Renewable Energy Resource: Solar PV System

ABSTRACT:

Solar energy has been reined by humans since ancient times. Most of the usable renewable energy sources in the world are derived from solar energy. Photovoltaic systems (PV) convert solar energy directly into electricity by the principle of photovoltaic effect. Basic unit of these systems is a solar cell which is a p-n junction diode. These cells can be connected in series and parallel to obtain the required voltage and power output. In this paper, A solar energy unit with a capacity of 15 MW was built and the total cost, amount of energy resulting from the project, and losses were calculated to give a comprehensive overview of the advantages and disadvantages of solar energy system.

Keywords: *renewable energy, photovoltaic system*

1. INTRODUCTION

Photovoltaics offers consumers the ability to generate electricity in a clean, quiet, and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from [photo], meaning light, and [voltaic], which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight". Photovoltaics are often referred to as PV. For some applications where small amounts of electricity are required, like emergency call boxes, PV systems are often cost-justified even when grid electricity is not very far away. When applications require larger amounts of electricity and are located away from existing power lines, photovoltaic systems can in many cases offer the least expensive, most viable option. In use today on street lights, gate openers, and other low-power tasks.

The first practical PV cell was developed in 1954 by Bell Telephone researchers. Beginning in the late 1950s, PV cells were used to power U.S. space satellites. By the late 1970s, PV panels were providing electricity in remote, or off-grid, locations that did not have electric power lines. Since 2004, most of the PV panels installed in the United States have been in grid-connected systems on homes, buildings, and central-station power facilities. Technological advances, lower costs for PV systems, and various financial incentives and government policies have helped to greatly expand PV use since the mid-1990s. Hundreds of thousands of grid-connected PV systems are now installed in the United States.[2]

1.1 AIM AND OBJECTIVES OF THIS STUDY

This research was conducted to understand the working principle of the solar system and its ability to provide electrical energy per day, month, and year, and to know the cost that the user needs in building a solar plant. Besides, we will discuss the efficiency, output power and losses in the system.

1.2 SOFTWARE TOOLS FOR SYSTEM CONFIGURATIONS:

System Advisor Model (SAM) [1]:

SAM is developed by the National Renewable Energy Laboratory (NREL) with funds from the U.S. Department of Energy.

2. PRINCIPLE OF PHOTOVOLTAIC CELL

A photovoltaic (PV) cell, also known as a solar cell, is an electronic component that generates electricity when exposed to photons, or particles of light. This conversion is called the photovoltaic effect, which was discovered in 1839 by French physicist Edmond Becquerel1. It was not until the 1960s that photovoltaic cells found their first practical application in satellite technology. Solar panels, which are made up of PV cell modules, began arriving on rooftops at the end of the 1980s. Photovoltaic capacity has been growing steadily since the start of the 21st century, led by the construction of huge solar farms [3]. A photovoltaic cell is made of semiconductor materials that absorb the photons emitted by the sun and generate a flow of electrons. Photons are elementary particles that carry solar radiation at a speed of 300,000 kilometers per second. In the 1920s, Albert Einstein referred to them as "grains of light". When the photons strike a semiconductor material like silicon, they release the electrons from its atoms, leaving behind a vacant space. The stray electrons move around randomly looking for another "hole" to fill [3]. To produce an electric current, however, the electrons need to flow in the same direction. This is achieved using two types of silicon. The silicon layer that is exposed to the sun is doped with atoms of phosphorus, which has one more electron than silicon, while the other side is doped with atoms of boron, which has one less electron. The resulting sandwich works much like a battery: the layer that has surplus electrons becomes the negative terminal

(n) and the side that has a deficit of electrons becomes the positive terminal (p). An electric field is created at the junction between the two layers [3]. When the electrons are excited by the photons, they are swept to the n-side by an electric field, while the holes drift to the p-side. The electrons and holes are directed to the electrical contacts applied to both sides before flowing to the external circuit in the form of electrical energy. This produces direct current. An anti-reflective coating is added to the top of the cell to minimize photon loss due to surface reflection [3].

3. Types of PV cells

A. 1st Generation Solar Panels

These are the traditional types of solar panels made of monocrystalline silicon or polysilicon and are most commonly used in conventional surroundings [4].

Monocrystalline Solar Panels (Mono-SI)

This type of solar panels (made of monocrystalline silicon) is the purest one. You can easily recognize them from the uniform dark look and the rounded edges. The silicon's high purity causes this type of solar panel has one of the highest efficiency rates, with the newest ones reaching above 20%. Monocrystalline panels have a high-power output, occupy less space, and last the longest. Of course, that also means they are the most expensive of the bunch. Another advantage to consider is that they tend to be slightly less affected by high temperatures compared to polycrystalline panels [4].

Polycrystalline Solar Panels (Poly-SI)

You can quickly distinguish these panels because this type of solar panels has squares, its angles are not cut, and it has a blue, speckled look. They are made by melting raw silicon, which is a faster and cheaper process than that used for monocrystalline panels. This leads to a lower final price but also lower efficiency (around 15%), lower space efficiency, and a shorter lifespan since they are affected by hot temperatures to a greater degree. However, the differences between mono- and polycrystalline types of solar panels are not so significant and the choice will strongly depend on your specific situation. The first option offers a slightly higher space efficiency at a slightly higher price but power outputs are basically the same [4].

B. 2nd Generation Solar Panels

These cells are different types of thin film solar cells and are mainly used for photovoltaic power stations, integrated in buildings or smaller solar systems [4].

Thin-Film Solar Cells (TFSC)

If you are looking for a less expensive option, you might want to look into thin-film. Thin-film solar panels are manufactured by placing one or more films of photovoltaic material (such as silicon, cadmium or copper) onto a substrate. These types of solar panels are the easiest to produce and economies of scale make them cheaper than the alternatives due to less material being needed for its production [4]. They are also flexible which opens a lot of opportunities for alternative applications and is less affected by high temperatures. The main issue is that they take up a lot of space, generally making them unsuitable for residential installations. Moreover, they carry the shortest warranties because their lifespan is shorter than the mono- and polycrystalline types of solar panels. However, they can be a good option to choose among the different types of solar panels where a lot of space is available [4].

Amorphous Silicon Solar Cell (A-Si)

Have you ever used a solar powered pocket calculator? Yes? Then you have definitely seen these types of solar panels before. The amorphous silicon solar cell is among the different types of solar panels, the one that is used mainly in such pocket calculators. This type of solar panel uses a triple layered technology, which is the best of the thin film variety [4]. Just to give a brief impression of what "thin" means, in this case, we're talking about a thickness of 1 micrometer (one millionth of a meter). With only 7% efficiency rate, these cells are less effective than crystalline silicon ones—that have an efficiency rate of circa 18% but the advantage is the fact that the A-Si-Cells are relatively low in cost [4].

4. Calculation of the PV system [5]

A. Output of a system

Nominal rated maximum (kW_p) power out of a solar array of n modules, each with maximum power of Wp at STC is given by:

$$kW_p = n \times W_p / 1000$$

- peak nominal power, based on 1 kW/m^2 radiation at STC

The available solar radiation (E_{ma}) varies depending on the time of the year and weather conditions. However, based on the average annual radiation for a location and taking into account the efficiency (η) of the cell, we can estimate an average PV system energy yield:

$$E_p = E_{ma} \times kW_p \times \eta$$

- average energy per year produced, kWh

The above calculation is carried out on an annual basis, but could easily be done for any time period (hours, day, month, etc.) by substituting the period mean solar radiation for the annual value.

For maximum power, any solar radiation should strike the PV panel at 90°. Depending where on the earth's surface, the orientation and inclination to achieve this varies. Software is normally used for the calculation of this or the use of correction coefficients from the concerned location.

B. Temperature

As the temperature of PV cells increase, the output drops. This is taken into account in the overall system efficiency (η), by use of a temperature derating factor η_t and is given by:

$$\eta_t = 1 - [\gamma \times (T_c - T_{stc})]$$

C. Efficiency & Performance

Efficiency: measures the amount of solar energy falling on the PV cell which is converted to electrical energy.

Several factors affect the measurement of PV efficiency, including:

- wavelength - PV cells respond differently to differing wave lengths of light, producing varying qualities of electricity
- materials - different PV materials behave differently
- temperature - cells work better at lower temperatures, with efficiency dropping off at higher temperatures
- reflection - any reflected light decreases the efficiency of the cell
- resistance - the cells electrical resistance creates losses, affecting the efficiency
- Manufactured PV cells or modules are typically sorted by a binning process into different levels of efficiency. More efficient cells would have a greater electrical output and hence higher cost.

With the latest development in solar technologies, PV cell are now starting to reach the theoretical maximum limit for semiconductor devices.

In a laboratory, efficiency is measured under standard conditions by the use of I-V curves. I-V curves are obtained by varying an external resistance from zero (short circuit) to infinity (open circuit). The illustration shows a typical I-V curve.

Power delivered by the PV cell is the product of voltage (*V*) and current (*I*). At both open and closed-circuit conditions, the power delivered is zero. At some point in between (around the knee point) the delivered power is a maximum.

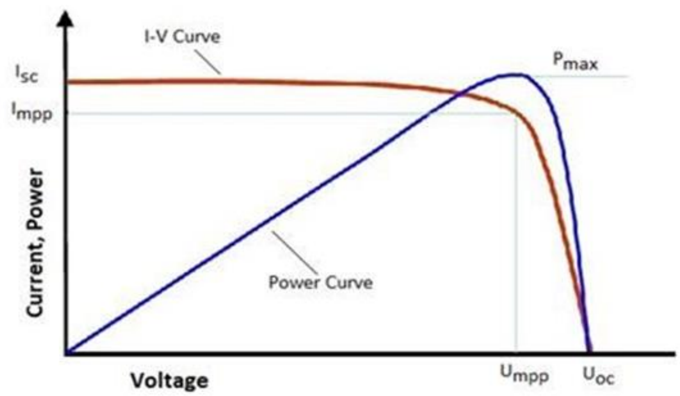


FIGURE 1PV CELL, I-V AND POWER CURVES

D. Fill Factor

One way to measure the performance of a solar cell is the fill factor. This is the ratio of the maximum power to the product of the open circuit voltage and short circuit current:

$$Fill\ Factor = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{U_{mpp} \times I_{mpp}}{V_{oc} \times I_{sc}}$$

The higher the fill factor the better. As a general rule, commercial PV cells will have a fill factor greater than 0.7. Cells with factors less than this are not really recommended for practical application in larger electricity generation projects.

E. Maximum Power Point Tracking (MPPT)

A PV module's I-V curve can be generated from the equivalent circuit (see next section). Integral to the generation of tie I-V curve is the current Ipv, generated by each PV cell.

The cell current is dependent on the amount of light energy (irradiance) falling on the PV cell and the cell's temperature.

As the irradiance decreases not only is the amount of power reduce, but the peak power point moves to the left. Similarly, as the temperature of the cell increases, the power output lowers and the maximum power point again shifts to the left.

With the maximum power point being a variable quantity, dependent on the solar irradiance and cell temperature, modern inverters have mechanisms to track this and always deliver the maximum possible power from a PV cell. This is called maximum power point tracking (MPPT).

F. PV Cell Equivalent Circuit

To understand the performance of PV modules and arrays it is useful to consider the equivalent circuit. The one shown below is commonly employed.

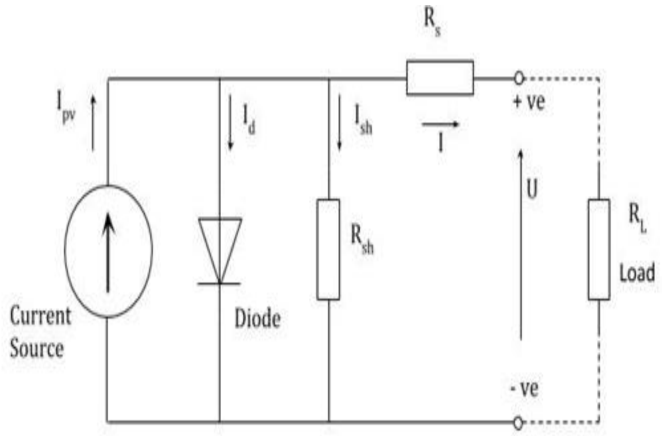


FIGURE 2 PV MODULE EQUIVALENT CIRCUIT

From the equivalent circuit, we have the following basic equations:

$$I = I_{pv} - I_d - I_{sh}$$

- load current in Amperes

$$U_{sh} = U + IR_s$$

- voltage across the shunt branches

$$I_{sh} = \frac{U_{sh}}{R_{sh}} = \frac{U + IR_s}{R_{sh}}$$

- *current through the shunt resistor*

The current through the diode is given by Shockley's equation:

$$I_d = I_0\left[e^{\frac{Ush}{nVT}} - 1\right]$$

And

$$V_T = \frac{kT}{q}$$

Combining the above equations give the PV cell (module) characteristic equation:

$$I = I_{pv} - I_0\left[e^{\frac{U+IRs}{nVT}} - 1\right] - \frac{U + IR_s}{R_{sh}}$$

At the limits, it is easy to use the equation to determine the open circuit voltage and short circuit current. During open circuit conditions, I=0 and the equation reduces to:

$$0 = I_{pv} - I_0\left[e^{\frac{Uoc}{nVT}} - 1\right] - \frac{U_{oc}}{R_{sh}}$$

Typically, R_{sh} is high compared to the open circuit voltage and the last term can be neglected. Neglecting the term and rearranging the equation gives:

$$U_{oc} \approx nV_T ln\left[\frac{I_{pv}}{I_o} + 1\right]$$

Similarly, for the short circuit current, we can set the output voltage to zero, giving:

$$I_{sc} = I_{pv} - I_0\left[e^{\frac{IscRs}{nVT}} - 1\right] - \frac{I_{sc}R_s}{R_{sh}}$$

The assumption that R_{sh} is much higher than Rs and that I_o is small compared to I. With these assumptions, the last two terms can be neglected, giving:

$$I_{sc} \approx I_{pv}$$

The series resistance (Rs), shunt resistance (R_{sh}) and reverse saturation voltage (I_o) are dependent on the area of the PV cell. Generally, the bigger the cell the larger I_o (bigger diode junction area) and the lower R_s and R_{sh} will be.

The characteristic equation can be used to evaluate the effect of various parameters on the performance of the PV cell or module:

- temperature (T) - affects the cell by being part of the exponential term and the value of the reverse saturation voltage. As the temperature increases, while the exponential will decrease the reverse saturation voltage will increase exponentially. The next effect is to reduce the open circuit voltage of the cell. Typically, the voltage will decrease by 0.35 to 0.5% for each degree increase in temperature.
- series resistance (R_s) - increasing has a similar effect to temperature in that the open circuit voltage will start to drop. Very high values of Rs will in addition reduced the available short circuit current.
- shunt resistance (R_{sh}) - decreasing will provide a greater path for the shunt current, again lowering the cell voltage

5. Design and calculations PV

I. <u>Site characteristics</u>

The selected location is Tafila which is located in the south with the coordinates 30.76160o N, 35.69096o E. The solar and wind data are shown in the proceeding sections. Figure 10 shows the location of Al Tafila in Jordan, while Figures 4 show the surface altitude and the project exact location respectively.

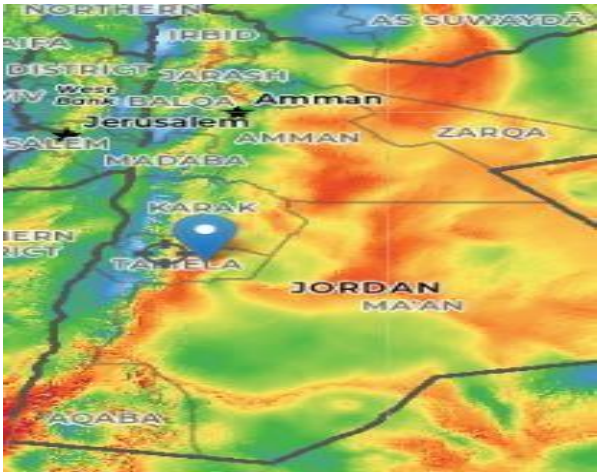


FIGURE 3 LOCATION OF AL TAFILA IN JORDAN [6].

II. Solar radiation

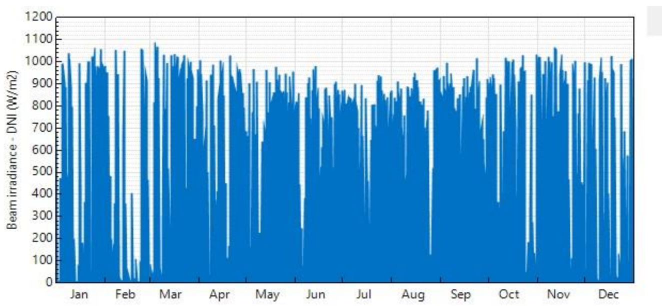


FIGURE 4 BEAM IRRADIANCE

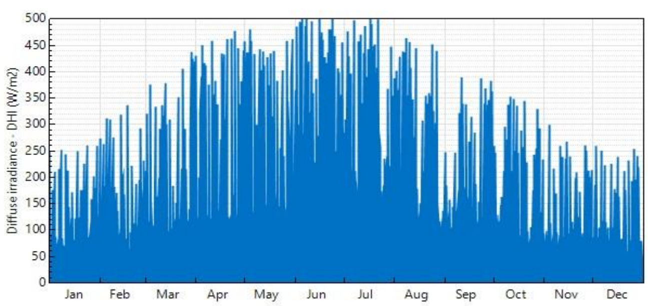


FIGURE 5 DIFFUSE IRRADIANCE

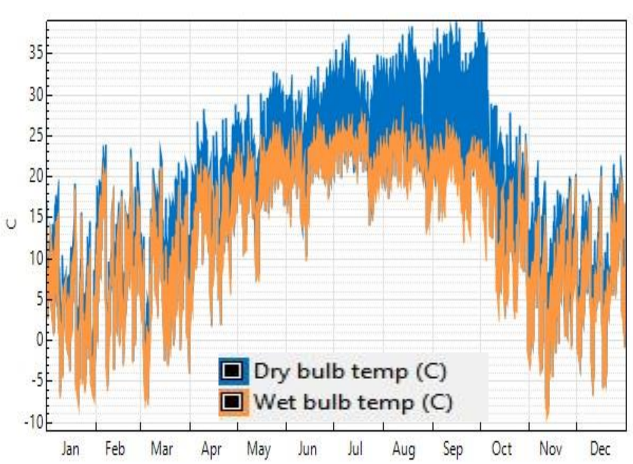


FIGURE 6 DRRY BULB TEMP, WET BULB TEMP

III. System design

- AC sizing

Number of inverters = 500

DC to AC ratio = 1.20

Desired array size = 150,000 KWdc

Desired DC to AC ratio =1.2

- Sizing summary

Nameplate dc capacity = 150,00.953 KWdc

Total AC capacity 125,000.00 KWdc

Total inverter DC capacity 129,511.430 KWdc

Number of modules = 370,359

Number of strings = 41,151

Total module area 718,496.4-meter square

- Electric configuration

Modules per string in subarray = 9

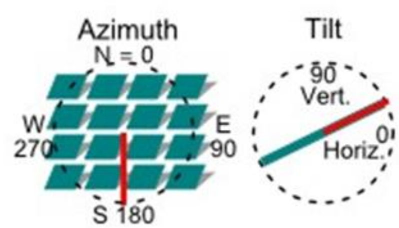
Strings in parallel subarray = 41,151

Number of modules in subarray = 370,359

String Voc at reference conditions (V) = 438.3

String Vmp at reference conditions (V) = 362.7

- *Tracking & Orientation Azimuth*



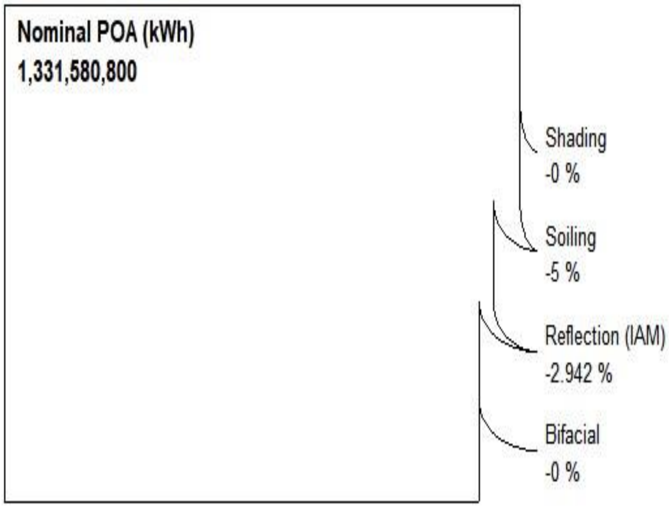
Tilt (deg) = 30

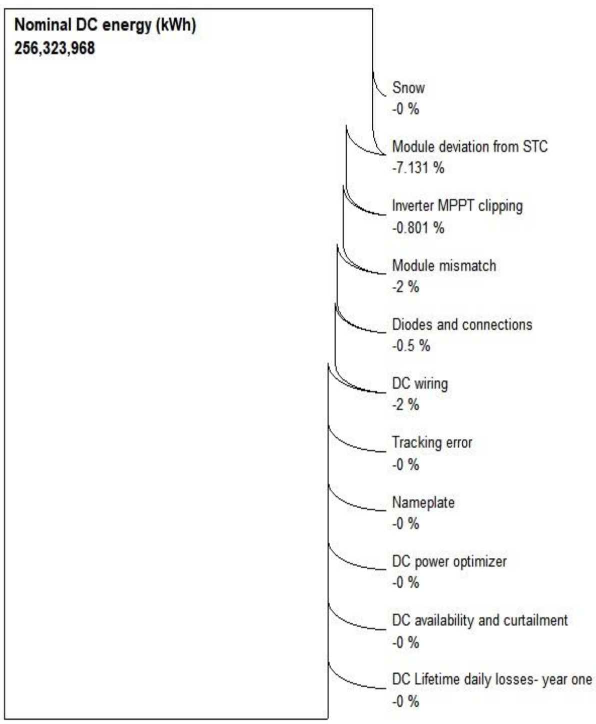
Azimuth (deg) = 180

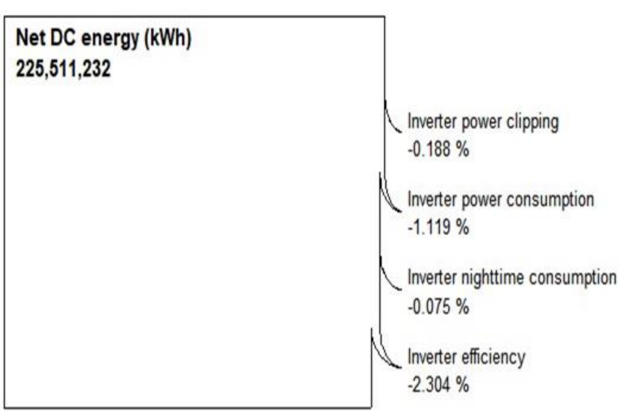
Ground coverage ratio (GCR) = 0.3

Tracker rotation limit (deg) = 45

IV. Losses







Annual AC energy (KWh) = 217,266,704

V. System cost

Direct capital cost

Module = 370,359 units 0.4 KWdc/unit 150,001.00KWdc 0.4 $/Wdc

Total module cost = 60,000,384.00 $

Inverter = 500 units 250KWac/unit 125,000.00KWdc 0.2$/Wdc

Total inverter cost = 25,000,000.00$

Balance of system equipment = 0.20$/Wdc = 30,000,190.00$

Installation labor = 0.13$/Wdc = 19,500,124.00$

Installer margin and overhead = 0.06$/Wdc = 9,000,057.00$

Subtotal = 143,500,752.00$

Contingency is 3% of subtotal so equal 4,350,022.00$

Total direct cost = 147,805,776.00$

Indirect capital cost

Permitting and environmental studies = 0.01$/Wdc = 1,500,009.50$

Engineering and developer overhead = 0.08$/Wdc = 12,000,076,.00$

Grid interconnection = 0.03$/Wdc = 4,500,028.50$

Land cost

Land area = 591.802 acres

Land purchase = 0.03$/acre = 4,500,028.50$

Land prep. & transmission = 0.02$/acre = 3,00,019.00$

Sales tax rate = 5% = 4,918,273.00$

Total indirect cost = 30,418,434.00$

Total installed cost

Total installed cost per capacity = 0.86$/Wdc

Total installed cost = 128,783,896.00$

VI. MODULE EFFICIENCY (%)

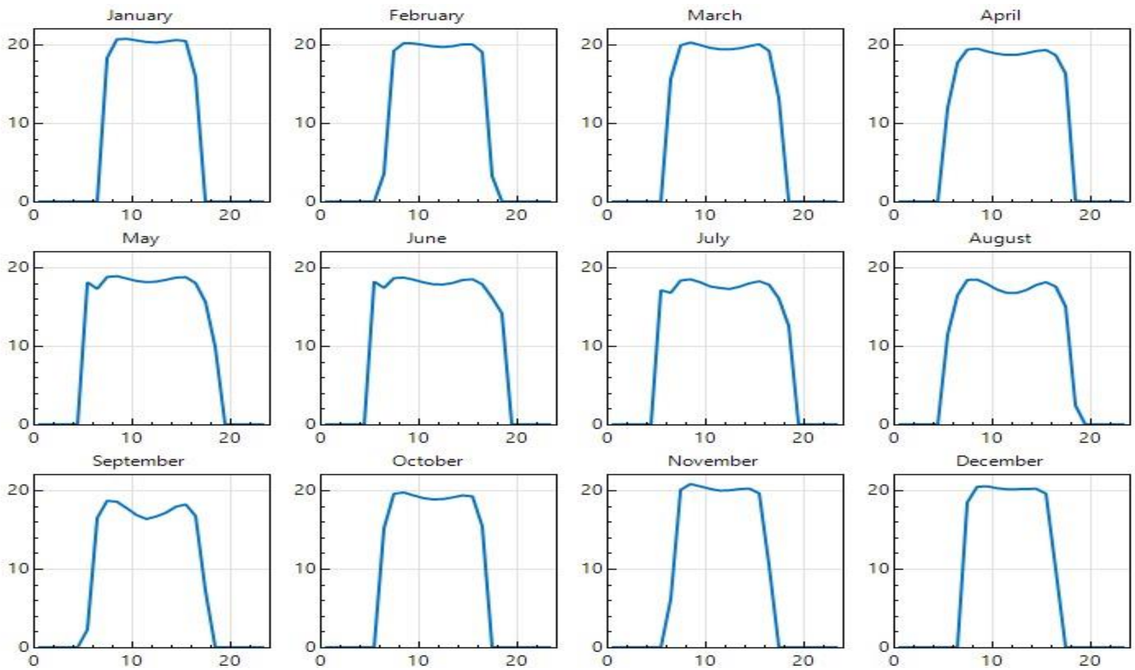


FIGURE 7 MODULE EFFICIENCY (%) VS TIME

VII. SYSTEM POWER GENERATED

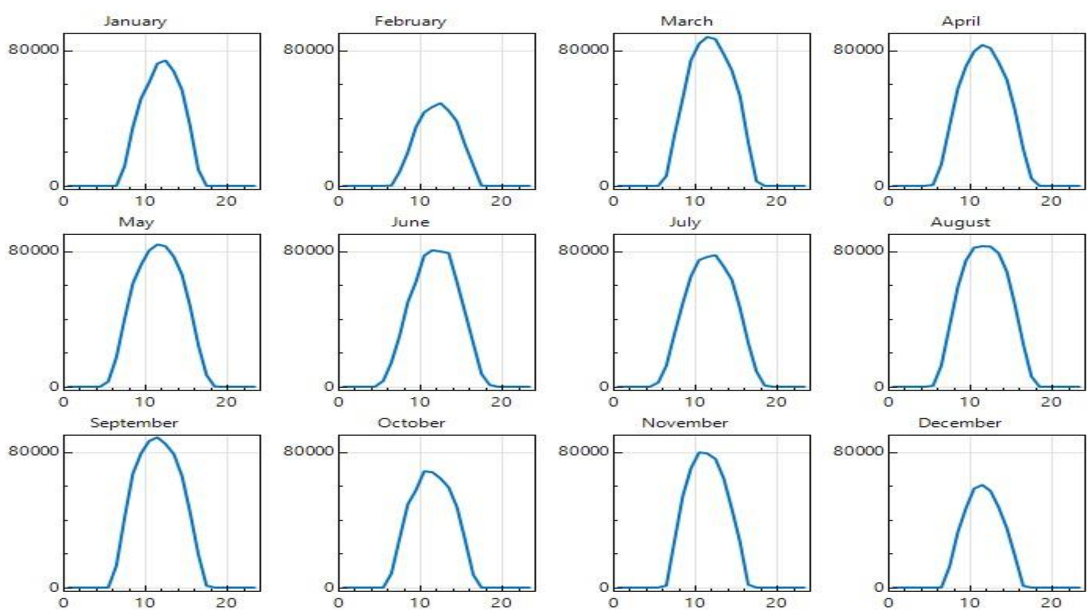


FIGURE 8 SYSTEM POWER GENERATED (KW)

VIII. Final results

Metric	Value
Annual energy (year 1)	215,090,656 kWh
Capacity factor (year 1)	16.4%
Energy yield (year 1)	1,434 kWh/kW
Performance ratio (year 1)	0.77
PPA price (year 1)	11.01 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	11.90 ¢/kWh
Levelized PPA price (real)	9.50 ¢/kWh
Levelized COE (nominal)	10.82 ¢/kWh
Levelized COE (real)	8.64 ¢/kWh
Investor IRR	11.00 %
Year investor IRR acheived	20
Investor IRR at end of project	11.73 %
Investor NPV over project life	$21,628,668
Developer IRR at end of project	25.92 %
Developer NPV over project life	$10,385,609
Sale of property	$135,523,088

6. ADVANTAGE AND DISADVANTAGES PV SYSTEM

Advantages of Solar PV [7].

•Although the feed-in tariff has changed quite a bit since it was introduced, solar PV systems are still a great investment because they substantially lower your electric bill.

•The price of solar panels has gone down by 45 percent or more, which makes the entire system much more affordable.

•Solar PV systems operate differently than solar thermal ones. These systems actually generate free electricity, while solar thermal systems heat up your water.

•Solar photovoltaic systems require daylight, so will work on days when the sun is not shining. All you need is light to create energy, so although the effectiveness of the solar PV array will be less when the sun is covered by clouds, it will still generate some electricity.

•Utilizing solar power helps lower your electric bills because you are generating some electricity you use. Some systems can generate as much as 40 percent of the electricity you use on an annual basis.

•There is very little maintenance involved in owning a solar PV system. Just make sure that you purchase the system from a company with a solid reputation so that you know you are buying quality panels and a good aftercare service.

•The feed-in tariff is designed to increase the amount of solar power being utilized in the UK, but it also makes the installation of solar PV systems look even more attractive to home and business owners.

•By using green energy instead of fossil fuels, you're doing what you can to protect the environment. Our world's fossil fuel reserves are rapidly decreasing, so we will have to find alternative fuels soon. Solar PV panels provide a green way to produce electricity.

Disadvantages of Solar PV [7].

•Solar PV panels are more expensive than panels designed for solar thermal energy. However, they do a lot more for your home or business than solar thermal panels do, and there are some incentives and grants to help pay for them.

•You need an adequate roof space to display your solar PV panels. The larger the panel covering the more electricity generated.

•These systems may not be a viable green energy option for you if your home or business if you have a predominantly north or east facing roof or if tall buildings and/or trees place your roof in the shade during the day

7.CONCLUSION

The Photovoltaic System is effective and is able to supply energy instead of fossil fuels, but there are problems in supplying energy in the absence of sunlight, as it needs a storage source for energy.

The cost of one watt of electricity produced by photovoltaics system was 0.8 $ per watt, with an efficiency of up to 20 percent, and an energy output of 217,266,704 kilowatt-hours.

8.REFERENCES

[1] https://sam.nrel.gov

[2]https://www.evwind.es/2012/08/05/a-short-history-of-photovoltaic-solar-power/21013

[3]https://www.lrc.rpi.edu/programs/nlpip/lightinganswers/photovoltaic/04-photovoltaic-panels work.asp

[4]https://www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels

[5]https://myelectrical.com/notes/entryid/225/photovoltaic-pv-electrical-calculations

[6]https://globalwindatlas.info

[7]https://www.greenpower-technology.co.uk/solar-pv/advantages-disadvantages-pv