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Effect of Dust Accumulation on the Performance Efficiency of Photovoltaic Module

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ABSTRACT
Despite the growing importance of renewable energy produced by solar cells, the cost of solar power cells must be significantly reduced and their efficiency improved before they can successfully replace the current use of fossil fuels. The performance of the solar energy system is related to the ability of the glass cover to allow radiation to penetrate through the collection surface. There are many factors that affectits effectiveness including the density of solar radiation at that area, the tilt angle of the panels and the gradual degradation of collectors resulting from accumulation of dust due to the shadowing effect. Accumulation of dust onPV panels obscures the incident irradiance on the surface leading to alteration in the solar spectrum of the module and increases the possibility of a phenomenon known as hot spot effect. To ascertain the extent to which solar radiation were measured, recorded and analyzed at half-hour interval for five days, at the same period two solar panels were subjected to test, one kept at outdoor environment to accumulate natural dust . Measurement of both the output current and voltage were made from which the power output and efficiencies were calculated. The result shows that the power output was increasing as the solar radiation increased, which is clear indication that the entire photovoltaic process depend on the radiation intensity and environmental conditions.It was also noted that as the mass of dust deposition increases, power output and the efficiency of the module decreases.It was also observed that the efficiency of the cleansolar panel is slightly greater than that with dust. The efficiency and energy output of both solar panels were determined to be 21%, 11% and 414kWh, 227kWh respectively. The difference of 187kWh is not supposed to be neglected, because considering the difference of many days and many panels cannot be neglected.Also few approaches that have been proposed to reduce the effect of dust on the solar photovoltaic system which include choosing the appropriate configurations and regular cleaning of the panel.

I. INTRODUCTION

With the increased demand on energy resources, energy prices will likely continue rising for the next decade. In addition the combustion of fossil fuels has led to a dramatic climate change. Theworld's leaders are actually conscious of this major problem and that it's time to implement other alternative technologies for obtaining safe and efficient energy. One option is the use of renewable resources energy especially solar energy that becomes a promising business, holding more than 24 billion market value. This sustainable energy resource can help to solve worldwide energy insecurity. Despite the growing importance of electrical energy production by solar cell, the cost of solar powercells must be significantly reduced and their efficiency improved before they can successfully replace the current use of fossil fuels (Salim, 2013).Currently, Scientists and engineers are working very hard to make solar electrical affordable on a large scale, long been trying to develop a low-cost solar cell, which is both highly efficient and easy to manufacture with high throughput. The drawback of solar cells can generate power when the exposure to the sun rays is enough. When the weather is cloudy or during sand or snow storms the power generation falls off or nearly stops. It can only provide power at night if excess is store in butteries. The performance of the solar energy system is related to the ability of the glass cover to allow radiation to penetrate through the collection surface. many factors its effectiveness including the density of solar radiation at that area, the tilt angle of the panels, the properties of the materials, and the gradual degradation of collectors resulting from accumulation of dust due to the shadowing effect. (Elminir H.K, 2010).

A photovoltaic (PV) system consist of array of solar panels to convert to electricity. Each solar panel is an arrangement of PV cells, made up of semiconductor materials. The capacity of PV cell can be estimated by estimated by knowing cell efficiency and fill factor (F.F). Solar energy refers primarily to the use of solar radiation for practical electricity generations. However, there are other renewable energies like natural gas, coal and bio fuel. Solar radiation long with other secondary solar powered resources such as wind, geothermal, tidal and waves power hydroelectricity and biomass, account for most of the available renewable energy on the earth. Only minuscule fraction of the available solar energy is used (Saito, 2011). The energy yield from a PV panel is affected by so many environmental factors among which is dust. Accumulation of dust on PV panels obscures the incident irradiance on the surface leading to alteration in the solar spectrum of the module and increases the possibility of a phenomenon known as hot spot effect (Elminir, 2010). All there are detrimental to the efficient performance of PV installations leading to poor energy harvest. There is need to device a means of detecting the performance of PV system under soiling conditions. There is enough literature to show that the output electrical current of a PV module reduces greatly by soiling, bird droppings, dust, leaves, snow, soot and snow (Levitan, 2010).

Dust and soil has adverse effect on the environment through obscuring the irradiance that falls on the module surface (Rahoma et al, 2015). There are items tend to alter the solar spectrum that affects the dependent PV module. These lead to the reduction in the power output of the module (Gxasheka, 2005). The rate at which dust occur is a function of the climatic condition of a place. While snow may not be a problem in a place like Sokoto, dust at certain periods of the Year could have significant effect on PV performance. The amount and nature of dust accumulated on a module is largely determined by factors such as type of local soil, the weather pattern of the place, agricultural activities, level and type of industrialization and transportation (Gxasheka, 2005)). Studies have also shown that a single washing in the middle of dry season could reduce the losses due to dust accumulation by as much as half. Regular cleaning of modules could therefore improve the energy harvest from modules. Another factor that is of great concern due to dust accumulations is that they tend to produce spots that have varying concentrations of dust particles. The variation in dust spots con centration’s can cause different transmittance of light in to the module which can lead to inhomogeneous shading on the cell (Heiman, 2014). This can trigger the hot spot effect where the operating current of a module exceeds the short circuit current of the affected cell. This effect can cause the cell to become reverse biased leading to dissipation of heat.The knowledge of how solar spectrum is selective attenuated by dust can help in the process of better selections of technology under specific dusty environments. In measuring the soiling of a PV module the method that is generally accepted is to compare the electrical output of the soiled PV with a clear one and express them as ratio of each other. The measurement is usually done simultaneously. In most of the studies on the effect of dust on PV panel.Moreover, most of this experiments are rather done under a controlled environment and may not reflect the actual situation (Nimmo, 2011).

SOLAR RADIATION

Solar radiation is the radiation, or energy we get from sun. It is also known as short wave radiation. Solar radiation comes in many ways such as visible light, radio waves, heat (infrared), X-rays and Ultraviolet rays. Measurements of solar radiation are higher on clear sunny days and usually low on cloudy days. When the sun is down or there are heavy cloudy blocking the solar radiation is measured at zero Bailey and Robert, (2008).

Solar radiation is the total frequency spectrum of electromagnetic radiation produced by the sun. This spectrum covers visible light and near visible radiation, such as X-rays, ultraviolet, infrared radiation and radio waves. Also solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy Bailey and Robert, (2008).

COMPONENT OF SOLAR RADIATION

Direct solar radiation: it also called “Direct Beam radiation” it is used to describe solar radiation traveling on a straight line from the sun down to the surface of the earth, Bailey and Robert.
Diffuse solar radiation: diffuse solar radiation describes the sunlight that has been scattered by air molecules and particle in the atmosphere such as aerosol and still made it down to the surface of the earth, Bailey and Robert, (2008).

PHOTOELECTRIC EFFECT

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in (1839), who found that certain materials would produce small amounts of electrical current when exposed to light. The theory of the solar cell is the solar effect of semiconductor material. The solar effect is a phenomenon that the semiconductor material absorbs the solar energy, and then the electron-hole excited by the photon separates and produces electromotive force.

PHOTOVOLTAIC CELL

The basic unit of a photovoltaic system is (PV) cell also called solar cell. It is a semiconductor device that can convert sunlight into direct electrical current (DC). When sunlight shines on PV/solar cell, it may be reflected, absorbed or passed through. But only the absorbed sunlight generates electricity Aldo Vieira Da Rosa, (2005).

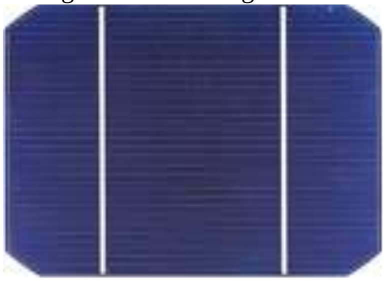

FIGURE: 1 SOLAR PHOTOVOLTAIC CELL
(Http://org.ntnu.no/solarcell/pages/hiztory.php)

EFFICIENCY OF THE SOLAR CELL

Solar cell efficiency is the ratio of the electrical output of a solar cell to the incident energy in the form of sunlight. The energy conversion (n) of a solar cell is the percentage of the solar energy to which the solar cell is expose that is converted into electrical energy. Efficiency is calculated by dividing s cell's power output (in watt) at its maximum power point (Pm) by the input light (E, in W/m2) and the surface area of the solar cell (Ac in m2).

η=Pm/E.A…………………………………………… ………………………………………………..i

Where n is the energy conversion efficiency, Pm is the maximum power point, E is the input light, and A is the surface area of the solar cell.

FILL FACTOR (FF)

The fill factor (FF) is essentially a measuring of the quality of solar cell. It is calculated by comparing the maximum power to the theoretical power (PT) that would be output at both the open circuit voltage and short circuit current where:

$FF = Pmax/P_T = Imp.V_{MP}/I_{SC}.Vo$ c= Imp.vmp/Isc.Vo…………………………………… ………ii

Dust and light absorbance

The cause of the reductions of solar cells power is the attenuation in transmittance of light due to the dust accumulations on the glass cover. The dust accumulations process is very easy it starts first by a simple layer accumulation until it covers all the surface, then a second layer will deposit on the top of it and so on. To calculate the scattered light efficiency, we suppose that the dust particles are spherical and are composed mainly by siO_2, thus the refractive index for the silicon oxide as function of the wavelength was used. When there particles are illuminated they will absorb and scatter the light, which will reduce the intensity of the light beam, this effect is known as the extinction efficiency that is governed by the ration of the particle size to the wavelength of the incident light. The particle extinction efficiency can be obtained by combining the effects of scattering and absorption. The Mie theory can serve as the basis of a computational procedure for calculating the scattering and absorption of light as a function of the wavelength (Nimmo, 2011).This effect was reported in previous work in which they show that larger particles lead to more output due to the dependence of small particles to the light wavelength. Just to mention that we did not take in to account the internal scattering betweenparticles due to the computational limitation (Nimmo, 2011).

Dust characterization.

Desert dust in region represents a large fraction of the naturally particles composed mainly of feldspars, Gypsum, chart, and mica with a dominate compound of quartz. There particles having diameters up to several microns and, therefore, they are able to scatter and absorb both the solar and terrestrial radiation affecting the solar cells efficiency. The analysis of a sample of dusts from a solar cells panel using an Olympus CX211 microscope and the image J analyzer software gave more information on the grain size distribution. Various particle size and shapes.Moreover the same image shows overlapped particle which add difficulty to the analysis of particles (Levitan, 2012). The figure shown is that of clean panel and dusty panel.

EFFECT OF DUST ON SOLAR PANEL

Dust consists of tiny solid particles carried by air currents. These particles are formed by disintegration which is a process of fracturing the solids into small pieces through grinding, crushing, or impact among other ways. The Mine Safety and Health Administration (MSHA) defines dust as

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finely divided solids that may become airborne from the original state without any chemical or physical change other than fracture. Dust is generally measured in micrometers. Dust is covered on the solar panel naturally. The layer of the dust on the solar panel increasing with the time respectively. It also acts as a barrier between solar panel and sun rays. There are two primary ways that dust affects the photovoltaic panels. First, dust settles directly on the solar photovoltaic panels, blocking the cells from the sun rays. The tracing sensor may be covered by dust, inhibiting the panels from following the sun direction (Nguyen and Sagar, 2009).The value of short circuit current, power decrease with respect the amount of dust on the solar panel.

EXPERIMENTAL METHODS

The experimental setup was designed to investigate how dust affects the output power and efficiency of PV panels during operation. Two 180W monocrystalline solar modules were used in the experiment to determine the open circuit voltage (Voc) and the short circuit current (Isc) of the two monocrystalline solar panels.One of the PV was installed and kept at the outdoor environment for one month to achieve the amount of dust on the solar panel. For the measurements of output voltage and current, Lurton DM-9080 Digital multimeter were used and the experiments were conducted from 8:00am to 5:00pm for three days. Pyranometer was used to capture global solar irradiance.In this research natural dust was used to represent the dust accumulation. It is not a complicate study of the fundamental aspect of the dust effect.

Parameter	value
Maximum power (PM)	180W
Maximum power voltage (Vmp)	36.663V
Maximum power current (Imp)	4.370A
Open circuit voltage (Voc)	44.322V
Short circuit current (Isc)	4.677A
Maximum system operating voltage (v)	1000V
Fuse series rating	15A
Cell technology	mono-Si
Application class	Class A
Standard test condition (stc)	25’C, 1.5Am, 1000W/M2

Table 1: Electrical Characteristics of Module

Figure: 2. Clean Solar module

Figure: 3. Dusty Solar module

II. RESULT AND DISCUSSION

The averageresults for solar radiation, open circuitvoltage for clean (V_1) and dusty (V_2) PV short circuit current for clean (I_1) dusty (I_2) PV, output power for clean (P_1) and dusty (P_2) PV and the efficiencies (ŋ)for both clean and dusty PV were recorded for three days starting from November 10, 2021 is as shown in the Table 2 respectively.

Time	Solar rad.(W/m ^{2})	V_1 (Volt)	V_2 (Volt)	I_1 (A)	I_2 (A)	P_1 (W)	P_2 (W)	η_1 (%)	η_2 (%0
8:00am	336	27.2	24.24	1.31	1.08	35.63	26.17	13.15	9.66
8:30am	386	28.35	25.18	1.85	1.13	52.44	28.45	16.84	9.14
9:00am	513	32.41	31.82	3.04	1.97	98.53	62.68	23.81	15.15
9:30am	634	33.42	33.35	3.39	2.02	113.29	67.36	22.15	13.17
10:00am	685	34.32	33.56	4.08	2.15	140.03	72.15	25.34	13.06
10:30am	737	34.49	34.38	4.18	2.22	144.17	76.32	24.25	12.84
11:00am	801	36.8	34.71	4.2	2.21	154.56	76.7	23.92	11.87

11:30am	848	36.41	34.16	4.38	2.43	159.48	83	23.32	12.13
12:00pm	902	36.84	32.72	4.31	2.61	158.78	85.39	21.82	11.74
12:30pm	953	34.8	33.34	4.96	2.97	172.61	99.02	22.45	12.88
1:00pm	999	36.85	32.48	5.01	2.88	184.62	93.54	22.91	11.61
1:30pm	991	36.45	29.45	4.67	3.09	170.22	91	21.29	11.38
2:00pm	879	36.06	28.8	4.13	3.12	148.93	89.85	21	12.67
2:30pm	805	35.18	20.15	3.43	3.41	120.67	68.71	18.58	10.58
3:00pm	715	33.79	29.36	3.68	2.38	124.35	69.87	21.56	12.11
3:30pm	558	32.68	29.11	2.79	1.98	91.18	57.63	20.26	12.8
4:00pm	389	31.9	29.02	1.87	0.96	59.65	27.85	19.01	8.88
4:30pm	253	31.56	28.79	1.23	0.57	38.81	16.41	19.02	8.04
5:00pm	197	30.04	25.66	1.15	0.51	34.54	13.08	21.74	8.27

Table 2: Average values of solar radiation and electrical parameters

Source: Authors' computation

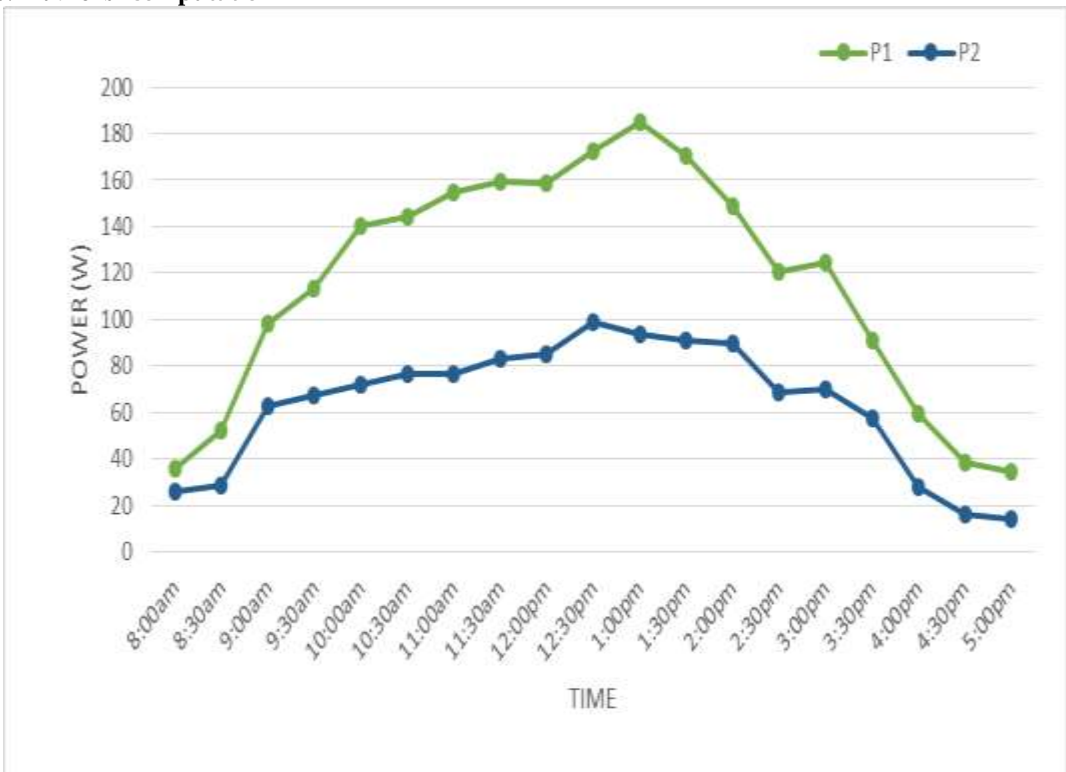

Figure: 4. Graph of P1 and P2 against

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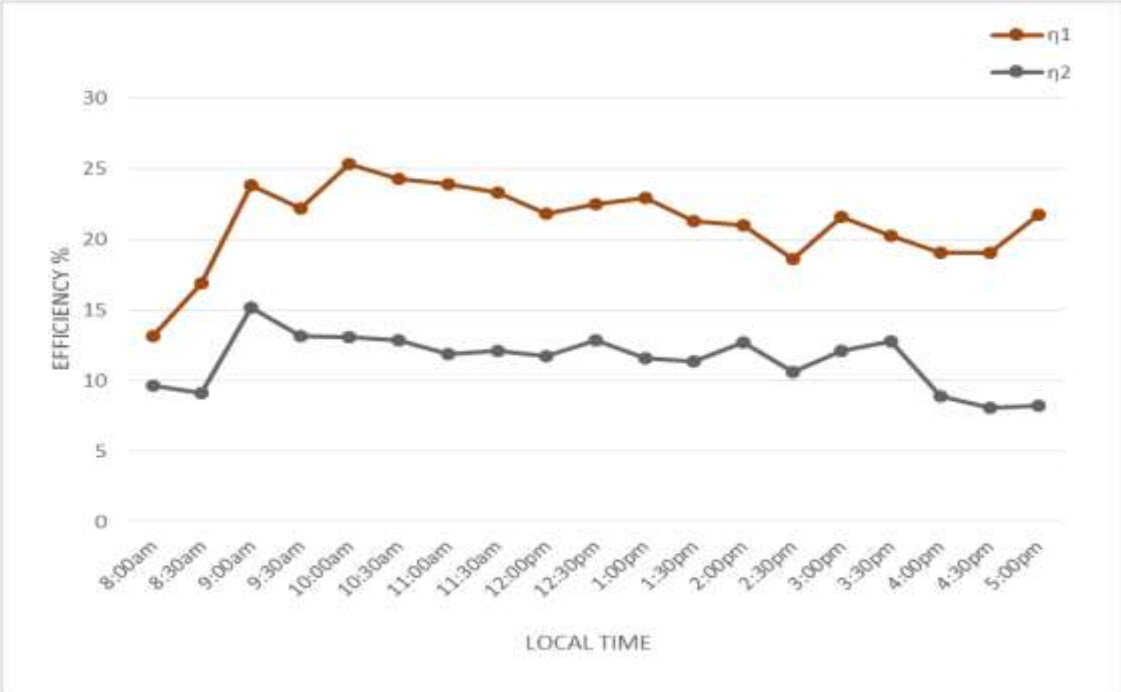

Figure: 5. Graph of η_1 and η_2 against local time

The length of the panel was measured using meter tape as 118.7cm = 1.187m; and the breadth was measured to be equal to 104cm = 1.04m
The area of the panel is given by:

$$A = L*B \quad \text{iii}$$

Where
A is the area of the panel
L is the length of the panel
B is the breadth of the panel
Substituting the values gives $Area, A = 1.187m * 1.04m = 1.24m^2$
The power output is given by:

$$P_{out} = I*V \quad \text{iv}$$

While the power input is:

$$P_{in} = E*A \quad \text{v}$$

Where
I= Current
V= Voltage
E= Solar radiation
A= Area of the module
Therefore the efficiencies of the two panels are calculated using:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{I * V}{E * A} \text{vi}$$

III. DISCUSSION

It can clearly said that the output power of clean solar module is greater than the output power of dusty module. When the sun intensity is at peak (1pm-1:30pm) the clean module attain it maximum power to about 180W and the dirty module 93W and 25% , 13% efficiency respectively From the figure 4 and 5 we can see that when the power of dusty module fall then the power of clean panel does not fall. So it can be easily said that maximum power point is decreasing for dusty module.

IV. CONCLUSION AND RECOMENDATION

The effect of dust accumulation on the overall performance of solar photovoltaic module has been investigated. The result shows that the output power of PV module mainly depends on solar irradiance, which clearly indicates that the entire photovoltaic process depends on the radiation intensity. It also shows that the output power and efficiency of clean PV module 115W, 21% is slightly greater than dusty PV 63W, 11% respectively. It was also noted that as the mass of dust deposition increases, power output and the efficiency of the module decreases, and as the size becomes smaller, power output decreases as smaller particle block more radiation on PV module surface. The accumulation of dust on the solar panels lower the overall performance of solar module especially in the regions known to have high rate of dust, low frequency and intensity of rain. Dust has become a major challenge in Sokoto especially in SabonBirni, isa, Gwadabawa, and Gada to mention but few. The accumulated dust on

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the solar panel block the cells from solar radiation and act as a barrier that obstruct solar radiation from reaching the cells.Solar panel conversion efficiency, typically in the 20% range, is dust, grime, pollen, and other particles that can be accumulate on the solar panel. A dirty solar panel can reduce its power capabilities by up to 50% in high dust/pollen or desert area, saysSeamusCurran, associated professor of physics at the university of Houston and director of the institute for Nanoenergy, which specializes in the designengineering,andassemblyofnanostructures.Paying to get solar panels cleaned is often not a good investment; researchers found panel that had not been cleaned or rained on, for 145 days during a summer drought in California, lost only7.4% of their efficiency. Overall, for a typical residential solar system of 5 kw, washing panels halfway through the summer would translate in to a mere $20 gain in electricity production until the summer drought ends-in about2 ½ months. For large commercial rooftop systems, the financial losses are bigger but still rarely enough to warrant the cost of washing the panels. On average, panels lost a little less than 0.05% of their overall efficiency per day.Therefore a highly technological PV systems that cleaned it self automatically is needed to reduce the energy lost due to dust and save the investment cost of washing panels especially in a very large arrays of PV system.

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