Bachelor Thesis in Electrical Engineering 2014

Solar Energy

Blekinge Institute of Technology

This thesis aims on supporting the use of the solar energy, explaining the manufacture of the Photovoltaic (PV) cell, as well as explaining the electrical properties and the chemical modification of the materials used in the PV cell and the improvements of the PV cells since the first invention.

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Abstract

This thesis is about Photovoltaic (PV) cells and it stretches in various directions by calculating the power generated using solar cells under different conditions to improve its efficiency. Our research studies found that using multi-junction cells with larger substrates can increase the efficiency to some extent which in practice is limited to 43 percent.

The experiment was conducted using ten solar cells each with an area of $20.9 cm^2$, where each cell gives 0.5 V and 0.4 A and a 1.25 Ω resistor was used. The cells were connected in series. Once, the PV cells were fixed horizontally and the other time tested in tilted position under same outdoor condition. The purpose of testing PV cells was to investigate the efficiency under above mentioned conditions. The data collected from the readings was used in calculation, and we have obtained from the calculations that horizontally fixed cells gave 4.8 percent efficiency whereas tilted cells gave 6.6 percent efficiency. Hence, the ratio showed that fixed cells produced 37.5 percent more power compared to horizontally fixed cells. Our other experiment consisted of testing PV cells under different temperature conditions that was done using a freezer and an oven for temperature variation and a tungsten bulb was used as a light source. The purpose of performing this experiment was to investigate how the efficiency of PV cells is affected under extreme conditions. The result was that the efficiency decreases with increasing of temperature, the efficiency at 100°C was found to be 6% of the efficiency at 10°C.

Part of our thesis was also including studies and analysis of produced energy by the solar panel installed on the roof of "BTH" building in Karlskrona, Sweden. The data consisted of energy produced from February up to August 2014. The investigation also included finding the highest produced energy during these months. We have found that the highest energy was generated on the 1^{st} of July which was 12.86 kWh. Furthermore, we went deep into investigation of the 1^{st} of July to know exactly which hour of that day the highest energy was produced. The data showed that the highest produced energy was at 12:19 and 13:19 which was 2.03 kWh, this shows that the solar energy has a maximum during the hour when the sun elevation angle is highest.

Acknowledgement

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The Authors

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1. Introduction

The solar energy is one of the renewable energies those we get through streams which repeat naturally and periodically, and so unlike the nonrenewable energy that found often rigid in the ground and cannot be used without a human intervention. Since the engineers are looking for sources of energy that give less carbon and helping in stopping the increasing of the global warming and the pollution levels, this thesis focus on the solar energy.

The solar energy is taken direct from the sun which known as the first natural light source since the beginning of mankind, the first light the human had during his days and its reflected light via the moon at nights. The sun takes place in the outer space accurately. In other worlds, the earth's orbit around the sun is accurate and specified, and any change in the earth's path will lead to sudden changes in its temperature, structure, and its atmospheric cover [1].

The sun is formed by the condensation of clouds between stars under the influence of gravity. The gravity caused these clouds to collapse and spin together to form a *Protostar* that will become our sun. This small *Protostar* is just a grouping of hydrogen and helium, and the temperature and pressure of the materials have increased during about fifty million years which stared the fusion and drove the sun to what it is now [1].

According to *NASA* measurements, the temperature at the sun's core is immense, and is about 15 million degrees Celsius (about 27 million degrees Fahrenheit). Furthermore, the temperature is ranging between the core and the outer surface of the sun until it reaches about 5500° degrees Celsius (about 10,000 degrees Fahrenheit) and lies 149.6 million kilometers (about 92.96 million miles) from earth [2].

The sun is the main source of energy on earth and has distributed and returned to other forms of energy whether been stocked in wind, underground thermal and other forms of energy. Since the solar energy is the most important source of the renewable energy now and during the coming century, the effort of the power engineering science is focusing to develop this form of energy to exploit it as the main energy source instead of gas and oil. The most shares of researches in electrical power engineering are given to the field of solar energy conversion where the sunlight can be converted to electrical power and that is known as *Photovoltaic*.

Since the electrical power becomes one of the most necessary factors in life, the developing of solar energy is the new hope in the developing countries, where is no need of generating centralization for the production of electrical power from the sunlight because it can be produced and used in the same area which leads to reducing the cost of the electrical transportation [3].

There are many materials which can be used to manufacture what is named as solar panel, which can be exposed to the sunlight by the right angle to the sun to produce as much of electrical power and we will talk about it more later.

2. Background

Since the beginning of the human being, the human was trying to take advantages of the sunlight. The uses were useful but limited. For example, the direct sunlight is used for drying agricultural crops, heating houses, cooking, steaming water, etc. If we look through the history books, we find that one of the smartest uses of the sunlight was in a war when the Greek mathematician Archimedes burned the ships were attacking Greece by focusing the sunlight to their ships via hundreds of mirrors [4].

With the rise of the global warming and the pollution levels caused by using the oil for producing the electricity, the scientists started looking for new energy sources to cover the needs of the human's life, but most of the sources have disadvantages such as the cost of use, the depletion and the negative impacts on the environment. With the uses of the sunlight during the history, many prospects of new science have started in the field of solar energy. In the modern era, the scientists are alerted to the possibility of taking advantage of converting the solar energy into electrical power because it is renewable, permanent and clean. In addition, the technology used in converting the sunlight to electrical power comparing to the other sources is:

- Relatively simple technology and not complicated.
- Provides the environmental safety factor and does not cause any pollution.

The importance of the solar energy has appeared again as an important factor in the global economy with the use of solar water heaters in most countries, even in the rich countries like Germany, China and USA. Likewise, the Middle East countries begin to use solar energy because of the high concentration of sunlight in the region throughout the year [5].

The prosperity in the solar energy uses and making full uses of it depends on several factors, including:

- Geographic Location.
- The quality and efficiency of the materials used in the manufacture of solar panel.

3. Energy

In fact, the process of generating power is a process of converting energy from one form to another according to the available source in the centers of demands and the quantities required for this power. According to the available sources of energy, the type of energy source can be decided as well as where it must be placed.

3.1. Types of Energy Sources

- **Thermal (Non-Nuclear Power Plants):**

  This type of plants uses different types of fuel such as oil, gas or coal. It is characterized by its large size and low cost for the huge potential.

  The non-nuclear thermal plant is almost used in every country and there are four stations in Sweden with total capacity of about 2500 MW [6].

- **Thermal (Nuclear Power Plants):**

  These plants work in the same principle of the non-nuclear Power plants where it generates steam. The different between the Non-Nuclear and the Nuclear plants is the nuclear reactor that used to generate heat as a result of the fission of uranium atoms those strikes the electrons in the outer layer of the atom instead of using oil, gas and coal.

  The world is cautious about using these plants, where they have massive damages to the human life and the environments in case of any nuclear leak or a meltdown of a nuclear reactor like what happened in Fukushima, Japan in 2011. In Sweden, there are ten nuclear stations and provide about 40% of its electric power (about 9000 MW) [6].

- **Hydroelectric Power Plants:**

  The use of this plant is often near the river embankments like the station in the Nile River which provides about 1800 MW and about 11 hydro power plants in Sweden where *Letsi* station is the first and the largest in the *Lesser Lule* River with capacity of 456 MW [6].

- **Tide Power Plants:**

  Tide is a natural phenomenon known to the inhabitants of the seas coasts, and this phenomenon is caused by the gravity of the moon. The highest tide is in Nova Scotia, Canada (16.27 meters). The use of this phenomenon is by putting a turbine in the tide's stream so it can move by the strength of elongated and entrained water.

- **Wind Power Plants:**

  The wind is used through the history in many ways such as pushing the ships, recycling the windmills, etc. According to the instability and the lack of continuity of wind speed, it is difficult to rely on the wind as a primary source of energy.

  In Sweden, about thirty eight wind farms built to generate energy where the largest one is *Markbygden Wind Farm* and located in Piteå with capacity of about 4000 MW [6].

- **Solar Power Plants:**

  The advantage can be taken from the sun by converting its incident light on the ground to electrical power by using a photovoltaic cell. This energy is eco-friendly and easy to use, but the problem that is facing this energy source is that the concentration of sunlight must be strong enough to use it as power source.

  The concentration of the sunlight is strong throughout the year in some parts of the earth as in the Middle East, but in other parts it may be strong only in summer as in the Scandinavian countries.

3.2. Waste of Energy

Leaking portion of the energy used in homes every day through the leak of cooling and heating through windows, doors and other gaps at homes. This daily waste of energy costs our environment a lot, because it consumes wealth and as it emits dangerous and toxic gases through the issuance of energy. The energy can be wasted through window in three ways, crossing of the optical power through the glass in both directions, crossing of the heat or cold as a result of contact between air and glass, as well as heat that leaks through the glass [7].

Many governmental institutions consider the environment as the most important priorities, and offer special discounts on improving the maximum efficiency of energy in homes. There is an improvement on the technology of doors and windows, helping to reduce energy use, including keep of the temperature in our homes comfortable in any climate [7].

The loss of heat and cool can be reduced by adding an invisible film on the glass pane of what is known as thermal insulator. This film works as an insulator where it reflects the thermal waves. Also, the heat exchange in the air between the glass panes can be prevented by filling the space between the panes with Argon gas, where this gas is heavier and less conductive than air which leads to the reduction of heat exchange between the inside and outside environments [7].

Researchers worked on deeper studies of the designs of windows and doors trying to create better isolate. Traditional windows made of aluminum with one or two glass panes, let heat and cold pass freely between the inside and outside environments. In October 1983 Winchester began to manufacture Bristol windows which named after its inventor. Bristol windows have a high capacity of insulation to provide power protection where they are made of three panes of glass to eliminate the connection between the two environments and thus limit the waste of energy [8].

4. Solar Energy

4.1. Earth Location about the Sun

As known that the sunlight is one of the important factors of life and the sun radiates enormous amount of rays on the surrounding space. As the earth revolve around the sun in a specified orbit, we find that there are varying amounts of this rays falls on the surface of the earth every day and these amounts determined by the location of the earth about the sun or the four seasons (see figure 4.1.1) [9].

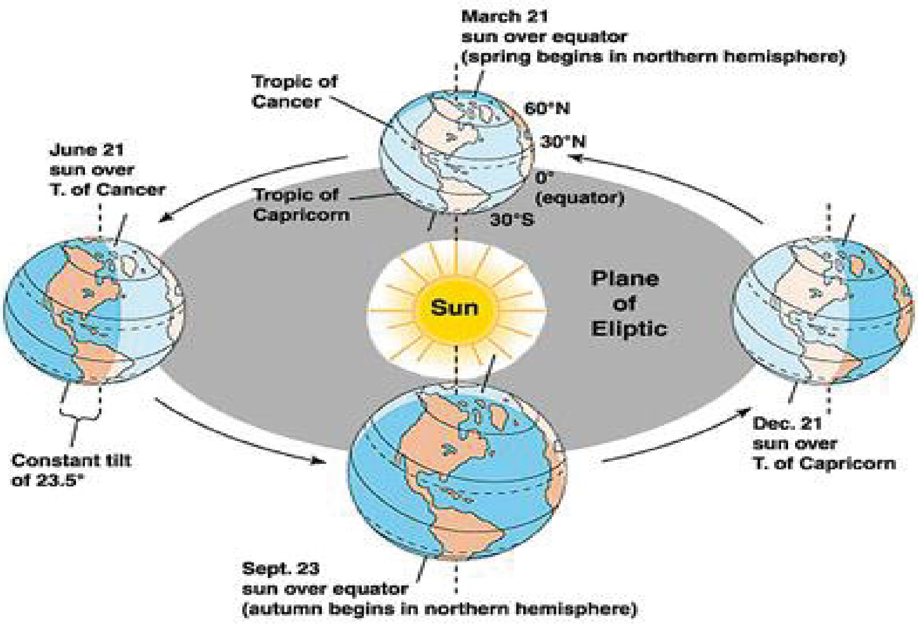


Figure 4.1.1: Earth location about the sun
<http://quizlet.com/9491089/astronomy-quiz-review-flash-cards/>

As shown in the above figure, the countries which located on the equator are the countries those have almost one season over the year which is the summer. In other words, the falling of the sun rays is incessant over the year on the equator then less rays as we move away from the equator gradually until we reach the Arctic and the Antarctic where the sun rays eliminated in most days of the year [9].

The amount of the sun rays that reaches the ground also varies due to weather conditions and the clouds come on one of the major weather factors that control the amount of rays reaches the earth; so cloudy climate areas receive fewer rays than areas with desert climate [9].

In general, the largest amount of rays received by the earth is in the afternoon when the sun becomes vertical on the earth. Thus as a result of the fall of rays vertically to the earth during the afternoon, we find that losses in the rays are few, these losses are an absorption of the rays by the clouds or scattering of rays in space due to reflections through the airborne volcanic ash or fumes as a result of burning forests and other of environmental pollutants [9].

4.2. Conversion of Solar Energy

As known, there are some materials which do the process of photoelectric conversion called semiconductors such as silicon, germanium and others. This phenomenon is discovered by physicists in the late nineteenth century where they found that the light can liberate the electrons in metals, also knew that the blue light has a greater capacity than the yellow light in the liberation of electrons and thus. The physicist *Albert Einstein* awarded the Nobel Prize in 1921 for being able to explain this phenomenon [10].

And over the time, there have been several attempts for manufacturing many models of solar cell that can produce electricity in a scientific manner and characterized by that it does not include movable parts, does not consume fuel, does not cause of air pollution, does not require a lot of maintenance and has a long life term.

Achieved the best use of solar energy in a "Photovoltaic cell" under the console applications of solar radiation, i.e. without light lenses and so can be installed on the roofs of buildings where it used to produce electricity and estimate high efficiency depends on the amount of sunlight falling on the cells, and the remains can be utilized to provide heat for heating and water heating.

The efficiency of a solar cell can be obtained by the formula:

$$\eta = \frac{V_{oc} * I_{sc} * FF}{G_{incident} * A_c} = \frac{P_{max}}{P_{in}}$$

where P_{max} is the maximum output power in (watts), V_{oc} is the open-circuit voltage, I_{sc} is the sort-circuit current, P_{in} is the input power, A_c is the surface area of the cell in (m^2), $G_{incident}$ is the light intensity in (watts/m^2) which according to *NASA*, the average intensity of sunlight in the best atmosphere is approximated to 1360 watts/m^2 [2] and FF is the fill factor in (m^2) and given as:

$$FF = \frac{V_{oc} - \ln(V_{oc} + 0.72)}{V_{oc} + 1} = \frac{V_{mp} * I_{mp}}{V_{oc} * I_{sc}}$$

Where V_{mp} and I_{mp} are the maximum power points.

The thermal conversion of solar energy depends on the conversion of solar radiation into thermal energy through solar panels and thermoelectric materials. If an isolated black body exposed to the solar radiation it absorbs the radiation and its temperature rises. The thermal energy used in air heating, water heating, power generation, etc. The application of solar water heater is the most prevalent in the field of thermal conversion of solar energy, and followed by the solar dryer that is often used in the drying of some agricultural crops such as dates in Saudi Arabia and coconuts in India.

Although solar energy has taken occupy an important position within the alternatives related to renewable energy, but the extent of taking an advantage is linked to the presence of sunlight throughout the time of use.

After the discovery and development of electric and thermal conversion technologies, another technology is required which is the storage technology to get advantage of them during the occultation of the solar rays. There are several technologies of storing such as electrical, thermal, and chemical. The most common technology used to store solar energy is to keep the power in amount of batteries connected together, and there is much research going about the storing technologies to develop them.

5. Photovoltaic Cells (PV Cells)

The world *Photovoltaic* is a compound of two words, *Photo* which means light and comes from the Greek *phos* and the other word *voltaic* which refers to the production of electricity. The photovoltaic (or PV) cell is an adapter that converts direct light into DC electricity and considered as the primary part of a solar energy system.

The PV cell is an optically sensitive device surrounded by a conductor of electricity (electrode) and covered by anti-reflection film to avoid the loss of light. Most PV cells used to be made of a material such as crystalline silicon. It is one of the semiconductor materials known with physical properties that fall between conductors and insulators.

The simple components of a PV cell consist a system of two levels with energies E_1 and E_2. To build an ideal PV cell, the following factors must be considered:

- The energy of the electrons must not be between E_1 and E_2, but equal to E_1 or E_2.
- Cannot absorb a photon with energy less than E_g [E_g= E_2 - E_1].
- The total absorption of a photon happens in a situation where the photon has energy equal to or greater than E_g, and then the electron that absorbs this energy moves from the level 1 to level 2, leaving a gap in level 1.
- The output voltage of this ideal cell equal to [E_g / q] (q: electron charge)

The maximum power produced by the cell [IE_g / q] and if M considered as the power received from the sun, yield is given by the relation:

$$\mu = [IE_g \, / \, q]^* \, M$$

The yield μ is estimated as 46 percent in the field [0.9-1.5 $exp \ v$]

5.1. History of PV Cells

There has been noticeable development for many techniques for the production of solar cells through sequential processors of chemical, physical and electrical in the form of condensate self- automated or high mechanism. It has also been development for different materials from semiconductors to manufacture solar cells in the form of elements as silicon or in the form of compounds such as gallium arsenic, carbide cadmium, indium phosphide, copper sulfide and other promising materials for the manufacture of solar cells.

The first idea of PV cell came in 1839 when the French physicist Edmond Becquerel at the age of 19 years found the effect of light via an electrode in a conductive. In the 1873, Willoughby Smith found the selenium has a photoconductivity, when in 1876 W. G. Adams with one of his students discovered the material selenium can produce electrical current. Werner von Siemens which is an electrical power expert said about the discovery "it was scientifically of the most far-reaching importance". Later, Heinrich Hertz started his studies of the effect in solids such as selenium where the converting of light into electricity started at one to two percent efficiency [10].

During the 20th century, the science of PV cells were refined and developed. Then the Polish scientist Czochralski has developed the studies of solar cells when he found the method of producing a single crystal silicon cell. By this time, the PV cell was ready for the commercial uses, but has not been used because of its cost compared to the energy it produces [10].

Over the past 25 years, the efficiency of a PV cell has increased when The Institute of Energy Conversion at University of Delaware developed the first film PV cell with efficiency of 10 percent in 1980 followed by creation of a silicon PV cell by the Centre for Photovoltaic Engineering at the University of New South Wales with efficiency of 20 percent in 1985. In 1994, NREL has developed a two-terminal concentrator cell to exceed 30 percent efficiency.

Today as a result of technologies improvements, the cost of a PV cell has decreased as its efficiency has increased. Commercially, PV devices are available with conversion efficiency up to 17 percent.

5.2. Main Elements of PV Cells

PV cell composes of absorbent components and assembly structure. Absorbent components must have two levels of energy and be carrier to allow the current flow. The simplest structure for assembling is electric field. Thus, selected elements must be within semiconductors and the structure of the assembly will become p-n junction, non-homogeneous or Schottky barrier.

Semiconductor element is a quad element (the outer shell of the atom has four electrons), atoms are linked to each other via valence bonds and it works as insulator in the degree of absolute zero [11]. Furthermore, the ability of conductivity increases by the increasing of its temperature, pass a volt difference through it or when it is exposed to strong rays and there are two types of semiconductor elements:

- **Pure Semiconductor elements**

  These elements have a crystalline format sets atoms according to an engineered system. Silicon (Si) is the second most abundant element in the earth after oxygen and it is one of the semiconductor elements and has fourteen electrons, ten of these electrons linked to the nucleus and the other four are in the outer shell. Germanium is another element which has thirty-two electrons, twenty-eight of these electrons linked to the nucleus and the other four are in the outer shell.

  The white sand (SiO_2) and carbon (C) are the primary elements used in the manufacture of silicon, where we get 50 gram of single crystal silicon out of 1 kilogram of white sand.

$$SiO_2+2C \longrightarrow Si+2CO$$
$$SiO_2+3C \longrightarrow SiC+2CO$$
$$SiO_2+3C \longrightarrow 3Si+2CO$$

Here are the steps of manufacturing silicon for photovoltaic use:

1. By the reduction of silicon from white sand and carbon in an electric oven, single-crystalline silicon is produced with purity of less than 98 percent.

2. Extracting the polycrystalline silicon by increasing the purity of the single-crystalline silicon through the reduction of hydrogen at a temperature of 1,000 Celsius degrees.
3. Cutting the silicon ingots into disks and polish them mechanically.
4. Chemical cleaning of the front and rear surface of the disk in order to remove impurities.

- **Distorted Semiconductor Elements (not pure)**

  These elements are pure elements, but they are distorted by adding amount of impurities such as phosphorus, boron, arsenic, antimony, gallium, indium, etc. This distortion is to control the process of electrical conductivity and by this distortion we can have two types of distorted elements:

1. Negative type (n-type): By distorting a pure layer of silicon via atoms of pentavalent elements such as phosphorus which has fifteen electrons (ten electrons linked to the nucleus and five are sat in the outer shell), a creation of a layer that has big numbers of free electrons will be caused (see figure 5.2.1) [12].

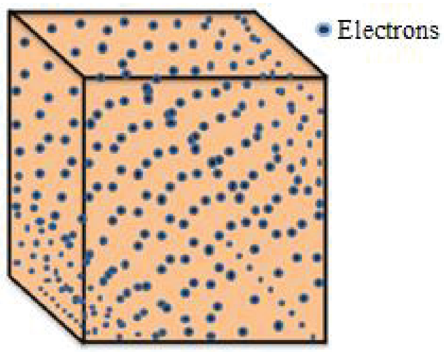


Figure 5.2.1: n-type (Silicon distorted via phosphorus).

The electric charges in this type carried by the free electrons in the atom.

2. Positive type (p-type): By distorted a pure layer of silicon via atoms of trivalent elements such as boron which has five electrons (two electrons linked to the nucleus and three are sat in the outer shell), creation of a layer that has big numbers of free holes will be caused (see figure 5.2.2) [12].

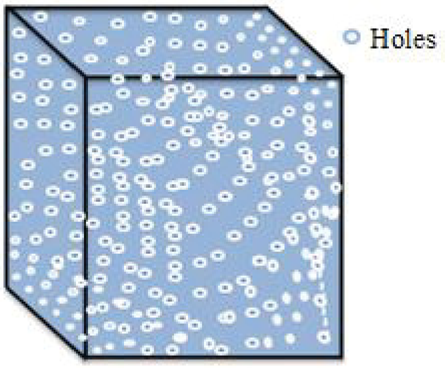


Figure 5.2.2: p-type (Silicon distorted via boron).

The electric charges in this type will be carried by the gaps caused by the freed electrons from the valence bonds because of the high temperature.

5.3. Forming of a p-n junction

After the processing of two types of silicon layers, which vary depending on the type of the existing charge, where as we mentioned earlier that the n-type contains a large amount of negative charge while p-Type contains a large amount of positive charge. Now imagine what will happen when the two layers connected to each other (see figure 5.3.1) [12].

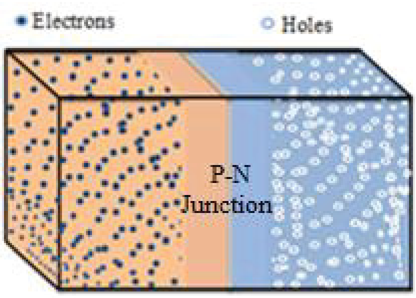


Figure 5.3.1: p-n junction.

Now because of the difference in between the two layers, a diffusion of electrons and hole will be processed between n-type and p-type and this causes something to happen!

Because of the spread of the electrons from n-type toward p-type, the electrons leave positive charges of phosphorus ions at the junction of the two layers. It also gets the same thing with the holes when they spread from p-type toward n-type, they leave negative charges of boron ions at the junction of the two layers (see figure 5.3.2) [12].

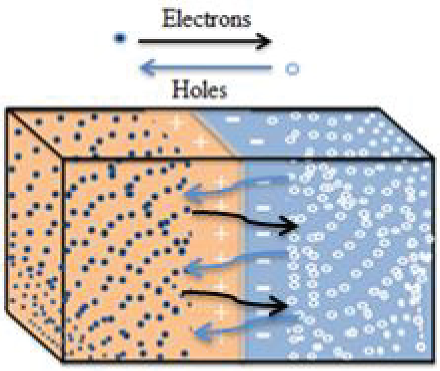


Figure 5.3.2: Diffusion through p-n junction.

These ions placed at the junction create an electric field, and this field indicates from the positive ions in the n-type to the negative ions in the p-type. Due to this electric field, the electrons will be attracted to the positive phosphorus ions and the holes to the negative boron ions which will cause to something to happen! [12]

This electric field causes a flow of the electrons and the holes in the opposite direction of the diffusion happened previously.

5.4. Chemically Different Types of PV Cells

PV cells been manufactured of different materials, but the most of these materials are naturally few, have toxic properties, nature polluter, costly and complex to manufacture and some are still under studies and researches. Thus, the focus was on the manufacture of silicon PV cells since silicon is the second most available element exists in nature after oxygen. Also, the scientists and researchers were able to study this element extensively and know its properties and suitability for the manufacture of a PV cells. Here we indicate the types of PV cells depend on silicon:

- **Crystalline silicon (c-Si) PV cells:**

  These cells are made of silicon bars through the development of silicon single crystalline (sc-Si) or polycrystalline (pc-Si), then formatted to thin layers and processed chemically and physically through various stages to become PV cells.

  The efficiency of these cells ranging from 15-17 percent. sc-Si PV cells are expensive because of its efficiency while pc-Si PV cells are cheaper and has less efficiency.

- **Amorphous silicon (a-Si) PV cells:**

  Material of these cells is a form of silicon, where the configuration of crystalline is split by the coexistence of another element such as hydrogen or other elements were added intentionally to give it characteristic electrical properties.

  The a-Si PV cells cost less compared to the c-Si PV cells where the disposing of a thin layer uses less quantities of the raw materials used in manufacturing the c-Si PV cells and the needed silicon is only 1 percent of the used silicon in the c-Si PV cells. The efficiency of these cells ranging from 4-9 percent.

5.5. Incident Radiation (light) on PV Cells

The total radiations those hit the surface of a PV cell is divided into three basic parts (see figure 5.5.1):

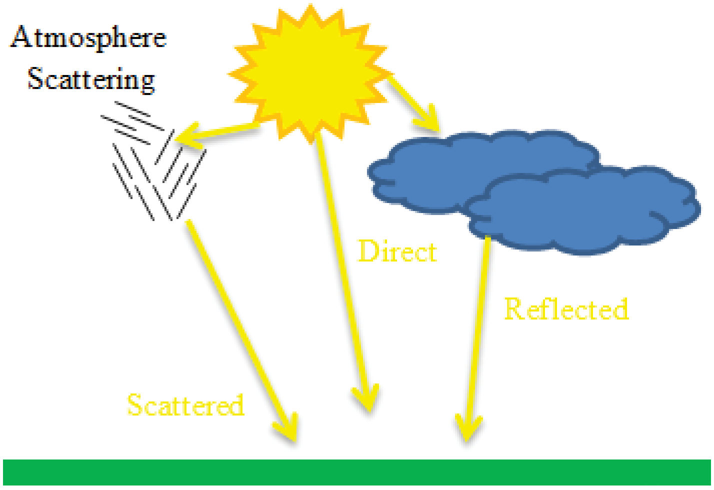


Figure 5.5.1: Total radiation parts.

1. **Direct Radiation (G_{direct}):**

   It is a radiation in any direct line from the sun to the earth and it is the most presence type on sunny days. But on cloudy days the sun is obscured by clouds and the direct radiation in such days is almost zero [13].

2. **Scattered Radiation ($G_{scattered}$):**

   It is the most presence type on cloudy days. The molecules of this type are scattered outside the direct radiation path and since this radiation comes from different parts of the atmosphere, some name it as Sky Radiation. The amount of the scattered radiation is about 10-20 percent for the sky clear and up to 100 percent of the cloudy sky [13].

3. **Reflected Radiation ($G_{reflected}$):**

   This type is a radiation that reflected by different interfaces surrounding the PV cell and called (Albedo Radiation) [13].

The amount of the reflected radiation by interfaces is different because of the refractive index of each interface and this refractive index (n) is taken into account when we want to find the amount of the radiation reflected by interface at a certain point in the ground and to calculate refractive index we use Snell's law [14]:

$$n = \frac{c}{v} = \frac{Speed\ of\ Light\ (ray)\ in\ space}{Speed\ of\ Light\ (ray)\ in\ a\ material}$$

where C is 3x10^8 meters per second (m/s).

The following table shows the refractive index of some materials at 20 Celsius degrees:

Material	Refractive Index	Material	Refractive Index
Solids			
Diamond	2.419	*Ice*	1.309
Glass (Crown)	1.523	*Quartz (Molten)*	1.458
Liquids			
Water	1.333	*Carbon Tetrachloride*	1.461
Ethyl Alcohol	1.362	*Gasoline*	1.501
Gases			
Air	1.000293	*Carbon Dioxide*	1.000139
Oxygen	1.000271	*Hydrogen*	1.00045

Table 5.5.1: Refractive index.

<http://www.smsec.com/ar/encyc/phys/sec3/10.htm>

From the above table, we can find the speed of light (rays) in one of the material such as diamond [14]:

$$v = \frac{c}{n} = \frac{3x10^8}{2.419} = 1.24x10^8\ m/s$$

The result shows that the speed of the ray in the material is slower than in the space and that is true.

After knowing the three parts of the incident radiation (rays) on a surface in the horizontal position, the following equation used to calculate these parts and find the final total amount of the incident rays to the surface ($G_{incident}$) per square meter [15]:

$$Total\ Radiation = Direct\ Radiation + Scattered\ Radiation + Reflected\ Radiation$$

$$G_{total} = G_{direct} + G_{scattered} + G_{reflected}$$

Now, we can calculate the incident radiation on a horizontally installed PV cell (see figure 5.5.2) [15].

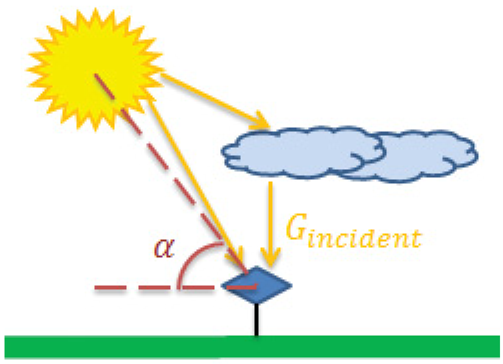


Figure 5.5.2: Horizontally installed PV cell

And to calculate the incident radiation on the horizontal PV cell ($G_{horizotal}$) [15]:

$$G_{horizotal} = G_{total} * \sin \alpha$$

where α is the sun elevation angle and given as [15]:

$$\alpha = 90 - \emptyset + \delta$$

where δ is the latitude; and $\emptyset$ is the declination angle and given as [15]:

$$\emptyset = 23.45° * \sin[0.9863 * (d - 81)]$$

where d is the number of the day in the year.

After the analyzing of the total incident radiation on a horizontal PV cell, we can increase the amount of the incident radiation by installing the PV cell in a carefully selected inclination angle and it can be tilted so it faces the sun for most of the time and throughout the year where that makes it produce the maximum energy (see figure 5.5.3) [15].

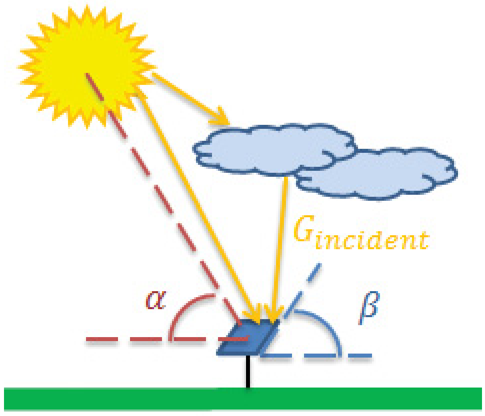


Figure 5.5.3: Tilted PV cell.

Applying an inclination angle of a PV cell will change the previous equation and this angle most be added because it impacts on the amount of incident radiation on the PV cell. To calculate the radiation in a tilted PV cell ($G_{tilted\ cell}$), we use the equation [15]:

$$G_{tilted\ cell} = G_{total} * \sin(\alpha + \beta)$$

where α is the sun elevation angle as explained previously; and β is the tilt angle of the PV cell.

Finally, to get the total light intensity arrived into the cell in (W/m^2) depending on the distance between the light source and the cell [16]:

$$G_{incident} = \frac{Source\ output\ power\ in\ watts\ (W)}{Surface\ Area(m^2)} = \frac{Source\ P_{out}}{4 * \pi * r^2}$$

Where, r is the distance between the light source and the cell.

In case we do not have the Light output power in watts (W) and we have it in Luminous Flux (lm), we can find the output power from the light by using the formula [16]:

$$G_{incident}(w) = \frac{Luminous\ flux\ (lm)}{Luminous\ efficiency\ (lm/w)}$$

Where, $Luminous\ efficiency$ is a constant and specified for each kind of light source as follow:

Tungsten incandescent light bulb: 15 lm/W
Halogen lamp: 20 lm/W
Mercury vapor lamp: 50 lm/W
Fluorescent lamp: 60 lm/W
LED lamp: 60 lm/W
Metal halide lamp: 87 lm/W
High pressure sodium vapor lamp: 117 lm/W
Low pressure sodium vapor lamp: 150 lm/W

Another way of finding the power in watts/m^2, we have to find E_v which is the illuminance with unit (Lux) using the same previous formula with using $Surface\ Area$ instead of $Luminous\ efficiency$ (lm/w) as follow [16]:

$$E_v = \frac{Luminous\ flux\ (lm)}{Surface\ Area(m^2)} = \frac{Source\ P_{out}}{4 * \pi * r^2}$$

Then, we convert Lux to W/m^2 using the formula [16]:

$$G_{incident}(w) = \frac{E_v\ (lux) *\ Surface(m^2)}{Luminous\ efficiency(lm/w)}$$

5.6. Connections of PV Cells

As we explained previously, when the sunlight penetrates into the cell, the material in the cell absorbs photons from the light. This action frees the electrons in the negative layer n-type and let them move to the positive layer p-type and so on. This vibration or we can say the alternating of the electrons between the negative and the positive layers is forming an electric current.

Then, to increase the output, we can make a module which made of many PV cells connected together. Therefore, we can have a PV array by connecting many modules together either in series to increase the voltage or in parallel to increase the current:

- **Series connection (PV array):**
  Due to the small voltage generated by a single solar cell, the PV array is often a collection of cells in series to get the output voltage commensurate with the load voltage. Since the cells are connected in series, the current flowing in a single cell is the same as the current flowing in all the connected cells (see figure 5.6.1).

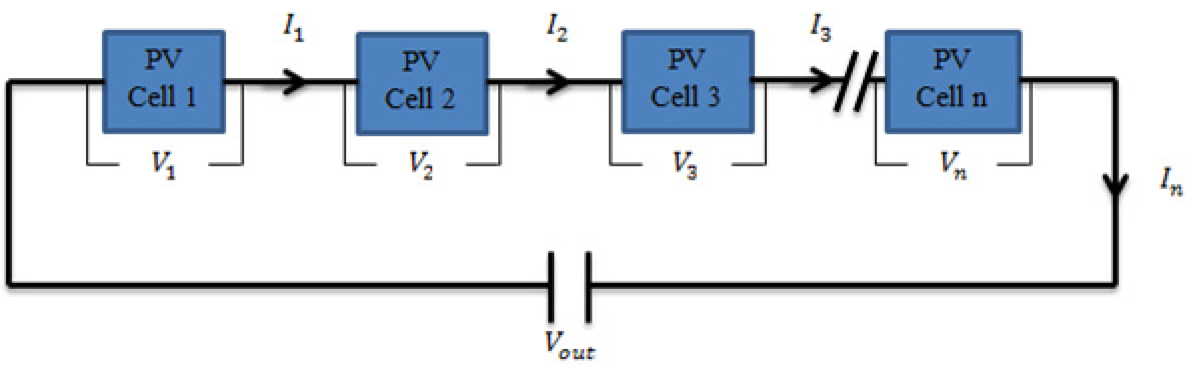


Figure 5.6.1: Series connection PV array.

From the above figure, we get the relation of voltage and current as:

$$I_{out} = I_1 = I_2 = I_3 = I_n$$
$$V_{out} = V_1 + V_2 + V_3 + V_n$$

- **Parallel Connection (PV array):**
  The current of a single PV cell is very small and may not commensurate with the load current, and in order to obtain a large current we must assemble a number of PV cells in parallel. In this case, we note that the generated voltage is the same in every cell and the current is equal to the sum of the current in every connected cell (see figure 5.6.2).

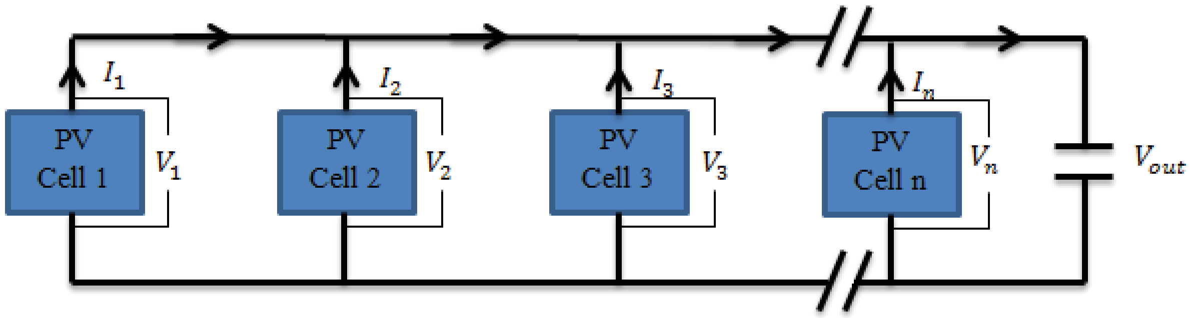


Figure 5.6.2: Parallel connection PV array.

From the above figure, we get the relation of voltage and current as:

$$I_{out} = I_1 + I_2 + I_3 + I_n$$
$$V_{out} = V_1 = V_2 = V_3 = V_n$$

- **Series and Parallel Connection (PV module):**
  To get more power, PV cells are assembled in series and parallel at the same time. When connecting the cells in this way we get the advantages of serial and parallel connection, thereby we get the voltage and the current relatively large and this method is the most widely used (see figure 5.6.3).

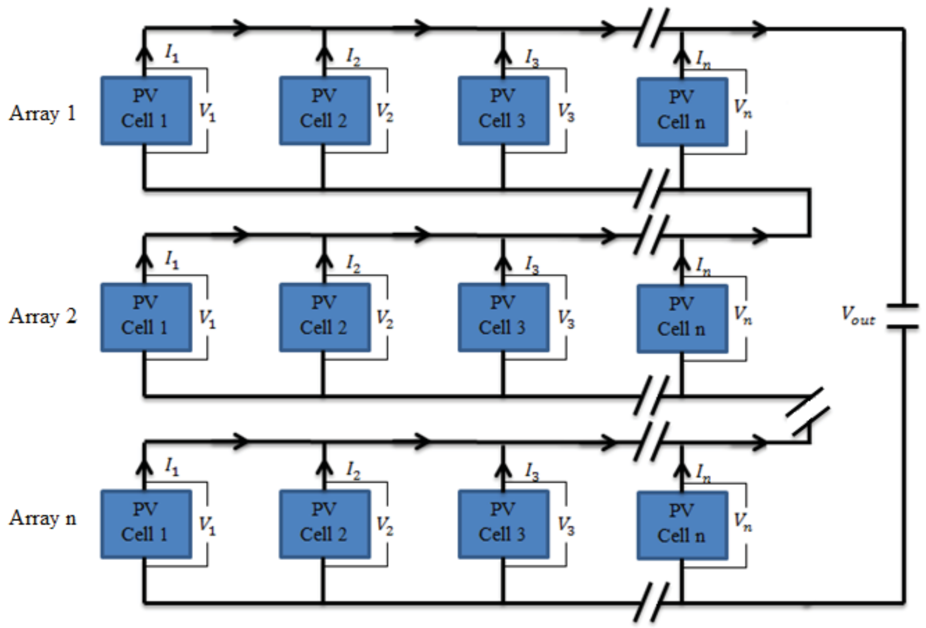


Figure 5.6.3: PV module in series.

In this connection method, every array has the relation:

$$I_{array} = I_1 + I_2 + I_3 + I_n$$

$$V_{array} = V_1 = V_2 = V_3 = V_n$$

Then, to find total output of the whole module:

$$I_{out} = I_{array\ 1} = I_{array\ 2} = I_{array\ n}$$

$$V_{out} = V_{array\ 1} + V_{array\ 2} + V_{array\ n}$$

That means, in every array we increase the current by connecting the cells in parallel then we increase the voltage by connecting the array together in series. We can also do the way around where we increase the voltage in every array by connecting the cell in series and then increase the current by connecting the arrays together in parallel (see figure 5.6.4).

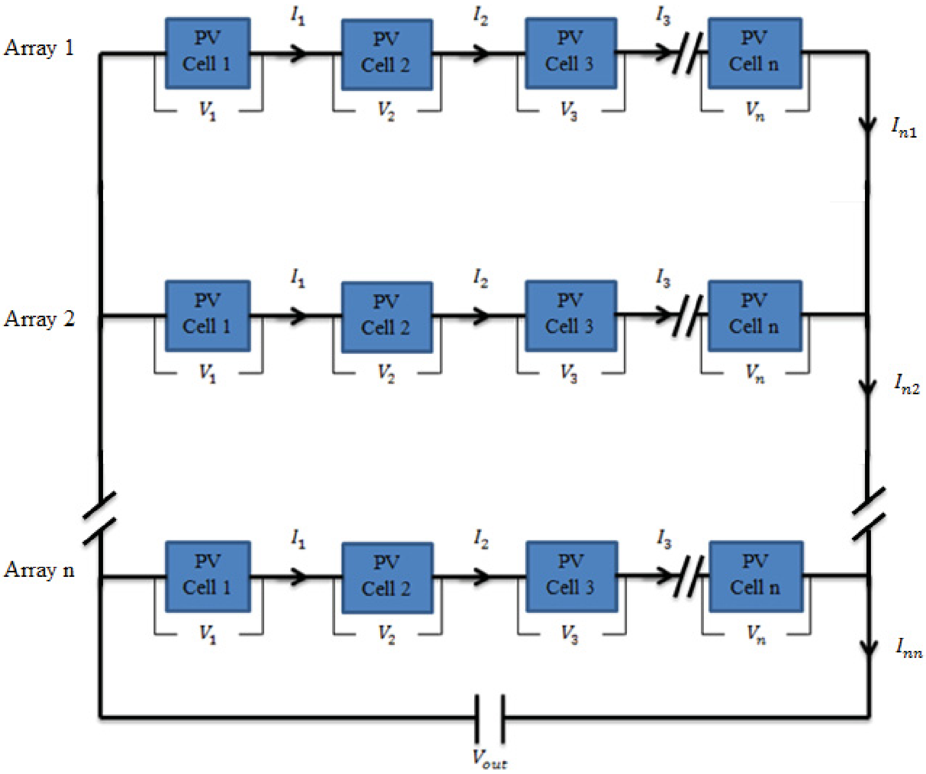


Figure 5.6.4: PV module in parallel.

In this connection method, every array has the relation:

$$I_{array} = I_1 = I_2 = I_3 = I_n$$

$$V_{array} = V_1 + V_2 + V_3 + V_n$$

Then, to find total output of the whole module:

$$I_{out} = I_{array\,1} + I_{array\,2} + I_{array\,n}$$

$$V_{out} = V_{array\,1} = V_{array\,2} = V_{array\,n}$$

5.7. PV Panel

In order to get a large amount of electric power, PV panel must be created and that is by connecting many PV modules together is series and parallel (see figure 5.7.1).

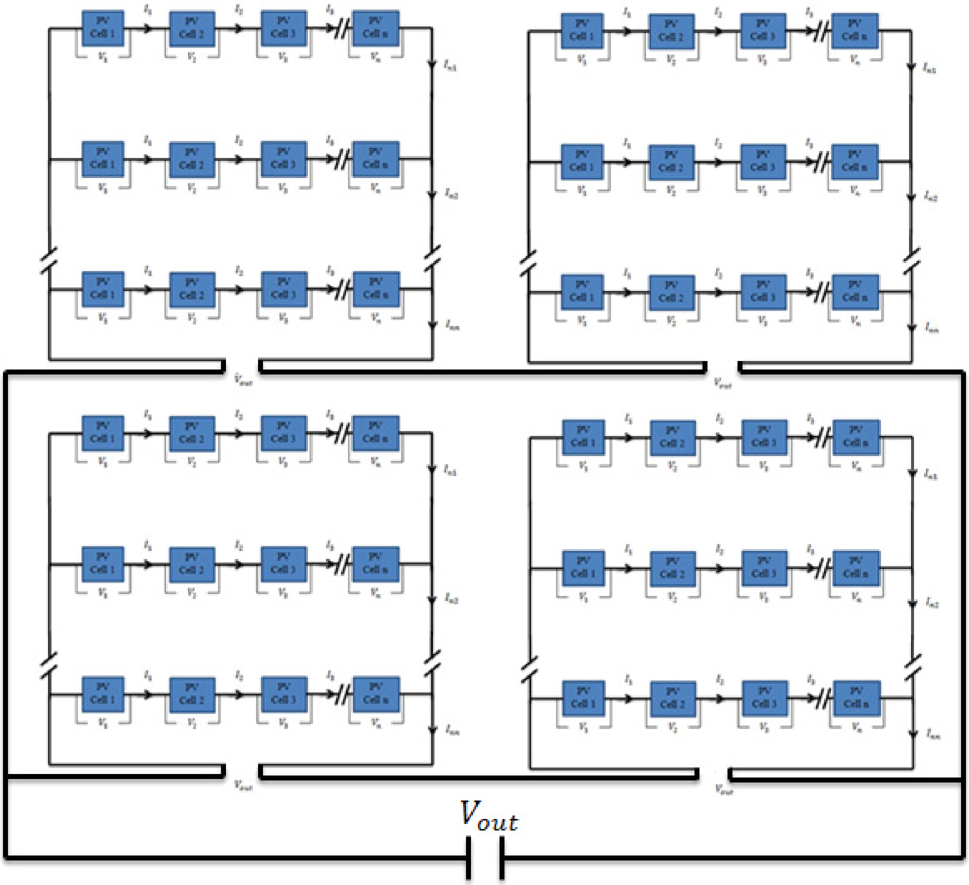


Figure 5.7.1: PV Panel.

After the installation of a PV panel by connecting the arrays, the PV panel gives us direct current (DC) but the required current for building appliances is the alternative current (AC). So, we need to convert the output electricity from DC into AC and this process is happens with a specific device called DC/AC inverter. At the same time, we might connect the DC output to a group of batteries connected together in series and parallel to keep some of the output for later use or an emergency.

After connecting the output of the PV panel to the DC/AC inverter, the output of the inverter will be AC and we can connect it directly into a building or into the public electricity network (see figure 5.7.2).

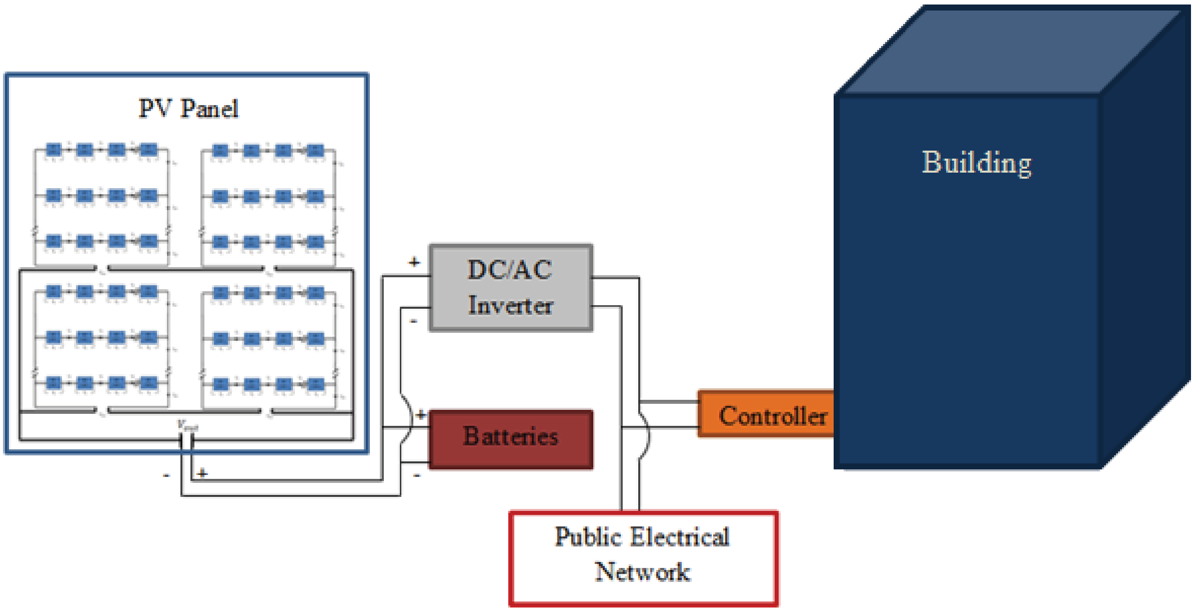


Figure 5.7.2: PV panel network.

5.8. Problems Facing PV Cells

The most important problem facing the PV cells is the dust and how to keep them clean. The ongoing researches on this topic have proved that up to 50 percent of the PV cell efficiency is lost because of dust. The best way to keep the cells clean of the dust is to use normal cleaning methods for no longer than several days periods. These periods vary from country to country based on the weather and the dust status in each country [17].

The second problem is the store of solar energy and using it during the disappearing of the sun rays like at night, in cloudy days or dusty days. Storing the solar energy depends on the amount of the energy, type of use and the period of use in addition to the total of the storage method. The subject of storing solar energy needs more research and new discoveries.

The common method of storing PV electric power is to use a liquid batteries (lead-acid batteries), and there are currently many ways of storing the PV electric power but most of them are costly or has a complex techniques.

The third problem facing the PV cells is the losses, where the important losses factors are:

- **Sunlight reflection on the PV surface:** The PV cell absorbs part of the incident sunlight while the rest light is reflected and that leads to the incomplete absorption of photons. This problem can be avoided by applying an anti-reflection film.
- **Excess power:** Together with the first factor they are as a compatibility source between the voltage and current, where the cell just absorbs the electrons with energy over E_g while the other electrons are lost.
- **Yield of assembly:** This depends on the assembling structure, the absorption coefficient and in particular the material's characteristics (purity, defects and electrical properties).

5.9. Temperature Effects on PV Cells

Today, the human is facing one of the most difficult challenges throughout history represented as the remarkable increasing in the temperature as a result of the pollution caused by the human himself by producing different kind of gases which absorb the heat such as Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N2O) which effect on the atmosphere. These gases absorb the Infrared radiation (IR) from the earth and send it back again and this process slowly affects in the produced energy.

The efficiency of the PV cell usually varies inversely with the temperature. In other words, the performance of the cell decreases while the temperature rises. This means that the electric power generated by the cell decrease with increasing temperature (see figure 5.9.1).

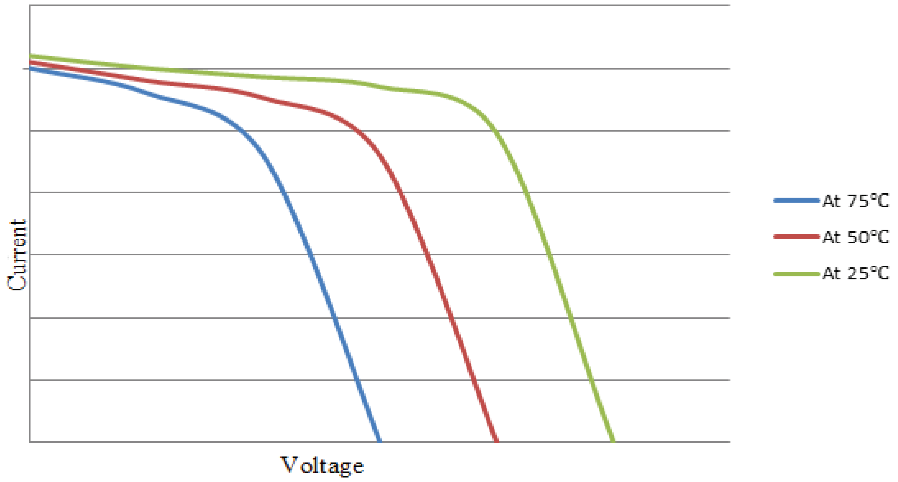


Figure 5.9.1: Temperature effect on PV cells.

Generally, the temperature is one of the factors affecting the output of a cell and there are other factors that play a role in the decreasing in the performance of the PV cell such as air speed, dust, and intensity of the incident light.

The effect of the air speed is not as big as temperature or light intensity or dust, but in the calculation of the energy it is taken into account. Figure 5.9.2 shows the effect of the intensity of the incident light on a PV cell.

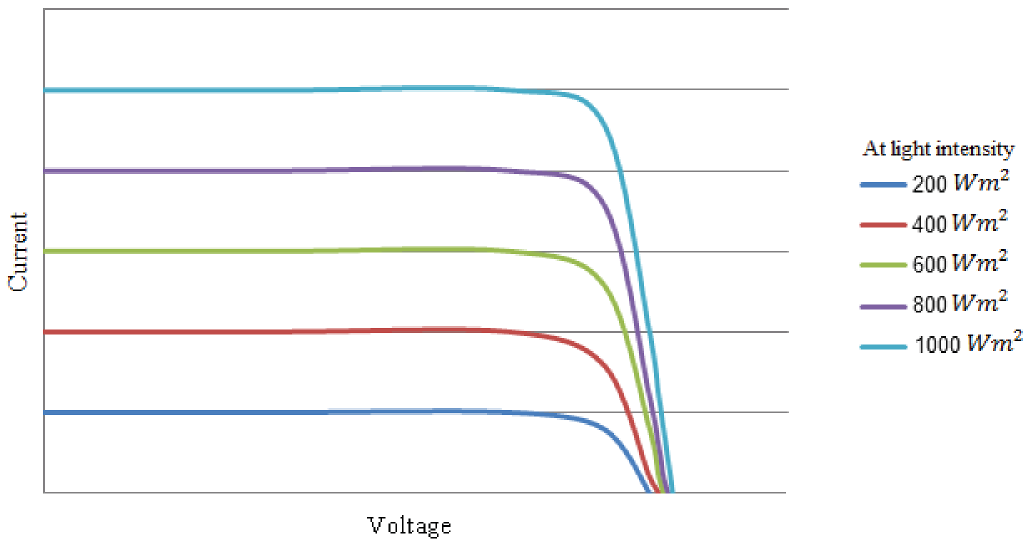


Figure 5.9.2: Light intensity effect on generated power from PV cells.

The efficiency of PV cells ranging from 8 percent to 21 percent depending on the cell type. With the external effects such as rising in the temperature or decreasing in the light intensity, the efficiency of the cells will be affected and that effects on the cost of making a PV panel project.

5.10. Improving Methods for PV Cells Efficiency

Most of the solar energy researches aim to improve the efficiency of the PV cell, i.e. increasing the performance of the PV cells in generating electric power. Lately, the researchers came with several methods to improve the performance of the PV cells by:

- **Improving the parameters of the cell** (open-circuit voltage and short-circuit current): This is also in happens in many methods such as:
  1- Using Coated Crystalline Silicon layers: When the use of crystalline dyes with efficient amount comparable to one as paints and protection of the solar cell, the efficiency will increase by 3.8 percent when coating in yellow and 6.85 percent when coating in standard dark blue. This method reduces the reflectivity from 40 percent to 20 percent and the best colors are dark blue, brown and gray.
  2- The use of multiple gaps method because it is more proportionate with the solar spectrum than single gap method, and thus a higher efficiency.
  3- Buried Contact Solar Cells: It is an attempt to develop the efficient at the lowest possible cost in terms hardening by the electroless deposition of nickel (Ni), copper (Cu) and silver (Ag). The higher efficiency obtained from this method is 18-16 percent.
  4- Screen Printed Solar Cells: Typically used where layers of silicon inlaid with boron and this method gives an efficiency of between 10 percent and 13 percent.

- **Using Solar Concentrators [18]:**
  With the remarkable improvement on the efficiency of the PV cells during the past twenty years, the high cost remains as a barrier to the spread of use. The solar energy researchers aspire to reduce the cost of producing the electric power via solar cells by using cheap materials to assemble the incoming sun rays and direct it into the solar cells, including the use of lenses and other optical techniques.

The concentrators are parts of the visual increase of the amount of the incident rays on the surface of the solar cells. Fresnel lenses is the most used material in this method, where used to concentrate the sun rays on the cells.

The concentration of sunlight (rays) is achieved either with optics-imaging or non-imaging-optics, where the first type transmits the light to one point and the second type transmits the rays from a certain area to another and transmits both direct radiation and diffused radiation.

There are standards to select the concentrator including the ratio of concentration and the heat that produced due to the concentration, where the concentration to one point produce heat between high to very high and the concentrations to a big area the produced heat will be medium to high. And in order to find out the best concentrator for a PV panel, we must compare with them in terms of the concentration ratio, incident angle and the surface area of the concentrator.

The concentrators either be fixed and do not need a tilter to follow sunlight but it has a wide receiving angle and the ability to focus the direct and scattered rays or be able to tilt with concentration ratio more than the fixed concentrator.

The most important factor for evaluating the performance of a concentrator is the concentration ratio(C), which can be defined in two ways:

1- **Geometrical Concentration Ratio (C_g):**

It is the ratio between the area of entrance aperture A_1 and the area of absorber aperture A_2, where

$$C_g = \frac{A_1}{A_2}$$

2- Flux Concentration Ratio F.C.R (C_f):

It is the ration between the incident rays on the entrance aperture $G_1$and the incident rays on the absorber aperture G_2, where

$$C_f = \frac{G_1}{G_2}$$

The solar concentrators are classified in several ways and some of them:

1- Point Focus Concentrators:

These concentrators are 3-Dimensional and generally used when the required concentration ratio is high (C = 500-1000) and are used in the central receivers that appeared for the first time by Soviet scientists in 1960 and their latest project is Solar 2 with power production of 10 megawatts (MW) in California desert in 2000 and Fresnel lenses is one of this concentrator type (see figure 5.10.1).

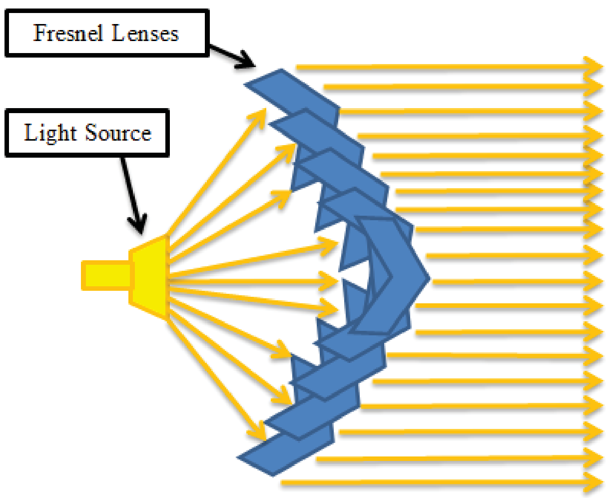
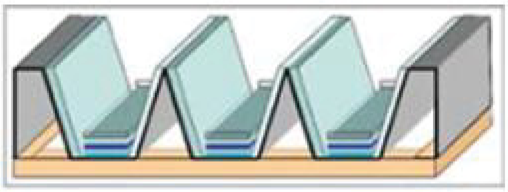


Figure 5.10.1: Fresnel Lens.

2- **Linear Focus concentrator:**

These concentrators are 2-Dimensional and generally used when the required concentration ratio is medium or low. One of these concentrators is v-trough (see figure 5.10.2).



*This picture is taken from <http://smallb.in/v-trough-solar-photovoltaic-modules>

Figure 5.10.2: V-Trough Concentrator.

- **Using a Cooling System:**

Since the temperature effects on the PV cells reversely, the PV cell need a cooling system in some countries because of the high temperature. It is also needed in the case of using light concentrator, because it increases the cell temperature.

The cooling system must be installed in the back of the cell of it does not isolate the sun rays from the cell surface. Normally, the cooling system consists of small water pipes. When the water runs in the pipes and cool and since the pipes connected to the back of the cell, then the pipes will cool the cell and decrease its temperature.

5.11. Measurements Devices of PV Panels

In the process of testing a PV cell efficiency, where the most PV cell researches focus on the improvements of the cell's efficiency (the ratio of the produced power to the input incident sun rays). There are several measurements devices to be used in testing the cell's efficiency such as:

- **Voltmeter and Ammeter:** These two devices are used to measure the output voltage (V_{out}) and current (V_{out}), so the output power can be calculated by the equation:

$$P_{out} = I_{out} * V_{out}$$

- **Digital Thermometer:** The aim of using this device is to measure the temperature of the PV cell.

- **Solarmeter:** This device is used to measure the intensity of the incident light on the PV cell surface.

6. Uses of Solar Energy

The uses of solar power were very limited in the past, because of the high price of the photovoltaic cells while the cheap price of using oil. One more thing that makes the photovoltaic cells not used in every country around the world is that the cells are dependent on the sunlight, where some countries has shorter appearance of the sun than other countries and some countries has cloudy weather most of the time such as Sweden.

Looking into the countries located in the sunny areas like Saudi Arabia for instance, we do not see a huge uses of the solar power and the reason here is that the weather is dusty for most of the time during the year and that make an isolator layer of dust on the PV cells' surfaces. In this case, the cells need to be cleaned every day which will cost more.

PV cells are used for specified kind of appliances those do not need that much of power for example we the calculator, school-walk signs, etc. and we can use it with big appliances as well in case in far places where the electrical network does not reach it such as satellites, country houses, country antenna tower, etc. The main reason of using the PV cells in such kind of appliances and places mentioned previously is that the PV cell is a good and cheap alternative power source while the increasing in the grid-connected electricity price and easy to use as well without need of any grid-connection.

Furthermore, the uses of the solar energy can be extended to be used in bigger areas and here we will explain some ways:

- **Feeding a House:** If we placed PV panels on the roof of a house, it helps in decreasing the usage of the grid-connected electrical network which will reduce the cost of the electrical invoice.
- **Solar Airplane:** With the heavy researches on developing the solar energy and extending the use of it, the researchers tried to get advantage of the solar energy on an airplane. In 2013, the *Sunseeker Due* tested a plane that can fly with a solar panel on its wings and tail to power the plane (see figure 6.1) [19].

Figure 6.1: An airplane uses solar energy.

<https://solar-flight.squarespace.com/sunseeker-duo1/>

- **Solar Car:** The first solar car was built by Alfred Pandori in 1985 in the aim of reducing the need of oil and gas. Since that time, there are many researches aim to develop the use of solar energy in the cars. Lately, Ford has displayed its first vehicle that uses solar panel that generates 300 watts as maximum. At the same time, the solar panel cannot charge the battery as fast as needed so they used Fresnel lens as a concentrator which will concentrate the light up to 10 times as Ford says. Furthermore, ford says that the car will be able to run up to 100 miles per hour (see figure 6.2) [20].

Figure 6.2: Solar Car.

<http://www.computerworld.com/s/article/9245116/Ford_builds_solar_powered_car>

7. Experiments on PV Panels

In this part, we are doing some experiments to see how does a solar panel works under several cases such as horizontally installed, tilted panel, temperature and dust effects and etc.

To build a small panel, we brought ten solar cells. Each cell gives 0.5V and 0.4A in its best performance which means 0.2W as maximum output power, and that means that the maximum output power of the panel is 2W. The area of each cell $A_c = 20.9\ cm^2$ = 0.00209 m^2 and the total area of the panel $A_c = 209\ cm^2$ = 0.0209 m^2. First, we connect them in series and all to a resister R = 1.25 Ω as shown in the following figure.

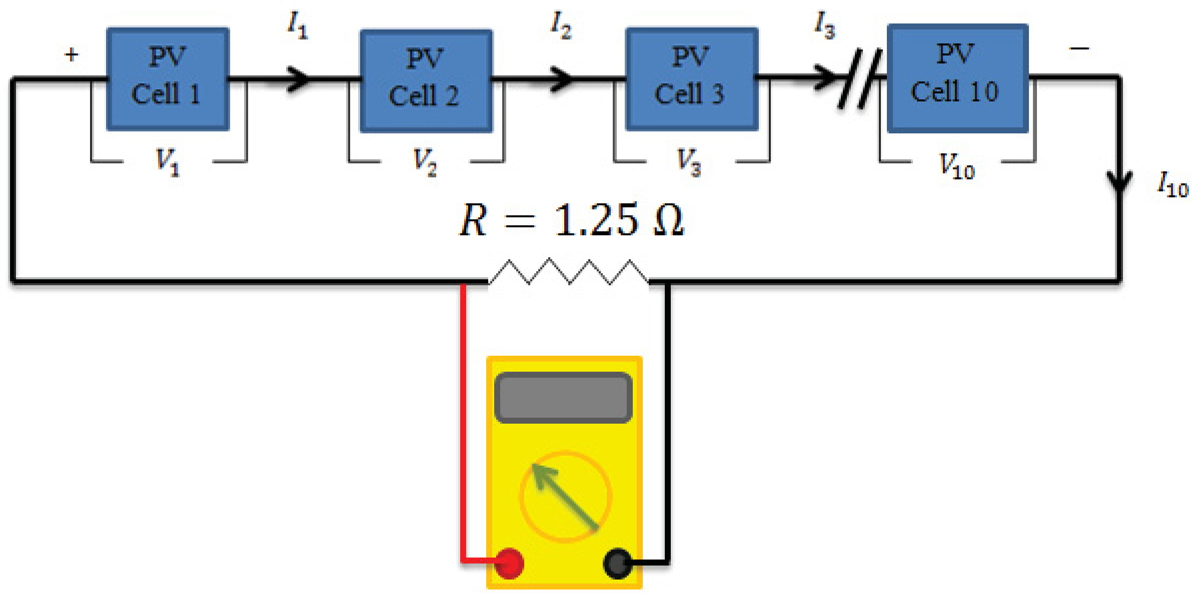


Figure 7.1: PV panel diagram.

In this panel case "series connection", the output voltage and current will be calculated as:

$$I_{total} = I_1 = I_2 = \cdots = I_9 = I_{10}$$

$$V_{total} = V_1 + V_2 + \cdots + V_9 + V_{10}$$

$$P_{out} = I_{total} * V_{total}$$

7.1. Measurements on Sun light:

As we mentioned in (page 16), the intensity of the sunlight ($G_{incedint}$) on the earth is approximated to 1360 watts/m^2. The input power into the solar panel P_{in}:

$$P_{in} = A_c * G_{incedint} = 0.0209 * 1360 = 28.424\ W$$

Here we will measure the average power from two PV panels both connected in series and placed in the same place in a sunny day, but the only difference is one of the panels is fixed horizontally (see figure 7.1.1) and the other is tilted to face the sun during the day (see figure 7.1.2).

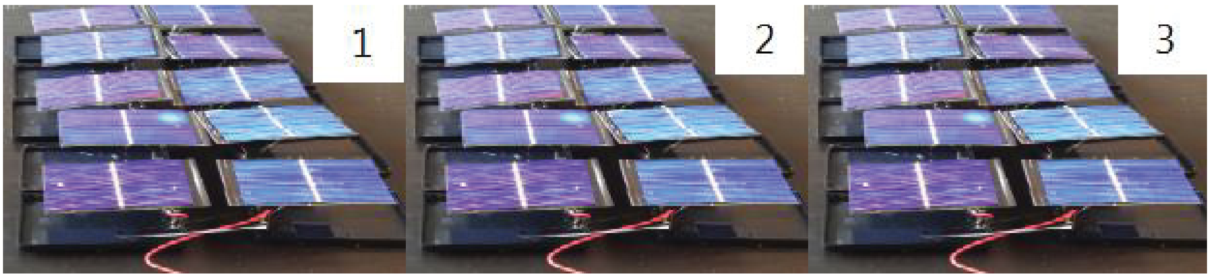


Figure 7.1.1: Horizontally fixed PV panel.

1. Morning: Facing the sky.
2. Afternoon: Facing the sky.
3. Evening: Facing the sky.

The data we have recorded is:

The average voltage V_{avg} = 4.25 V, The average current I_{avg} = 320.3 mA and the average power P_{avg} is 1.36 W.

So, the efficiency (η) is:

$$\eta = \frac{P_{out}}{P_{in}} * 100 = \frac{1.36}{28.424} * 100 = 4.79\ \%$$

Figure 7.1.2: Tilted PV panel.

1. Morning: Facing the sun to the east.
2. Afternoon: Facing the sky.
3. Evening: Facing the sun to the west.

The data we have recorded in this case is:

The average voltage V_{avg} = 4.96 V, The average current I_{avg} = 377 mA and the average power P_{avg} is 1.87 W.

So, the efficiency (η) is:

$$\eta = \frac{P_{out}}{P_{in}} * 100 = \frac{1.87}{28.424} * 100 = 6.58\ \%$$

From the calculation, we find that the tilted panel produces 37.5% more power compared to the horizontally fixed panel.

7.2. Temperature Effects:

We have used a freezer and an oven to experiment under the temperature conditions we want. Every time we specify the temperature and check it using a thermal device. To get a light source inside the freezer and the oven, we used a light bulb with data:

Tungsten incandescent light bulb

Luminous efficiency: 15 lm/W

Luminous flux: 190 lm

Nominal Voltage: 230 V

Energy consumption: 25 W

The distance between the light bulb and the PV panel $r = 10\ cm = 0.1\ m$.

Applying the formulas we have mentioned previously in our investigation, we can obtain the total output light power in (w) as:

$$G_{incident}(w) = \frac{Luminous\ flux\ (lm)}{Luminous\ efficiency\ (lm/w)} = \frac{190}{15}$$

$$= 12.67\ W$$

To be sure of the result, we can use the other way by finding E_v (Lux):

$$E_v = \frac{Luminous\ flux\ (lm)}{Surface\ Area} = \frac{190}{4 * \pi * 0.01}$$

$$= 1511.972\ lux$$

Where, E_v is the incident illuminance in Lux from the bulb to the total surface area 10 cm away.

Then, we can convert the power from E_v Lux to W as follow:

$$G_{incident}(W) = \frac{E_v(lux) * Surface(m^2)}{Luminous\ efficiency(lm/w)} = \frac{1511.972*4*\pi*0.01}{15}$$

$$= 12.67\ W$$

We have obtained the same result.

Then, we calculate the incident power that reaches the PV panel to be converted into electric power by using the formula:

$$P_{in} = \frac{A_c(m^2)}{Surface(m^2)} * G_{incedint} = \frac{0.0209}{4 * \pi * 0.01} * 12.67 = 2.107\ W$$

$$= 2107\ mW$$

Now, we can obtain the efficiency as follow:

$$\eta = \frac{P_{out}}{P_{in}} * 100$$

The following table shows the values measured from the built PV panel in six different temperature conditions:

$Temperature$	I_{out} mA	V_{out} mV	P_{out} mW	η
10 C	0.0879	109.02	9.5829	$(9.5829/2107) * 100 = 0.455\%$
18 C	0.0734	97.25	7.1382	$(7.1382/2107) * 100 = 0.339\%$
26 C	0.0486	73.96	3.5945	$(3.5945/2107) * 100 = 0.171\%$
45 C	0.034	54.87	1.867	$(1.867/2107) * 100 = 0.089\%$
60 C	0.023	49.0	1.13	$(1.13/2107) * 100 = 0.054\%$
100 C	0.016	35.0	5.6	$(0.5\ 6/2107) * 100 = 0.027\%$

Table 7.2.1: Temperature effects on a PV panel.

From the values above, we can clearly see how the temperature does effect on the efficiency of the solar panel. Where, when the temperature goes high the efficiency goes lower (see figure 7.2.1).

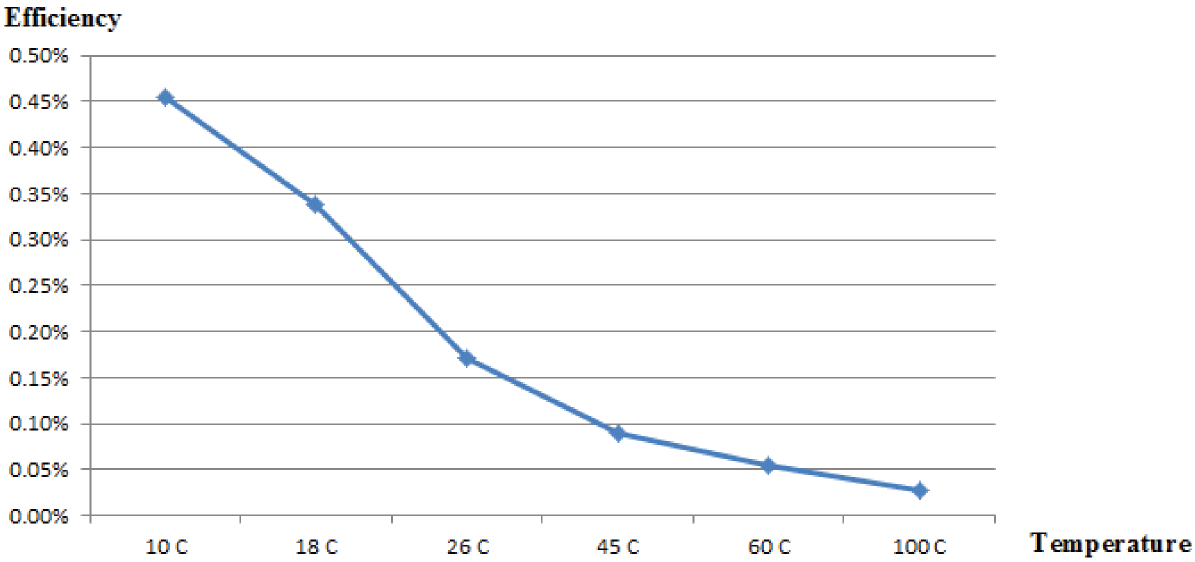


Figure 7.2.1.: Temperature effects on a PV panel's efficiency.

7.3. Concentrator:

In this part, we will use the V-Through to concentrate the incident light to improve the producing of the power.

First, to see the difference caused by the V-Through we have found V_{out}= 4.25 V, I_{out}= 320.3 mA and P_{out}= 1.36 W without using the V-Through. After using the V-Through method, we have found V_{out}= 5.13 V, I_{out}= 410 mA and P_{out}= 2.11 W. Comparing P_{out} with and without using the V-Through method, we found that with using this method P_{out} is increased 35.55%.

8. Statistics

In this chapter, we show the statistics reading from a PV panel fixed on the roof of Blekinge Institute of Technology (BTH). The panel consists of 12 PV module, and every module has the properties [21]:

- Polycrystalline silicon PV cell.
- 48 cells.
- 1.31 m^2.
- 2,400 N/m^2 mechanical load-bearing capacity (245 kg/m^2).
- 1,000 V DC maximum system voltage.
- 15 A over-current protection.

The following figure shows the connection diagram for the PV panel on BTH roof.

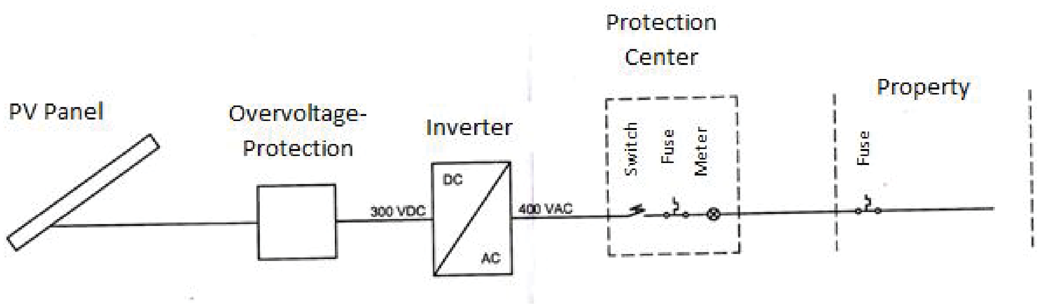


Figure 8.1.: Connection diagram [21].

See the next figure for the PV panel connection.

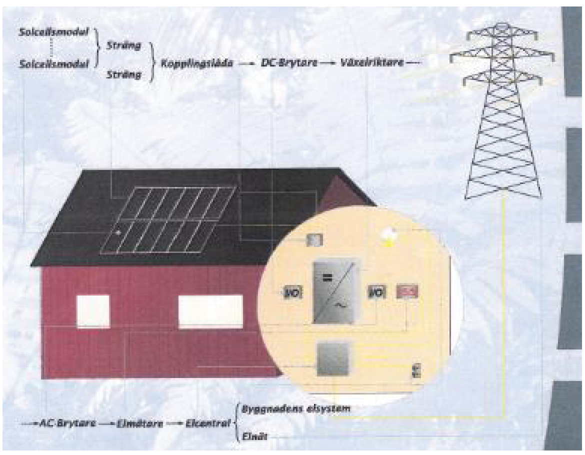


Figure 8.2.: Connection of the PV panel on the roof of BTH [21].

Figure 8.3 shows the produced energy every month for the period between February and August, the values were taken from BTH energy logged data [21]:

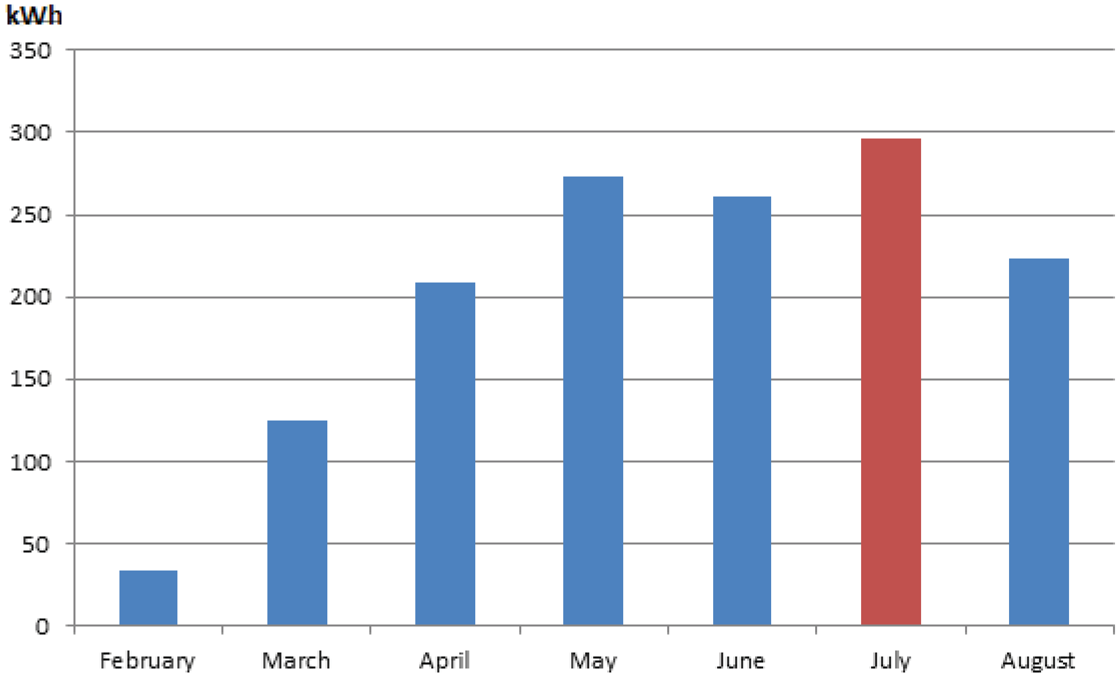


Figure 8.3.: Monthly produced energy recorded by BTH.

In the statistics above, it shows that the maximum produced power for the period between February and August was in July reaching 269.7 kWh. Figure 8.4 shows the daily produced energy during July [21].

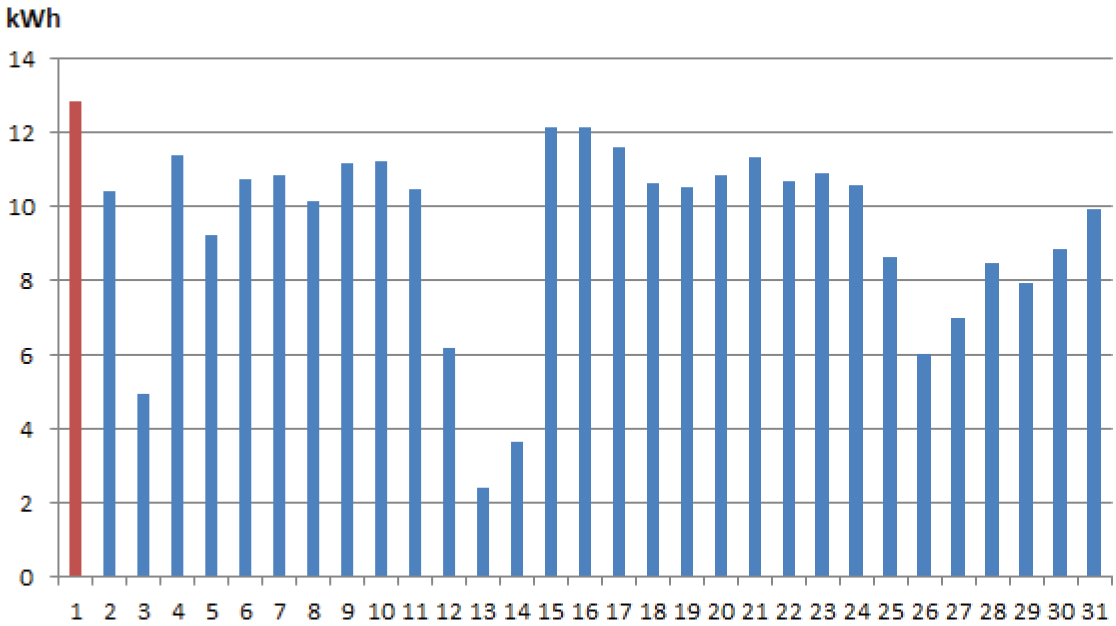


Figure 8.4.: Daily produced energy during July recorded by BTH.

We can see from the above figure that on the 1st of July, the production of the electric energy was the highest which reaches 12.86 kWh [21].

Depending on the recorded data from BTH, the following figure gives us the details of the produced electric power hour per hour during the 1st of July [21].

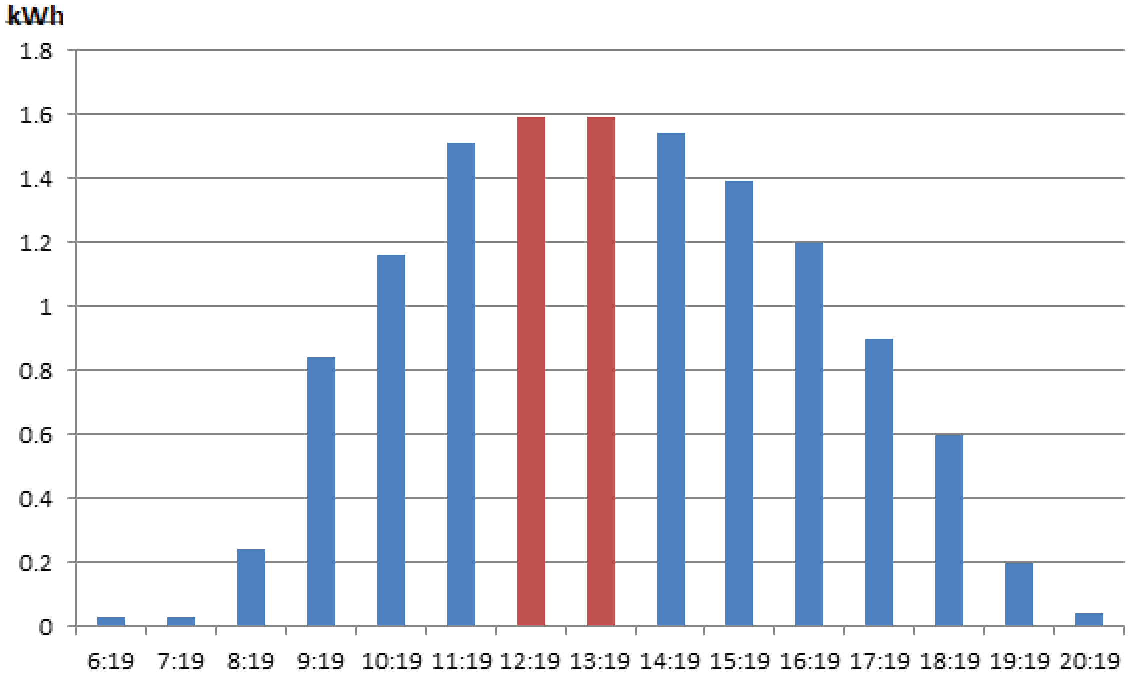


Figure 8.5.: Hourly recorded produced energy by BTH.

We can see that the highest produced energy was at 12:19 and 13:19 when the sun was facing the PV panels [21].

Returning to the recorded energy data, the highest production of the energy at a specified hour was on the 23th of June at 12:19 with 2.03 kWh [21].

9. Conclusion

Solar energy is being on research for decades now and has been implemented in different ways to counter greenhouse effects. One of the ways is to use solar panel to produce electricity that is our final year project as mentioned in our thesis report.

Sun is the key behind driving the solar energy that is an inexhaustible renewable resource. The sun radiates huge amount of heat energy that can be converted into electricity. Solar panels have the capacity to contribute energy to progressive world if planned and designed according to needs. Here it should be mentioned as the global demand for energy is growing and in the same time the fossil fuel reserves are going down and the cost of production is increasing. Hence there is a shift seen towards renewable energy.

Along with increasing demand of solar panels there are some drawbacks to it. The initial cost purchasing and installing solar panels on a roof is very high. There is one of major drawback that solar panel requires constant sunlight to be effective.

The experiment carried out by us showed solar cells connected in series positioned in two different ways. Once solar cells were positioned horizontally and the other time solar cells were positioned in tilted position. The test showed minor difference in the result but if considered in larger scale the output of the power production will definitely have greater impact as a whole on the rate of production. As the experiment was performed and the output power was calculated for both tests, we came to a conclusion based on the results that tilted solar cells gave slightly more power output compared to horizontally fixed solar cells i.e. 37 percent more. As drawn from the conclusion the tilted position can generate power at different rates depending on the angle of incident. As per the research the power density will be at its peak when the PV module is perpendicular to sun. In other words, when incident sunlight is perpendicular to solar panel, the power density is equal to that of sunlight. It was also observed that during winter time steeper panel position give larger loads while lower tilt angles use greater fraction of light during summer hence generating more power.

The matter of efficiency is still to be improved as current technology has struggled to do so. Cheap inexpensive silicon can provide maximum theoretical efficiency up to 34 percent while practical efficiency is around 22 percent. There is an alternative to increase the efficiency by using multi-junction cells that use multiple substrates that can capture larger portion of sun spectrum. This improves the efficiency by 87 percent in theory but in reality in practice it is limited to 43 percent.

Coming to an end it can be said that solar cells will play a major role in future to replace non-renewable energy sources since it is environment friendly method and long term investment can pave the way to implement solar energy globally.

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