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ASSESSING THE INFLUENCE OF DUST ON SOLAR PANEL EFFICIENCY USING PREDICTIVE MODELS

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Abstract: The power delivered by a photovoltaic (PV) module defends on the amount of solar irradiance that reaches the solar cells, however dust particles deposition on the surface of the modules are mostly responsible for limiting the amount of radiation reaching the solar cells, thereby reducing the power delivered by the cells. Despite the significance of this, the effect of dust on the performance of solar modules have not been properly modeled, hence the need to study the resultant effects on the PV system. In this study, a test bed for the measurement of cell temperature TC, open circuit voltage (VOC), short circuit current (ISC), module load current (IL), and module load voltage (VL), from two identical PV modules was installed, also the mass of the dust deposition on the PV module was measured and recorded using a high precision balance measurement. The generated data were pre-processed and utilized to generate I-V and P-V characteristic curves as a function of dust, the curves generated for the PV module were found to compare satisfactorily well with those obtained from existing conventional PV model. The results obtained shows that ISC drops by about 1.84%, for every 1 (g/m2) increase in dust on the surface of the module, similarly, However, the effect of dust on VOC and cell temperature TC is fairly insignificant as both only decrease by less than 0.01%. As a corollary, the findings of this study will assist in achieving an optimum utilization of PV infrastructure for cost effective energy delivery.
Keywords: Photovoltaic (PV) module, Mass of dust (d), Open Circuit Voltage (VOC), Short Circuit Current (ISC) and Solar Irradiance (G)

Introduction

Nigerian electric power industry has historically been incapable of meeting the power needs of the nation due to poor maintenance, inadequate transmission and distribution network, vandalisation of electrical power facilities to mention of few. Recent survey estimates that Nigerian power sector operates at approximately sixty percent of its installed capacity, according to [1]. To augment the power generated by the generating stations, supplementary power using solar cells is seen as a viable option and its one of the promising energy sources for the future [2]. Because of their diverse applications in addition to being clean and a renewable source of energy that can be harness in all areas of the world and its availability, no one can turn sunlight into a monopoly.

Factors affecting the Performance of PV System.

PV system consists of photovoltaic array that contains several solar modules connected in series and or parallel arrangements to obtain the desired power output. The performance of the PV system also refers to as the conversion efficiency is the percentage of the solar energy shining on the PV device that is converted via photovoltaic into usable electricity. The efficiency of the solar cell used in PV system determines the energy output of the system, example a solar panel with 20% efficiency and an area of 1 m^2 will produce 200 W power at standard test conditions (STC). Efficiency η is calculated as follows;

$$\eta = \frac{power\ of\ PV\ panel}{area\ of\ PV\ panel * 1000W/m^2} * 100 \qquad ...(1)$$

PV module electrical performance depends on environmental conditions such as temperature, solar irradiance, angle of incidence, solar spectral (air mass), and the type of PV cells, each PV is rated under industrial STC of solar irradiance 1000 W/m^2 with zero angle of incidence, solar spectrum of 1.5 air mass and 25^{0}C cell temperatures. [3] These intermittent characteristics of the solar system coupled with the varying weather conditions and parameters listed adversely affects the performance of the PV system hence the need to study their resulting effects.

Literature Review

A study by [4] in Iran, investigates the effect of air pollution result from local industries on the efficiency of PV systems, in their experiment several PV modules were installed with different tilt angles. The Investigation shows that the output of the system varies with the season due to the amount of dust that exists in the air in different seasons. They observed the variation in output during winter, spring and summer. They observed that the power output of a PV system decreases by more than 60% because of air pollution that covered the surface of the PV panel.

[5] Investigates the impact of dust on solar panel. test carried out on the performance of three set of solar panels reveals an average of 1% loss of incident solar radiation due to dust or dirt accumulation on the surface of the panel with a tilt angle of 30^0. The maximum degradation in the output power was found to be 4.7%, a correlation factor of 0.99 for a glass plate inclined at 45^0. [6] Investigate the effect of dust accumulation on the performance of solar modules in Sahara environment. They investigated a framework of weekly cleaning on modules and found that dirt accumulation on solar module have a significant impact on output power and system efficiency. They reported that once a week cleaning and rinsing every three (3) days during sand and dust storm months (February – May) and once a month cleaning in other months will maintain a 2 to 2.5% loss in performance.

[7] Developed a simple model for the typical behavior of the relative transmittance losses due to the presence of dust on the solar cell. Their result shows 4.4% mean daily energy loss caused by dust deposition on the surface of the PV module. They report that in long period without rain, daily energy losses can be higher than 2%.

In their study [8] Found fifteen types of dust mentioned in different researches and reported that six of these have more significant effect on PV performance. Ash, Calcium, Lime stone, Soil, Sand and Silica. They suggest different pollutant types and different PV technologies should be investigated in future studies.

[9] Carried out a study in Norway reported that the effect of soiling can be accurately determined by a combination of optical measurement and high precision balance measurement, combining the quantitative dust measurement and the optical characterization, an approximately linear correlation between the increase in soil density and the reduced transmittance is observed. The reduction in transmission per unit of soiling density of 2.8% for every 10 mg/m^2 is found.

[10] Carried out an experiment on optical losses of PV cells due to aerosol deposition particularly role of particle refractive index and size. They investigate cell degradation as a function of intensive particle parameter

such as size and complex refractive index. Their result shows that for normally incident solar radiation deposited aerosol degrade PV cell performance due to scattering into the backward hemisphere. They found that for small particles with a relatively large imaginary part of their refractive index absorption losses dominates, while for large particles with a relatively small imaginary part of their refractive index, backscattering losses dominates. Per optical depth, fine particles result in higher optical losses than coarse ones due to their large absorption and hemispheric backscattering. This research therefore, will involve the use of an in situ field measurement, the measured data will be analyzed statistically using regression and correlation analysis.

Methodology

Description of the Experimental setup

Two identical photovoltaic modules were used, the specifications of the modules are presented in Table 1, while, the list of equipment used are listed in Table 2. The experimental setup is shown in Plate I. The photovoltaic modules were fixed at 30^0 inclination angle facing Southward for maximum solar energy harvest as suggested by, [2], and at a location devoid of overcasts from nearby trees and buildings.

Table 1: Solar Module Specifications.

S/N	Parameter	Value
1	Type	Polycrystalline
2	Manufacturer	Man-Tech. Solar
3	Model	KL-SP-80W
4	Surface Area	(113.67 × 46.99 cm^2)
5	Power Rating	80 Watts
6	Maximum Power Voltage V_{MP}	18 V
7	Maximum Power Current I_{MP}	4.44 A
8	Open Circuit Voltage V_{OC}	21.6 V
9	Short Circuit Current I_{SC}	4.94 A

Table 2: List of Equipment and Materials Used.

S/N	Equipment	Type/Range	Model No.	Purpose
1	Multi-meter	Digital	Megger M7027	Current and Voltage Measurement
2	Weighing Balance	Digital	Camry	Dust Weight measurement
3	Thermometer	Infrared	DT802	Module Temperature Measurement
4	Rheostat	150W/100Ω	Popular	Module Load
5	Electric Blower	Manual	BBL6501	Blowing Dust on Module
6	Dust	-	-	Dust Source
7	Sieve	63µm	-	Sieving of sand
8	Change Over Switch	30A	PL 200	Switching during measurement
9	Connectors	8 mm Cable	-	Connecting the modules to load
10	Nylon Cover	4g/5341.35 cm^2	-	Covering the module surface

Procedure for Dust Weight Measurement

Quantity of sand collected at the experimental site was sieved using a 63µm sieve. The modules were cleaned and placed in an enclosed room. A nylon material (that is exactly the size of the module surface area) was cut and placed on the control module surface. a quantity of the sieved dust was blown arbitrarily into the room and the room was then locked to allow the dust settles on the module surface. The nylon material was then removed and weighted to get the average mass of the dust that settles on the experimental module

Plate I: Experimental Photovoltaic Module

Procedure for Measuring the I-V Curve Trace Data

The PV module was connected to a 150Watts/100Ω Rheostat. Voltmeter was used to measure its terminal voltage and an ammeter was connected in series to measure the load current. At a particular solar irradiance (G), module temperature (Tc), and mass of dust (d), the rheostat was varied from minimum to maximum values in steps and recorded the corresponding current and voltage values from the two modules alternately by moving the changeover switch. The procedure was repeated for various mass of dust (d) values at a fixed G and T_C for 10 days.

Result

The Experimentally generated I-V curves data with respect to the experimental PV test bed for different dust accumulation were generated. **S**olar irradiance and temperature were held at the experimentally determine average value for each dust accumulation level. Figure 1 depicts the resulting plot of experimental PV module I-V characteristics curve as a function of mass of dust accumulated on the experimental PV module. Similarly, the plots of the family of Power-voltage characteristics curve relatively developed from Figure 1 are shown in Figure 2. From these figures the critical parameter of interest comprising of maximum power deliver to the load (P_{Lmax}), voltage and current at maximum power delivered to the load (V_{Lmax}) and (I_{Lmax}) respectively for every incremental level of dust accumulation have been carefully extracted. Table 3, shows the extracted maximum power delivered to the load and the corresponding load current and voltage at maximum power, V_{Lmax} and I_{Lmax} respectively.

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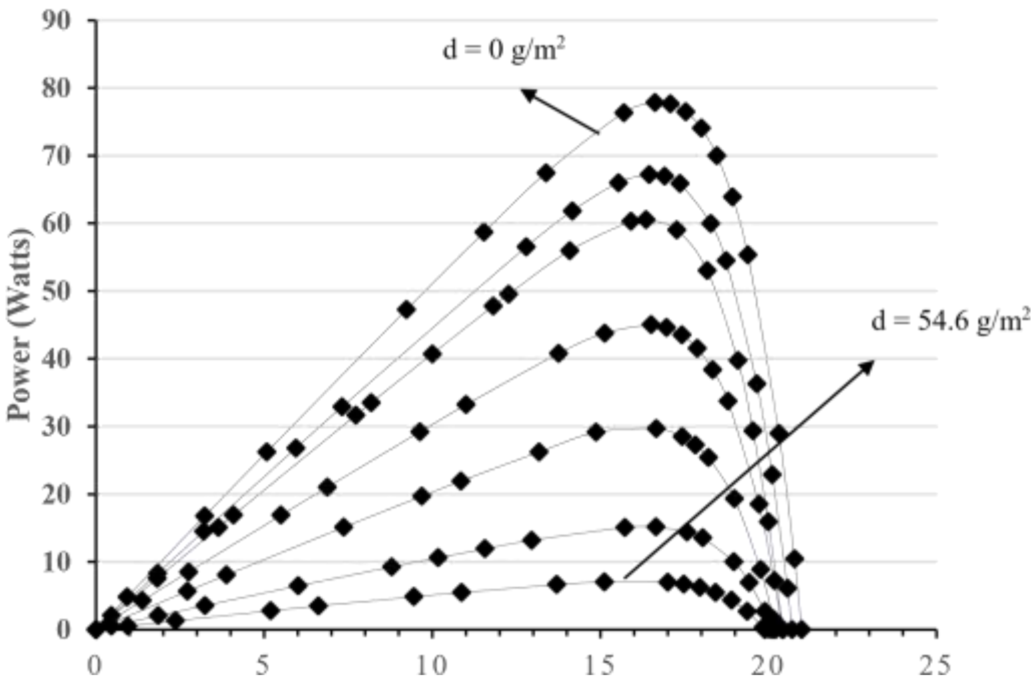
Table 3: Current, Voltage and Maximum Power Delivered to the Load from the I-V Curves

d (g/m^2)	I_{Lmax} (A)	V_{Lmax} (V)	P_{Lmax} (watts)
54.6	0.46631	15.1185	7.04996
43.3	0.90997	16.6521	15.1528
26.4	1.78111	16.6619	29.6767
20.7	2.72709	16.5046	45.0096
7.5	3.70041	16.3608	60.5415
3.8	4.08484	16.4538	67.2114
0	4.68389	16.6184	77.8389



Voltage (V)

Figure 1: Measured I-V Characteristic curves as Function of Mass of dust (d). (T=49.3, G=988W/m^2)

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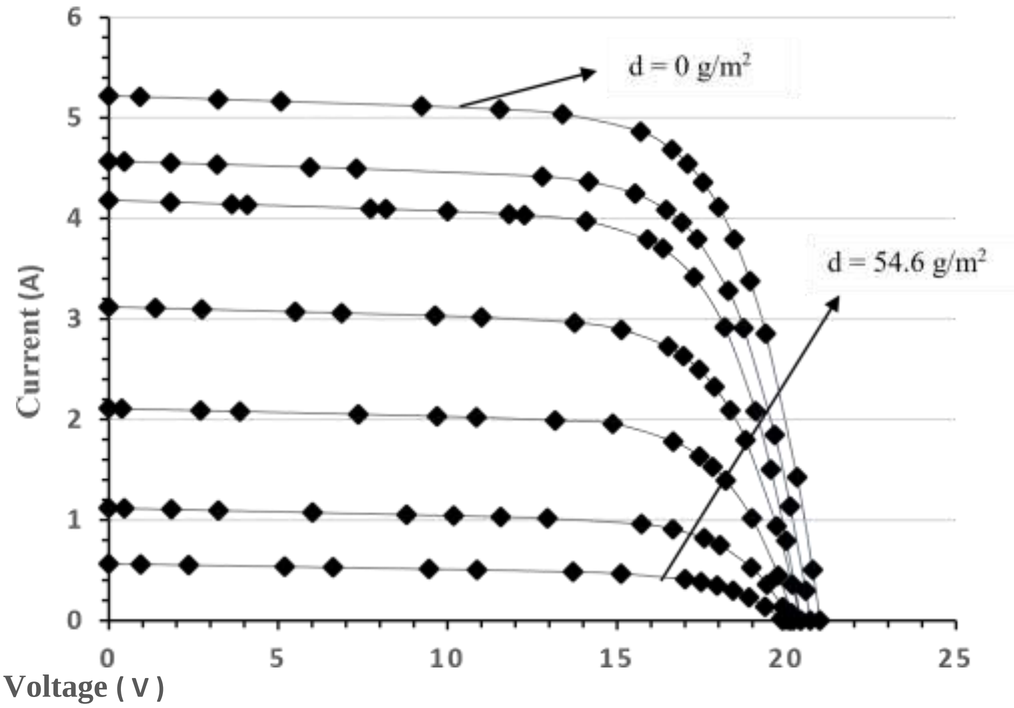

Figure 2: Measured P-V Characteristic curves as Function of Mass of dust (d). (T=49.3, G=988W/m²)

Discussion of Result

Figure 1 indicate the dust effects on the module I-V curves, while Figure 2, indicate these effects on the P-V curves, the short circuit currents I_{SC} decrease uniformly from 5.22A at 0 g/m^2 to a value of 0.62A at 54.6 g/m^2 level of dust accumulation on the module surface. The effect of dust on the module open circuit voltage V_{OC} is relatively insignificant for all dust accumulation conditions, V_{OC} drops from a value of 20.99 at 0 g/m^2 to 19.89V at 54.6 g/m^2. The effects of dust on the module power output was depicted in Figure 2, from which a gradual drop of the module maximum power output (P_{Lmax}) with increase in dust accumulation is observed. From these results, P_{Lmax} drops from a value of 77.84 watts at 0 g/m^2 to a smaller power output of 0.62 watts at 54.6 g/m^2.

Conclusion

The PV module installed has been completely modelled, this paper presents the result that emerged from the analysis of field measurement parameters of a polycrystalline silicon PV module. I-V and P-V characteristic curves as a function of mass of dust (d) have been obtained and compared exhaustively. Furthermore, an in depth sensitivity analysis of critical parameter of PV module with respect to dust have been accurately developed.

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