BUILDING INTEGRATED PHOTOVOLTAIC SOLAR CELLS FOR SMALL ROOF TILES

A THESIS STUDY SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
ALI TARBOUSH

In Partial Fulfillment of the Requirement for the Degree of Master of Science in Architecture

NICOSIA, 2019

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Approval of Director of Graduate School of

Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Architecture

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I am thankful for your support of me until I reached this scientific stage, and I extend my thanks and gratitude to my supervisor Assist. Prof. Dr. Lida Ebrahimi Vafaei for helping and encouraging me from the beginning of my Master's degree until the completion of the Master's thesis. I also thank my Co-supervisor Assist. Prof. Dr. Kozan Uzunoğlu for helping me to finish this thesis.

I also extend my thanks to my father and mother, who have been a source of happiness and success throughout my life and a reason for my academic success, as well as my brothers and sisters who I derive my strength from them to continue to achieve success

To my parents...

ABSTRACT

This era is undergoing a series of technological and architectural developments. It is worth mentioning that the most important of these developments are photovoltaic cells (PV), which is the most important technology for renewable energy. PV cells are a distinctive group of electricity production directly from the sun without any environmental pollution or noise, In order to increase the importance of these cells and expand their spread in the world, and the so-called building integration photovoltaic has been manufactured. The benefit of these systems is the generating electricity while also serving as construction material.

BIPV technology is used with common architectural materials such as glass and metal. It is worth mentioning that the roofs of buildings are the common place for installation of solar cells in most countries of the world and many residential buildings have a red sloping roof, but also using solar systems on the roof is have been limited because of the effect on the aesthetics of the building, so homeowner don't need a negatively effect on their building's design. Therefore, this research aims at designing and constructing the photovoltaic roof tile in order to benefit from solar energy without infringing on architectural design. The goal is to implantation of solar cells within the existing roof tiles or replace conventional roofing tiles with tiles that integrate photovoltaic (PV) cells and be connected together. This will allow a roof that is structurally modified to produce electricity for the occupants of the building.

Keywords: Building integrated; photovoltaic; solar Cells; solar architecture; solar radiation; south face

ÖZET

Bu çağ bir dizi teknolojik ve mimari gelişmelerden geçiyor. Bu gelişmelerden en önemlisinin yenilenebilir enerji için en önemli teknolojisi olan fotovoltaik hücreler (PV) olduğunu belirtmekte fayda var. PV hücreleri ayırt edici bir elektrik üretim grubudur ve herhangi bir çevre kirliliği ya da gürültüsü olmadan doğrudan güneş ışığından elektrik üretirler. Böylece fatovoltaik hücrelerin önemini arttırıp dünyaya yayılmasını sağlar. Sözde bina entegrasyonu fatovoltaik üretildi. Binanın geleneksel malzemeleri yerine fatoelektrik elemanlarının kullanılması bu sistemin yararınadır.

BIPV teknolojisi, cam ve metal gibi ortak mimari malzemelerle kullanılır. Binaların çatılarının dünyanın birçok ülkesinde güneş hücreleri montajı için ortak yer olduğunu belirtmekte fayda var ve birçok konut binalarının eğimli çatıları vardır. Ancak bu evlerin sahiplerinin çoğu binanın estetiğini korumak için çatılara güneş paneli döşemek istemiyor.

Bu nedenle, bu araştırma, çatının şeklini ve tasarımını değiştirmeden elektrik üreten binalar elde etmek için fotovoltaik kiremit tasarlamayı ve inşa etmeyi amaçlamaktadır. Amaç, güneş pillerinin mevcut çatı kiremitlerine yerleştirilmesi veya geleneksel çatı kiremitlerinin fotovoltaik (PV) hücreleri birleştiren ve birbirine bağlanan kiremitlerle değiştirilmesidir. Bina sakinleri yapısal olarak değiştirilmiş çatıdan elektirik üretebileceklerdir.

Anahtar Kelimeler: Bina entegre; fotovoltaik; güneş hücreleri; güneş mimarisi; güneş radyasyonu; güney yüzü

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LIST OF ABBREVIATIONS

PV: Photovoltaic

BIPV: Building Integrated Photovoltaic

BAPV: Building Applied Photovoltaic

Whr: Watt Hour

DC: Direct Current

AC: Alternating Current

V: Voltage

I: Current

Voc: Open Circuit Voltage

Isc: Short Circuit Current

P: Power

$\boldsymbol{V_{max}}$**:** Maximum System Voltage

$\boldsymbol{P_{max}}$**:** Maximum System Power

STC: Standard Test Condition

mA: Millie Ampere

Psc: Power Per Unite Area

Esc: Energy Per Unite Area

$\mathbf{E_m}$**:** Energy of Meteorological Data

$\boldsymbol{\Delta t}$**:** Time Interval in Seconds

η_{T}**:** Theoretical Efficiency

η_{p}**:** Practical Efficiency

CHAPTER 1
INTRODUCTION

Solar energy can be harnessed using solar cells which are PV devices that produce electrical energy from solar radiation without pollution or noise, making them long lasting, robust and reliable. Solar cells are made from semiconducting material. Light shining on a solar cell raises the electrons into higher energy states and this energy can be dissipated in an external circuit as electric energy (Nyaga, 2016).

Solar energy is a clean source of renewable energy, which has gained widespread popularity around the world. There are three main areas of the building for the application of integrated photovoltaic systems: flat and curved roof, facades and Pitched roofs, the previous application types are divided into different photovoltaic products, an annotation will be included with pictures of each of these products.

A flat and curved roof (continuous roof) is characterized by a layer with a main function to be Water Insulator. Membranes are used to isolate water. In the first type of applications, the Photovoltaic system was placed on the roof top, self-bearing and lightweight systems represent the second generation types of photovoltaic systems.

solar floors, Flexible membranes and different solutions can be used for integrating solar systems in the building casing, PV membranes, metal panels and solar glazing is a Categories within this application.

Facades increase the requirements regarding energy efficiency in buildings results in a growing of photovoltaic systems in the facades segment. Photovoltaic systems are an alternative to conventional materials in most conventional facades as curtain walls or cold facade, either transparent or opaque. Moreover, Transparent solar facades that have a basic climate-related function such as reducing summer temperatures and permitting solar gains in winter, as well as enhancing comfort due to increased natural light, These solar applications include cold facades, warm facades, accessories and solar glazing.

The pitched roof is used all over the world and consists of angel and sloping parts. It is called the discontinuous because it consists of multiple parts such as ceiling tiles and panels. At the same time, these small elements must retain the main physical building characteristics such as water tightness.

These ceilings are very suitable for solar systems because of their easy installation, ease of control of the tilt and the direction of the roof towards the sun. Over the past several years, good solutions have been developed for solar systems. They have started from the first generation with BAPV systems and then developed to the second generation where these solar systems were replaced with conventional materials. Categories within this application area include in-roof mounting systems, solar glazing, full roof solutions, small tiles, large tiles and metal panels (Jelle et al., 2012).

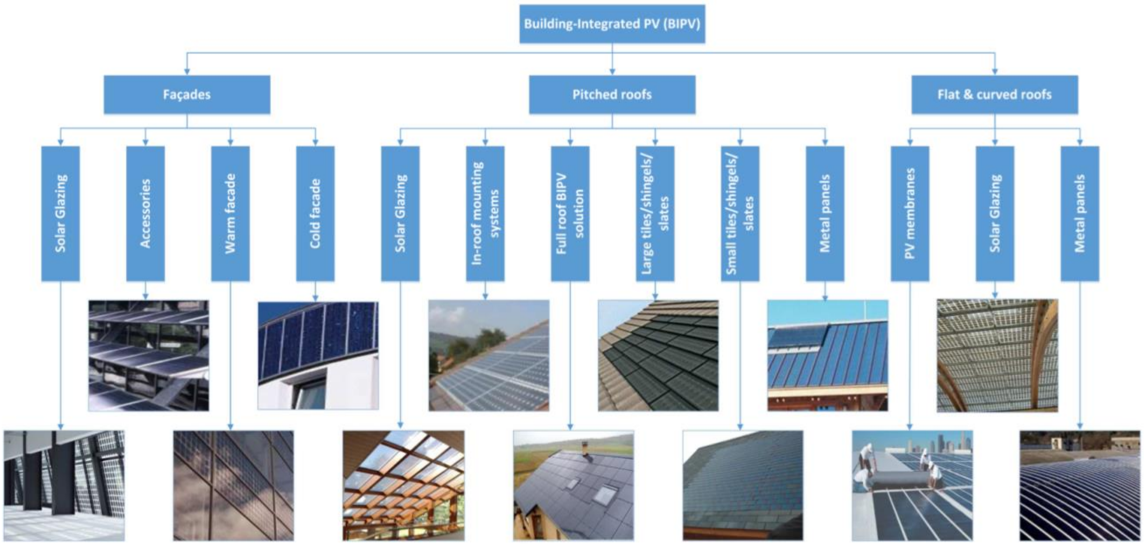

Figure 1.1: The bipv Segmentation (Frontini et al., 2015)

Solar cells have been used extensively on roofs to gain direct exposure to solar radiation but have been limited because of the increased cost of installation and the aesthetic capture of buildings, The use of glass containers for solar cells increases the temperature of solar cells, which leads to the decline of the efficiency of the solar system, and this system of cells does not contain insulation materials for the roof of buildings (Corrales, 2008). It is also difficult to remove large solar panels in order to replace or repair the ceiling beneath it, because of the way solar panels are connected by wires passing through the channels under the thresholds, so that the owners of houses to pay the cost and a large installation time for the roof and insulation of buildings, so many owners of buildings avoided installation of such systems.

In order to solve the problems of the solar systems above, it is possible to use solar roof tiles as they turn solar radiation into high efficiency electrical energy and it gives an attractive form of buildings and form an insulating layer to prevent the leakage of rain to the basic roof materials and can be installed on the roofs of unfinished buildings to form a roof Full of building.

This research deals with small solar panels. These systems are characterized by the size of small solar cells that are proportional to their height and width with the roof tiles where they merge with it and become a solar element. Normally only part or the whole roof is used for this solar system, and the same construction method is used for the traditional ceiling tile.

Figure 1.2: Small Sized Solar Tile (Frontini et al., 2015)

Figure 1.3: Big solar panels on the building’s roof in Northern Cyprus

1.1 Aim and Scope of the Study

The main objective of this project is to replace conventional roofing tile with tile that integrate photovoltaic (PV) cells and be connected together, and come up with the cost per Whr generated from it. The following are the design objectives that need to consider in making the solar integrated roofing tile:

1- The tiles should be Appropriate to install easily like a standard tiles, although the electrical connections may need a certified electrician to be done by him.
2- The power generated by the tiles will be harnessed and pass through a storage system, either batteries, the national grid or other air compression storage systems.
3- The system must be strong and provide more energy than required, so If the tile fails it will operate at a proportional level of efficiency

1.2 Methodology

This research was based on qualitative and quantitative methodologies. Initially, the qualitative methodology relied on data collection from previous research, articles, books, and Internet resources in the field of solar systems, this method provides a wide range of data that is difficult to obtain by quantitative methodology.

The first step of the research was to provide sufficient information about the sun and the climate and its relationship with the solar systems in addition to a detailed explanation of the parts and components of the solar systems and the function of each of them in order to enable the reader to understand the integrated solar system, which is the basis of this research.

In the second step of this research we began using the quantitative methodology to conduct the experiment of merging solar cells with roof tiles to obtain the daily energy data produced by these cells and compare them with meteorological data in order to reach the end result of this research.

CHAPTER 2
THE SUN AND CLIMATE

2.1 The Sun

2.1.1 Solar radiation

Solar radiation is the amount of solar rays falling on a given area and capable of generating electrical power. Solar radiation reaches the Earth's surface through direct solar radiation or by diffuse sky radiation.

50% of solar radiation is reflected in space, the earth absorbs the remaining part and re-radiated it as thermal infrared (Kocagöz, 2010).

2.1.2 Relation of solar radiation with ground

The energy obtained from sunlight that hits the earth's surface is called insolation. The amount of energy reaching the Earth from sun rays is subject to climatic conditions like a seasonal temperatures, the angle where the solar radiation hits the earth and cloudy conditions. The axis of the sun is approximately 23.5 degrees and the Earth orbits around it in an oval. The angle of the solar ray changes continuously during rotation. when the Earth's axis is tilted towards the Sun, the angle is + 23.5 on 21-22 June and when the Earth's axis moves away from the sun, the angle is -23.5 degrees on December 21-22, this so-called winter summer equinox, is 0 degrees. (Gevorkian, 2008).

The declination angle was shown in Figure 2.1.

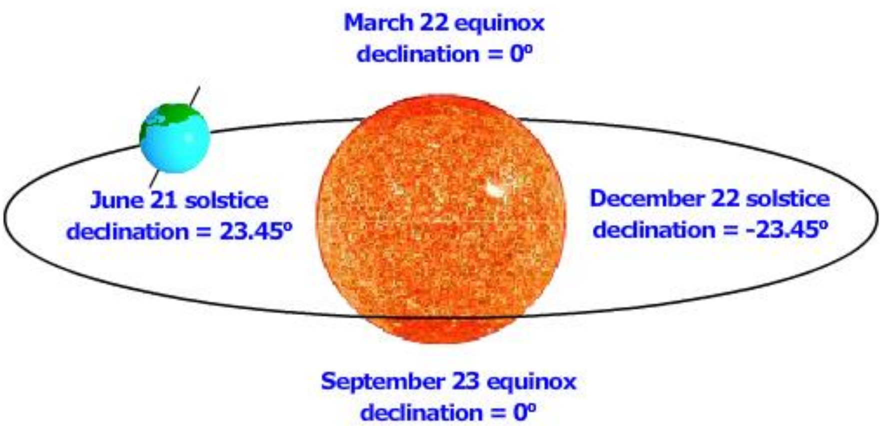

Figure 2.1: The Declination Angle (Gevorkian, 2008)

If we consider the Earth a 360 degree sphere within 24 hours it means that it rotates 15 degrees every hour and this so-called hour angle and is the rotation of the Earth daily gives the idea of sunrise and sunset, meaning that one hour after noon (12 o'clock in solar time) the point of departure has deviated at a 15 degree angle from noon.

Solar hour angle was shown in Figure 2.2.

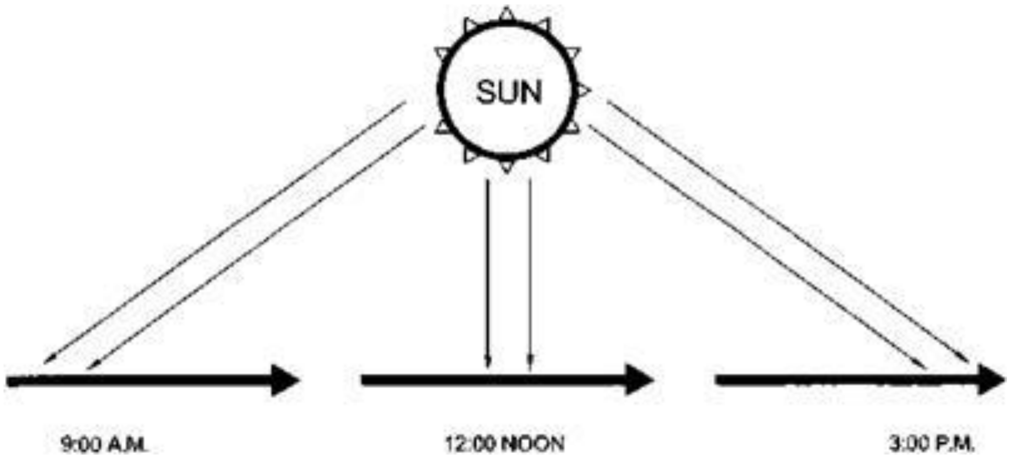

Figure 2.2: Solar hour angle (Gevorkian, 2008)

Figure 2.3 shows how the earth rotates revolves the sun. By determining the movement of the sun during the day and over the seasons we can see how the building benefits from natural energy and the effectiveness of solar equipment.

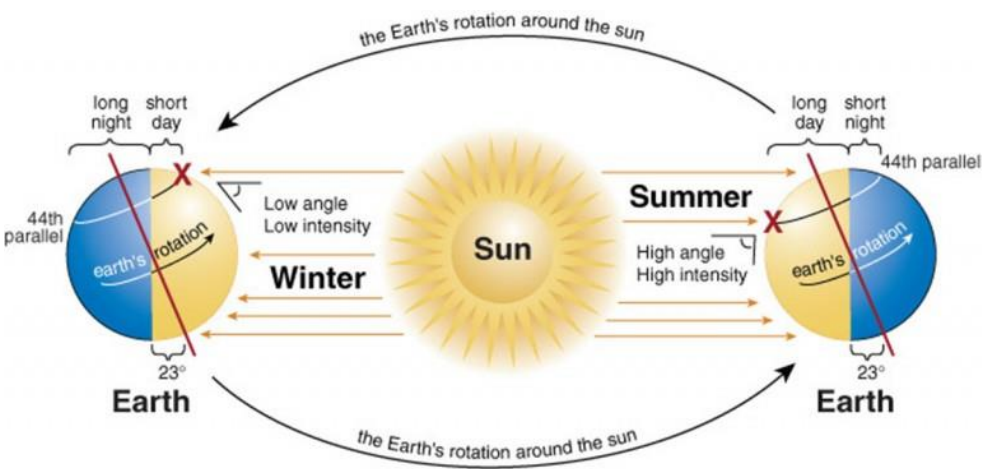

Figure 2.3: Earth’s rotation around the sun (National Weather Service, n.d.)

2.1.3 The sun angles

The sun rises early in the summer months compared to the winter, and its height changes over the horizon during the year. Designers consider directing the building to the sun to benefit greatly from the sun rays.

The northern hemisphere leads to the sun to receive the Earth's more sun and heat because the sun's path is higher in the sky. On the day of the summer solstice 21 June the northern hemisphere will be more towards the sun. This is the first day of summer. This is the longest day of the year, because the sun stays in the sky for extra hours, as these extra hours give the sun a longer time to warm the earth and supply it with heat.

The earth continues to rotate around the sun and reaches a side slant for the sun. This is called autumnal equinox, where the night and day are equal in length and hours by 12 hours each.

As the earth continues to rotate around the sun, it reaches the other side of the sun, leading to the Arctic's deviation from the sun. The path of the sun becomes low, reducing heat and light emissions. The day becomes shorter than night, and these days become colder than others and the winter season begins.

The earth continues to turn towards the summer to reach and pass at another point, its orbit sideways tilted towards the sun and equated once again with the night and day, and this is called the spring equinox (McHenry, 2008). Seasonal configuration of earth and sun was shown in Figure 2.5.

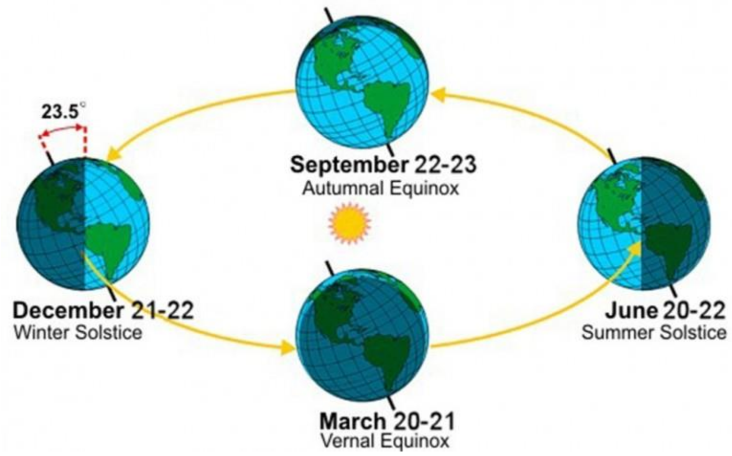

Figure 2.4: Seasonal configuration of Earth and Sun (National Weather Service, n.d.)

2.2 Climate

2.2.1 Climate sensitive buildings

Energy-efficient and climate-sensitive buildings benefit from natural energy such as heat, breezes and light to maintain comfortable conditions that require heating, cooling and lighting less than normal buildings, In order to use heat and breeze in the design of energy-saving buildings the Orientation of the buildings must be observed (Ochoa et al., 2005). The sun's movement in three season was shown in Figure 2.3.

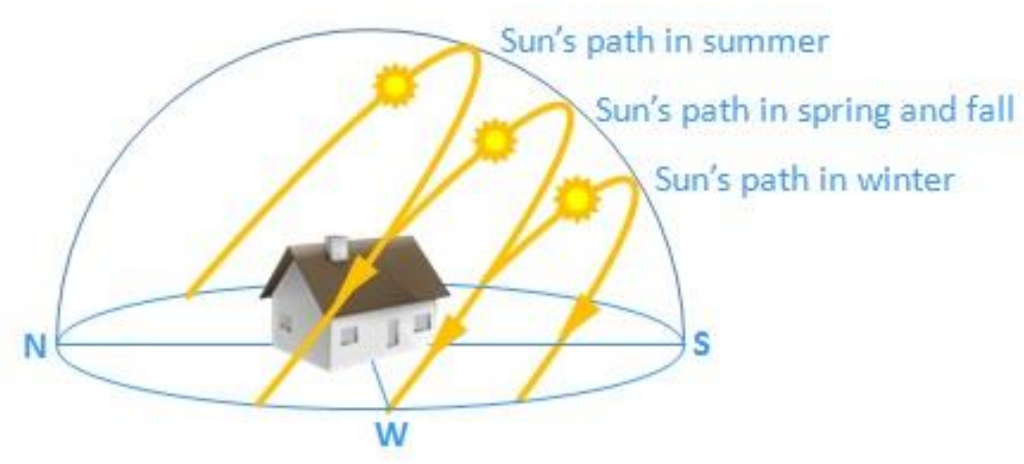

Figure 2.5: Sun's movement in three season

2.2.2 The climate effects on solar energy

Desert cities

More than one-third of the earth's surface and 25 percent of the world's population live in the same environmental conditions. The desert environment is low in water and natural resources and is classified under extreme climatic conditions due to high temperatures. It is abundant in energy from sunlight and light. A clear and abundant sky is attributed to the great daytime swing of the heat.

It is necessary to promote the desert cities to stay in harmony with nature and to maintain population growth and urban expansion. The natural resources of these cities must be exploited to move to modern cities where new technologies are integrated in construction, transport and infrastructure, Desert cities have a chance to be a model for solving environmental problems of our time.

The type of climates

- **Mixed-Humid**

This climate receives more than 20 inches of precipitation per year, approximately 5,400 heating degrees days or less and the average temperature in winter months falls below 45 ° F.

- **Hot Humid**

And this climate is the area that receives more than 20 inches of rainfall each year and occurs one of both cases:

1- The temperature of 67°F or higher for 3000 hours or more during the last six months of the year.

2- The temperature of 73°F or higher for 1500 hours or more for the last six months of the year.

- **Hot-Dry**

This climate is defined as an area that is exposed to less than 20 inches of annual rainfall, with a monthly average of 45°F over the year.

- **Mixed-Dry**

It is defined as the area that receives less than 20 inches of rain annually and has 50 degrees Fahrenheit or less and the average temperature during winter months less than 45°F

- **Marin**

The sea climate is characterized by the average temperature of the coldest month between 27°F and 65°F and the warmer months above 72°F, and more than four months of the year the temperature is more than 50°F, the dry season in the summer and the cold season is October through March in the northern hemisphere and April through September in the southern hemisphere.

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2.2.3 Cyprus climate

The following map Figure 2.5., obtained by NASA on January 30, 2001, shows three distinct geological areas in Cyprus. In the western and central parts of the island is the trudos mountain range with the surface layer mostly composed of basalt rocks, a mountain range on the north-eastern fringes of the island forms a fine arch called the Kyrenia Group formed of limestone. The capital city of Nicosia lies between these two mountain ranges, Cyprus land is on the latitude of 34°-35°North and Longitude of 32°-34° east.

Figure 2.6: The map of Cyprus was acquired by NASA's Terra satellite on January 30, 2001 (Nasa, 2001)

The summer season in Cyprus runs between mid-May and mid-September. This season is somewhat variable and rainy, while winter runs from mid-November to mid-March.

The bright sky and the extreme sun rates are significant differences in daily temperatures between the sea and the inner part of the city, which lead to great local effects especially near the coast. The summer season in Cyprus is a high season with clear skies and low rainfall, Thunderstorms sometimes occur and are accompanied by rain that accounts for approximately 15% of the annual rainfall (Department of Meteorology, 2018).

In the winter, Cyprus is located near the track of small depressions that cross the Mediterranean Sea from west to east between the continental region of Eurasia and the low pressure belt in North Africa (Department of Meteorology, 2018). Figure 2.7 shows the average min and max temperatures in a year in North Cyprus.

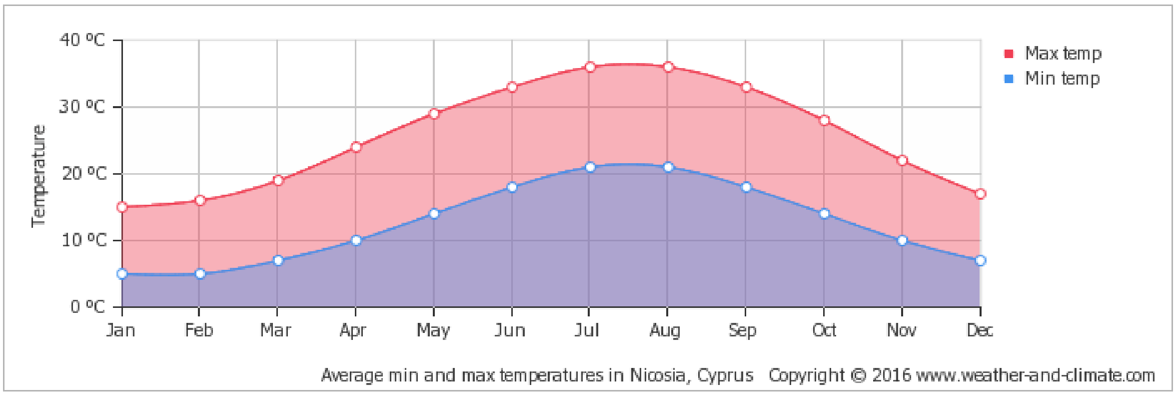

Figure 2.7: Average min and max temperatures in a year (nearest weather station, 2016)

CHAPTER 3
HOW THE SOLAR SYSTEM WORKS

3.1 Solar Cells

3.1.1 Definition of solar cell

Is a semiconductor photovoltaic device that converts solar energy into direct electrical energy. The solar cell is a source of electricity that gets electrical energy from light .

3.1.2 What is the solar cells

The solar cell is a solid-state electrical device that converts solar or photovoltaic energy into electricity. Light energy is transferred by photons, electrical energy is stored in the electromagnetic fields, which form the flow current of electrons.

Solar cells combine with each other to form solar modules which are used to capture energy from the sun. When a group of modules is grouped together and all oriented in one plane is referred as a solar panel. Photovoltaic is the field of technology and research related to the practical application of light photovoltaic to produce electricity from light, and is often referred to as solar photovoltaic, not if it depends on a source of light other than the sun called photovoltaic cells. It is also used to detect light or other electromagnetic radiation near the visible range, for example infrared detectors or light intensity measurements.
Figure 3.1 shows the solar panel diagram.

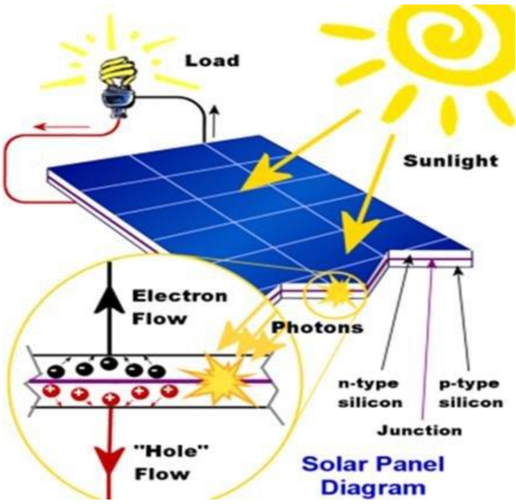

Figure 3.1: Solar panel diagram (SOFFAR, 2015)

3.1.3 Solar cells structure

How solar cell systems work

The solar cell is an electronic device that converts solar energy into electricity. The light on the solar cell produces both voltage and current to generate electricity. This process requires:

1. A material in which the absorption of light by raising the electron to a higher energy state.

2. The movement of this electron from the photovoltaic cell to an external circuit, then the electron wastes its energy in the external circuit and returns to the solar cell. There is a variety of materials that can meet the requirements of photovoltaic power conversion but in fact each photovoltaic power transform uses semiconductor materials (Hu & White, 1983). Solar cell structure was shown in Figure 3.2.

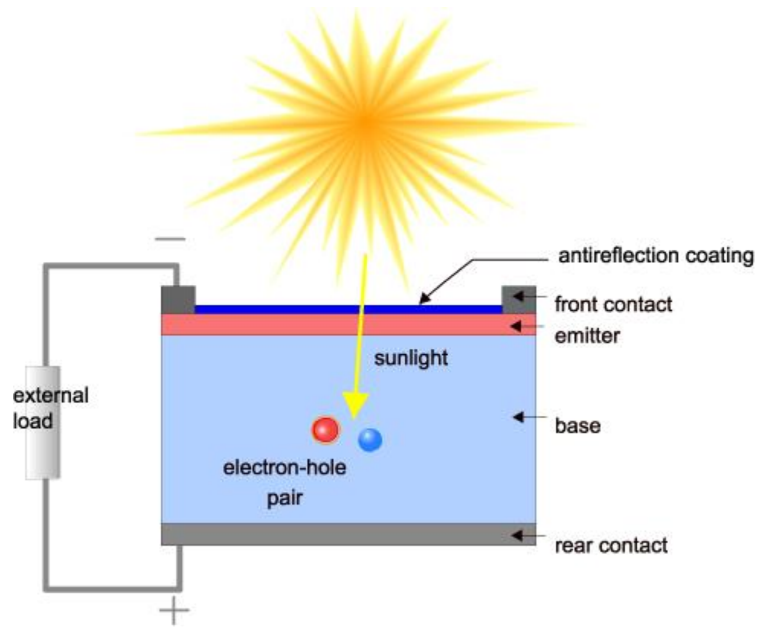

Figure 3.2: Solar cell structure (PV Education, 2013)

The light enters the semiconductor and produces an electron and a hole. It is a negatively charged particle and another positively charged particle. Both are free to move and spread through semiconductors to eventually encounter an energy barrier that allows the passage of particles charged from one sign and reflects other particles. Positive charges are collected at the upper and negative contact at the bottom contact. The electric currents caused by the aforementioned charging group flow through metal wires to reach the electric load shown on the right side of Figure 3.3 (Hu & White, 1983).

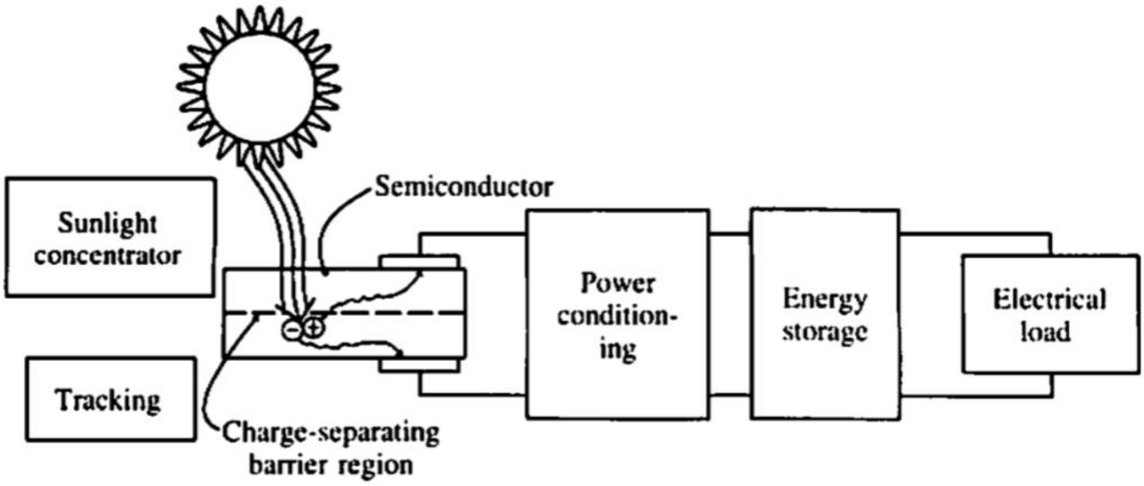

Figure 3.3: functional elements of solar cell system (Hu & White, 1983)

3.2 Method of operation of solar power generation system

Solar system components for electric power generation is PV photovoltaics, Charger Controllers, batteries and Power Inverters as shown in Figure 3.4.

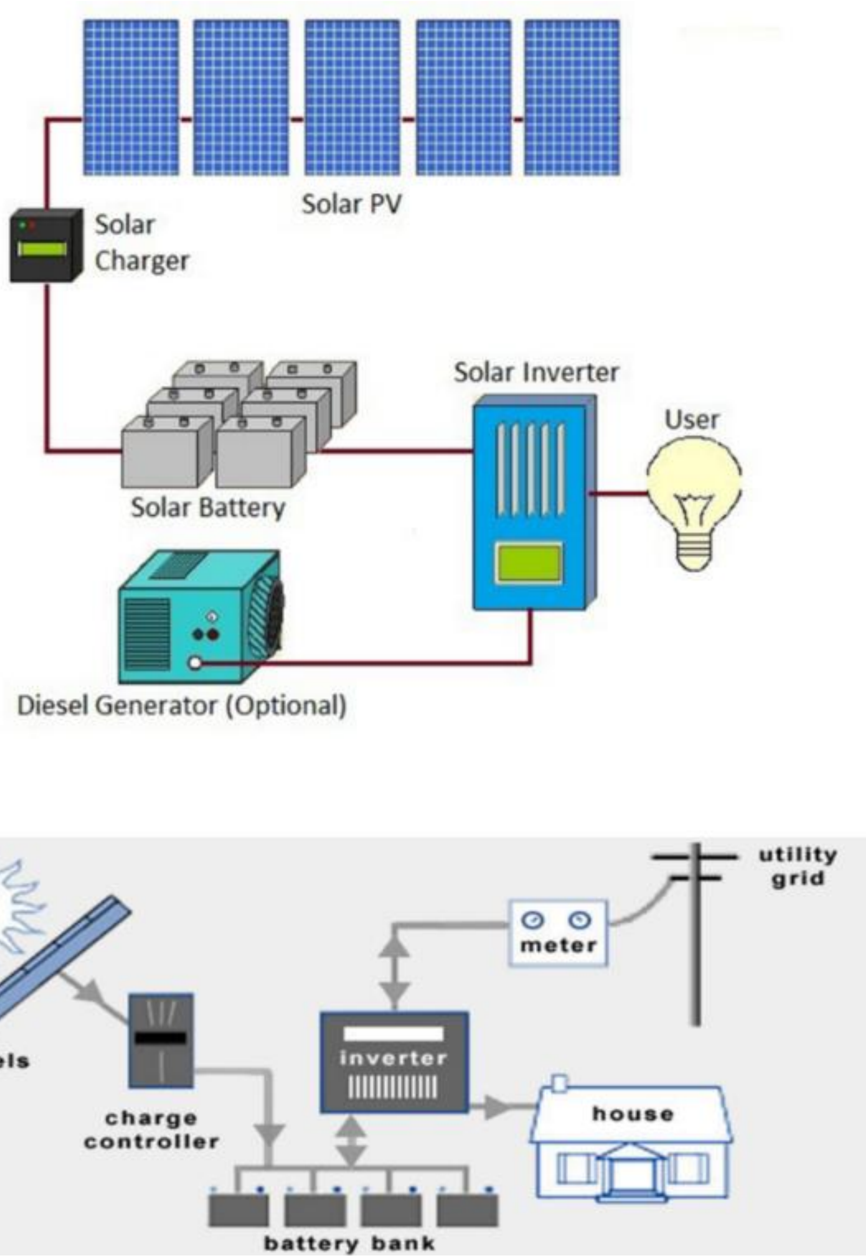

Figure 3.4: Components of the solar power system (Maehlum, 2013)

3.2.1 PV photovoltaic

The apparent part of the solar system, which is installed on the roof of the building, generates electric power, The performance of the solar modules, which are exposed to different temperatures and different environments, depends on the behavior of the current and voltages, short circuit current, open circuit voltage and the maximum power and efficiency of photovoltaic module (Hussein., et al, 2004). The solar panels consist of solar cells, solar module and solar array as shown in Figure 3.5.

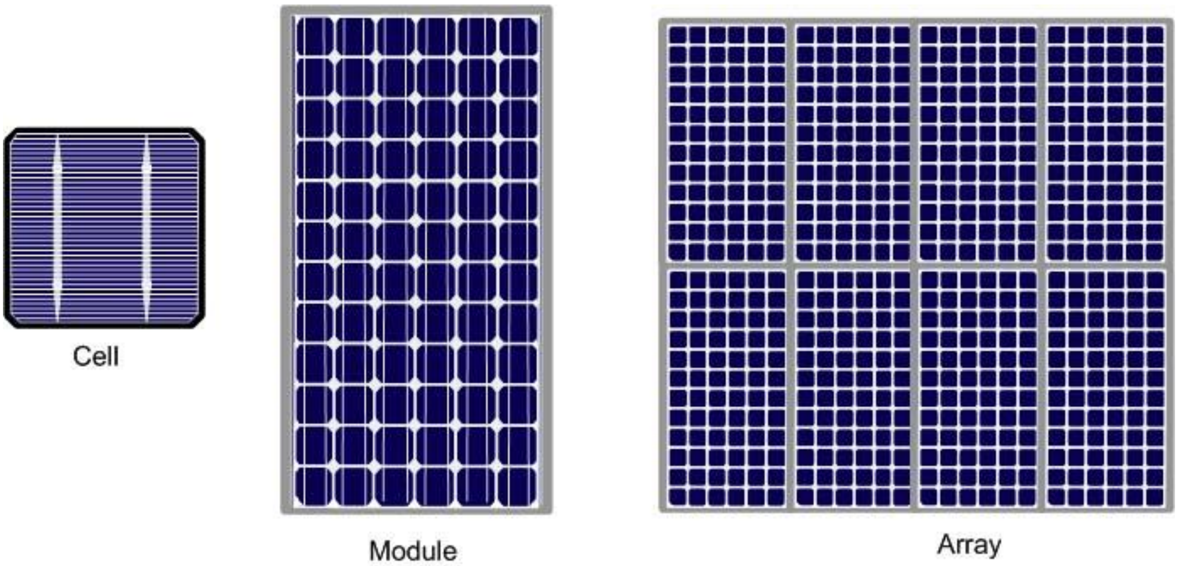

Figure 3.5: Components of solar panels in the solar system (Agriculture and Natural, 2011)

Solar Cells:

Is the main component of the solar system and is the smallest part of it. Responds to direct and indirect solar radiation, converted to electrical energy .the dimensions of one cell FROM 1CM * 1CM TO 15CM * 15CM. And the least the solar cell can produce from the energy between: 1-2 Watt.

Types of solar cells:

a- Crystalline Silicon Solar Cells: There are two types of these cells Mono Crystalline and Poly Crystalline as shown in figure 3.6.

Mono Crystalline:

Silicon is one-way, higher purity and more expensive. This is one of the most regular crystalline builds. In one color and from blue to black, the cells can be made in other colors, but they will be cost-effective as the cell is less efficient, the other colors if it is used, it will reflect a fraction of the solar radiation that it will reach, so the designer will need more solar cells, the color The golden or purple color will be of special appearance if it is used but it will cause a loss of efficiency of up to 20% and the amount of a mono-crystallized cell of 15 to 20% (Green, 2003).

Poly Crystalline:

The silicon bloat is in different directions, so it looks like irregular pieces that give multiple gradients of one color. They usually have different gradients of blue, but as they do, they can also be made of other like leaden, and have this kind of light gloss in the exterior appearance and the efficiency of the cell. Solar from 10 to 14% (Green, 2003).

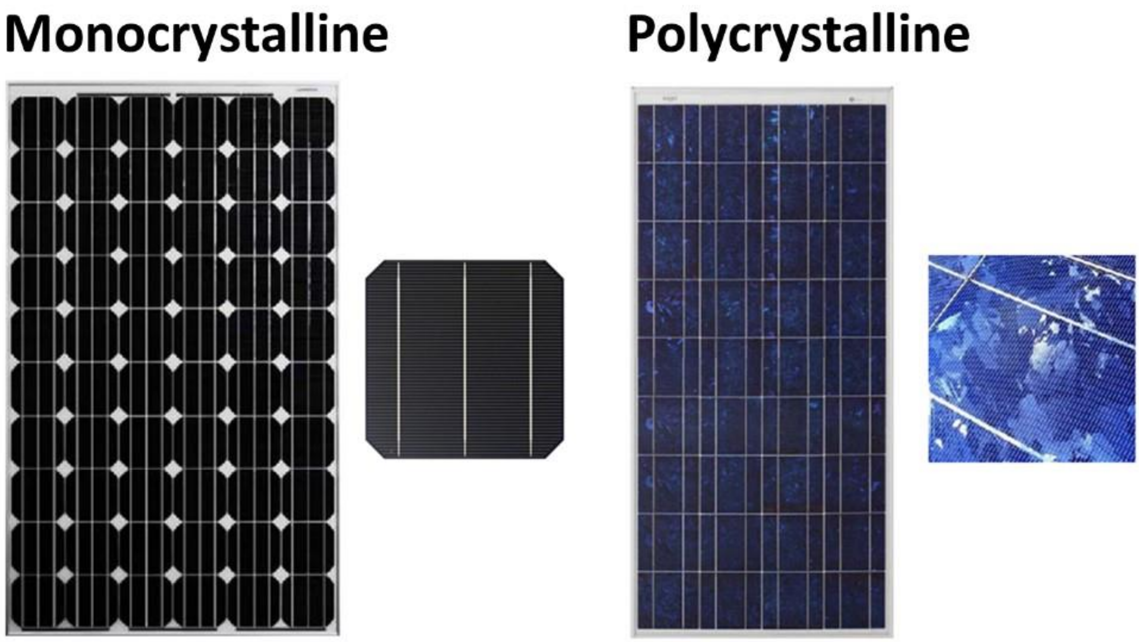

Figure 3.6: Mono crystalline & Poly crystalline Solar Panels (Daniel, 2014)

b- Thin Film solar cells : is one of the types of cells that attracts wide attention from designers because of their ability to form, the specification of solar cells of this type is flexible, collapsible and lightweight and can be used on horizontal and curved surfaces with high performance and the glass is not using in it . Figure 3.7.

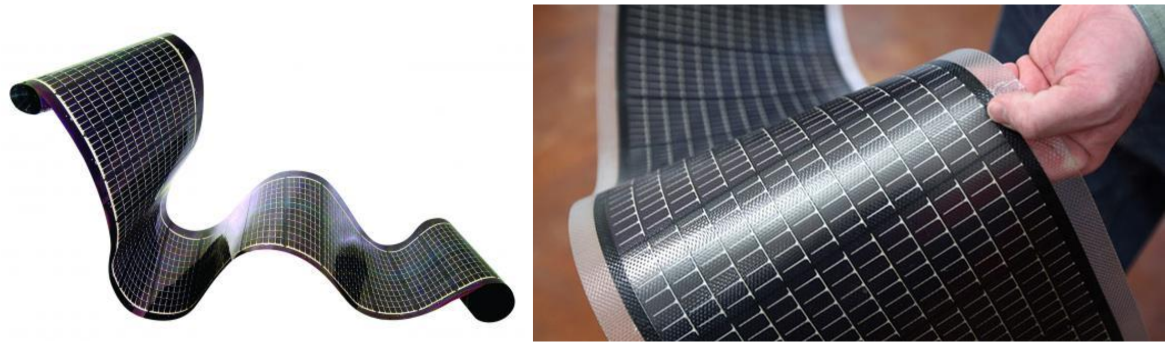

Figure 3.7: Thin film Solar Panels (Daniel, 2014)

c- Organic photovoltaic cells: The idea of working organic solar cells makes it possible to use them in light lighting conditions such as the sky to be overcast or inside the houses where electric power can be generated from domestic lighting, not necessarily from direct sunlight (Kippelen and Brédas, 2009). Figure 3.8.

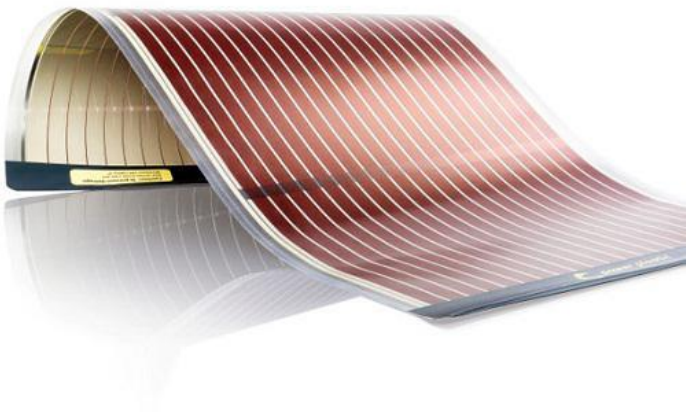

Figure 3.8: Organic photovoltaic cells (Daniel, 2014)

d- Concentrated photovoltaic cells: Spectrolab invented what is called a concentrated solar cell, Solar energy is transformed into an electricity with efficiency 7.4% and is a world record, where the main idea of this type of cell is based on the use of semi-conductive PV materials with the least capacity and maximum possible aggregation of sunlight and focus on cells using overlapping assembly lenses Full-fledged, power-generating efficiency of about 20 to 30% (Du and Kolhe, 2012).

Solar Module:

Is a group of solar cells assembled in a closed unit, and this group of cells covered with a layer of plastic or glass to protect them from rain and physical damage, the size of the unit can be $4m^2$, but the typical sizes are 1.33 * 0.33 m^2 or 0.5 * 1.0 m^2 (

Solar Array:

It is a number of photovoltaic modules connected in parallel or series.

3.2.2 Charger Controllers

It is the second phase of the solar system, and it does many functions as follows:

a- Contains the inner incisor that protects the solar cell from damage.

b- Organizing battery chargers.

c- Do not return electrical current from battery to solar cell .

d- Works to purify and stabilize the voltage who going out from the solar cell into a device that operates on constant voltage (DC) (Roos, 2009).

3.2.3 Batteries

It is the unit responsible for storing and unloading energy when needed, which has a dual function, can be like as the balloon you can enter the air inside to fill it under external pressure or open it to bring the inner pressure out again. There are many types of batteries but most batteries used with solar systems are of the type with acid and lead plates (Clean Energy, 2010).

3.2.4 Power Inverters

The importance of this phase comes when the use of these cells is needed to generate a variable high power that can operate large electrical and electronic appliances in homes or factories, It converts continuous current, whether 12 volts, 24 volts, or any other value to a high variable stream to operate devices that work on the changing current and heavy equipment, And this is the last stage without which there will be no real value for solar panels (Clean Energy, 2010).

Figure 3.9 shows the components of the solar power system.

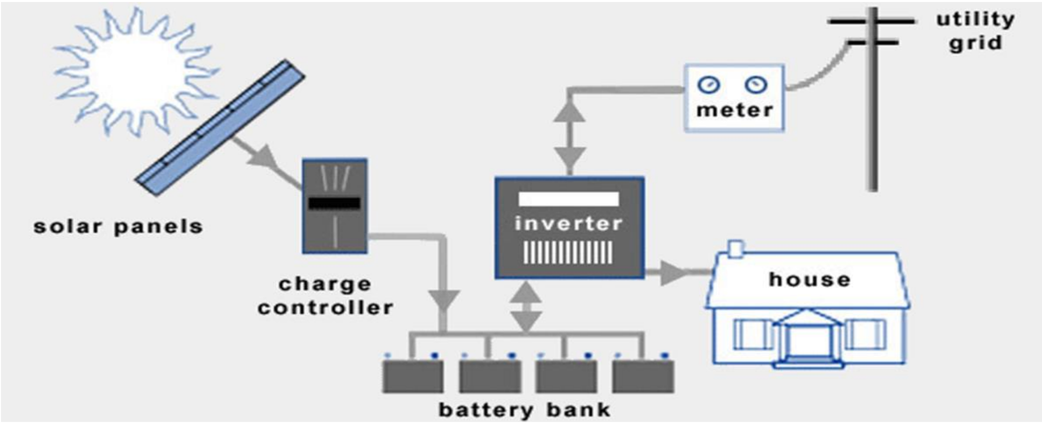

Figure 3.9: Components of the solar power system (Maehlum, 2013)

3.3 Methods of connecting solar panels

There's more than one way to connect depending on the nature of the use:

3.3.1 Parallel:

It's by linking beginnings with beginnings and endings with ending (positive with positive and negative with negative) in order to maintain the same effort , But with the collection of the different values of all the solar cells in order to increase the overall current and thus raise the total capacity (Warren, 2018). Figure 3.10.

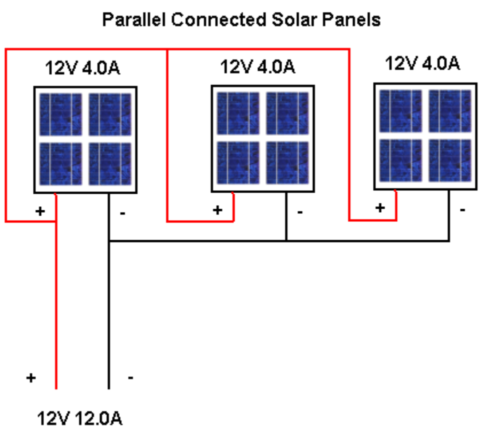

Figure 3.10: Parallel Connected Solar Panels (Lensun Solar Energy, 2015)

3.3.2 Series:

It is done by connecting the endings with the beginnings (positive with negative and negative with a positive, in order to maintain the same current, but combining the different effort values of all the solar cells in order to raise the total voltage difference (Warren, 2018). as follows. Figure 3.11.

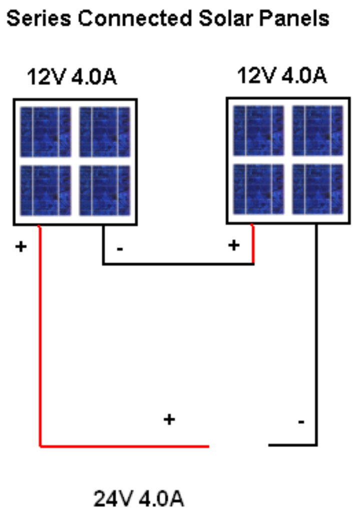

Figure 3.11: Series Connected Solar Panels (Lensun Solar Energy, 2015)

3.3.3 Combining two methods:

They are often the method used in large systems to enjoy each feature that is present in the parallel or series connection and its shape (Warren, 2018). Figure 3.12.

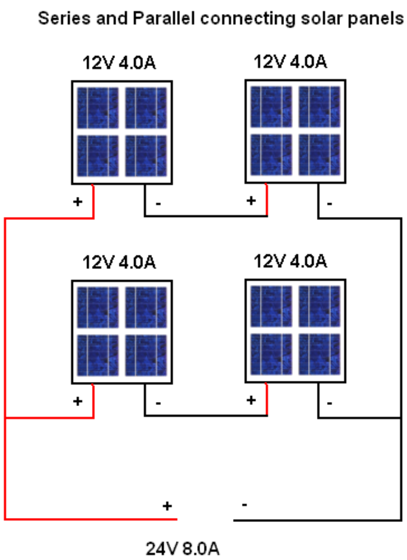

Figure 3.12: Series & Parallel Connected Solar Panels (Lensun Solar Energy, 2015)

3.4 Building Integrated Photovoltaics (BIPV)

Building-Integrated Photovoltaics are one of the best ways to harness solar power, which is the most abundant, inexhaustible and clean of all the available energy resources. BIPV are considered a functional part of the building structure, or they are architecturally integrated into the building's design. This category includes designs that replace the conventional roofing materials, such as shingles, tiles, slate and metal roofing. These types of products can be indistinguishable from their non-photovoltaic counterparts. Aesthetically, this can be attractive if there is a desire to maintain architectural continuity and not to attract attention to the array. BIPV modules can also be architectural elements that enhance the building's appearance and create very desirable visual effects. These types of arrays include custom-made module sizes and shapes with opaque or transparent spaces between the cells and can be used for curtain walls, awnings, windows and skylights. Thus, BIPV are multifunctional solar products that generate electricity while also serving as construction materials (Peng et al, 2011).

3.4.1 Steps to design integrated solar cells with the building

a- Apply a design that cares about the energy to reduce the energy requirements for building.

b- Choice between the Solar System interactive with the building and Independent solar cell system.

c- Provision of adequate ventilation, the efficiency of solar cells is reduced with high temperatures.

d- Designers have to know that there are effects of climate and environment on energy production.

e- Should study the site and the buildings direction at the beginning of the design phase.

f- The use of solar cell systems is relatively new, so those who work on the project must be well trained and their operators have experience in solar cells and their devices.

3.4.2 Sites and methods of solar cell integration with the building

This part of the discussion talks about the relationship between the solar cells and the building as an external finishing material that integrates with them, so The integrated design of the building begins with thinking about the design of the building as an integrated system, The buildings contain multiple and varied systems that are connected to each other in relationships that vary in their levels of overlap and their compatibility based on the type of system and its location within the building, The location and space of the solar systems used in buildings depends on the shape and orientation of the building, Preferably these shaded surfaces (Wall et al, 2012).There are five main sites in the building that can be integrated with solar systems:

1. Horizontal surfaces.
2. Sloping surfaces.
3. Curved surfaces.
4. Building Facades.
5. Architectural Details

Figure 3.13: Sites and methods of solar cell integration with the building

Horizontal surfaces

Horizontal surfaces in buildings are exposed to the effect of solar radiation in summer more than walls. Most of the time solar panels integrated with horizontal surfaces are not visible in the outer shape, but their effect can be seen when used in the roofing of internal spaces. The horizontal ceiling can provide a good possibility to provide the required space for the installation of solar systems. There are several different ways to integrate solar panels with horizontal surfaces:

1. Sloping solar modules designed for horizontal surfaces as shown in Figure 3.14.
2. Solar unit heat-insulating with horizontal position as shown in Figure 3.15.
3. Solar modules used as natural roof lighting as shown in Figure 3.16.

Figure 3.14: Sloping solar modules designed for horizontal surfaces (bombard, 2015)

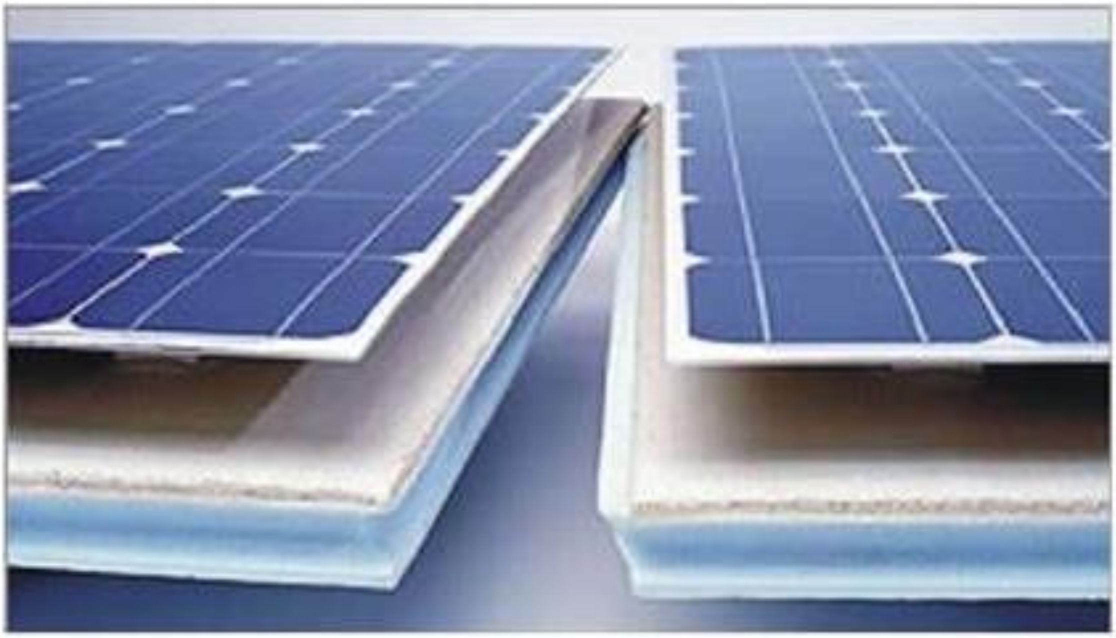

Figure 3.15: Solar unit heat-insulating with horizontal position

Figure 3.16: Solar modules used as natural roof lighting

Sloping surfaces

This type fits the south or south-west surfaces. This does not mean that solar modules cannot be placed on other directions. But it's better to fits the south or south-west surfaces because it is more efficient to receive the direct solar radiation on which the solar modules depend on generating power. This type is characterized by the possibility of installation of solar units without the need to use sloping structures used in horizontal surfaces. Cleaning this kind is easier than cleaning other species and preventing water gathering on its surface. And it's better that there's no space between the solar panels to prevent dust and foliage beneath them (Eiffert and Kiss, 2000). There are several different ways to integrate solar modules with sloping surfaces:

Solar modules are used in place of the original surface finish materials as shown in Figure 3.17.

Add solar modules to sloping surfaces above external finish materials as shown in Figure 3.18.

Add solar modules within conventional traditional surface materials as shown in Figure 3.19.

Figure 3.17: Solar modules are used in place of the original surface finish materials (Sinapis & Donker , 2013)

Figure 3.18: Add solar modules to sloping surfaces above external finish materials (Sinapis & Donker , 2013)

Figure 3.19: Add solar modules within conventional traditional surface materials (Sinapis & Donker , 2013)

Curved surfaces

Thin film solar cells are used in this type of ceiling. , and there is two type from this kind of roof (Eiffert and Kiss, 2000):

1. Thin film solar cells. Figure 3.20
2. Curved surfaces in traditional solar panels. Figure 3.21

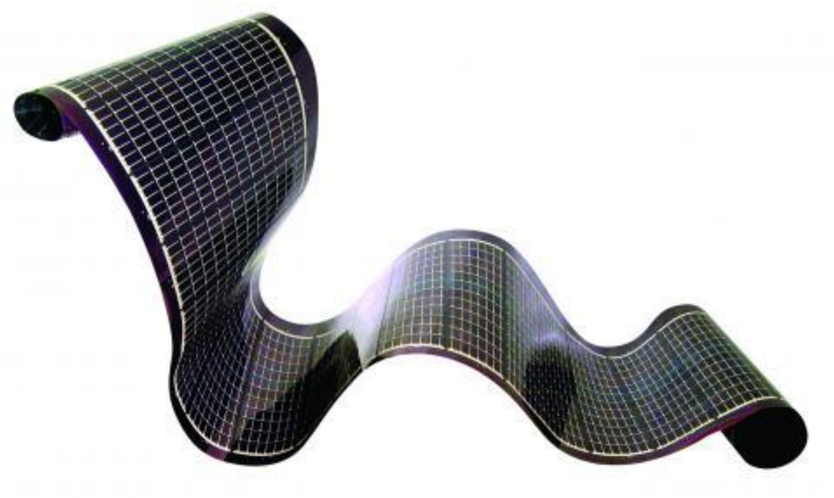

Figure 3.20: Thin film solar cell (Community Develobment Department, 2006)

Figure 3.21: Curved surfaces in traditional solar panels (Community Develobment Department, 2006)

Building Facades

Integrated solar panels with building facades are more visible than other types of integration and large areas of these facades can be exploited to invest in power generation when they are in the right direction (Probst and Roecker, 2007) as shown in Figure 3.22.

The sections and methods of installing solar cells in curtain walls was shown in Figure 3.23.

Figure 3.22: Solar Cells on Building Facades (Krawietz, 2011)

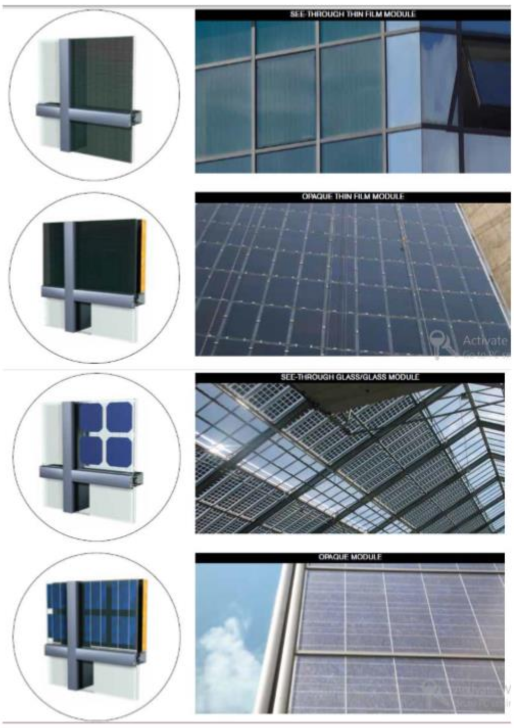

Figure 3.23: Some sections and methods of installing solar cells in curtain walls (Krawietz, 2011)

Architectural Details

One of the most effective ways to integrate solar modules with the buildings is to replace or use shading elements as basic window elements or as additives such as handrail (Munari Probst et al, 2013) as shown in Figure 3.24, Figure 3.25 and Figure 3.26.

Figure 3.24: Models of sun shields (Krawietz, 2011)

Figure 3.25: Solar cell windows (Krawietz, 2011)

Figure 3.26: Solar cells for handrails (Krawietz, 2011)

3.4.3 The advantages of connecting the solar cells with the structure of the building

There are many benefits and advantages to this system that are summarized in the following points:

1- These systems operate with high efficiency and unlimited ability.

2- it reduces the cost of electricity .

3- Reduce the use of fuel and emissions harmful to the ozone layer.

4- We could replace the traditional building materials with solar systems like glass and other.

5- When increasing the amount of electrical power produced can be returned to the network and utilized.

3.4.4 Methods of connecting solar cells

The solar cell contains two faces, the front face is the opposite side of the sun, which picks up the light and is called the negative face, This face is used to connect cells to each other using Tabbing Wires and Flux Pen, The back face has six white squares and is spread on two sides, three squares on each side. Each tab line is connected to a group of three squares. The back side is usually gray and is the positive side of the cell. Methods of connecting solar cells was shown in Figure 3.27.

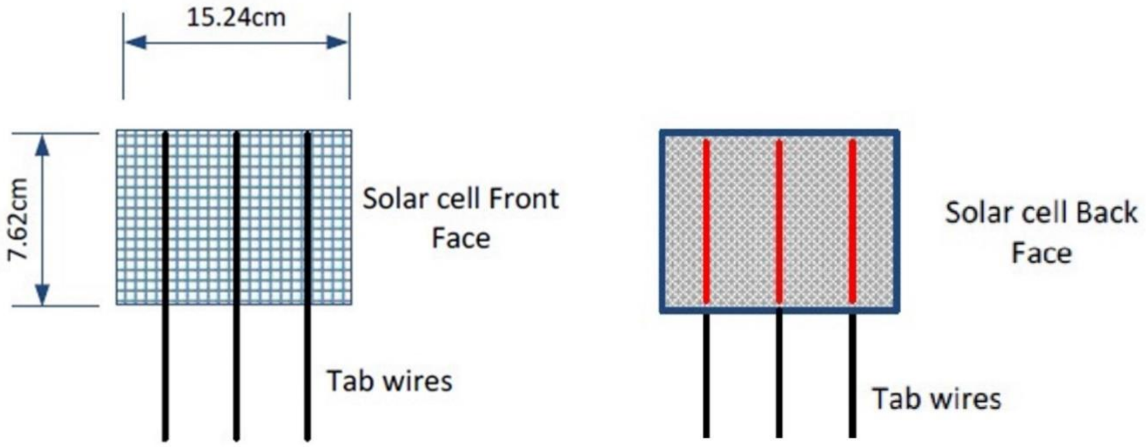

Figure 3.27: Methods of connecting solar cells (Nyaga, 2016)

Soldering the tabbing wires to the solar cell using Soldering Iron

The electrodes in the solar cell are in parallel at the top of each cell from the top down. The wires are welded on these electrodes after they are cut to about twice the height of the cell. The cells are placed on the cardboard before welding for support.

The flux is applied to two lines of solar cells to ensure that the wire is stable during the welding process. As shown in Figure 3.28.

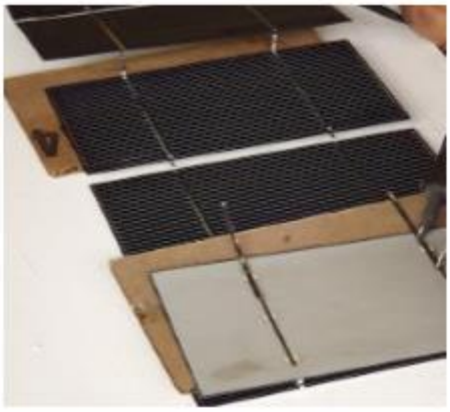

Figure 3.28: solar cells with tabbing wires (Nyaga, 2016)

Connecting the solar cells together in series

In the following Figure 3.29, the wires are connected to the upper face of the solar cell and then connected to the positive points on the next cell.

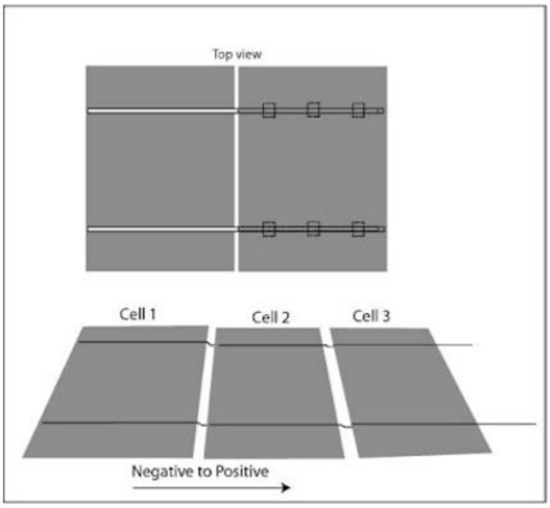

Figure 3.29: Connecting the solar cells together in series (Nyaga, 2016)

Two wires are connected from the positive poles of the first cell to the negative electrodes of the second cell and then the second cell of the third is joined and so to reach the last cell (Nyaga, 2016).

Mounting the solar tile

After connecting the solar cells to each other, the packaging phase begins to form the solar panel, and enters within this stage the following materials:

1. Plastic base.
2. Transparent glass and silicone
3. Screws
4. Electric wires
5. Tabbing and BUS

The following Figures 3.30, 3.31, 3.32 was shown the solar cells electrical connection.

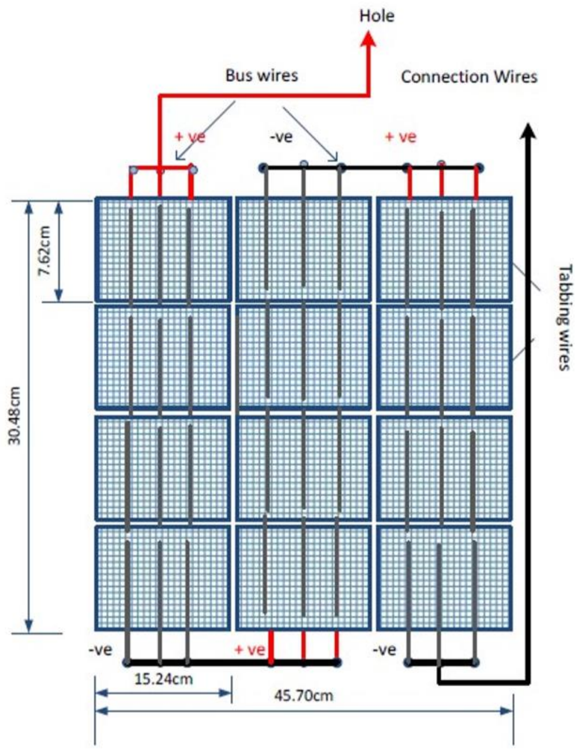

Figure 3.30: Cells Electrical connection Front view

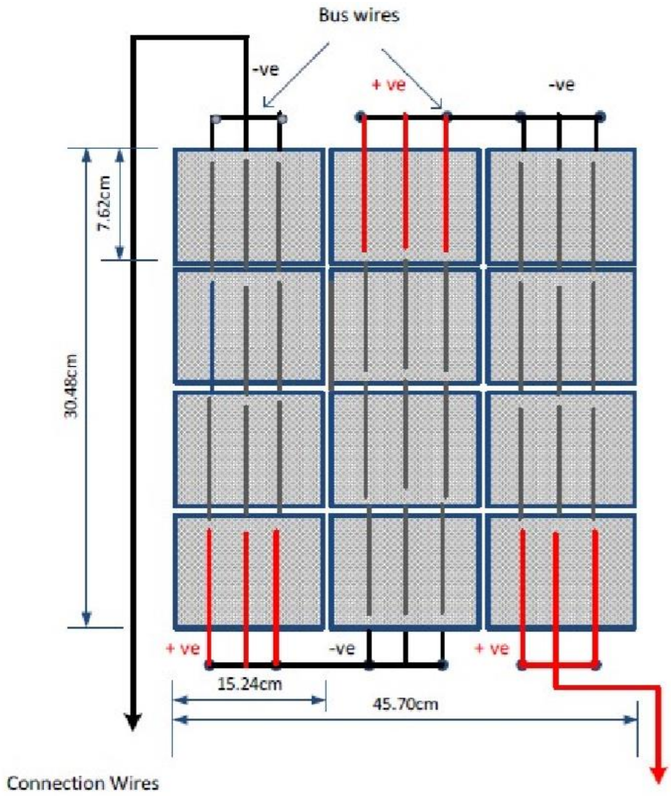

Figure 3.31: Cells Electrical connection Back view

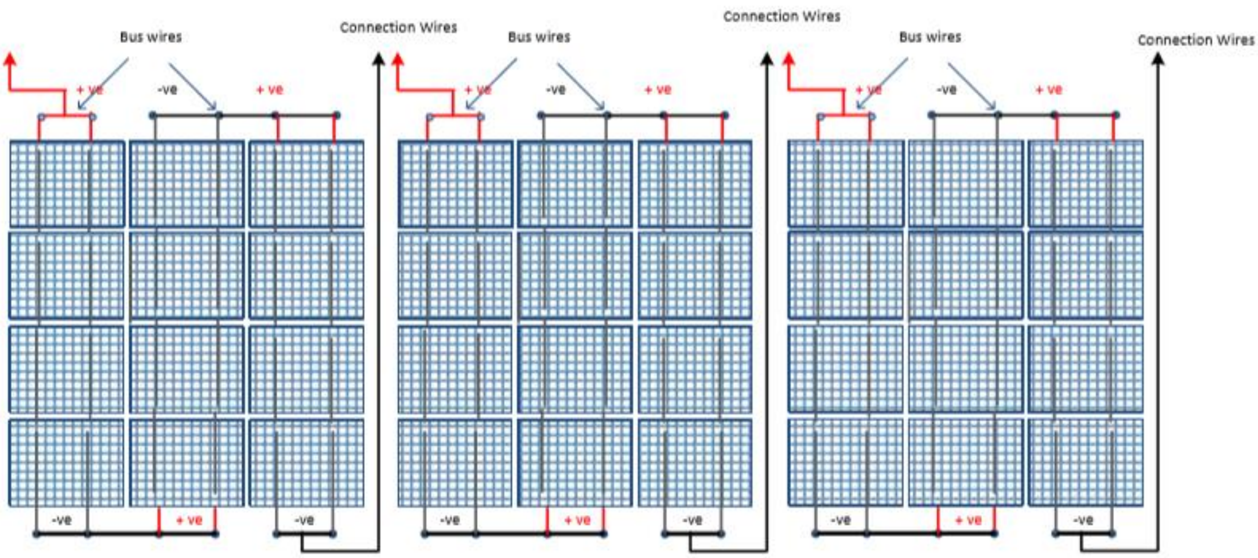

Figure 3.32: Electrical connection of three tiles in series

CHAPTER 4

EXPERIMENTAL STUDY

4.1 Materials and Method

4.1.1 Materials

The experimental study is based on the application and integration of solar cells with the small roof tiles to obtain a complete and useful roof tile from being an electric generator, which meets the need of many people who believe that the big size of solar panels give their building an ugly shape and extra weight. So it’s better to use solar tile that combines the shape of the roof tile with the benefits of solar panels. This kind of application is good for the future.

This section has been explained how this experiment was done. The solar cells with the specification below and the multimeter were used to measure the voltage and current to reach the energy received by the solar cells from the sunlight.

Table 4.1: Module specifications

Open Circuit Voltage	$\boldsymbol{V_{oc}}$**(V)**	**4.8V**
Short Circuit Current	I_{sc}(A)	0.1A
Power of Each Solar Cell	P(W)	0.48W
Number of Solar Cells	N	25
Maximum System Voltage	V_{max}(V)	120V
Maximum System Power	P_{max}((W)	12W
Standard Test Condition Solar irradiance	STC	1000W/m^2

4.1.2 Roof Materials

The hip roof with the dimension 200cm x 200cm used in this experiment has slope angle 33% taken from the architecture office in TRNC (Kocagöz, 2010), and is located in the laboratory on the roof of the faculty of law in Near East University in Northern Cyprus:

- MDF Wood: Dimensions is 200 cm * 200 cm and the thickness is 1.5 cm.
- Plate: The Dimensions is 20 cm * 20 cm and the thickness is 2 cm.
- Stud: The Dimensions is 10 cm * 10 cm * 33 cm.
- Rafters made by wood: The dimensions is 5 cm * 10 cm.
- Glass Wool: It’s a heat insulation material, the Dimensions is 200 cm * 200 cm and the thickness is 8 cm.
- OSB Materials: is a heat insulation material with thickness 1.5 cm.
- Yalteks: It’s a water insulation material, the thickness of it 1 cm.
- Roof battens: It’s a wooden materials, the dimension of them are 2cm * 5 cm.
- Roof tiles: this roof tiles has 4 cm height.

Figure 4.1: Hip roof used for the experiment

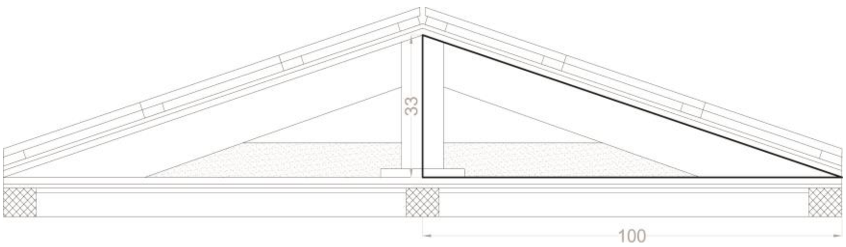

Figure 4.2: Section for the hip roof used in the experiment

4.1.3 Method

After buying the solar cells it have been connected in series and applied to a horizontal surface in northern Nicosia just for checking if there is any problem in the solar cells before starting the experiment, after a suitable location was chosen where the shadows did not affect the solar cells.

Figure 4.3: Applying solar cells in to a horizontal surface in Northern Nicosia

After ensuring the effectiveness of solar cells were applied to the south face of the hip roof which was explained in the previous section to gain direct exposure to the solar radiations:

Figure 4.4: solar cells integrated on the hip roof

Initially, the voltage was measured by connecting the positive terminal (red wire) to the V.Ω.CAP and the negative terminal (black wire) to the neutral pot, the pointer was set to 200V, and then for the measuring of the current the positive terminal was connected to mA and the negative terminal remained on the neutral pot and taking the pointer to 200 mA.

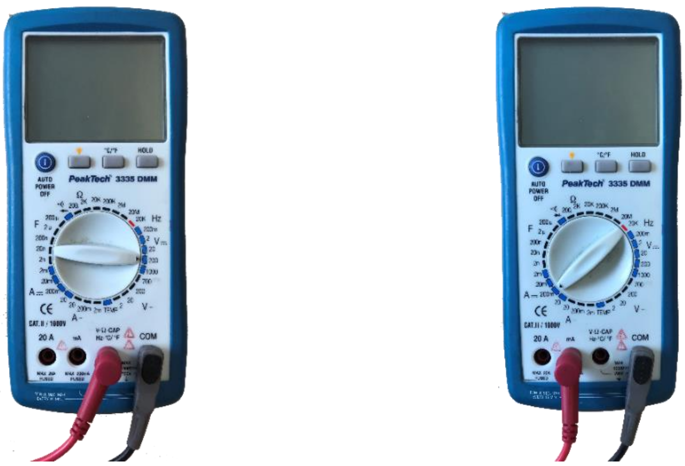

Figure 4.5: Multimeter used for measurement the current and voltage

This readings started at 07:30 and finished at 16:00 with 30 minute interval daily.

The power generated at each interval of 30mins can be given as:

P=I×V

Where:

I= current and V=voltage

The power per unit area were calculated by the formula below:

$$Psc = \frac{I_{sc}V_{oc}}{Area} \quad \left(\frac{W}{m^2}\right)$$

The area of the solar cell is given as:

I_{sc}: Short circuit current

V_{oc}: Open circuit voltage

A=N×l×w

N: Number of used solar cells

l: Length of solar cell (0.06m)

w: Width of solar cell (0.06m)

The energy per unit area were calculated by the formula below:

$$Esc = \frac{I_{sc}V_{oc}}{Area} \times \Delta t$$

Δt: Time interval in seconds (30min*60=1800s).

Figure 4.5 shows that the open circuit voltage (V_{oc}) is the maximum voltage that a solar cell can provide, and is a voltage in which no current is flowing through the external circuit. The short circuit current (I_{sc}) is the current that passes through the cell when the voltages in the solar cell are zero (i.e., when the solar cell is short circuited).The most important factors on which the short circuit current depends is the area of the solar cell and the number of photons (i.e., the power of the incident light source) (Atia, 2009).

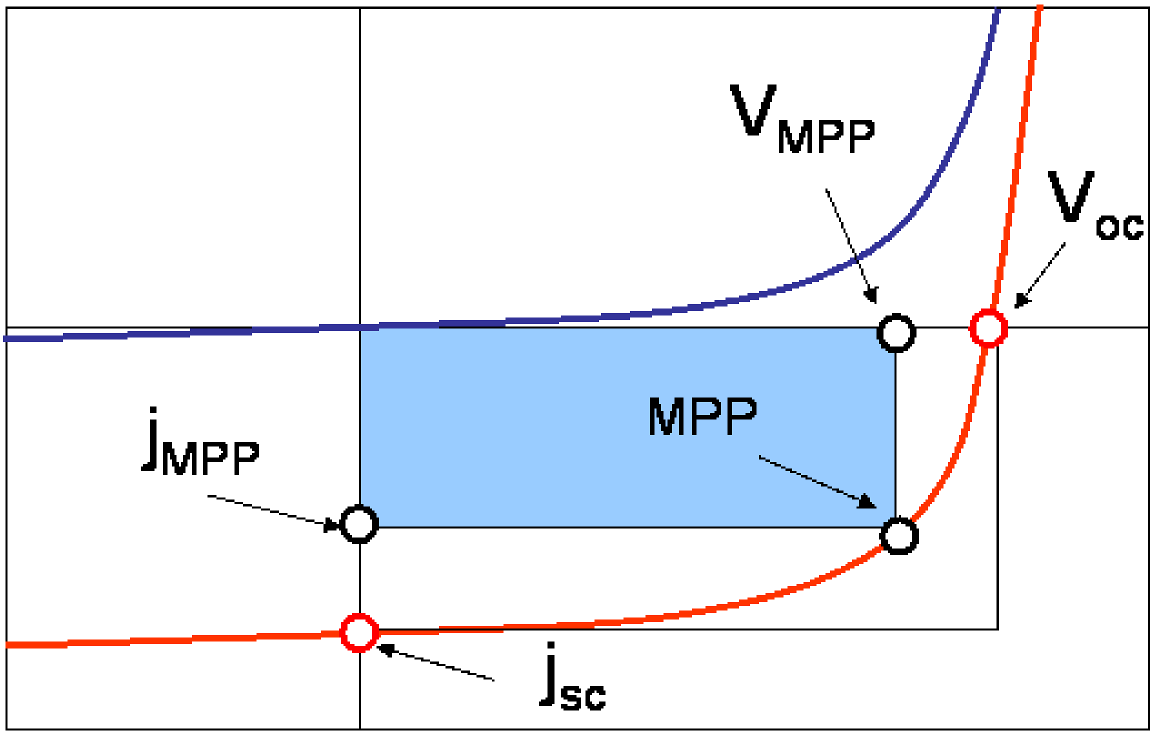

Figure 4.6: Open circuit voltage and short circuit current

The power and energy per unit area calculated using the given formulas by Microsoft excel. (Solve the equation in appendix 1).

4.1.4 Result of the Experimental Study

The following tables and images show the performance of 25 solar cells where the current (Isc), voltage (Voc), power per unite area and energy per unite area were computed which give the amount of daily energy obtained during the experiment period.

Table 4.2: Current, Voltage, Power and energy for the hip roof (19/11/2018)

DATE	**19/11/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	105	0.84	9.33	16800
08:30AM	0.012	12	108	1.296	14.40	25920
09::00AM	0.019	19	110.5	2.0995	23.33	41990
09:30AM	0.0312	31.2	112.8	3.51936	39.10	70387.2
10:00AM	0.044	44	113.2	4.9808	55.34	99616
10:30AM	0.053	53	114.5	6.0685	67.43	121370
11:00AM	0.062	62	115.3	7.1486	79.43	142972
11:30AM	0.067	67	115	7.705	85.61	154100
12:00PM	0.073	73	116	8.468	94.09	169360
12:30PM	0.07	70	114.8	8.036	89.29	160720
13:00PM	0.068	68	114.5	7.786	86.51	155720
13:30PM	0.07	70	114	7.98	88.67	159600
14:00PM	0.063	63	113	7.119	79.10	142380
14:30PM	0.042	42	112.3	4.7166	52.41	94332
15:00PM	0.0256	25.6	112	2.8672	31.86	57344
15:30PM	0.015	15	110	1.65	18.33	33000
16:00PM	0.009	9	106	0.954	10.60	19080
Average	0.04065556	40.6555556	105.938889	4.62414222	51.379358	1664691.2

The remaining part of tables are shown in the appendix 3.

To determine the rate of temperature effect on the performance of solar cells, you should find the daily average of short circuit current (Isc), open circuit voltage (Voc) and daily total energy received.

Table 4.3: Summary of the daily average temperature, energy, short circuit current and open circuit voltage

Days	**Avg. Tem(c°)/Dates**	**E_{sc} (J/m^2)**	**E_m (J/m^2)**	**Avg. Solar Rad (cal/cm^2)**	**Avg. I_{sc} (mA)**	**Avg. V_{oc} (V)**
19/11/2018	16	1664691.2	12213096.00	291.9	40.65	105.9
21/11/2018	16.1	1676406	5870152.00	140.3	40.79	106.6
22/11/2018	16.1	1676824.2	10723592.00	256.3	40.89	106.1
23/11/2018	14.4	1287895.2	8778032.00	209.8	31.76	104.8
26/11/2018	14.6	1300701.6	11146176.00	266.4	31.8	105.3
27/11/2108	16	1554408	11497632.00	274.8	37.9	105.8
28/11/2018	16.3	1602143.6	7861736.00	187.9	38.7	106.4
29/11/2018	16.9	1638255	6786448.00	162.2	39.7	107.3
04/12/2018	13.9	1145407	5945464.00	142.1	28.5	104.1
05/12/2018	14.6	1407943	7610696.00	181.9	34.5	105.5
07/12/2018	12.2	875934	5807392.00	138.8	21.6	104.8
10/12/2018	15.3	1252831.4	10263352.00	245.3	30.8	105.8
12/12/2018	14.1	1150612	8874264.00	212.1	28.6	103.8
13/12/2018	10.5	761016.8	11681728.00	279.2	19	103.3
18/12/2018	13.8	907190	8924472.00	213.3	22.6	104
19/12/2018	11.3	775656	3543848.00	84.7	19.5	103
20/12/2018	13.1	902709	11719384.00	280.1	22.5	103.9
21/12/2018	11.6	834706.8	11531104.00	275.6	20.9	103.2
24/12/2018	12.4	839598	10024864.00	239.6	21	103.8
25/12/2018	12.8	877062	10606440.00	253.5	21.8	104.4
03/01/2019	10.8	740784	8857528.00	211.7	18.8	103
10/01/2019	7.3	688608	3573136.00	85.4	17.4	102.57
Average	13.64090909	1161881.036	8810933.455	210.5863636	28.62227273	104.6986364

The following figure shows the difference in energy, short circuit current and open circuit voltage when solar cells are subject to different temperatures, whether the sky is clear, cloudy or rainy day has been experienced in this experiment.

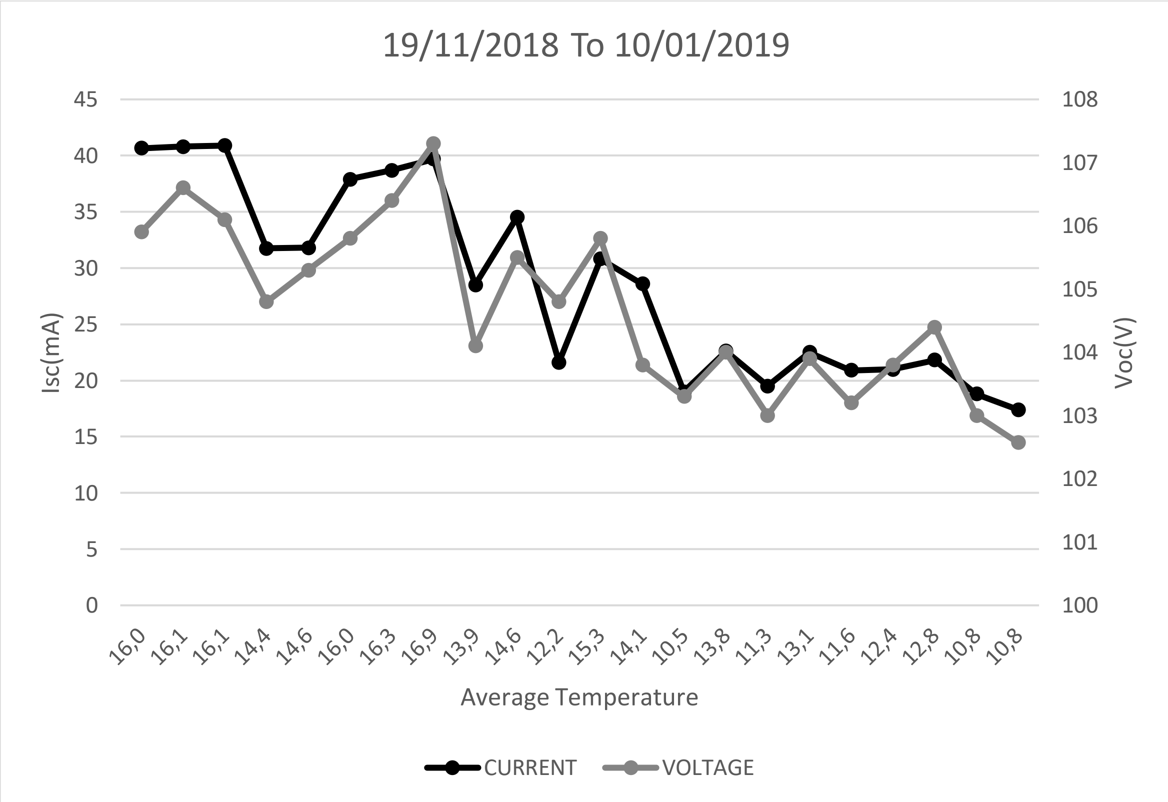

Figure 4.7: The difference in short circuit current and open circuit voltage when solar cells are subject to different temperatures

Three days were chosen from all the days of the experiment based on the weather during the experiment, which is clear sky when there is much solar radiation. On this day, the solar cells receive a large amount of solar radiation. The second day was a cloudy day, Solar cells receive less solar radiation in this day, while the third day was rainy day and during this day there was a loss of solar radiation.

The following Figure shows the voltage against time, during sunrise and sunset the amount of solar radiation falling on the solar cells is low compared to the solar radiation that is during the noon, so the amount of the current at peak at noon, and also the amount of power obtained directly proportional to current, furthermore the solar cells receive the solar radiations directly at noon, Thus, the number of photons strike the solar cells is very high at noon. Thus, the number of photons hitting the solar cells is very high at noon and this leads to obtaining the highest amount of energy produced and then convert to electricity.

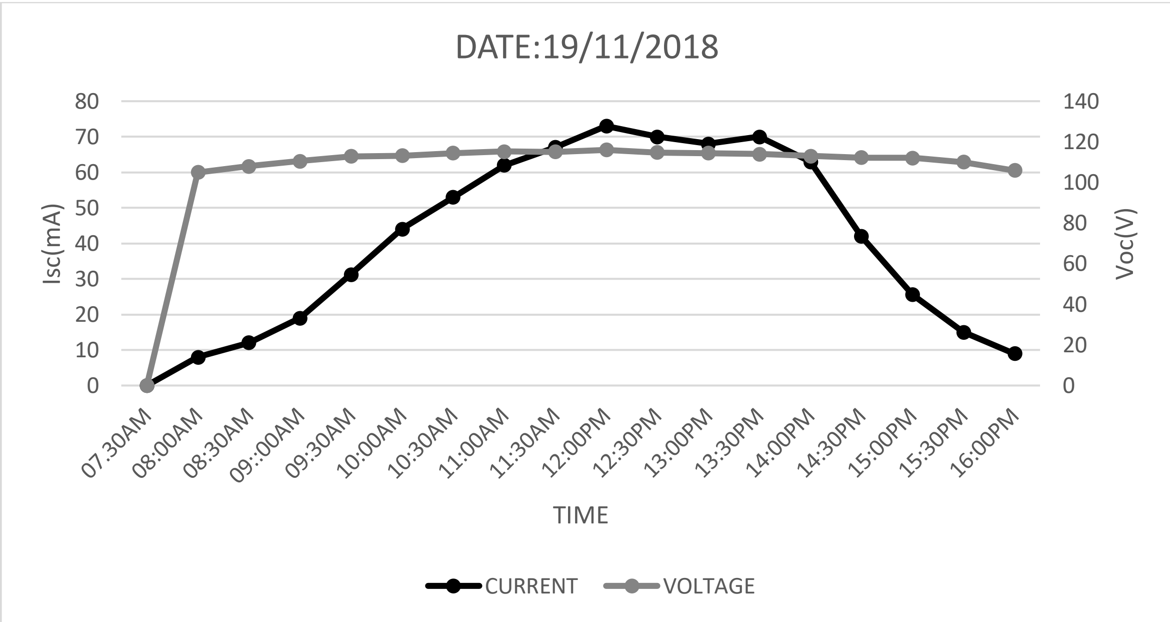

Figure 4.8*:* Variation of solar cell short circuit current (Isc) and open voltage (Voc) against the local time (19/11/2018)

The Figure 4.9 shows the difference in the shape of the current diagram from the previous plan of 19/11/2018. This is because the previous day was sunny, but the following chart in 07/12/2018 was cloudy, which does not allow the direct light towards the solar cells in every hours Day and this leads to lower power production.

At 8:00 am it was cloudy and after that time the sun began to appear, which led to a rise in the current until 11:00 as the clouds began to thicken in the sky and the weather became volatile and the sun appears from time to time until 12:30, then the sun gradually disappeared until sunset.

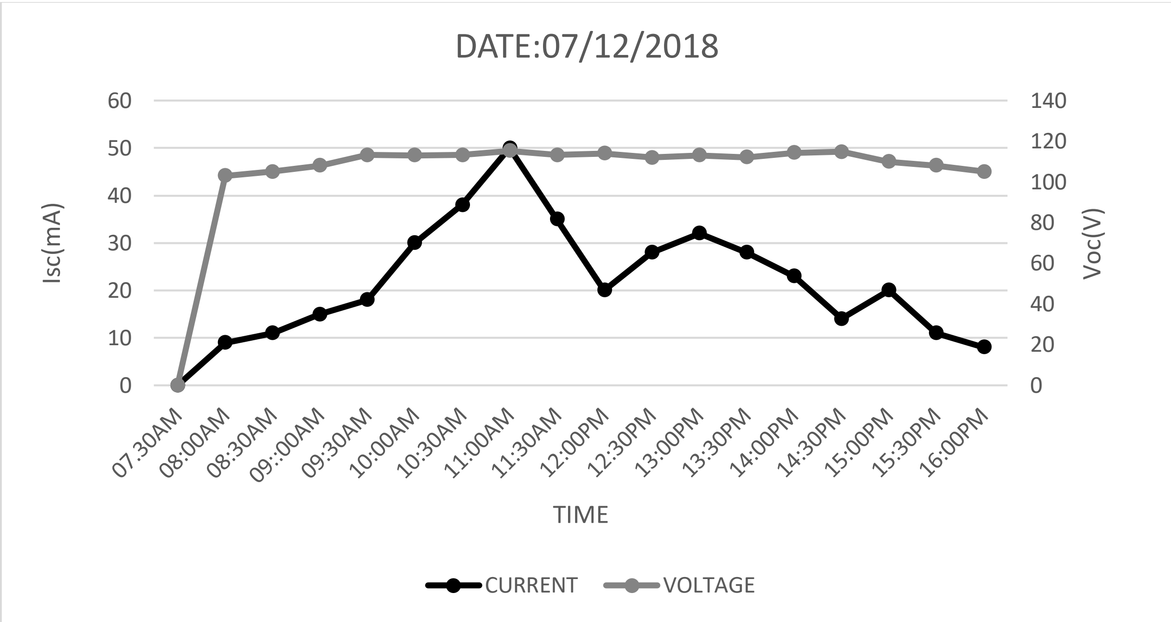

Figure 4.9: Variation of solar cell short circuit current (Isc) and open voltage (Voc) against the local time (07/12/2018)

In the Figure 4.10, we observe the random behavior of the current, because 03/01/2019 was a rainy day, leading to a decrease in current.

It was cloudy until 13.00 pm and then it started to rain until sunset, as it is clear in the chart. (The remaining part of *Isc* and *Voc* graphs are shown in the appendix 4.l).

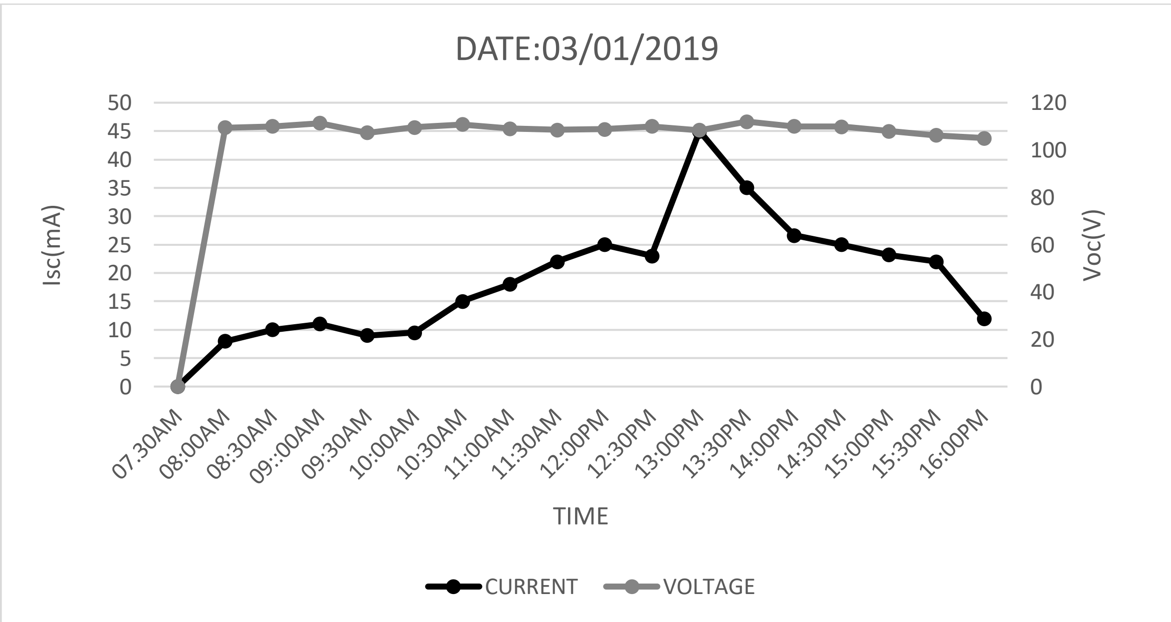

Figure 4.10: Variation of solar cell short circuit current (Isc) and open voltage (Voc) against the local time (03/01/2019)

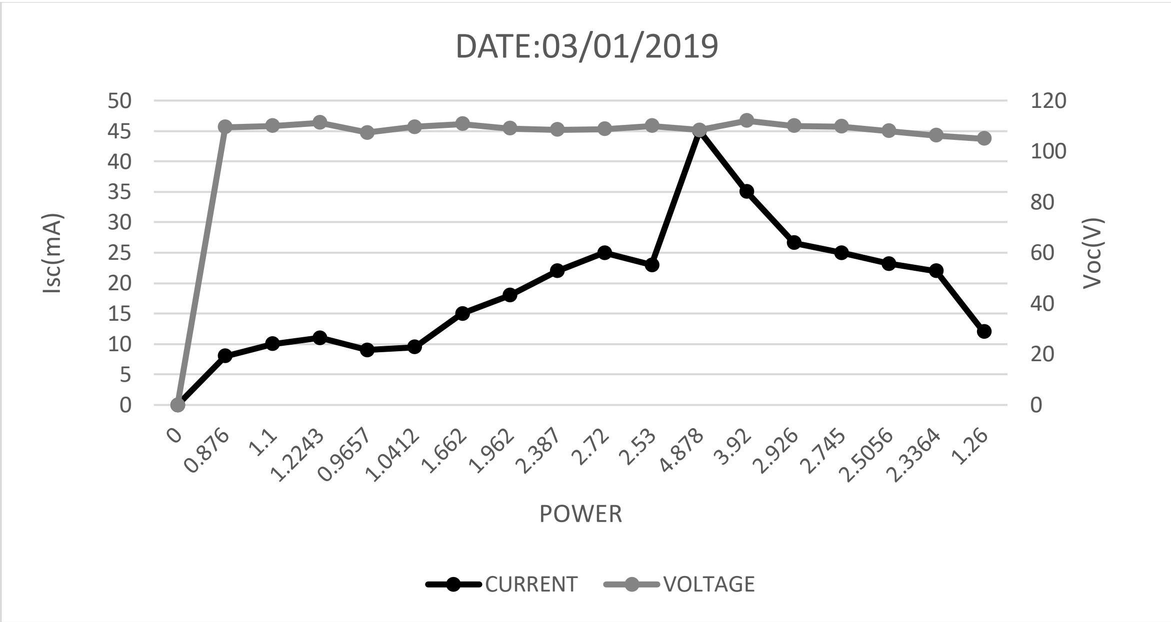

Figure 4.11: Relationship between (isc) and (voc) against solar cell's power

The remaining part of *Isc* and *Voc against powe of solar cell* graphs are shown in the appendix 5.

The following table shows a comparison between the energy generated by solar cells and energy from meteorology, the average of solar cell's energy was 1.16 multiply by ten exponent 6 were the average energy of meteorological is 8.81 multiply by ten exponent 6,

Table 4.4: Daily energy per unit area for solar cells and meteorological data.

DAY	Esc(J/m2) * 10^6	EM(J/m2) * 10^6
19/11/2018	1.6646912	12.21
21/11/2018	1.676406	5.87
22/11/2018	1.6768242	10.72
23/11/2018	1.2878952	8.78
26/11/2018	1.3007016	11.15
27/11/2108	1.554408	11.50
28/11/2018	1.6021436	7.86
29/11/2018	1.638255	6.79
04/12/2018	1.145407	5.95
05/12/2018	1.407943	7.61
07/12/2018	0.875934	5.81
10/12/2018	1.2528314	10.26
12/12/2018	1.150612	8.87
13/12/2018	0.7610168	11.68
18/12/2018	0.90719	8.92
19/12/2018	0.775656	3.54
20/12/2018	0.902709	11.72
21/12/2018	0.8347068	11.53
24/12/2018	0.839598	10.02
25/12/2018	0.877062	10.61
03/01/2019	0.740784	8.86
10/01/2019	0.688608	3.57
Average	1.161881036	8.810933455

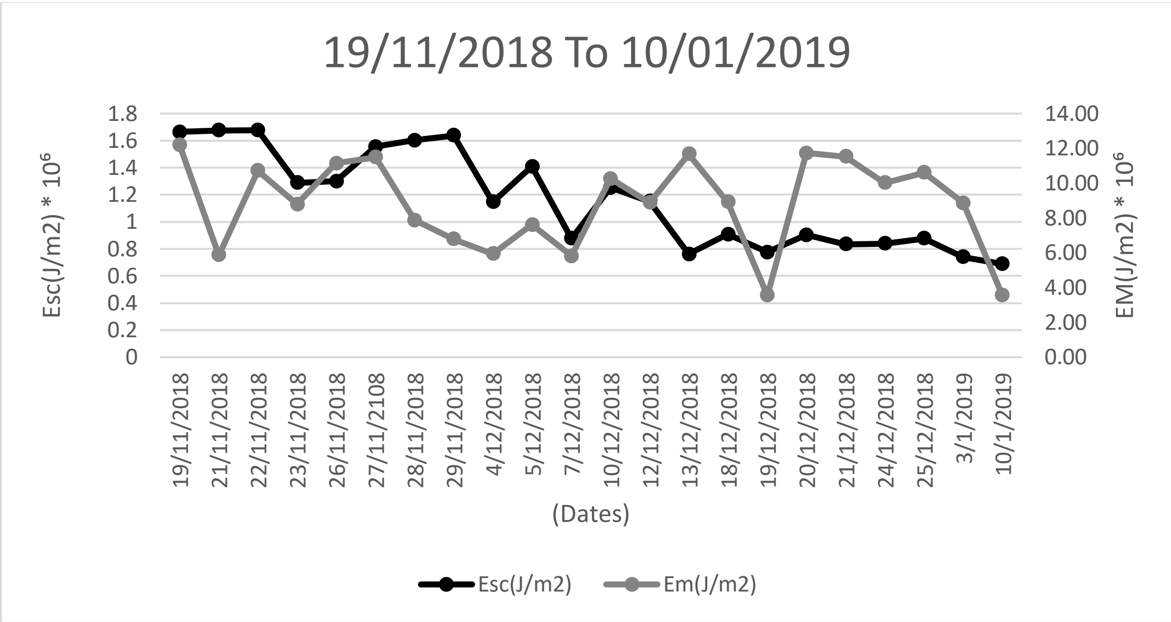

Figure 4.12: Energy per unit area meassured from solar cells and meteorological data against number of days

Theoretical efficiency of solar cells (η_T)

Efficiency $\eta_T = \frac{\text{Maximum power rating of solar cells}}{(\text{Solar irradiance W/m}^2)\times(\text{surface area m}^2)} \times 100\%$

Where:

Maximum power rating of solar cells = 12 W
Solar irradiance = 1000 W/m^2
Surface area (A) = $N \times l \times b$ = 25 × 0.06 × 0.06 = 0.09 m^2
From table 4-1, the values of the maximum power and power input gives at standard test condition from the factory.

Efficiency $\eta_T = \frac{12}{1000\times0.09} \times 100\% = \frac{12\ W}{90\ W} = 0.1333\times 100\%$

Efficiency η_T = 13.3 %

Practical efficiency

Overall efficiency $(\eta_p) = \frac{\text{Average energy of solar cell } (A_{E_{sc}})}{\textit{Average energy of meteorology data}(A_{E_m})} \times 100\%$

$$(\eta_p) = \frac{1.161}{8.81} \times 100\%$$

$$(\eta_p) = 0.1317 \times 100\%$$

$$(\eta_p) = 13.1\ \%$$

CHAPTER 5
CONCLUSION

In this study, the Isc and Voc of the solar cell was measured using a multimeter at a 30 minute interval between all measurements. The energy per unit area was measured and compared with the data from the meteorological organization in Northern Cyprus - Nicosia. The diagrams of short circuit current and open-circuit voltages were plotted against local time for different days, It was found that the energy produced by the solar cells depends on the weather during the experiment, also the power graphs that were plotted show that the energy is strongly dependent on the current produced by the solar cells.

Data were taken from the meteorological organization in Northern Cyprus to give independent testing of solar cells, energy per unit area was obtained at the Near East University using solar cells and then a comparison was made between them which showed that the energy per unit area measured during the 22 day period is $1.161 \times 10^{6} (\mathrm{J/m^{2}})$ and The energy calculated from the data taken from the meteorological is $8.81 \times 10^{6} (\mathrm{J/m^{2}})$.

The theoretical efficiency calculated of the solar cells is η_{T} = 13.3 % while the practical efficiency of solar cells was η_{p}= 13.1%. It can be seen that the energy per unit area from meteorological office were approximately similar to data from solar cells, and the data from the meteorological office was approximately 8 times greater than the data from solar cells, the last result expected because it was due to the solar cell's efficiency begin approximately 10% and solar cells are generally sensitive to only the red side of the visible solar spectrum and the near infrared.

This indicates that the application of solar cells on the roof tile achieved the goal of reaching the highest possible energy their production from these cells.

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APPENDICES

APPENDIX 1

The frank derivation of equation

The frank derivation of equation (4.1) in page 39.

$$s = \frac{I_{sc}V_{oc}}{25xy} \quad \left(\frac{W}{m^2}\right)$$

The frank derivation of equation in the first day (19/11/2018) at 08:30 am

S= $\frac{(0.012)(108)}{(25)(0.06)(0.06)}$=$\frac{1.29}{0.09}$= 14.4 $\frac{W}{M^2}$

The frank derivation of equation (4.2) in page 39.

$$S = \sum s * \Delta t(s)$$

$S = \sum \left(\frac{I_{sc}V_{oc}}{25xy}\right) * \Delta t(s)$

Δt(s) : unit of time in seconds, it’s the time between each data reading (30 minute).

$\Delta t(s)$=30*60=1800 second

S=14.4*1800= 25920 J/m^2

APPENDIX 2

DAILY AVERAGE TEMPERATURE AND SOLAR RADIATION FOR NEAR EAST UNIVERSITY

Days	Avg. Tem(c°)/Dates	Avg. Solar Rad (cal/cm^2)
19/11/2018	16,0	291.9
21/11/2018	16,1	140.3
22/11/2018	16,1	256.3
23/11/2018	14,4	209.8
26/11/2018	14,6	266.4
27/11/2108	16,0	274.8
28/11/2018	16,3	187.9
29/11/2018	16,9	162.2
4/12/2018	13,9	142.1
5/12/2018	14,6	181.9
7/12/2018	12,2	138.8
10/12/2018	15,3	245.3
12/12/2018	14,1	212.1
13/12/2018	10,5	279.2
18/12/2018	13,8	213.3
19/12/2018	11,3	84.7
20/12/2018	13,1	280.1
21/12/2018	11,6	275.6
24/12/2018	12,4	239.6
25/12/2018	12,8	253.5
3/1/2019	10,8	211.7
5/1/2019	10,8	85.4

APPENDIX 3

DAILY CURRENT, VOLTAGE, POWER AND ENERGY FOR EACH DAY

DATE	**19/11/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	105	0.84	9.33	16800
08:30AM	0.012	12	108	1.296	14.40	25920
09::00AM	0.019	19	110.5	2.0995	23.33	41990
09:30AM	0.0312	31.2	112.8	3.51936	39.10	70387.2
10:00AM	0.044	44	113.2	4.9808	55.34	99616
10:30AM	0.053	53	114.5	6.0685	67.43	121370
11:00AM	0.062	62	115.3	7.1486	79.43	142972
11:30AM	0.067	67	115	7.705	85.61	154100
12:00PM	0.073	73	116	8.468	94.09	169360
12:30PM	0.07	70	114.8	8.036	89.29	160720
13:00PM	0.068	68	114.5	7.786	86.51	155720
13:30PM	0.07	70	114	7.98	88.67	159600
14:00PM	0.063	63	113	7.119	79.10	142380
14:30PM	0.042	42	112.3	4.7166	52.41	94332
15:00PM	0.0256	25.6	112	2.8672	31.86	57344
15:30PM	0.015	15	110	1.65	18.33	33000
16:00PM	0.009	9	106	0.954	10.60	19080
Average	0.04065556	40.6555556	105.938889	4.62414222	51.379358	1664691.2

DATE	**21/11/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.009	9	108	0.972	10.80	19440
08:30AM	0.012	12	109.8	1.3176	14.64	26352
09:00AM	0.019	19	111	2.109	23.43	42180
09:30AM	0.0295	29.5	112.8	3.3276	36.97	66552
10:00AM	0.042	42	113.1	4.7502	52.78	95004
10:30AM	0.0553	55.3	114	6.3042	70.05	126084
11:00AM	0.066	66	114.2	7.5372	83.75	150744
11:30AM	0.07	70	114.6	8.022	89.13	160440
12:00PM	0.075	75	116.2	8.715	96.83	174300
12:30PM	0.073	73	116	8.468	94.09	169360
13:00PM	0.07	70	115.8	8.106	90.07	162120
13:30PM	0.068	68	115	7.82	86.89	156400
14:00PM	0.05	50	114.2	5.71	63.44	114200
14:30PM	0.0395	39.5	113	4.4635	49.59	89270
15:00PM	0.029	29	111	3.219	35.77	64380
15:30PM	0.018	18	110.5	1.989	22.10	39780
16:00PM	0.009	9	110	0.99	11.00	19800
Average	0.04079444	40.7944444	106.622222	4.65668333	51.7409259	1676406

DATE	22/11/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.007	7	105	0.735	8.17	14700
08:30AM	0.013	13	109	1.417	15.74	28340
09::00AM	0.018	18	112	2.016	22.40	40320
09:30AM	0.0296	29.6	113.1	3.34776	37.20	66955.2
10:00AM	0.041	41	113.5	4.6535	51.71	93070
10:30AM	0.055	55	114	6.27	69.67	125400
11:00AM	0.0695	69.5	114.2	7.9369	88.19	158738
11:30AM	0.075	75	116	8.7	96.67	174000
12:00PM	0.075	75	115.7	8.6775	96.42	173550
12:30PM	0.07	70	115.9	8.113	90.14	162260
13:00PM	0.068	68	114.8	7.8064	86.74	156128
13:30PM	0.0665	66.5	114	7.581	84.23	151620
14:00PM	0.045	45	112.8	5.076	56.40	101520
14:30PM	0.045	45	112.3	5.0535	56.15	101070
15:00PM	0.03	30	112	3.36	37.33	67200
15:30PM	0.0185	18.5	110.9	2.05165	22.80	41033
16:00PM	0.01	10	104.6	1.046	11.62	20920
Average	0.04089444	40.8944444	106.1	4.657845	51.7538333	1676824.2

DATE	**23/11/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.006	6	103	0.618	6.87	12360
08:30AM	0.009	9	108	0.972	10.80	19440
09::00AM	0.0105	10.5	110	1.155	12.83	23100
09:30AM	0.018	18	111	1.998	22.20	39960
10:00AM	0.025	25	111.5	2.7875	30.97	55750
10:30AM	0.02	20	112	2.24	24.89	44800
11:00AM	0.0512	51.2	112.3	5.74976	63.89	114995.2
11:30AM	0.055	55	115.2	6.336	70.40	126720
12:00PM	0.063	63	116	7.308	81.20	146160
12:30PM	0.066	66	114	7.524	83.60	150480
13:00PM	0.06	60	113.3	6.798	75.53	135960
13:30PM	0.054	54	113	6.102	67.80	122040
14:00PM	0.048	48	112	5.376	59.73	107520
14:30PM	0.035	35	111	3.885	43.17	77700
15:00PM	0.023	23	110.5	2.5415	28.24	50830
15:30PM	0.018	18	108	1.944	21.60	38880
16:00PM	0.01	10	106	1.06	11.78	21200
Average	0.03176111	31.7611111	104.822222	3.57748667	39.7498519	1287895.2

DATE	26/11/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	$Esc(J/m^2)$
07.30AM	0	0	0	0	0	0
08:00AM	0.009	9	106.5	0.9585	10.65	19170
08:30AM	0.012	12	107	1.284	14.27	25680
09::00AM	0.015	15	110	1.65	18.33	33000
09:30AM	0.018	18	111	1.998	22.20	39960
10:00AM	0.025	25	112.2	2.805	31.17	56100
10:30AM	0.0356	35.6	112.5	4.005	44.50	80100
11:00AM	0.048	48	112.7	5.4096	60.11	108192
11:30AM	0.056	56	113	6.328	70.31	126560
12:00PM	0.065	65	118	7.67	85.22	153400
12:30PM	0.0625	62.5	117.5	7.34375	81.60	146875
13:00PM	0.053	53	116	6.148	68.31	122960
13:30PM	0.047	47	115.3	5.4191	60.21	108382
14:00PM	0.043	43	114	4.902	54.47	98040
14:30PM	0.0353	35.3	112.1	3.95713	43.97	79142.6
15:00PM	0.0232	23.2	110	2.552	28.36	51040
15:30PM	0.015	15	105	1.575	17.50	31500
16:00PM	0.01	10	103	1.03	11.44	20600
Average	0.03181111	31.8111111	105.322222	3.61306	40.1451111	1300701.6

DATE	27/11/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.01	10	108	1.08	12.00	21600
08:30AM	0.0112	11.2	110	1.232	13.69	24640
09::00AM	0.019	19	112	2.128	23.64	42560
09:30AM	0.029	29	112.9	3.2741	36.38	65482
10:00AM	0.0395	39.5	113	4.4635	49.59	89270
10:30AM	0.045	45	113.3	5.0985	56.65	101970
11:00AM	0.06	60	115	6.9	76.67	138000
11:30AM	0.068	68	117	7.956	88.40	159120
12:00PM	0.073	73	118	8.614	95.71	172280
12:30PM	0.075	75	116.2	8.715	96.83	174300
13:00PM	0.0675	67.5	115	7.7625	86.25	155250
13:30PM	0.055	55	113.5	6.2425	69.36	124850
14:00PM	0.043	43	112	4.816	53.51	96320
14:30PM	0.033	33	109.5	3.6135	40.15	72270
15:00PM	0.025	25	108	2.7	30.00	54000
15:30PM	0.0195	19.5	106.4	2.0748	23.05	41496
16:00PM	0.01	10	105	1.05	11.67	21000
Average	0.03792778	37.9277778	105.822222	4.3178	47.9755556	1554408

DATE	**28/11/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.011	11	105	1.155	12.83	23100
08:30AM	0.016	16	106	1.696	18.84	33920
09::00AM	0.022	22	112.4	2.4728	27.48	49456
09:30AM	0.0296	29.6	112.8	3.33888	37.10	66777.6
10:00AM	0.024	24	113	2.712	30.13	54240
10:30AM	0.0465	46.5	114	5.301	58.90	106020
11:00AM	0.058	58	115	6.67	74.11	133400
11:30AM	0.073	73	117	8.541	94.90	170820
12:00PM	0.075	75	119	8.925	99.17	178500
12:30PM	0.07	70	118.5	8.295	92.17	165900
13:00PM	0.068	68	117	7.956	88.40	159120
13:30PM	0.063	63	115	7.245	80.50	144900
14:00PM	0.055	55	113.5	6.2425	69.36	124850
14:30PM	0.038	38	111	4.218	46.87	84360
15:00PM	0.022	22	110	2.42	26.89	48400
15:30PM	0.015	15	109	1.635	18.17	32700
16:00PM	0.012	12	107	1.284	14.27	25680
Average	0.03878333	38.7833333	106.4	4.45039889	49.4488765	1602143.6

DATE	**29/11/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.01	10	111.7	1.117	12.41	22340
08:30AM	0.014	14	112	1.568	17.42	31360
09::00AM	0.018	18	112.5	2.025	22.50	40500
09:30AM	0.025	25	114	2.85	31.67	57000
10:00AM	0.0305	30.5	114.8	3.5014	38.90	70028
10:30AM	0.038	38	115.5	4.389	48.77	87780
11:00AM	0.045	45	116.9	5.2605	58.45	105210
11:30AM	0.053	53	117	6.201	68.90	124020
12:00PM	0.0685	68.5	117.5	8.04875	89.43	160975
12:30PM	0.07	70	116	8.12	90.22	162400
13:00PM	0.068	68	115	7.82	86.89	156400
13:30PM	0.065	65	114.5	7.4425	82.69	148850
14:00PM	0.067	67	113	7.571	84.12	151420
14:30PM	0.063	63	112.2	7.0686	78.54	141372
15:00PM	0.044	44	111	4.884	54.27	97680
15:30PM	0.025	25	110	2.75	30.56	55000
16:00PM	0.012	12	108	1.296	14.40	25920
Average	0.03977778	39.7777778	107.311111	4.55070833	50.5634259	1638255

DATE	4/12/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	$Esc(J/m^2)$
07.30AM	0	0	0	0	0	0
08:00AM	0.0098	9.8	106	1.0388	11.54	20776
08:30AM	0.012	12	108	1.296	14.40	25920
09::00AM	0.018	18	109	1.962	21.80	39240
09:30AM	0.024	24	110.5	2.652	29.47	53040
10:00AM	0.0255	25.5	111.7	2.84835	31.65	56967
10:30AM	0.028	28	113	3.164	35.16	63280
11:00AM	0.033	33	114	3.762	41.80	75240
11:30AM	0.04	40	115.4	4.616	51.29	92320
12:00PM	0.042	42	110	4.62	51.33	92400
12:30PM	0.049	49	112.8	5.5272	61.41	110544
13:00PM	0.054	54	112.5	6.075	67.50	121500
13:30PM	0.058	58	112	6.496	72.18	129920
14:00PM	0.043	43	111	4.773	53.03	95460
14:30PM	0.035	35	110	3.85	42.78	77000
15:00PM	0.018	18	107.5	1.935	21.50	38700
15:30PM	0.015	15	107	1.605	17.83	32100
16:00PM	0.01	10	105	1.05	11.67	21000
Average	0.02857222	28.5722222	104.188889	3.18168611	35.3520679	1145407

DATE	5/12/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	$Esc(J/m^2)$
07.30AM	0	0	0	0	0	0
08:00AM	0.009	9	105	0.945	10.50	18900
08:30AM	0.013	13	110	1.43	15.89	28600
09::00AM	0.02	20	112.2	2.244	24.93	44880
09:30AM	0.028	28	113	3.164	35.16	63280
10:00AM	0.035	35	110	3.85	42.78	77000
10:30AM	0.0425	42.5	113.5	4.82375	53.60	96475
11:00AM	0.049	49	114.3	5.6007	62.23	112014
11:30AM	0.056	56	113.2	6.3392	70.44	126784
12:00PM	0.062	62	114	7.068	78.53	141360
12:30PM	0.065	65	116.5	7.5725	84.14	151450
13:00PM	0.068	68	116	7.888	87.64	157760
13:30PM	0.062	62	114	7.068	78.53	141360
14:00PM	0.04	40	112.5	4.5	50.00	90000
14:30PM	0.032	32	111	3.552	39.47	71040
15:00PM	0.02	20	110	2.2	24.44	44000
15:30PM	0.012	12	108	1.296	14.40	25920
16:00PM	0.008	8	107	0.856	9.51	17120
Average	0.03452778	34.5277778	105.566667	3.91095278	43.4550309	1407943

DATE	7/12/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.009	9	103	0.927	10.30	18540
08:30AM	0.011	11	105	1.155	12.83	23100
09::00AM	0.015	15	108	1.62	18.00	32400
09:30AM	0.018	18	113.2	2.0376	22.64	40752
10:00AM	0.03	30	113	3.39	37.67	67800
10:30AM	0.038	38	113.2	4.3016	47.80	86032
11:00AM	0.05	50	115.2	5.76	64.00	115200
11:30AM	0.035	35	113.3	3.9655	44.06	79310
12:00PM	0.02	20	114	2.28	25.33	45600
12:30PM	0.028	28	112	3.136	34.84	62720
13:00PM	0.032	32	113	3.616	40.18	72320
13:30PM	0.028	28	112.2	3.1416	34.91	62832
14:00PM	0.023	23	114.4	2.6312	29.24	52624
14:30PM	0.014	14	114.8	1.6072	17.86	32144
15:00PM	0.02	20	110	2.2	24.44	44000
15:30PM	0.011	11	108	1.188	13.20	23760
16:00PM	0.008	8	105	0.84	9.33	16800
Average	0.02166667	21.6666667	104.85	2.43315	27.035	875934

DATE	**10/12/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	110	0.88	9.78	17600
08:30AM	0.015	15	111	1.665	18.50	33300
09::00AM	0.018	18	112.2	2.0196	22.44	40392
09:30AM	0.025	25	113.5	2.8375	31.53	56750
10:00AM	0.0423	42.3	113.9	4.81797	53.53	96359.4
10:30AM	0.055	55	114	6.27	69.67	125400
11:00AM	0.062	62	115.7	7.1734	79.70	143468
11:30AM	0.025	25	111	2.775	30.83	55500
12:00PM	0.068	68	112	7.616	84.62	152320
12:30PM	0.063	63	112.2	7.0686	78.54	141372
13:00PM	0.048	48	113	5.424	60.27	108480
13:30PM	0.02	20	114.5	2.29	25.44	45800
14:00PM	0.038	38	113	4.294	47.71	85880
14:30PM	0.025	25	112.5	2.8125	31.25	56250
15:00PM	0.018	18	111	1.998	22.20	39960
15:30PM	0.015	15	110	1.65	18.33	33000
16:00PM	0.01	10	105	1.05	11.67	21000
Average	0.03085	30.85	105.805556	3.48008722	38.6676358	1252831.4

DATE	**7/12/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	105	0.84	9.33	16800
08:30AM	0.01	10	105.5	1.055	11.72	21100
09::00AM	0.013	13	106	1.378	15.31	27560
09:30AM	0.018	18	110.2	1.9836	22.04	39672
10:00AM	0.025	25	107.5	2.6875	29.86	53750
10:30AM	0.032	32	110	3.52	39.11	70400
11:00AM	0.049	49	112	5.488	60.98	109760
11:30AM	0.06	60	114	6.84	76.00	136800
12:00PM	0.033	33	116.5	3.8445	42.72	76890
12:30PM	0.058	58	115	6.67	74.11	133400
13:00PM	0.045	45	113	5.085	56.50	101700
13:30PM	0.055	55	112.2	6.171	68.57	123420
14:00PM	0.034	34	112	3.808	42.31	76160
14:30PM	0.03	30	111	3.33	37.00	66600
15:00PM	0.02	20	110	2.2	24.44	44000
15:30PM	0.015	15	106	1.59	17.67	31800
16:00PM	0.01	10	104	1.04	11.56	20800
Average	0.02861111	28.6111111	103.883333	3.19614444	35.512716	1150612

DATE	13/12/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	$Esc(J/m^2)$
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	107	0.856	9.51	17120
08:30AM	0.01	10	108.3	1.083	12.03	21660
09::00AM	0.012	12	110	1.32	14.67	26400
09:30AM	0.0122	12.2	110.7	1.35054	15.01	27010.8
10:00AM	0.013	13	111	1.443	16.03	28860
10:30AM	0.018	18	102	1.836	20.40	36720
11:00AM	0.025	25	113	2.825	31.39	56500
11:30AM	0.033	33	113.5	3.7455	41.62	74910
12:00PM	0.04	40	114	4.56	50.67	91200
12:30PM	0.03	30	115	3.45	38.33	69000
13:00PM	0.038	38	114	4.332	48.13	86640
13:30PM	0.028	28	112.7	3.1556	35.06	63112
14:00PM	0.025	25	107	2.675	29.72	53500
14:30PM	0.02	20	107.2	2.144	23.82	42880
15:00PM	0.014	14	108.3	1.5162	16.85	30324
15:30PM	0.01	10	103.8	1.038	11.53	20760
16:00PM	0.007	7	103	0.721	8.01	14420
Average	0.01906667	19.0666667	103.361111	2.11393556	23.4881728	761016.8

DATE	**18/12/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.009	9	109.5	0.9855	10.95	19710
08:30AM	0.011	11	110	1.21	13.44	24200
09::00AM	0.015	15	111.5	1.6725	18.58	33450
09:30AM	0.021	21	111.8	2.3478	26.09	46956
10:00AM	0.03	30	112	3.36	37.33	67200
10:30AM	0.038	38	112.5	4.275	47.50	85500
11:00AM	0.045	45	113.3	5.0985	56.65	101970
11:30AM	0.042	42	110.5	4.641	51.57	92820
12:00PM	0.035	35	109.3	3.8255	42.51	76510
12:30PM	0.03	30	115	3.45	38.33	69000
13:00PM	0.028	28	114.2	3.1976	35.53	63952
13:30PM	0.025	25	113	2.825	31.39	56500
14:00PM	0.023	23	110.7	2.5461	28.29	50922
14:30PM	0.02	20	108	2.16	24.00	43200
15:00PM	0.015	15	107	1.605	17.83	32100
15:30PM	0.012	12	105	1.26	14.00	25200
16:00PM	0.009	9	100	0.9	10.00	18000
Average	0.02266667	22.6666667	104.072222	2.51997222	27.9996914	907190

DATE	**19/12/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	$Esc(J/m^2)$
07.30AM	0	0	0	0	0	0
08:00AM	0.007	7	105	0.735	8.17	14700
08:30AM	0.0095	9.5	107	1.0165	11.29	20330
09::00AM	0.011	11	109	1.199	13.32	23980
09:30AM	0.015	15	109.8	1.647	18.30	32940
10:00AM	0.021	21	110.2	2.3142	25.71	46284
10:30AM	0.026	26	110.4	2.8704	31.89	57408
11:00AM	0.019	19	110.2	2.0938	23.26	41876
11:30AM	0.027	27	110.5	2.9835	33.15	59670
12:00PM	0.033	33	111	3.663	40.70	73260
12:30PM	0.042	42	111.2	4.6704	51.89	93408
13:00PM	0.048	48	111.5	5.352	59.47	107040
13:30PM	0.035	35	112	3.92	43.56	78400
14:00PM	0.002	2	113	0.226	2.51	4520
14:30PM	0.02	20	110.2	2.204	24.49	44080
15:00PM	0.015	15	107.2	1.608	17.87	32160
15:30PM	0.012	12	105	1.26	14.00	25200
16:00PM	0.01	10	102	1.02	11.33	20400
Average	0.01958333	19.5833333	103.066667	2.1546	23.94	775656

DATE	20/12/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	109.5	0.876	9.73	17520
08:30AM	0.01	10	109.8	1.098	12.20	21960
09::00AM	0.011	11	110	1.21	13.44	24200
09:30AM	0.0118	11.8	110.5	1.3039	14.49	26078
10:00AM	0.022	22	110.5	2.431	27.01	48620
10:30AM	0.028	28	110.8	3.1024	34.47	62048
11:00AM	0.033	33	110.9	3.6597	40.66	73194
11:30AM	0.03	30	111.5	3.345	37.17	66900
12:00PM	0.035	35	112.9	3.9515	43.91	79030
12:30PM	0.038	38	115.6	4.3928	48.81	87856
13:00PM	0.042	42	112.2	4.7124	52.36	94248
13:30PM	0.0375	37.5	113.3	4.24875	47.21	84975
14:00PM	0.04	40	113.5	4.54	50.44	90800
14:30PM	0.025	25	109.6	2.74	30.44	54800
15:00PM	0.013	13	107	1.391	15.46	27820
15:30PM	0.011	11	103	1.133	12.59	22660
16:00PM	0.01	10	100	1	11.11	20000
Average	0.02251667	22.5166667	103.922222	2.507525	27.8613889	902709

DATE	**21/12/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	105	0.84	9.33	16800
08:30AM	0.009	9	107	0.963	10.70	19260
09::00AM	0.0105	10.5	109	1.1445	12.72	22890
09:30AM	0.011	11	109.5	1.2045	13.38	24090
10:00AM	0.012	12	110	1.32	14.67	26400
10:30AM	0.018	18	111	1.998	22.20	39960
11:00AM	0.025	25	112.2	2.805	31.17	56100
11:30AM	0.031	31	111.14	3.44534	38.28	68906.8
12:00PM	0.033	33	110.9	3.6597	40.66	73194
12:30PM	0.035	35	112	3.92	43.56	78400
13:00PM	0.045	45	109.5	4.9275	54.75	98550
13:30PM	0.048	48	112.8	5.4144	60.16	108288
14:00PM	0.035	35	115	4.025	44.72	80500
14:30PM	0.02	20	110.2	2.204	24.49	44080
15:00PM	0.016	16	105.4	1.6864	18.74	33728
15:30PM	0.012	12	105	1.26	14.00	25200
16:00PM	0.009	9	102	0.918	10.20	18360
Average	0.02097222	20.9722222	103.202222	2.31863	25.7625556	834706.8

DATE	24/12/2018					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	P_{sc}(W/m^2)	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.009	9	107.5	0.9675	10.75	19350
08:30AM	0.01	10	108.2	1.082	12.02	21640
09::00AM	0.012	12	109	1.308	14.53	26160
09:30AM	0.015	15	109.5	1.6425	18.25	32850
10:00AM	0.018	18	110.2	1.9836	22.04	39672
10:30AM	0.018	18	110	1.98	22.00	39600
11:00AM	0.023	23	111	2.553	28.37	51060
11:30AM	0.03	30	112.5	3.375	37.50	67500
12:00PM	0.043	43	113.3	4.8719	54.13	97438
12:30PM	0.049	49	113	5.537	61.52	110740
13:00PM	0.04	40	110.3	4.412	49.02	88240
13:30PM	0.033	33	113.2	3.7356	41.51	74712
14:00PM	0.025	25	113.3	2.8325	31.47	56650
14:30PM	0.018	18	110	1.98	22.00	39600
15:00PM	0.015	15	108	1.62	18.00	32400
15:30PM	0.011	11	105.1	1.1561	12.85	23122
16:00PM	0.009	9	104.8	0.9432	10.48	18864
Average	0.021	21	103.827778	2.33221667	25.9135185	839598

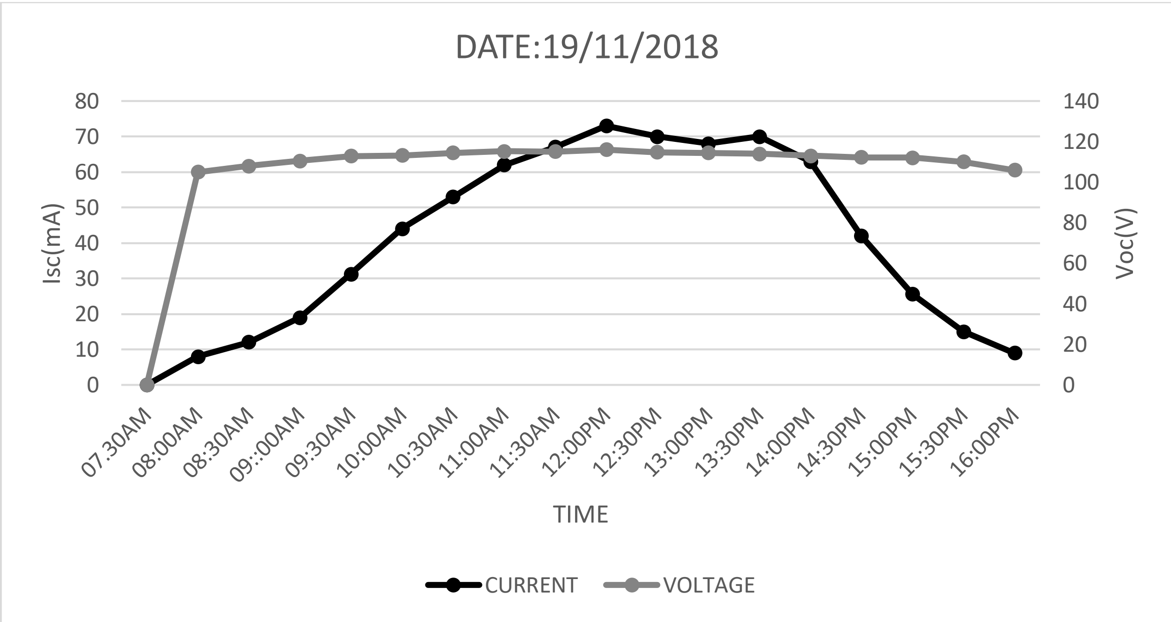
DATE	**25/12/2018**					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	$Esc(J/m^2)$
07.30AM	0	0	0	0	0	0
08:00AM	0.009	9	105	0.945	10.50	18900
08:30AM	0.011	11	108	1.188	13.20	23760
09::00AM	0.016	16	110	1.76	19.56	35200
09:30AM	0.0212	21.2	110.5	2.3426	26.03	46852
10:00AM	0.028	28	111.2	3.1136	34.60	62272
10:30AM	0.033	33	112.7	3.7191	41.32	74382
11:00AM	0.035	35	114	3.99	44.33	79800
11:30AM	0.031	31	111	3.441	38.23	68820
12:00PM	0.028	28	112.7	3.1556	35.06	63112
12:30PM	0.022	22	111.9	2.4618	27.35	49236
13:00PM	0.03	30	113.5	3.405	37.83	68100
13:30PM	0.04	40	113.5	4.54	50.44	90800
14:00PM	0.032	32	112.2	3.5904	39.89	71808
14:30PM	0.02	20	111	2.22	24.67	44400
15:00PM	0.015	15	109	1.635	18.17	32700
15:30PM	0.012	12	108	1.296	14.40	25920
16:00PM	0.01	10	105	1.05	11.67	21000
Average	0.02184444	21.8444444	104.4	2.43628333	27.0698148	877062

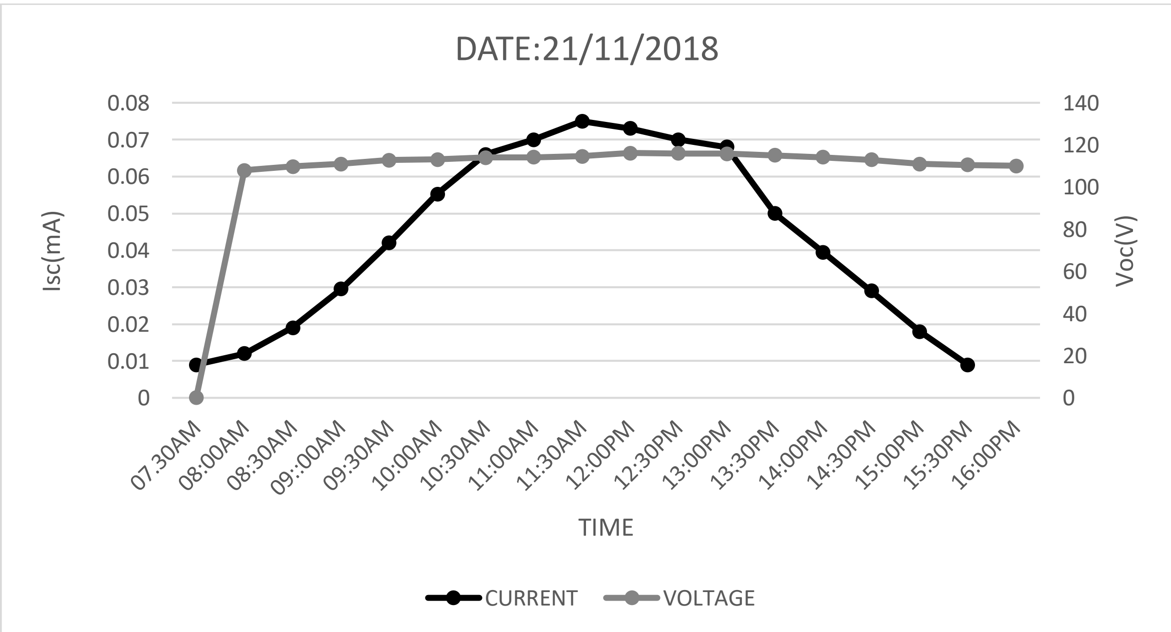
DATE	3/1/2019					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	Esc(J/m^2)
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	109.5	0.876	9.73	17520
08:30AM	0.01	10	110	1.1	12.22	22000
09::00AM	0.011	11	111.3	1.2243	13.60	24486
09:30AM	0.009	9	107.3	0.9657	10.73	19314
10:00AM	0.0095	9.5	109.6	1.0412	11.57	20824
10:30AM	0.015	15	110.8	1.662	18.47	33240
11:00AM	0.018	18	109	1.962	21.80	39240
11:30AM	0.022	22	108.5	2.387	26.52	47740
12:00PM	0.025	25	108.8	2.72	30.22	54400
12:30PM	0.023	23	110	2.53	28.11	50600
13:00PM	0.045	45	108.4	4.878	54.20	97560
13:30PM	0.035	35	112	3.92	43.56	78400
14:00PM	0.0266	26.6	110	2.926	32.51	58520
14:30PM	0.025	25	109.8	2.745	30.50	54900
15:00PM	0.0232	23.2	108	2.5056	27.84	50112
15:30PM	0.022	22	106.2	2.3364	25.96	46728
16:00PM	0.012	12	105	1.26	14.00	25200
Average	0.01885	18.85	103.011111	2.05773333	22.8637037	740784

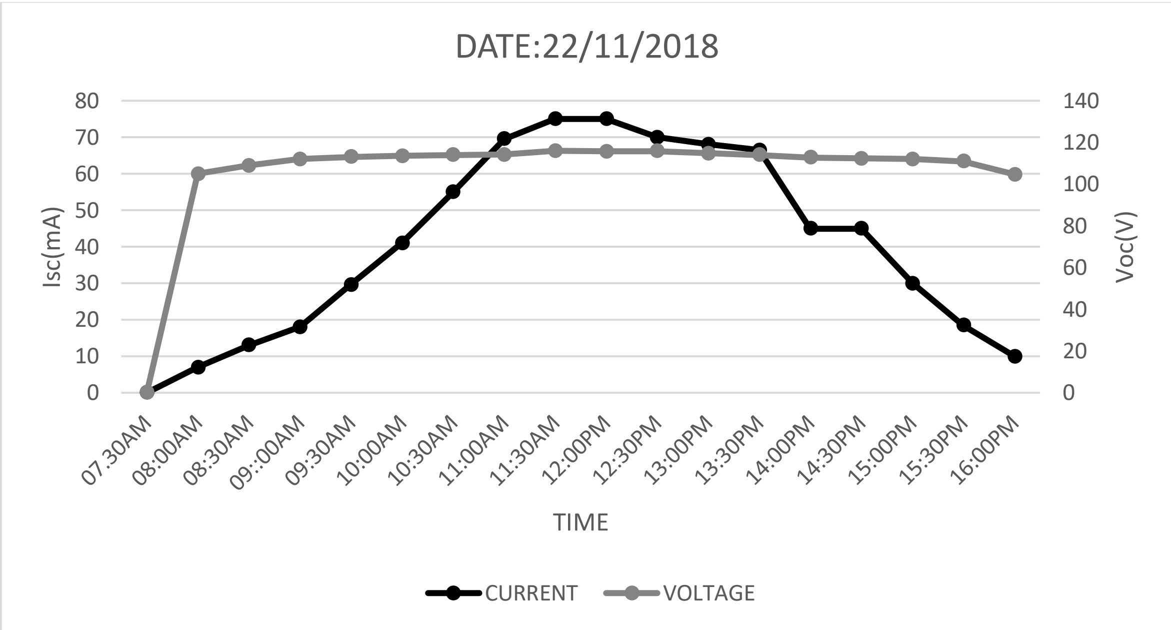
DATE	10/1/2019					
TIME	Current(A)	I_{sc}(mA)	V_{oc}(V)	Power(W)	$P_{sc}(W/m^2)$	$Esc(J/m^2)$
07.30AM	0	0	0	0	0	0
08:00AM	0.008	8	103	0.824	9.16	16480
08:30AM	0.009	9	106.2	0.9558	10.62	19116
09::00AM	0.012	12	108	1.296	14.40	25920
09:30AM	0.013	13	110.8	1.4404	16.00	28808
10:00AM	0.011	11	111.1	1.2221	13.58	24442
10:30AM	0.015	15	112.7	1.6905	18.78	33810
11:00AM	0.014	14	112.7	1.5778	17.53	31556
11:30AM	0.018	18	112.8	2.0304	22.56	40608
12:00PM	0.023	23	114	2.622	29.13	52440
12:30PM	0.028	28	113.3	3.1724	35.25	63448
13:00PM	0.035	35	110.6	3.871	43.01	77420
13:30PM	0.04	40	109	4.36	48.44	87200
14:00PM	0.033	33	110	3.63	40.33	72600
14:30PM	0.02	20	107.2	2.144	23.82	42880
15:00PM	0.017	17	106	1.802	20.02	36040
15:30PM	0.01	10	100	1	11.11	20000
16:00PM	0.008	8	99	0.792	8.80	15840
Average	0.01744444	17.4444444	102.577778	1.9128	21.2533333	688608

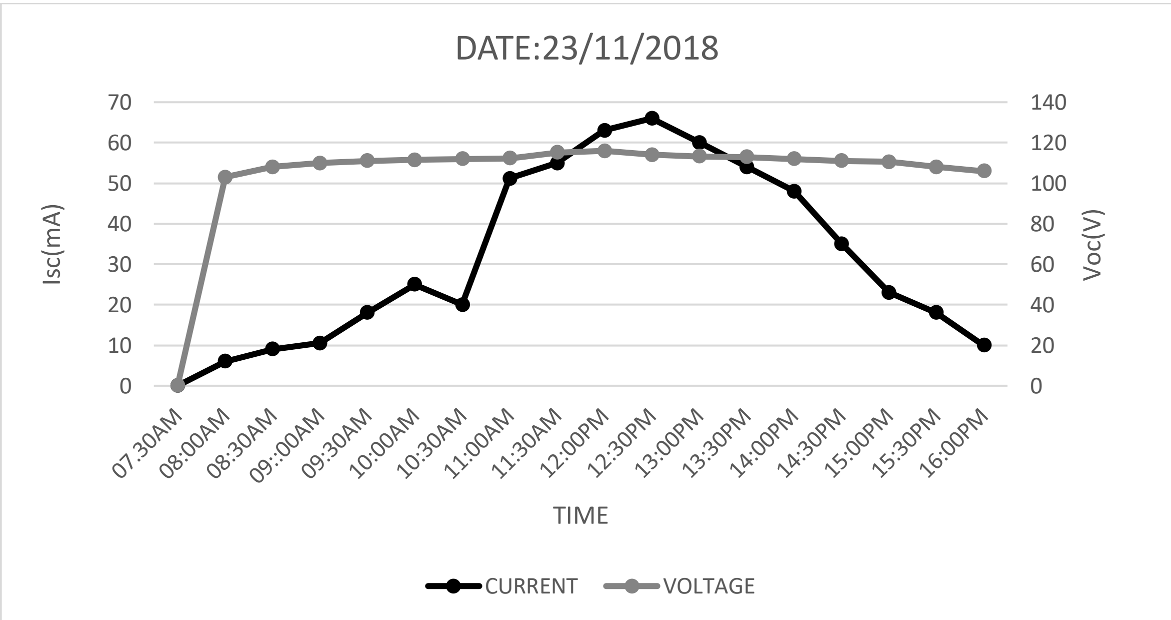
APPENDIX 4

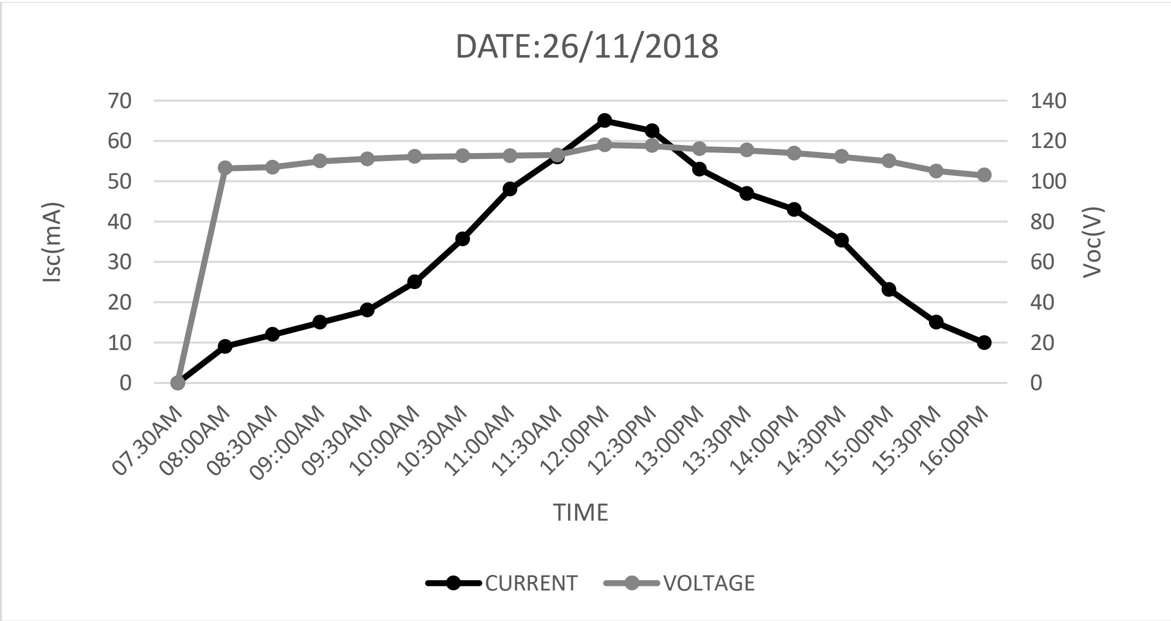
RELATIONSHIP BETWEEN SHORT CIRCUIT CURRENT (Isc) AND OPEN CIRCUIT VOLTAGE (Voc) AGAINST THE LOCAL TIME.

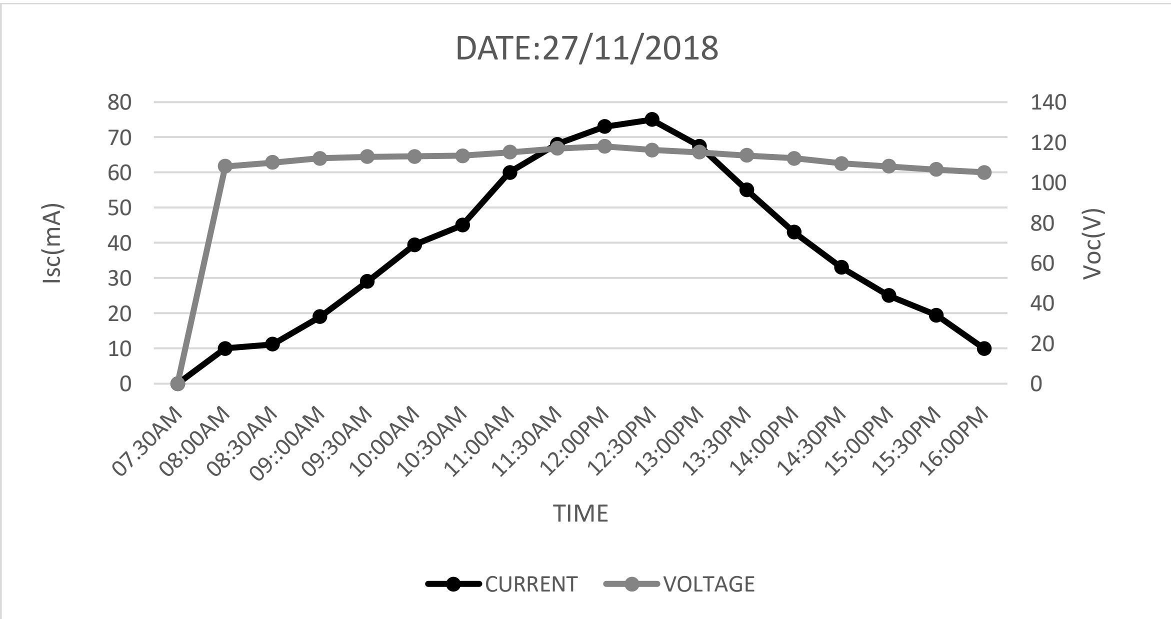


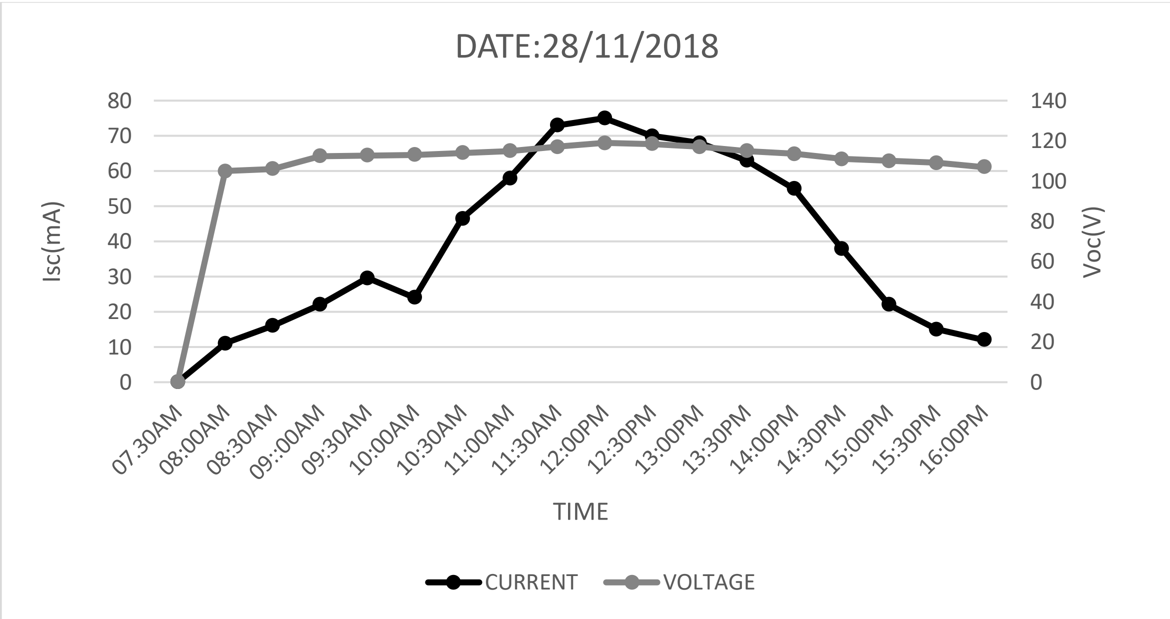


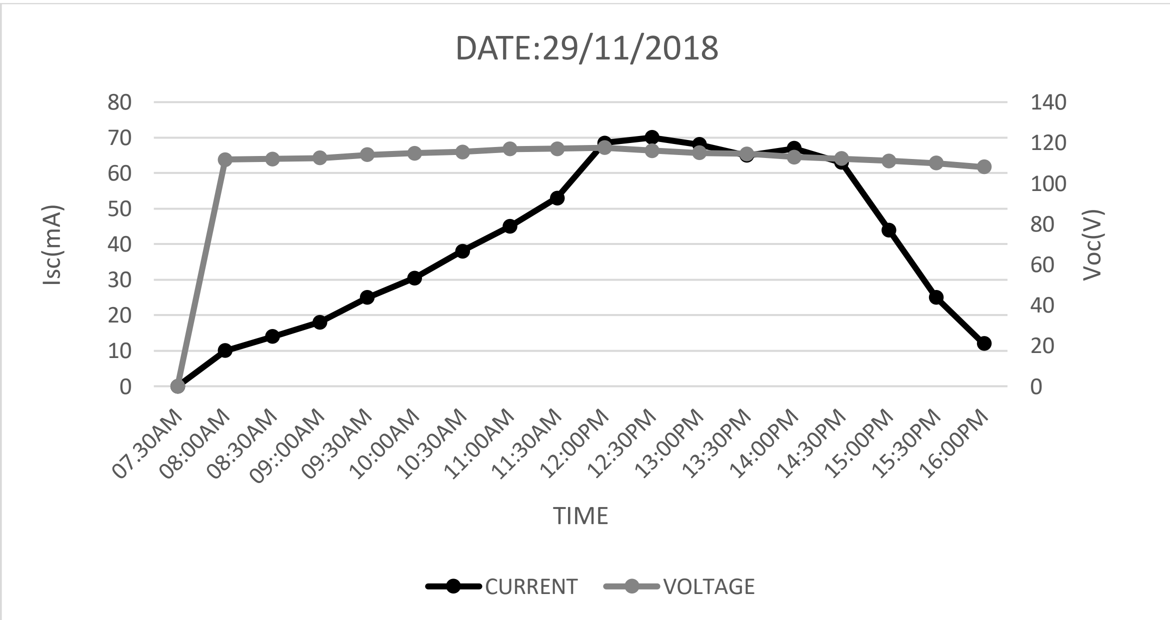

DATE:22/11/2018
80
70
60
50
40
30
20
10
0
Isc(mA)
140
120
100
80
60
40
20
0
Voc(V)
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

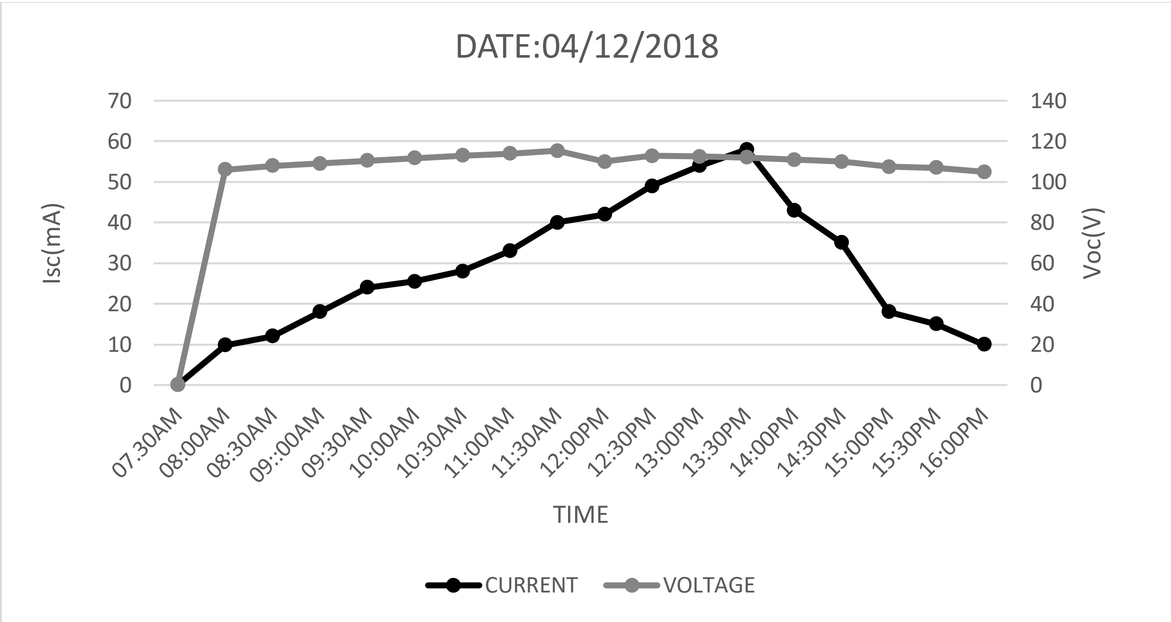

DATE:23/11/2018
70
60
50
40
30
20
10
0
Isc(mA)
140
120
100
80
60
40
20
0
Voc(V)
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

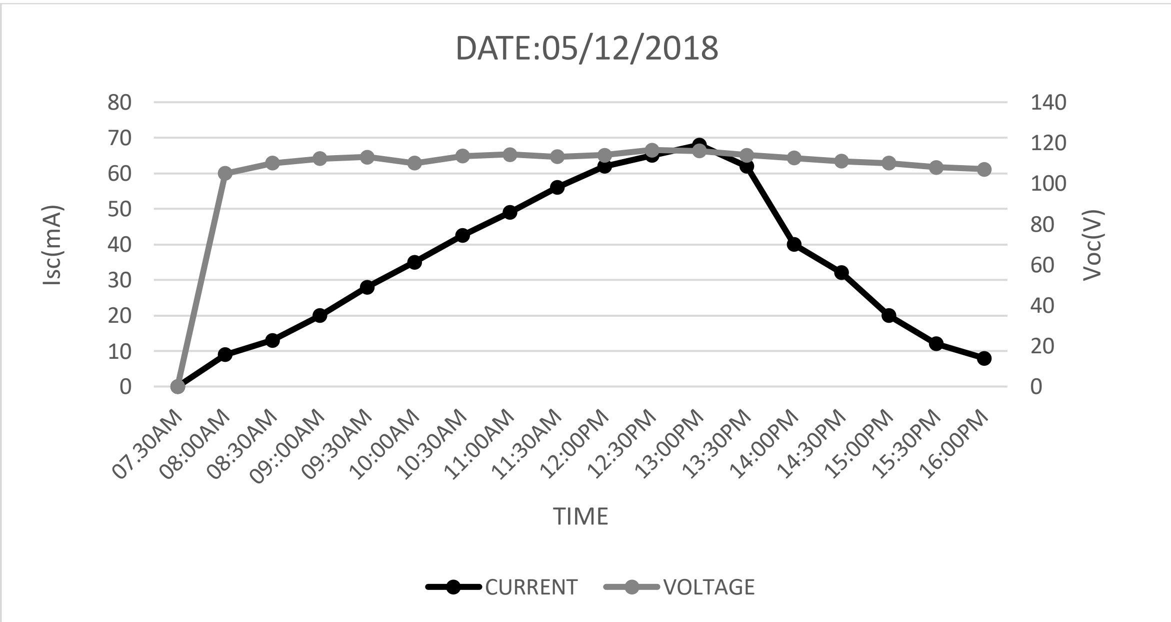

DATE:26/11/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

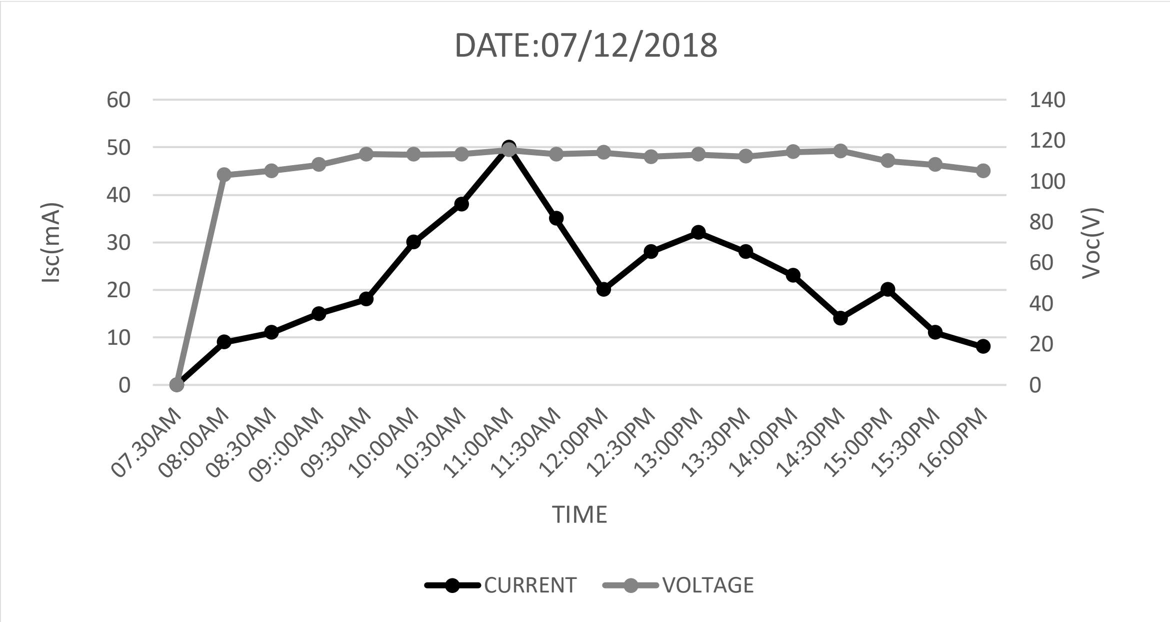

DATE:27/11/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

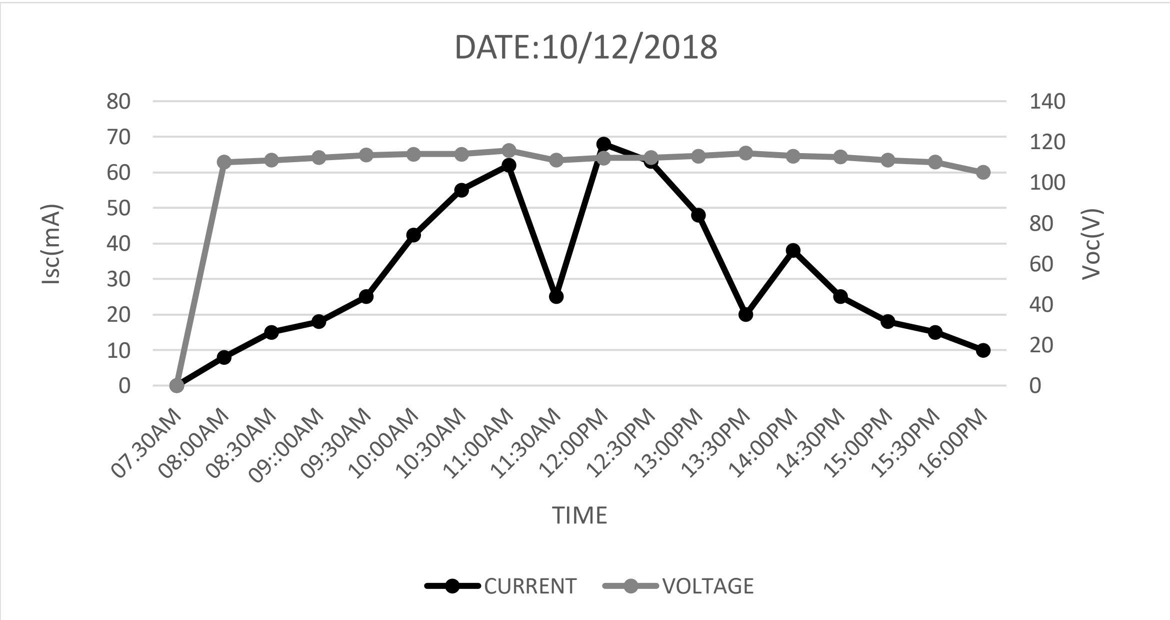

DATE:28/11/2018
80
70
60
50
40
30
20
10
0
Isc(mA)
140
120
100
80
60
40
20
0
Voc(V)
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

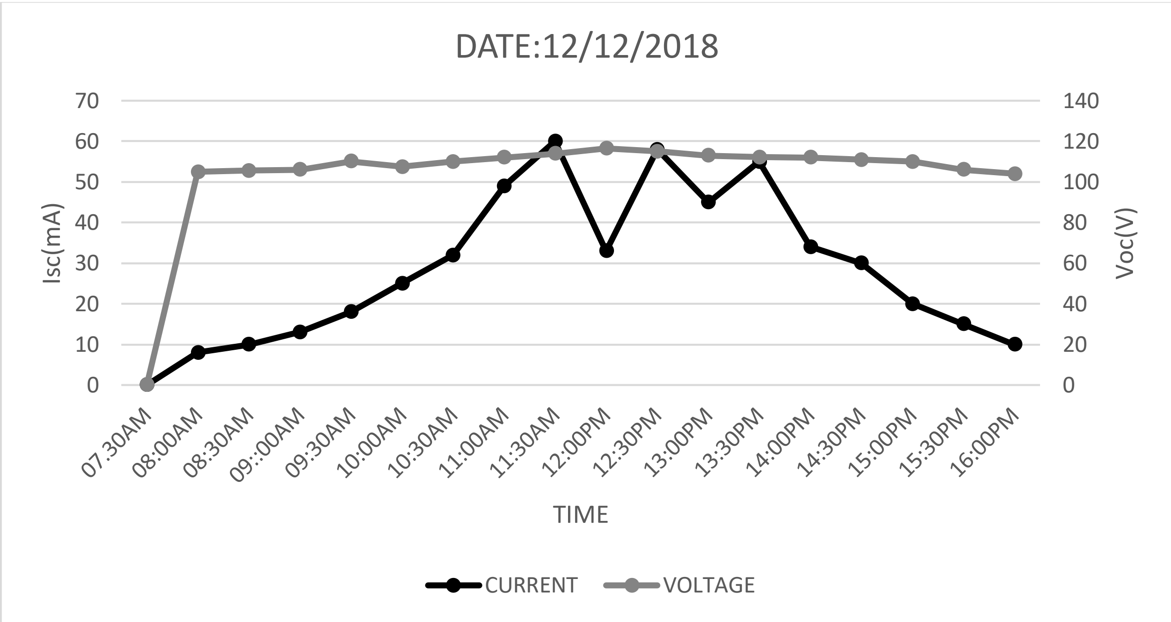

DATE:29/11/2018
80
70
60
50
40
30
20
10
0
Isc(mA)
140
120
100
80
60
40
20
0
Voc(V)
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

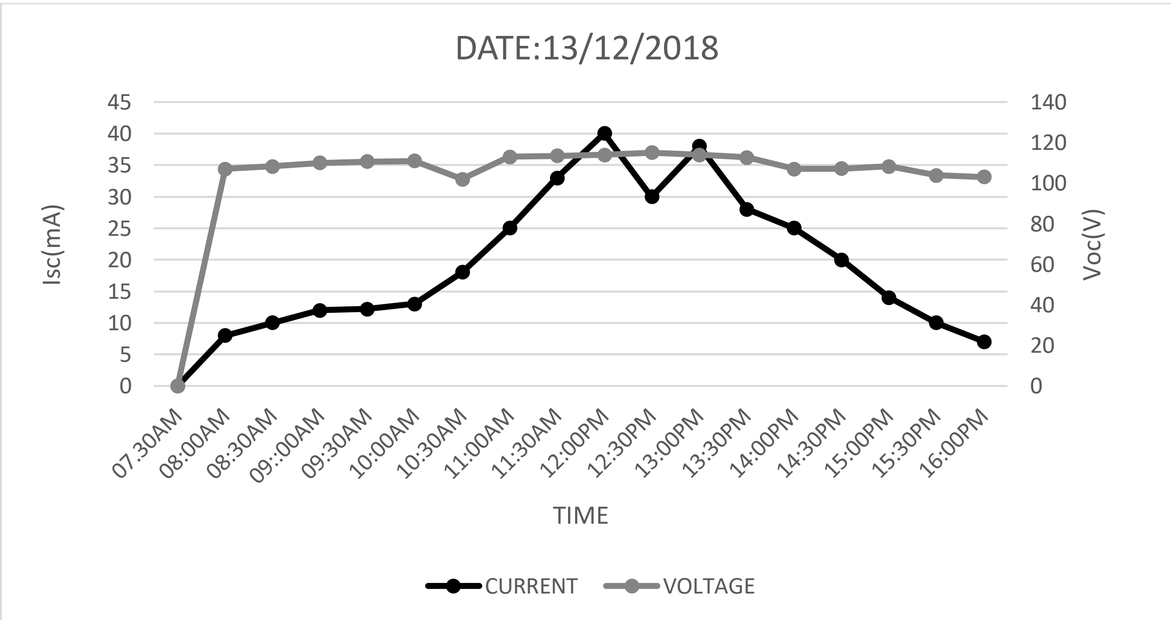

DATE:04/12/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

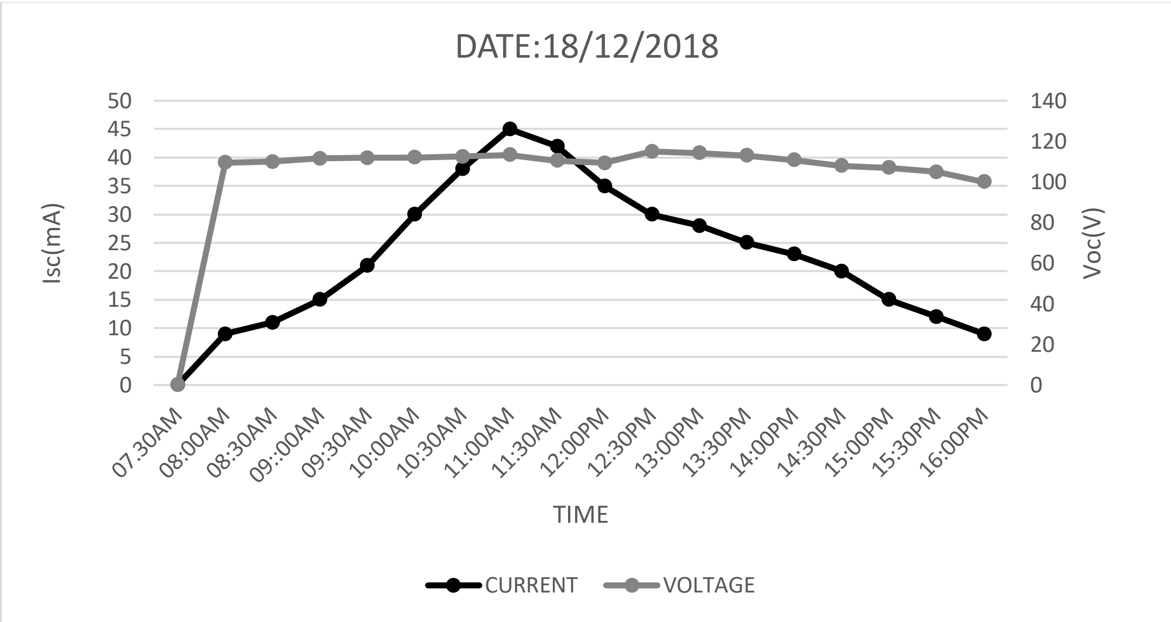

DATE:05/12/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

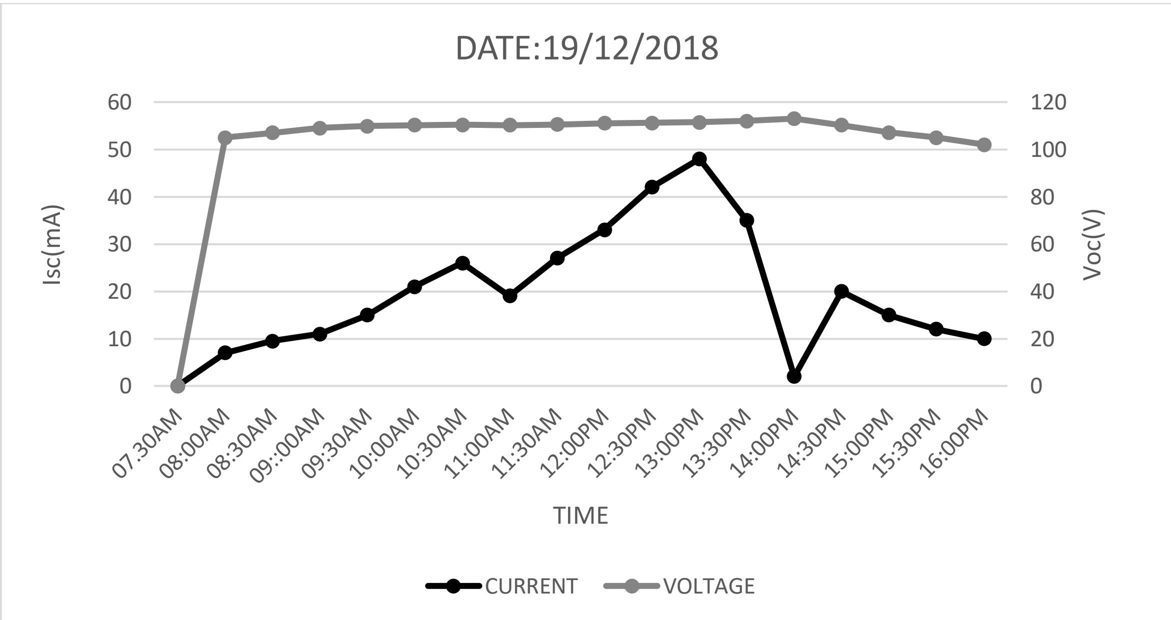

DATE:07/12/2018
Isc(mA)
Voc(V)
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

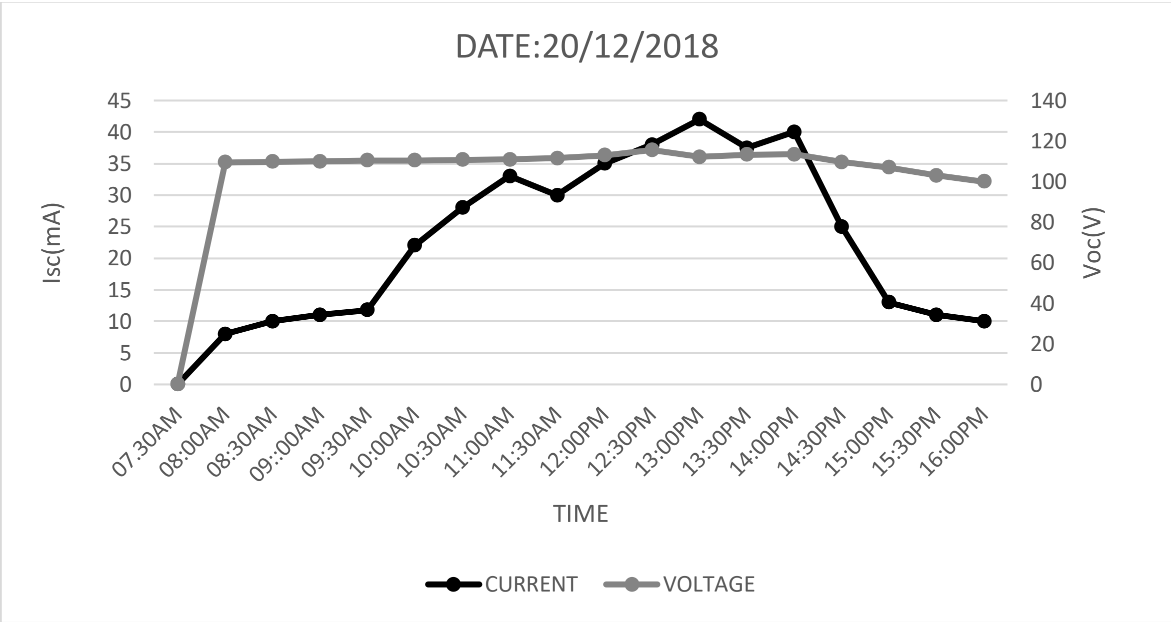

DATE:10/12/2018
Isc(mA)
Voc(V)
80
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

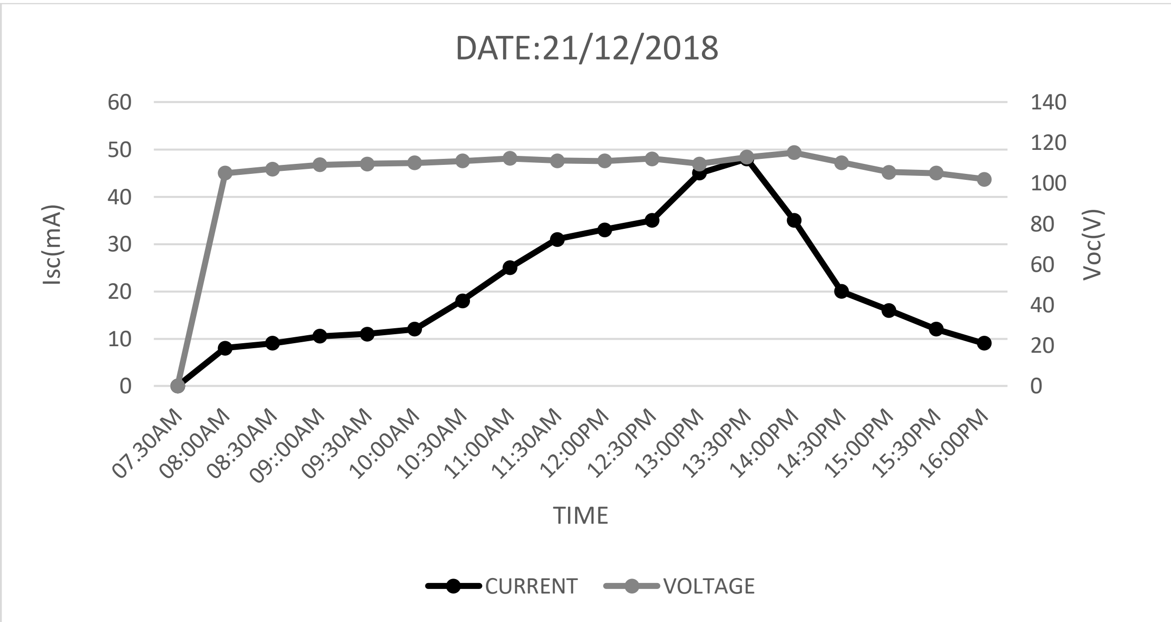

DATE:12/12/2018
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
Isc(mA)
Voc(V)
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

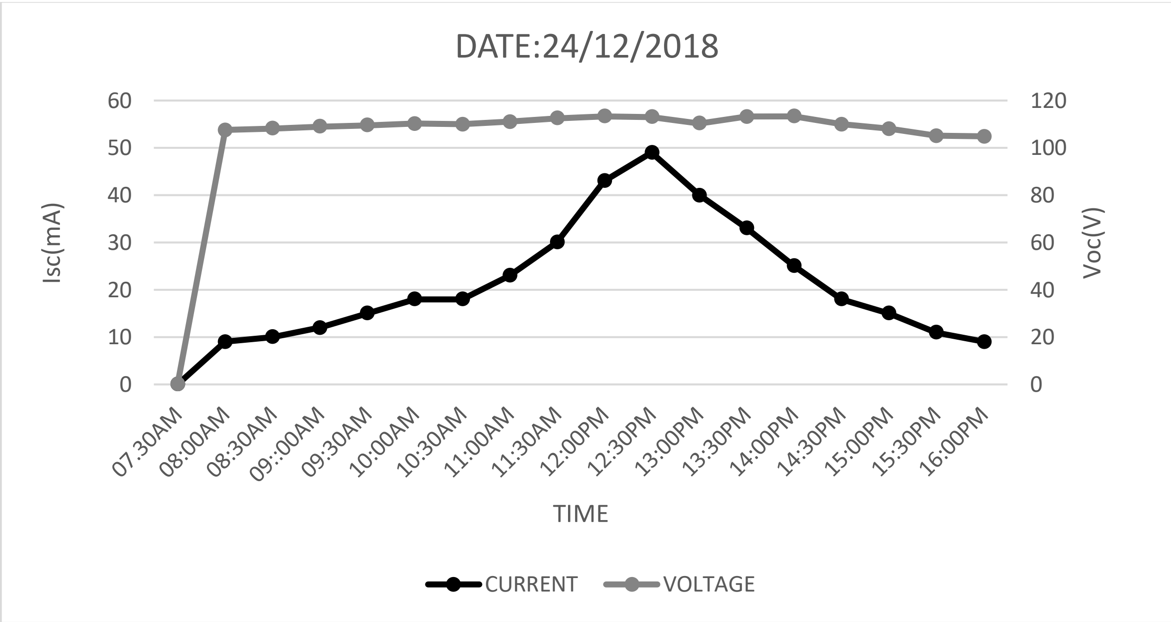

DATE:13/12/2018
45
40
35
30
25
20
15
10
5
0
140
120
100
80
60
40
20
0
Isc(mA)
Voc(V)
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

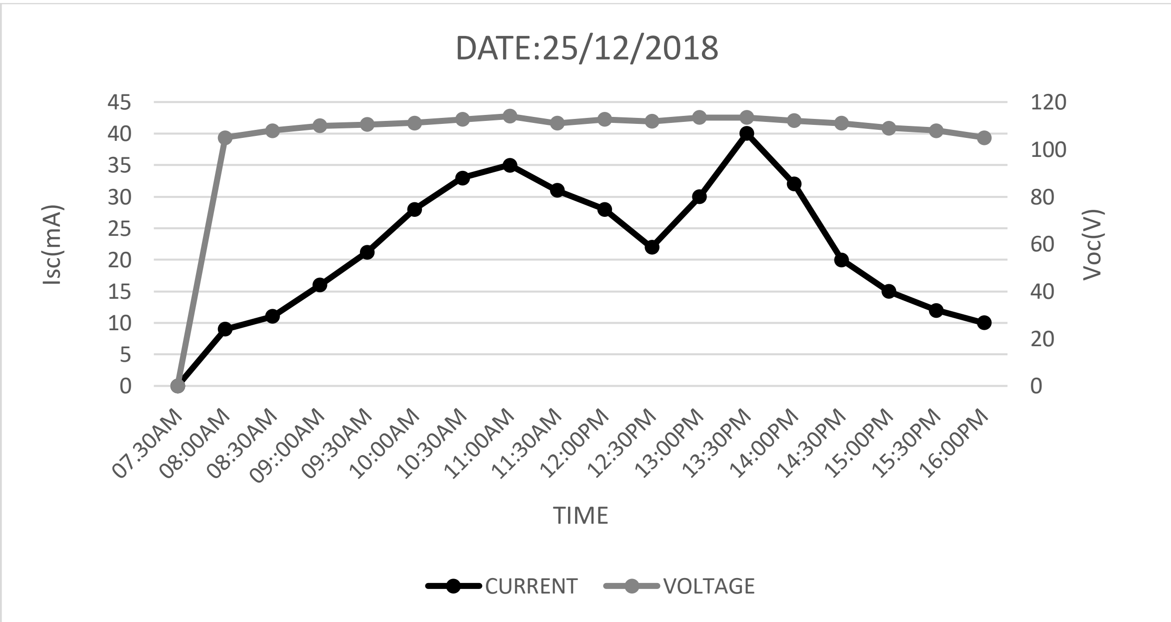

DATE:18/12/2018
Isc(mA)
Voc(V)
50
45
40
35
30
25
20
15
10
5
0
140
120
100
80
60
40
20
0
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

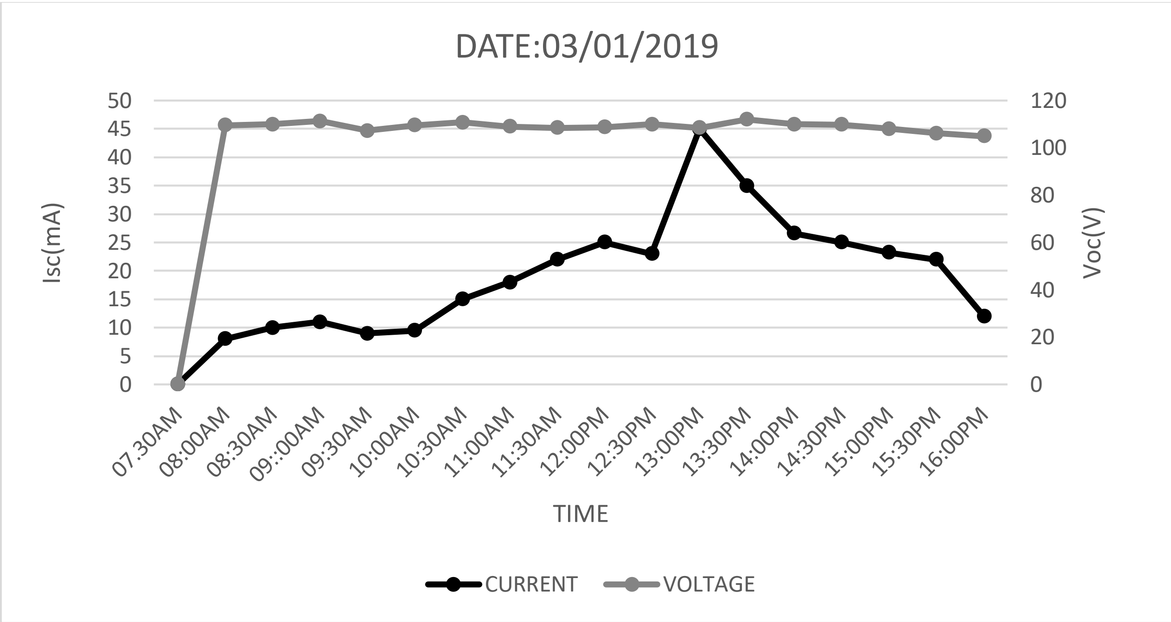

DATE:19/12/2018
Isc(mA)
Voc(V)
60
50
40
30
20
10
0
120
100
80
60
40
20
0
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

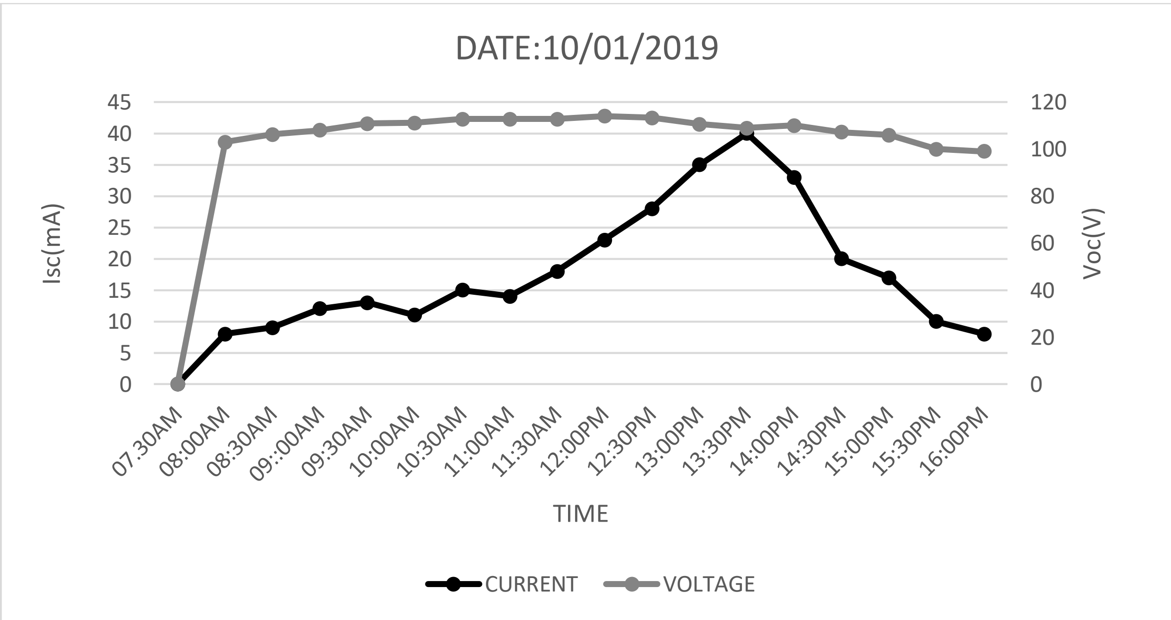

DATE:20/12/2018
Isc(mA)
Voc(V)
0
5
10
15
20
25
30
35
40
45
0
20
40
60
80
100
120
140
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE


DATE:21/12/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
0
20
40
60
80
100
120
140
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE


DATE:24/12/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
0
20
40
60
80
100
120
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

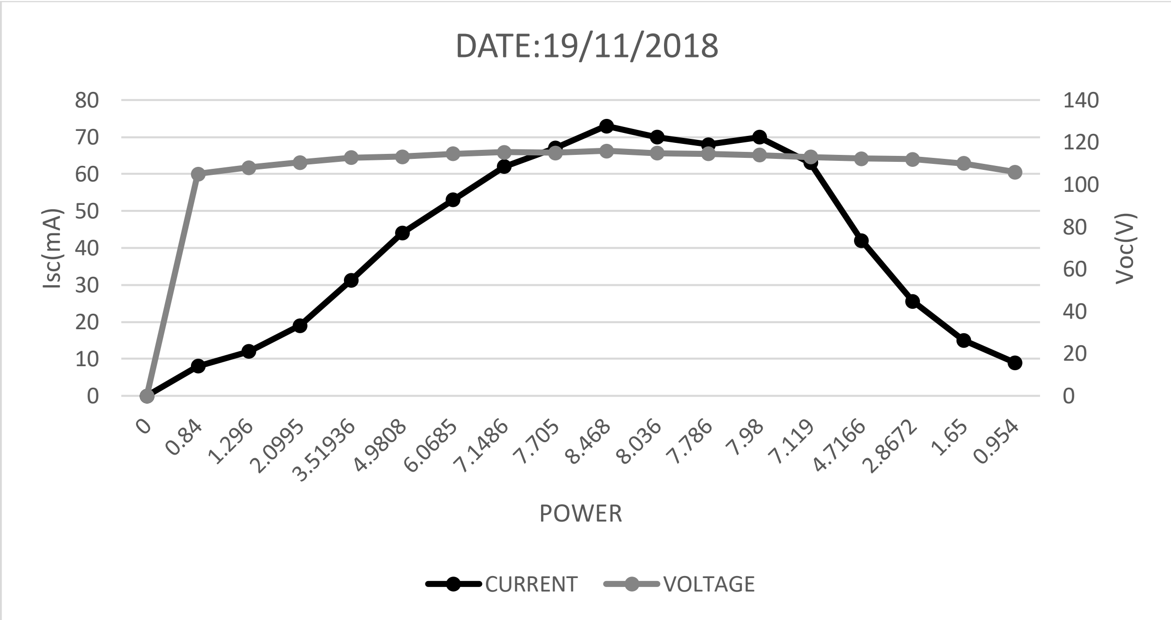

DATE:25/12/2018
Isc(mA)
Voc(V)
0
5
10
15
20
25
30
35
40
45
0
20
40
60
80
100
120
07.30AM
08:00AM
08:30AM
09::00AM
09:30AM
10:00AM
10:30AM
11:00AM
11:30AM
12:00PM
12:30PM
13:00PM
13:30PM
14:00PM
14:30PM
15:00PM
15:30PM
16:00PM
TIME
CURRENT
VOLTAGE

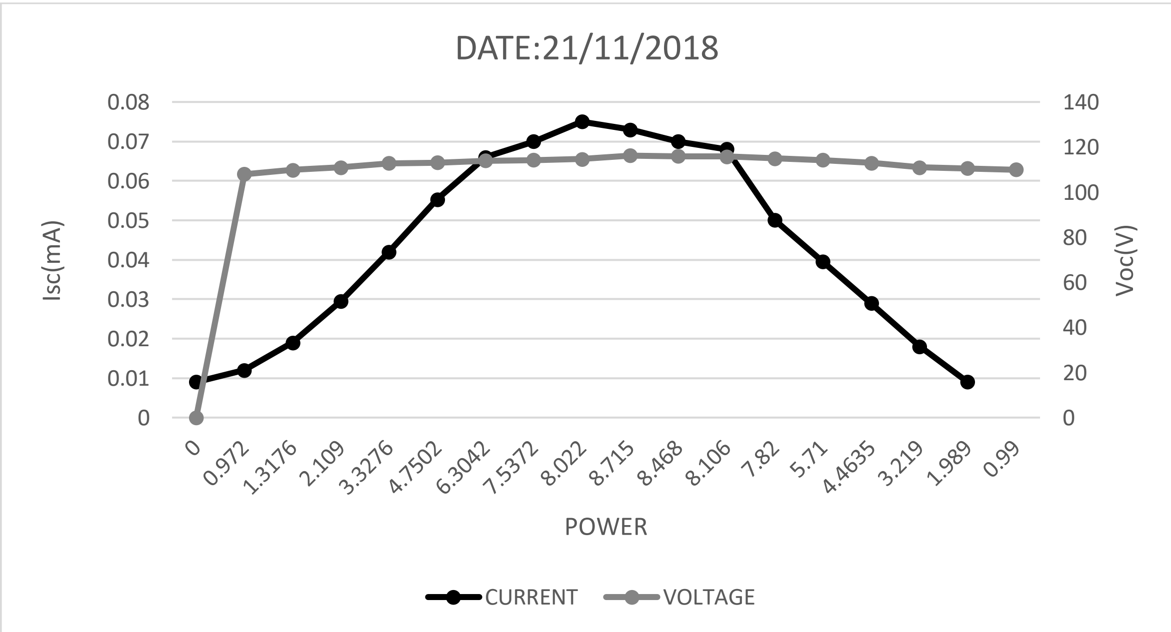

DATE:03/01/2019
Isc(mA)
Voc(V)
TIME
07.30AM 08:00AM 08:30AM 09::00AM 09:30AM 10:00AM 10:30AM 11:00AM 11:30AM 12:00PM 12:30PM 13:00PM 13:30PM 14:00PM 14:30PM 15:00PM 15:30PM 16:00PM
CURRENT
VOLTAGE

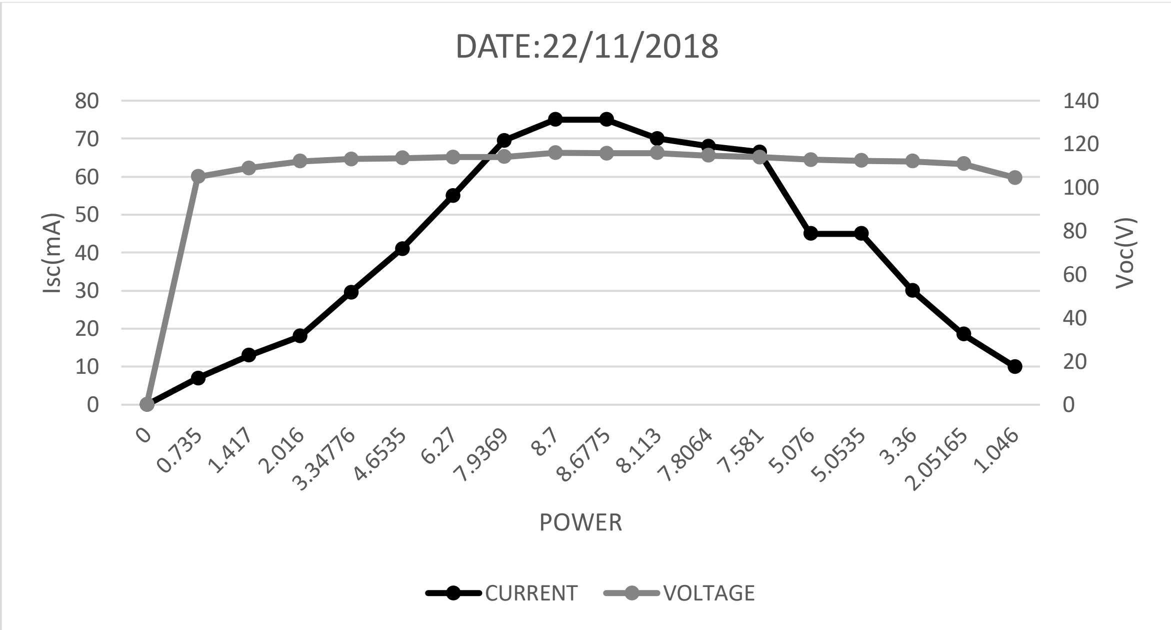

DATE:10/01/2019
Isc(mA)
Voc(V)
TIME
07.30AM 08:00AM 08:30AM 09::00AM 09:30AM 10:00AM 10:30AM 11:00AM 11:30AM 12:00PM 12:30PM 13:00PM 13:30PM 14:00PM 14:30PM 15:00PM 15:30PM 16:00PM
CURRENT
VOLTAGE

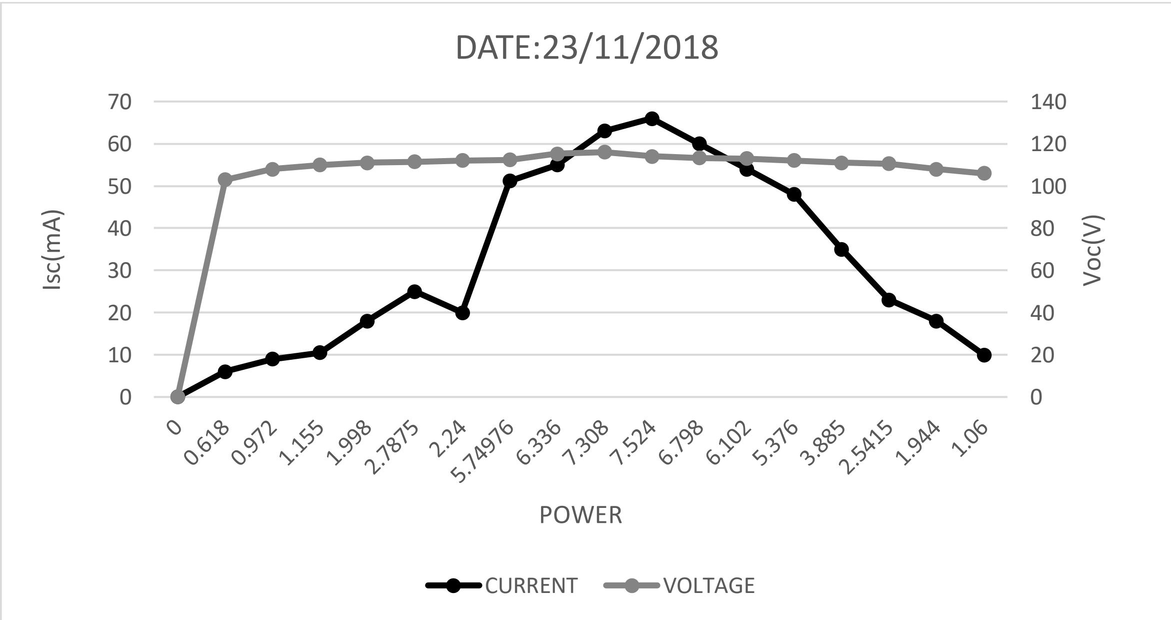
APPENDIX 5

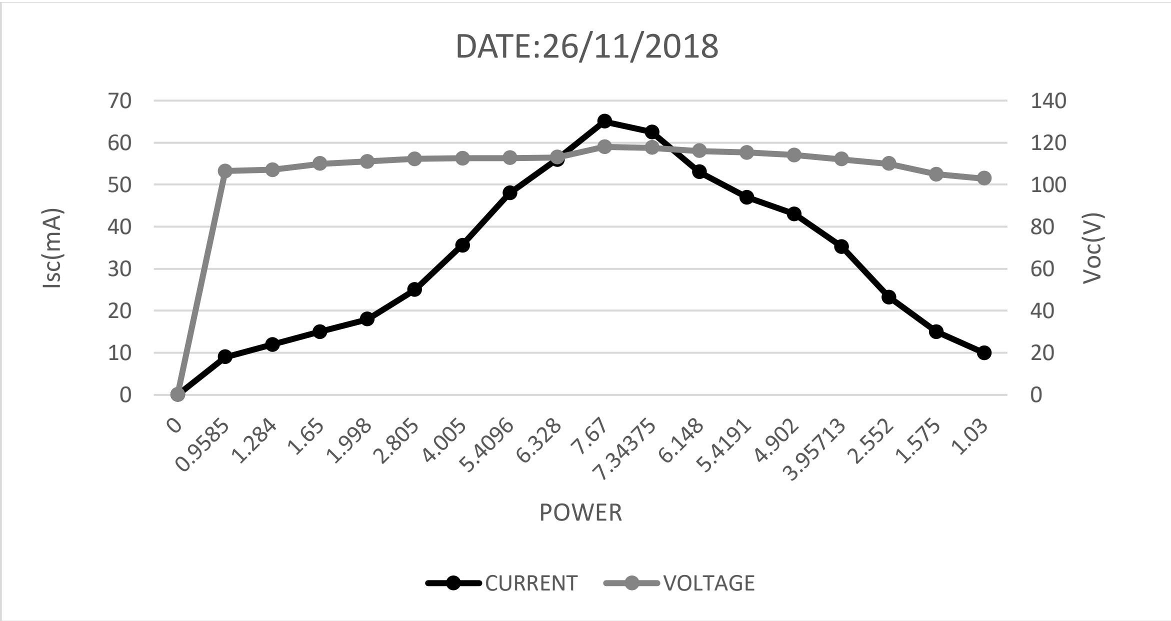
RELATIONSHIP BETWEEN SHORT CIRCUIT CURRENT (Isc) AND OPEN CIRCUIT VOLTAGE (Voc) AGAINST SOLAR CELL'S POWER

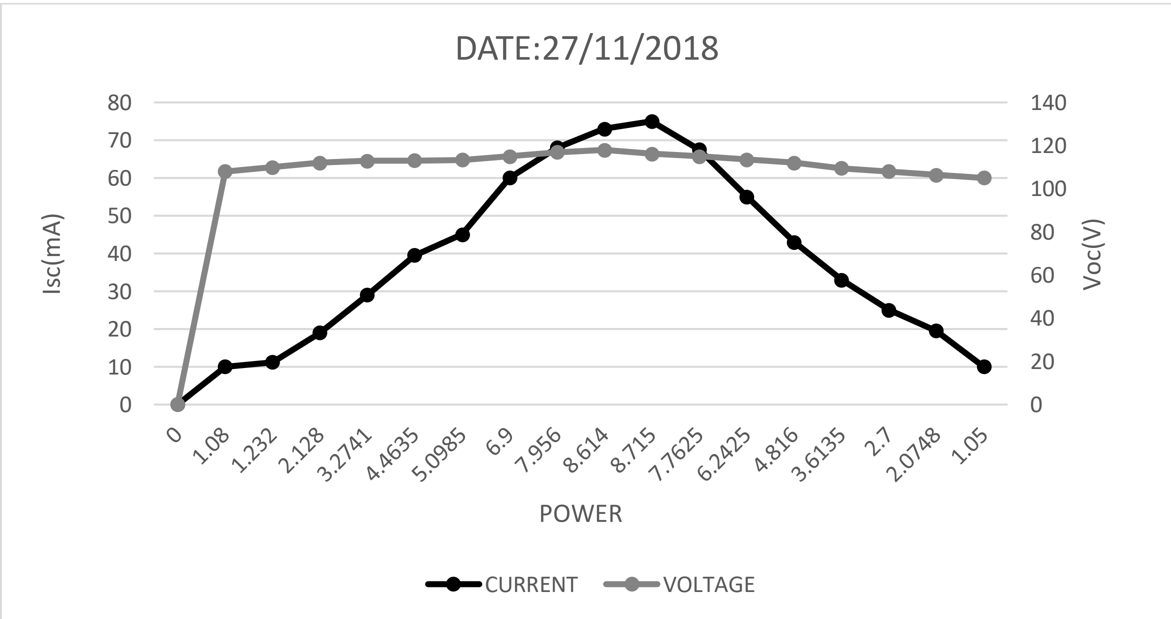


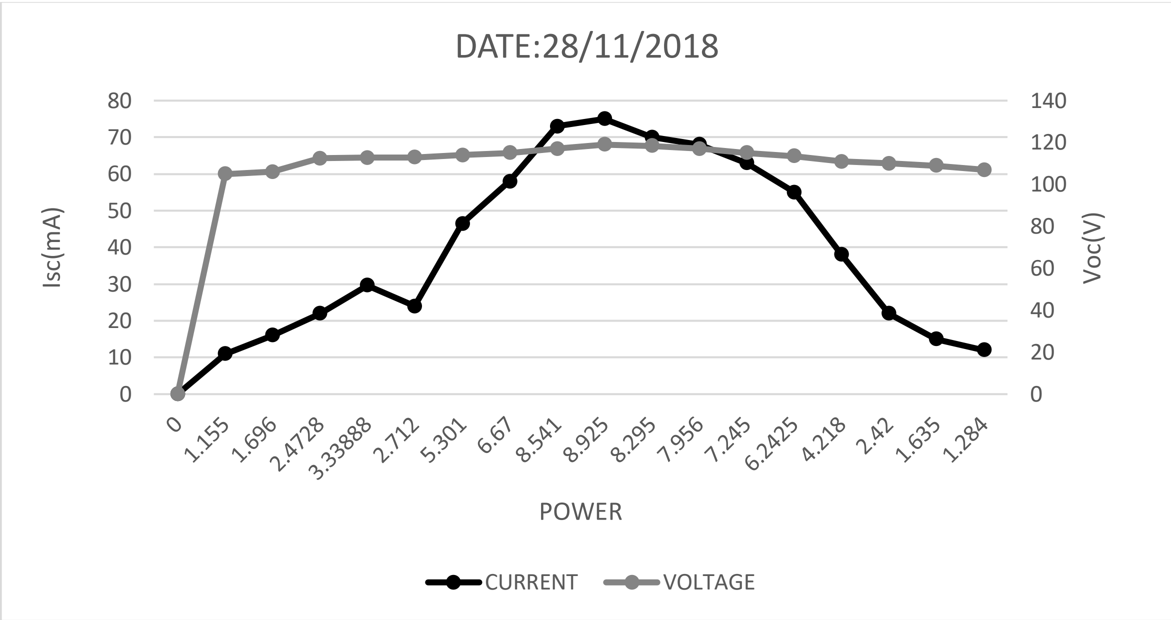


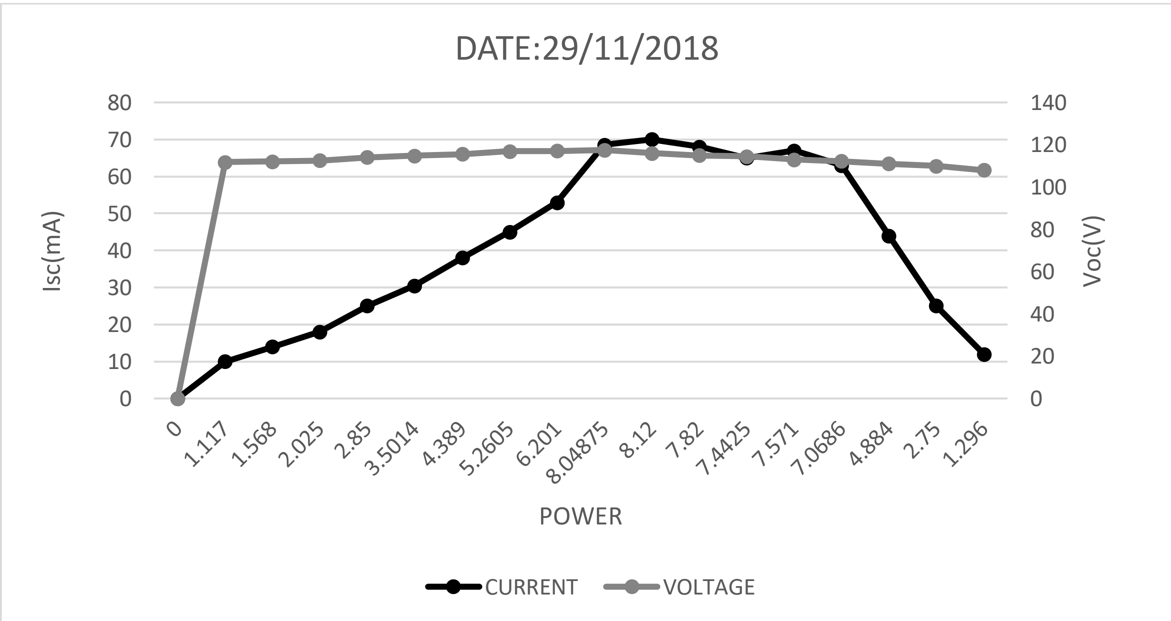

DATE:22/11/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
0
0.735
1.417
2.016
3.34776
4.6535
6.27
7.9369
8.7
8.6775
8.113
7.8064
7.581
5.076
5.0535
3.36
2.05165
1.046
POWER
CURRENT
VOLTAGE

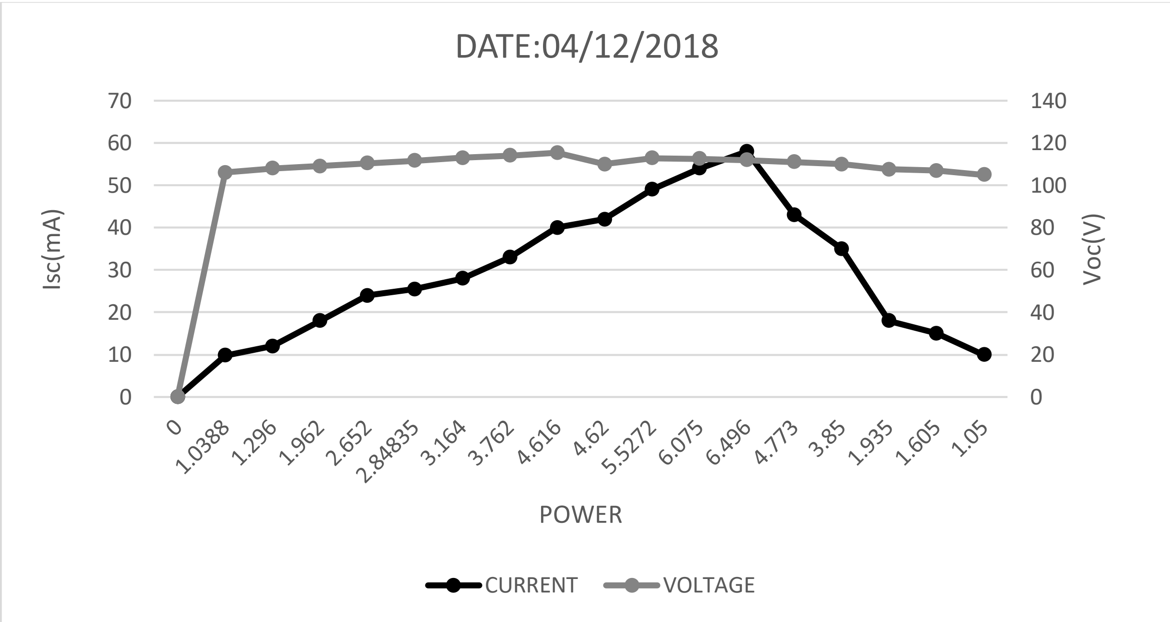

DATE:23/11/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
0
0.618
0.972
1.155
1.998
2.7875
2.24
5.74976
6.336
7.308
7.524
6.798
6.102
5.376
3.885
2.5415
1.944
1.06
POWER
CURRENT
VOLTAGE

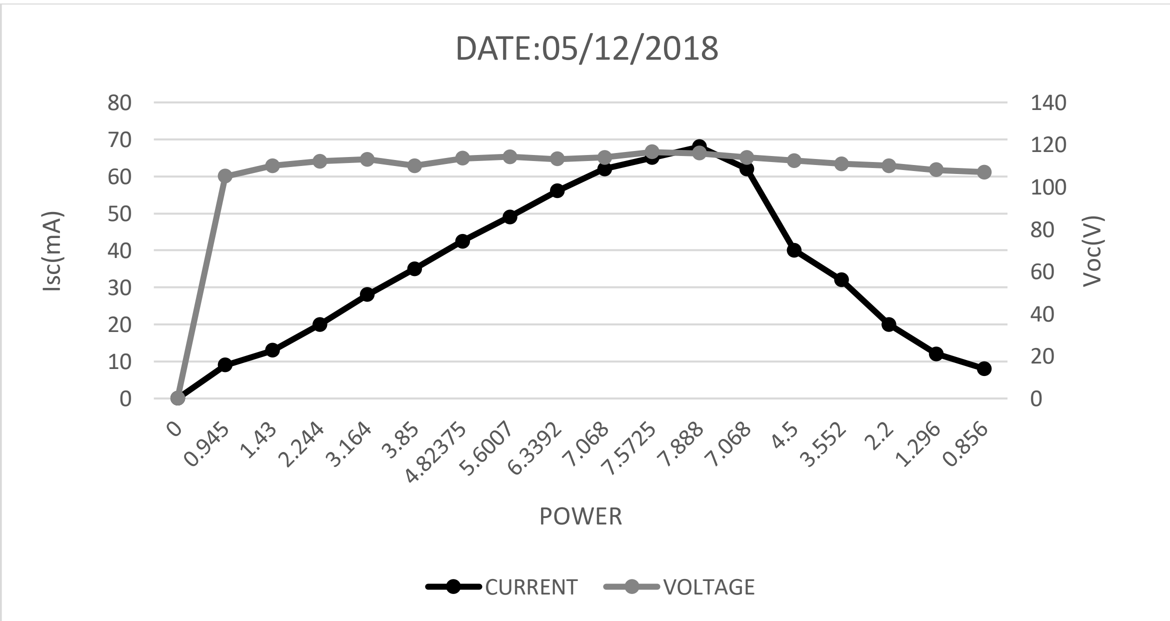

DATE:26/11/2018
Isc(mA)
Voc(V)
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
0
0.9585
1.284
1.65
1.998
2.805
4.005
5.4096
6.328
7.67
7.34375
6.148
5.4191
4.902
3.95713
2.552
1.575
1.03
POWER
CURRENT
VOLTAGE

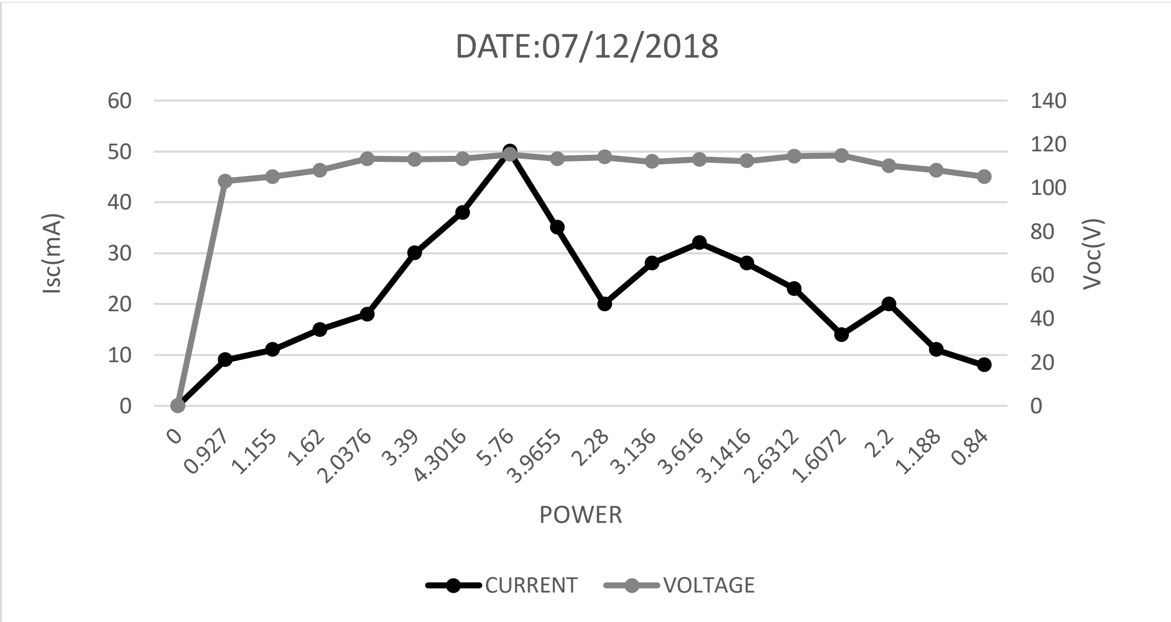

DATE:27/11/2018
Isc(mA)
Voc(V)
80
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
0
1.08
1.232
2.128
3.2741
4.4635
5.0985
6.9
7.956
8.614
8.715
7.7625
6.2425
4.816
3.6135
2.7
2.0748
1.05
POWER
CURRENT
VOLTAGE

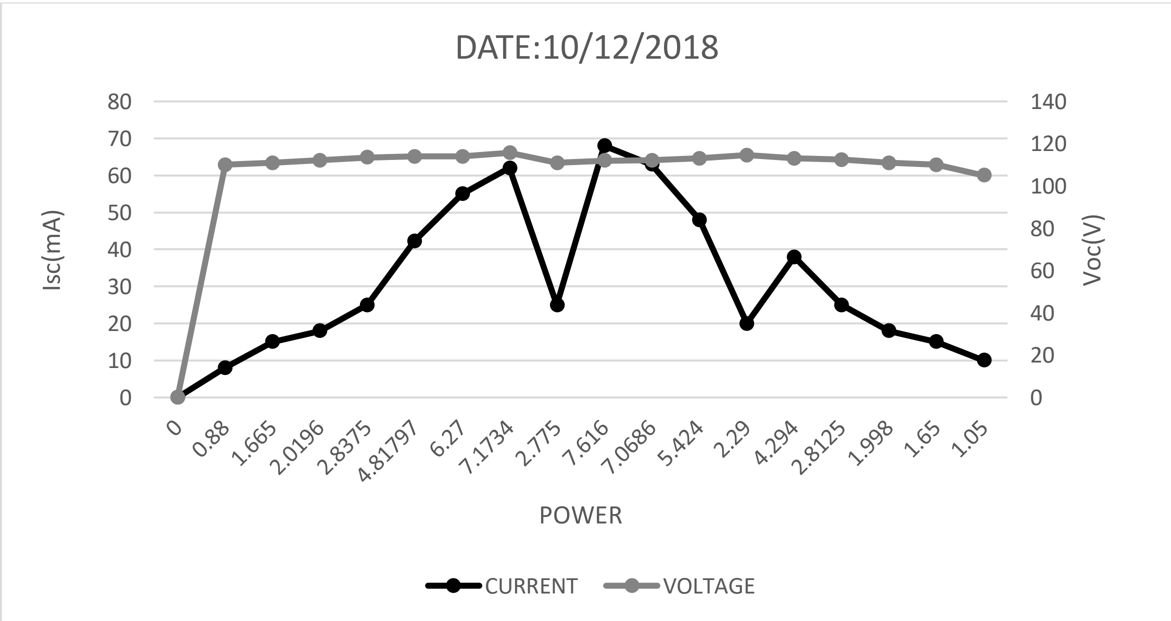

DATE:28/11/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
0
1.155
1.696
2.4728
3.33888
2.712
5.301
6.67
8.541
8.925
8.295
7.956
7.245
6.2425
4.218
2.42
1.635
1.284
POWER
CURRENT
VOLTAGE

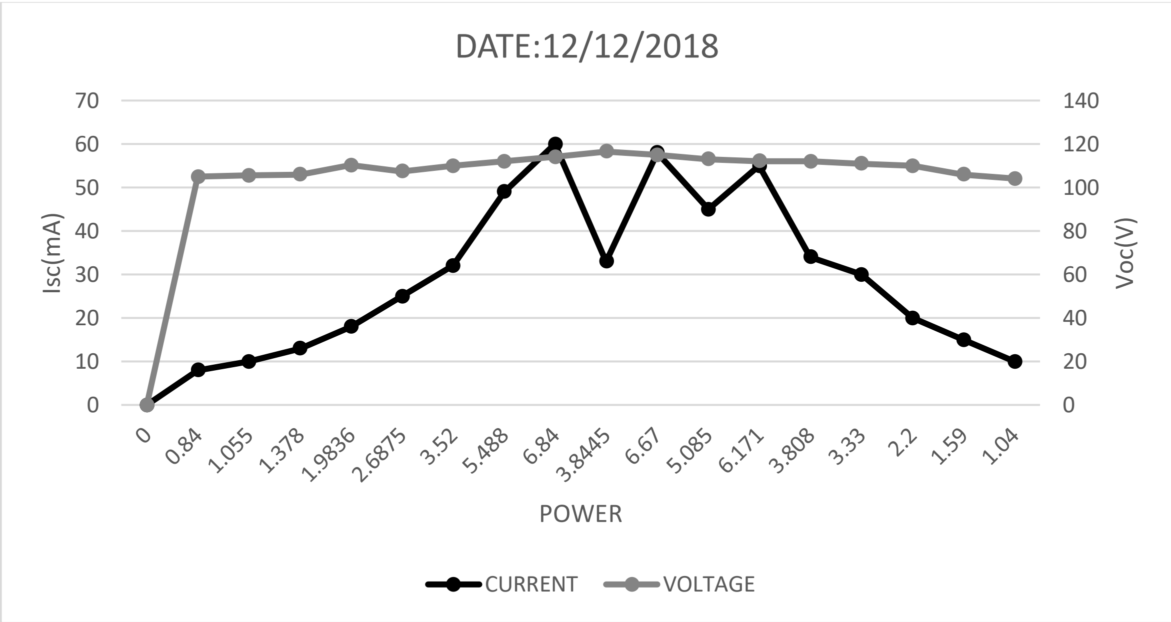

DATE:29/11/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
0
1.117
1.568
2.025
2.85
3.5014
4.389
5.2605
6.201
8.04875
8.12
7.82
7.4425
7.571
7.0686
4.884
2.75
1.296
POWER
CURRENT
VOLTAGE

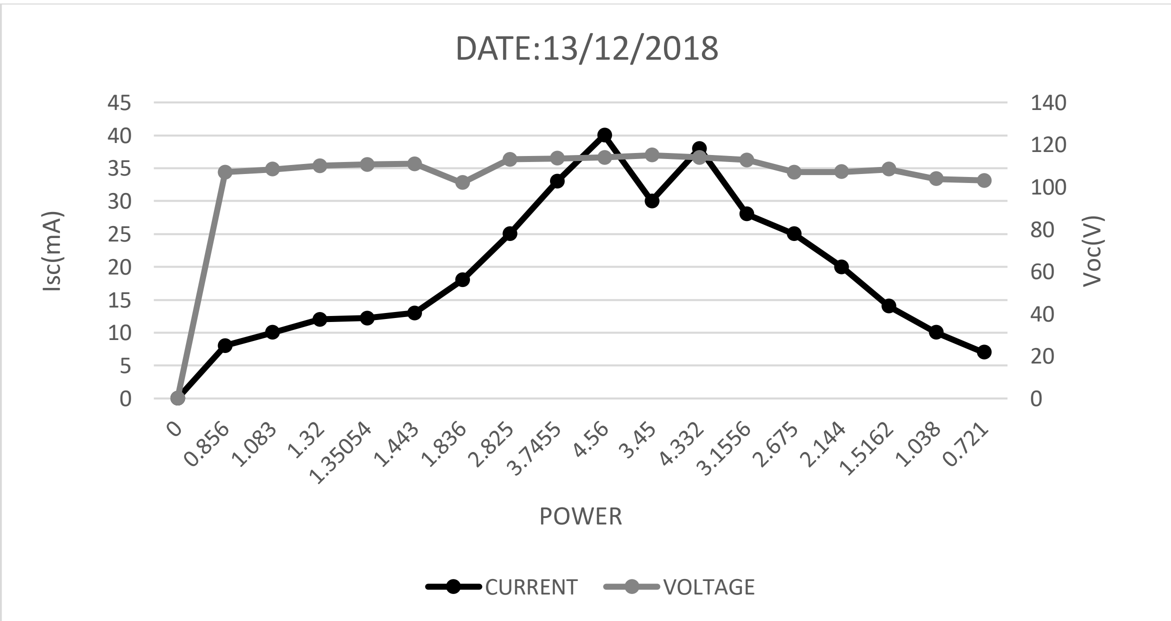

DATE:04/12/2018
Isc(mA)
Voc(V)
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
0
1.0388
1.296
1.962
2.652
2.84835
3.164
3.762
4.616
4.62
5.5272
6.075
6.496
4.773
3.85
1.935
1.605
1.05
POWER
CURRENT
VOLTAGE

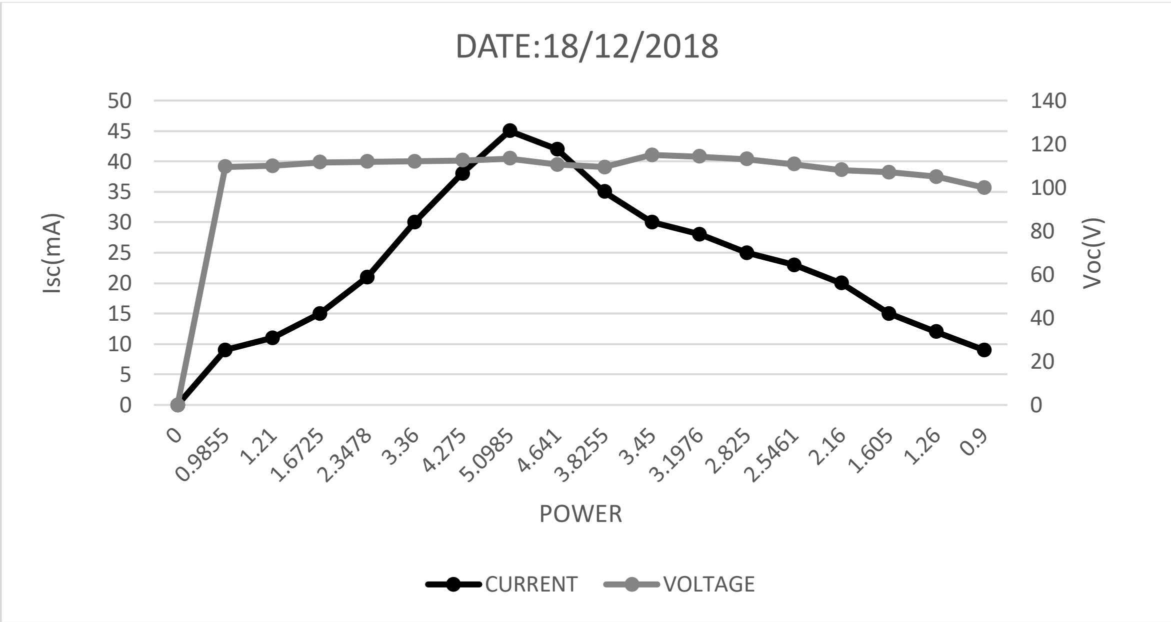

DATE:05/12/2018
Isc(mA)
Voc(V)
80
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
0
0.945
1.43
2.244
3.164
3.85
4.82375
5.6007
6.3392
7.068
7.5725
7.888
7.068
4.5
3.552
2.2
1.296
0.856
POWER
CURRENT
VOLTAGE

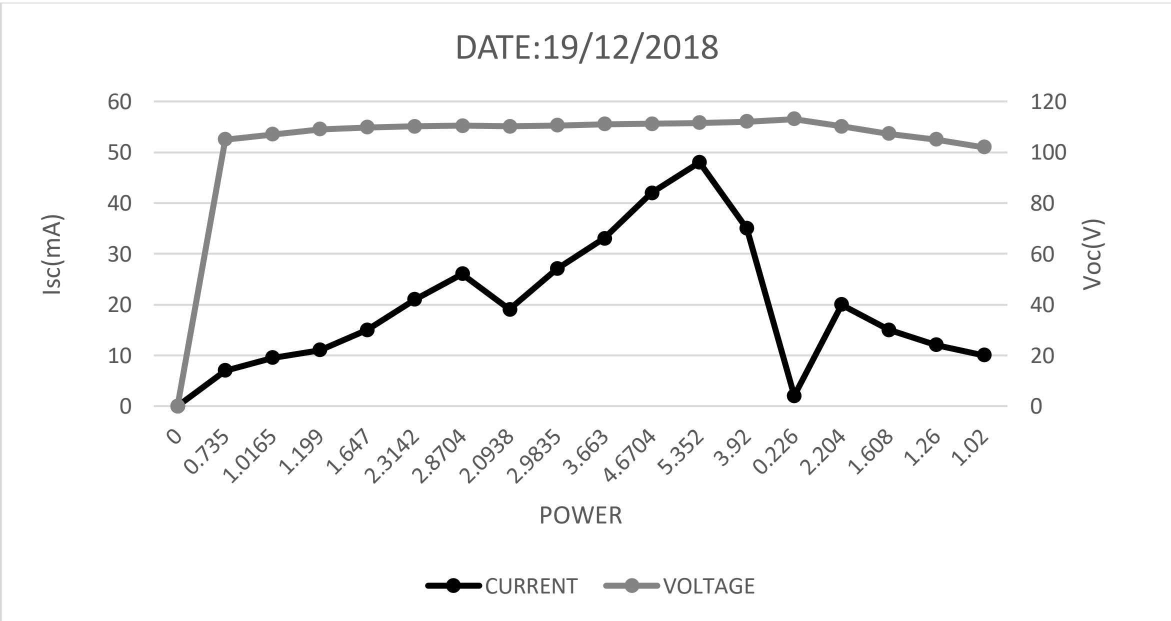

DATE:07/12/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
0
20
40
60
80
100
120
140
0
0.927
1.155
1.62
2.0376
3.39
4.3016
5.76
3.9655
2.28
3.136
3.616
3.1416
2.6312
1.6072
2.2
1.188
0.84
POWER
CURRENT
VOLTAGE

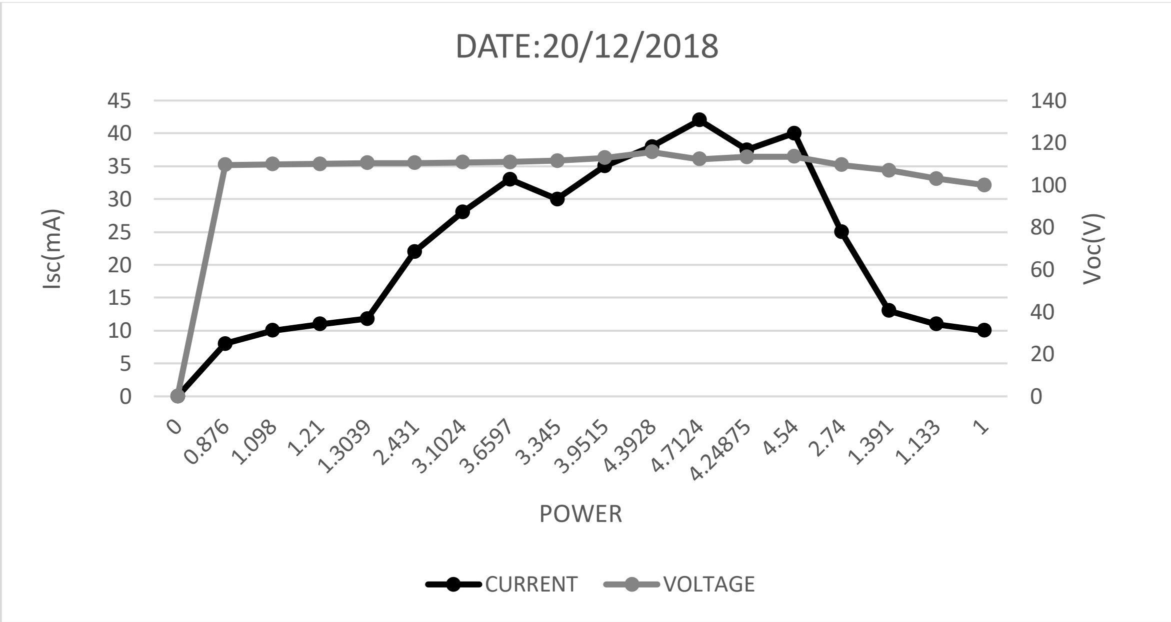

DATE:10/12/2018
Isc(mA)
Voc(V)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
0
0.88
1.665
2.0196
2.8375
4.81797
6.27
7.1734
2.775
7.616
7.0686
5.424
2.29
4.294
2.8125
1.998
1.65
1.05
POWER
CURRENT
VOLTAGE

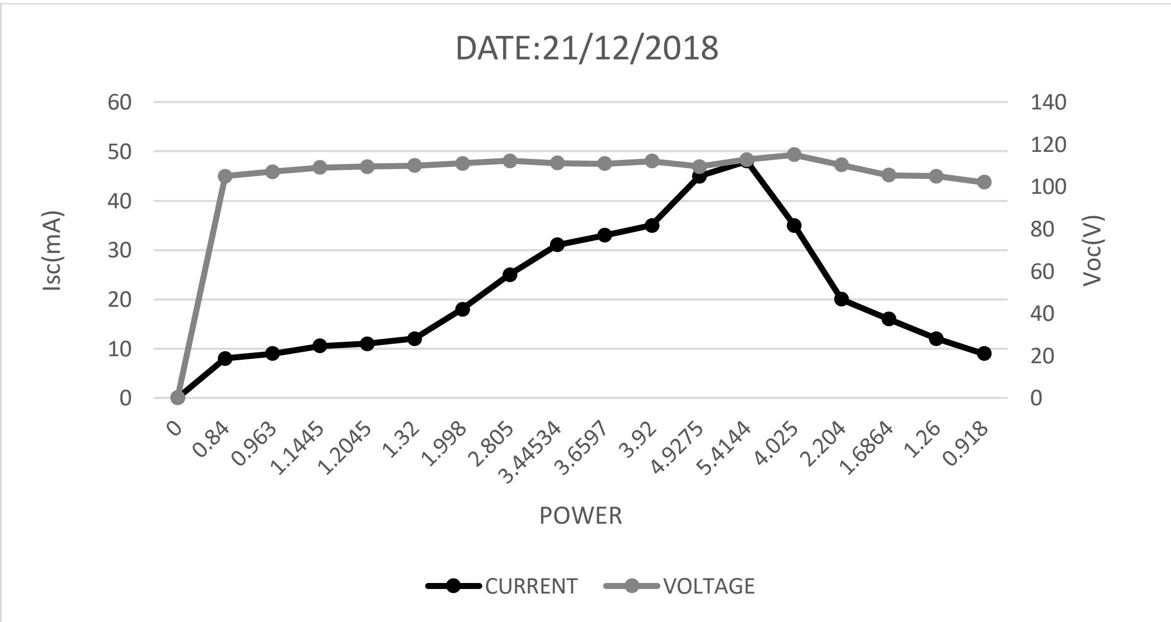

DATE:12/12/2018
Isc(mA)
Voc(V)
70
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
0
0.84
1.055
1.378
1.9836
2.6875
3.52
5.488
6.84
3.8445
6.67
5.085
6.171
3.808
3.33
2.2
1.59
1.04
POWER
CURRENT
VOLTAGE

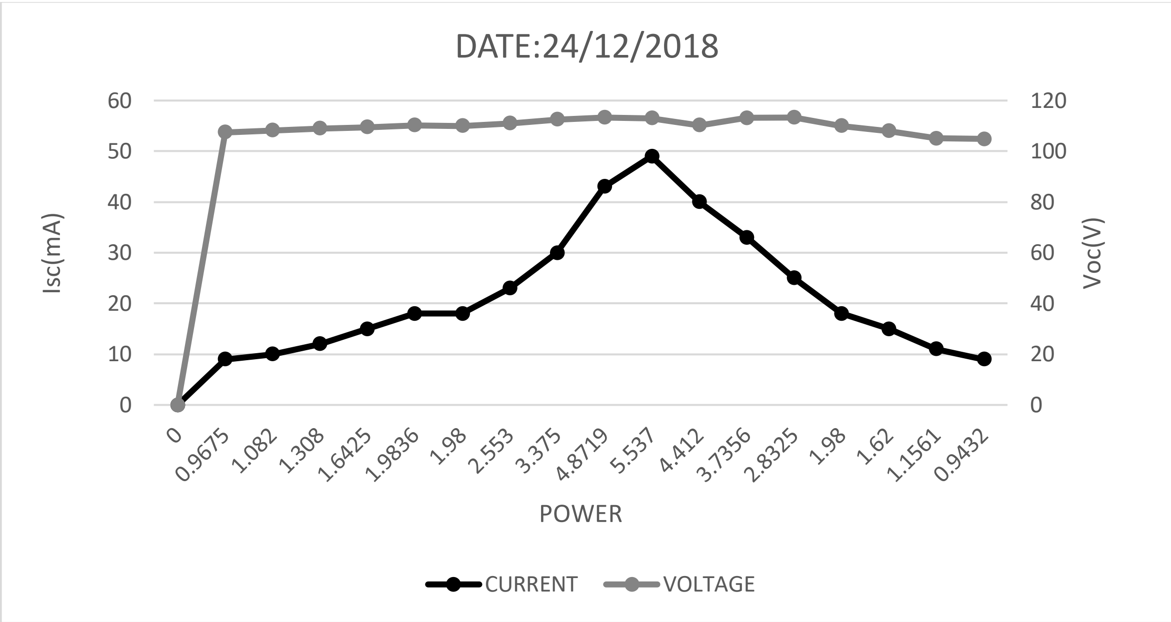

DATE:13/12/2018
Isc(mA)
Voc(V)
45
40
35
30
25
20
15
10
5
0
140
120
100
80
60
40
20
0
0
0.856
1.083
1.32
1.35054
1.443
1.836
2.825
3.7455
4.56
3.45
4.332
3.1556
2.675
2.144
1.5162
1.038
0.721
POWER
CURRENT
VOLTAGE

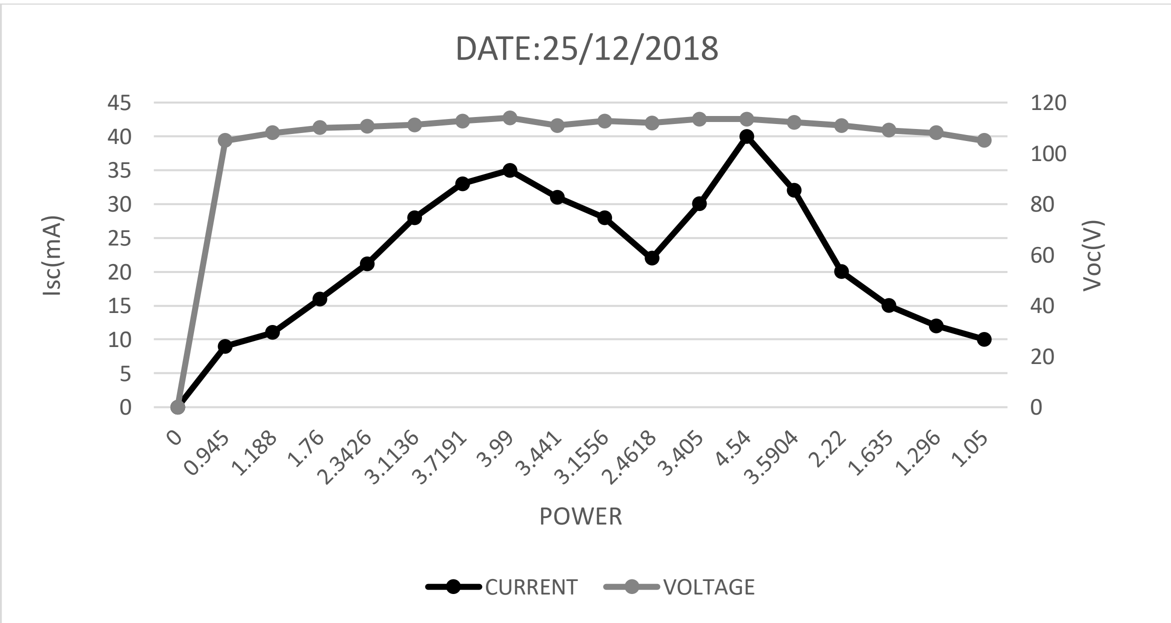

DATE:18/12/2018
Isc(mA)
Voc(V)
50
45
40
35
30
25
20
15
10
5
0
140
120
100
80
60
40
20
0
0
0.9855
1.21
1.6725
2.3478
3.36
4.275
5.0985
4.641
3.8255
3.45
3.1976
2.825
2.5461
2.16
1.605
1.26
0.9
POWER
CURRENT
VOLTAGE

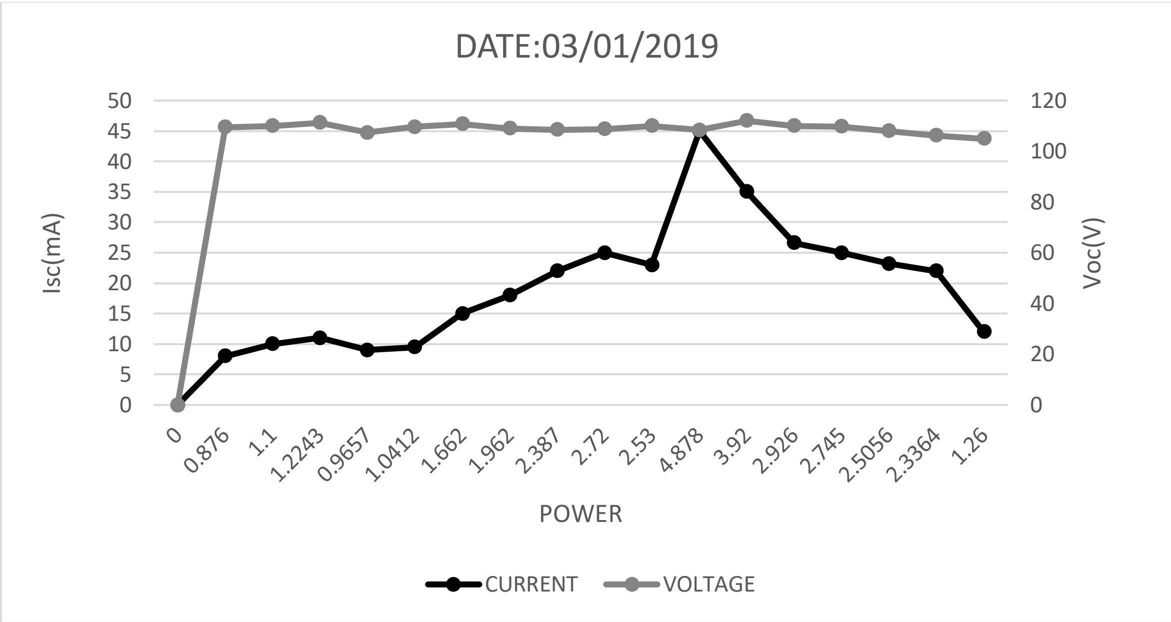

DATE:19/12/2018
Isc(mA)
Voc(V)
60
50
40
30
20
10
0
120
100
80
60
40
20
0
0
0.735
1.0165
1.199
1.647
2.3142
2.8704
2.0938
2.9835
3.663
4.6704
5.352
3.92
0.226
2.204
1.608
1.26
1.02
POWER
CURRENT
VOLTAGE


DATE:20/12/2018
Isc(mA)
Voc(V)
45
40
35
30
25
20
15
10
5
0
140
120
100
80
60
40
20
0
0
0.876
1.098
1.21
1.3039
2.431
3.1024
3.6597
3.345
3.9515
4.3928
4.7124
4.24875
4.54
2.74
1.391
1.133
1
POWER
CURRENT
VOLTAGE

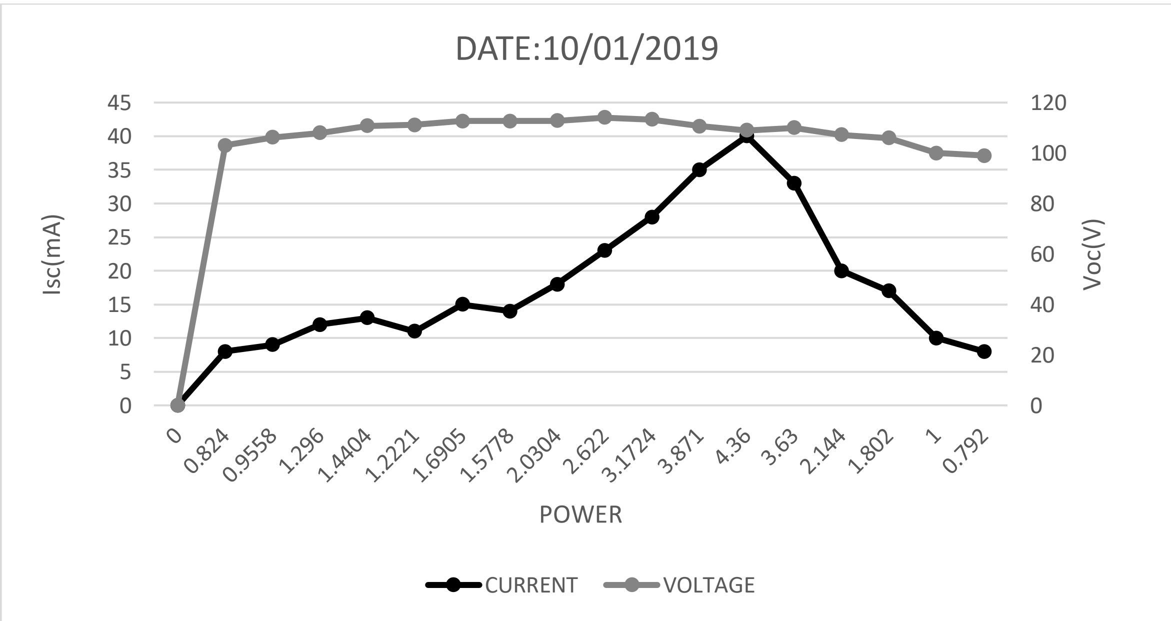

DATE:21/12/2018
Isc(mA)
Voc(V)
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
0
0.84
0.963
1.1445
1.2045
1.32
1.998
2.805
3.44534
3.6597
3.92
4.9275
5.4144
4.025
2.204
1.6864
1.26
0.918
POWER
CURRENT
VOLTAGE


DATE:24/12/2018
Isc(mA)
Voc(V)
60
50
40
30
20
10
0
120
100
80
60
40
20
0
0
0.9675
1.082
1.308
1.6425
1.9836
1.98
2.553
3.375
4.8719
5.537
4.412
3.7356
2.8325
1.98
1.62
1.1561
0.9432
POWER
CURRENT
VOLTAGE


DATE:25/12/2018
Isc(mA)
Voc(V)
45
40
35
30
25
20
15
10
5
0
120
100
80
60
40
20
0
0
0.945
1.188
1.76
2.3426
3.1136
3.7191
3.99
3.441
3.1556
2.4618
3.405
4.54
3.5904
2.22
1.635
1.296
1.05
POWER
CURRENT
VOLTAGE



DATE:03/01/2019
Isc(mA)
Voc(V)
0 5 10 15 20 25 30 35 40 45 50
0 20 40 60 80 100 120
0 0.876 1.1 1.2243 0.9657 1.0412 1.662 1.962 2.387 2.72 2.53 4.878 3.92 2.926 2.745 2.5056 2.3364 1.26
POWER
CURRENT
VOLTAGE



DATE:10/01/2019
Isc(mA)
Voc(V)
0 5 10 15 20 25 30 35 40 45
0 20 40 60 80 100 120
0 0.824 0.9558 1.296 1.4404 1.2221 1.6905 1.5778 2.0304 2.622 3.1724 3.871 4.36 3.63 2.144 1.802 1 0.792
POWER
CURRENT
VOLTAGE

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