAs solar cell may have a FF approaching 0.89.

The above equation also demonstrates the importance of the ideality factor, also known as the "n-factor" of a solar cell. The ideality factor is a measure of the junction quality and the type of recombination in a solar cell. For the simple recombination mechanisms discussed in Types of Recombination, the n-factor has a value of 1. However, some recombination mechanisms, particularly if they are large, may introduce recombination mechanisms of 2. A high n-value not only degrades the FF, but since it will also usually signal high recombination, it gives low open-circuit voltages.

A key limitation in the equations described above is that they represent a maximum possible FF, although in practice the FF will be lower due to the presence of parasitic resistive losses, which are discussed in Effects of Parasitic Resistances. Therefore, the FF is most commonly determined from measurement of the IV curve and is defined as the maximum power divided by the product of I_{sc}*V_{oc}, i.e.:

$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}} \qquad \textbf{(2.12)}$$

2.6 Efficiency

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. Terrestrial solar cells are measured under AM1.5 conditions and at a temperature of 25°C. Solar cells intended for space use are measured under AM0 conditions. Recent top efficiency solar cell results are given in the page Solar Cell Efficiency Results.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max} = V_{OC} I_{SC} FF \qquad \textbf{(2.13)}$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}} \qquad \textbf{(2.14)}$$

where :

V_{oc} is the open-circuit voltage;
I_{sc} is the short-circuit current;
FF is the fill factor
η is the efficiency.

The input power for efficiency calculations is 1 kW/m^2 or 100 mW/cm^2. Thus the input power for a 100 × 100 mm^2 cell is 10 W and for a 156 × 156 mm^2 cell is 24.3 W

2.7 Photovoltaic Charge Controller

A charge controller is needed in photovoltaic system to safely charge sealed lead acid battery. The most basic function of a charge controller is to prevent battery overcharging. If battery is allowed to routinely overcharge, their life expectancy will be dramatically reduced. A charge controller will sense the battery voltage, and reduce or stop the charging current when the voltage gets high enough. This is especially important with sealed lead acid battery where we cannot replace the water that is lost during overcharging. Unlike Wind or Hydro System charge controller, PV charge controller can open the circuit when the battery is full without any harm to the modules.

Most PV charge controller simply opens or restricts the circuit between the battery and PV array when the voltage rises to a set point. Then, as the battery absorbs the excess electrons and voltage begins dropping, the controller will turn back on. Some charge controllers have these voltage points factory-preset and non adjustable, other controllers can be adjustable. [1]

2.7.1 DC-DC Converters

There are various dc to dc converters topologies like buck converter, boost converter, buck-boost converter and others converter topology are used in PV charge controller. Since solar panels are only capable of producing a DC voltage, the DC-DC converter becomes quite useful by providing the flexibility to adjust the DC voltage or current at any point in the circuit. DC-DC converters are often preferred in modern electronics since they are smaller, light weight, provide a high quality output, and more efficient. [7]

2.7.2 Buck (Step-Down) Converter

One of the researches made is about buck converter topology which is one of many topologies that were used in PV charge controller development. A buck converter is called a step-down DC to DC converter because the output voltage is less than the input. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode) and an inductor and a capacitor.

A buck converter can be remarkably efficient (easily up to 95% for integrated circuits) and self regulating. Most buck converters are designed for continuous-current mode operation compared to the discontinuous-current mode operation. The continuous-current mode operation is characterized by inductor current remains positive throughout the switching period. Conversely, the discontinuous-current mode operation is characterized by inductor current returning to zero during each period.

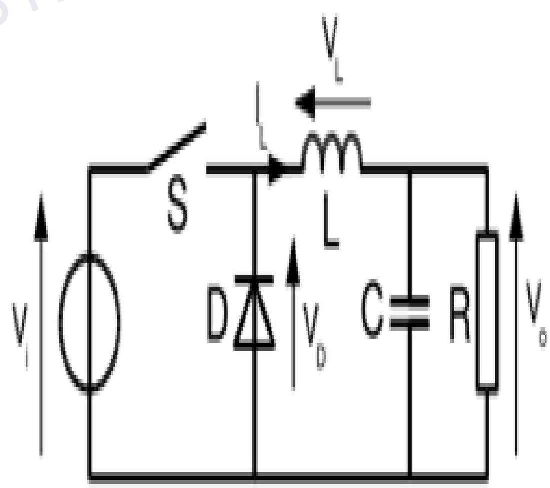

Figure 2.8: A basic buck converter topology circuit

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