The Performance of Amorphous Silicon PV System under Harmattan Dust Conditions in a Tropical Area.

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ABSTRACT

Photovoltaic power is one of the most promising renewable energy technologies in the world. Among the main obstacles for using solar energy is the very low photovoltaic cell conversion efficiency due to atmospheric factors. This paper presents the influence of the Harmattan dust on the performance of the photovoltaic system in a tropical area. Two Amorphous Silicon Photovoltaic Systems of the same dimensions and materials were set-up. One served as control experiment which was constantly cleaned-up before each daily reading commenced, while the other served as the test system for the period of the experiment. The variation of the power output of the two systems were monitored in different months of the years between 2006 and 2008.

It was observed that due to the daily aggregation of dust particles on the surface of the system's solar array, the performance of the clean surface of the system was better than the unclean surface by 20% during Harmattan periods as a result of reduction in the solar flux intensity caused by absorption, scattering, and reflection of dust particles common during the periods of the years. This information can be used as the baseline to determine the effectiveness of the system at any particular period of the year.

(Key words: photovoltaic, PV, dust, power, solar flux, clouds, renewable energy)

INTRODUCTION

Solar energy conversion has become a very practical and widely distributed technology, especially when the world faces problems associated with petroleum supply and there has been a growing demand for using renewable energy sources. One of the promising applications of renewable energy technology is the Photovoltaic (PV) solar system to generate power (Macheshwa *et al.*, 2006).

Manufacturers report photovoltaic module power output at standard testing condition (STC), which correspond to 1000w/m^2, 25^{O}C, air mass 1.5 and normal incidence (Malik *et al.*, 2003). In real operating conditions, however, the photovoltaic module output rating is strongly affected by various environmental factors such as temperature, irradiance, cloud and dust among others.

Attenuation of solar radiation due to the effect of dust is very prominent in Nigeria especially during the Harmattan period; December, January, and February (Ajadi *et al.*, 2007), and reported that dust particles affect the amount of solar radiation received per surface area due to the scattering, reflection and partial absorption by the particles. Hence, dust is one of the major reducing agents of solar radiation. Solar radiation depletion from dust accumulation and the dust effect on solar energy devices have been carried out elsewhere. Yahaya and Sambo (1991) stated that dust particles are of various sizes and chemical compositions; their optical properties are dependent on parameters, which affect atmospheric properties such as visibility and scattering.

In Saudi Arabia, Sayigh, *et al.* (1985) investigated the dust effect on a photovoltaic panel, it was found that a reduction of power of 2%, 14%, and 30% after one, thirteen, and thirty-two days, respectively, without cleaning the surface of solar panel. In a rainless, thirty day experiment in India, Grag (1994) found that dust reduced the transmittance by an average of 8% for glass cover tilted at 45^O.

THEORETICAL ANALYSIS

The two well known theories for solar radiation scattering due to dust particles or aerosols according to Iqbal (1983) are; the Rayleigh theory and the Mie theory. The Rayleigh theory is limited to spherical particles with diameter smaller than the light wavelength (λ) while Mie's theory is more general and can be used for any particle size. If D represents the particle diameter in micron and n is the index of refraction, then the following cases will result:

If $\frac{\pi D}{\lambda} < \frac{0.6}{n}$ scattering is governed by Rayleigh's theory.

If $\frac{\pi D}{\lambda} > 0.6$ the scattering is a reflection.

If $\frac{0.6}{n} < \frac{\pi D}{\lambda} < 0.6$ scattering is governed by Mie's theory.

The Mie's theory in terms of dust scattering coefficient (K_d) is given as:

$$K_d = 0.08128\lambda^{-0.75} \quad \textbf{(1)}$$

which is valid for a wide range of number of particles per cubic centimeter (ma) between 1 and 800. An atmosphere with zero particles per cubic centimeter ($m_a = 0$) is a clean atmosphere, while an atmosphere with 800 particles per cubic centimeter ($m_a \neq 0$) is a very dusty one. Therefore, the spectral transmittance (T_d) can be expressed as:

$$T_d = \exp\left[-0.08128\lambda^{-0.75}\left(d/800\right)m_a\right] \quad \textbf{(2)}$$

Iqba (1983).

However, the work reported in this article was embarked upon for the sole purpose of studying the effect of dust on the performance of amorphous silicon photovoltaic system in a tropical area. The result obtained can be used in designing the effectiveness of the system at any particular period of the time.

MATERIALS

A functional six flat plate photovoltaic solar modules of the same material were used for this study. Each solar module containing seventy two amorphous silicon solar cells, rated 27W peak, 19v, model G100, ARCO. SOLAR INC, active area of 27cm^2 and manufacture by Bp solar system LTD. A 5.7kΩ variable resistor was used as a load in the study. A low resistance ammeter, high resistance voltmeter and five in one Auto raging Digital multimeter (serial number M58209) were used for monitoring and measuring the output current, voltage and ambient temperature, respectively.

EXPERIMENTAL SET UP

The photovoltaic solar system, array included three flat amorphous silicon solar modules connected in parallel configuration. The solar array was mounted horizontally on a metal plate frame, which was raised above the roof-top using an iron steel pole at the back of Pure and Applied Physics Department building, Ladoke Akintola University of Technology, Ogbomoso. A similar photovoltaic solar array system of the same dimension and the same power output rating were set up as a control experiment (see Figure 1).

To each of the photovoltaic solar array, a low resistance ammeter was connected in series while high resistance voltmeter was connected in parallel to the 5.7KΩ variable resistor using as a load. Figure 2 shows the circuit model of the experimental set up.

MEASUREMENTS

A week experimental test was observed before the commencement of taking the readings. This allows for the cleaning of the photovoltaic solar array of control experimental set up. The maximum output current and voltage values of each of the set up were monitored measured and recorded in hourly interval concurrently. The readings were taken for a period of eleven hours, from 8:00 a.m., to 6:00 p.m. per day, for the whole experimental days (December 2006, January and February 2007, December 2007, January and February 2008).

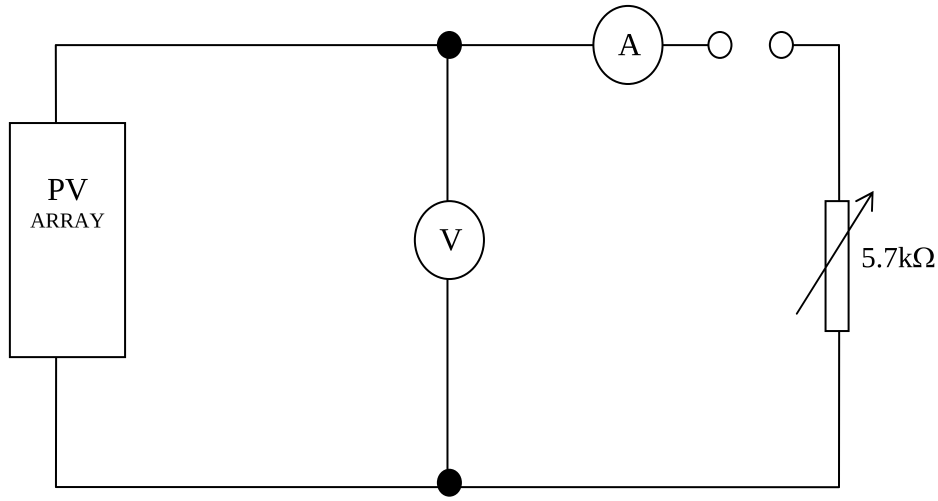

Figure 1: Circuit Model of the Experimental Set-up.

Figure 2: The Prototype of Solar Array of Test and Control ASPS.

From the recorded values of the maximum output currents and voltages, daily average current, voltage and power output values were estimated. More so, hourly mean power output values of each system set up were determined. These are presented in Tables 1 and 2

RESULTS AND DISCUSSION

Table 1 presents the daily average maximum power output generated by the clean and unclean surfaces of the photovoltaic solar array in each of the year 2007and 2008 Harmattan/hazy period.

Table 2 presents the monthly average variation of daily integrated values of power output produced by the system.

Figures 3 and 4 displayed the variation of maximum power output obtained for both the clean and unclean solar array surfaces. Generally, the power outputs of the clean surface (control) are always higher in magnitude than the unclean surface (test photovoltaic solar array) with differences between 5.0W to 10W. These differences were attributed to the deposition of dust particles on the surface of the test photovoltaic solar array.

The deposited dust reduced the intensity of the solar radiation and hence reduced the photon energy that is responsible for the production of the electric current in the photovoltaic solar system. The attenuation of the solar radiation intensity was due to absorption, scattering and reflection by the dust particles accumulated on the surface of the solar array.

Table 1: Daily Electrical Parameters of PV Solar Array System Continuous in Harmattan Period.

No of Day	Power output, P_o(W) (Clean surface) 2007	Power output, P_o(W) (Clean surface) 2008	Power output P_o (unclean surface) 2007	Power output P_o (unclean surface) 2008
1.00	74.44	69.60	65.67	64.26
2.00	74.62	67.65	69.25	66.74
3.00	74.62	68.88	67.60	64.98
4.00	74.85	69.98	67.64	60.62
5.00	74.44	66.90	58.00	64.60
6.00	75.03	69.00	57.62	64.94
7.00	75.03	67.60	59.76	66.74
8.00	74.26	68.00	56.10	69.20
9.00	75.03	66.80	62.72	66.32
10.00	74.03	65.07	64.52	66.32
11.00	73.85	65.59	63.38	62.12
12.00	75.03	65.56	65.18	61.37
13.00	74.62	66.56	57.39	65.36
14.00	75.40	66.19	57.11	65.74
15.00	75.07	65.91	59.36	67.47
16.00	75.21	63.79	63.17	64.60
17.00	75.03	63.33	57.12	64.60
18.00	74.66	65.57	64.52	69.82
19.00	75.40	65.78	58.00	61.38
20.00	74.62	65.14	58.05	61.25
21.00	74.26	63.79	61.13	61.15
22.00	74.21	63.63	64.26	60.43
23.00	73.85	63.79	64.64	58.28
24.00	73.49	63.44	61.20	58.38
25.00	73.31	63.07	63.24	58.80
26.00	73.71	66.66	66.85	56.38
27.00	74.85	66.98	59.76	57.09
28.00	73.49	63.23	61.11	57.44
29.00	74.26	65.83	57.55	57.40
30.00	74.26	65.83	58.63	62.42
31.00	70.62	66.99	58.70	61.45
32.00	70.62	65.74	62.18	61.84
33.00	69.65	65.49	58.12	61.84
34.00	70.95	65.49	63.07	62.01
35.00	70.20	66.22	63.66	62.01
36.00	69.84	66.64	61.20	61.60
37.00	69.81	66.95	65.65	61.34
38.00	69.09	67.68	61.90	61,10
39.00	98.92	67.37	59.57	60.86
40.00	70.95	67.73	58.80	60.59
41.00	70.77	67.77	61.20	60.26
42.00	70.41	64.60	59.47	59.85
43.00	69.09	65.66	59.47	59.78
44.00	69.92	66.11	65.45	59.62
45.00	68.50	67.03	68.29	59.52
46.00	68.71	66.22	58.46	59.78
47.00	69.45	66.11	60.86	59.85
48.00	70.59	67.79	65.12	59.52
49.00	70.56	67.72	65.90	59.78
50.00	70.23	67.06	63.88	59.78
51.00	71.13	67.06	64.40	59.71
52.00	71.71	68.54	60.00	59.75
53.00	71.74	68.52	57.05	59.71
54.00	70.59	66.18	60.52	59.41
55.00	71.13	66.94	69.08	59.71

No of Day	Power output, P_o(W) (Clean surface) 2007	Power output, P_o(W) (Clean surface) 2008	Power output P_o (unclean surface) 2007	Power output P_o (unclean surface) 2008
56.00	70.98	67.06	63.80	59.42
57.00	70.77	66.10	62.56	59.16
58.00	71.53	67.34	58.67	59.24
59.00	71.34	68.54	60.48	58.90
60.00	70.41	67.06	59.29	59.07
61.00	70.70	67.06	59.74	58.90
62.00	70.68	67.06	59.30	59.07
63.00	71.20	66.34	58.80	58.76
64.00	71.50	66.36	59.00	58.43
65.00	70.80	66.01	52.54	58.36
66.00	71.68	66.90	57.90	58.76
67.00	70.50	67.11	59.80	58.36
68.00	70.80	67.70	59.00	58.36
69.00	71.00	68.54	58.58	58.29
70.00	70.83	67.90	58.40	58.30

Table 2: The monthly Average Variation of Daily Intregated Values Power Output of the PV System for the Year 2007 and 2008.

Month	Power (W) Output 2007	Power (W) Output 2008
January	61.8	60.5
February	63.7	58.3
March	66.2	68.5
April	71.2	64.1
May	62.8	63.0
June	57.6	59.6
July	60.1	57.6
August	57.5	59.3
September	56.6	57.3
October	62.8	60.0
November	68.3	67.5
December	62.9	61.8

The figures further show that, the maximum power output of the photovoltaic solar system with clean surface are fairly constant in magnitude of a mean value of 73.0 Watts and 7% variation for the whole period of the experiment, while the maximum power output of test photovoltaic solar array (unclean surface) varies in magnitude and has a mean value of 66.5 Watts with about 12% variation. This could also be due to multiple scattering by an increasingly dense deposit of dust on the upper face of the test photovoltaic solar array as the day progressed. The results in the foregoing discussions are similar to that of Sayigh (1978) and Ajadi *et al*. (2007).

The monthly means variation of daily integrated values of power output of the photovoltaic system is presented in Figure 5. From the pattern of the variation, it was seen that the highest monthly average value of the power of about 68Watts was produced by the system in the months of March, April and November, compared to low value of about 61Watts produced during the months of December, January and February. The low value of the power output produced by the system in the months of December, January and February was due to the Harmattan dust, which is generally severe during the period. This is expected to be so, because Harmattan dust, found to consist of large size particles that cause scattering, absorption and reflection of solar radiation, thus resulted to decrease in solar flux. The decrease in solar flux causes decrease in photon from the sun which strikes the solar cell junction, hence decreasing the electron-pair production and the mobility carriers during this period. Conversely, high flux due to the clean and clear atmosphere enhances highest power production by the system during the months of March, April and November.

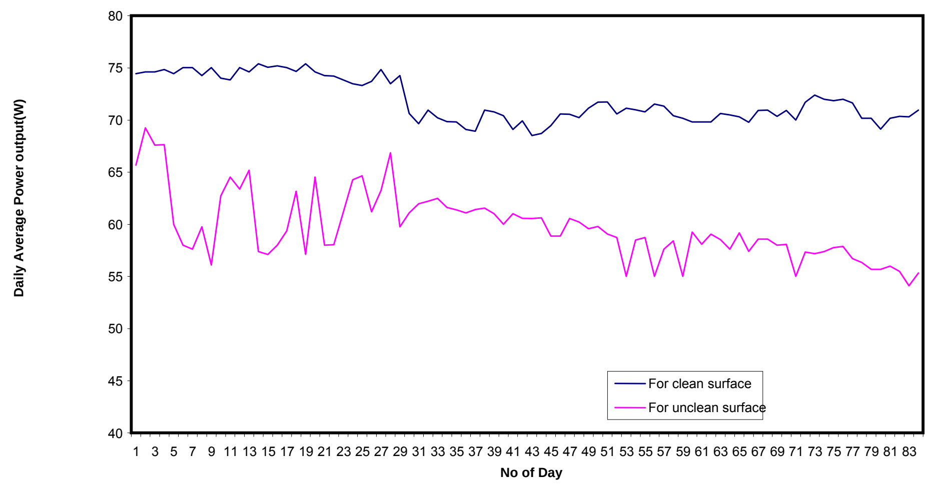

Figure 3: Daily Average Power output Variation in the day for 2007 Harmattan Period

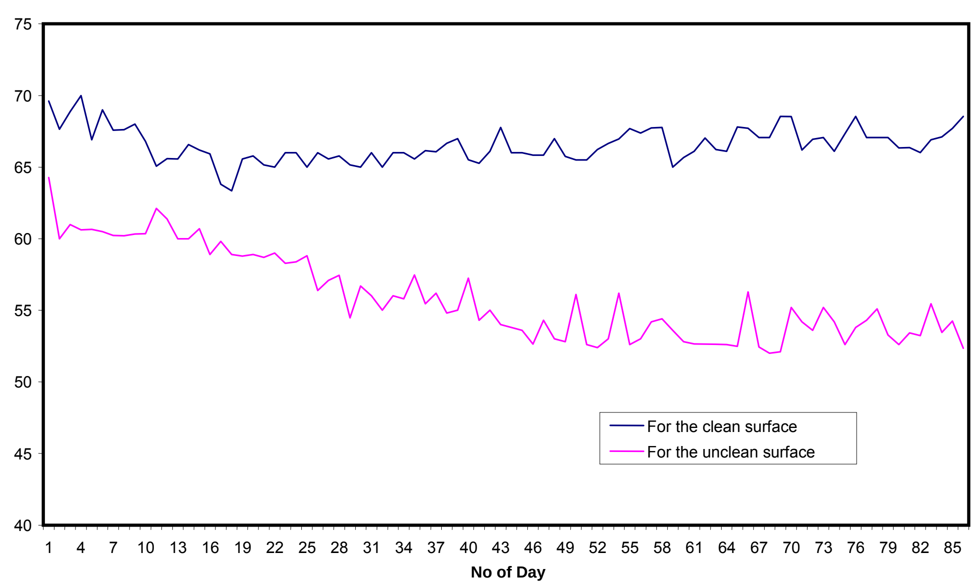

Figure 4: Daily Average Power output Variation in the day for 2008 Harmattan Period,

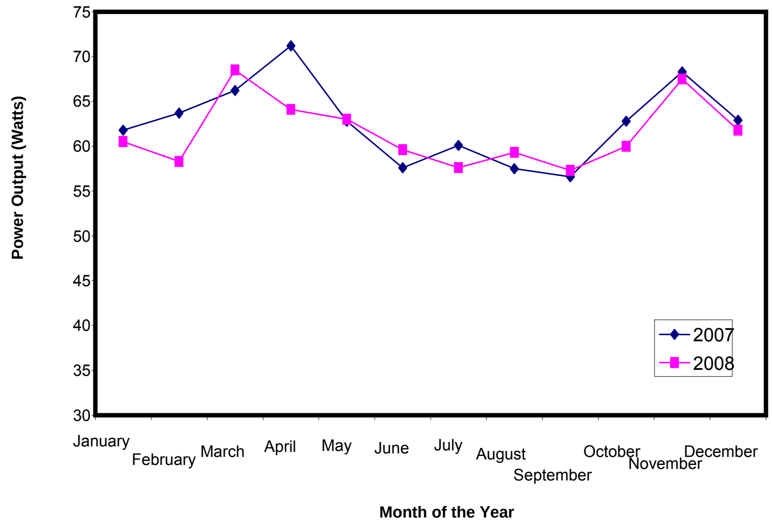

Figure 5: Monthly Mean Variation of Daily Integrated Values of Power Output of the Photovoltaic System for the Year 2007 and 2008.

While a low value of the power generated during the months of May to October was caused by absorption, scattering and reflection of solar radiation by different types of clouds, covering atmosphere during the period.

CONCLUSION

The goal achieved via this study is the investigation of the influence of the Harmattan dust on the photovoltaic system in a tropical area. The obtained results show that the application of photovoltaic technology in the conversion of solar energy to electricity within the region under study is not favorable during Harmattan period compared to period of reasonable clean and clear atmosphere. It is revealed from the study that during Harmattan dust period, the performance output difference between the clean surface and the unclean surface of photovoltaic solar arrays increases as the hour of each day progressed.

Thus, the performance of the clean surface system found to be better by the average of 20% than unclean surfaces. It is therefore inferred that Harmattan dusts have a strong influence with the conversion efficiency of photovoltaic system. However, it is advisable that for the better performance, especially during Harmattan dust period, the arrays of photovoltaic system should be incorporated with cleaning device.

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SUGGESTED CITATION

Sanusi, Y.K. 2012. "The Performance of Amorphous Silicon PV System under Harmattan Dust Conditions in a Tropical Area". *Pacific Journal of Science and Technology*. 13(1):168-175.

Pacific Journal of Science and Technology