University of Southern Queensland

Faculty of Engineering and Surveying

Investigation of Cost and Performance Characteristic of Photovoltaic Panels

A dissertation submitted by

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ABSTRACT

There is a large number of roof mounted Photovoltaic (PV) power generation installation systems for domestic applications. However, the roof inclination angle and the direction are not only fixed but also not at the recommended values. As a result, consumers are often misled because the published output power generated from such systems is given for ideal conditions.

The project has investigated the cost and the performance characteristics of two different makes of PV panels and their power output due to variations in inclination angle, direction, temperature, shading and aging effects.

A dual Panel Frame was constructed to carry out the tests on the two different PV modules. The project uses a data acquisition Lab-Jack U6 device to collect data and analyse the effects of the mentioned variables and compares their output with variations.

The need to understand the effects of these variations is important particularly to consumers and engineers and the information in this report is beneficial to them.

While there are some published information, one of the interesting findings in this dissertation is the effects of shading on panels, the report highlights the energy generated from a particular PV module or a system compared to its rated value. Other information presented allows consumers to make better judgement about buying their own PV systems.

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Certification Page

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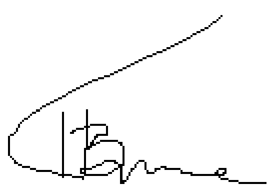

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Non-menclature

Term	**Description**
A	Cross sectional area
c	velocity of light in vacuum
D	Diffusion coefficient
E	Energy
h	Planks constant
I	Current
I_l	light generated current
Io	Diode saturation current
Isc	short – circuit current
K	Boltzmann’s constant
FF	Solar cell fill factor
Q	electronic charge
R	Resistance
T	lifetime
T	time
T	temperature
V	voltage potential
Voc	Open- circuit voltage

Glossary

- STC – Standard Test Conditions
- Bypass Diode –A diode that is connected in parallel with a PV Module
- Cable – A single cable core
- PV Cell – The basic unit of photovoltaic conversion; a semiconductor device that can convert light directly into electrical energy
- PV Module – An assembly of several PV Cells electrically connected to form a larger conversion device, and which are encapsulated together to protect them from the environment. A PV Module is the smallest ready to use photovoltaic conversion device
- PV Module –An enclosure affixed to a PV Module, where the electrical connections to the PV module are made
- PV String – A circuit formed by one or more series connected PV modules
- Voc – Open circuit voltage
- ISC – Short circuit Current
- Ipk – Maximum peak current
- Vmax – Maximum peak voltage
- Standalone –are PV systems that are not connected to the grid
- Grid Connected –PV Systems which are connected to the national grid
- PV – Photovoltaic
- AM – Air mass of 1.5 is used as spectral density for solar systems, also part of the Standard Test Conditions
- Irradiance – 1000 watts/m^2 under nominal operating conditions.
- Test temperature – 25 degrees under Standard Test Conditions
- MPP – Maximum Power Point
- Pmax – Maximum Power Output for a panel

1.0 Introduction

1.1 Background

Recently, solar systems are increasingly used for alternative power source in Fiji. They are mainly used in rural areas with homes, telecommunication transmitter sites, hotels and resorts. With the influx of many different makes of solar panels available in the Fiji market and lack of stringent quality control it is very difficult for consumers to choose the most cost effective panels for their application.

Although the major components of a solar system consists of PV Panel, batteries invertors and controllers, this project will investigate the controls available and carry out tests on different PV brands to compare the costs and performance of such panels. Indeed it is one the most expensive component of a solar system hence this component was chosen for further experiments.

The current trend is that when countries progress with developments, power is one the main components to any business. Solar systems are rather more demanding for rural projects and business that operate outside the national power grid. With fierce competition among providers, sources say that increasing levels of consumers fall victim to questionable advertising and sale tactics.

Although in developed countries, certified panels are a requirement to qualify for rebates; the concern here is that there are still some flexibility in the brands used for standalone systems.

In Fiji, the number of installations has increased from residential systems, transmitter sites and resort applications. The current systems are standalone systems and online or grid systems is still something for the future

The project was therefore selected to investigate the potential problems if quality controls are not in place for PV selection and more importantly the installation practices and standards that are adopted to ensure their optimum performance to a system.

1.2 The Problem

For Fiji, It has been noted that a number of companies are providing cheaper solar systems and interviews with the department of Energy further revealed that standards are in the process of being formulated to monitor and control the quality of these systems.

Research has found that even in Australia which is a developed country, controls had to be put in place to avoid the selling of some cheap lower end panels. Records prove that there were some brands that had to be rejected. [5] “Buyers beware: not all solar panels are created equal”. A number of solar panels have been withdrawn from the Australian market following amendments to Australian Standard ASNZS5033 [5].
Since the new standards came into place for Australia, the list of panels reduced from 50 pages to 30pages of approved panel brands.

Solar power systems can potentially be very dangerous if sub-standard modules and or sub- standard systems are installed.
A Fiji Solar installer commented that a number of panels had to be replaced after routine checks were carried out on some systems, as they had failed to produce the expected output power over a short period of time.(This is the Conergy brand and it was part of the Japanese funding for Rural Electrification).In the market Conergy brands is one of the well-known brand, although the cause is unknown, installation methods, handling and manufacture defects are some of the reasons for the defects.

Roofs used for installation of panels have different angles and directions, hence the need for further study of the effects of this variance. Since panel outputs are also dependent on temperature and irradiance, cloud and shadow movements will also have an effect on panel outputs.

1.3 Introduction to Theory

Solar energy has been one of the fastest growing sources of renewable energy on the market today. It uses sun's energy to generate electric power [2].It is indeed playing a vital role in providing electricity to homes and business where the traditional supply cannot access. There has been much effort by Engineers around the world collaborating to lower the material costs of solar cells, increase their energy conversion efficiency and create innovative and efficient new products and applications based on photovoltaic (PV) technology.

Semiconducting materials are used mainly for the production of PV cells. The common ones are made of silicon with two varieties, crystalline and the thin film type. The crystalline types are commonly known as Monocrystalline and Polycrystalline. The Monocrystalline have a better efficiency at **12- 18%,** with Polycrystalline slightly lower with **11-14%.** The Thin films have 6**-8% efficiency** and are at least twice the size of the other panel's types. Figure 1.1 below shows the market share of the different types of Panels.

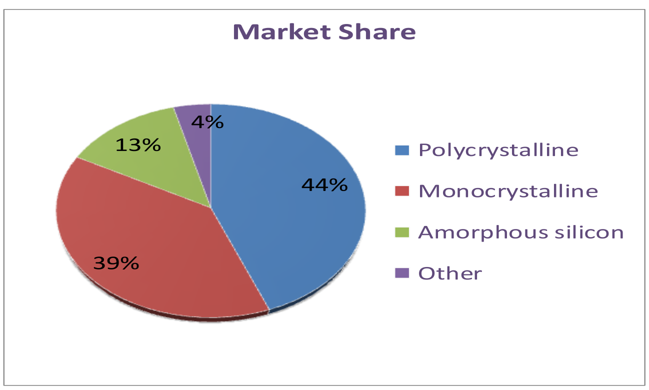


Figure 1.1 Panel Market Share (Source: http://ec.europa.eu/research/energy/publications)

Many of the I-V analysis parameters, including the maximum efficiency (Nmax), are affected by ambient conditions such as temperature and the intensity spectrum of the incident light. Experiments will therefore be carried out under similar lighting and temperature conditions.

Module Performance is generally rated under Standard Test Conditions (STC); that is an irradiance of 1000W/m^2, solar spectrum of AM 1.5 and module temperature of 25°C.

1.4 Project Aims and Objectives

The aims and objectives of this Project are as follows:

- Conduct literature review on Solar Panel Performance, cost and payback period.
- Develop a test frame, select appropriate panels and testing device (Data Logger) to carry out experimental work.
- Carry out experimental work to determine panel output variations due to changes in incline angle, aging, temperature, direction, and shading
- Analyse and compare experimental data with manufacturers' specifications and determine performance against cost.

2.0 Literature Review

2.1 Introduction to How Solar Works

The "photovoltaic effect" is the basic physical process through which a PV cell converts sunlight into electricity. 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 strikes a PV cell, they may be reflected, absorbed or they pass right through. Only absorbed photons generate electricity. As these photons are absorbed, the energy of the photons is transferred to an electron in an atom of the cell, which is usually a semiconductor for example silicon. The amount of light that is absorbed which is in different wavelengths, defines the value of band gap for a particular semiconductor device and this is proportional to the voltage potential for a cell.

With its newfound energy, the electron is able to escape from its normal position associated with that atom to be part of the current in an electric circuit. Figure 1 below shows the components of a solar cell.

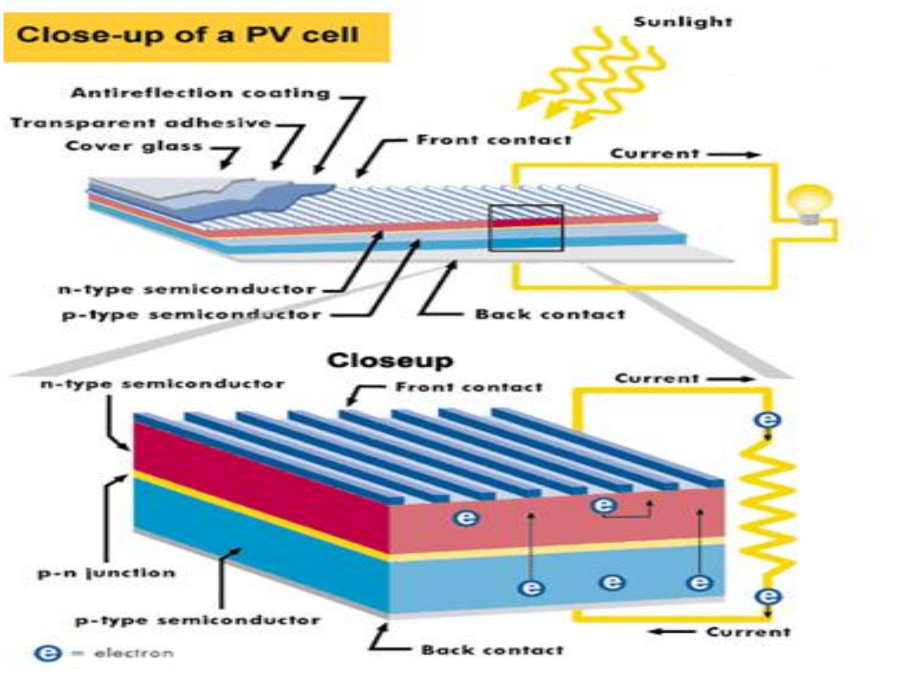


Figure 2.1 Parts of a cell (Clean energy, Union of Concerned Scientists, 2011)

All PV materials must be made into a p-type and n-type configurations to create the necessary electric field that characterises a PV cell. This is however done in different ways depending on the characteristics of the material. The most common way of making a p-type or n-type silicon material is to add an element that has an extra electron or is lacking an electron. In silicon this process is called **doping.**

In a PV cell, photons are absorbed in the p layer. It's very important to "tune" this layer to the properties of the incoming photons to absorb as many electrons as possible. One of

the challenges is to keep the electrons from meeting with holes and recombining with them before they escape the cell. To do this the material is designed so that the electrons are freed as close to the junction as possible. This will allow the electric field to send them through the conduction layer (N Layer) into the electric circuit. By maximising all these characteristics, the conversion efficiency is improved for a PV cell.

The figure 2.1 below illustrates the different layers in a cell when receiving light or photons.

The first layer is absorption followed by reflection layer and reconstruction layer and last but not least is the conduction layer. The absorption layer is the P layer, reflection layer is usually the top part of the cell that is why, antireflective coating is usually applied to this layer to minimise and avoid reflection. The recombination layer happens between the holes as the electrons move around and the conduction layer is the N Layer.

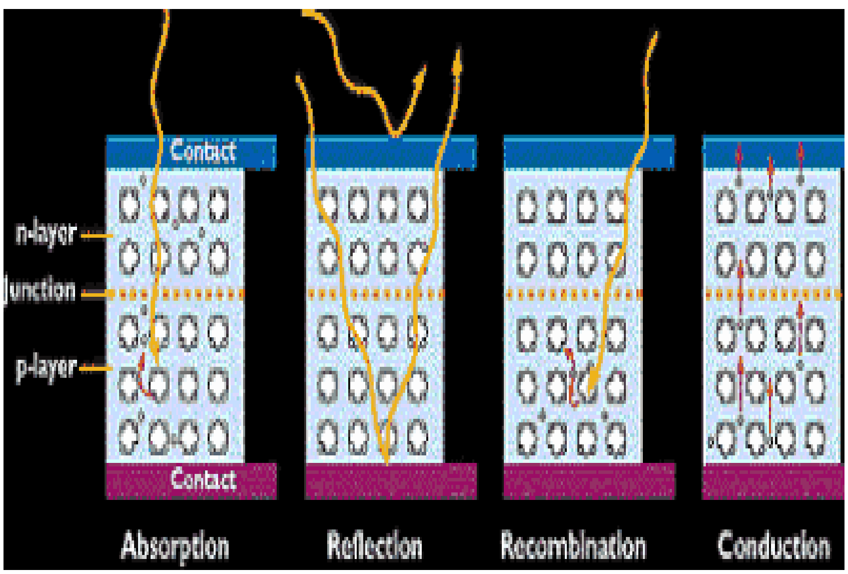


Figure 2.2 Absorption and Conduction Layer (http://inventors.about.com/photovoltic_cel.htm)

2.1.1 The Solar Cell

The I-V characteristics of the solar cell can be obtained by drawing an equivalent circuit of a current generator in parallel with a diode which represents a p-n junction. . The output current I is equal to the difference between the Light generated current I_l and the diode currentI_D. This is shown on equation (1.0) below where k is the Boltzmann's constant i.e. 1.38E-23 and *T* is the temperature

$$I = I_l - I_o\left[e^{\left(\frac{qV}{kT}\right)} - 1\right] \tag{1.0}$$

Under the open circuit I= 0, current I_l is passed through the diode. On the other hand under short circuit (V=0) and all the current passes through the external load.

I-V characteristics consist of two important components that are used in this project. One is the short-current I_{sc} which is simply the light generated current I_l and the open circuit voltage V_{OC} and is mathematically defined by equation 1.1 below.

$$V_{OC} = \frac{kT}{q} ln\left(\frac{I_l}{I_o} + 1\right) \tag{1.1}$$

$I_l \; and \; I_o$ both are dependent on the semiconductor material. However it is $I_o \; that$ varies by many orders of magnitude and is dependent on geometry and processing of the device. This determines the open-circuit voltage.[solar cells, pg 79]. I_o needs to be very small for maximumV_{OC}.

2.2 Solar System Components and Performance

The core element of a (PV) system is the PV solar cell. These cells are then wired in series to produce a module. Solar cell modules generally contain sufficient series connected solar cells to generate the required voltage. They are connected in series to increase the system voltage output and in parallel to increase the output current of the system. Figure 2.2 below shows the components of a PV generating system.

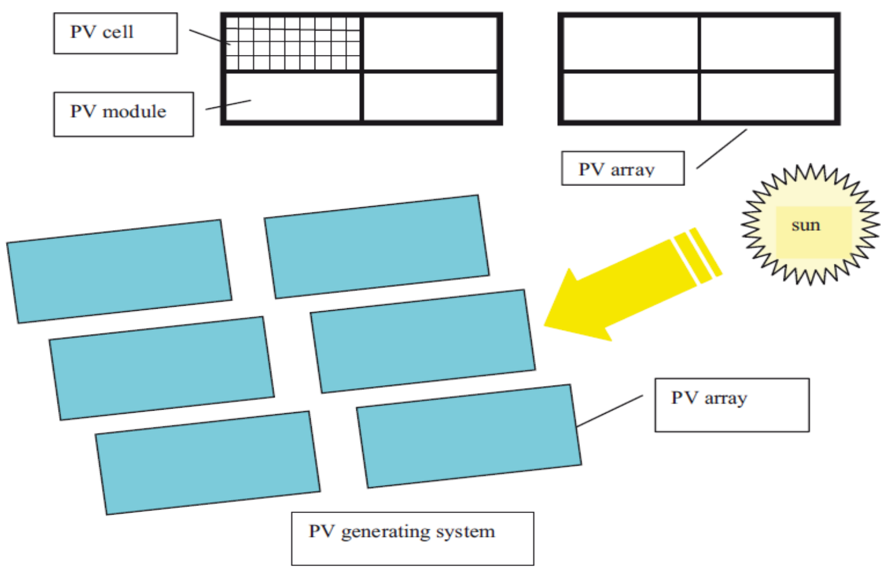


Figure 2.3 Various Components of a PV Generating Unit (ELE 3805, 2011)

For optimum performance, a module or arrays are generally mounted facing South in the Northern Hemisphere and North in the Southern Hemisphere at an angle equal to the latitude of the site. This angle is normally increased by 10-15deg to boost the winter output of the system.

Modules will generally be able to generate sufficient voltage during the hour of sunlight. However the current output will be very closely proportional to the irradiance on the module. Hence design for systems focus on the output current of the module.

2.2.1 Solar Power –Performance Characteristics

The electrical characteristic of photovoltaic generators is usually represented by current – voltage relationships often called I-V curves or I-V characteristics. Figures 2.4 through to 2.5 illustrate the characteristics of a typical 50W –peak power module.

Figure 2.3 below shows the cell characteristics at a given insolation of 1000W/m^2 and temperature of 25°C. The graph also shows 2 segments, the almost constant voltage segment and the almost constant current segment. The current is limited as the current is short circuited.

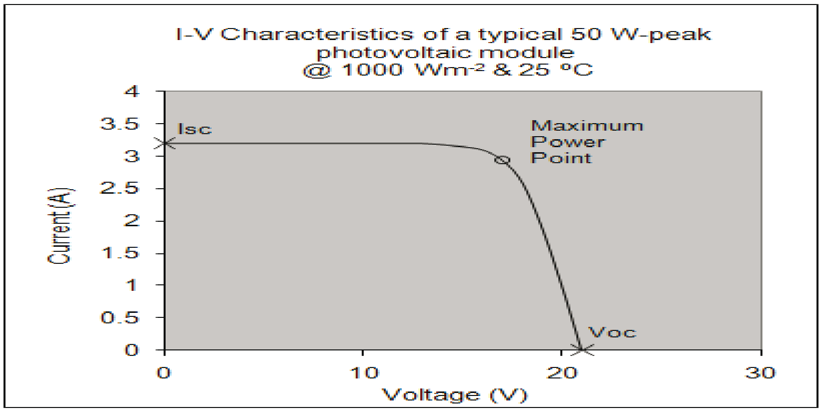


Figure 2.4: I-V Characteristic of a 50W solar module with Maximum Power Point(Ele3805, pg 13.6)

The result of the produced power is the product of the voltage and current. The maximum power (Pmax) produced by the device is reached at a point on the characteristic where the IV is maximum as shown on figure 2.4 below. The efficiency of a solar cell is defined as Pmax at Standard Test Conditions (STC) divided by the cell at the maximum power point. Figure 2.3 below shows a typical diagram of the IV – Characteristics (ELE3805, pg 163)

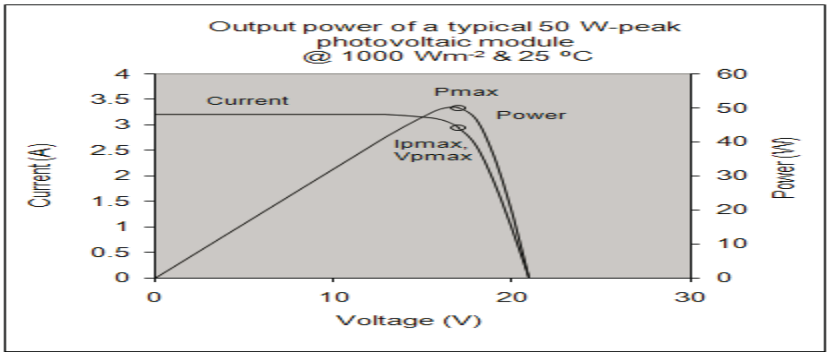


Figure 2.5: Produced Power and Maximum power point of a 50W module (Ele3805, pg 13.6)

2.2.2 Power Losses

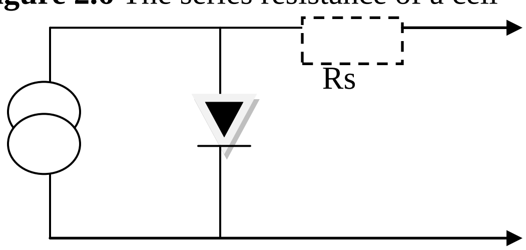
As stated by the Thomas Markvart, that fundamental losses reduce the maximum theoretical efficiency of a silicon cell to about 48%. Additional voltage losses (~36%) , current losses (~10%), and losses associated with fill factor (~20%) then explains the efficiency of the about 23% for the best silicon in the market today.

The power losses in a cell can be called fundamental Losses, Recombination losses and Ohmic losses. [Solar Electricity -pg42]
Fundamental losses involve losses due to considerable dissipation of the generated carrier energy into heat. This also includes the inability of a semiconductor to absorb below bandgap light or photons.

Recombination is the opposite of energy generation when an electron hole pair is annihilated. They are common in impurities and defects of the crystal structure.

Ohmic losses involve the transmission of electric current produced by the solar cell. These can be grouped together and included as a resistance in an equivalent circuit as shown on figure Fig 2.5. This series resistance can affect performance of a cell by reducing the fill factor of a cell.

Figure 2.6 The series resistance of a cell



2.2.3 Temperature and Irradiance Effects

Practically, solar cells do not operate under the standard conditions. The two most important effects that must be allowed for are due to the variable temperature and irradiance. For Temperature, Voltage decreases as temperature increases. These changes vary slightly on different semiconductor materials. The crystals used to make PV cells, like all semiconductors, are sensitive to temperature. Figure 2.6 depicts the effect of temperature on the I-V curve. The voltage decrease of a silicon cell is 2.3mv per degrees Celsius. The temperature variation of the current and Fill Factor is very small and are usually neglected in PV systems design. [Solar Electricity, pg43-44]

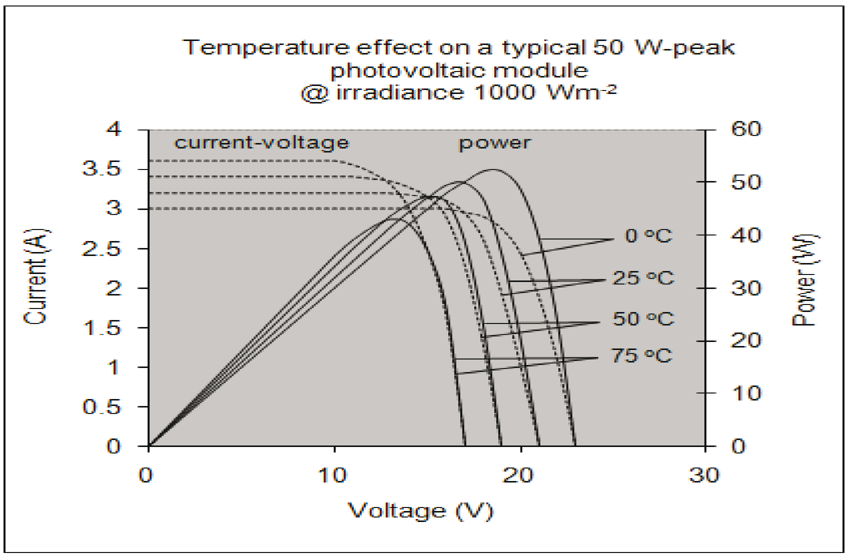


Figure 2.7 Effect of Temperature on the output of Power with constant irradiance (Ele3805, pg 13.6)

For Irradiance effects, current is directly proportional to the level of the irradiance on the solar panel. So the higher the output of irradiance, the higher power output. These effects are shown on the figure 2.7. It's also noticed that the open circuit voltage is not being affected significantly by irradiance level. This leads to an important safety consideration that PV device should be considered at nearly full voltage even at very low irradiance levels.

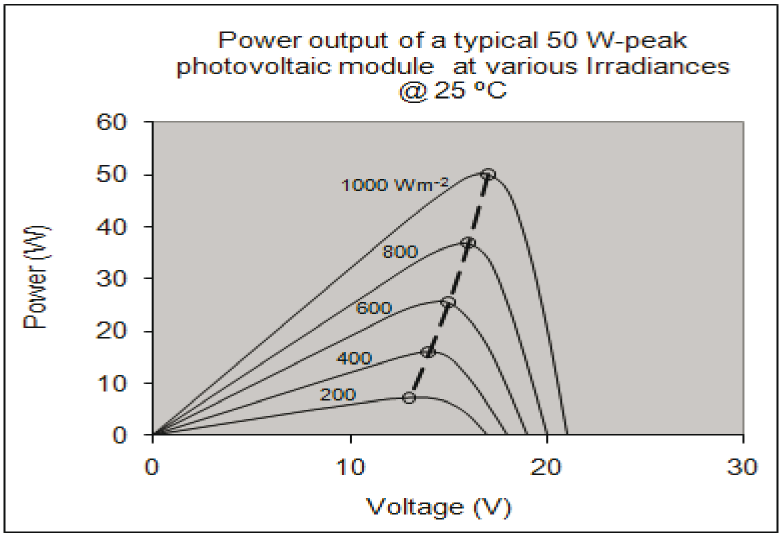


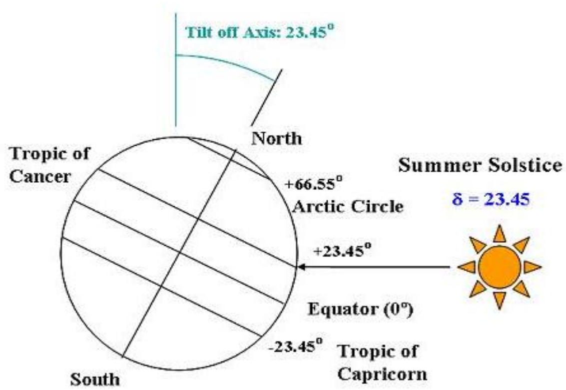
Figure 2.8 Effect of Solar Irradiance (Ele3805, pg 13.7)

2.2.4 Panel Angle with respect to Ground

The panels can be either installed on fixed mounting or on a tracker. The tracker system although is a more expensive option, it does produce up to 40% more of the solar energy as compared to the fixed tilt ones. The optimum angle of inclination depends on the latitude. Some have mounts and can be varied between summer and winter.

2.2.5 Earth and Sunlight

In order to further understand the STC condition parameters, research was also carried out to understand the relationship of sunlight and solar cells on earth. The earth revolves around the sun in an elliptical orbit (close to a circle) with the sun in one of the foci. The plane of this orbit is called the ecliptic. A year is the time taken for earth to complete this orbit. The motion of the earth around the sun is pictured by the apparent motion of the Sun in the ecliptic which is tilted at 23.45° to the celestial equator. Solar declination angle denoted by (δ) is the angle between the lines joining the centers of the Sun, Earth and the equatorial plane.



Declination (°)	Approximate dates
+23.45	June 22
+20	May 21, July 24
+15	May 1, Aug 12
+10	Apr 16, Aug 28
+5	Apr 3, Sept 10
0	Mar 21, Sept 23
−5	Mar 8, Oct 6
−10	Feb 23, Oct 20
−15	Feb 9, Nov 3
−20	Jan 21, Nov 22
−23.45	Dec 22

Figure 2.9: Solar Declination (δ)(*http://www.geog.ucsb.edu/ideas/Insolation.html*)

The declination angle is zero on 21st March and 23rd September. On these days the sun rises exactly on the east and sets exactly in the west. It is 23.45° at summer solstice which falls around 21st and 22nd June and -23.45° at the winter solstice around 21st to 23rd December.

These motion and changes of the angles affects the radiation of the sun around the earth and therefore the design of Photovoltaic system relies on a careful assessment of solar radiation at a particular site. Although there are solar radiation data that have been recorded for most of the world, most locations will need to be analyzed and processed to determine the amount of

2.3 Yearly Radiation Levels for Test Sites

Knowledge of the radiation levels for the test sites is important to the testing phase to compare with the current readings. Below are radiation figures for Toowoomba and Fiji. Although the Project was aimed for Fiji, results will be compared and related to the Toowoomba data where tests were carried out.

2.3.1 Fiji Radiation Yearly Data.

Fiji is located at 18 degrees latitude and experiences two seasons per year (summer and winter).Although the average angle of incline for installation should be around latitude, there are still some installations that have been installed on flat roofs.

2.3.2 Toowoomba Radiation Yearly Data

It is important to understand the radiation and temperature levels during the year as this is related to the experimental work. Below though is a copy of radiation pattern for Brisbane and temperature data for Toowoomba for the year.

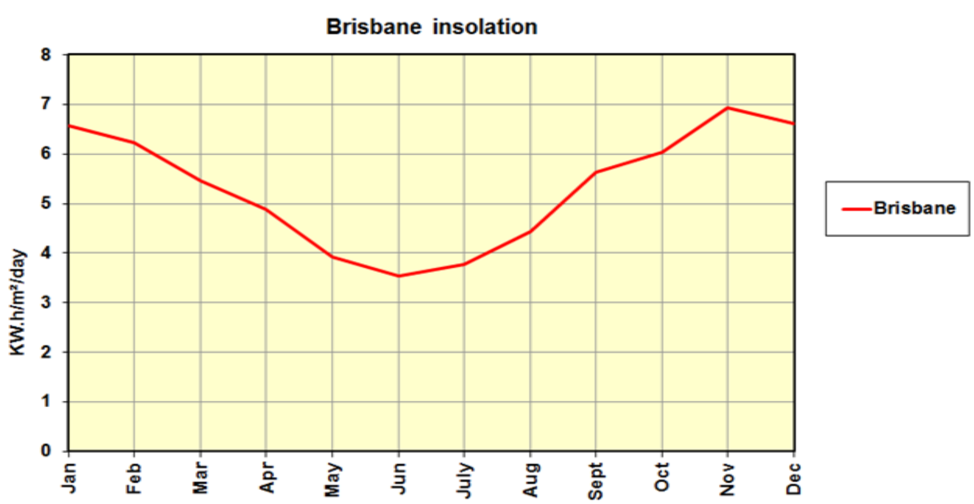


Figure 2.10 –Brisbane Insolation level **(BoE, http://www.bom.gov.au/)**

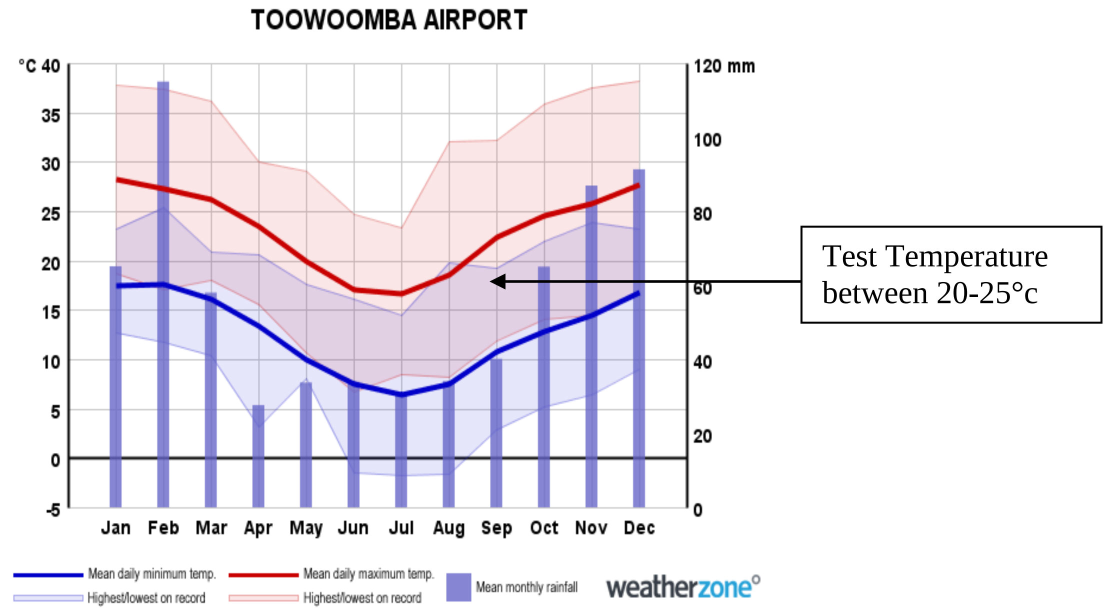


Figure 2.11: Toowoomba Yearly Temperature Data (http://www.bom.gov.au/)

Since the tests were carried out during mid –August to mid- September, the temperature around this period is between 20-25°c mean temp and peaks at 30-34°c which is quite good for the experiment as it will not have any great effects to the cell temperature during the tests. However it should be noted that temperature and the radiation varies throughout the year as per the figure above.

2.4 Economics of PV panels

As stated by Thomas Markvart, the economic viability of a PV system must be assessed relative to the alternatives, for example diesel, extending the grid etc.
At present, PV's is most competitive where small amounts of energy are required far from the grid. As stated earlier they would be found in rural areas where the National grid cannot reach.

The economics of PV systems is different to that of other small power systems because of the following:

1. Initial cost is high
2. No fuel costs
3. Maintenance costs is low
4. Reliability of the system is high, so replacement costs are low
5. The output of the system depends on location and installation standards

"The economic benefits of the system can either be money that has been saved or revenue that has been collected, by operating the system. In addition to the economic benefits, there are also social and environmental benefits which should be taken into account when choosing between systems.

There are two ways of looking at the value of electricity generating system. The economic approach takes the standpoint of the government so considers its value to the economy as a whole. It therefore looks at cost which excludes taxes and subsidies. In contrast, a financial assessment is an evaluation from the buyers' point of view. Therefore taxes, subsidies, interest payments on a loan etc., must be taken into account.

However in economic evaluation, the following parameters are usually considered.

- The lifecycle costs – The sum of all the cost of the system over its lifetime expressed in today's money
- Payback period – The time it takes for the total cost to be paid for by the monetary profits and other benefits of the system
- Rate of return- The magnitude of the profits and benefits expressed as a percentage annual return on the initial investment"(Solar Electricity p152)

2.5 Solar Panel Selection

In selecting a solar panel it is important to consider some important factors such as:

1. Cost of Panels
2. Durability
3. Size and Watts
4. Type

2.5.1 Costs of Current Panels

‘The cost of a solar panel is determined in part by size (in Watts), the physical size, the brand, the durability/longevity (or warranty period) and any certifications the solar panel might have. Choosing a solar panel on price alone is not wise, as it may not fit the planned area or it may not have the certification to qualify for government rebates, or may not have the warranty required for economic payback of the power produced’[6].

Generally the efficiency of the panel is the differentiating factor. A list of panel brands is provided on table 2.1 below.

Panels may also be cheaper when bought in large quantities. For example buying more than 10 panels may qualify for some discount which will be much less than buying 2 panels. Companies who carry out large number of installations will find a better discount to the cost of panels.

In Fiji most rural installation are funded by Government aids. “Despite the initiatives for promotion of renewable energy undertaken by the Department and the energy sector as a whole, the level of uptake for such technologies has been rather limited because of high costs. As such, locally the demand for such technologies has been limited to the rich or those who qualify to Governments grants”.(Fiji Department of Energy)

In Australia, there are more than 50 different panel types to choose from and costs vary as well for different panel brands. The most expensive panels are the mono-crystalline, followed by the polycrystalline with the cheapest being the amorphous thin film brands.

The table on the next page is a list some top panel brands with their efficiency and tolerance levels.

Brand	Manufactured	Watts	Module Efficiency	Tolerance	Cell Type
Sunpower	Phillipines	300	18.40%	Plus/Minus 5%	Mono
Hyundai	Korea	220	15.20%	plus 3%	Mono
Hyundai	Korea	215	14.88%	plus 3%	Mono
Full Green	China	215	14.88%	plus minus 3%	Mono
China Synergy co Ltd	China	190	14.88%	plus minus 3%	Mono
Solar Fun	China	190	14.88%	plus minus 3%	Mono
Juli Solar	China	190	14.88%	plus minus 3%	Mono
CSA	China	190	14.87%	plus 2.7%	Mono
CEEG	China	190	14.50%	plus minus 3%	Mono
Suntech	China	185	14.49%	plus minus 3%	Mono
Solar Power Supply	China	185	14.49%	plus minus 3%	Mono
Sun Tech	China	185	14.46%	plus 5%	Mono
Trina	China	185	14.46%	plus minus 3%	Mono
Trina Solar	China	185	14.30%	Plus/Minus 3%	Mono
BP	China	180	14.24%	plus 5%/minus3%	Mono
REC	Singapore	235	14.24%	plus 2%	Poly
Sharp	Japan/China	188	14.16%	Min179W/Typical 188	Mono
Sillex Solar	Australia	180	14.14%	Plus/Minus 3%	Mono
Kyocera	Australia	180	14.13%	Plus/Minus 3%	Mono
Conergy	Japan	225	14.10%	plus minus 5%	Poly
Schott	Germany	225	13.84%	plus 2.5%	Mono
REC	China	170	13.72%	Plus/Minus 3%	Mono
BP	China	225	13.64%	plus minus 3%	Mono
Q Cells Q Pro	Germany	170	13.60%	plus 4.99%	Poly

Table 2.1 Solar Panel Comparison Table by Module Efficiency (Future Sustainability, 2011)

The above table shows a solar comparison by module efficiencies. It also shows the efficiencies are higher for Monocrystalline than Polycrystalline Panels

2.5.2 The Durability of Panels

The warranty or durability of a solar panel is important for a number of reasons**.** Firstly, panels to be used in a critical system should not compromise and take the risk for panels that are not as robust as others. Reputable solar panels will have a warranty period of 25years. Also if solar panels have a short warranty period of about 10years, then it should be able to pay for itself within that period to be worth the investment.

Another important point about warranty is that it will only be honoured for as long as the company operates. A lot of new companies can promise cheaper brands but care must be taken to ensure these modules cover the warranty period.

Also it may not be possible to buy panels directly from the manufacturer, so careful selection of retailer is also important. Choosing a service agent that can provide backup service and fast turnaround time for warranty replacements will be ideal for critical users such as communication transmitter sites and medium scale business.

Typical manufacture defects are shown on appendix L.

2.5.3 Size and Watts

Since Solar Panels are generally priced in dollars per Watt. The size of Solar will directly affect the price. Watts are related to the output of each panel; meaning a 100Watt panel under ideal conditions will generate 100 Watts of electricity each hour and a 220Watt panel will generate 220Watts each hour. The cost of the 200W panel will therefore be expected to double.

The output of a panel also affects the physical size of the panel, meaning the 200Watts panel will be larger in size than the 100Watt panel.

The type of cells or semiconductors used during its production also determines the size of solar panel. The key point to consider is that the overall system should have enough watts for the appliances and that the solar panels can physically fit in the proposed area.

While some may tempted to buy thin film type which is a bit cheaper than mono and polycrystalline, they do require a larger area.

2.6 Tariff Rates and Payback period

In Fiji the local tariff rates for the prepay system is worth $14 for $30days of electricity. This is one of the programs setup by Department of Energy and is used specifically for lighting purposes. System is designed to provide lighting and radio cassette power for the users. Each Solar Home System (SHS) consists of 2 x 50W panels, 12v battery and a prepayment meter.

At the end of the experiment, payback period will be calculated with respect to these rates.
Australia though is way ahead with encouraging tariff rates and rebates by Government which is an incentive for its consumers to buy solar systems.

For medium to large solar systems, consumers are resorts, hotels, transmission sites for telecommunication operators and other remote stations. The savings generated by the solar system is dependent on the size of the solar PV system, the products used, location of the system and how much electricity the household consumes.

The table below shows the tariff rates for different cities in Australia

City	1.5kW system daily production	Feed-in Tariff		Based on 50% of electricity being fed into the grid		Based on 30% of electricity being fed into the grid	
				Daily savings	Annual savings	Daily savings	Annual savings
Adelaide	6.3 kWh	Net	44c per kWh	$2.02	$736	$1.71	$625
Brisbane	6.3 kWh	Net	44c per kWh	$2.02	$736	$1.71	$625
Canberra	6.45 KWh	Gross	45.7c per kWh	$2.97	$1,084.05	$2.97	$1,084.05
Darwin	6.6 kWh	N/A	N/A	N/A	N/A	N/A	N/A
Hobart	5.25 kWh	Net	20c per kWh	$1.05	$383	$1.05	$383
Melbourne	5.4 kWh	Net	60c per kWh	$2.16	$788	$1.73	$631
Perth	6.6 kWh	Net	*47c per kWh	$1.86	$680	$1.56	$570
Sydney	5.85 kWh	Gross	20c per kwh	$1.17	$427.05	$1.17	$427.05

Table 2.2 1.5kw System under the feed - In Tariff Schemes (ASI –Australian Solar Institute)

2.7 Current Energy Suppliers in Fiji.

The Department of Energy is responsible for the overall energy policy and planning, promoting the development of renewable energy resources and renewable energy service companies (RESCO), energy conservation and co-ordination of the rural electrification activities through the Rural Electrification Programme. The Fiji Electricity Authority (FEA) is the national utility responsible for the urban and peri-urban electricity supply. It is responsible for the generation, transmission and distribution of electricity in Fiji.

In the past and to date, foreign aid has been the main source of funding for renewable energy projects including solar systems.

2.8 Energy Consumption Levels For Equipment's

Household appliances have different amounts of energy level. The Australian Government through its Energy departments have been proactive and playing a major role in putting policies in place to reduce the energy levels on household appliances. They include Department of Climate Change and Energy Efficiency (DCCCE).For example the following products are regulated on the basis of Minimum Energy Performance Standards (MEPS). This means that they have regulated minimum energy efficiency levels. Some of the items include Televisions, Refrigerators and Freezers, Single phase air-conditioners.

With the knowledge of equipment energy ratings, consumers are able to choose the most efficient products and reduce their total kWh per day/ Year.

2.9 Typical I-V Test System

“This system is based on virtual instrumentation technologies developed by National Instruments. The figure below illustrates an example of a test system for I-V characterization.

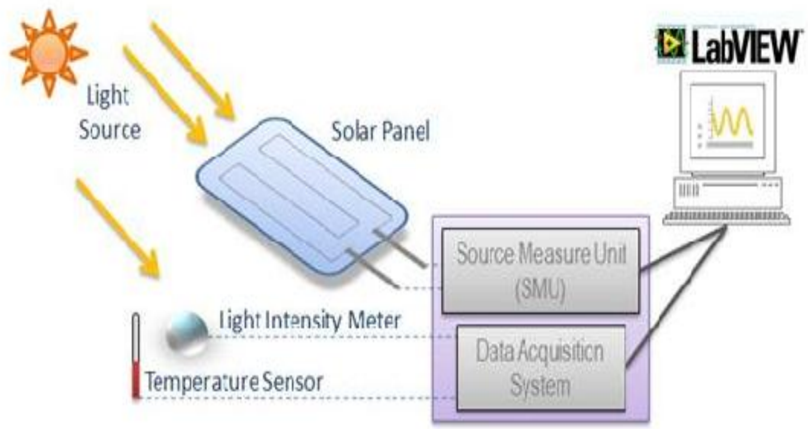


Figure 2.12- Example of a Test System for I-V characterization (National Instruments, 2011)

A light source provides incident radiation to excite the solar panel. Then a Source Measurement Unit such as the PXI – 4130 is used to sweep the voltage and measure the current from the PV cell or module. Additionally, several sensors are required to measure the ambient conditions in which the test is conducted. A light intensity meter, or pyrometer, is used to measure the irradiance of the incident light and a temperature and a temperature sensor (thermocouple, thermistor, or RTD) is needed to obtain the temperature at which the test is conducted. A data acquisition system with analog input capabilities, such as NI M Series data acquisition (DAQ), is then used to acquire these sensor measurements and along with the SMU, interface with a computer. Software such as Lab View is used to acquire, analyze, and display the results of the I-V characterization tests and assess the main performance parameters for the solar panel.

A cooling system can be added to counter balance the heating from the light source by maintaining the ambient temperature and the temperature of the solar cell” (National Instruments, 2011)

SMU for I-V Characterization

"An SMU (Source Measurement Unit) is a precision power sourcing instrument that provides voltage and current sourcing and measurement resolution at or below 1mV and 1uA, respectively. In addition, SMUs feature a four quadrant output that can both source and sink current and voltage for testing either forward or reverse PV characteristics. An example of an SMU is the PXI-4130

As shown on the figure below.

Figure 2.13: PXI -4130 Power SMU (National Instruments, 2011)

With the PXI -4130 Power SMU, it allows you to perform sweeps of both current and voltage to determine the IV characteristics of PV cells or modules and diodes. This module can sink up to 10W and has isolated outputs capable of sourcing upto +-20V and 2A. It also has a 1nano amp current measurement resolution rating, and provides software selectable output capacitance to enhance stability. NI SMUs are shipped with ready –to –run Lab View example programs for performing IV sweeps.

It is possible to cascade multiple PXI -4130 Power SMUs in series to attain larger voltages when sourcing power (for reverse bias tests)

Other Test System Options
In place of the PXI-4130 Power SMU, other third –party SMUs with a GPIB interface may be used that meet required specifications for PV testing. Drivers for these third party instruments specifically created for NI software can be found at the instrument Diver Network portal".

2.10 Panel Selection

After a careful study on the different types of panel available, two panels were selected for the experiment. The panels were also available at the University labs. Both the Panels are approximately 19years old. The panel details are as follows:

1. BP Brand- 75Watts
2. Solarex Brand – 50Watts

The BP Panel is a Mono-crystalline type and the Solarex brand is a Polycrystalline. Due to time and frame size limitations, it was not possible to test a thin film type.

Panel Characteristics

2.10.1 Type 1 – PB275 specifications

The BP panel is a Monocrystalline type and has the following Electrical Characteristics below:

	BP 275
Maximum power (P_{max})[2]	75W
Voltage at P_{max} (V_{mp})	17.0V
Current at P_{max} (I_{mp})	4.45A
Warranted minimum P_{max}	70W
Short-circuit current (I_{sc})	4.75A
Open-circuit voltage (V_{oc})	21.4V
Temperature coefficient of I_{sc}	(0.065±0.015)%/°C
Temperature coefficient of voltage	-(80±10)mV/°C
Temperature coefficient of power	-(0.5±0.05)%/°C
NOCT[3]	47±2°C
Maximum system voltage	600V (U.S. NEC rating) 1000V (TÜV Rheinland rating)
Maximum series fuse rating	20A

Figure 2.14 BP Panel (75W)

2.10.2 Type 2 : Solarex 50watts Specifications

The Solarex model is a polycrystalline model and has the following electrical characteristics below:

Maximum Power (Pmax)	50W
Voltage at Pmax (Vmp)	16.8W
Current at Pmax (Imp)	2.97A
Warranted Minimum Pmax	45W
Short Circuit Current (Isc)	3.23A
Open Circuit Voltage (Voc)	21V
Temperature coefficient of Isc	0.065%/
NOCT	47+-2

Figure 2.15: Solarex Panel(50W)

2.11 PV Generation vs Home Electricity Use

As stated in the presentation of the Manly Council workshop on 19th July 2011, the figures below shows the PV output vs Home Electricity Use for an average NSW household in winter.

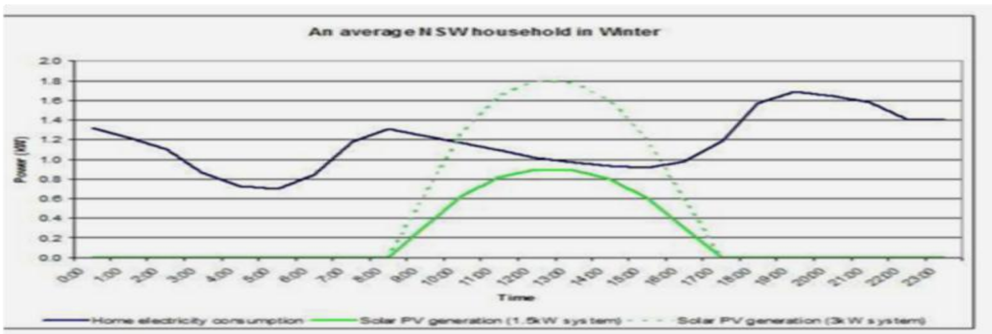


Figure 2.16 – An average NSW household in winter(ASI,2011)

The above figure shows the PV output vs. the electricity use for a domestic home in NSW. The figure illustrates 1.5kW and 3kW system. The output produced is only 0.9kW/1.5kW and 1.8kW/3kW respectively. This equates to a maximum of 60**%** during the day, which overall may only be 40-50% efficient.

This project will investigate if the above output can be improved if panels are installed on flexible angles

The figure below shows the PV output vs the electricity usage during the summer months

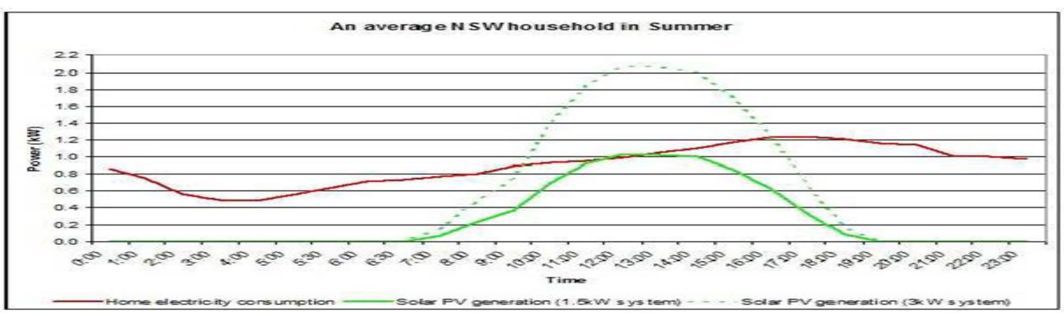


Figure 2.17: An average NSW household in winter(ASI,2011)
Source: http://www.solarchoice.net.au/blog/home-energy-consumption-versus-solar-pv-generation.html

The output figures only increased by 6% in summer.(1kw/1.5kw = **66%** and 2.1kw/3kw**= 66%)**

2.12 Installation Standards and Connection Option

While the installation and connection options are available for Australia with Grid system and standalone systems, Fiji has only the standalone option for its consumers. Few businesses have started installing smart meters and could potentially a growth area and an option for Fiji in the near future.

To be eligible to claim Renewable Energy Certificates (RECs) Electrical power systems must be designed and installed by accredited personnel. This is a requirement by the Office of the Renewable Energy Regulator (ORER)

2.12.1 Australia Standards and PV Requirements:

Clean Energy Council (CEC) is the body that controls the standards for PV modules in Australia.

Typical Standards used are as follows:

1. **IEC 61730.1** – Requires modules to have this minimum requirements::
   - Manufacture mark
   - Type of Model and serial number
   - Terminal Polarity
   - Maximum System Voltage and safety class
2. **IEC 61730.2** –applies for a reverse test current
3. **AS/NZS 5033:2005-** All installation of photovoltaic (PV) arrays are to use this standard.
4. **AS 477** -Grid Connection of energy systems via inverters
5. **AS/NZS 3000** – Earthing

2.12.2 Other Relevant Standards and Codes

These were the following standards that were researched to obtain a greater understanding of PV systems and testing requirements.

1. AS/NZS 5033:2005-Installation of Photovoltaic (PV) arrays
2. ISO – International standards for Organization
3. IEC 61730- Photovoltaic
4. IEEE – Institute of Electrical and Electronics Engineering for international standards
5. ASTM – American Society of testing and Materials

2.13.3 Fiji Standards and PV Requirements

The following current standard is currently being followed by Fiji. The following information was obtained from the Fiji Department of Energy:

1. AS/NZS 5033:2005- All installation of photovoltaic (PV) arrays are to use this standard.
2. IEC 61215 or equivalent
3. IEC 61646 or equivalent
4. Modules must be labeled indicating at a minimum: Manufacture, Model Number, Serial Number, Peak Watt Rating, Peak current and voltage rating, Open circuit and Short Circuit current of each module.

2.13 Common Solar Panel defects

Solar panels are normally manufactured to withstand hail, storm, wind and rain.
The Monocrystalline and Polycrystalline are normally rigid but the thin films are more flexible. They are also generally bigger in size for a same wattage as the mono and poly types. Their structure is made to avoid corrosion to the internal connections and the frame of the PV modules.

Below are some common panel defects:

1. Scratches on Frames
2. Excessive or uneven glue marks on glass
3. Gap between frame and glass due to poor sealing
4. Lower Output than stated in data sheet
5. Lower FF then stated in the requirements.
6. Degradation over time.

2.14 Future of Solar Cells with improved efficiency

With the ongoing research in improving efficiencies of solar cells, an article confirmed that **Spectrolab-** a subsidiary of the US giant Boeing has set a new world record for terrestrial solar cell efficiency at **40.7%.**

The Technology used is similar to that used in space-based solar cells (**Multi-Junction Solar Cells**), these new Photovoltaic (PV) cells convert concentrated sunlight into electricity better than any previous cells. Solar panels made from these cells will achieve higher power output per surface area and use up fewer raw materials during the manufacture process than existing PV modules.

These solar cells offer almost double the efficiency of Sun Power's soon to be released SPR-315 Solar Panels which are rated at an impressive 22+% efficiency far better than the 12-18% industry average.

The latest multi-Junction solar cell has been used in these cells which enable more of the solar spectrum to be captured than is the case with conventional silicon solar cells. Each multi-Junction solar cell is made of layers with each layer designed to capture a different range of wavelength of sunlight. This increases the photon number whose band gaps are matched and this way more sunlight is absorbed and converted into electric current increasing overall efficiency.

For example if silicon is alloyed with carbon in a layer, the band gap increases and more blue light is absorbed. Conversely, if silicon is mixed with germanium in another layer, the band gap is decreased and more red light is absorbed. These new solar cells also use an **optical concentrator** to increase the intensity of sunlight hitting the solar cell. More photons of light means more electricity generated and thus efficiency is further increased.

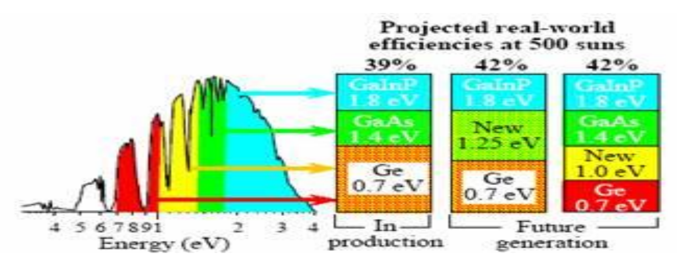


Figure 2.18 Future cell layers

With this improvement the US Department of Energy believes that solar cells with such high efficiencies will eventually lead to installation costs of just $3 per watt and generate electricity at a competitive 8-10cents per kWh. Spectrolab scientist said, they believe that these multijunction solar cells are capable of even higher efficiencies in the near future.

3.Methodology and Design Overview

3.1 Background

3.1.1 Preliminary Tasks

The preliminary tasks may be divided into research of industry methods requirements, standards and technical experimental work. Identification of testing location, gathering of materials for experimental work, preparation of panel frames, test equipment setup, analysis, validation, reporting and conclusion.

3.1.2 Testing Methodology

Firstly, locations will need to be identified to conduct tests. A test frame will be designed and constructed to allow for the ease of movement between angles, direction and also to maintain the same environmental condition during the tests. Two different panels (BP and Solarex brand) will be setup on the same location. Depending on the availability, a data logger will be used for measurements in different scenarios. Multiple voltage and current meters will need to be used if Data logger is not available. A variable resistor will also be used to obtain the IV characteristic curve. Power output variations will be calculated from I and V readings then analyzed and compared between the two different brands.

3.2 Test Locations

The two options that were identified for test locations were: the Top Floor of the Z – Building and Steel Rudd College ground (adjacent to I Block building). Steel Rudd was selected for ease of access and safety reasons.

3.2.1 Initial Tests

Preliminary tests were carried out to have a feel of the requirements of the project. Some initial tests were carried out in Fiji during the mid-semester break in April. Other tests were carried out at Steel Rudd College (Block I).

3.3.2 Final Experimental

Final experimental work will be carried out in these locations once all materials are collected. The aim is to complete this testing during the June Semester break or early Semester 2.

3.3 Frame Design and Preparation

A frame was designed to allow for ease of movements during the experiment. It was designed to house two different panel types to allow for each measurement to be carried out on similar conditions. The design was approved by the supervisors and materials were ordered after necessary project resource forms were signed. The frame was constructed at the USQ workshop. The frames and the experiment layout is shown on the figure below.

Figure 3.1 – Layout of the Experiment Setup (Steel Rudd College)

Other materials on the figure above are:

- **2 x Panels**
- **2 x Variable resistors**
- **1 x Data Logger(LabJack U6)**
- **1 x Laptop**
- **1 x Pyranometer**
- **3 x Temperature sensors**

3.4 Data Logger Setup

A Lab- Jacku6 is used to perform data logging. LabJackU6 (figure 3.1) is a USB controlled data acquisition device capable of reading digital and analogue inputs and outputting digital and analogue signals. A Lab Jack software namely Lab Jack Express is used to control and configure the Lab Jack and perform necessary calculations from analogue voltage measurements. Excel and Matlab are also used to interpret and display the experimental results.

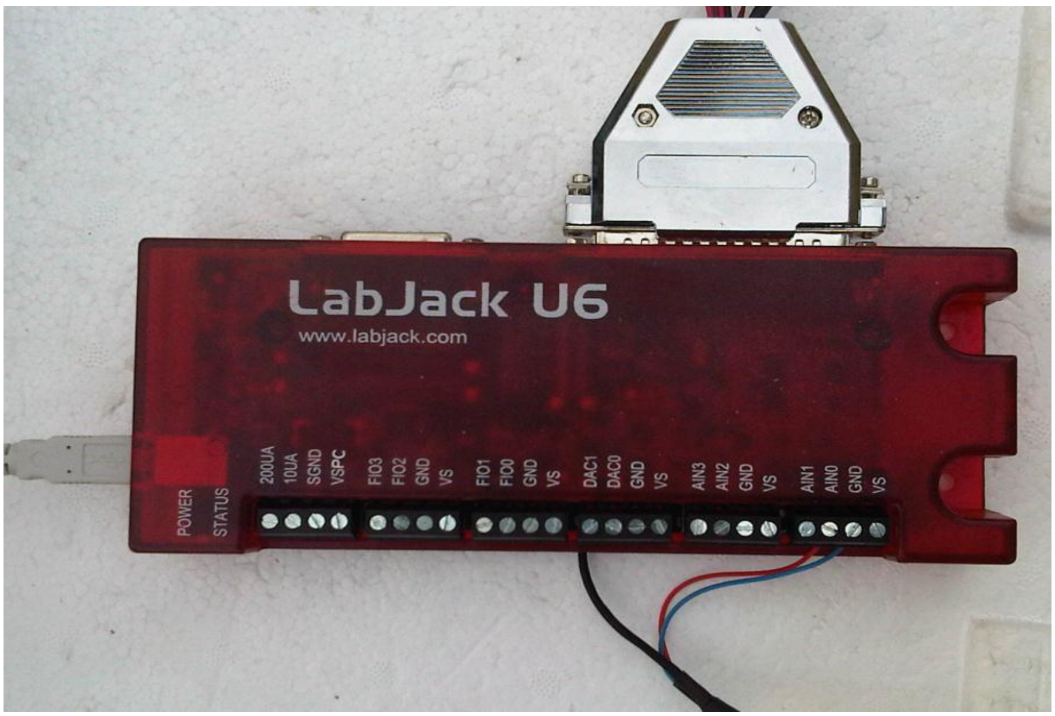


Figure 3.2 –*U6- LabJack* (LabJack Corporation 2010)

The two methods for acquiring data that was identified were: 1) to use a data logger and (2) by manual connections. The latter option was used for the initial tests, but was found to have a lot of disadvantages which included the inaccuracy of data readings, time consuming and the use of more equipment’s e.g. (4 x Digital Millimeters etc.).

The second option was then chosen and a list of requirements and specifications were put together to assist with the design and setup of the Data Logger.

These specifications are: it must be easy to program (ideally using USB2.0 port), it must have multiple analogue/digital input and outputs, and ease of communicating with the device. It must be able to connect to the computer for further data analysis.

The LabJackU6 has 3 different I/O areas:

- Communication edge
- Screw Terminal edge
- DB Edge

The communication edge has a USB type connector (with white cable connected in Figure 3.1). All Power and communication is handled by the USB interface.

The screw terminal edge has convenient connections for 4 analog inputs, both analog outputs and 4 flexible digital I/O. The screw terminals are arranged in blocks of 4, with each block consisting of Vs, GND and two I/O. Also on this edge are two LEDS. One simply indicates the power and the other serves as a status indicator. The Pyranometer was connected to one of the inputs of the screw terminal edge.

The DB Edge has 2 D-sub type connectors: a DB 37 and DB15.The DB37 has some digital I/O and all the analog I/O. The DB 15 has 12 additional digital I/O (3 are duplicates of the D37 I/O). For this project, the DB 37 was used as shown in (Figure 3.1)

The U6 has a full speed USB connection with USB version 1.1 or 2.0. This connection provides both communication and power. USB ground is connected to the U6 ground and USB ground is generally the same as the ground of the PC chassis and AC mains.

3.4.1 Data logger Configuration

The data logger is configured for 9 channels. The channel names are as follows:

Channel 1- Ambient Temperature (°C)

Channel 2 – Current for panel 1 (Amperes (A))

Channel 3- Voltage for panel 1 (Volts (V))

Channel 4-Temperature for Panel 1 (°C)

Channel 5-Temperature for Panel 2 (°C)

Channel 6- Current for panel 1 (Amperes (A))

Channel 7 –Current for panel 2 (Amperes (A))

Channel 8 – Pyranometer (w/m^2)

The channels are then verified after configuration. The circuit and configuration was tested in the workshop to ensure the configuration and the voltage divider was working correctly. Two power suppliers and loads were connected. The voltage for the power supplies were then altered for both the circuits and it was confirmed, that the readings were similar. Temperature sensors were also tested by holding the sensors in the hand and observing the changes in the readings. Ambient temperature was also noted and confirmed to be working correctly.

The laptop via a USB cable is used to configure the data- logger data. A brief step by step procedure for data logger setup can b found on Appendix K.

3.4.2 Data Logger Conversion Table

A conversion table had to be setup to convert the analogue readings to meaningful electrical values. The following is a list on conversion formulas used for this experiment.

1. Current =value/0.1
2. Voltage =Value-273
3. Ambient Temperature=Value x 100
4. Pyranometer =Value/0.125
5. Temperature for panel 1=Value -273
6. Temperature for panel 2 =Value -273

3.4.3 File Set-up and Test Initialization

Once the configuration is done, and the panels are ready for test. Open circuit voltage and short circuit current are taken before other readings are recorded. The panels are connected to the DB37 connector and then connected to the data logger. The variable loads are also connected. A File is then created before the data logger is initialized to start recordings of the test.

For different orientation, that is direction and angles, the loads are varied simultaneously. The test duration for a certain orientation is done for a few seconds

3.5 Voltage Measurements

The nominal maximum analog input voltage range for the U6 is (+-10volts) A voltage divider circuit is required for this project to handle the higher voltages from the solar panels. Resistor values were chosen as 1k for R1 and R2 respectively.

The divider is easily implemented by putting a resistor (R1) in series with signal wire, and placing the second resistor (R2) from the AIN terminal to a GND terminal. To maintain the specified analog input performance, R1 should not exceed 10kohms. Generally R1 can be fixed at 10k and R2 can be adjusted for the desired values.

Since the DB37 connection was used, the voltage divider circuit was wired to this as per **figure 3.2.**

The open circuit voltage required for the IV curve is captured using two multi-meters. After the open circuit voltage measurements are taken, the panel cables are connected back to the data logger for other measurements. This could been made easier with a control switch.

The readings or data were sampled at 1second intervals. Each tests required the varying of the resistance to capture the maximum output of the panels at that hour and produce the I- V curves.

3.6 Current Measurements

A simple way of measuring the current is to measure the voltage drop across the low value resistor and using ohms law to calculate the current. A 5watt, 0.1 Ohms resistor was used in this setup. As the orientation of the angle and direction is changed, the time is noted for analysis purposes. The short circuit current required for the IV curve is also measured by shorting out the cables form the panels and taking the readings with a multi-meter. Two multi-meters is used to capture readings simultaneously to ensure the conditions are the same. The other method of taking the short circuit current is by reducing the resistance to a minimum.

3.7 Temperature Measurements

3.7.1 Ambient Temperature

The U6 has an internal temperature sensor. The sensor is physically located near AIN3 screw terminal. It is labeled U17 on the PCB. With the UD driver, the internal temperature sensor is read by acquiring analog input channel 14 and returns degrees K.

3.7.2 Panel Temperatures Measurement

The LM 35 temperature sensor is used to measure the panel temperatures. It is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature (in degrees Celsius). This was chosen for the following reasons:

- Better accuracy over a thermistor.
- The circuitry is sealed and not subject to oxidation
- It generates a higher output voltage than thermocouples and does not require that the output be amplified. Figure 3.3 below shows a LM35.

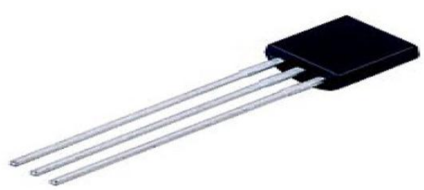


Figure 3.3: ***LM35 Temperature Sensors***

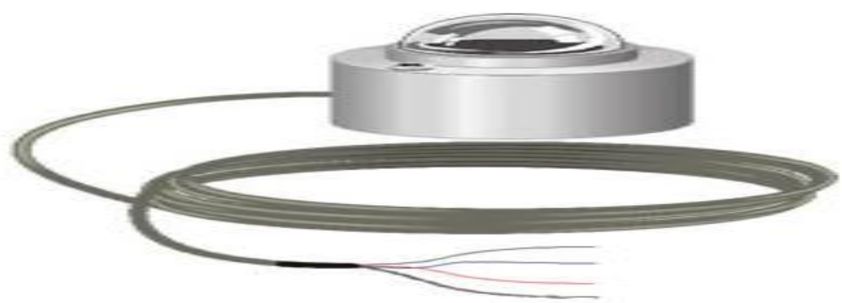
3.8 Pyrometer (Irradiance) Measurements

A CM3 Pyrometer is used to measure the Solar irradiance. This was supplied by the University with some specifications as follows: a 180 degrees field of view, output expression in w/m^2 , thermal equilibrium and a sensitivity of 15uv per watt/m^2.

This is mounted on the Solar testing Frame with the same angles as the panels.

The Sensor properties consist of a thermopile sensor, housing, a dome and a cable. The paint absorbs the radiation, converts it to heat. The resultant energy flow is converted to current by the thermopile. The thermopile is shunted by a resistor to generate a voltage output. Figure 3.5 shows a CM3 Pyranometer

Figure 3.4: ***CM3 Pyranometer***



Irradiance (E) = U emf/Sensitivity

E Solar =Irradiance w/m^2

Uemf = Output Voltage (UV)

3.9 Direction Measurements

Direction Measurements will be taken for the following directions; (North, NE, and NW). A Direction chart and a compass will be used to ascertain the North and other directed test points. The test is carried every hour between 7am and 5pm. The readings for all the directions should be all completed within a time of 15minutes.Caution is taken when moving the frame around to prevent damages to cables and to avoid back injuries.

3.10 Angle Incline Measurements

Measurements will be taken during changes in the following angles (36, 27, 22 and 18 degrees. The latitude angle is 27 degrees. An angle is obtained by the varying the test frame and locking it securely. A typical Test Frame sketch is found under Appendix H. A protector is used to measure and mark the above angles. A tower threaded bolt was used support the panel frame and for adjusting to different angles.

Caution has to be taken to avoid back injury and other accidents that can be caused if the frame is not supported well.

Figure 3.5: GPS Explorist Magellan

3.11 Shading and Cloud Movement Measurements

There are two types of shading test that is carried. The first is taken during cloud movement and the second is the shading caused by covering certain parts of the panels. Partial Shading tests will be conducted for the following panel block percentage: (25%, 50% and 75% shading). A cardboard material is be used for blocking off the surface area of the panels. Output Variations is measured and compared for the different panels. Environmental conditions will need to be recorded as reference, for example ambient temperature, irradiance level, time and date of test. The measurements is taken only at only one direction and that is N at an incline angle of 36 deg

3.12 Temperature Measurements

Readings to be taken at different Temperatures, as different panels perform differently over the standard 25 degrees Celsius ambient temperature. The temperature reading is closely observed and the load is varied at certain temperatures and recorded. An electric fan was used for controlling the temperature.

3.13 Aging Measurements

Previous test data should be acquired and comparison to be carried with similar setup for example Panel temp, panel incline angle. Other important data to be acquired is the date of when the test was carried out and comparison to be made on the insolation table to see if there is much difference. Again the data logger readings are observed for the similar conditions before the test is carried out.

4.0 Results and Discussions

The data collected was analyzed and the results are now presented in turn. Discussions of the recorded data are provided below the respective results.

Power versus hourly time graphs were obtained for the day and the data is summarized on table 4.2 with the best orientation and average output by the panels during a day. The I-V plots are also obtained and graphed by mat lab software.

The performance outputs were then discussed and compared with cost.

The typical output from the data logger is shown on table below.

TheTime	VoltPanel	CurrentP1	Power1	TempP1	VoltPanel	CurrentP2	Power2	TempP2	Pryo	AmbTemp
12:18:44 PM	1.379451	1.493743	2.060545	24.32451	0.334777	1.195582	0.400253	24.35606	606.2894	22.51053
12:18:45 PM	2.178783	1.486644	3.239075	24.34817	0.942401	1.193215	1.124487	24.30873	611.5488	22.51781
12:18:46 PM	4.265312	1.474812	6.290533	24.36395	2.423199	1.188483	2.879931	24.32451	606.2894	22.5251
12:18:47 PM	6.574474	1.459825	9.597582	24.36395	4.881782	1.182172	5.771106	24.29295	606.2894	22.53968
12:18:48 PM	8.674888	1.445627	12.54065	24.37973	6.389246	1.17744	7.522954	24.30873	606.2894	22.54696
12:18:49 PM	10.03861	1.432217	14.37747	24.36395	8.135121	1.171129	9.527276	24.38762	601.0299	22.55425
12:18:50 PM	10.02962	1.432217	14.36459	24.4034	8.695568	1.168763	10.16306	24.37184	601.0299	22.56883
12:18:51 PM	11.91718	1.413287	16.8424	24.45862	10.10678	1.163241	11.75662	24.3324	601.0299	22.56883
12:18:52 PM	12.59265	1.403032	17.66789	24.45862	10.63678	1.158509	12.32281	24.32451	601.0299	22.5834
12:18:53 PM	12.56946	1.400666	17.60562	24.43495	10.61374	1.156142	12.27099	24.35606	606.2894	22.60527
12:18:54 PM	12.54942	1.3983	17.54785	24.32451	10.59213	1.153776	12.22095	24.3324	601.0299	22.60527
12:18:55 PM	12.53428	1.396722	17.5069	24.45073	10.57619	1.15141	12.17753	24.41129	601.0299	22.61984
12:18:56 PM	12.52134	1.395145	17.46908	24.46651	10.56357	1.150621	12.15467	24.34817	601.0299	22.63442
12:18:57 PM	12.51061	1.393567	17.43437	24.50596	10.55236	1.148255	12.1168	24.39551	601.0299	22.64171

Table 4.1: Sample of results from data logger

The results show a 9 column data from the data logger that was used. The power columns (4 & 8) had to be created and obtained with a simple multiplication of current and voltage values. It can be seen that the first column is the time taken for the test. The sweeps were carried at a sample rate of 1 second interval. This could be varied in the configuration setup. The next columns are the current, voltage, power and temperature data for panel 1. This is followed by the voltage, current, power and temperature for panel2. The last two rows are the pyrometer readings capturing the irradiance level in (W/m^2 and the temperature sensor reading for the ambient temperature in degrees Celsius. It can be seen that the above test was carried out at around 12.18pm on 24th August 2011 .The current and voltage values were then later used to plot I-V curves and determine the hourly power output for the two panels. An important note also is that the pyranometer may have not been calibrated properly, so readings will used as references only in this experiment.

4.1 Output Variations due to Direction and Angle variations

With changes to the angles and directions of the panels, the output varied accordingly. The directions and angles used were North, NE and NW at changes in angle from 36°, 27°, 22° and , and 18°.

4.1.1 Results for North Direction

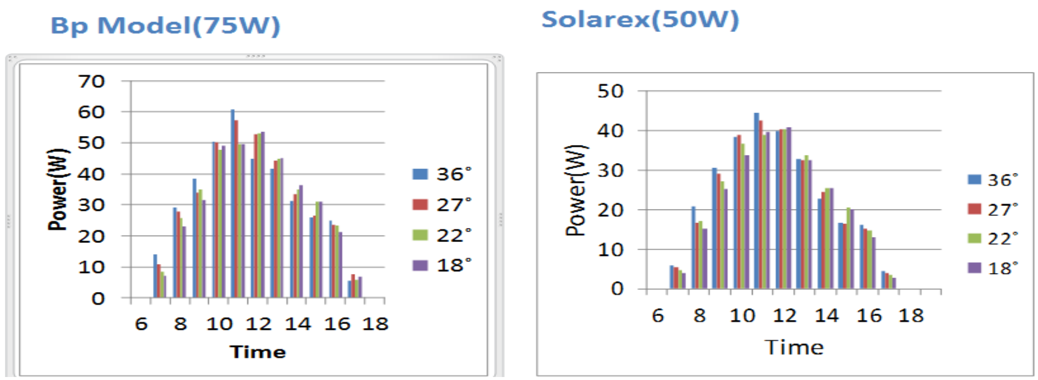


Figure 4.1 – North Direction with angle changes

The data showing the above figure can be found on Appendix E.

The figure above shows the changes in output of the two different panels as the angles were varied from 18° to 36°.

It was noted that in the morning between (7-11am), the higher tilt angle produced higher outputs and in the afternoon between (12pm to 5pm) the lower angle produced more output. Similar variations were observed on both types of panels. The panel reached its peak around 11am at 36° for both the panels.

It was also observed that during 7am and 5pm, the outputs were significantly low. The panels started to generate 10-30% from 7-8am, 50% at 9am then it was around 80% between 10am to 2pm. So it could be said the main window for producing the power is between 9-3pm. This however may change at different times of the year.

At this direction the power is got a more uniform spread throughout the day and is not quite so with the other directions discussed below.

4.1.2 Results for North East Direction

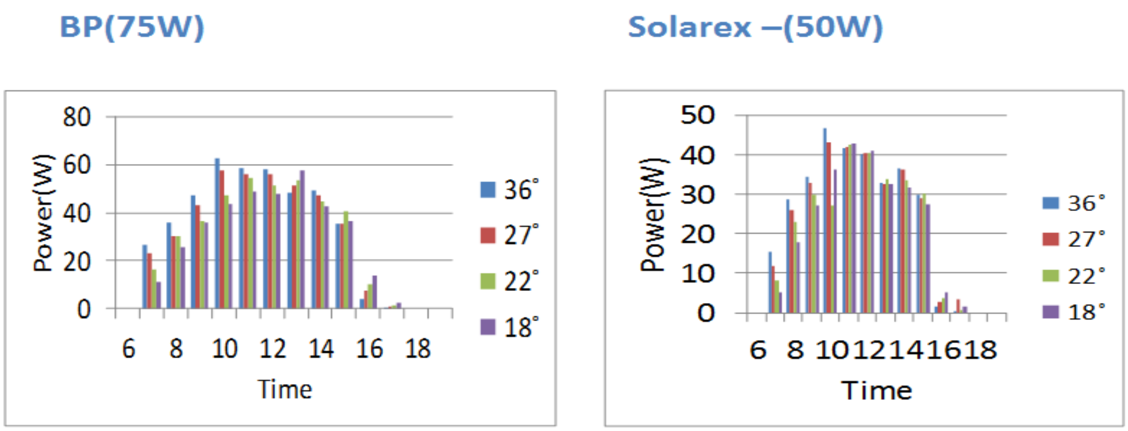


Figure 4.2 NE Direction with angle changes

The figure above shows the changes in output of the two different panels as the angles were varied from 18° to 36°. The data showing the above figure can be found on Appendix E.

It was noted that in the morning between 7am-12pm, the higher tilt angles produced more outputs and in the afternoon between (1pm to 5pm) the lower angle produced more output. Similar variations were observed on both types of panels. The panel reached its peak around 10am at 36° tilt for both the panels.

It was also observed that around 4-5pm the output was significantly reduced. This was obviously due to the shading from the panel frame.

The panels started to generate 20-30% from 7-8am, 50% at 9am then it was around 80% between 10am to 3pm.

So for North East facing roofs, although they may generate more power in the morning to the early afternoon, they will lose power between 3-5pm because of shading from the panel frames or other edges.

4.1.3 Results for North West Direction

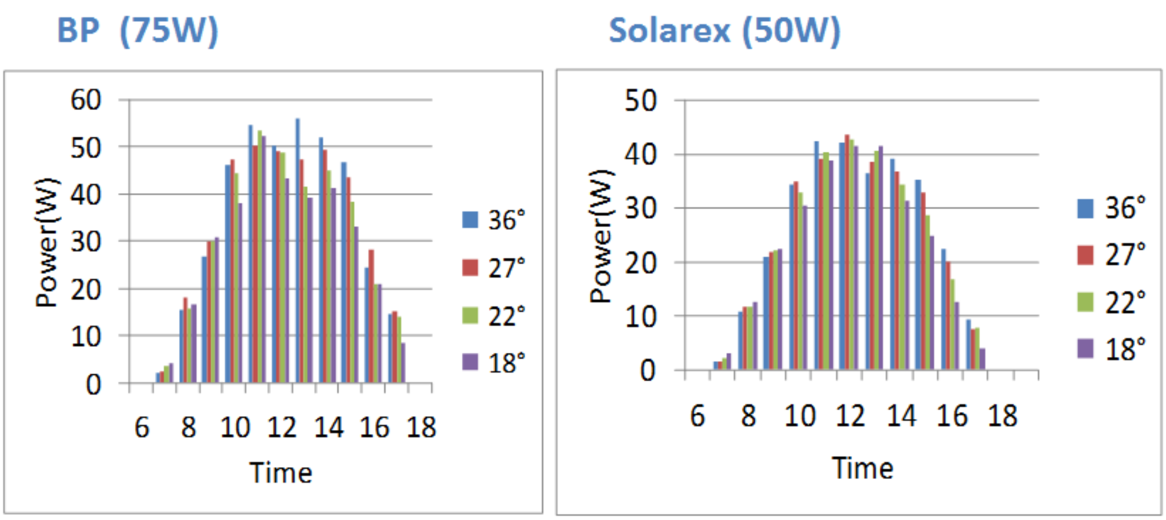


Figure 4.3 - NW with angle changes

The figure above shows the changes in output for the two different panels as the angles were varied from 18° to 36°. The data showing the above figure can be found on Appendix E.It was noted that in the morning from 7am-9am, the lower angles were producing more output than the higher lower angles. This changed at 10am where 27 degrees (latitude angle) had the highest output. In the afternoon however the higher angles produced more output. Similar variations were observed on both types of panels. This was the only direction that had its latitude angle (27°) peaking at certain hours of the day. This was not the case for North and North East Directions. Again this may vary during the year. The summary below shows the best orientation during the test or at this particular time of the year.

4.1.4 Summary of Best Orientation (angle and direction results)

The table below shows the summary of the output variations due to changes in angle and direction.

	BP Panel (75Watts)			Solarex (50watts)		
Best Orientation(Direction and Angle)	**NE-36**	**N-36**	**NW-36**	**NE-36**	**N-36**	**NW-36**
Daily average (W)	**49.35**	40.3	43.52	**37.1**	30.8	32.6
% compared to Rating on panel	**65.8**	53.73	58.03	**49.47**	41.07	43.47

Table 4.1 - Summary for Direction and angle variations

From the table above, the best angle and direction during the tests were at North East, at angle of 36°.This was similar to both the panels. North West direction had the second highest output followed by the North direction with the least. Although these tests were carried out in August, outputs will vary throughout the year because of the changes to the insolation level as shown in figure xxx on page 10.Changes in readings were also noted on different days in the same month.

The percentage was also calculated and as shown on the last row above, the BP panel produced **65.8%** of the rated panel (75W) and the Solarex panel produced 49.47% of the rated panel (50W). Clearly we can see the difference in output for the different panel brands. As the BP is a mono-crystalline and the Solarex panel is a polycrystalline.

These results are not too far from the results shown in the **figure 2.10 & 2.11** of a typical solar system in Melbourne during summer and winter months. The results showed that in summer a 1.5kW and 3kW system only peaked 66% during peak hour around midday and 60% of the rated capacity in winter.

So on average the daily outputs would be much less of around 40-50% only or even less. The losses however may include the inverter conversion losses. Therefore it is recommended that in order to harvest maximum output power from a system, the panels would need to be on an adjustable frame. This is also the reason why maximum power is achieved with an automatic tracker system or frame.

4.2 Output Variations due to Shading.

Shading has a major effect on the power output of the panels.

4.2.1 Shading due to Cloud Movement

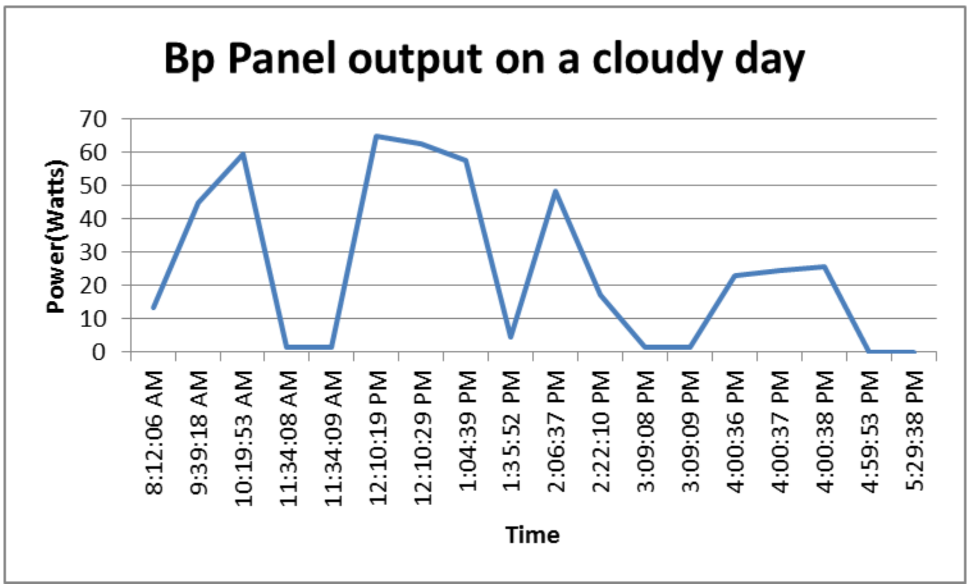


Figure 4.4: Shading effects on a cloudy day for 75W BP Panel

The figure above shows the effect of shading over a cloudy day. The Power level intermittence can be seen as the insolation levels are affected by the clouds through the day. The Solarex panel had similar effects as the BP Panel.

More data can be seen on appendix F.

4.2.2 Shading due to Partial Shading

The results for partial shading was interesting as the two panels under test gave different results.

Below is a table of results when panels were partly shaded.

TheTime	VoltP1	CurrentP1	Power1(W)	TempP1	VoltP2	CurrentP2	Power2(W)	TempP2	Pryo(W/m^2)	A/Temp(℃)
10:29:45 AM	8.01235	1.97017	15.78568175	31.33798	0.177505	0.040799	0.007242	31.18809	1605.585	44.83349
10:29:46 AM	8.09234	1.98121	16.0326393	31.33009	0.224998	0.05342	0.0120193	31.16442	1605.585	44.86264
10:29:47 AM	8.12957	1.98989	16.17694391	31.30643	0.227207	0.054208	0.0123165	31.14075	1610.844	44.89179
10:29:48 AM	8.13052	1.98989	16.17882833	31.29854	0.217582	0.051053	0.0111082	31.06186	1610.844	44.92094
10:29:49 AM	8.13478	1.99068	16.1937236	31.28276	0.226575	0.05342	0.0121036	31.1802	1610.844	44.94281
10:29:50 AM	8.13904	1.99226	16.21504729	31.28276	0.227522	0.054208	0.0123336	31.14864	1610.844	44.91366
10:29:51 AM	8.13888	1.99147	16.20831094	31.26698	0.227995	0.05342	0.0121794	31.06975	1610.844	44.9501
10:29:52 AM	8.28025	2.02854	16.79682645	31.27487	0.2291	0.054208	0.0124191	30.99875	1610.844	44.97925
10:29:53 AM	8.28025	2.02617	16.77722506	31.27487	0.229573	0.054208	0.0124448	31.21176	1610.844	45.03026
10:29:54 AM	8.25864	2.01986	16.68131531	31.26698	0.229415	0.054997	0.0126172	31.26698	1610.844	44.96467
10:29:55 AM	8.17186	1.99857	16.33199356	31.26698	0.23052	0.054208	0.0124961	31.11709	1610.844	44.97196
10:29:56 AM	8.23055	2.01434	16.57914658	31.26698	0.219948	0.052631	0.0115761	31.21176	1605.585	45.05213
10:29:57 AM	8.2345	2.01434	16.58709114	31.27487	0.184921	0.042377	0.0078363	30.92775	1610.844	45.0667
10:29:58 AM	8.23308	2.01513	16.59071844	31.26698	0.183974	0.043165	0.0079413	31.11709	1610.844	45.12501

Table 4.2: Results for Partial shading

The table above shows when parts of the panels were shaded as per figure 4.5 below.
A card- board was used to shade parts of the panels and results were logged. As highlighted on table xx above when 25% of the panels were covered, the BP Panels still produced 16Watts whereas the Solarex panel with almost 0watt.
The reasons for the difference results are discussed further under (section 5.4)

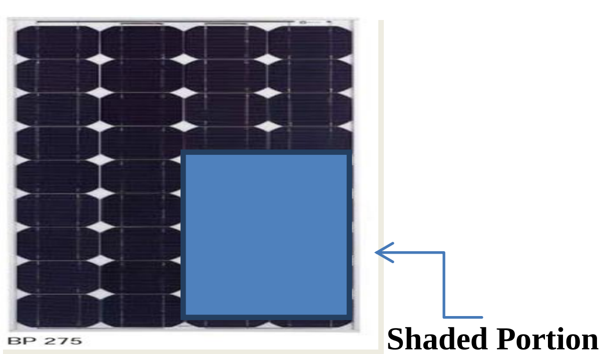


Figure 4.5: Partial Shading

4.3 Output Variations due to Temperature variations

The table and figure below shows the output power for the two different panels due to the above changes.

TheTime	VoltP1	CurrentP1	Power1(W)	TempPanel1	VoltP2	CurrentP2	Power2(W)	TempP2	Pryo(W/m^2)	A/Temp(℃)
10:03:24 AM	**15.7577**	**4.30577**	**67.84887**	28.50577	**13.3**	**3.224339**	**42.88248**	29.76	958.25	26.12534
10:10:16 AM	**13.2576**	**4.74749**	**62.94021**	29.56292	**15.049**	**2.841778**	**42.76492**	29.2	974.028	28.97493
10:15:15 AM	**15.3113**	**4.12987**	**63.23366**	30.55695	**13.867**	**3.184111**	**44.15356**	30.068	984.547	33.87971
10:18:03 AM	**16.3173**	**3.69682**	**60.3223**	31.14864	**14.231**	**3.098922**	**44.0998**	31.164	989.807	37.3342
10:20:46 AM	**14.7761**	**4.25923**	**62.93479**	31.25909	**13.709**	**3.224339**	**44.20163**	31.149	1000.325	40.05989

Table 4.3: Summary of Temperature Variation Tests

The table above shows the output power for the two panels with changes in temperature shaded in the last column. The temperature range recorded for these tests are between 26℃ and 40℃. Although theory says that as when temperature increases, voltage should decrease significantly with a slight increase in temperature and decrease in power. The readings on the table are taken from the maximum readings during sweeps at the recorded times.

The results would have been better if the temperature range was greater. More data is available on Appendix G.

4.4 Output Variations due to Aging.

Data was compared with 1993 test data for the same panel (BP 75Watts).The availability of the 1993 data enabled this test to be carried. To minimize the variables changes, effort was made to carry out test on similar conditions although tests were carried at different times of the year. Some parameters and conditions for the tests were as follows:

1. Incline angle of 45, with changes in direction
2. The April insolation level is quite similar to the August data.
3. Tests were carried out at approximately 1000w/m^2

The tests were carried out at the following temperatures and direction:

1. North at 25℃
2. North East 26℃
3. North West at 30 ℃

Figure 4.6 below shows the IV curves at an incline angle of 45 degrees with different directions and temperature as specified on the graphs.

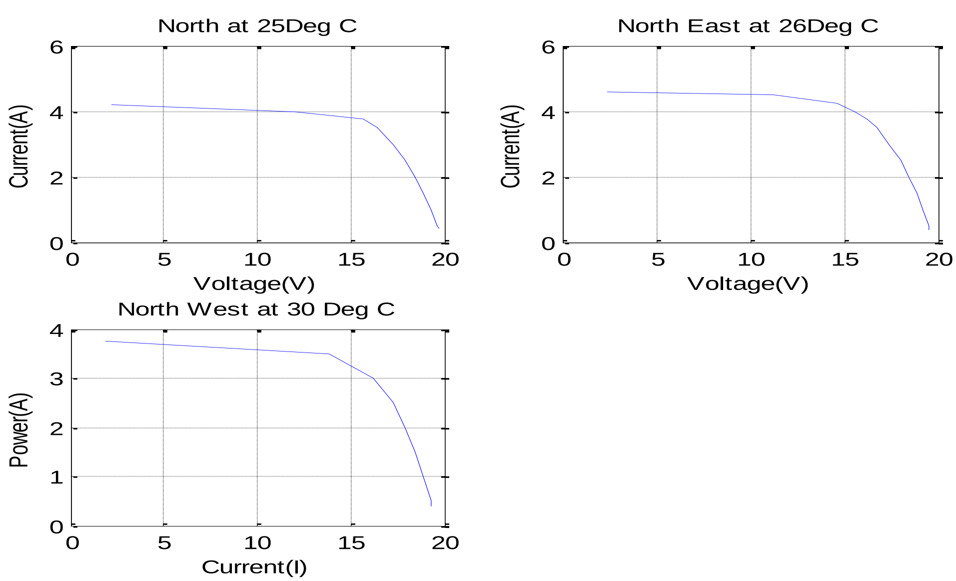


Figure 4.6 1993 Data (L. Bowtell)

The tables 4.4 to 4.6 below contain the data for the graphs in Figure 4.6

I	4.2	4	3.75	3.5	3	2.5	2	1.5	1	0.5	0.394
V	2.15	12.07	15.7	16.47	17.32	17.92	18.44	18.88	19.29	19.64	19.73
P	9.03	48.28	58.875	57.65	51.96	44.8	36.88	28.32	19.29	9.82	7.7736

Table 4.4 North at 25 °C

Ine	4.6	4.5	4.25	4	3.75	3.5	3	2.5	2	1.5	1	0.5	0.391
Vne	2.39	11.24	14.6	15.55	16.19	16.73	17.44	18	18.45	18.86	19.23	19.54	19.52
Pne	10.99	50.58	62.05	62.2	60.71	58.56	52.32	45	36.9	28.29	19.23	9.77	7.6323

Table 4.5 NE at 26 °C

Inw	3.75	3.5	3	2.5	2	1.5	1	0.5	0.387
Vnw	1.9	13.9	16.25	17.23	17.88	18.4	18.86	19.27	19.35
Pnw	7.125	48.65	48.75	43.08	35.76	27.6	18.86	9.635	7.488

Table 4.6 NW at 30 °C

Figure 4.7 below shows the graph of the tests carried out on 27th September 2011. This data is then compared with the 1993 data.

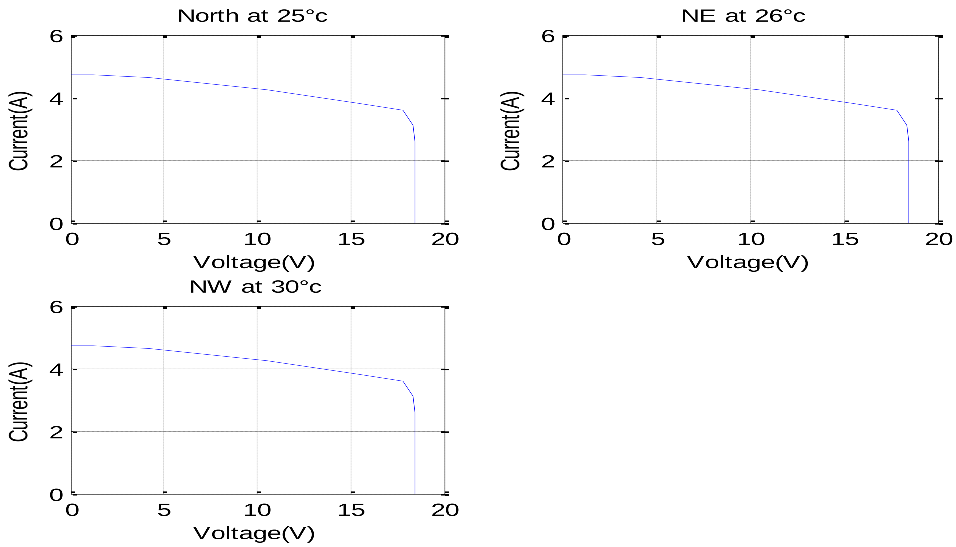


Figure 4.7 2011 data

The above tests shows that the panel still produced similar open circuit voltage (Voc) and short circuit current (Isc) values. The graphs showed that it had a greater decline on the IV curve than the initial tests. The steep fall also on the IV curve was also caused by the variable resistor that was used which could not bring the current down to zero on minimum resistance. The former tests probably used a 330ohms variable resistor which gave a better fall on the curve.

Data for the above figures can be found on Table 4.7 to 4.9 below

	Bp Panel (75W)			
TheTime	**Voltage(v)**	**Current(A)**	**Power(W)**	**Temperature(°C)**
9:49:36 AM	1.30	5.08	6.60	25.28
9:49:37 AM	1.30	5.09	6.62	25.29
9:49:38 AM	1.30	5.09	6.63	25.26
9:49:39 AM	1.30	5.09	6.63	25.25
9:49:40 AM	1.30	5.09	6.63	25.21
9:49:41 AM	1.30	5.09	6.63	25.19
9:49:42 AM	1.30	5.10	6.64	25.17
9:49:43 AM	1.30	5.10	6.65	25.13
9:49:44 AM	3.56	5.08	18.08	25.11
9:49:45 AM	10.33	5.00	51.59	25.08
9:49:46 AM	13.77	4.82	66.37	26.15
9:49:47 AM	17.15	3.75	64.37	26.71
9:49:48 AM	18.41	2.61	48.08	26.39
9:49:49 AM	18.51	2.31	42.68	25.04
9:49:50 AM	18.45	2.31	42.53	25.01
9:49:51 AM	12.45	4.88	60.69	25.00

Table 4.7 Aging Data at 25°C

	Bp Panel (75W)			
TheTime	Voltage(v)	Current(A)	Power(W)	Temperature(°C)
9:49:35 AM	0.28	5.07	1.45	25.29
9:49:36 AM	1.30	5.08	6.60	25.28
9:49:37 AM	1.30	5.09	6.62	25.29
9:49:38 AM	1.30	5.09	6.63	25.26
9:49:39 AM	1.30	5.09	6.63	25.25
9:49:40 AM	1.30	5.09	6.63	25.21
9:49:41 AM	1.30	5.09	6.63	25.19
9:49:42 AM	1.30	5.10	6.64	25.17
9:49:43 AM	1.30	5.10	6.65	25.13
9:49:44 AM	3.56	5.08	18.08	25.11
9:49:45 AM	10.33	5.00	51.59	25.08
9:49:46 AM	13.77	4.82	66.37	26.15
9:49:47 AM	17.15	3.75	64.37	26.71
9:49:48 AM	18.41	2.61	48.08	26.39
9:49:49 AM	18.51	2.31	42.68	25.04
9:49:50 AM	18.45	2.31	42.53	25.01

Figure 4.8 Aging Data at 26°C

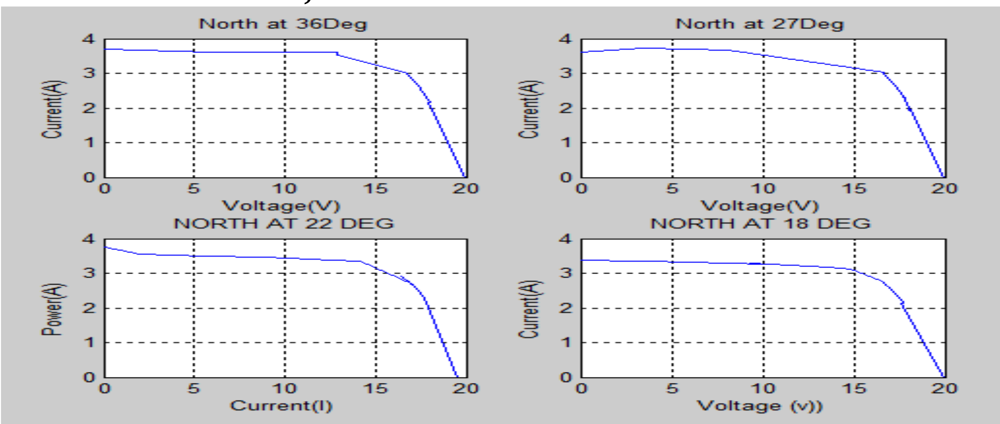
	Bp Panel (75W)			
TheTime	Voltage(v)	Current(A)	Power(W)	Temperature(°C)
10:01:20 AM	1.09	4.42	4.80	30.04
10:01:21 AM	1.09	4.41	4.79	29.85
10:01:22 AM	1.08	4.41	4.78	30.07
10:01:23 AM	1.29	4.42	5.71	29.74
10:01:24 AM	10.60	4.32	45.81	29.87
10:01:25 AM	14.92	4.18	62.42	30.14
10:01:26 AM	17.10	3.41	58.29	29.75
10:01:27 AM	18.20	2.53	45.96	30.12
10:01:28 AM	18.03	2.51	45.25	30.00
10:01:29 AM	18.03	2.52	45.50	29.65

Figure 4.9 Aging Data taken at 30°C

4.5 BP PANELS IV CURVES

IV curves were produced for the two panel types. Graphs were at the 10am, 12pm and 2pm.Some of the graphs didn't turn out to be 100 percent accurate as there were limitations on the equipment and maintaining the standard test conditions.

4.5.1 North IV Curves, 10am Data



Figures 4.8 North 10am IV Curves

The data for the above graphs are found on appendix I and matlab script on appendix I Note the ambient conditions were at Temperatures of 27-30°C and insolation of 800-1000Watts/M^2.The graphs shows that with different angles and directions the IV curves varied as well. The curves confirmed that the MPP decreased as the angles decreased at around midday.

4.5.2 North IV Curves, 12pm Data

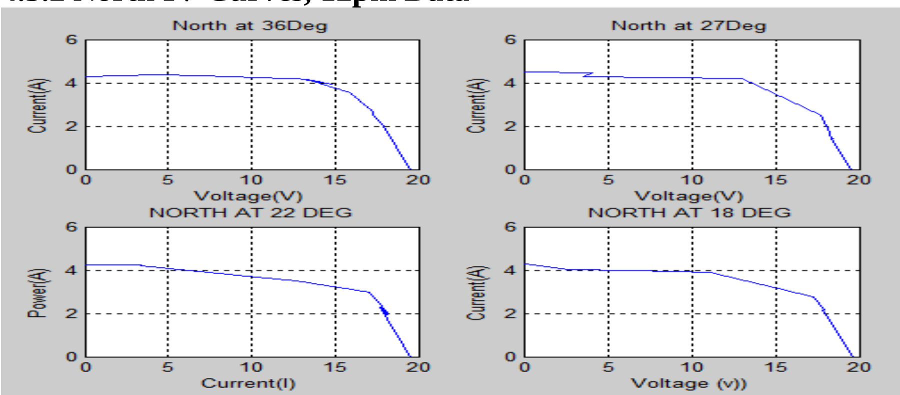


Figure 4.9 North IV Curves, 12pm Data

Similar results were noted on other direction during the same period.
However in the am the North and NE had higher MPP with higher angles in the morning to about midday while NW had higher MPP with the low angles.

4.5.3 North IV Curves, 12pm Data

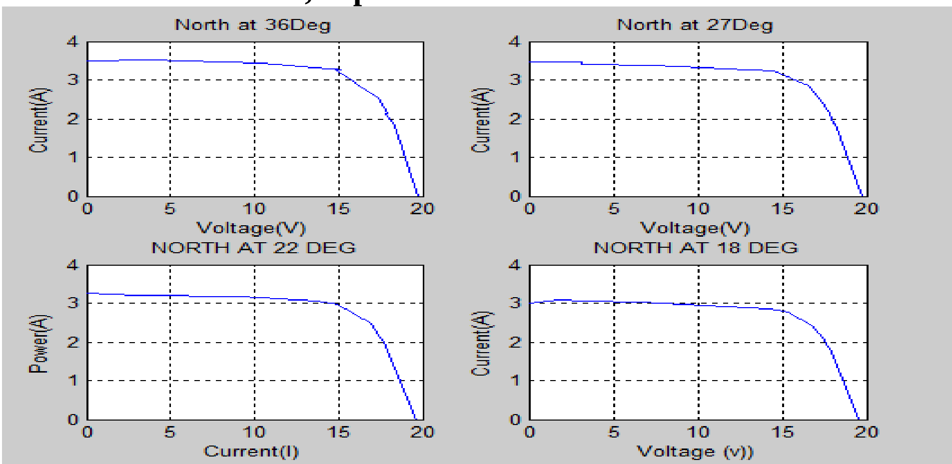


Figure 4.10 North IV Curves, 2pm Data

4.6 Solarex IV Data

More data for BP and Solarex IV curves are found on appendix J. The graphs were quite similar to the BP curves.

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT
	19.47	3.74	72.82			19.11	3.06	58.48		
10:10:20 AM	1.99	3.55	7.08	29.39		0.81	2.92	2.37	31.40	40.53
10:10:21 AM	1.99	3.55	7.08	29.36		0.81	2.92	2.37	31.42	40.53
10:10:22 AM	2.00	3.55	7.08	29.33		0.81	2.92	2.37	31.49	40.56
10:10:23 AM	5.64	3.50	19.76	29.30		0.98	2.91	2.84	31.38	40.60
10:10:24 AM	8.89	3.46	30.79	29.27		4.55	2.91	13.22	31.58	40.62
10:10:25 AM	12.60	3.39	42.70	29.24		9.42	2.88	27.18	31.62	40.64
10:10:26 AM	14.18	3.34	47.36	29.21		11.91	2.83	33.75	31.41	40.67
10:10:27 AM	17.08	2.67	45.64	29.18		13.69	2.69	**36.79**	31.27	40.69
10:10:28 AM	16.37	2.91	47.65	29.17		15.05	2.40	36.20	31.61	40.72
10:10:29 AM	16.42	2.91	**47.78**	29.14		15.42	2.27	34.94	31.60	40.73

Figure 4.10 A set of Data for BP and Solarex IV curves

5.0 Further Discussion of Results

Before deciding on a suitable way of presenting the data for statistical analysis, a quality and comparison analysis was performed. The quality check investigated how the recorded compared with some relevant available data. Details of the accuracy and data validation are covered on section 5.6 below.

5.1 Direction

The results showed that for standalone systems, while the general rule for panels are to face true North for sites in the Southern Hemisphere. The results showed that NE produced the best results in the period between 7am-5pm. The second best results were the NW direction followed by the North direction as the least in terms of performance. The results were taken during mid-August and results would vary over the year depending on the insolation level. It's also important to note that, the ratings on the panels were obtained during standard test conditions. The results could therefore vary if the tests were carried out at the same (STC) Standard Test Conditions, that is temperature of 25°C, irradiance level of 1000w/m^2. However all tests were carried out on a clear day , that is, the irradiance level ranged between 800 to 1000W/m^2, so we can confidently say that the readings were taken at relatively similar conditions to the Standard Test Conditions.

5.2 Angles

Results showed that angle changes have a great impact as well to the output power of the panels. In Fiji, a lot of panels are installed on flat roofs and it is assumed that the losses is negligible but after this experiment if consumers are informed of the losses due to having the incorrect angles, this information will better inform them to make right decisions in having the angles corrected for their system. Informed consumers will then weigh the options of having it on a flat roof or spending a bit more money on frames to maximize on the solar outputs. As per the theory, the optimum direction for panel output is when the sun light is hitting the panels at 90 degrees. This cannot be achieved over a day because as the sun moves, fixed panels would suffer the loss on the direct path of sunlight on the panels. This is the main reason why trackers are used but costs and benefits may have to be weighed with a fixed system as it will require additional costs on operation and maintenance as well. However a cheaper system and less operational cost is to have an adjustable panel frames for installations. Ideally the more cost effective method as it could be varied during the changes in seasons to maximize the output with the suns declination angle. The idea could also be used with Telecommunications sites and this additional work could be roped in with the maintenance team. For example, routine maintenance could be scheduled for the different seasons, so that the angles and directions could be corrected to reflect the new orientation for maximum output for that new season.

5.3 Temperature

Temperature was also confirmed to be an important factor to the output of the panels. It is proportional to the amount of irradiance falling on the panels. The results showed in Table 4.4 didn't really reflect the theory that as temperature increases, voltage would decrease and a slight increase in current. This could be due to the temperature range during the tests and the level of irradiance that was continuously increasing as the time moved.

Figure 2.7 also shows that the temperature range that explains the theory of temperature effects are between 0-75°C. The results therefore could have been improved if the range was larger than (25 – 40°C).

It was also noted that winds speed and the cloud movement affected the temperature level.

5. 4 Shading

Test were carried out for two types of shading, one being shading due to cloud movement and partial shading being the second. They were different effects on the panel outputs. The first test was shading due to cloud movements and the second was the partial shading test in which certain parts of the panel was deliberately covered. This could be related to houses that have multiple roofs that give shadings on panels during some part of the day. Another typical example are transmitter sites that have overgrown trees and shading from transmitter towers and guyed wires of masks. After the experiments the effects of cloud movement were quite obvious, similar outputs were seen for both the panels. The fluctuation or the intermittence effect was seen as the irradiance level varied over the day as the shading from the clouds moved over the panel. Refracted light was also observed during cloud movements. Temperature was also noticed to be lower during the test. The result showed the output varied from 0- 35%. Longer periods of cloudy days will not be good for any system and more importantly for power systems for critical services. However, the partial shading tests gave some interesting results. When 25% of the panels were shaded, the BP panel was still able to generate 25% of the power while the Solarex model produced closed to 0 watts.

This was one of the interesting finding in that, different panels could have different shading effects when partially shaded. The possible cause to this effect could be due to how the cells are wired in the modules. Generally cells are wired in series and then in parallel to obtain and maintain the desired voltage and current values.

Further tests were carried out to determine the cause of this effect to the panels. It was found that 9 cells were wired in series with the Voltage of 1.3v and diodes could be placed in between these panels to avoid affecting other cells.

The table below shows the comparison due to changes in the shadowing percentage placed over the modules. Although it may not be applicable to installations that have no partial shading effects, it is quite clear that this partial shading effect could vary with different panel brands. If this is true, this could be a topic for further research to determine the effects on other panel brands.

5. 5 Aging

The results shows that the BP Panel has survived the test of age and the warranty as specified. This may explain why BP brand is one of more reputable brand.

Data was also not available for the Solarex model but was only compared to the Max power rating.

Other factors of aging that were checked against BP panels are: Panel frame corrosion, cabling and material conditions. There have been some signs of corrosion on panel frames and gaps found between the frame glass on the top layer.

5.5 Performance against Cost

Solar Panels are generally priced in dollars per Watt. It rather important to ensure the ratings are producing as much power as possible. Although watt peak is a convenient measure, and it is the standardised number in the photovoltaic Industry on which prices, sales and growth numbers are based. It is arguably not the most important number for actual performance. Since the job of the solar panel is to generate electric power at minimal cost, the amount of power that it generates under the real life conditions in relation to its cost should the most important number to evaluate. This “cost per watt” measure is widely used in industry.

If a cost of a 1 watt is a dollar. Then an example could be if ,panel cost is $600 and rating is 75watts.The cost per watt is 600/75 = $8 per watt
In this case output is only 60% which relates to 60% efficiency.

It is possible that a panel from brand A and a panel from brand B to have the similar rating, but their power output is different in real situation. This difference can be caused by different degradation rates at higher temperatures. At the same time, though brand A can be less productive then brand B it may as well cost less. An accurate analysis of long term performance versus cost, both initial and on-going is required to determine which panel may give the consumer better results.

6.0 Safety

The potential risks involved with the performance of the research project were assessed, especially with regard to the experimental components of the project. Members of the Institution of Engineers Australia have an obligation to safeguard the welfare, health and safety of members of the public and the workforce (IEAust 2000, p6)

Safety issues arising during the execution of the project were more fully analyzed in the Risk Management section of the Project Appreciation. They were mainly associated to the dc systems and lifting or handling of panels and test panel frames during the testing phase.

6.1 Limitations

Since the experiment had to be carried outdoors, the main constraints in the experiment were weather and test equipment unavailability for Fiji. Although a setup was carried out and effort was made to carry out a few tests with the available test equipments. Raw data has been kept with the author of the dissertation. This data was captured manually and could be used for other investigations and experiments. The two panels that were used in Fiji for tests were Conergy and a BP Panel of 170Watts each.

7.0 Conclusions

The aim of this project was to investigate the cost and performance characteristic of Photovoltaic Panels. This has been successfully achieved with the project objectives as defined in Appendix A, fully addressed. Experimental work was carried which included the design and construction of a dual Panel frame. Selection of appropriate test equipment's (Data logger, pyranometer, temperature sensors, variable loads were carried out. The output variations due to changes in incline angle, direction, temperature, cloud movement, and shading were successfully recorded, analysed and tabulated. The experimental results justified the need for the investigation of the PV panels carried out in this project. The results of this research would be beneficial for consumers and other current and future PV projects. The summary of the output power variations from PV panels are as follows:

7.1 Angle Variation

- ✓ Angle is a critical variable with installations of PV directly affect the output of the panels. It can be said that fixed angles on the rooftops and other fixed panel installation will not generate the maximum output. It was evident that although latitude angle, is the general angle that most installations would take. The test carried out showed that angles greater than latitude generated better results and this would vary through the year.
- ✓ Therefore to harvest maximum output, the angles should ideally be mounted on flexible frames to allow movement at different times of the year. This could be applied to communications sites where routine maintenance could be used to carry out this important task. Smaller systems could be easier to work with, but a little of bit of planning and proper installations would see the panels producing more than the average fixed type systems.

7.3 Direction Variation

- ✓ The Direction is also another critical variable to the installation because the general rule of thumb is that North direction will not produce the maximum result at a specific time of the year. It was also noticed that during the morning, the NE was better and NW was better in the afternoons during the test period. The north was only good at around mid-day.

- ✓ Even with the optimum orientation, the average panel output per day will not produce the rated output of the panel itself. This is the most misunderstood fact by consumers in which they think they can produce 75watts out from a 75watts panel. But as confirmed in the results, that even with the best orientation which was NE at an angle of 36 deg, it produced only 67% of the total rated power. Whilst it may difficult for larger installations to have adjustable frames, power point trackers would be ideal for smaller systems either mechanically or electronically.

7.4 Cloud movement and Partial Shading

- ✓ Cloud Movement-It can be concluded that for a cloudy day, the output will vary according to the insolation level. The maximum average output during the test was less than 30% with insolation level fluctuating between 0-500Watts/m^2. 2. For partial Shading –When number cells are blocked, the power output between the two different panels varied. This means that different panels will respond differently to partial shading.

7.5.4 Temperature Variations

- ✓ It can be concluded that as the temperature increases, the voltage decreases significantly while the current increases slightly. Also different panel brands will react differently at high temperatures

7.5.5 Aging Measurements

- ✓ Since there were only data for BP Panel from 1993, the conclusions were that for the BP brand, the drop in output after 19 years was minimal and this could very well confirm that the BP brand is reputable brand that may survive the warranty period of 25years.

7.5.6 Cost versus Performance

- ✓ Since the average output per day is 67%, the cost per watt then in this case is only 67% efficient for a ideal sunny day.If Panel cost is $600 and rating is 75watts.The cost per watt is 600/75 = $8 per watt. In this case output is only 60% which relates to 60% efficient. This figure is even less for the Solarex model with on 49.7% efficient

8.0 Future Work

The following can be carried out to further improve the results

- Tests during other parts of the year
- Test a Thin Film Type Panel and compare results with the Mono and Poly
- Frame to be automated with actuators for easy adjustments on the orientation.
- For Smoother IV curves, tests with a bigger resister value could be carried out

9.0 List of References

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Appendix A – Project Specifications

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/2 – Research Project
PROJECT SPECIFICATION

FOR: **Thomas Bruce**
STUDENT NO: w0066187

TOPIC: Comparison of Cost and Performance Characteristics of Photovoltaic Panels

SUPERVISOR: DR. RON SHARMA

ENROLMENT: ENG 4111- S1, X, 2011
ENG 4111- S2, X, 2011

PROJECT AIM: This project will analyse the performance of cheaper and expensive brands of PV panels and determine their payback periods

PROGRAMME: Issue C, Feb 9, 2011

1. Conduct literature review on solar panel performance, cost and payback period
2. Review current methodologies and select appropriate panels for tests
3. Carry out experimental work to determine panel output variations due to changes in incline angle, temperature, direction, cloud movement etc
4. Analyse experimental data to determine performance against cost.
5. Recommendation and Conclusion
6. Submit an academic dissertation on the research.

Agreed: ______ (Student) ______ (Supervisor)
Date: 6/3/2011 Date 10/3/11

Examiner/ Co- Examiner: ______

Appendix B – Project Timeline

The Project Schedule was been broken down into two phases.

Phase 1 – March – June 2011

Phase 2 – July – October 2011

Appendix C – Resources

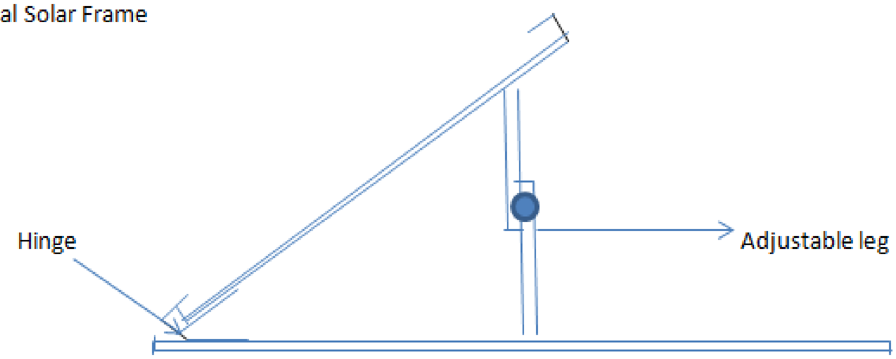
Test Equipment Resources

While evaluating resources, these necessary materials were identified for the experimental work to be carried out:

- Two Fluke Digital multimeters, for current and voltage measurements
- Power supply for calibration and meter tests
- 2 Brands of Solar Panels
- 2 x Variable loads
- A lux meter
- 2 x temperature sensors
- Pyrometer
- Data Logger
- Extension leads
- A variety of hand tools such as screw drivers, cutters, pliers for lead and cable connections

Appendix D – Panel Test Frames (Initial Design)

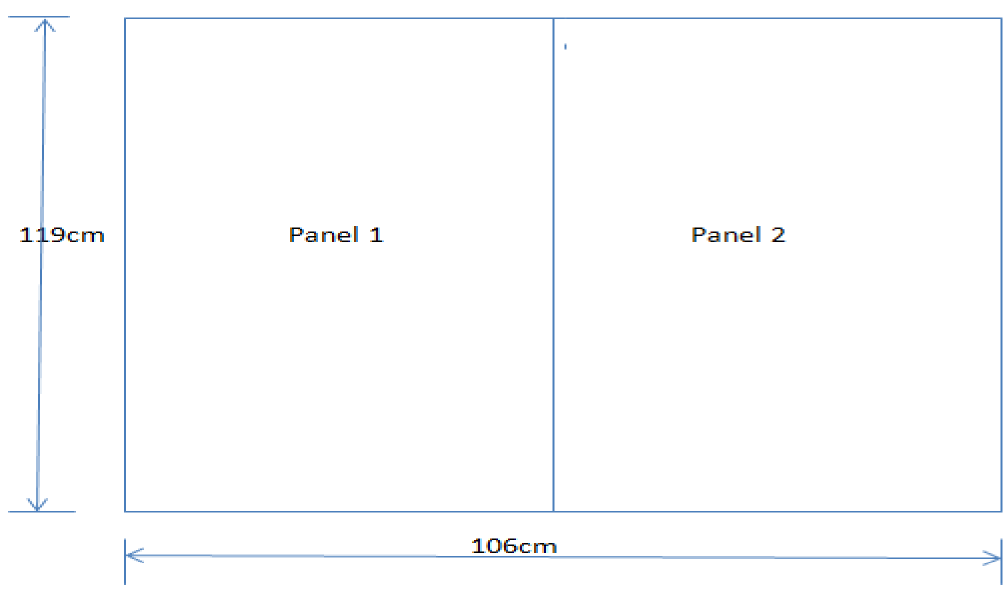
Figure 4: Typical Solar Frame



Side View

Note: Vertical leg to be adjustable for angle between 0 and 60 deg.

Front View



Appendix E – Results

Table 3 and 4 North Direction Readings at various angles

Table 3: BP 75w at North

Time	Angle Variations			
	36	**27**	**22**	**18**
6	0	0	0	0
7	13.93	10.73	8.54	7.26
8	29.2	27.92	25.84	23.2
9	38.53	34.08	35.02	31.68
10	50.4	50.21	47.8	49.2
11	**60.8**	57.4	49.54	49.65
12	44.8	52.8	53	53.5
13	41.6	44.4	44.92	45.1
14	31.4	33.4	35.13	36.27
15	25.9	26.5	31.14	31
16	24.9	23.51	23.4	21.12
17	5.58	7.61	5.74	6.94

Table 4: Solarex 50W at North

Time	Angle Variations			
	36˚	27˚	22˚	18˚
6	0	0	0	0
7	5.97	5.51	4.73	3.98
8	20.9	16.64	17.21	15.22
9	30.56	29.21	27.27	25.16
10	38.5	38.9	36.8	33.8
11	44.5	42.5	38.9	39.6
12	40	40.5	40.4	40.9
13	32.8	32.6	33.67	32.5
14	22.8	24.4	25.5	25.5
15	16.67	16.35	20.6	20.1
16	16.1	15.27	14.6	13.02
17	4.36	3.9	3.34	2.76

Table 5 and 6 North East Reading at various angles

Table 5: BP Panel at North East

Time	Angle Variations			
	36˚	27˚	22˚	18˚
6	0	0	0	0
7	26.5	22.78	16.16	11.06
8	35.8	30.23	30.35	25.55
9	47.11	43.31	36.24	35.99
10	62.6	57.7	47.4	43.5
11	58.3	55.8	54.5	48.8
12	58.2	55.9	51.4	47.5
13	48	51.4	53.6	57.6
14	49.2	47.2	44.6	42.6
15	35.6	35.2	40.48	36.34
16	3.98	7.44	10.16	13.97
17	0.51	0.78	1.51	2.46

Table 6: Solarex Panel at North

Time	Angle Variations			
	36	**27**	**22**	**18**
6	0	0	0	0
7	15.44	11.85	8.31	5.23
8	28.78	26.11	22.9	17.88
9	34.31	32.87	29.97	27.02
10	**46.7**	43.2	27.3	36.2
11	41.7	41.9	42.6	42.8
12	42.9	43.5	42.6	41.5
13	36.4	32.6	33.67	32.55
14	36.5	36.1	33.4	31.7
15	29.9	29	30.1	27.45
16	1.38	2.68	3.72	5.15
17	0.26	3.33	0.69	1.52

Table 7: BP Panel at North West West

Time	Angle Variations			
	36°	**27°**	**22°**	**18°**
6	0	0	0	0
7	2.01	2.48	3.6	4.2
8	15.38	18	15.88	16.54
9	26.9	30.04	30.01	30.7
10	46.2	47.3	44.3	38.1
11	54.6	50.3	53.5	52.3
12	50.3	49.1	48.8	43.3
13	56.14	47.32	41.59	39.1
14	51.9	49.4	44.9	41.2
15	46.8	43.5	38.3	33
16	24.39	28.19	20.86	20.86
17	14.53	15.16	14.04	8.6

Table 8: Solarex Panel at North

Time	Angle Variations			
	36°	**27°**	**22°**	**18°**
6	0	0	0	0
7	1.56	1.53	2.17	2.89
8	10.7	11.76	11.66	12.67
9	21.03	21.75	22.25	22.55
10	34.3	35	32.8	30.5
11	42.5	39.2	40.45	39
12	42	43.5	42.6	41.5
13	36.4	38.7	40.51	41.4
14	39.3	36.9	34.4	31.4
15	35.2	32.9	28.7	24.7
16	22.39	20.15	16.87	12.7
17	9.37	7.65	7.68	3.81

Appendix F – Results for Shading – Cloudy Day

	Bp Panel Output for a cloudy day					
TheTime	**VoltP1**	**CurrentP1**	**Power 1**	**TempP1**	**Pryo**	**AmbTemp**
8:12:06 AM	7.80	1.75	**13.61**	17.78	**832.45**	10.51
9:39:18 AM	13.98	3.20	**44.76**	21.97	**1305.80**	22.61
10:19:53 AM	16.11	3.70	**59.65**	24.32	**1563.51**	24.37
11:34:08 AM	2.65	0.62	1.64	22.12	285.46	24.62
11:34:09 AM	2.64	0.62	1.63	22.04	285.46	24.58
12:10:19 PM	16.29	3.98	64.89	28.94	1716.03	36.33
12:10:29 PM	16.03	3.90	62.44	29.10	1705.51	36.55
1:04:39 PM	15.68	3.68	57.66	32.52	1600.33	32.33
1:35:52 PM	4.53	1.04	4.71	21.67	385.39	22.77
2:06:37 PM	14.14	3.42	48.33	22.26	1363.65	20.51
2:22:10 PM	8.68	2.00	17.40	19.71	758.81	18.63
3:09:08 PM	0.63	2.27	1.43	20.50	879.78	17.88
3:09:09 PM	0.63	2.27	1.43	20.45	885.04	17.87
4:00:36 PM	12.87	1.79	23.09	20.64	727.26	17.05
4:00:37 PM	13.75	1.77	24.39	20.70	727.26	17.05
4:00:38 PM	14.55	1.76	25.56	20.77	732.52	17.05
4:59:53 PM	0.87	0.19	0.16	13.66	90.86	16.47
5:29:38 PM	0.06	0.01	0.00	12.22	38.27	14.92

BP Panel -Cloudy day

	Solarex Panel Output for a cloudy day					
TheTime	**VoltP2**	**CurrentP2**	**Power2**	**TempP2**	**Pryo**	**AmbTemp**
8:12:06 AM	7.04	1.43	**10.06**	18.53	**832.45**	10.51
9:39:18 AM	12.74	2.67	**34.06**	22.35	**1305.80**	22.61
10:19:53 AM	14.49	3.06	**44.30**	23.62	**1563.51**	24.37
11:34:08 AM	1.43	0.49	0.69	21.16	285.46	24.62
11:34:09 AM	1.42	0.49	0.69	21.18	285.46	24.58
12:10:19 PM	15.95	2.85	45.47	26.04	1716.03	36.33
12:10:29 PM	15.71	2.80	44.01	26.13	1705.51	36.55
1:04:39 PM	15.28	2.69	41.10	28.97	1600.33	32.33
1:35:52 PM	4.06	0.83	3.36	25.01	385.39	22.77
2:06:37 PM	9.23	2.90	26.73	27.26	1363.65	20.51
2:22:10 PM	7.87	1.61	12.68	21.63	758.81	18.63
3:09:08 PM	1.91	1.74	3.32	21.89	879.78	17.88
3:09:09 PM	1.90	1.74	3.31	21.89	885.04	17.87
4:00:36 PM	11.63	1.47	17.14	24.60	727.26	17.05
4:00:37 PM	12.29	1.46	17.98	24.68	727.26	17.05
4:00:38 PM	12.95	1.45	18.75	24.67	732.52	17.05
4:59:53 PM	0.73	0.14	0.10	14.21	90.86	16.47
5:29:38 PM	0.05	0.00	0.00	12.34	38.27	14.92

Solarex Panel – cloudy day

Appendix G – Result for Temperature Variations

TheTime	VoltPanel1	CurrentPanel1	Power	TempPanel1	VoltPanel2	CurrentPanel2	Power	Temp	Pryo	Amb Temp
10:03:15 AM	1.22929	4.928906	6.059	28.561	0.92324	3.410493	3.1487	29.68	1552.99	26.22009
10:03:16 AM	1.22992	4.932061	6.066	28.569	0.92355	3.412859	3.1519	29.82	1552.99	26.2128
10:03:17 AM	1.23071	4.933638	6.0719	28.569	0.92402	3.412859	3.1536	29.72	1558.25	26.2128
10:03:18 AM	1.23086	4.930483	6.0687	28.569	0.92402	3.41207	3.1528	29.82	1552.99	26.22009
10:03:19 AM	1.23055	4.931272	6.0682	28.561	0.92387	3.413648	3.1538	29.59	1558.25	26.20551
10:03:20 AM	1.22897	4.930483	6.0594	28.545	0.92402	3.413648	3.1543	29.78	1558.25	26.17636
10:03:21 AM	3.50752	4.972289	17.44	28.537	4.17058	3.402605	14.191	29.83	1552.99	26.1545
10:03:22 AM	6.97402	4.937582	34.435	28.514	4.65482	3.402605	15.839	29.78	1558.25	26.13992
10:03:23 AM	12.5835	4.799545	60.395	28.506	10.3293	3.36711	34.78	29.67	1558.25	26.06704
10:03:24 AM	**15.7577**	**4.305765**	**67.849**	28.506	**13.2996**	**3.224339**	**42.882**	29.76	1558.25	26.12534
10:03:25 AM	17.1577	3.576138	61.358	28.506	15.4035	2.709262	41.732	29.81	1558.25	26.08162
10:03:26 AM	17.8656	3.016889	53.898	28.506	16.0976	2.343265	37.721	29.6	1552.99	26.10348
10:03:27 AM	18.3373	2.501811	45.877	28.514	16.7638	1.899968	31.851	29.84	1558.25	25.9723
10:03:28 AM	18.2353	2.498656	45.564	28.522	16.674	1.89839	31.654	29.67	1558.25	26.0306
10:03:29 AM	18.0316	2.688754	48.482	28.537	16.3957	2.074289	34.009	29.85	1552.99	26.03789

10:10:11 AM	1.25532	4.972289	6.2418	29.539	0.93791	3.468863	3.2535	29.23	1584.55	28.91663
10:10:12 AM	1.25437	4.969923	6.2341	29.531	0.9368	3.468863	3.2496	29.14	1574.03	28.98222
10:10:13 AM	1.25406	4.970711	6.2335	29.531	0.9368	3.469652	3.2504	29.11	1574.03	28.95307
10:10:14 AM	4.98627	4.94547	24.659	29.547	1.6574	3.465708	5.7441	29.29	1574.03	28.96764
10:10:15 AM	7.74385	4.947837	38.315	29.555	5.0458	3.45151	17.416	29.31	1574.03	28.98222
10:10:16 AM	**13.2576**	**4.747485**	**62.94**	29.563	11.7817	3.367898	39.68	29.22	1574.03	28.97493
10:10:17 AM	17.1288	3.551685	60.836	29.571	**15.0487**	**2.841778**	**42.765**	29.2	1574.03	28.97493
10:10:18 AM	17.8805	2.794451	49.966	29.594	16.0668	2.343265	37.649	29.25	1574.03	28.95307
10:10:19 AM	18.2024	2.368506	43.113	29.594	16.6971	1.897601	31.684	29.27	1574.03	28.91663
10:10:20 AM	18.1168	2.373239	42.995	29.602	16.6065	1.896024	31.486	29.31	1584.55	28.94578

10:15:10 AM	1.24333	4.733287	5.8851	30.305	0.95132	3.533543	3.3615	29.86	1584.55	33.82141
10:15:11 AM	1.24286	4.730132	5.8789	30.36	0.95116	3.534332	3.3617	29.98	1589.81	33.87243
10:15:12 AM	1.24223	4.734076	5.8808	30.415	0.95132	3.537487	3.3653	29.95	1589.81	33.89429
10:15:13 AM	1.47023	4.734076	6.9602	30.462	3.64168	3.523289	12.831	30.05	1589.81	33.89429
10:15:14 AM	9.02837	4.669395	42.157	30.518	6.60423	3.515401	23.217	29.96	1589.81	33.87243
10:15:15 AM	**15.3113**	**4.129866**	**63.234**	30.557	**13.8668**	**3.184111**	**44.154**	30.07	1584.55	33.87971
10:15:16 AM	17.396	3.015311	52.454	30.604	15.6077	2.582267	40.303	30.18	1584.55	33.87243
10:15:17 AM	18.0772	2.282529	41.262	30.652	16.472	2.023018	33.323	30.23	1589.81	33.84327
10:15:18 AM	18.0302	2.190241	39.49	30.683	16.5492	1.891291	31.299	30.3	1589.81	33.8287
10:15:19 AM	16.7808	3.205408	53.789	30.731	14.9106	2.820481	42.055	30.38	1589.81	33.8287

10:17:58 AM	1.23418	4.723821	5.8301	31.03	0.95337	3.544586	3.3793	31.2	1589.81	37.41436
10:17:59 AM	1.23545	4.727765	5.8409	31.054	0.9551	3.547742	3.3885	31.36	1584.55	37.4508
10:18:00 AM	1.23576	4.723033	5.8365	31.078	0.95542	3.543009	3.3851	31.47	1589.81	37.43623
10:18:01 AM	4.34299	4.704891	20.433	31.109	3.6065	3.532755	12.741	31.29	1595.07	37.38521
10:18:02 AM	11.7325	4.578685	53.719	31.141	10.3622	3.490949	36.174	31.27	1589.81	37.36335
10:18:03 AM	**16.3173**	**3.696822**	**60.322**	31.149	**14.2307**	**3.098922**	**44.1**	31.16	1589.81	37.3342
10:18:04 AM	17.0238	3.174646	54.044	31.18	15.6426	2.541251	39.752	31.43	1589.81	37.3342
10:18:05 AM	17.7119	2.570436	45.527	31.204	16.1999	2.161845	35.022	31.47	1589.81	37.29776
10:18:06 AM	18.0464	2.173676	39.227	31.212	16.5416	1.884192	31.168	31.46	1589.81	37.29047

10:20:40 AM	1.24965	4.753006	5.9396	31.314	0.96078	3.567461	3.4276	31.32	1589.81	40.22751
10:20:41 AM	1.24965	4.751429	5.9376	31.299	0.9611	3.562728	3.4241	31.2	1595.07	40.24937
10:20:42 AM	1.24917	4.748274	5.9314	31.291	0.96031	3.564306	3.4228	31.2	1595.07	40.26395
10:20:43 AM	1.24854	4.749851	5.9304	31.283	0.96047	3.564306	3.4234	31.06	1595.07	40.21293
10:20:44 AM	6.28957	4.715145	29.656	31.259	4.92683	3.551685	17.499	31.2	1595.07	40.16192
10:20:45 AM	10.8598	4.633111	50.315	31.259	8.92112	3.532755	31.516	31.17	1595.07	40.14005
10:20:46 AM	**14.7761**	**4.259226**	**62.935**	31.259	**13.7087**	**3.224339**	**44.202**	31.15	1600.33	40.05989
10:20:47 AM	16.5641	3.51619	58.243	31.267	15.3587	2.680077	41.162	31.17	1595.07	40.02345
10:20:48 AM	17.5625	2.72346	47.831	31.251	16.2048	2.160267	35.007	31.27	1595.07	40.06718
10:20:49 AM	18.0508	2.169732	39.165	31.243	16.5211	1.882614	31.103	31.31	1595.07	40.0526
10:20:50 AM	17.9404	2.168944	38.912	31.228	16.4654	1.881826	30.985	31.27	1595.07	40.01616

Appendix H: Sample Detail Results

Attached is a sample of the detail results of the hourly tests, Sweeps were carried out at different angles. The results are quite large with the author as Raw data. Data below if for the 12pm and 2pm readings at the 4 different angles.

Readings at 2pm at angle of 36°

	Bp Panel					Solarex Panel				
TheTime	**VoltP1**	**CurrentP1**	**Power1**	**TempP1**		**VoltP2**	**CurrentP2**	**Power2**	**TempP2**	**AmbT**
2:05:00 AM	**19.73**	**3.48**	**68.66**			**19.06**	**2.77**	**52.80**		
2:05:35 PM	3.85	3.53	13.59	26.66		0.80	2.86	2.29	23.28	37.86
2:05:36 PM	3.86	3.53	13.60	26.65		0.80	2.87	2.29	23.34	37.95
2:05:37 PM	3.85	3.53	13.60	26.69		0.80	2.87	2.29	23.29	37.76
2:05:38 PM	5.74	3.51	20.10	26.70		5.12	2.85	14.60	23.30	37.90
2:05:39 PM	10.38	3.43	35.63	26.72		16.50	1.82	29.96	23.07	37.90
2:05:40 PM	15.15	3.25	**49.24**	26.73		13.63	2.68	**36.50**	23.16	37.91
2:05:41 PM	14.74	3.30	48.65	26.65		15.16	2.40	36.38	22.98	37.90
2:05:42 PM	17.40	2.55	44.32	26.83		13.23	2.74	36.22	23.11	37.90
2:05:43 PM	17.94	2.13	38.28	26.82		15.73	2.20	34.62	23.05	37.90
2:05:44 PM	17.85	2.13	38.07	26.77		16.28	1.96	31.87	23.07	37.92
2:05:45 PM	18.03	2.02	36.38	26.73		11.14	2.81	31.34	23.11	37.87
2:05:46 PM	18.31	1.80	32.93	26.79		9.33	2.75	25.62	23.07	37.87
2:05:47 PM	18.26	1.80	32.80	26.75		6.67	2.84	18.98	23.31	37.92
2:05:48 PM	18.14	1.86	33.73	26.82		16.43	1.81	29.77	23.10	37.89
2:05:49 PM	18.14	1.86	33.69	26.79		9.54	2.83	27.01	23.17	37.90

Readings at 2pm at angle of 27°

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT1
2:06:00 AM	19.7	3.38	66.59			19	2.69	51.11		
2:06:17 PM	3.183	3.47	11.03	27.3		0.781408	2.81	2.198	23	38.085
2:06:18 PM	3.1836	3.47	11.03	27.2		3.148003	2.81	8.837	23	38.07
2:06:20 PM	3.1879	3.46	11.04	27.3		4.1747	2.8	11.69	23	38.107
2:06:21 PM	7.3783	3.41	25.19	27.4		6.878794	2.79	19.19	23	38.121
2:06:22 PM	14.529	3.25	47.16	27.4		14.47481	2.49	36.08	23	38.231
2:06:23 PM	16.549	2.84	47.03	27.2		13.72076	2.61	35.81	23	38.209
2:06:24 PM	17.202	2.53	43.55	27.2		15.25837	2.3	35.16	23	38.252
2:06:25 PM	17.855	2.12	37.94	27.5		15.55864	2.2	34.16	23	38.274
2:06:30 PM	17.905	2.01	35.98	27.5		16.41084	1.81	29.63	23	38.282
2:06:29 PM	17.908	2.01	35.99	27.6		16.32312	1.83	29.87	24	38.34
2:06:28 PM	17.911	2.01	35.99	27.4		16.17289	1.94	31.43	23	38.274
2:06:27 PM	17.916	2.01	36.03	27.3		15.96132	1.99	31.79	24	38.369
2:06:26 PM	17.941	2.01	**36.1**	27.3		11.659	2.74	**31.99**	23	38.194
2:06:34 PM	18.061	1.88	33.9	27.6		8.703561	2.78	24.23	23	38.107
2:06:33 PM	18.065	1.88	33.91	27.6		10.50466	2.77	29.07	23	38.15
2:06:32 PM	18.067	1.88	33.93	27.5		16.37976	1.8	29.54	24	38.311
2:06:31 PM	18.096	1.88	33.98	27.6		16.38371	1.8	29.56	24	38.296

Readings at 2pm at angle of 22°

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT
2:07:00 AM	**19.62**	**3.20**	**62.78**			**18.92**	**2.57**	**48.62**		
2:07:08 PM	2.97	3.24	9.65	28.51		0.74	2.66	1.96	24.49	38.42
2:07:09 PM	2.99	3.25	9.71	28.43		0.74	2.66	1.96	24.52	38.47
2:07:10 PM	2.99	3.25	9.70	28.43		0.74	2.66	1.96	24.46	38.53
2:07:11 PM	9.12	3.17	28.94	28.58		9.63	2.61	25.15	24.43	38.24
2:07:12 PM	13.69	3.06	41.92	28.54		15.05	2.19	32.99	24.48	38.19
2:07:12 PM	13.69	3.06	41.92	28.54		15.05	2.19	32.99	24.48	38.19
2:07:13 PM	14.94	2.98	**44.59**	28.48		14.87	2.24	**33.38**	24.47	38.29
2:07:13 PM	14.94	2.98	44.59	28.48		14.87	2.24	33.38	24.47	38.29
2:07:14 PM	16.90	2.48	41.95	28.62		14.69	2.27	33.30	24.47	38.23
2:07:14 PM	16.90	2.48	41.95	28.62		14.69	2.27	33.30	24.47	38.23
2:07:15 PM	17.31	2.25	38.93	28.58		13.30	2.48	32.96	24.47	38.26
2:07:15 PM	17.31	2.25	38.93	28.58		13.30	2.48	32.96	24.47	38.26
2:07:16 PM	17.75	1.99	35.29	28.62		15.28	2.14	32.72	24.51	38.19
2:07:16 PM	17.75	1.99	35.29	28.62		15.28	2.14	32.72	24.51	38.19
2:07:17 PM	17.72	1.99	35.23	28.69		11.27	2.59	29.18	24.41	38.23
2:07:17 PM	17.72	1.99	35.23	28.69		11.27	2.59	29.18	24.41	38.23

Readings at 2pm at angle of 18°

	Bp Panel					Solarex Panel				
TheTime	**VoltP1**	**CP1**	**Power1**	**TP1**		**VoltP2**	**CP2**	**Power2**	**TP2**	**AmbT**
2:07:00 AM	**19.55**	**3.00**	**58.65**			**18.81**	**2.40**	**45.14**		
2:07:50 PM	1.73	3.08	5.31	28.79		0.69	2.48	1.70	24.39	39.02
2:07:51 PM	3.35	3.05	10.22	28.81		6.84	2.47	16.92	24.32	38.79
2:07:52 PM	3.34	3.05	10.19	28.73		2.80	2.49	6.96	24.47	38.68
2:07:53 PM	3.34	3.05	10.19	28.77		4.17	2.48	10.35	24.32	38.72
2:07:54 PM	3.34	3.05	10.20	28.82		5.56	2.48	13.80	24.47	38.76
2:07:55 PM	3.34	3.05	10.20	28.43		6.37	2.46	15.71	24.40	39.04
2:07:56 PM	6.55	3.02	19.75	29.07		8.02	2.47	19.80	24.41	38.81
2:07:57 PM	9.13	2.98	27.16	28.58		9.09	2.46	22.33	24.32	38.87
2:07:58 PM	12.95	2.89	37.47	28.81		14.96	2.09	31.28	24.32	38.95
2:07:59 PM	14.31	2.85	40.82	28.80		13.82	2.28	31.56	24.27	38.83
2:08:00 PM	15.34	2.76	42.36	28.78		14.47	2.19	31.73	24.32	38.91
2:08:01 PM	16.73	2.41	40.38	28.77		13.50	2.32	31.32	24.46	38.82
2:08:02 PM	17.45	2.08	36.21	28.64		12.34	2.40	29.60	24.28	38.89
2:08:03 PM	17.50	2.01	35.19	28.81		15.68	1.88	29.52	24.24	38.97
2:08:04 PM	17.57	1.97	34.58	28.87		12.12	2.41	29.21	24.42	38.88
2:08:05 PM	17.56	1.97	34.56	28.85		15.97	1.75	28.01	24.29	38.97
2:08:06 PM	17.56	1.97	34.56	28.88		15.99	1.75	28.05	24.31	38.96

Readings at 12pm at angle 36°

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT
11:45:14 AM	19.51	4.30	83.89	30.66		18.57	3.80	70.57	28.77	42.14
11:45:15 AM	4.21	4.37	18.36	30.66		0.99	3.59	3.55	28.67	42.14
11:45:16 AM	7.00	4.32	30.28	30.66		0.99	3.58	3.54	28.57	42.14
11:45:17 AM	7.00	4.33	30.29	30.66		0.99	3.58	3.56	28.76	42.14
11:45:18 AM	7.01	4.33	30.37	30.68		1.20	3.59	4.31	28.60	42.16
11:45:19 AM	7.01	4.33	30.35	30.68		1.19	3.59	4.27	28.66	42.13
11:45:20 AM	12.03	4.21	50.68	30.69		1.07	3.59	3.84	28.88	42.17
11:45:21 AM	12.01	4.21	50.63	30.69		3.60	3.58	12.89	28.88	42.21
11:45:22 AM	12.74	4.19	53.44	30.70		5.95	3.57	21.25	29.02	42.22
11:45:23 AM	14.85	3.92	**58.16**	30.71		9.08	3.54	32.16	29.03	42.23
11:45:24 AM	13.29	4.16	55.28	30.74		10.56	3.52	37.18	29.16	42.25
11:45:25 AM	15.92	3.54	56.34	30.75		14.70	2.92	**42.89**	29.07	42.25
11:45:26 AM	17.27	2.67	46.06	30.78		15.25	2.63	40.13	29.03	42.24
11:45:27 AM	17.30	2.51	43.51	30.81		16.02	2.17	34.78	29.28	42.25
11:45:28 AM	17.78	2.13	37.81	30.83		16.36	1.88	30.82	29.41	42.09
11:45:29 AM	17.84	2.01	35.84	30.86		16.40	1.81	29.68	29.38	41.96
11:45:30 AM	17.97	1.87	33.68	30.87		16.38	1.82	29.75	29.32	42.18
11:45:31 AM	17.96	1.86	33.48	30.88		16.38	1.82	29.76	29.62	42.23
11:45:32 AM	17.79	2.01	35.72	30.88		16.38	1.82	29.74	29.55	42.18
11:45:33 AM	17.82	2.01	35.79	30.87		16.38	1.82	29.74	29.55	41.93

Readings at 12pm at angle 27°

	Bp Panel					Solarex Panel				
TheTime	**VoltP1**	**CP1**	**Power1**	**TP1**		**VoltP2**	**CP2**	**Power2**	**TP2**	**AmbT**
11:46:49 AM	1.05	1.10	1.15	30.89		0.27	0.89	0.24	28.99	42.57
11:46:50 AM	1.23	1.27	1.57	30.96		0.33	1.01	0.33	28.90	42.71
11:46:51 AM	1.48	1.59	2.35	31.03		9.40	1.26	11.84	28.94	42.73
11:46:52 AM	1.75	1.67	2.92	31.09		11.54	1.28	14.76	29.07	42.81
11:46:53 AM	2.18	3.73	8.14	31.16		15.94	1.77	28.13	29.10	42.89
11:46:54 AM	2.69	2.72	7.32	31.12		14.85	1.64	24.36	29.08	42.87
11:46:55 AM	3.53	4.49	15.85	31.54		1.02	3.69	3.75	29.38	42.62
11:46:56 AM	4.09	4.47	18.30	31.59		1.01	3.67	3.71	29.37	42.92
11:46:57 AM	4.09	4.48	18.33	31.57		1.01	3.68	3.73	29.29	42.86
11:46:58 AM	12.99	4.30	**55.89**	31.50		1.02	3.69	3.77	29.32	42.58
11:46:59 AM	13.76	4.02	55.37	31.20		16.36	1.81	29.67	29.00	42.92
11:47:00 AM	17.68	2.50	44.21	31.46		5.51	3.68	20.28	29.26	42.71
11:47:01 AM	17.98	1.65	29.69	31.24		16.31	1.81	29.46	29.14	42.92
11:47:02 AM	18.24	1.72	31.30	31.42		10.84	3.63	39.34	29.22	42.82
11:47:03 AM	18.35	1.41	25.90	31.35		14.84	2.93	**43.51**	29.23	42.81
11:47:04 AM	18.36	1.41	25.93	31.31		15.95	2.33	37.17	29.18	42.84
11:47:05 AM	18.36	1.41	25.91	31.27		16.34	1.98	32.33	28.98	42.89
11:47:06 AM	18.45	1.38	25.42	31.39		13.66	3.32	45.38	29.18	42.84
11:47:07 AM	19.51	4.20	81.94	31.61		18.62	3.36	62.56	29.45	42.98

Readings at 12pm at angle 22°

	Bp Panel					Solarex Panel				
TheTime	**VoltP1**	**CP1**	**Power1**	**TP1**		**VoltP2**	**CP2**	**Power2**	**TP2**	**AmbT**
11:49:15 AM	19.49	3.50	68.22			18.84	3.20	60.29	26.02	38.94
11:49:16 AM	3.36	4.22	14.18	28.71		0.95	3.46	3.28	25.95	38.97
11:49:17 AM	3.35	4.22	14.16	28.66		0.95	3.45	3.28	25.88	39.00
11:49:18 AM	3.36	4.22	14.17	28.55		0.95	3.46	3.28	25.82	38.98
11:49:19 AM	5.13	4.20	21.55	28.74		0.95	3.45	3.29	25.91	39.00
11:49:20 AM	12.70	4.04	**51.36**	28.66		3.47	3.45	11.95	25.93	39.02
11:49:21 AM	17.09	2.98	50.96	28.64		7.97	3.40	27.10	25.78	38.97
11:49:22 AM	17.85	2.33	41.61	28.63		13.27	3.21	**42.55**	25.93	39.00
11:49:23 AM	18.09	2.04	36.93	28.64		15.52	2.61	40.57	25.85	39.00
11:49:24 AM	18.17	1.93	35.09	28.64		16.28	2.16	35.14	25.78	39.06
11:49:25 AM	18.02	2.04	36.69	28.72		16.70	1.84	30.65	25.89	39.11
11:49:26 AM	18.04	2.04	36.76	28.62		16.64	1.83	30.52	25.88	39.12
11:49:27 AM	17.89	2.15	38.55	28.70		16.63	1.83	30.48	25.74	39.10
11:49:28 AM	17.75	2.28	40.53	28.66		16.63	1.83	30.48	25.77	39.12
11:49:29 AM	4.18	4.19	17.52	28.57		16.59	1.86	30.88	25.87	39.12
11:49:30 AM	2.84	4.23	11.99	28.61		16.59	1.86	30.88	25.78	39.17
11:49:31 AM	2.86	4.23	12.08	28.58		16.43	1.97	32.34	25.77	39.17
11:49:32 AM	2.88	4.23	12.17	28.59		10.50	3.39	35.62	25.70	39.03
11:49:33 AM	2.84	4.23	12.00	28.58		0.94	3.45	3.24	25.79	39.08
11:49:34 AM	2.82	4.24	11.96	28.59		0.95	3.46	3.29	25.80	39.05
11:49:35 AM	2.77	4.11	11.38	28.56		0.94	3.35	3.17	25.77	39.10

Readings at 12pm at angle 18°

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT
11:49:56 AM	19.62	4.30	84.37	29.09		18.29	3.60	65.84	26.08	38.81
11:49:57 AM	2.70	4.00	10.83	29.03		0.90	3.28	2.96	26.08	38.94
11:49:58 AM	2.71	4.01	10.87	28.98		0.90	3.29	2.96	26.08	39.07
11:49:59 AM	2.68	4.02	10.78	29.11		0.90	3.29	2.97	26.13	39.13
11:50:00 AM	2.68	4.02	10.78	29.32		0.90	3.29	2.98	26.15	39.19
11:50:01 AM	2.70	4.01	10.83	29.26		0.90	3.29	2.98	26.17	39.20
11:50:02 AM	2.72	4.02	10.96	29.38		0.90	3.30	2.98	26.22	39.19
11:50:03 AM	6.42	3.99	25.58	29.31		0.91	3.31	3.00	26.13	39.21
11:50:04 AM	11.09	3.90	43.26	29.45		1.47	3.31	4.88	26.25	39.19
11:50:05 AM	17.24	2.75	**47.46**	29.34		6.42	3.30	21.15	26.15	39.21
11:50:06 AM	17.89	2.15	38.39	29.24		12.12	3.21	38.85	26.41	39.24
11:50:07 AM	17.78	2.14	38.12	29.41		14.51	2.86	**41.46**	26.38	39.21
11:50:08 AM	17.78	2.14	38.13	27.72		14.45	2.86	41.32	26.42	39.19
11:50:09 AM	17.93	2.03	36.36	27.79		15.88	2.31	36.69	26.53	39.22
11:50:10 AM	18.18	1.80	32.70	29.26		16.00	2.18	34.89	26.49	39.28
11:50:11 AM	18.11	1.80	32.52	29.71		16.54	1.82	30.12	26.53	39.28
11:50:12 AM	18.16	1.78	32.26	29.74		16.50	1.82	30.08	26.72	39.29
11:50:13 AM	17.86	2.02	36.10	29.70		16.50	1.82	30.07	26.75	39.31
11:50:14 AM	17.90	2.02	36.22	29.63		16.50	1.82	30.05	26.82	39.27
11:50:15 AM	17.89	2.02	36.21	29.99		16.49	1.82	30.00	26.90	39.37

Appendix I: Matlab script for IV curves

1993 Aging Data

```
% plot IV Characteristic Curve for 1993 Data
% Measurements done on April 1993
% Incline angle was 45 deg with changes in temperature
% define values for 25deg Celcius at an angle 45deg North Direction
x= [2.15    12.07   15.7    16.47   17.32   17.92   18.44   18.88
19.29   19.64   19.73];
%define i
y =[4.2 4   3.75    3.5 3   2.5 2   1.5 1   0.5 0.394];
%Define P
figure(1)
subplot(221);
plot(x,y);
xlabel('Voltage(V)');
ylabel('Current(A)');
title('North at 25Deg C');
Grid on;

%define values for 26Deg Celcius at an angle 45deg North East Direction
BV1=[2.39   11.24   14.6    15.55   16.19   16.73   17.44   18  18.45
18.86   19.23   19.54   19.52];
BI1=[4.6    4.5 4.25    4   3.75    3.5 3   2.5 2   1.5 1   0.5 0.391];
p1=[5.28804 12.5625 14.9184 17.9944 24.585  28.6016     39.6864 43.344
45.39   45.3176 44.0153 42.9856 41.1099 ];

subplot(222);
plot(BV1,BI1);
xlabel('Voltage(V)');
ylabel('Current(A)');
title('North East at 26Deg C');
Grid on;

%define values for 22 Deg
B1=[1.9 13.9    16.25   17.23   17.88   18.4    18.86   19.27   19.35];
I1=[3.75    3.5 3   2.5 2   1.5 1   0.5 0.387];

Subplot(223);
plot(B1,I1);
xlabel('Current(I)');
ylabel('Power(A)');
title('North West at 30 Deg C');
Grid on;
```

2011 Aging data

```
% plot characteristic curve at 45 deg angle with different directions
and temperature.
% Measurements done on 27th August
%Figure 1 - Tests done on North 25deg
% define v
x= [0.00000 1.214303    1.219982    1.219351    4.220078    10.51659
15.47588    17.8578 18.37773    18.47021    18.45000 18.42856 18.42856
];
%define i
y =[4.722244    4.726188    4.722244    4.707257    4.630745    4.236352
3.800000 3.595767   3.094712    2.599882    2.299093 1.00000 0.00000];
%Define P
figure(1)
subplot(221);
plot(x,y);
xlabel('Voltage(V)');
ylabel('Current(A)');
title('North at 25°c ');
Grid on;

%Figure 2 - Tests done on North East 26deg
% define v
x1= [0.00000 0.284957   1.299494    1.30186 1.302333    3.556743
10.32802    12.4462 17.14854    18.41211    18.50792    18.4475  ];
%define i
y1 =[5.079564   5.092973    5.094551    5.083508    4.995164    4.876057
3.753615    2.611453    2.306192    2.305404 0.00000];
%Define P
subplot(222);
plot(x,y);
xlabel('Voltage(V)');
ylabel('Current(A)');
title('NE at 26°c ');
Grid on;

%Figure 3 - Tests done on North East 30Deg NW
% define v
x2= [0.00000 1.085876   1.085088    1.084614    1.291784    10.60338
14.92034    17.09555    18.19974    18.03425    18.02842  ];
%define i
y2 =[4.416195   4.41304 4.409885    4.416984    4.319963    4.183503
3.409704    2.525475    2.50891 2.523897 0.00000];
%Define P
subplot(223);
plot(x,y);
xlabel('Voltage(V)');
ylabel('Current(A)');
title('NW at 30°c');
Grid on;
```

Characteristic IV Curve for 10am, 12pm and 2pm

```
% plot characteristic curve at North direction with changes in angle
% Measurements done on 24th August
%%%Variations with angles 36, 27,22,18
% define v
x= [0.0000 0.6969   0.6931 0.6941  0.6991  1.2378  4.1229  7.6342
9.8106  12.5618 13.9686 13.4449];
%define i
y =[0.7704  0.7712  0.7720  0.7791  0.7759  0.7602  0.7057  0.6710
0.6340  0.5914  0.5953 0.0000];
%Define P
figure(1)
subplot(221);
plot(x,y);
xlabel('Voltage(V)');
ylabel('Current(A)');
title('North at 36Deg');
Grid on;

%define values for 27 Deg
BV1=[0.0000 3.3749  3.3840  5.9535  8.1271  16.6369     17.1849 17.8324
18.1873 18.1900 18.1974 18.1009 19.9100];
BI1=[3.7134 3.7221  3.6984  3.6700  3.6000 3.0185       2.7022  2.2896
1.9031  1.9457  1.9449  1.9347   0.0000];
p1=[5.28804 12.5625 14.9184 17.9944 24.585  28.6016     39.6864 43.344
45.39   45.3176 44.0153 42.9856 41.1099 ];

subplot(222);
plot(BV1,BI1);
xlabel('Voltage(V)');
ylabel('Current(A)');
title('North at 27Deg');
Grid on;
%define values for 22 Deg
B1=[0.0000  1.9952  5.6397  8.8883  12.5991 14.1760 16.3725 16.4203
16.4127 17.2236 17.6695 17.9768 17.9300 17.9311 19.4700];
I1=[ 3.7400 3.5509  3.5044  3.4641  3.3892  3.3411  2.9104  2.9096
2.9088  2.5610  2.2683  2.0333  2.0325  2.0333   0.0000];
p1=[5.28804 12.5625 14.9184 17.9944 24.585  28.6016 33.9876 39.6864
43.344  45.39   45.3176 44.0153 42.9856 41.1099 39.3625 37.4595 35.7552
34.64   33.7754];

Subplot(223);
plot(B1,I1);
xlabel('Current(I)');
ylabel('Power(A)');
title('NORTH AT 22 DEG');
Grid on;
%define values for 18 Deg
v1=[0.0000 3.0574   3.6441  10.2405 9.3025  13.5230 14.8491 16.4925
17.0232 17.6737 17.6647 17.6551 17.6526 19.9200];
```

```
i1=[3.3800 3.3576   3.3482  3.2732  3.2811  3.1865  3.1108  2.7668
2.5349  2.1745  2.1350  2.1342  2.1334   0.0000];
p1=[5.28804 12.5625 14.9184 17.9944 24.585  28.6016 33.9876 39.6864
43.344  45.39   45.3176 44.0153 42.9856 41.1099 39.3625 37.4595 35.7552
34.64   33.7754];
%Plot P- I curves
Subplot(224);
plot(v1,i1);
xlabel('Voltage (v))');
ylabel('Current(A)');
title('NORTH AT 18 DEG');
Grid on;
```

Appendix J Results for Both Bp and Solarex IV data

Readings taken at angle of 18 deg

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT
10:09:52 AM	19.92	3.38	67.33	31.12		19.02	3.02	57.44		
10:09:53 AM	3.06	3.36	10.27	31.12		0.77	2.78	2.15	30.52	40.07
10:09:54 AM	3.64	3.35	12.20	31.16		2.00	2.78	5.55	30.63	40.07
10:09:55 AM	10.24	3.27	33.52	31.17		3.86	2.77	10.67	30.83	40.10
10:09:56 AM	9.30	3.28	30.52	31.23		6.41	2.76	17.68	30.87	40.13
10:09:57 AM	13.52	3.19	43.09	31.03		8.96	2.74	24.56	31.04	40.16
10:09:58 AM	**14.85**	**3.11**	**46.19**	**29.22**		12.74	2.65	33.77	31.06	40.18
10:09:59 AM	16.49	2.77	45.63	29.25		14.36	2.45	**35.12**	31.07	40.16
10:10:00 AM	17.02	2.53	43.15	29.28		15.28	2.21	33.74	31.01	40.19
10:10:01 AM	17.67	2.17	38.43	29.30		15.96	1.94	30.91	31.17	40.20
10:10:02 AM	17.66	2.14	37.71	29.33		16.20	1.80	29.14	31.24	40.19
10:10:03 AM	17.66	2.13	37.68	29.35		16.17	1.80	29.09	31.27	40.25
10:10:04 AM	17.65	2.13	37.66	29.37		16.17	1.80	29.05	31.25	40.27
10:10:05 AM	17.65	2.13	37.64	29.40		16.16	1.80	29.04	31.16	40.29
10:10:06 AM	17.65	2.13	37.62	29.41		16.16	1.80	29.02	31.40	40.26

Readings taken at angle of 22 deg

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT
	19.47	3.74	72.82			19.11	3.06	58.48		
10:10:20 AM	1.99	3.55	7.08	29.39		0.81	2.92	2.37	31.40	40.53
10:10:21 AM	1.99	3.55	7.08	29.36		0.81	2.92	2.37	31.42	40.53
10:10:22 AM	2.00	3.55	7.08	29.33		0.81	2.92	2.37	31.49	40.56
10:10:23 AM	5.64	3.50	19.76	29.30		0.98	2.91	2.84	31.38	40.60
10:10:24 AM	8.89	3.46	30.79	29.27		4.55	2.91	13.22	31.58	40.62
10:10:25 AM	12.60	3.39	42.70	29.24		9.42	2.88	27.18	31.62	40.64
10:10:26 AM	14.18	3.34	47.36	29.21		11.91	2.83	33.75	31.41	40.67
10:10:27 AM	17.08	2.67	45.64	29.18		13.69	2.69	**36.79**	31.27	40.69
10:10:28 AM	16.37	2.91	47.65	29.17		15.05	2.40	36.20	31.61	40.72
10:10:29 AM	16.42	2.91	**47.78**	29.14		15.42	2.27	34.94	31.60	40.73
10:10:30 AM	16.41	2.91	47.74	29.13		15.39	2.27	34.87	31.61	40.75
10:10:31 AM	17.22	2.56	44.11	29.11		15.69	2.15	33.74	31.34	40.77
10:10:32 AM	17.67	2.27	40.08	29.09		16.11	1.95	31.47	31.52	40.79
10:10:33 AM	17.98	2.03	36.55	29.08		16.35	1.81	29.63	31.24	40.82
10:10:34 AM	17.93	2.03	36.44	29.07		16.32	1.81	29.57	31.46	40.84

Table :Readings taken at angle of 27 deg

	Bp Panel					Solarex Panel				
TheTime	**VoltP1**	**CP1**	**Power1**	**TP1**		**VoltP2**	**CP2**	**Power2**	**TP2**	**AmbT**
	19.91	3.60	71.68			19.03	2.90	55.19		
10:10:44 AM	3.37	3.71	12.53	28.81		0.85	3.06	2.61	31.37	40.95
10:10:45 AM	3.38	3.72	12.54	28.80		0.85	3.06	2.61	31.08	40.97
10:10:46 AM	3.38	3.72	12.57	28.77		0.85	3.06	2.61	31.01	40.97
10:10:47 AM	3.38	3.72	12.57	28.75		0.85	3.06	2.62	31.01	40.96
10:10:48 AM	3.38	3.72	12.60	28.71		0.85	3.06	2.62	30.97	40.98
10:10:49 AM	5.95	3.70	22.02	28.67		3.67	3.06	11.24	30.93	41.00
10:10:50 AM	8.13	3.67	29.83	28.65		6.26	3.05	19.08	30.89	41.03
10:10:51 AM	16.64	3.02	**50.22**	28.61		9.40	3.03	28.50	30.84	41.03
10:10:52 AM	16.75	2.92	48.89	28.55		13.93	2.79	**38.93**	30.80	41.04
10:10:53 AM	17.18	2.70	46.44	28.51		14.76	2.61	38.58	30.57	41.07
10:10:54 AM	17.83	2.29	40.83	28.45		15.81	2.24	35.48	30.98	41.09
10:10:55 AM	17.69	2.33	41.25	28.40		16.02	2.11	33.88	30.63	41.09
10:10:56 AM	18.19	1.90	34.61	28.37		16.33	1.84	30.07	30.59	41.09
10:10:57 AM	18.07	1.93	34.95	28.32		16.36	1.82	29.71	30.60	41.12
10:10:58 AM	18.16	1.94	35.28	28.28		16.46	1.83	30.11	30.48	41.05
10:10:59 AM	18.19	1.95	35.39	28.23		16.50	1.83	30.23	30.40	41.12
10:11:00 AM	18.20	1.94	35.39	28.18		16.51	1.83	30.23	30.38	41.05

Table :Readings taken at angle of 36 deg

	Bp Panel					Solarex Panel				
TheTime	VoltP1	CP1	Power1	TP1		VoltP2	CP2	Power2	TP2	AmbT
	19.95	**3.51**	70.02			**19.11**	**2.80**	53.51		
10:11:19 AM	5.92	3.68	21.80	29.39		2.35	3.05	7.17	30.06	41.09
10:11:20 AM	12.85	3.62	46.51	29.44		5.48	3.08	16.88	30.07	41.09
10:11:21 AM	12.85	3.61	46.39	29.31		8.68	3.05	26.50	30.18	41.10
10:11:22 AM	16.67	3.02	50.37	29.36		11.09	3.03	33.66	29.85	41.09
10:11:23 AM	17.44	2.59	45.10	29.43		14.43	2.67	**38.51**	29.87	41.08
10:11:24 AM	17.45	2.53	44.20	29.48		15.02	2.56	38.40	30.09	41.09
10:11:25 AM	17.99	2.16	38.88	29.27		16.04	2.14	34.29	29.97	41.05
10:11:26 AM	17.91	2.16	38.65	29.42		16.11	2.05	33.03	29.73	40.96
10:11:27 AM	18.06	2.04	36.87	29.35		16.50	1.83	30.11	30.00	41.01
10:11:28 AM	18.04	2.04	36.80	29.40		16.45	1.82	29.99	29.93	41.04
10:11:29 AM	18.03	2.04	36.77	29.23		16.44	1.82	29.95	30.00	41.04
10:11:30 AM	18.03	2.04	36.78	29.39		16.45	1.82	29.97	29.82	41.07
10:11:31 AM	18.03	2.04	36.78	29.29		16.45	1.82	29.98	29.95	41.07
10:11:32 AM	18.05	2.04	36.84	29.39		16.46	1.83	30.05	29.78	41.07
10:11:33 AM	18.05	2.04	36.84	29.34		16.46	1.82	30.00	29.93	41.04
10:11:34 AM	18.05	2.04	36.82	29.37		16.46	1.82	30.01	29.70	40.96
10:11:35 AM	18.05	2.04	36.82	29.36		16.47	1.82	30.03	29.75	40.96

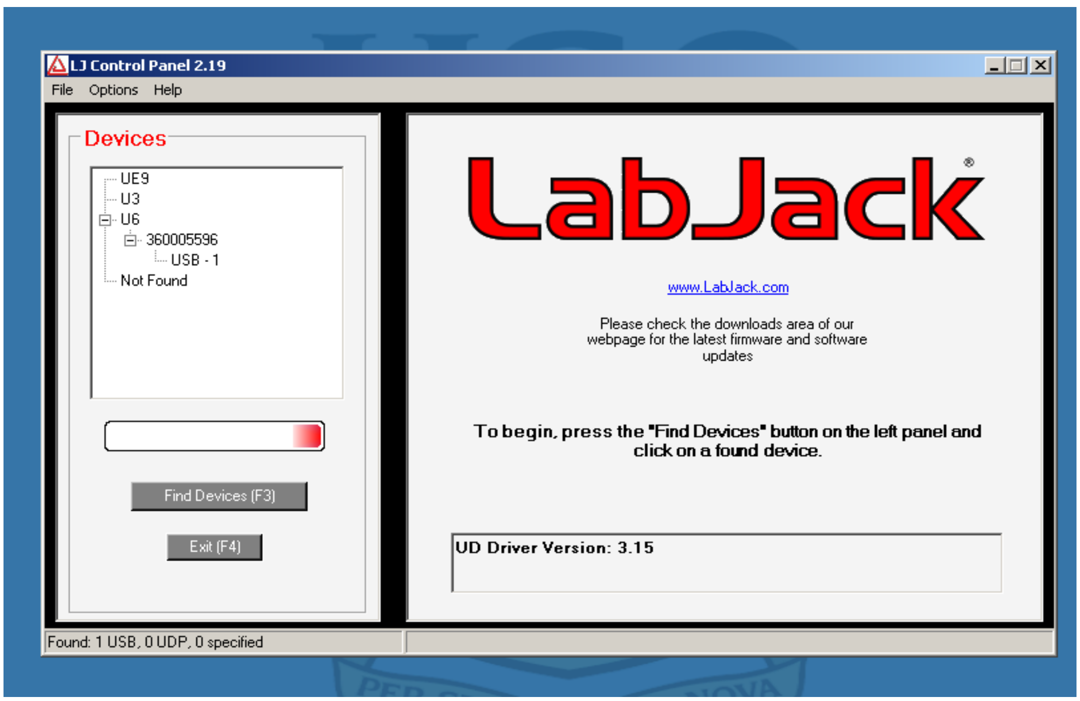
Appendix K Brief Procedure for Data Logger Setup

1.0Procedure for Data Logger Settup

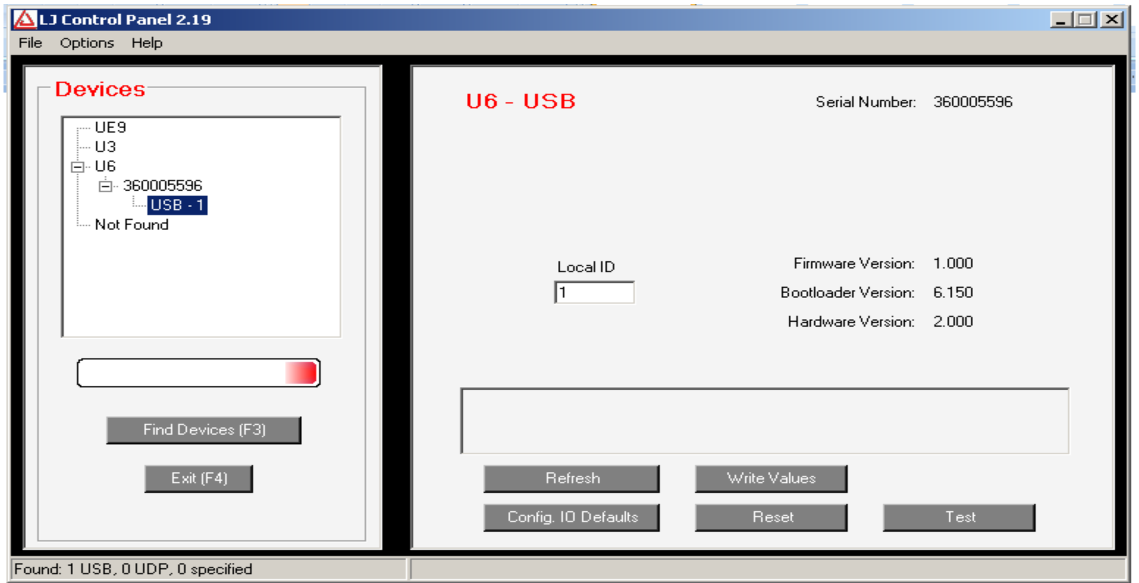
Once the data logger is connected to the laptop via a usb cable,it is then ready to start with the configuration setup. Below is brief summary of the procedures used for configuration of the data logger before the readings are taken.

1.1LabJack Control Panel Initialisation

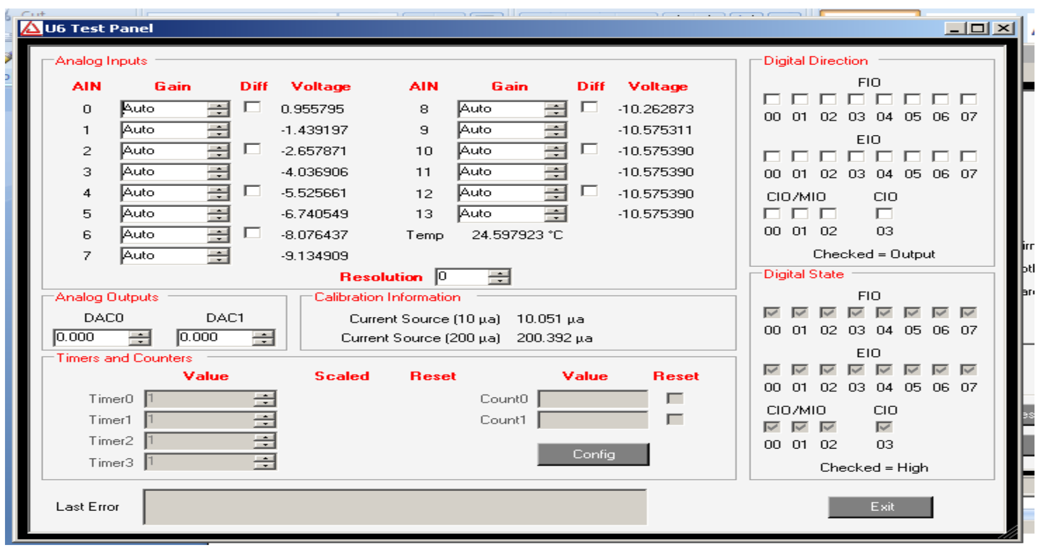
The figure below shows a screen shot of the LabJack software being initialised. It can be assessed from the drive that it was installed into for e.g start/My Programs/ LJ Control Panel 2.19. This is first initialised to test the labjack and the voltage divider if it is working to design.



1.2 Pressing the Find Devices button will do a search for availble devices, USB-1 under U6- will be highlighted to confirm that it is communicating with the data logger and its ready for test.



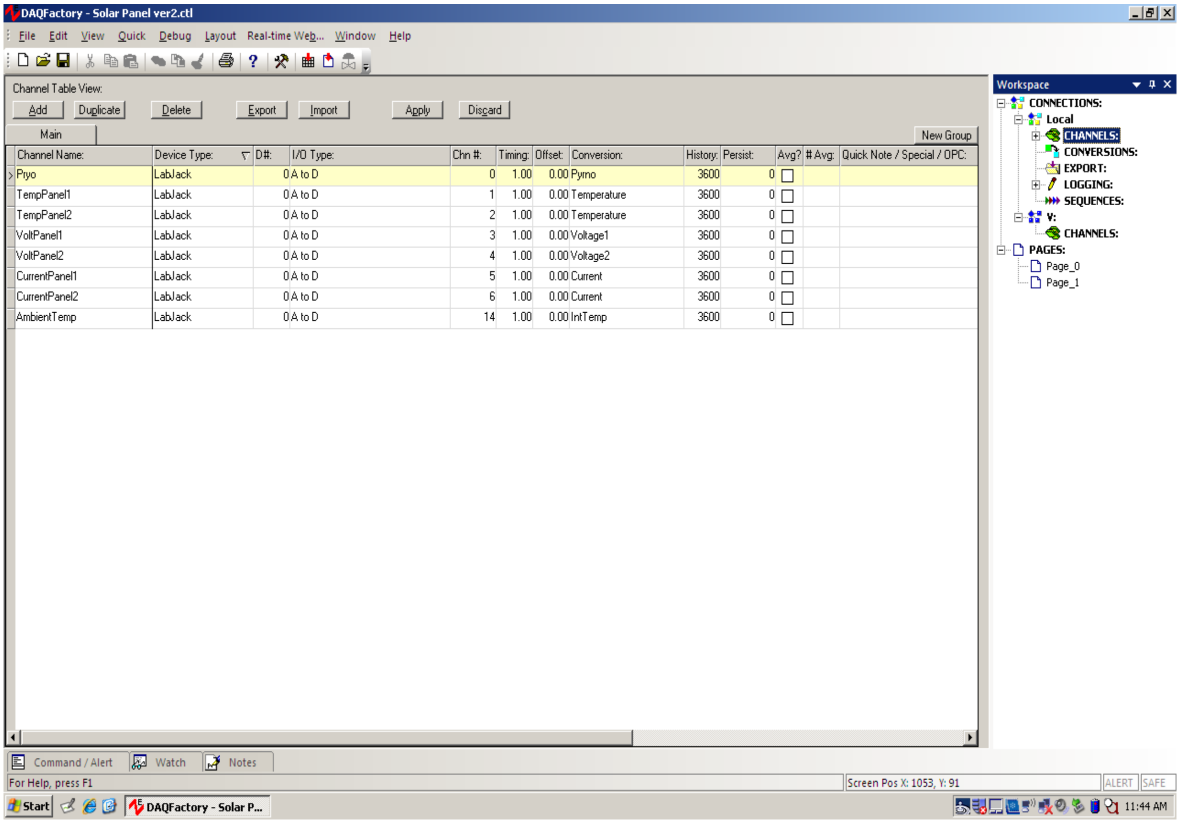
1.3After pressing the find devices button, the figure above will appear, showing the different channels selected.



1.4 The data logger is tested by connecting the voltage divider circuit to two variable loads and while varying the dual power supply with known voltages

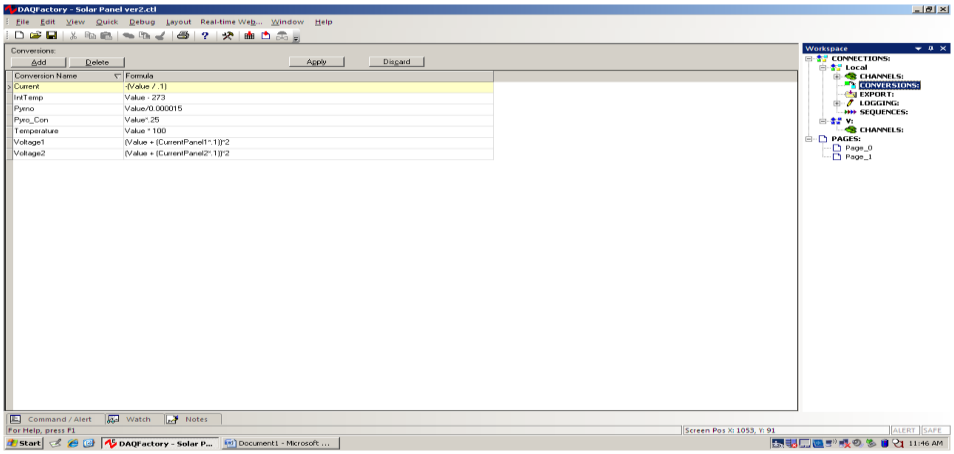
The values are checked with the figure above to confirm any differences.

1.5 The figure below shows channel that have been created. A new channel can easily be added by clicking on the add button and filling the necessary details.



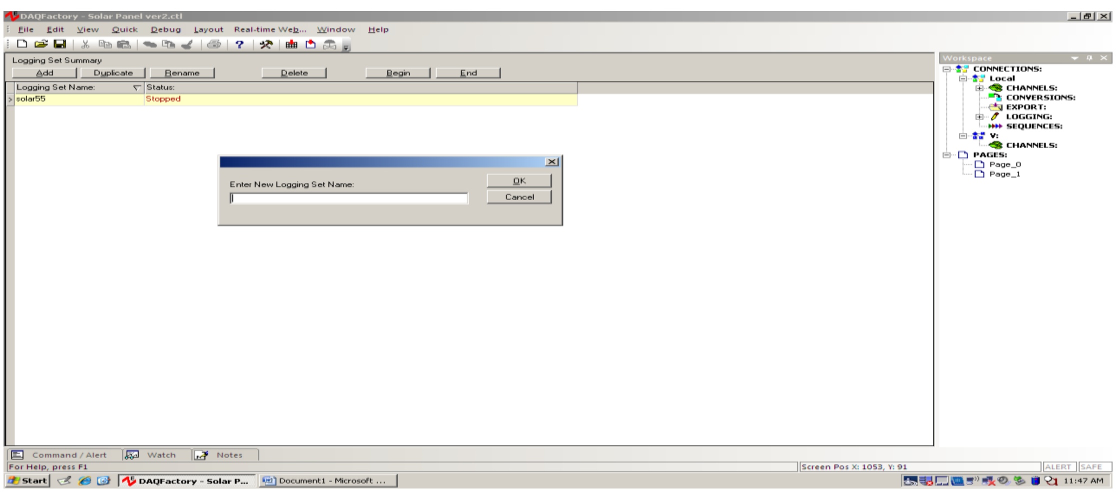
1.6 Conversion Table

A conversion table is also used to input conversion formulas as shown on the figure below.These would provide output electrical values .



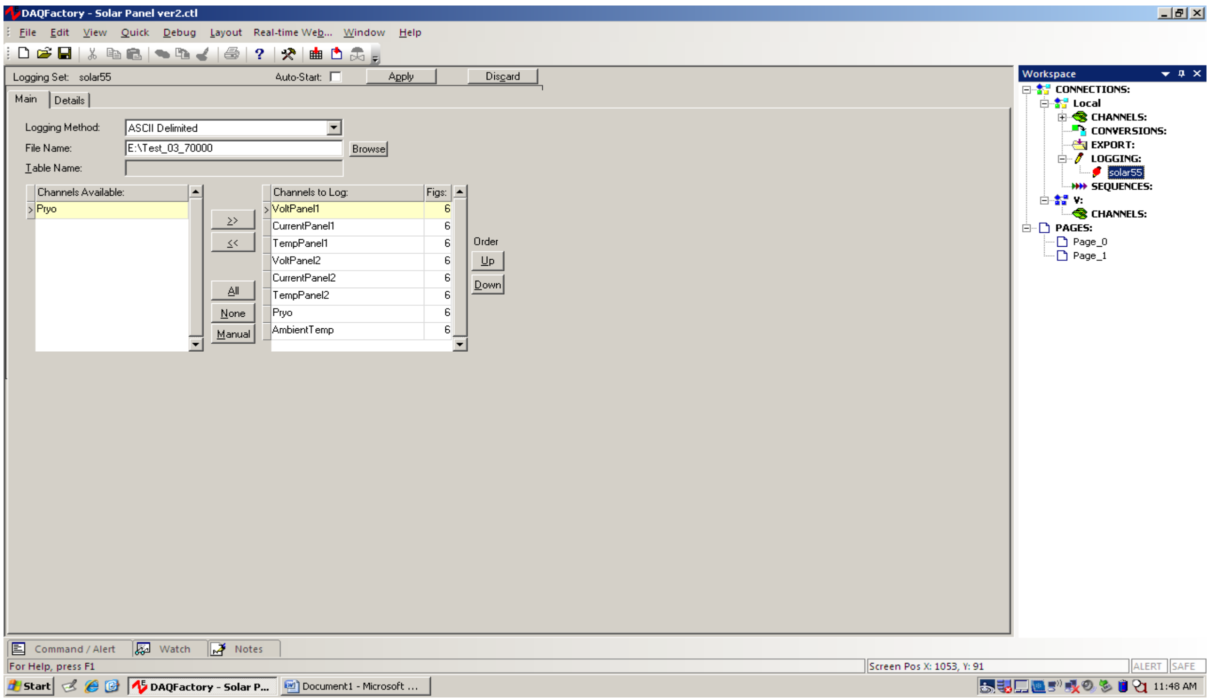
1.7. Creation of Folder Name and File Name

A folder name and file will need to be created before a file name is given.



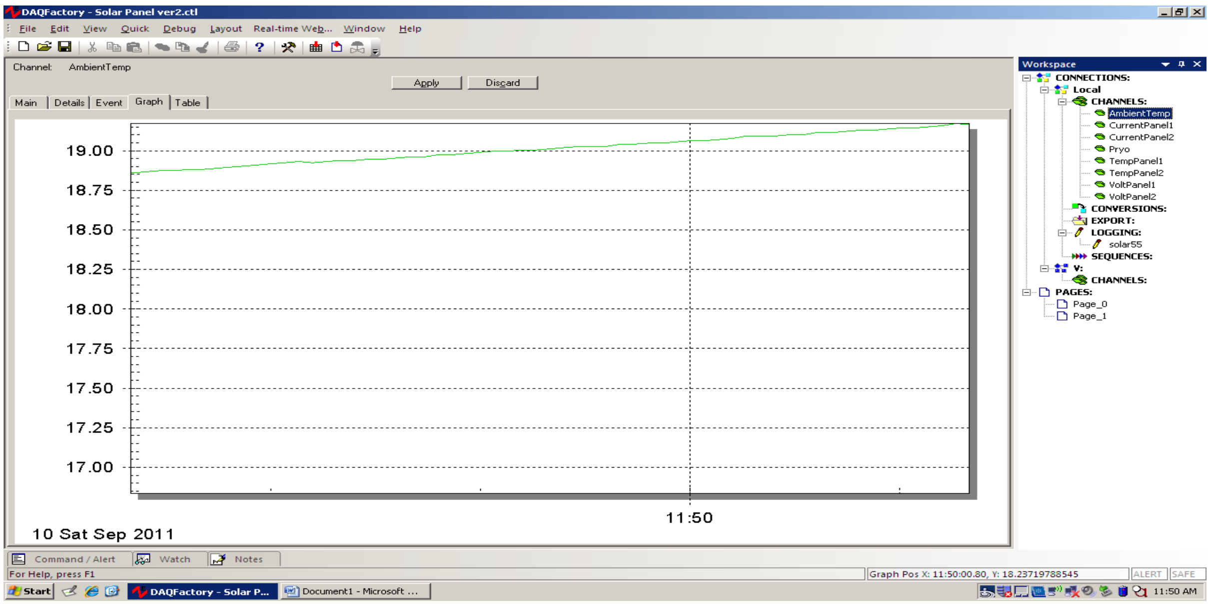
1.8. Begin Testing

Once the file name is created, right clicking on the red logging icon will allow the user to click the begin logging button to start the logging data. The data file can be retrieved opening the file in the excel spreadsheet.



1.9 Display View of Results

Clicking on a channel will allow the user to view the results while the test are in progress. The advantage is to detect errors before the test is carried out. The figure below shows a graph of the ambient temperature of a module.



Appendix L – Comparison of Panel Manufacturer Standards

Hyundai Vs. Typical Solar Panel

All panels are not created equal. Hyundai Solar Power Panels are manufactured in a fully automated facility. This ensures that there is no room for Human error, therefore all product is manufactured with precision to ensure that your Hyundai Solar Power Panel is the best in Australia, because you deserve it! Find the photo's below noting some of the major points of difference between an automated manufacture and a human assembly line.

Please note: The 'Typical' 180w Solar Panel is manufactured in China by one of China's largest Solar Panel manufacturers distributing to Australia. Take a look at the difference for yourself!

HYUNDAI Hyundai MF220w Solar Power

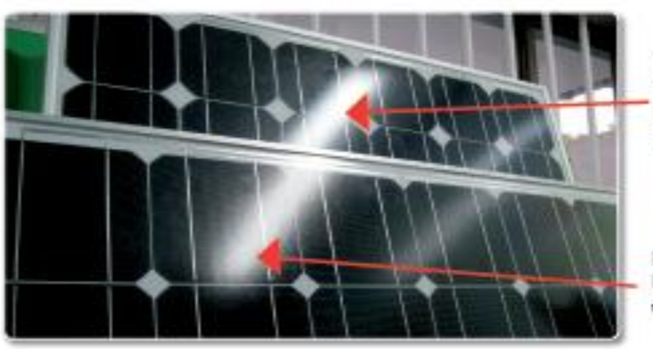
Note these straight cuts, automated manufacture, perfect every time

Typical 180w Solar Panel

Note these angled cuts, cut by human hands, certainly not precise, where else is there human error?

Note these Soldered joins are flat and large, covering the entire join, these are uniform on every join and will not burn out

Note these Soldered joins have minimal coverage and barely cover the entire join, this will create hot spots, potentially breaking the joint



Typical 180w Solar Panel—note how bright light is reflected off the glass cover of this panel, this means less sunlight shining through, therefore less electricity generated.

Hyundai MF220w Solar Panel—note how little light is reflected, this means more sunlight turned into electricity for you.