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Solar cell cleaning and efficiency performance analysis on dust particles accumulation on solar panel in Nigeria. A case study of Northern Nigeria

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Abstract: It is well known that natural dust accumulation on photovoltaic (PV) panels from outdoor environment mostly in northern part of Nigeria can obscure the solar radiation from reaching the solar photovoltaic panel, therefore decreases the power output and the efficiency of the panel. This study is based on the effects of dust particles accumulation on the performance of solar photovoltaic panels and also to remove dust particles accumulation on the surface of PV panel using mitigation method that require minimum amount of energy and less use of water.
The research was conducted to determine the influence of dust particle accumulation on solar panel with constant light source deliver by halogen lamp, to establish the output power generated and the efficiency. It was concluded from the study results that dust accumulation on the surface of PV panel can reduce solar panel system efficiency by up to 30-50%. It was notice that the output power of the solar panel after cleaning with pressurized water and soap is 2.31 W, water and surfactant is 2.295 W, while the output power for solar panel surface coated with thin glass nano-structure is 2.43 W. The results clearly show that Coating the surface of PV panel with conducting material is the best method to mitigate dust accumulation. This method has good advantages since water is not require, which is rare and quite expensive in northern part of Nigeria.

Keywords: Solar energy, dust deposit, surface, photovoltaic panel, coating.

1. Introduction

The challenges of reducing global climatic change, greenhouse gases and energy security requirement worldwide have led to development of renewable energy source alternatives which is vital for the future of mankind and living thing. Solar energy source as become the best source of energy due to rapid world population growth and demand for comfort, also growing shortage of order alternative source of energy (fossil fuel) has help to strengthen the awareness of environmental protection of carbon emission and global warming worldwide [1-2]. Solar energy business has rapidly entered a new era of growth worldwide due to conventional increasing price of fossil fuel and also due to the frighten environmental issues related to greenhouse emission (fossil fuel) [3]. The vital points of PV system that made it so desirable by individuals, countries are as follows: Its easy sources of sunlight, there have no moving parts that can wear out during it lifetime, PV system requires little maintenance and they can generate electricity from sunlight with little or no harm to the environment in question [3].

Solar energy is a clean and free source of energy that is independent and exhaustless which made it vital to many recent researches in energy sector. Solar cell also call a PV cell is simply a device that convert sunlight into electricity when a source of light shine on it. When light falls on PV cell material it either reflected, absorbed, or transmitted depending on the material. Most PV cell has the features of converting the energy incident photons to electricity when sunlight shine on them, the above phenomena is called photovoltaic effect [4].

Hosenuzzaman [5], state that solar cell is divided into two types such as crystalline solar cell and thin-film solar cells. Crystalline solar cell is sub-divided into two categories such as mono-crystalline solar cell and multi-crystalline solar cell. Secondly, thin-film solar cells comprise of amorphous silicon, cadmium telluride and copper indium gallium di-selenite.

It's obvious that the present of particles accumulation such as dust, dirt, talcum or any order soiling material on the surface of a solar cell will obscure the sunlight from reaching the solar cell. These dust particles on the surface will eventually reduce the rate of sunlight absorption and the electricity generated will be reduced, as a result of this, the efficiency of the renewable energy they produced will also be affected. Hence, solar panel efficiency depends on the cleanliness of the panel [1].

Power output of photovoltaic cell depends on influence of following: dust deposition, dust quality, size of the dust particle and amount of solar radiation on the surface of the solar panel. This simply means that the intensity of light is proportional to output of the solar cell [6]. Solar cell is mostly produced out of copper, cadmium sulphide, gallium arsenide and cambium telluride [7].

The accumulation of dust deposit on solar panel by wind in desert area can reduce solar radiation entering the panel, and therefore reduces the efficiency of the photovoltaic cell. According to [8], the deposition of 4 g/m2 of dust ranging from 0.5-10 um particles diameter on solar panel will reduce the efficiency by 40%, and the presence of mud and talcum on the surface of solar panels also reduces the power output by 18% with constant irradiance. Hence, the energy generated by the PV cell will dramatically be reduced. It is believed that the accumulation of pollution and dust or dirt caused by agricultural activities can obscure the power output of a solar panel during summer by 20% [8]. Kane and Verma [9], states that the accumulation of 1 g/m^2 of dust on solar PV cell module will reduce the efficiency by 30%. Show below is an example of sandstorms experience frequently in northern part of Nigeria. The occurrence of this always will spoil the surface of PV panels.

In order to achieve an optimal performance of the solar panel, it is necessary to clean the solar panel periodically to eliminate the dirt accumulated there upon. Also, power output loss depends on dust, dirt and debris which the solar panel has accumulated over a certain period of time. To eradicate the above problems or improve the efficiency of PV cell or solar cell, certain mitigation approach or technique needs to be in place.

Ghazia et al. [10] state that different climatic zones have different mitigation method as such panels should be clean with appropriate method in line with the environment in question in order to maintain the efficiency performance of the solar cell effectively. Furthermore, it is necessary to investigate the following, details about PV cell, details about PV cell efficiency, effects of dust accumulation on PV cell performance and efficiency.

Due to the introduction of photovoltaic cell, consumers are able or opportune to generate electricity in pure, quiet and reconcilable way. Photovoltaic cells are devices that convert light energy directly into electricity without emitting any pollutant such as air and water pollutant into the environment. Photovoltaic are often called solar cell since their source of light energy is generally the sun. The name photovoltaic is divided into two, photo which means light and voltaic which mean generating electricity.

PV cells produce electricity directly by converting direct sunlight in PV system without creating any pollutants that is harmful to the environment. PV array system are made of multiple PV module arrange in series or parallel and a PV module include a PV cell in parallel or series. The diagram of a PV cell, module and array is shown below. Through PV effect, PV cell absorbs protons when sunlight shines on it and produces free electrons [5].

When sunlight shine on the surface of a semiconductor materials it might be absorb, reflected or transmitted mainly converting the energy of incident photons into electricity and the liberated electrons is allowed to move across the crystal based on the principle of conservation of momentum and energy. This phenomenon is called photovoltaic effect [4].

In other for a photovoltaic energy conversion to take place effectively, the process must undergo four important steps together simultaneously. These steps are:

- Electrons and hole pairs charge carriers must be created principally by breaking the bond in between the atoms.
- Before recombination must take place, they will be separation of oppositely free.
- Suitable material must be used for the photovoltaic system for easy absorption of photons.
- They must be movement of charge carriers through electric contacts that will pass through an external circuit to generate current [11].

Dharmadasa [11] state that once any of these four steps are omitted, the device will show low photovoltaic energy conversion or the photovoltaic activity will be zero. Selecting the right materials and putting them together in a suitable device structure for the four stages to take place simultaneously is a taxing task in PV research.

The overall aim of this research is to remove dust particles deposition or accumulationon solar panels using different mitigation method and its effects on the PV system in order to improve the efficiency/performance of a solar cell in northern part of Nigeria. This research paper is based on natural phenomena that adversely or propitious affects the efficiency of photovoltaic cell devices. The accumulation of dust water, stain, carbon emission, pollen from agricultural sectors according to [10] on solar panel reduces the performance of the solar device.

2. Material and Methodology

The experimental setup comprises of a solar photovoltaic panel (rated 5W), halogen lamp (rated 230V, 500W (Max)) was used as source of light suspended by retort stand and clamps and electric circuit system which comprises of dc voltmeter and dc ammeter connected in series. The solar photovoltaic module used is made up of silicon mono-crystalline cells and the dimensions of the solar panel were 265mm by 200mm by 25mm with each cell having an area of 5cm^2. The set up was installed in an indoor lab and the radiation light was supply by the halogen lamp. The position of the halogen lamp was varied depending on the experimental requirements. M2000 fibre optic power meter or photo-radiometer was used to measure the irradiation on the solar photovoltaic panel. System load was varied also by using different resistors (rheostat) and the current and voltage reading was measure using analogue multimeter. Shown in below is the schematic representation of the system parameters used.

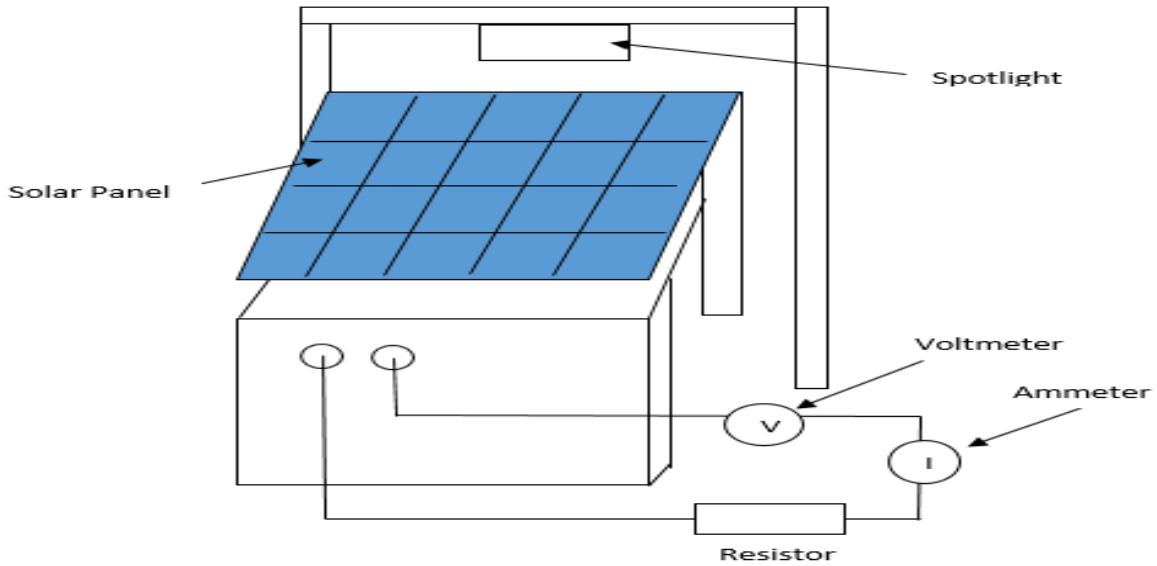

Figure 1. Block diagram representing the schematic of the system with the halogen lamp.

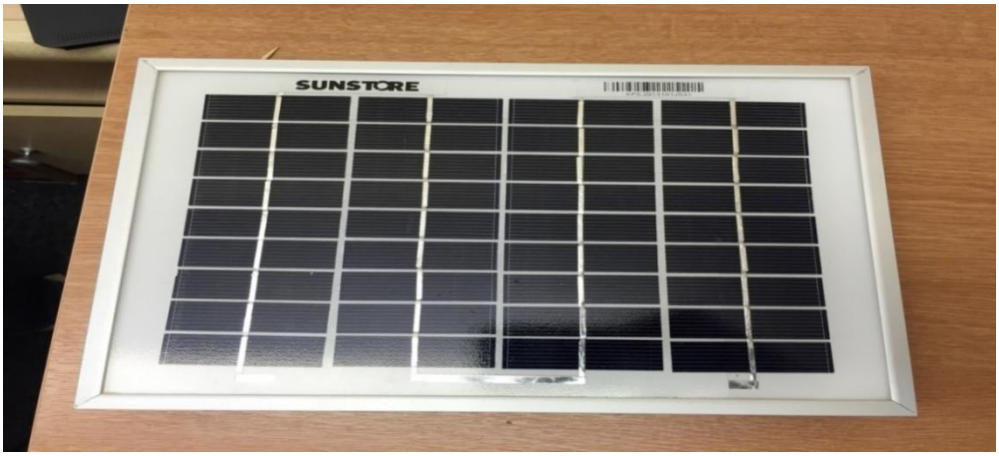

Figure 2. The solar PV panel.

The experiment were conducted by applying sample of dust and mud particles from Gombe in northern part of Nigeria on the surface of solar PV panel. Another experiment were also conducted with clean solar PV panel before cleaning and after cleaning in order to quantify the effects of dust and mud on the performance of the photovoltaic panel. During the experiment, the distance between the solar photovoltaic panel and halogen lamp used and also resistance was varied in order evaluate, analynised and develop I-V characteristics of the solar panel. The diagram below shows the solar panel made of silicon mono-crysta used and the specification.

Specification of the PV module used

1. PV modelSunstore-5/12
2. Rated power at STC (Wp) 5W
3. Open circuit voltage (VOC) 21.5V
4. Short circuit current (ISC) 0.32A
5. Voltage at max power (V) 17.5V
6. Current at max power (IMP) 0.29A
7. Dimensions:265mm×200mm×25mm
8. Max system voltage 1000V
9. Weight 0.75kg
10. Power tolerance ±3%
11. Numbers of cells 72

In this investigation, dust and mud particles sample from Nigeria were deposited on the surface of the solar panel. Since the test was carried out in indoor lab the use of natural dust deposition was avoided. The dust and mud were spread manually on the surface of the solar panel because it might not be well distributed on the surface if the natural way of dust accumulation is used since the experiment has been carried out in indoor lab and also since it would be exposed to the environment the effect of wind may affect the uniformity of the distribution which will in turn give wrong result of the principal aspect of the dust effects.

In all the tests, output voltage and current produced by the solar photovoltaic panel were measured by varying the resistance (rheostat). This measurement was conducted for clean solar panel, solar panel accumulated with dust particles and finally solar panel soil with mud particles. Throughout the experiment, only one halogen lamp was used and the irradiation were measured for different point on the solar panel by varying the distance between the halogen lamp and the surface of solar PV panel. This measurement between solar panel and halogen were taking from different position to examine the distribution of irradiation on the panel and also the effect.

Experiments were conducted again to determine the influence of cleaning on the performance of photovoltaic cell. In the first test, solar cell soil with dust particles was kept for a period of one week before cleaning it with non-pressurised water and soap. In the second instance, solar cell with dust particles accumulation on the surface was kept for another one weeks, after which it was clean using pressurised water from tap and soap. Another test was also conducted with solar panel kept for few days with surface soil with dust particles. The panel was clean with surfactant which is a mixture of aniodic surfactant (sodium dodecyl sulfate) and cationic surfactant (cetylpyridinum bromide). The ratio of the mixture is I:1 and it was also mix with 1 g/l of water. Lastly, the panel was covered with a small thin conducting glass which acts as surface coating, nano-surface coating just like the lotus leaf for repelling dust particles. Dust particles was spread on the surface of the glass and kept for some days. In all this test, I-V characteristic was measured at every point in time and to overcome the problem of choosing the best way to clean solar panel in northern part of Nigeria (Gombe), the efficiencies of the various mitigation or cleaning process was calculated, evaluated and compared. The efficiency calculation for the solar cell for various cleaning conditions is presented. Finally, the effect of tilt angle on the performance of solar cell was also conducted and the I-V characteristic was also used to analyse the best tilt angle when positioning solar panel.

2.1 Maximum Power and Efficiency Analysis:

In other to determine the efficiency of the solar PV cell, the equation below is used:

$$\eta=\frac{VpIp}{PsA}\times 100\% \quad [12]$$

Where I_p represent the electrical current produced by the solar PV panel, V_p is the voltage of the electricity generated, P_S is the incident solar radiation measured in W/M^2, and A is the area of the solar cell that is expose to light radiation. The efficiency equation above is only feasible for used under standard test condition; temperature of 25°C, irradiance of 1000 W/M^2 and with an air mass 1.5 spectrum [12]. In this experiment the required irradiance was not meant but the calculation for efficiency for the condition was meant which helps to determine different changes and effect that occur at different conditions of solar PV panel surface.

Efficiency calculation for clean surface:

$\eta=\frac{VpIp}{PsA}\times 100\% =\frac{2.5W}{466.4W/M2\times 0.053M2}\times 100$ =10% for irradiance of 466.4 W/M^2

Similarly, $\eta=\frac{1.6W}{402.8W/M2\times 0.053M2}\times$ 100= 7.3% for irradiance of 402.8 W/M^2

Efficiency calculation for solar panel with dust particles accumulation:

$\eta=\frac{1.17W}{466.4W/M2\times0.053M2}\times100=4.7\%$ for irradiance of 466.4 W/M^2

$\eta=\frac{0.94W}{402.8w/m2\times0.053M2}\times100=4.4\%$ for irradiance of 402.8 W/M^2

Efficiency calculation for solar PV panel with mud particles accumulation:

$\eta=\frac{0.68W}{466.4W/M2\times0.053M2}\times100=2.7\%$ for irradiance of 466.4 W/M^2

$\eta=\frac{0.51W}{402.8W/M2\times0.053M2}\times100=2.4\%$ for irradiance of 402.8 W/M^2

The peak power generated after cleaning with pressurised water and soap was 2.318 W and the efficiency of the solar panel is calculated as follows:

$\eta=\frac{VpIp}{PsA}\times100\%=\frac{2.318W}{466.4W/M2\times0.053}\times100=9.4\%$

The maximum power generated after cleaning solar panel with water and surfactants is 2.295 W and the efficiency was calculated based on the I-V characteristic reading recording from the solar panel after cleaning with water and surfactant. The efficiency is calculated as follows:

$\eta=\frac{VpIp}{PsA}\times100\%=\frac{2.29W}{466.4W/M2\times0.053}\times100=9.3\%$

The maximum power generated when solar panel is coated with thin glass nano-structure is 2.43 W and the efficiency is calculated to be 9.8% as follow:

$\eta=\frac{VpIp}{PsA}\times100\%=\frac{2.43W}{466.4W/M2\times0.053}\times100=9.8\%$

3. Result and Discussion

The figures below show the voltage-current characteristic and P-V characteristic for PV cell with clean surface at different irradiance conditions and temperature for different tests.

The figures above for voltage-current characteristic for irradiance of 466.4 W/M^2 and 402.8 W/M^2 has the same curve and shape but there is significant difference between the two irradiances, also the shape of the graph increases as the irradiance increases. This simply shows that, the closer the light intensity or radiation to the solar panel the higher the output produced.

P-V characteristic for photovoltaic cell with surface soil with dust particles at different irradiance condition and temperature are shown in figures below (Figure 5).

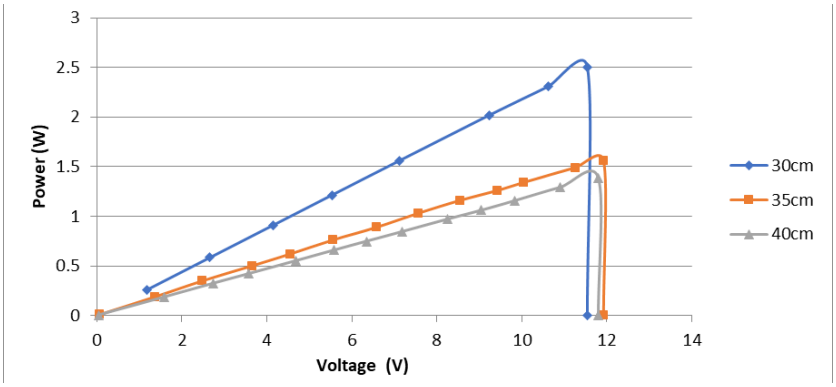

Figure 3.P-V characteristic of a PV cell at difference irradiance and height.

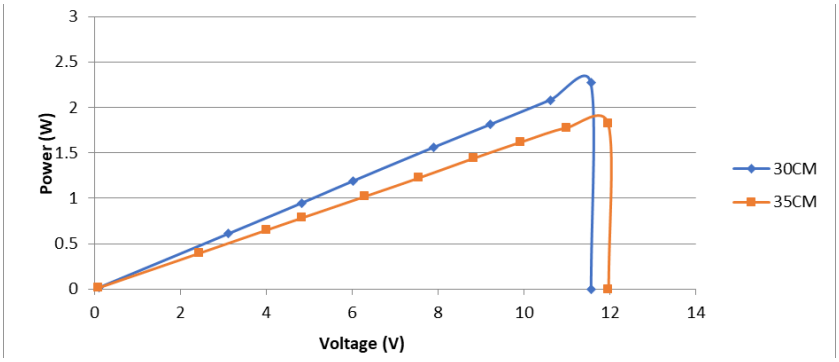

Figure 4. P-V characteristic of a PV cell at difference irradiance and height.

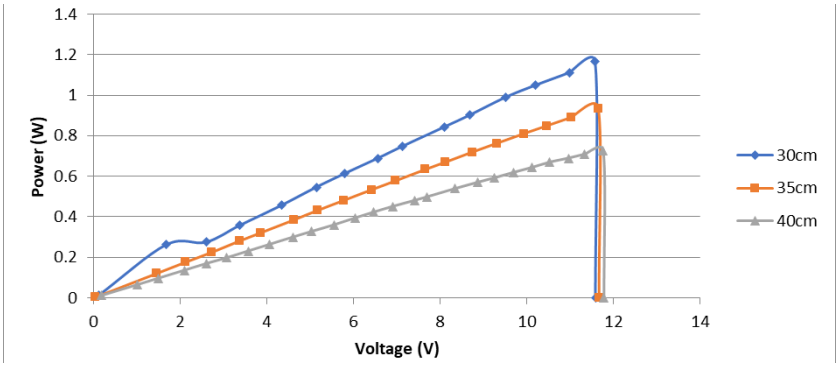

Figure 5. P-V characteristic of a PV cell at different irradiance and height.

The graph above for P-V characteristic of a PV cell at different irradiance has the same curve and shape but the curve and shape reduce compared to solar panel with clean surface mention above and different output power produced is due to the irradiance conditions and also the presence of dust particles. This simply means that the closer the sun or light to the solar photovoltaic cell the higher the output power generated in accordance with the dust particles on the surface of solar cell.

Similarly, the figures 6-8 show the voltage-current and P-V characteristic for a PV cell soil with mud particles at different irradiance condition and temperature and the combine graph for solar panel with dust, mud and clean surface.

From the graph, for irradiation of 402.8 W/M^2 and 466.4 W/M^2, the curves are similar but there is significant difference between solar panel with mud particles compare to the other two conditions. This was probably as a result of dust or mud particles accumulation on it surfaces that hinder the solar radiation from reaching the surface of the solar panel. Solar PV panel with irradiation of 466.4 W/M^2 produces higher output power compares to the other two conditions with irradiation of 402.8 W/M^2. This simply shows that the closer the light intensity or radiation to the solar panel the higher the output power produced. The maximum power produced and maximum voltage measured for the three experiments at different irradiance and temperature is show in the table 1.

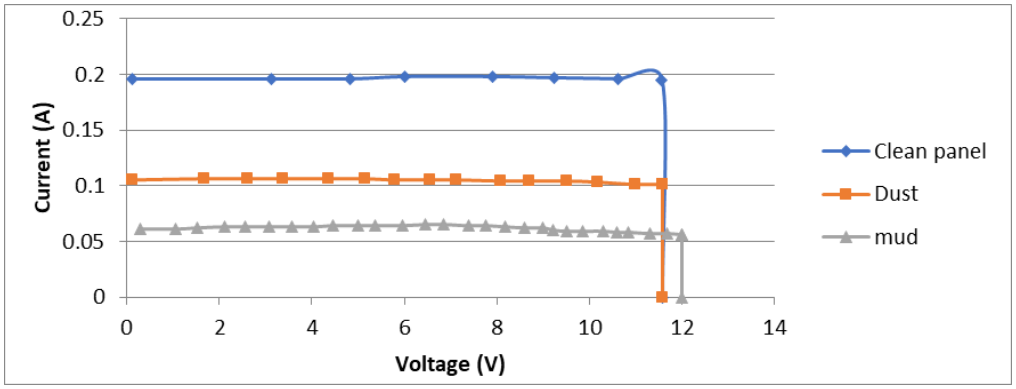

Figure 6. I-V characteristic of a PV cell with dust, mud and clean surface for irradiance of 466.4 W/M^2 at 30 cm.

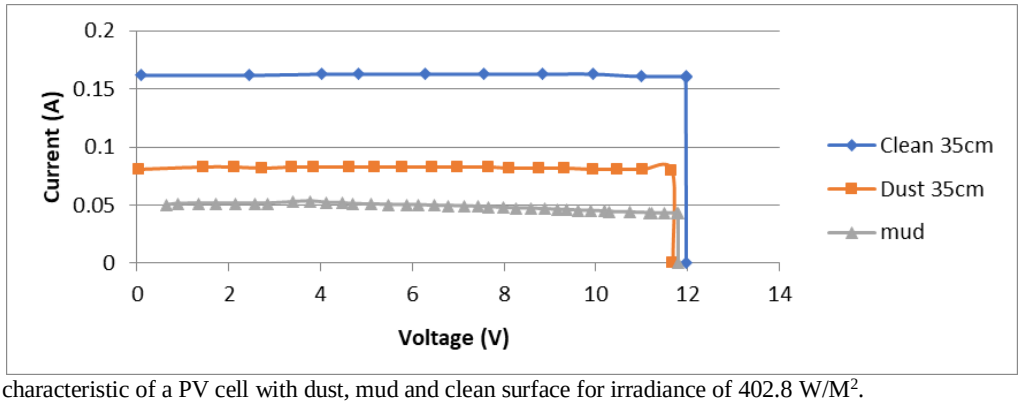

Figure 7.I-V characteristic of a PV cell with dust, mud and clean surface for irradiance of 402.8 W/M^2.

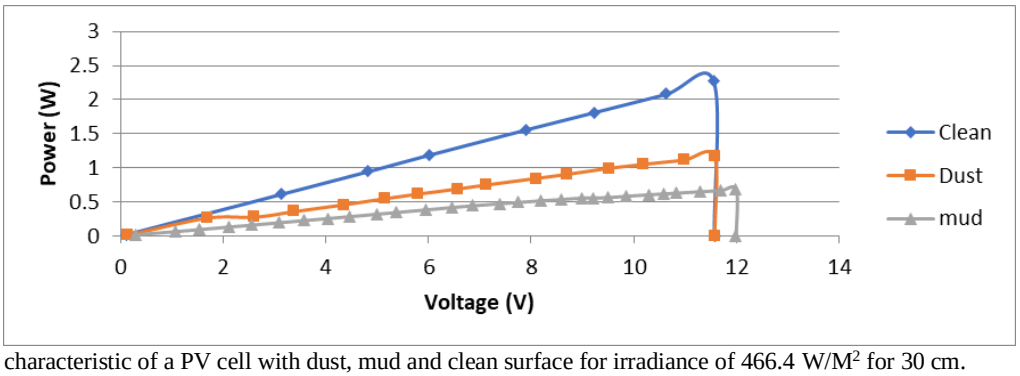

Figure 8.P-V characteristic of a PV cell with dust, mud and clean surface for irradiance of 466.4 W/M^2 for 30 cm.

Table 1. Maximum power and voltage generated for different conditions on the PV panel.

	Maximum power with irradiance of 466.4 W/M^2	Maximum voltage with irradiance of 466.4W/M^2	Maximum power with irradiance of 402.8 W/M^2	Maximum voltage with irradiance of 402.8 W/M^2
Clean surface	2.5W	11.54V	1.6W	11.9V
Dust particles	1.17W	11.58V	0.94W	11.65V
Mud particles	0.68W	11.98V	0.51W	11.78V

In general, the current-voltage characteristic shown above for the three conditions have the same curves which represent the power generated by the solar PV system. From the table above, it is shown that highest power is gotten from solar panel with clean surface and the curve reduces as soon as dust particles are deposited on the surface of the panel thereby reducing the energy generated. The graph of P-V characteristic clearly shows the trend on how dust or mud particles introduction reduces the energy generated by the solar PV system.

Peak power is obtained from calculation using the measured value of voltages and current for three conditions at different irradiations as shown in the table 1 above. It is clearly shown in the table above that the highest maximum power generated occurred when the solar PV system is clean and the lowest was when the panel is soil with mud simply because of the mud deposit on the surface of the solar PV cell. This mud or dust deposit reduces the solar radiation reaching the panel, therefore reduces the peak power of the solar PV system. The peak power value for irradiation of 466.4 W/M^2 for clean surface, panel with dust and panel with mud is 2.5 W, 1.17 W and 0.68 W. This value for the three conditions clearly shows that dust has effect on the peak power of a solar PV system and further investigation would be suggested for future purposes.

The highest efficiency calculated for solar panel with clean surface is 10%, solar panel soil with dust particles is observed to be 4.7%, solar panel soil with mud particles is also observed to be 2.7%. This calculated value clearly shows that solar PV system with dust or mud particles on its surface has great effect on the efficiency and the maximum power generated.

The cleaning methods on performance of PV panel were carried out using three different mitigation procedures namely: (1) cleaning with pressurised water with soap, (2) cleaning with water and surfactant, (3) and finally, solar panel coated with thin glass nano-structure. The figures 9 and 10 show the P-V and voltage-current characteristic for solar panel clean with pressurised water and soap:

The results above show that solar panel coated with thin glass nano-structure has the highest power generated and efficiency at the end of the cleaning. The result of the solar clean with pressurised water and chemical has small significant changes. The power generated by clean solar PV panel is 2.5W and efficiency was 10%. This cleaning experiment conducted shows that solar panel coated with glass is the best method used to clean solar panel in northern part of Nigeria. Solar panel clean with pressurised water has so many disadvantages since it requires much water and energy to hold the horse during cleaning. This water is rare and quite expensive in northern part of Nigeria. Secondly, cleaning with surfactant chemical is seen to be an effective method but has some drawback which made it very difficult to be used in the northern part of Nigeria. The drawback is the availability of the chemical in the market and the cost of getting it, also the inadequate qualify person to mix the water and the chemical in a right proportion (ratio). From the experimental result, coating seem to be the best effective cleaning method since it those do not require water and chemical, and the coating materials is easily available in the market. The coating material act as a lotus leaf which repelled particles when drop on the surface.

P-V and I-V characteristic for different tilt angle shows that maximum power was generated when the tilt angle is around 10-20 degree. It can be concluded that solar panel must be position rightly, facing the sun light before it can produce the require amount of energy needed at a particular time.

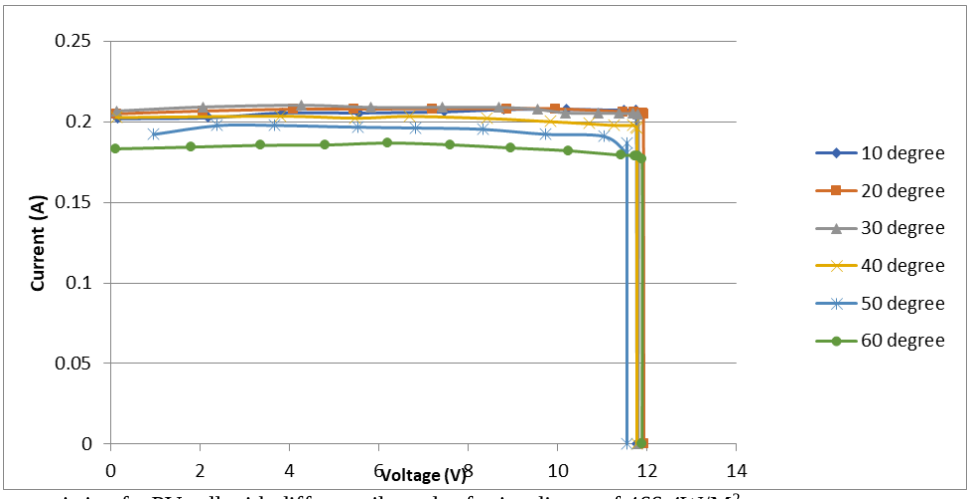

Figure 9.I-V characteristic of a PV cell with different tilt angles for irradiance of 466.4W/M^2.

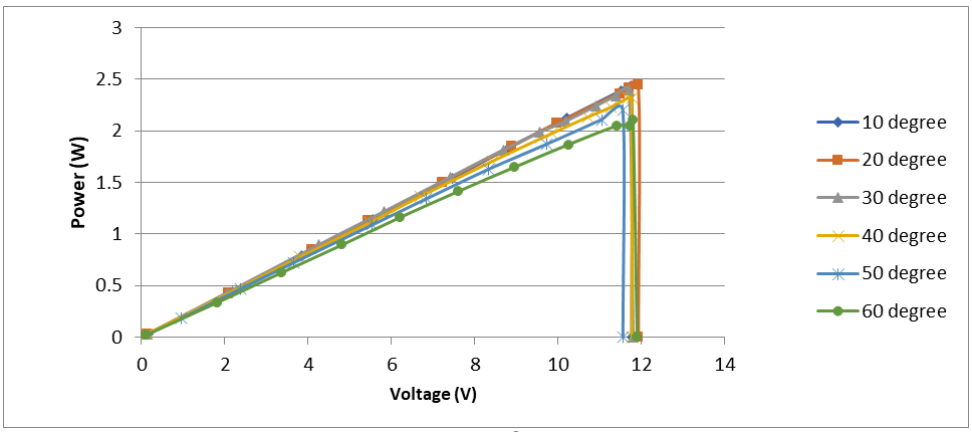

Figure 10.P-V characteristic of a PV cell for irradiance of 466.4W/M^2 with different tilt angle.

4. Conclusion and Recommendation

The effect of particles deposition on the surface of a solar PV panel was studied using dust and mud sample from Nigeria under different irradiance and temperature conducted in an indoor lab. The test results show that dust particles no matter the size or density has an effect on the performance of photovoltaic panel. The decrease in the maximum power generated from the test can be up to 10%, and it was also shown from the test conducted that under greater irradiance, the peak power generated reduces compared to when the irradiation is low. This clearly proof that maximum power will be generated when the light radiation is closer to the solar PV panel than when is far from it. In the study, it is shown clearly that the differences in results obtained by using dust particles and mud particles were significantly small but not negligible. Hence, in order to achieve high performance of a solar photovoltaic panel, dust particles no matter the size or thickness must be remove from the surface of the PV panel.

Similarly, another experiment has been conducted to study the influence of using different cleaning mitigation on the performance of photovoltaic panels. Three different types of test have been conducted using the following setup: cleaning with pressurised water and soap, no cleaning, cleaning with water and surfactant and finally cleaning by coating the surface of the solar PV panel with thin glass nano-structure. The results of the experiment conclude that: (1) dust accumulation on the surface of a PV panel continuously without proper mitigation can decrease the power generated and also decrease the efficiency of the photovoltaic panel to a very low level in northern part of Nigeria. Hence, cleaning must be done to avoid this in this area. (2) The peak power generated by the PV panel after the experiment shows that cleaning with non-pressurised water is not an effective method of cleaning dust particles deposition on the surface of a PV panel and the best method to mitigate dust deposition on the surface of PV panel is by the use of conducting coating material that can repelled dust particles as soon as they fall on the surface. (3) Cleaning using surface coated with thin glass has good advantages since they do not used water which is rare and quite expensive in northern part of Nigeria for cleaning as well as the energy for spraying the water. Once the right mitigation procedure is used and the necessary precautions are taking into consideration, the efficiency of the solar panel at the end of the cleaning will be ensured.

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