Sudan University of Science and Technology
College of Graduate Studies

Improving Soba Solar Contact Cover for fixed PV Modules by Using Acrylic sheets

تحسين غطاء سوبا سولر الملامس للبي في(PV) المثبت بإستخدام الواح الأكريلك

A dissertation submitted in partial fulfilment for the requirements of a Master degree in Physics

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بسم الله الرحمن الرحيم

الآيــــــة

قال سبحانه وتعالى :

{وَقُلِ اعْمَلُواْ فَسَيَرَى اللّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُونَ }

صدق الله العظيم

سورة التوبة

الآية (105)

Dedication

First I thank Allah for giving me the strength to complete this work. I dedicate this dissertation to each of the following: To the foundation of patience and optimism and hope, dear mom and dad, to those who have demonstrated to me how beautiful life is, my brothers, to those people who paved our way of science and knowledge, all our distinguished teachers and to my best friends.

Acknowledgement

I would like to express my gratitude to administration and academic staff of Physics Department at College of Science, Sudan University of Science and Technology (SUST) for moral support; special thanks extended to my supervisor professor (assistant) MAGDI ELFADIL YOUSIF SULIMAN for invaluable help and fruitful suggestions. I also thank teacher SAMAWAL of the Institute of Energy Research and ABD ALSAKHIE of the University of Nileen for their help.

Abstract

In this research specifications of acrylic plate had been examined to evaluate its reliability to be used as alternative for the glass cover in the SobaSolar fixed PV modules. The maximum power of a fixed PV module composed of $\mathbf{26 \times 20.5}\ \boldsymbol{cm}$ solar cell panel in outdoor test was found to be about: **3.42 Watts**, that is when acrylic cover was attached to the module replacing the normal glass. This results showed that no significant change in the maximum power was made by using acrylic glass cover, since the indoor test value of the maximum power was found to be: **3.58 Watts**.

المستخلص

في هذا البحث أختبرت مواصفات ألواح الأكرلك (**PMMA**) ودرجة كفاءة إعتماديتها كبديل للغطاء الزجاجي في خلايا سوباسولر الشمسية للنظام الثابت، ووُجِد أن القيمة القصوى للقدرة المنتجة من الخلية المكونة من $20.5\,cm \times 26$، لوح من الخلايا الشمسية والمغطاة بواسطة الأكرلك هى **3.42 واط**، وهذه النتيجة أوضحت أنه ليس هناك تغيير ملحوظ في القدرة. حيث وجد أن القدرة القصوي في المختبر الداخلى في الظروف المعيارية تساوى **3.58 واط.**

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CHAPTER ONE

INTRODUCTION

1.1 Energy and Life

The electricity demand in the world's developing countries is increasing rapidly and it is a great challenge to meet this demand, without affecting the climate and the environment. The most available energy source for power production in the world's developing countries today is fossil fuels. However, with threatening climate change the use of these must arguably decrease. The power generation is globally the largest source of green-house gases and, preferably, the generation should be shifted to more renewable sources. There are a lot of alternatives to fossil fuels, but the cost is in most cases higher than for conversion of fossil fuels. Solar power is often regarded as one of the most promising energy sources for the future (Osman, 2009).

Solar energy can be used in a number of ways. For electricity generation the most common processes is through solar photovoltaic (PV) cells. Solar PV cells have been used to power small electronic devices such as calculators. But large groups of solar PV cells can be added together powering small solar panels in individual households or larger arrays feeding power directly into the electricity grid.

1.2 Objectives of the dissertation

The Objectives of this dissertation are:

1. To improve the performance of fixed SobaSolar PV modules by using acrylic (i.e. poly(methyl methacrylate) (PMMA)) cover sheet instead of normal glass.
2. To provide a safe and easy cleaning cover for fixed SobaSolar PV modules.
3. To improve the usage of SobaSolar PV modules by providing a flexible cover so as to widen usage of SobaSolar PV modules, e.g. provide flexible unbroken mobile modules for usage in providing power to mobile cells, military torches. etc.
4. To increase life-time of SobaSolar PV modules via decreasing the brown-colored problem due to attachment of normal glass cover.

1.3 Statement of the problem of the dissertation

SobaSolar PV cells modules are encapsulated in the PV encapsulation unit located at the Institute of Energy Research building, Khartoum Sudan. The SobaSolar PV modules produced usually encounter a problem of full attachment when normal glass cover is used, which in turn decreases life-time of the PV cells; and when using SobaSolar cells in stands alone systems the cleaning is also another problem to be fixed. Therefore, motivated by proposing integrated fixed PV modules power system for street light in city of Khartoum we considered the above mentioned problems and searched for alternatives solutions.

1.4 Outline of the dissertation

In this dissertation, we checked alternatives of glass cover for fixed PV modules so as to solve many problems, i.e. degradation and decreasing of PV module life time, cleaning and flexibility. The Dissertation is composed of five chapters. In chapter one we presented an introduction including: Energy and life, objectives of the dissertation, statement of the problem of the dissertation and the outline of this dissertation. And in chapter two we presented a background including: Solar energy and electric power production, what is a semiconductor, importance of semiconductor, governing principles of solar energy, solar irradiance, solar constant, solar spectrum, solar radiation, ways of converting solar energy into electrical energy and finally details on PV cells. Furthermore, we presented in chapter three the alternatives for fixed PV modules glass cover including: SobaSolar, alternatives for the glass contact cover and the choice of the alternative to the normal glass which is the acrylic. And in chapter four we set out the methodology. Finally, in chapter five we presented: Dissertation results, discussion and conclusion.

CHAPTER TWO

BACKGROUND

2.1 Solar energy and electric power production

At present, the total energy consumption in the world is fourteen tera-watts (TW) at any given moment, and this consumption is estimated to be about two times higher by 2050 (WBGU, 2003). To meet this demand, all forms of energy need to be increased rapidly in the coming years. The use of traditional energy resources such as fossils fuel is not justifiable, due to its pollution and greenhouse gas emissions. Solar energy is available in abundance in most parts of the world. The amount of solar energy incident on the earth's surface is approximately $1.5\ x\ 10^{18}$ kWh/year, which is about 10,000 times the current annual energy consumption of the entire world. The density of power radiated from the sun (referred to as solar energy constant) is 1.373 kW/m^2 (WBGU, 2003).

For this reason, there has been rapid development of renewable energy technologies to meet the future energy demand and creates a sustainable free pollution energy economy.

Among the various ways of harvesting energy from mother nature, solar energy has become one of the dominant forms due to its availability. According to recent data, the annual energy reaching the earth's surface from the sun is larger than all forms of traditional energy resources that have ever been available, or will ever be available, from all of the non-renewable sources on the earth including oil, coal, natural gas, and nuclear power (Fang Lin Luo, 2010).

Solar energy currently provides only a quarter of a percent of the planet electricity supply; however, this industry is growing at staggering speed as photovoltaic (PV) panels have the advantage of being almost maintenance and pollution free.

2.2 What is a semiconductor?

The magic word semiconductor is composed of two words-Semi and Conductor. Semi means not completely while conductor mean something, which can conduct electricity. Everybody is familiar with "Electricity". It is present everywhere; it runs many appliances in your home and outside the home like TV, Bulb, Freeze, and Microwave Oven etc. In simple terms, the current must past through wires so that the electricity can reach all these appliances. So a conductor is nothing but a material having ability to conduct this electricity. Semiconductors conduct electricity to some extent, less than the conductors, how much do you think? Well, it depends on the type of material or it's mixture and size. A semiconductor is a material that has intermediate conductivity between a conductor and an insulator. It means that it has unique physical properties somewhere in between a conductor like aluminum and an insulator like glass. In a process called doping, small amounts of impurities are added to pure semiconductors causing large changes in the conductivity of the material. Examples include silicon, the basic material used in the integrated circuit, and germanium, the semiconductor used for the first transistors (Sze S. M., 2012).

2.3 Importance of semiconductors

To understand the importance of semiconductors let's first understand the difference between electricity and electronics. Both are concerned with generating, transferring, and utilizing electrical energy. The main difference is that electricity is concerned with uses of electrical energy in power applications for heat, light, and motors while electronics is concerned with power control and communications applications such as electronic thermostats, electric motor speed control and radio. Engineering importance of semiconductors results from the fact that they can be conductors as well as insulators. Semiconductors are especially important because of a varying conditions like temperature and impurity content can easily alter their conductivity. The combination of different semiconductor types together generates devices with special electrical properties, which allow control of electrical signals. Semiconductors are employed in the manufacture of electronic devices and integrated circuits. Imagine life without electronic devices. There would be no radios, no TV's, no computers, no video games, no PV cells and poor medical diagnostic equipment (Rockett A. , 2007).

2.4 Governing principles of solar energy

2.4.1 Solar irradiance

The Sun is the fundamental driving force for energy in the earth's climate system. It is of crucial importance to understand fully the conditions of its arrival at the top of the atmosphere and its transformation through the earth. The amount of solar power available per unit area is known as irradiance. Irradiance is a radiometric term for the power of electromagnetic radiation at a surface, per unit area. It is used when the electromagnetic radiation is incident on the surface.

Irradiance fluctuates according to the weather and the sun's location in the sky. This location constantly changes through the day due to changes in both the sun's altitude (or elevation) angle and its azimuth (or compass) angle. Figure 2.1. below shows the two angles (the sun's elevation angle and the sun's compass angle) used to specify the sun's location in the sky.

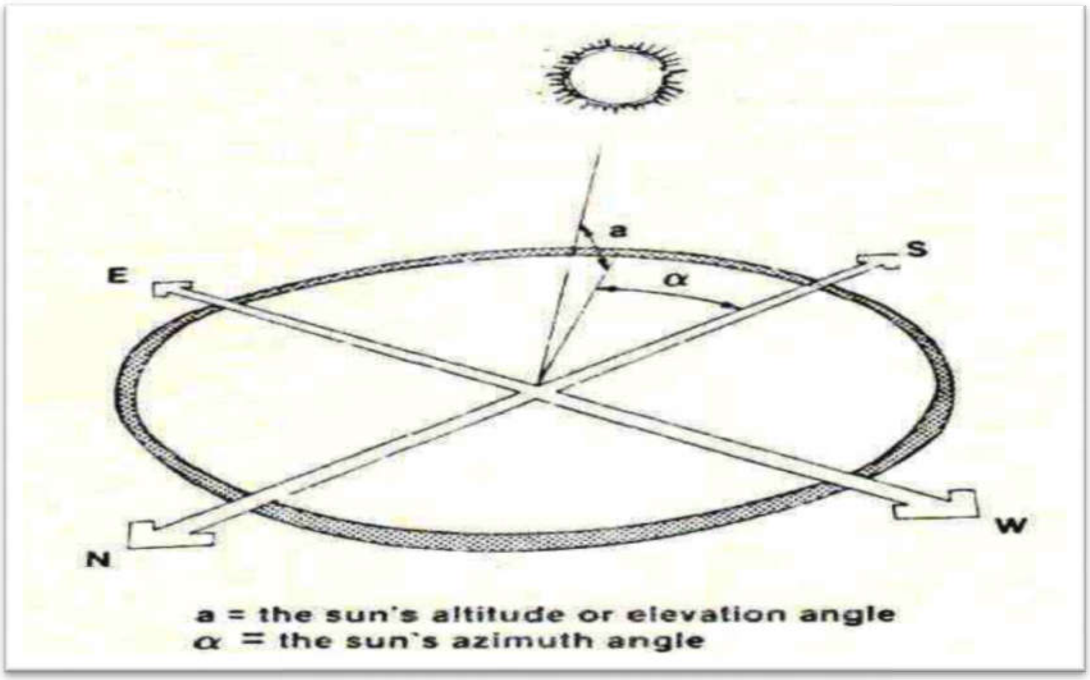


Figure 2.1. Sun's location in the sky

2.4.2 Solar constant

The solar constant is the amount of incoming solar electromagnetic radiation per unit area, measured on the outer surface of Earth's atmosphere on a plane perpendicular to the rays. The solar constant includes all types of solar radiation, not just the visible light. It is estimated to be roughly 1.366 watts per square meter (W/m^2) according to satellite measurements, though this fluctuates by about 6.9 % during a year (from 1.412 W/m^2 in early January to 1.321 W/m^2 in early July) due to earth's varying distance from the sun. For the entire planet (Earth has a cross section of $(127{,}400{,}000\ km^2)$, the power is $(1366\ W/m^2 \times\ 1.274 \times 10^{14}\ m^2 = 1.740 \times 10^{17}\ W)$, plus or minus 3.5 %. The solar constant does not remain constant over long periods of time. The average value cited, $1.366\ W/m^2$, is equivalent to 1.96 calories per minute per square centimeter, or 1.96 Langley's (Ly) per minute. Figure 2.2. below shows solar insulation level on the world map.

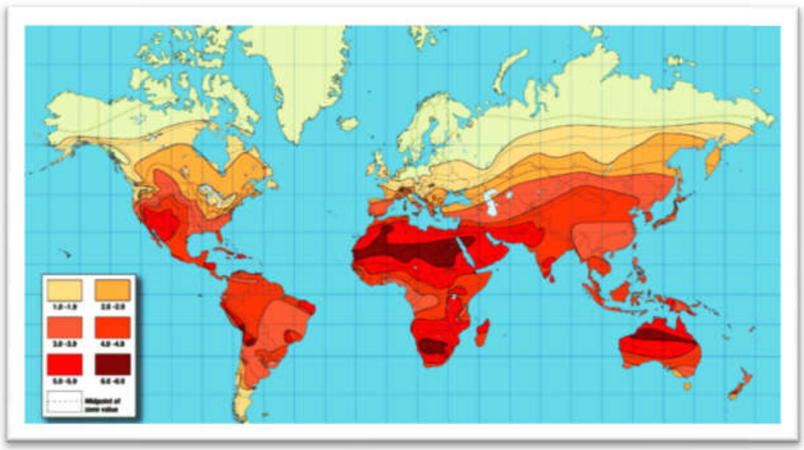


Figure 2.2.).

2.4.3 Solar spectrum

The map shows the amount of solar energy in hours, received each day on an optimally tilted surface during the worst month of the year. (Based on accumulated worldwide solar insulation data

The sun radiates power over a continuous band or spectrum of electromagnetic wavelengths. The power levels of the various wavelengths in the solar spectrum are not the same.

2.4.4 Ultraviolet, visible and infrared radiation

The sun's total energy is composed of 7% ultraviolet radiation, 47% visible radiation and 46% infrared (heat) radiation. Ultraviolet (UV) radiation causes many materials to degrade and is significantly filtered out by the layer of Ozone in the upper atmosphere.

Photovoltaic cells primarily use visible radiation. The distribution of colors within light is important, because, a photovoltaic cell will produce different amounts of current depending on the various colors reflecting on it.

Figure 2.3. illustrates the relative amounts of power in the various wavelengths of the solar spectrum.

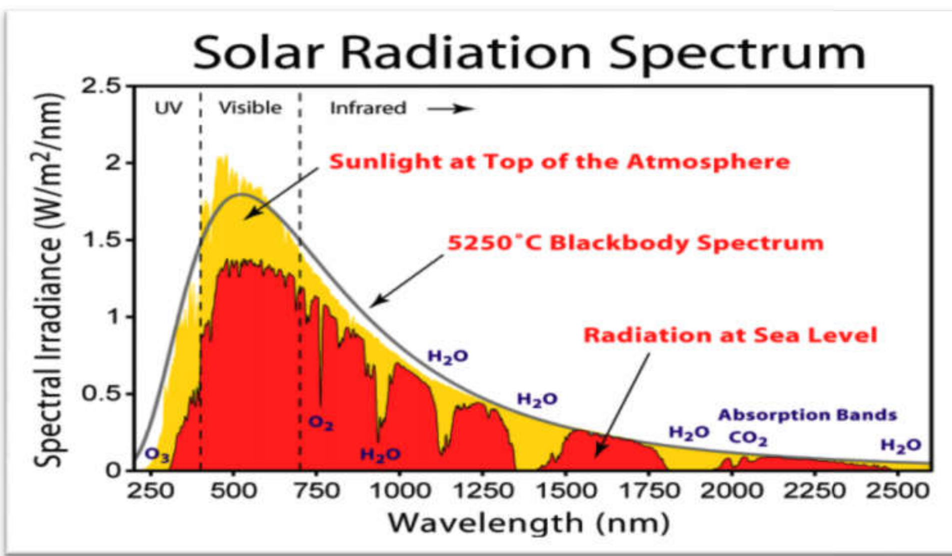


Figure 2.3 Solar Spectrum (juliantrubin.com))

Infrared radiation contributes to the production of electricity from crystalline silicon and some other materials. In most cases, however, infrared radiation is not as important as the visible portion of the solar spectrum.

2.4.5 Ways for converting solar energy into electrical energy

There are two ways by which we can convert solar energy into electrical energy:

I. Thermal energy:

Which generate electricity by concentrate solar radiation and focused it in one point with high pressure fluid to drives turbine, which convert high pressure to mechanical power and connected to generator for convert mechanical power to electrical power .

The solar collectors concentrate sunlight to heat a heat transfer fluid to a high temperature. The hot heat transfer fluid is then used to generate steam that drives the power conversion subsystem, producing electricity. Thermal energy storage provides heat for operation during periods without adequate sunshine.

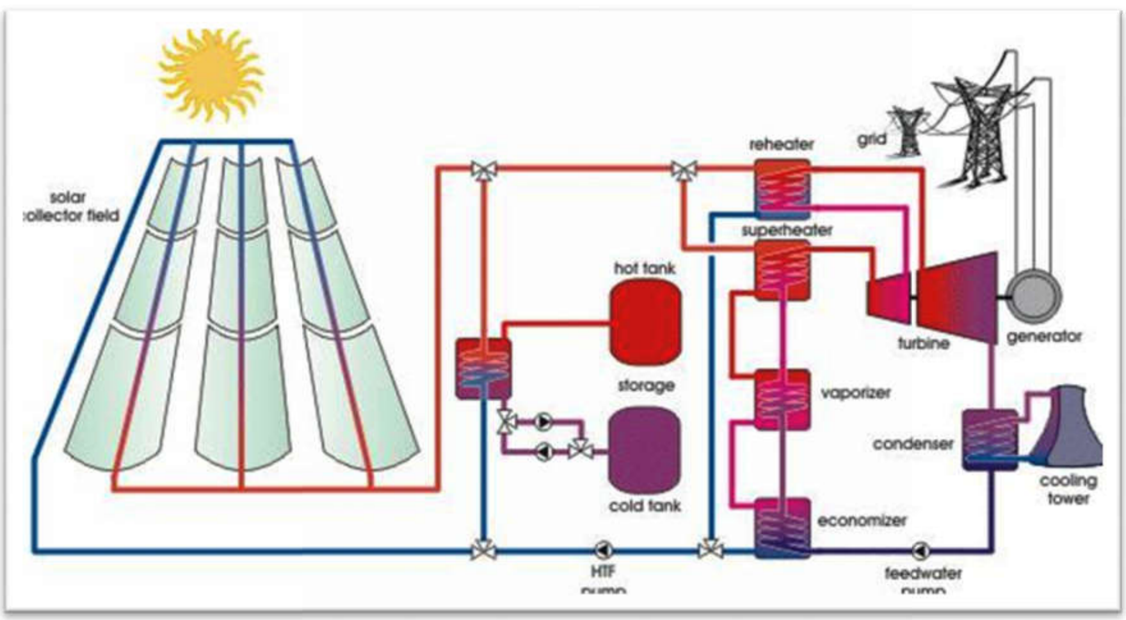


Figure 2.4. Solar thermal (.volker-quaschning.de/articles/fundamentals2/index_e.php)

II. Photovoltaic Energy:

Another way to generate electricity from solar energy is to use photovoltaic cells, magic slivers of silicon that converts the solar energy falling on them directly into electricity. Large scale applications of photovoltaic for power generation, either on the rooftops of houses or in large fields connected to the utility grid are promising as well to provide clean, safe and strategically sound alternatives to current methods of electricity generation

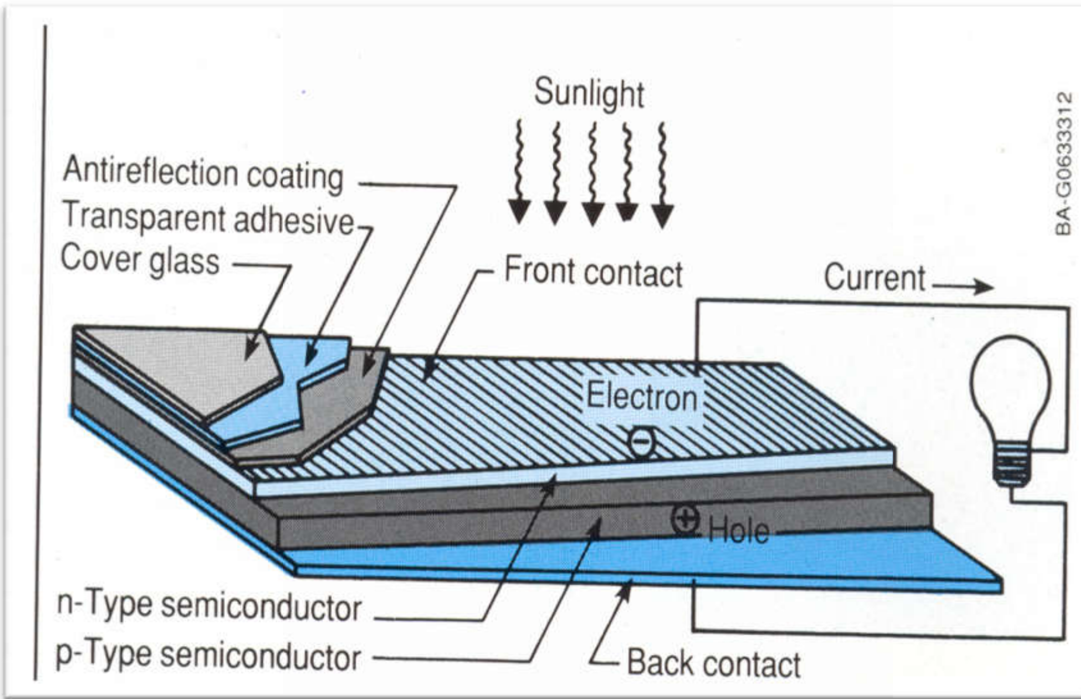


Figure 2.5. Photovoltaic Energy (uk.solarcontact.com&client=firefox-b&biw)

2.4.6 Comparison between solar photovoltaic plant and solar thermal power plant

Many people associate solar energy directly with photovoltaic and not with solar thermal power generation. In contrast to photovoltaic's plants, solar thermal power plants are not based on the photo effect, but generate electricity from the heat produced by sunlight. A fossil burner can drive the water-steam cycle during periods of bad weather or at night. In contrast to photovoltaic's systems, solar thermal power plants can guarantee capacity. Due to their modularity, photovoltaic operation covers a wide range from less than one Watt to several megawatts and solar thermal power plants are small units in the kilowatt range. On the other hand, Global solar irradiance consists of direct and diffuse irradiance. When skies are overcast, only diffuse irradiance is available. While solar thermal power plants can only use direct irradiance for power generation, photovoltaic systems can convert the diffuse irradiance as well. That means, they can produce some electricity even with cloud-covered skies. From economical point of view market introduction of photovoltaic systems is much more friendly of solar thermal power plants, cost reduction can be expected to be faster for photovoltaic systems. But even if there is a 50% cost reduction in photovoltaic systems and no cost reduction at all in solar thermal power plants. Thus we conclude that solar PV power plant is better than solar thermal power plant.

2.5 Photovoltaic cell

A device that produces an electric reaction to light, producing electricity . PV cells do not use the sun's heat to produce electricity. They produce electricity directly when sunlight interacts with semiconductor materials in the PV cells.

2.5.1 Photovoltaic characteristics

Voltage and Current outputs of the PV modules are affected by temperature and irradiance (LV Bin, April 2009). Power electronics components of a photovoltaic system, such as grid-direct inverters have maximum and minimum voltage inputs. During rating of power electronics equipment, these variations should be taken into account especially for the MPPT range of inverters.

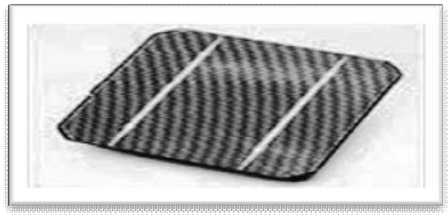


Figure 2.6. PV cell (wikipedia/commons/9/90/Solar_cell.png)

2.5.2 Principle of operation of PV cell

Solar cell is a device which converts photons in Solar rays to direct-current (DC) and voltage. The associated technology is called Solar Photovoltaic (SPV). A typical silicon PV cell is a thin wafer consisting of a very thin layer of phosphorous-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact (the P-N junction).

When the sunlight hits the semiconductor surface, an electron springs up and is attracted towards the N-type semiconductor material. This will cause more negatives in the n-type and more positives in the P-type semiconductors, generating a higher flow of electricity. This is known as Photovoltaic effect. Figure (**2.7**) below shows the working mechanism of a silicon solar cell.

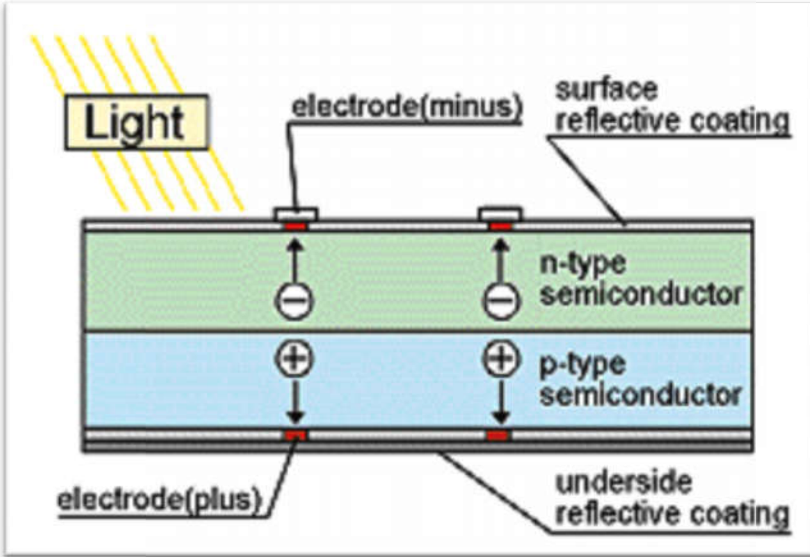


Figure 2.7 Silicon Solar Cell and its working (global)The amount of current generated by a PV cell depends on its efficiency, its size (surface area) and the intensity of sunlight striking the surface. For example, under peak sunlight conditions a typical commercial PV cell with a surface area of about 25 square inches will produce about 2 watts peak power:

2.5.3 Open circuit voltage and temperature

PV array is made up of a number of solar modules connected together. A solar module is made up of a number of solar cells. Solar cells are composed of silicon (Si). Silicon is a semi conductor with only four electrons in its outer shell. When a photon of solar radiation from the sun strikes an outer shell electron, a transfer of energy takes place. The incoming photon losses the amount of energy required to eject an electron from its shell and therefore a free electron is the performance of a solar cell is dependent on its output voltage and current and how they vary with each other. The typical I-V curve for a solar cell is not a straight line as expected as shown in the figure below, a PV module's voltage output is actually a variable value that is primarily affected by temperature. The relationship between module voltage and temperature is actually an inverse one. As elaborated in Figure.(**2.8.**) the module's temperature increases, the voltage value decreases and vice versa.

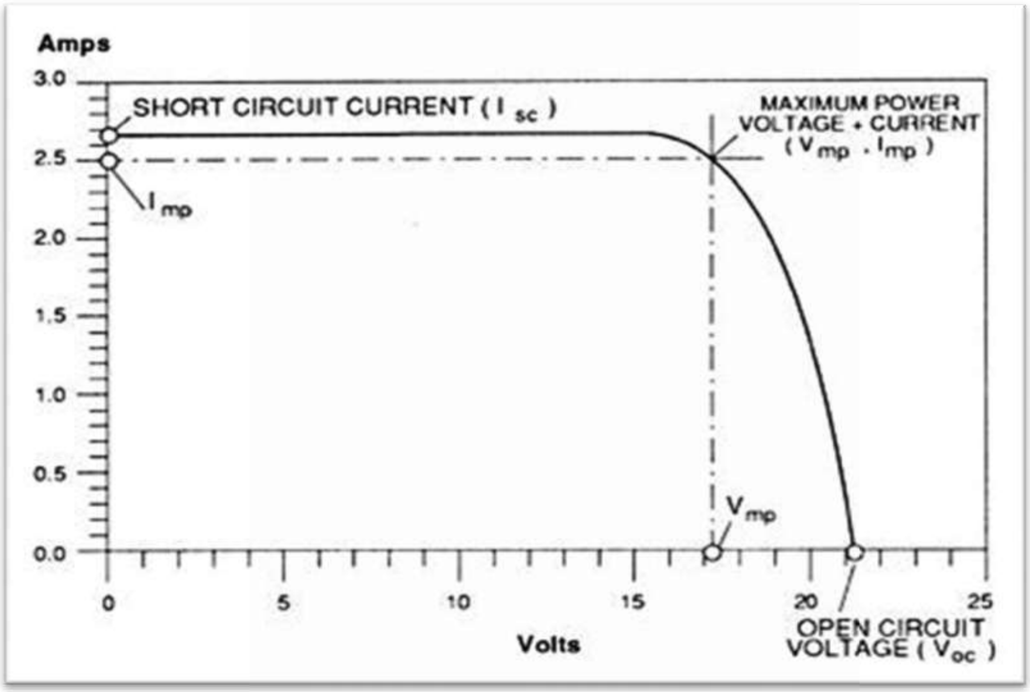


Figure 2.8. PV cell I-V curve (samlex, 2004 -2014)

PV module manufacturers will report the amount of change their modules experience in the form of temperature coefficients, most often in terms of a percentage per degree Celsius. For example for BP solar modules at NTNU, the open circuited voltage temperature coefficient is 0.086/°C . This means that for every degree change in temperature, the module's open circuited voltage, Voc will change in the opposite direction by 8.6%. For example, if the PV module got colder by 1°C, the PV voltage would increase by 8.6%.

To illustrate this phenomenon, let's consider the worst case of temperatures recorded in it shows for the data recorded the average maximum temperature was 14.4°C with irradiance of 123W/M^2 h in the month of August. On the other hand the minimum average temperature was obtained in January and the data recorded was -3.4°C with irradiance of 18W/M^2 h. The formula can be used to determine the averaged maximum and minimum voltages of the modules at these temperatures. Since the string voltage in this design will have a voltage, V_{oc} is obtained to be 300V.

2.5.4 Module current and irradiance

The amount of current produced by a PV module is directly proportional to how bright the sun is. Higher levels of irradiance will cause more electrons to flow off the PV cells to the load attached. However the amount of voltage produced by the PV module is affected by the irradiance value, but the effect is very small.

2.5.5 PV cell efficiency

The efficiency is the most commonly used parameter to compare the performance of one solar to another. Efficiency is defined as ratio of energy output from the solar cell to input energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of solar cell itself , the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell Therefore, conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another.

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

$P_{max} = V_{oc} \times I_{sc} \times FF = 1.2 \times 5.3 \times 49.88 =$

$3.17237\ w$ (2.1)

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{P_{in}} \quad (2.2)$$

Where V_{oc} is the open circuit voltage, I_{sc} is short circuit current , FF is the fill factor ,

and η is the efficiency.

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

2.5.6 Fill factor

The short circuit current and the open- circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points the power from the solar cell is zero. The" fill factor ", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc} determines the maximum power from the solar cell. The FF is defined as ratio of the maximum power from the solar cell to the product of V_{oc} & I_{sc},

$P_{max} = w$

$FF = \eta \times P_{in} / w$

CHAPTER THREE

Alternatives for pv modules glass cover

3.1 Soba solar

founded Institute of energy research was established in 1971 which donates the national center for research. It contains institute on several sections, including wind power and biomass research, oil and electricity research department.

In 2003 the unit was created to assemble solar cell with grant aid from china, in 2005 the institute received a consent from India to start another factory to assemble the cells. And this factory was been converted to a separate building where the unit was inaugurated in 2007 with the support of the International Bank. Afterwards, a project was pursued to install SobaSolar PV modules at 30 villages in Sudan – Chad border and 100 village in various States of Sudan for powering irrigation pumps. Then, the usage of SobaSolar PV modules increased rapidly as main source of clean energy in Sudan, the thing made the institute to be renamed as: The national energy research center, that is in order to increase the PV prior research production. Currently, the institute focus on improving PV research via cooperation with academic institutes in Sudan by facilitating research tools within its departments.

3.2 Alternatives for the glass contact cover

Glass cover for SobaSolar PV modules might be replaced by some other alternatives.Due to the outstanding physical properties of the poly (methyl methacrylate) (PMMA), it could be good alternative material for SobaSolar glass. Following section highlight its features and applications:

3.3 Poly (methyl methacrylate) (PMMA): Acrylic glass.

Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet is a lightweight, rigid and weather-resistant thermoplastic. ACRYLITE FF sheet is dimensionally stable and resistant to breakage, and can be easily sawed, machined, heat-formed and cemented. Because of its virtually distortion-free clarity, it is well suited for use in a variety of applications:

- Skylights
- Window glazing
- Signs
- Window frames
- Optical displays
- Picture framing

3.3.1 Availability:

ACRYLITE ff sheet is available in thicknesses from 0.060”(1.5 mm) to 0.944”(24 mm) and actual sheet sizes from 48 x 96 (1.22 m x 2.44 m) to 100 x 150 (2.54 m x 3.81 m).Custom sizes are also available. All sheets are protected with polyethylene film or paper masking (H, 2004).

3.3.2 Safety:

Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet is more impact resistant than glass. If subjected to impact beyond the limit of its resistance, it does not shatter into small slivers, but breaks into comparatively large pieces. ACRYLITE FF sheet meets the requirements of ANSI Z97.1 for use as a Safety Glazing Material in Buildings (for thicknesses 0.080 to 0.500 [2.0 mm - 12.0 mm]).

3.3.3 Weather resistance:

Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet will withstand exposure to blazing sun, extreme cold, sudden temperature changes, salt water spray, etc. It will not deteriorate after many years of service because of the inherent stability of acrylic resins.Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet has been widely accepted for use in school buildings, industrial plants and outdoor signs.

3.3.4 Dimensional stability:

Although Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet will expand and contract due to changes in temperature and humidity, it will not shrink with age. Some shrinkage occurs when Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet is heated to forming temperature, but post-forming stability is excellent.

3.3.5 Light weight:

Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet is only half the weight of glass and 43% the weight of aluminum.

3.3.6 Rigidity:

Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet is not as rigid as glass or metals. However, it is more rigid than many other plastics such as acetates, polycarbonates or vinyls.Under wind load an acrylic sheet will bow and foreshorten as a result of deflection. For glazing installations the maximum wind load and the size of the window must be considered when the thickness of a panel is to be determined. If Poly(methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet is formed into corrugated or domed shapes, rigidity will be increased and deflection minimized.

3.3.7 Cold flow:

Large, flat Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet, if insufficiently supported, may deform permanently due to continuous loads such as snow, or even their own weight. Increased rigidity obtained by forming will minimize cold flow.

3.3.8 Characteristics availability safety:

Localized, concentrated stresses must be avoided. For this reason, and because of thermal expansion and contraction, large sheets should never be fastened with bolts, but should always be installed in frames. All thermoplastic materials, including Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet, will gradually lose tensile strength as the temperature approaches the maximum recommended for continuous service–160°F (71°C). (htt01).

3.3.9 Expansion and contraction:

Like most other plastics,Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet will expand and contract from 3 to 8 times as much as glass or metals. The designer should be aware of its coefficient of expansion and make appropriate provisions. A 48 panel will expand and contract approximately .002 for each degree Fahrenheit change in temperature. In outdoor use, where summer and winter temperatures differ as much as 37.8°C, a 48 sheet will expand and contract approximately 3/16. Sash rabbets must be of sufficient depth to allow for expansion as well as or contraction.ACRYLITE FF sheet also absorbs water when exposed to high relative humidity,resulting in expansion of the sheet. At relative humidity of 100%,80%,and60%, the dimensional changes are 0.6%, 0.3% and 0.2%, respectively.

3.3.10 Heat resistance:

Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet can be used at temperatures from-30°F(-34°C) up to +190°F (+88°C), depending on the application. It is recommended that temperatures not exceed 160°F (71°C) for continuous service, or 190°F(88°C) for short, intermittent use. Components made of Poly (methyl methacrylate) (PMMA), i.e. ACRYLITE FF sheet should not be exposed to high heat sources such as high wattage incandescent lamps, unless the finished product is ventilated to permit the dissipation of heat.

CHAPTER FOUR

METHODOLOGY

4.1 Method

Some SobaSolar silicon cells ($4\,inc\ \ s\,cell\ \ \ alf\ cut$) were brought (i.e. of 0.5 volt/ unit cell), total number of cells were 10 cells; they were welded with each other and connected in series, so that the output voltage was 5 volt; the produced 5 volt SobaSolar PV module ($26\,cm\ \times 20.5\,cm$) was tested under standard conditions indoor test. The acrylic plate cover is attached to this module via putting it inside an oven of temperature $145\,°c$ and leaving it for 15 minutes; finally, an outdoor test was carried out for the module and under sun normal temperature, and that is to check the calculations on the maximum power, and to examine the effect on efficiency due to the covering with the acrylic glass.

4.2 Measurements

The outdoor measurements were taken by setting the module in a fixed position tilted with 15^o in the south direction accordingly to the geographical location (Khartoum, 15°00′N 30°00′E), see figure 4.1. Both V_{oc} and I_{sc} are recorded every 30 minutes in addition the simultaneous temperatures and irradiances are recorded too. Figure 4.2 shows the whole set of equipments used in the outdoor test.

Figure 4.1 fixed SobaSolar PV module with acrylic glass cover

Figure 4.2 Equipments used for outdoor test

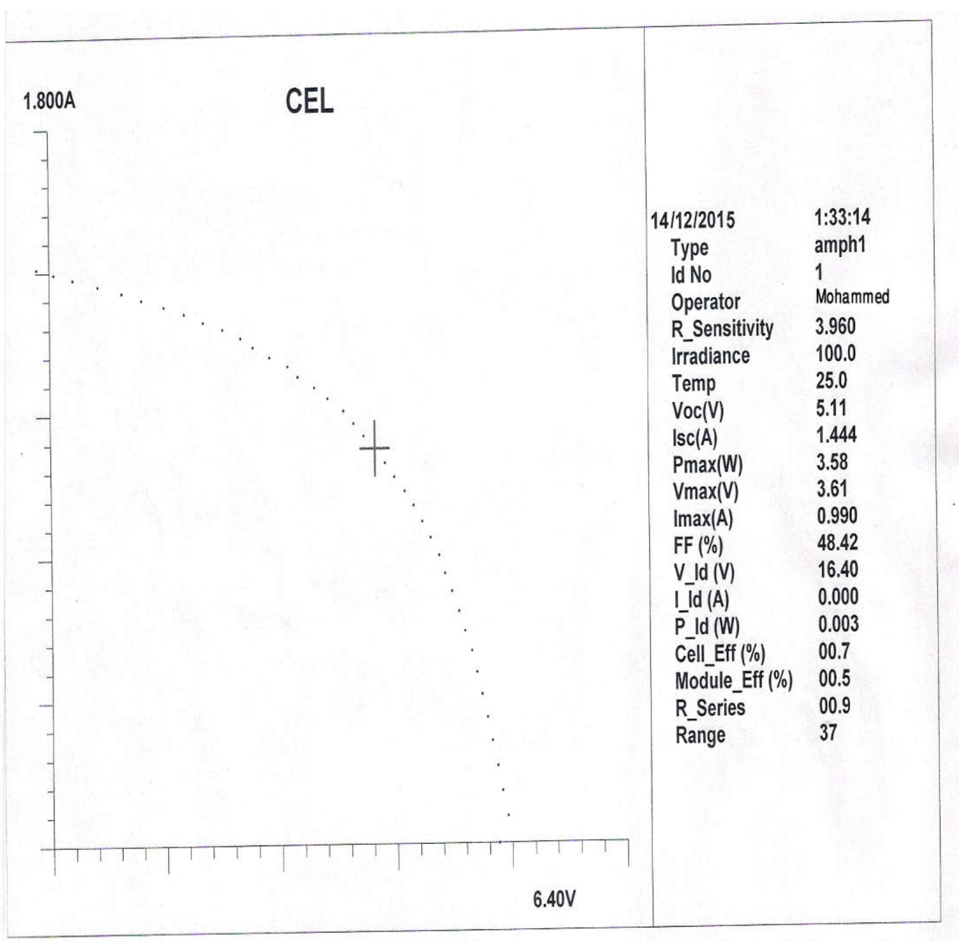
CHAPTER FIVE

RESULTS, DISCUSSION AND CONCLUSION

5.1 Results

Two tests were carried out: An indoor test under standard condition where the maximum power, fill factor and other parameters were obtained; and an outdoor test where measurements of the above parameters were recorded too, details are show below.

5.1.1. Indoor measurements



5.1.2. Outdoor measurements

The following table (table 5.1) shows outdoor test results for calculations of maximum power when the PV module is attached with acrylic.

Time h	I_{sc} A	V_{oc} V	P_{max} W	Radiation $\frac{W}{m2}$	Temperature C^0
10:00	0.84	5.5	1.9954	620.47	20
10:30	1.04	5.55	2.304456	991.39	20
11:00	1.14	5.56	2.879074	827.3	23
11:30	1.2	5.55	3.161594	893.48	24
12:00	1.21	5.49	3.322008	922.44	26
12:30	1.22	5.38	3.313479	879	28
13:00	1.26	5.54	3.273924	925.21	33
13:30	1.2	5.3	3.481824	920.37	36
14:00	1.16	5.4	3.172368	879	36
14:30	1.08	5.2	3.124483	723.88	38
15:00	0.82	5.3	2.801261	663.9	28
15:30	0.66	5.21	2.167785	548.08	29
16:00	0.46	5.18	1.715174	450	22
16:30	0.27	5.1	1.188541	196.4	24
17:00	0.23	4.98	0.686848	155.11	25

Table 5.1 outdoor measurements.

* Note: Data of this table were taken on: December 14, 2015.

5.2 Discussion

Looking at figure 5.1 it represents the maximum power as function of day time hours that is for the fixed SobaSolar PV module system with attached acrylic glass; we can see that as day time hour increase the maximum power increase till to maximum value and then it decrease as day time increase during the day which is a natural feature. As depicted in figure 5.1 the maximum power during the day (December 14, 2015) is found to be: 3.425 w as expected. This is because the radiation and temperatures of light that comes directly from the sun around the time between 12:30 and 13:00 are the highest. This result also clearly shows that no remarkable change was made by using acrylic glass cover, moreover it suggests that the acrylic glass as attachment cover does not affect the efficiency of SobaSolar PV module for fixed system because the standard indoor measurements maximum value was found to be 3.58 W.

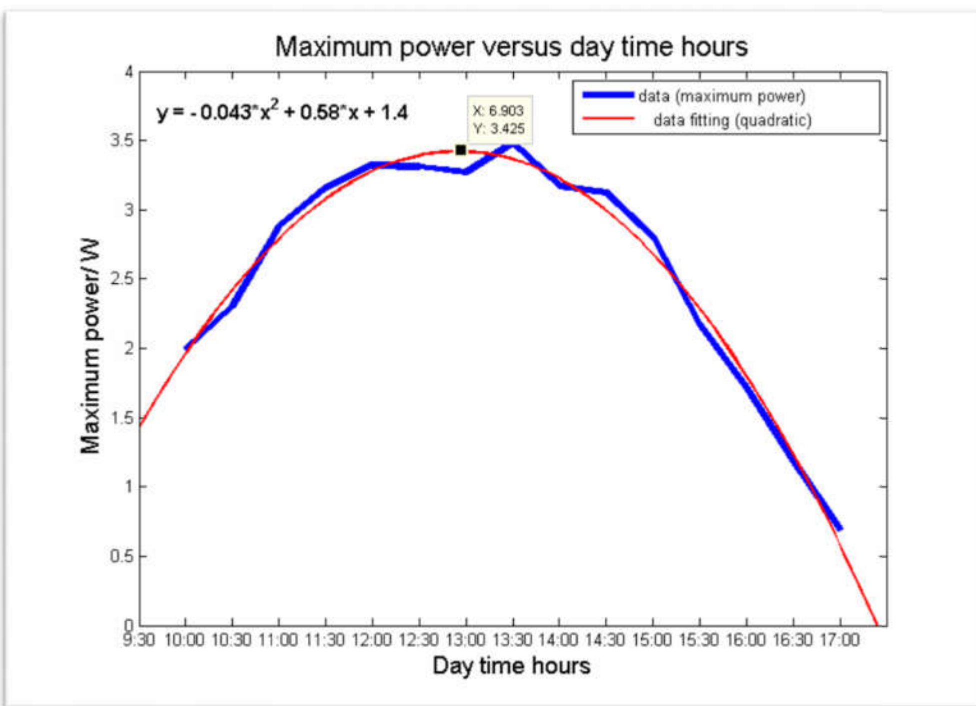


Fig.5.1. Maximum power result from outdoor test

5.3 Conclusion

In conclusion we studied the characteristics of acrylic plate cover as alternative to normal glass cover for SobaSolar fixed PV module. We found that the maximum power of a fixed PV module composed of $26 \times 20.5\, cm$ solar cell panel is $P_{Max} = 3.425\, w$ that is when acrylic cover is attached replacing the normal glass. Our results showed that: acrylic plate cover does not change noticeably the maximum power $P_{Max} = 3.58\, Watts$ resulted from indoor test. Therefore, we conclude that the acrylic cover is good alternative for the normal glass cover for SobaSolar PV modules.

5.4 Recommendations:

The researcher recommend that it is valuable to use acrylic instead of normal glass covers because of the following good characteristics of acrylic glass:

1) Cheaper than glass.
2) Easy to be reformed in different forms and can be used in flexible usages e.g. it can be carried easily.

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