ISSN XXXX XXXX © 2019 IJESC

Research Article Volume 9 Issue No.3

The Effect of Shadow on the Output Performance of Solar Module

J. A. Amusan[1], E. B. Otokunefor[2]
Department of Physics
University of Port Harcourt, Rivers State, Nigeria

Abstract:
The effect of shadow on output performance of solar module in a series-parallel solar cell array was studied. Measurements of the degradation of the power curve with time, current-voltage characteristics as function of total and partial shade were made on 250W monocrystalline silicon solar modules. The solar modules were positioned at the University of Port Harcourt environs (Longitude 7.01^0 East and Latitude 4.78^0 North) between the hours of 7.00a.m and 4.00p.m. The solar modules were raised to a height of 2.0m and inclined at an angle 15^0 to the horizontal. The open circuit voltage, Voc and short-circuit current (Isc) were recorded with a digital multimeter at 15minutes periodic interval. The results show that the power loss for partially shaded solar modules ranges between 12% - 40% when compared with the fully illuminated solar module. So, the power loss for partially shaded solar module can be as high as approximately 40%. For totally shaded module, the power loss ranges between 33% - 80% when compared with the fully illuminated solar module. So, the power loss for totally shaded solar module can be as high as 80%. Consequently, shadow has high significant effect on the output performance of installed solar module. Solar modules should therefore be installed in an area or environment free of shadow-cast for optimum power production.

Keyboard: Solar Module, Shadow, Digital Multimeter, Short Circuit Current, Open Circuit Voltage.

1.0 INTRODUCTION

At present in the world, especially in industrialized and emergent countries, energy has become vital for all human beings. Accordingly, the energy demand has been increasing dramatically in last years. Because of the green house effect, environmental impact and the increasing cost of the fossil fuel based energy sources; much more energy usage from renewable sources is becoming indispensable (Falhreuburch and Bube, 1983). Solar energy is simply the energy derived from the sun. It is the energy that comes from within the Sun, which is a big ball of gas made up mostly of hydrogen and Helium. It can also be seen as the energy produced when the Sun's radiation impacts on a surface. In comparison to other renewable energy sources such as hydropower, wind and geothermal, Solar has unmatched portability and flexibility. The sunlight that powers Solar cells travels through space at 186,282 miles per hour to reach the earth 8.4 minutes after leaving the surface of the Sun (Benerjee, 2010).

Although, the solar energy that reaches the earth's surface is reduced due to water vapour, ozone layer, absorption and scattering by air molecules, yet there is still plenty of power to collect out of the billions of Megawatt per second generated by the sun. The energy obtained is either stored or used for specific purposes. Some practical areas of solar energy usage include Solar Architecture, Photovoltaic technology, Solar Dryer, Solar Distiller, Solar Thermal, Solar Refrigerator, Solar Egg Incubator. Photovoltaic cell is a device that converts sunlight to electricity (Muneer et al, 2005). A photovoltaic (PV) cell also known as solar cell is a semiconductor device that generates electricity when exposed to light. When light strikes PV cell, the photon dislodge the electrons from the atoms of the cell. The free electrons then move through the cell, creating and filling holes in the cell. This movement of electrons and holes generates electricity. The physical process by which a PV cell converts light into electricity is known as Photovoltaic effect. Solar Photovoltaic cells are produced from semiconductor materials. The absorber layer of the semiconductor material captures the radiant energy (photons) coming from sunlight and convert it to direct current useable for electricity. The major types of materials for building PV cells include crystalline and thin films, which differ in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production (Olivia, 1998).

A number of series/parallel connected PV modules are used to form solar array for a desired current and voltage level. For solar energy, PV is identified to be of good potential for wide scale application. Port Harcourt metropolis belongs to the sub tropical climate region with typically hot and wet climate of characteristic distribution of total, diffuse and direct solar radiation (Akpabio and Udoimuk, 2003). The average solar radiation potential for a tropical climate region is about 16.4 ± 1.2 W/m^2 per day (Green, 2002). The average temperature distribution throughout the year in hot/wet climate region is about 28 ± 1^0C (Olusegun et al, 1980). Shadow is a significant factor affecting the performance of many, if not most, of today's photovoltaic system (David, 2012). Measuring the extent of shade on a solar array can be challenging due to the fact that shadows move as the sun positions move throughout the day and year. Performance of series connected string of solar cells is adversely affected if all its cells are not equally illuminated (partially shaded).

In a solar array spread over vast area, it is likely that shadow may fall over some of its cells due to tree leaves falling over it, birds or bird litters on the array, shade of a neighbouring construction e. t. c. In a series connected string, cells are forced to carry the same current as the other fully illuminated cells. If the system is not approximately protected, hot-spot problem can arise and in several cases, the system can be irreversibly damaged (Quaschning et al, 1996). With a physical solar PV module, it is difficult to study the effects of partial shade since the field testing is costly, time consuming and depends heavily on the prevailing weather condition. Moreover, it is difficult to maintain the same shade under varying numbers of shade under varying numbers of shaded and fully illuminated cells throughout the experiment (Alonso et al, 1997). In this paper, the effect of partial and total shadow on the output performance of typical solar modules is reported. Attempt is made to quantify the typical percentage loss in output performance due to shadow in this geographical location.

2.0 MATERIALS AND METHODS

Three 250 Watts monocrystalline silicon solar modules with the same specifications and a digital multimeter were employed in taking the measurements. One solar module was set up in a place where shadow was cast partially on the surface area of the module (Figure 1). Thus, partial shading occurs when part of the PV modules get covered by shadows of passing clouds, buildings trees e.t.c. The second module was located in a place where shadow was cast on the whole surface area of the module, total shading (Figure 2). The third module was situated in a place where it could not experience any trace of shadow (fully illuminated). The three modules were set up in an open place and inclined at angle of 15^0 to the horizontal with height 2.0m above the ground level.

Figure.1. Partially shaded monocrystalline solar module in situ.

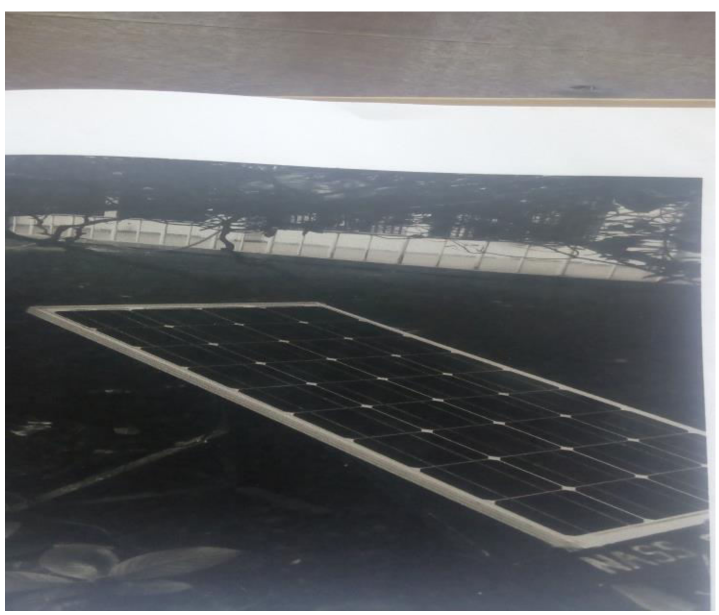

Figure.2. A fully shaded PV module in situ.

The study area was Faculty of Science building, University of Port Harcourt (Longitude 6^0 54^1 East and Latitude $4^0 53^I$ North). The University of Port Harcourt falls within humid region characterized with two seasons, the dry season (November to March) and wet season (April to October) with moderate tropical monsoon climate. The monthly mean maximum temperature ranges from 28^0C to 33^0C while the monthly minimum temperature ranges from 17^0C to 24^0C (Ogbonna et al, 2007). The short circuit current, I_{sc} and open circuit voltage, V_{oc} at periodic interval of 15 minutes were measured from the three solar modules (the partially shaded, totally shaded and fully illuminated) simultaneously. The results were therefore analysed and compared.

3.0 RESULTS

Table 1 is a typical table showing data collection for partial shadowed and fully illuminated solar module. The open circuit voltage, Voc and short circuit current, Isc were measured which consequently determined the periodic output power.

Table.1. Typical data collection for partially shaded and fully illuminated solar module for day 1.

Day 1	Partially shaded			Fully Illuminated		
Time of the day	Isc	Voc	P = IV	Isc	Voc	P = IV
7.00 a.m	0.32	19.08	6.1056	0.53	18.97	10.0541
7.15 a.m	0.44	19.99	8.7956	1.03	19.45	20.0335
7.30 a.m	0.43	19.68	8.4624	1.23	19.78	24.3294
7.45 a.m	0.47	19.98	9.3906	1.27	19.73	25.0571
8.00 a.m	0.52	20.24	10.5248	1.22	19.88	24.2536
8.15 a.m	0.77	19.87	15.2999	2.02	19.99	40.3798
8.30 a.m	1.82	19.64	35.7448	1.98	19.01	37.6398
8.45 a.m	2.16	19.55	42.228	2.13	19.06	40.5978
9.00 a.m	1.86	19.63	36.5118	1.17	19.08	22.3236
9.15 a.m	0.97	19.45	18.8665	0.86	17.76	15.2736
9.30 a.m	0.95	18.9	17.955	0.74	19.21	14.2154
9.45 a.m	0.82	18.88	15.4816	0.95	19.31	18.3445
10.00 a.m	0.76	20.34	15.4584	2.22	19.91	44.2002
10.15 a.m	2.06	19.98	41.1588	3.11	19.98	62.1378
10.30 a.m	2.14	19.89	42.5646	3.15	20.02	63.063
10.45 a.m	2.32	19.32	44.8224	3.45	20.41	70.4145
11.00 a.m	1.84	19.45	35.788	1.17	19.72	23.0724
11.15 a.m	1.78	19.78	35.2084	2.51	19.71	49.4721
11.30 a.m	2.14	19.91	42.6074	3.11	20.41	63.4751
11.45 p.m	2.31	19.86	45.8766	2.72	19.92	54.1824
12.00 p.m	2.23	19.17	42.7491	3.15	20.15	63.4725
12.15 p.m	1.48	19.32	28.5936	0.95	19.85	18.8575
12.30 p.m	1.5	19.22	28.83	0.87	19.78	17.2086
12.45 p.m	1.53	18.99	29.0547	0.99	19.88	19.6812
1.00 p.m	1.23	19.42	23.8866	1.22	19.66	23.9852
1.15 p.m	1.36	19.54	26.5744	0.8	19.77	15.816
1.30 p.m	1.44	19.5	28.08	1.24	19.85	24.614
1.45 p.m	1.08	19.44	20.9952	0.93	19.38	18.0234
2.00 p.m	1.16	18.83	21.8428	1.16	19.89	23.0724
2.15 p.m	1.64	19.71	32.3244	3.15	20.15	63.4725
2.30 p.m	1.36	19.53	26.5608	1.71	20.35	34.7985
2.45 p.m	1.38	19.62	27.0756	1.08	19.97	21.5676
3.00 p.m	1.19	19.46	23.1574	0.85	19.31	16.4135
3.15 p.m	0.47	18.72	8.7984	1.46	19.67	28.7182
3.30 p.m	0.48	18.56	8.9088	0.8	19.77	15.816
3.45 p.m	0.44	18.56	8.1664	0.79	19.76	15.6104
4.00 p.m	0.45	18.16	8.172	0.81	19.91	16.1271

Similar Table 2 was produced for totally shaded and fully illuminated solar module for day 1.

Table .2. Totally shaded and fully illuminated solar module

Day 1	Fully shaded			Fully Illuminated		
Time of the day	Isc	Voc	P = IV	Isc	Voc	P = IV
7.00 a.m	0.42	16.35	6.867	0.53	18.97	10.0541
7.15 a.m	0.45	18.25	8.2125	1.03	19.45	20.0335
7.30 a.m	0.49	18.79	9.2071	1.23	19.78	24.3294
7.45 a.m	0.65	19.4	12.61	1.27	19.73	25.0571
8.00 a.m	0.74	19.95	14.763	1.22	19.88	24.2536
8.15 a.m	0.88	20.02	17.6176	2.02	19.99	40.3798
8.30 a.m	1.05	21.01	22.0605	1.98	19.01	37.6398
8.45 a.m	0.99	18.05	17.8695	2.13	19.06	40.5978
9.00 a.m	0.71	19.21	13.6391	1.17	19.08	22.3236
9.15 a.m	0.55	19.08	10.494	0.86	17.76	15.2736
9.30 a.m	0.6	19.42	11.652	0.74	19.21	14.2154
9.45 a.m	0.5	18.36	9.18	0.95	19.31	18.3445
10.00 a.m	0.51	19.2	9.792	2.22	19.91	44.2002
10.15 a.m	0.6	19.3	11.58	3.11	19.98	62.1378
10.30 a.m	0.87	19.5	16.965	3.15	20.02	63.063
10.45 a.m	0.51	19.11	9.7461	3.45	20.41	70.4145
11.00 a.m	0.65	19.42	12.623	1.17	19.72	23.0724
11.15 a.m	0.48	18.32	8.7936	2.51	19.71	49.4721
11.30 a.m	1.59	18.55	29.4945	3.11	20.41	63.4751
11.45 p.m	1.42	18.4	26.128	2.72	19.92	54.1824
12.00 p.m	0.99	18.45	18.2655	3.15	20.15	63.4725
12.15 p.m	0.4	17.6	7.04	0.95	19.85	18.8575
12.30 p.m	0.39	17.63	6.8757	0.87	19.78	17.2086
12.45 p.m	0.41	17.7	7.257	0.99	19.88	19.6812
1.00 p.m	0.45	17.79	8.0055	1.22	19.66	23.9852
1.15 p.m	0.44	16.43	7.2292	0.8	19.77	15.816
1.30 p.m	0.49	18.02	8.8298	1.24	19.85	24.614
1.45 p.m	0.5	18.5	9.25	0.93	19.38	18.0234
2.00 p.m	0.48	18.35	8.808	1.16	19.89	23.0724
2.15 p.m	1.3	18.38	23.894	3.15	20.15	63.4725
2.30 p.m	0.89	17.95	15.9755	1.71	20.35	34.7985
2.45 p.m	0.92	17.8	16.376	1.08	19.97	21.5676
3.00 p.m	0.88	17.42	15.3296	0.85	19.31	16.4135
3.15 p.m	0.38	16.5	6.27	1.46	19.67	28.7182
3.30 p.m	0.42	17.1	7.182	0.8	19.77	15.816
3.45 p.m	0.42	17.2	7.224	0.79	19.76	15.6104
4.00 p.m	0.8	16.44	13.152	0.81	19.91	16.1271

The graphs of periodic output power against time of the day were plotted. Figure 3 shows the behaviour of partially shaded module when compared with fully illuminated module. At each Periodic interval, there was significant drop in the output power due to partial shadow when compared with fully illuminated solar module.

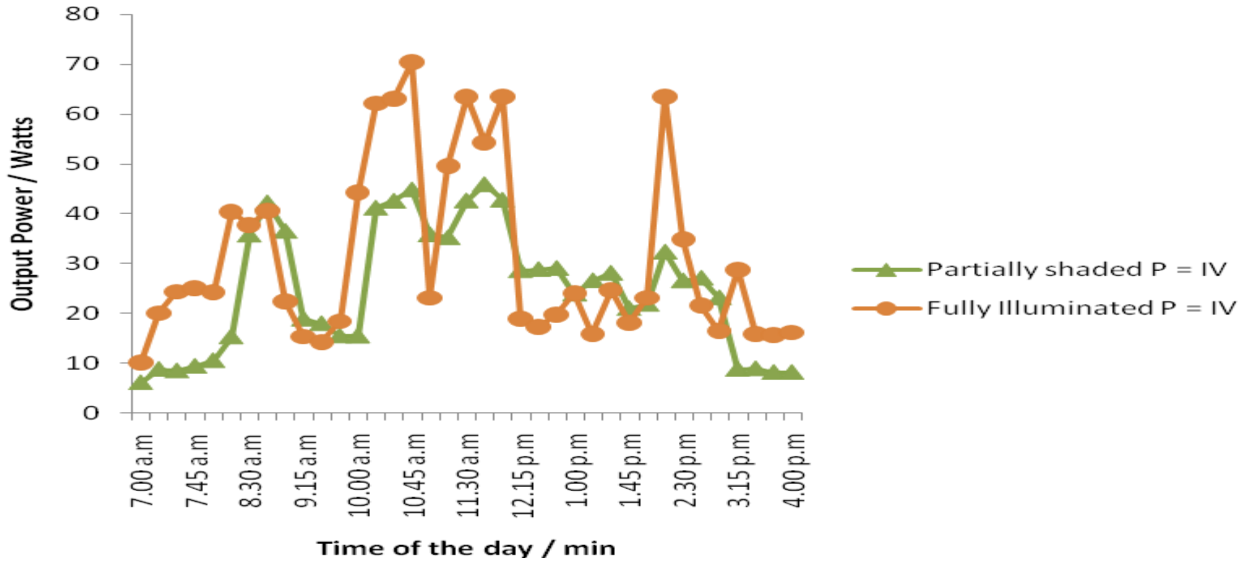

Figure .3. Partially shaded and fully illuminated solar module against time of the day for day 1

Similar trends were obtained for totally shaded solar module (Figure 4) when compared with fully illuminated solar module. The drop in output power is enormous when compared to Figure 3.

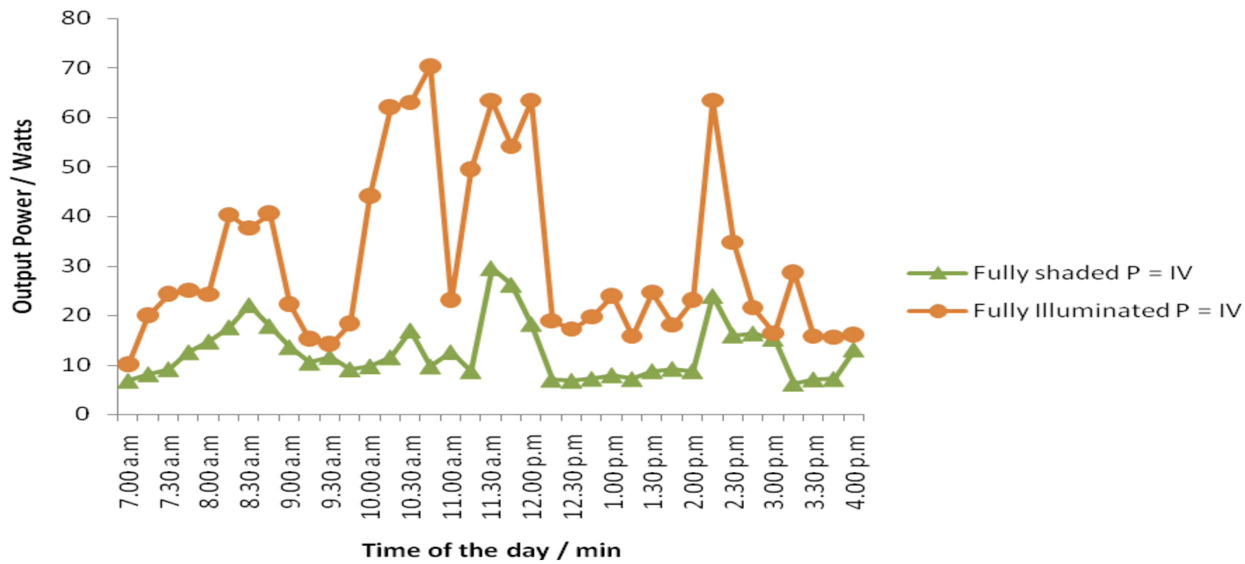

Figure.4. Totally shaded and fully illuminated solar module against time of the day for day 1.

The observed power output for each day of measurements varies due to diverse shade conditions. Table 3 summarizes average daily power output produced by both fully illuminated and partially shadowed solar panel.

Table.3. Summarized Power Output and Percentage Power Loss to Partial shading.

Days	Average Daily Power Output for Partially Shaded module	Average Daily Power Output for fully illuminated module	% Power Loss
Day 1	865.418	1085.207	20.25%
Day 2	578.534	960.723	39.78%
Day 3	1092.319	1345.172	18.80%
Day 4	1206.942	1446.404	16.56%
Day 5	780.108	896.445	12.98%

Figure 5 vividly depicts the variations in the average daily power output. The effect of shadow results in the drop of output power. Similar Table 4 was produced for totally shaded solar module. The percentage loss in power output is higher in totally shaded solar module when compared with partially shaded module (Figure 6).

Table .4. Summarized Power Output and Percentage Power Loss for Total shading.

Days	Average Daily Power Output for Totally Shaded module	Average Daily Power Output for fully illuminated module	% Power Loss
Day 1	467.248	1085.207	56.94%
Day 2	317.659	960.723	66.94%
Day 3	887.949	1345.172	33.99%
Day 4	824.398	1446.404	43.00%
Day 5	523.902	896.445	41.56%

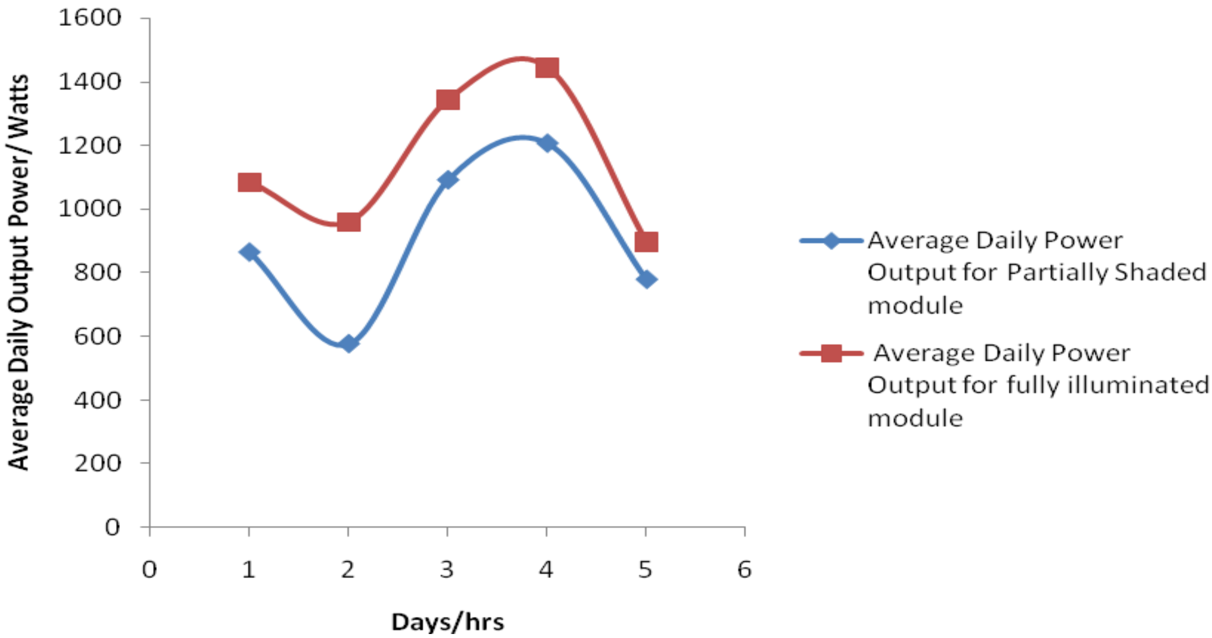

Figure.5. Variations of Daily Output Power for Partially Shaded and fully illuminated Solar module.

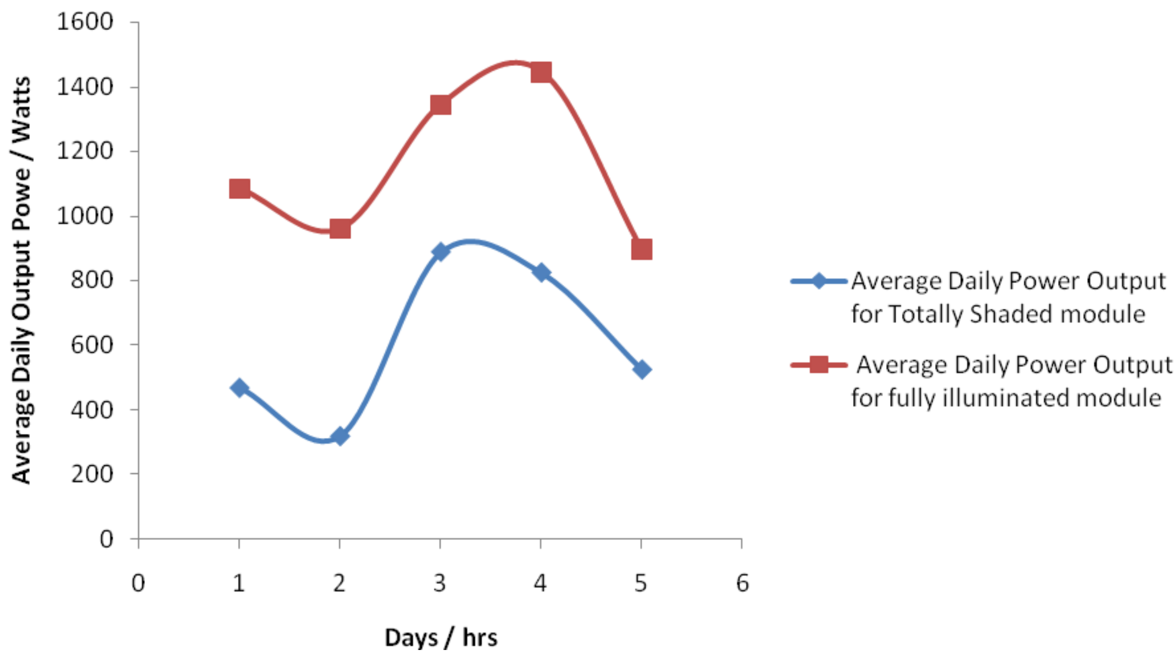

Figure.6. Variations of Daily Output Power for Totally Shaded and fully illuminated Solar module.

4.0 DISCUSSION

For a typical day, the maximum power generated by the partially shaded module was 45.88Watts at 11.45a.m while the corresponding fully illuminated module (Figure 3) yielded 54.18Watts at the same time of measurement. Hence, the percentage power loss is inferred as 15.32%. Also, the minimum power produced by the partially shaded module was 6.10Watts by 7.00a.m and that of fully illuminated module was 10.05Watt at the same time of measurement. Hence, percentage power loss was 39.30% (Figure 3). The power loss for partially shaded solar modules ranges between 12% - 40% when compared with the fully illuminated solar module. So, the power loss for partially shaded solar module can be as high as approximately 40%. The maximum power generated by fully illuminated module was 70.41watts at 10.45a.m while the corresponding value for the totally shaded was 9.74Watt at the same time of measurements (Figure 4). The percent power loss is 86.16% when compared with fully illuminated module. The minimum power produced by the totally shaded module was 6.27 Watts at 3.15p.m while that of the corresponding fully illuminated module was 28.19 Watts. This amounts to 77.76% power loss. For totally shaded module, the power loss ranges between 33% - 80% when compared with the fully illuminated solar module. So, the power loss for totally shaded solar module can be as high as 80%. The power loss is as a result of inability of the incident solar radiation (photons) to dislodge electrons from the absorber layer of solar cell due to shadow to produce photo-voltage necessary for power production. Thus, power cannot be produced from the cells without the internally generated voltage activated by the incident photons. The distributions also agree with Patel (2006) that the current loss is not proportional to the shadowed area. The result shows that the solar module can suffer loss of output power as high as 40% of fully illuminated solar module due to partial shadow and loss of 80% due to total shadow. The study reveals a significant loss in output voltage and consequently loss in output power when solar module is installed under shady environment. Hence, solar modules are to be installed at a point where it can fully harness the incoming solar radiation without any obstruction, that is, area that is void of shadow for maximum power production.

5.0 CONCLUSION

In the study, the power loss for partially shaded solar modules ranges between 12% - 40% when compared with the fully illuminated solar module. So, the power loss for partially shaded solar module can be as high as approximately 40%. For totally shaded module, the power loss ranges between 33% - 80% when compared with the fully illuminated solar module. So, the power loss for totally shaded solar module can be as high as 80%. Consequently, shadow has high significant effect on the output performance of installed solar module. Solar modules should therefore be installed in an area or environment free of shadow-cast for optimum power production.

6. REFERENCES

[1]. Akpabio, I. E. and Udoimuk, A. B. (2003): Characteristic distribution of total, diffuse and direct solar radiation in Port Harcourt, Global Journal of Pure and Applied Sciences, Vol. 9, No 1, Pages 45 – 49.

[2]. Alonso, M. C., Arribas L. M., Chenlo, F. and Cruz, I. (1997): Shading effect on a roof-integrated grid connected PV plant. In proceedings of the 14th E C PV Solar energy conference, Barcelonia, Pages 1891 – 1894.

[3]. Benerjee Partho (2010) : How to generate free electricity with home made solar panel system within 24 hours – simple Green and Free energy at your home. http://www. Article base. com/diy-articles 3022964.html

[4]. David Brigg (2012): Emphase Energy, "Shaded Impact, How Solar Systems Handle Sub-optimal conditions", Page 4.

[5]. Falhreuburch, A. and Bube, R. (1983): Fundamentals of Solar Cell, Academic Press, New York, Page 2.

[6].Green, M. A. (2002): Photovoltaic Technological Overview, Energy Policy, Vol. 28, Pages 989 – 998.

[7]. Muneer, T., Asif, N. and Nunawars (2005); Sustainable production of solar electricity with particular reference to growing economy, Renewable Sustainable Energy Review, Vol. 9, Pages 444 – 473.

[8]. Ogbonna, D. A., Amangabara, G. T. and Ekere, T. O. (2007): Urban Solid Waste generation in Port Harcourt metropolis and its implications for waste management, Management of Environmental Quality, Vol. 18, Number 1, Pages 71 – 88.

[9]. Olivia, Mah (1998): Fundamenmtals of Photovoltaic Material, Natural Solar Power Research Institute Inc., Energy Annual, Vol.1, Pages 2 – 12. http://userwww. sfsu.edu/ ciotola/ solar/pv.pdf

[10]. Olusegun A., Bola A., Goh C. L. and Ohiweriei I. (1980): Certificate Physical and Human Geography for Senior Secondary School, University Press, Nigeria, Pages 201 – 203.

[11]. Patel, Mukund R. (2006) : Wind and Solar Power System, Design, Analysis and Operation, CRC Press Taylor and Francis Group, Boca Raton, USA, ISBN: 13: 978-0-8493-1570-1, Pages 173.

[12]. Quaschning, V., Piske, R. and Hanitsch, R. (1996): Cost Effectiveness of Shadow tolerant Photovoltaic Systems. In proceedings of the EuroSun '96, Freiburg, Pages 819 - 824.