ISLAMIC UNIVERSITY
OF
TECHNOLOGY

THESIS ON:
MODEL OF PHOTOVOLTAIC MODULE
IN MATLAB

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DECLARATION

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ABSTRACT

This paper proposes a solution to the problem of using Matlab for the purpose of the implementation of a photovoltaic-array model. A PV model is represented here based on the Shockley diode equation, and then Matlab has been used to simulate, analyze & optimize the efficiency of the model depending on various environmental factors like temperature, solar irradiance etc. The basic circuit equations of the photovoltaic module taking into account the influence of solar irradiance & cell temperaturehas been implemented through Matlab simulation. Finally the outputs of the simulation program has been put for understanding the dynamicity of PV power system.

CONTENTS

CHAPTER 1: INTRODUCTION

1.1 PV cell

Solar PV cell is a semiconductor device which converts sunlight directly into electricity. Therefore, a solar PV panel or a solar PV module is when exposed to sunlight, generates voltage & current at its output terminal. This device does photovoltaic conversion which is a direct energy conversion process from sunlight to electricity with no interruption of heat energy. The main advantage of this type of cell is that it's made of semiconductor materials, therefore they are rugged but simple in design and easy for maintenance. It is thoroughly dependent on the availability of sunlight. The more sunlight falls on it, the higher the intensity is, the more electricity will be generated. So far, this is the only device which can be used to generate electricity from microwatt to megawatt range. The amount of electricity generated also depends on the size of the PV module; the larger the size of the module is, the higher amount of electricity will be generated from it. Nowadays this module is being used in various electronics, starting from small watches, calculators to larger satellites, remote buildings, communication purposes, even in space shuttles also in power plants.It is also the cell that can generate electricity without adding any pollution to the environment.

1.1.1 Background

During 60's & 70's, the solar cells required energy than it could possibly deliver throughout its lifetime. But after that, scientists have discovered several ways to improve itsefficiency and methods of manufacturing, which has drastically changed the arena of solar PV module. The idea of generating electricity from sunlight was invented by Henry Becquerel in 1839. But at that time, generating electricity was done using traditional generators which was not

clean in general. Since then, noted industrialists looked upon the scientistsfro new means of producing electricity using newer and cleaner sources. That search became more influential after the worldwide oil crisis in 70's. During that time price of electricity from fossil fuels rose dramatically and then the need for safe means of energy was felt by all. In the year 1996,
The energy payback periods were reduced and simultaneously the panel lifetime was increased. The solar PV cells available in the market have efficiency in the range 13 to 16%. This has been possible by scientists nonstop research of solar cell taking two parameters as the basis, the efficiency of solar cells & their cost of production. Historically, it has been about 72 years since the first experimental silicon solar cell was demonstrated in 1950's. And since then it's been a wild ride in the production & commercialization of solar cell of different types, for example: Silicon based solar cells, PV modules made of thin-film technology, like thin-film amorphous silicon, thin-film cadmium telluride etc. Even recently, there's been research activities being conducted about concentrated PV technologies.

1.2 Why PV cell?

In the perspective of a semi-poor developing country like Bangladesh, the prospect of electricity for mass population is almost impossible. To be precise, as the growth rate of population is increasing here, the amount of electricity production is not increasing at the same rate. There are several reasons to talk about: the infrastructure, the availability of necessary fuels and other machineries, the lack of proper administration, the mismanagement & most of all, the concept of "Load-shedding". This phenomenon has taken the progress of the country abaft. The rural population is the worst sufferer of this. Due to load-shedding, the farmers don't get to work in their fields properly as there's not enough energy for water pumping, not enough fertilizer to grow good crops in those fields, not to feed their families properly under light & to earn money using their cultivated crops. Children of those poor peasants cant study at night properly due to lack of electricity. Well, in recent times, the cities are also facing this problem. When a transformer gets damaged, it takes several hours or even days to repair. Then those areas which are under that distribution zone see nothing but darkness even in the daytime. That's why the alternative to traditional means of electricity rises. And among all the other procedures for completion of this purpose, the PV cell is by far the simplest & clearly the most economical method for electricity generation. It is simple in design; pretty light in weight, its manufacturing cost is pretty, can be used for a vast number of purposes. With the help of proper authorities, PV cell can be made available for the whole population in general.

1.3 Problems

It is certain that the electricity that's being supplied to us is not enough for our regular activities. During load-shedding, the work of the professional workers gets halted, which is why the development of the country's economy & welfare is lagging in great measures. So there may be different alternatives, among which PV cell is one of them. But to think that PV cell can solve the problem of electricity straight-forward will be wrong. That's because the PV cells that are available in the market are not all up to the mark. Reason for that is their working efficiency is still in the range of 13 to 16%, which is not enough to mitigate the ever-increasing problem of electricity throughout the country. Even for the poor, who needs the electricity in less amounts compared to the urban people, aren't eligible to afford a single PV cell for his own purposes because the cost is too high for them. This is because the companies who are the manufacturers of the cells, they either have to buy these cells from developed countries or they buy ingredients to produce these cells by themselves, which is very costly. And last but not the least, the main thing needed for these cells to run is the sunlight, which is not available during night. The solar cell is a cell which runs only by sunlight without any batteries. So the question of how the solar cell can be conducted at the time of night still remains unanswered.

1.4 Solution to the problem

It's obvious that the problems regarding the production of PV cell with better efficiency & less cost is not possible overnight. After relentless research, many PV cells have been made which possess efficiency around 20-25%. But the matter of cost still remains there. If the proper Manufacturing infrastructure & support from the government is not available, then this process will be worthless. Now the question becomes that using what kind of technology or using what type of engineering prospective will bring the best out of a PV cell. Several people has worked behind solving the problem, using different kinds of materials & programs. And there we are, presenting an already existing method, using the Newton's formula, but with a different approach. We used the data collected from a PV cell of our own & compared the data with the computed Matlab program we implemented using Newton's formula. We found great similarity between these two.

Chapter 2:PV cell &its working mechanism

2.1 The p-n junction

Since the start of PV cell, there has been numerous materials have been used to make it work better, such as silicon (Si), gallium arsenide (GaAs), cadmium telluride (CdTe), copper indium diselenide (CIS) and so on. But nevertheless, the main property for the working mechanism of the PV cell is the p-n junction, or in equal sense, the Schottky diode equation to make the photovoltaic effect enable to work. P-n junction can illustrate the functionality of the conversion of light into electricity. Here is a basic diagram of a p-n junction with working direction of the majority & minority carriers:

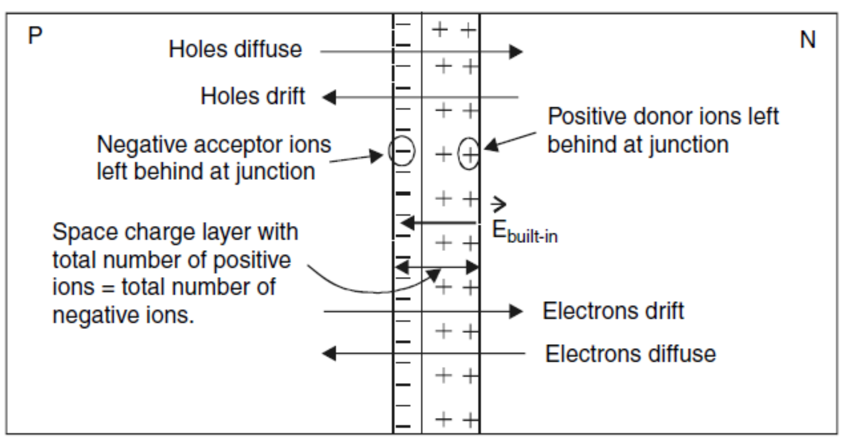

Figure 2.1: the p-n junction showing the electron &hole drift & diffusion

The junction consists of a layer ofn-type Si joined to a layer ofp-type Si, with an uninterrupted Sicrystal structure across the junction. Then-layer has an abundance of free electrons and thep-layer has an abundance of free holes. Under thermal equilibrium conditions, meaning that temperature is the only external variable influencing the populations of free holes and electrons, the relationship between hole density p, and electron density n, at any given point in the material, is given by:

$$np=$$

where is the approximate density of electrons/holes in intrinsic material. When impurities are present, then & , where & are the densities of the donor & acceptor impurities.Both electrons and holes are subject to random diffusion within the Si crystalline structure, so each tends to diffuse from regions of high concentration to regions of low concentration.The net result is that the electrons diffuse across the junction into thep-region and the holes diffuse across the junction into then-region.

Before formation of the junction, both sides of the junction are electrically neutral. Each free electron on then-side of the junction comes from a neutral electron donor impurity atom, such as arsenic (As), whereas each free hole on thep-side of the junction comes from a neutral hole donor (acceptor) impurity atom, such as boron (B). When the negatively charged electron leaves the As atom, the As atom becomes a positively charged As ion. Similarly, when the positively charged hole leaves the B atom, the B atom becomes a negatively charged B ion. Thus, as electrons diffuse to thep-side of the junction, they leave behind positively charged electron donor ions that are covalently bound to the Si lattice. Gauss's law requires that electric field lines originate on positive charges and terminate on negative charges, so the number of positive charges on then-side must be equal to the number of negative charges on thep-side& vice-versa for n-side.

Electric fields exert forces on charged particles according to the familiar relationship. This force causes the charge carriers to drift. In the case of the positively charged holes, they drift in thedirection of the electric field, i.e., from then-side to thep-side of the junction. The negatively chargedelectrons drift in the direction opposite the field, i.e., from thep-side to then-side of the junction. If noexternal forces are present other than temperature, then the flows of holes are equal in both directions and the flows of electrons are equal in both directions, resulting in zero net flow of either holes or electrons across the junction. This is called the *law of detailedbalance*, which is consistent with Kirchoff 's current law. From thorough studying of flow of electron & hole across the junction, leads us to the common diode equation:

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where***q*** is the charge of electron, ***k*** is the Boltzmann's constant, ***T*** is the temperature of the junction in K and ***V*** is the externally applied voltage across p to n junction.

2.2 Illuminated p-n junction

The energy of a photon is given by:

—

Where ***λ*** is the wavelength of photon, c is the velocity of light (3× m)& h is the Planck's constant (6.63× Js).

If a photon has an energy that equals or exceeds the semiconductor bandgap energy of thep-n junction material, then it is capable of creating an electron-hole pair (EHP). For Si, the bandgap is 1.1 eV, so if the photon wavelength is less than 1.13mm, which is in the near infrared region, then the photon will have sufficient energy to generate an EHP. The following figure illustrates the photonic effect on the p-n junction area:

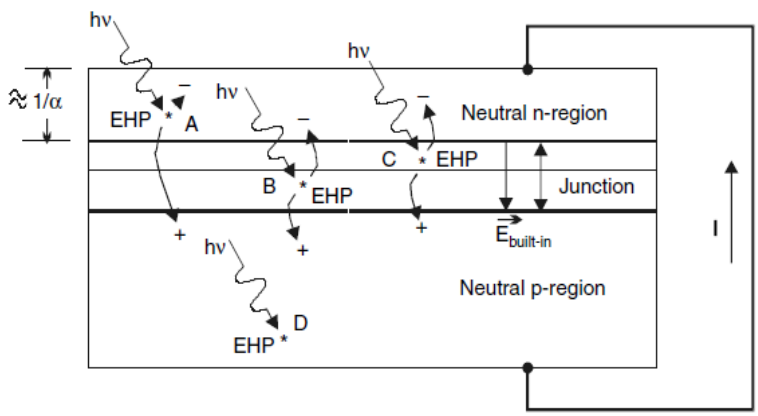


Figure 2.2: The illuminated p–n junction showing desirable geometry and the creation of electron-hole pairs.

If an EHP is created within one minority carrier diffusion length, Dx, of the junction, then, on the average, the EHP will contribute to current flow in an external circuit. The diffusion length is defined to:

Where and are the minority carrier diffusion length and lifetime for electrons in the p-region, if x=n, and and are the minority carrier diffusion length and lifetime for holes in the n-region if x=p. So the idea is to quickly move the electron and hole of the EHP to the junction before either has a chance to recombine with a majority charge carrier. InFigure 20.4, points A, B, and C represent EHP generation within a minority carrier diffusion length of the junction. But if an EHP is generated at point D, it is highly unlikely that the electron will diffuse to the junction beforeit recombines.

The amount of photon-induced current flowing across the junction and into an external circuit isdirectly proportional to the intensity of the photon source. Note that the EHPs are swept across the junction by the built-in E-field, so the holes move to the p-side and continue to diffuse toward the p-side external contact. Similarly, the electrons move to then-side and continue to diffuse to then-side external contact. Upon reaching their respective contacts, each contributes to external current flow if an external path exists. In the case of holes, they must recombine at the contact with an electron that enters the material at the contact. Electrons, on the other hand, are perfectly happy to continue flowing through an external copper wire. When no photons impinge on the junction, the diode dissipates power. But when photons are present, the photon-induced current flows opposite to the passive direction. Therefore, current leaves the positive terminal, which means that the device is generating power. This is called the photovoltaic effect. When the photocurrent is incorporated into the diode equation, the result is:

It is evident that the ideal curve closely represents that of an ideal current source for cell voltages below 0.5 V, and it closely represents that of an ideal voltage source for voltages near 0.6 V. The intersection of the curve with the V=0 axis represents the short circuit current of the cell. The intersection of the curve with the I=0 axis represents the open circuit voltage of the cell. To determine the open circuit voltage of the cell, simply set I=0 and solve Equation 20.4 for V_{OC}. The result is:

Here is the figure that signifies the dependence of V_{OC} on I_l alongside the dependence of I on I_l:

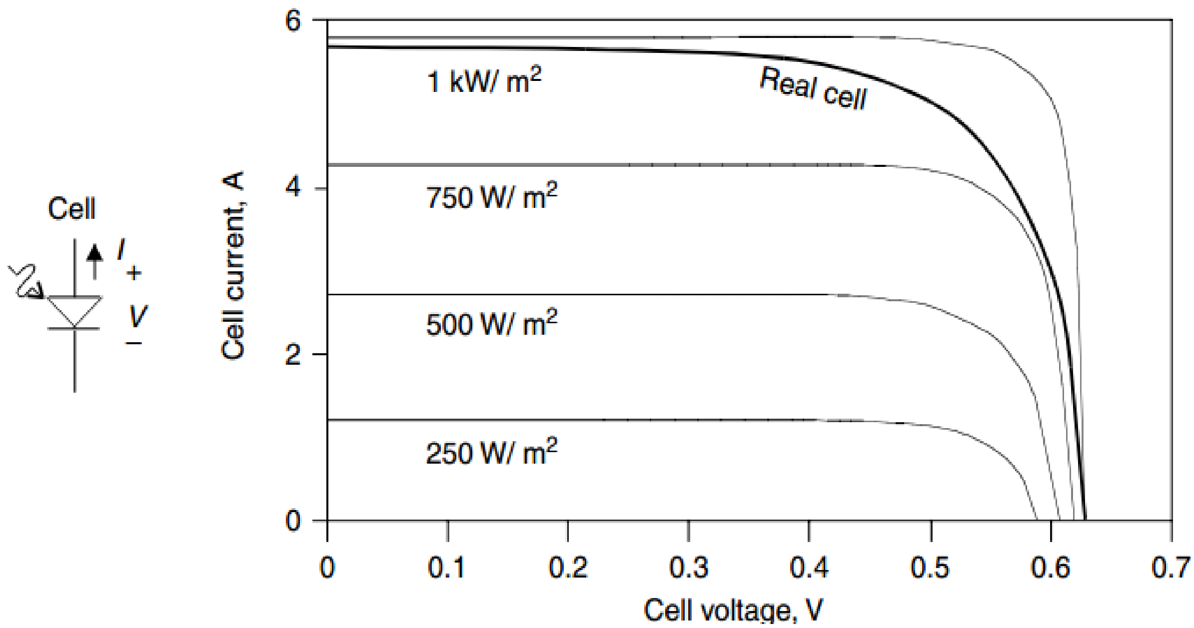


FIGURE 2.3:*I–V*characteristics of real and ideal PV cells under different illumination levels

2.3 Properties of the PV cell

In every single curve of a PV cell, there is a particular point at which the power delivered by the cell is maximum. This point is called the *maximum power point* of the cell. This maximum power point of the cell remains at a constant voltage level as the illumination level of the cell changes.The maximum available power from a Si PV cell decreases at approximately 0.47%/^{o}C, despite the kT/q multiplying factor. The maximum power voltage also decreases by the same factor. Because of the temperature degradation of the performance of a PV cell, it is important during the system design phase to endeavor to keep the PV cells as cool as possible. Here is the reason for that through graphic evidence:

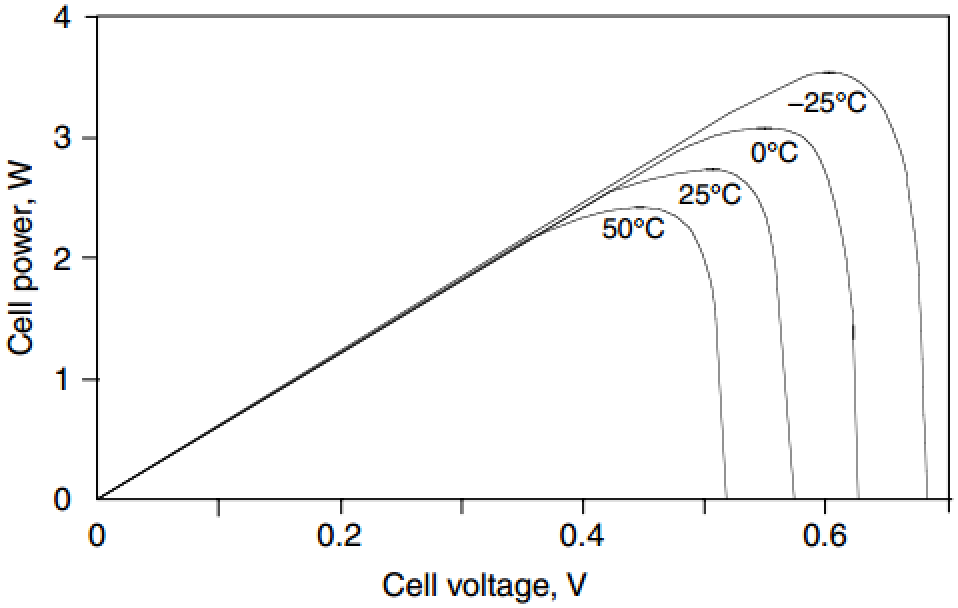
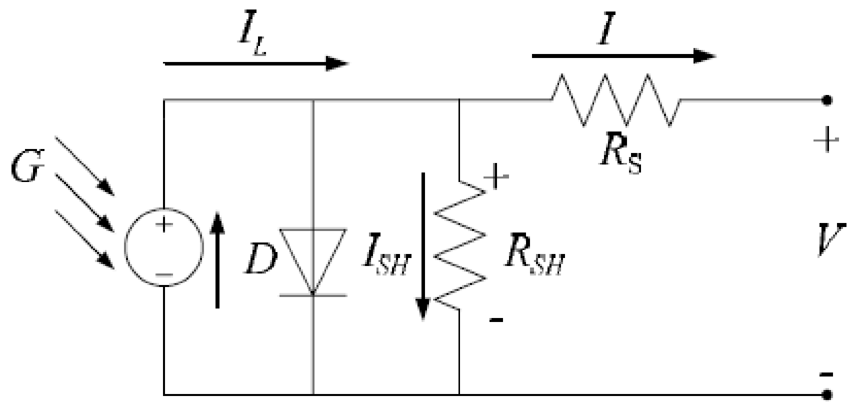


Figure 2.4: Temperature dependence of the power vs. voltage curve for a PV cell

Depending on the value of the maximum power point gained from the graph from which we get the values of V_{max}&I_{max}, the dissipated power can be calculated using this equation:

$$P_{max} = V_{max}I_{max}$$

Chapter 3: Our circuit-based simulation model for a PV cell:

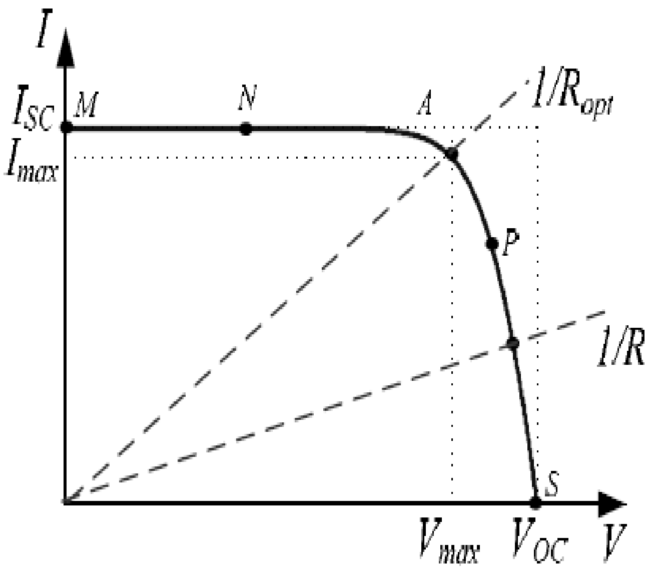


Thus the simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of The current source is directly proportional to the light falling on the cell. The diode determines the I-V characteristics of the cell. Increasing sophistication, accuracy and complexity can be introduced to the model by adding in turn

- Temperature dependence of the diode saturation current Io.
- Temperature dependence of the photo current IL
- Series resistance RS, which gives a more accurate shape between the maximum power point and the open circuit voltage
- Shunt resistance RP in parallel with the diode.

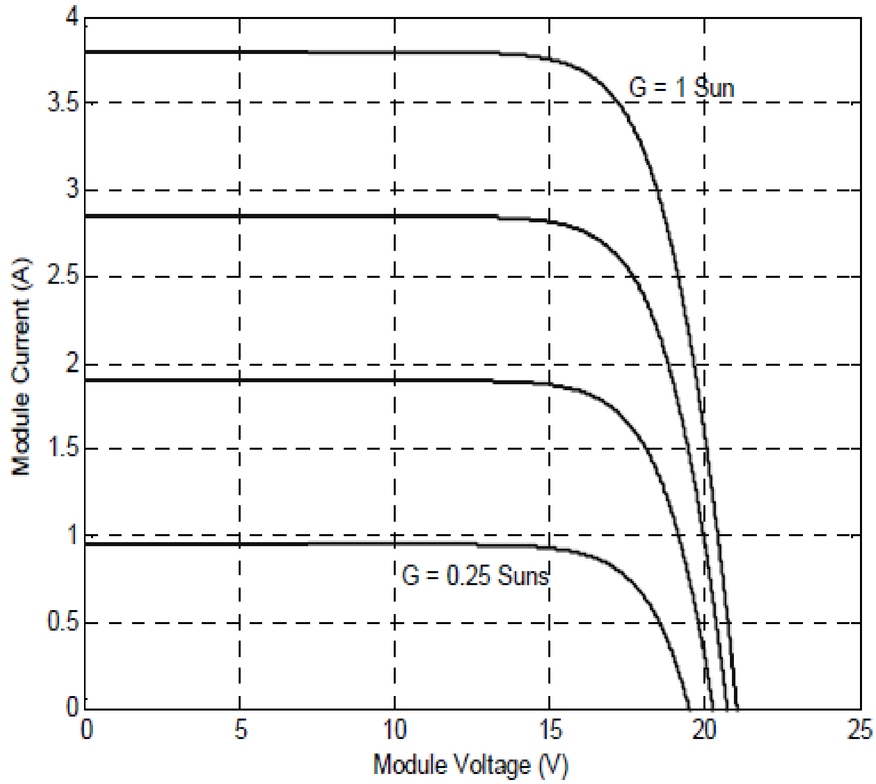
For this research work, a model of moderate complexity was used. The model included temperature dependence of the photo-current IL and the saturation current of the diode I0. A series resistance RS was included, but not a shunt resistance. A single shunt diode was used with the diode quality factor set to achieve the best curve match

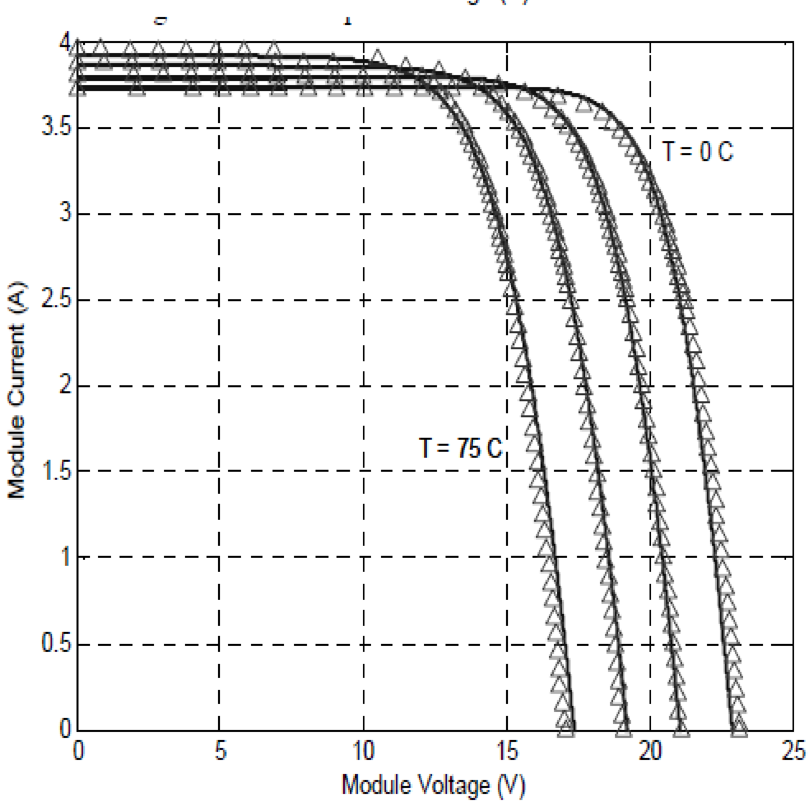
Chapter 4: *Considerations in the model about environment variables:*



The comparison of different interfacing options between PV module and load was done without confusing the issue by including converter losses. The DC DC converters were assumed to be 100% efficient, which many designs can approach quite closely. Instead, matching efficiency was evaluated, which was calculated as the fraction of actual power extracted from the solar panel divided by the maximum power available at the MPP. With an appropriate setup, the MPP PV panel voltage will always be less than the battery voltage. Thus a MPPT based on the boost converter topology should always be able to operate at the maximum power point, so its matching efficiency is 100%. The buck converter MPPT can also achieve perfect matching, so long as its input voltage always exceeds its output voltage. This may not occur for simultaneous low insolation levels and high panel temperatures. Inspection of figure 8 shows the maximum power point falls logarithmically with falling insolation, reaching 13.8V at around 150Wm2 (0.15 Suns) and 50_C. However the curve is quite flat, and at 50Wm2 (0.05 Suns), the constant power curve of 2W remains in approximate tangential contact from 12V to 14V. At these very low insolation levels where power matching may not be perfect, the power available is very low anyway. The power forfeited by failing to track theMPP at these low levels overall proves to be insignificant. The PV panel temperature was assumed to be a constant 50_C in both cases.

Chapter 5: Projected result of our model (Matlab code avoided for clarity):





Chapter 6: Conclusion

We tired to implement new Matlab codes for simulating this project and increase the efficiency. But there were slight errors. We are now working on it in order to complete the code to have the most efficient result from Matlab simulation.