Weather Effect on Photovoltaic Module Adaptation in Coastal Areas

M.E. Emetere, M.L. Akinyemi

Department of Physics, Covenant University Canaan Land, P.M.B 1023, Ota, Nigeria.

(moses.emetere@covenantuniversity.edu.ng, marvel.akinyemi@covenantuniversity.edu.ng)

‡ Corresponding Author; Department of Physics, Covenant University Canaan Land, P.M.B 1023, Ota, Nigeria, Tel: +234 8035267598, moses.emetere@covenantuniversity.edu.ng

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Abstract- The climatic factors in the coastal areas are cogent in planning a stable and functional solar farm. The experiment performed in this study entails a day-to-day solar radiation pattern in coastal areas. Two dissimilar photovoltaic modules (SW 175 poly solar world and sharp solar module) were adopted under two conditions- clean surface module and dusty surface module. Meteorology parameters for the days were monitored using the Davis Pro weather station and ground data set from the Nigerian Meteorological Center. The results show that the solar radiation pattern in coastal region portends danger to the performance of solar PV module and its lifecycle. The solar radiation pattern in coastal areas was traced to the solar sectional shading theory which was summarized and explained.

Keywords- PV Module; Davis weather station; solar sectional shading; coastal areas

1. Introduction

The quest to meet the energy budget in a growing economy is of utmost importance as the cost to procure energy is extremely high. The energy option from fossil and nuclear sources has been reported severally to be dangerous because of the massive release of anthropogenic pollution (Emetere et al., 2013; Emetere, 2013; Emetere 2014a) from automobiles, multi-purpose generators, and industrial machinery. Hence, the promotion of clean renewable energy source is one of the ways of curbing air pollution in our environment. Climate change is evident in coastal areas of the tropics because of its abnormal activation of convective updraft and downdraft, cloud formation, frequent cloud movement (Uno et al.,, 2012a) e.t.c. which reduces the sunshine hour and solar irradiance. Coastal regions are influenced by geomorphological and oceanographical factors e.g. storm event and open-ocean convection intensity that controls the seasonal variability of the hydrology, hydrodynamics and biogeochemistry (Stabholtz et al., 2013). These events in the coastal areas engender a process known as atmospheric shading. Atmospheric shading occurs when the cloud movement cast its shadow on the earth-surface. Atmospheric shade is inimical to solar power generation because the solar cell is designed in such a way that little shade on one panel can gradually shut down solar power production. Atmospheric shading differs from atmospheric scattering because there is energy transformation due to the absorption. The bypass diodes assist in minimizing the effects of partial shading by preventing damage from reverse bias on partially shaded cell or cells. Bypass diodes allows the flow of electricity from non-shaded parts to pass by the shaded part of the module. However, the failure of the bypass diode has been reported (Greacen et al., 2001). It causes great power loss during large shading, hence, causes the module's performance to drop by 1/3 instantly. The failure of the bypass diode is evident when probed by Signal Transmitter Device.

Solar cells are classified- based on its inherent band gap. The main objective of material scientists to seek for different material and manufacturing technology of the materials is to seek ways of improving the inherent band gap.The band gap of the PV module is expected to be between 1.1eV and 1.7 eV (Tyagia et al., 2012). The types of solar cell are silicon solar cells, III-V group solar cells, thin films solar cells e.t.c. PV modules do not only converts solar irradiation directly into electric but it also produces plenty of waste heat, which can be recovered for thermal use (Tian et al., 2013). Materials used on PV panels are mono-crystalline silicon, polycrystalline silicon, micro- crystalline silicon, copper indium selenide, and cadmium telluride (Razykov et al., 2011). The main objective of this paper is to examine the challenges of solar radiation irregularities due to climate change.

1.1. Location of Study Area

The study area is located on a narrow coastal plain of the Bight of Benin-specifically on the south west of Nigeria. It lies approximately on longitude 2.48'E and 3.26'E respectively and between latitude 6.24'N and 6.25'N (as shown in figure 1 below). The dominant vegetation in this area is swamp forest - consisting of fresh water and mangrove swamp forest. It has two climatic seasons i.e. dry season (November-March) and wet season (April – October).The coastal areas in the south west of Nigeria is characterize with an annual average daily global irradiation of about 4200WH/M2/Day.The mean daily sunshine duration the coastal plain is given as 4.6hours per day (Ojoso et al., 1987). The location has a monthly rainfall between 400 mm - 500 mm during raining season and 25 mm-100 mm during the dry season.

Fig. 1. Location of study area in the enclave of Nigeria

2. Theories

Much research work had expanded the concept of global radiation (Qiu et al., 2014; Uno et al., 2012 b-c; Uno et al., 2013; Emetere, 2012). The solar radiation cannot be dissociated from the principles of radiative transfer popularly governed by the Stefan-Boltzmann and Wien's displacement law. The Stefan-Boltzmann relates the solar intensity to the temperature and it is given as

$$E = \sigma T^4 \qquad (1)$$

Here, E is the total intensity, T is the temperature and σ is the Stefan-Boltzmann constant. The Wien displacement relates traveling radiation to temperature

$$\lambda_{max} = \frac{b}{T} \qquad (2)$$

Here, λ_{max} is the wavelength at maximum emission, T is the Temperature and b is constant. In this research we discussed solar radiation over the region in the form of surface temperature as their relationship has been proven mathematically or experimentally (Makowski et al., 2009; Allen, 1997).

We propose that the coastal regions are characterized by solar sectional shading (SSS). The SSS are represented by the trough of every undulation as shown in the Figures 3a & b. Solar sectional shading is an atmospheric event due to cloud movements and formation over area- leading to physical shades over a region during solar radiation. To explain this model we reform equation [1] as shown below

$$E = \sigma T(x)^4 \qquad (3)$$

Here $T(x)$ represent the solar coverage in a square area (x), Stefan–Boltzmann constant (5.6693×10^{8}W/m^{2}K^4). We presents the collective effect of $T(x)$ in a polynomial scheme i.e. Taylor series. Therefore $T(x)$ is expressed as

$$T(x) = T_o(x) + (x - x_o)\left(\frac{\partial T_0(x)}{\partial x}\right)_{x_0} + \frac{(x-x_o)^2}{2!}\left(\frac{\partial^2 T_0(x)}{\partial x^2}\right)_{x_0} + \frac{(x-x_o)^3}{3!}\left(\frac{\partial^3 T_0(x)}{\partial x^3}\right)_{x_0} \ldots\ldots\ldots \qquad (4)$$

Here $T_o(x) = \frac{ftby}{x}$ is derived from equation [2] where f is the frequency, t is the time, b is constant, y is length of the coastal region, x is the area of the coastal region, $fy = V$ is velocity at which solar radiation reaches the PV module and $Vt \approx \lambda_{max}$ is the wavelength at maximum emission. Therefore, equation [2] has been proven as

$$T_o(x) = \frac{\lambda_{max}\, b}{x} \qquad (5)$$

3. Methodology

The satellite data used for this research were harvested from the Giovanni NASA satellite database. The ground data set was obtained from Nigerian Meteorological Agency and Davis weather station. The temperature measurement was obtained from the Davis weather station. The field work comprise of primarily-two PV modules from different producers i.e. SW 175 Poly SolarWorld and Sharp Solar Module are shown in table 1.

Table 1. SW 175 Poly SolarWorld and Sharp Solar Module

Specification	**SW 175 Poly SolarWorld**	**Sharp Solar Module**
Rated Max. Power	Pmax 175W (+/- 8%)	Pmax 121W
Open Circuit Voltage	Voc 44.4V	Voc 59.2V
Rated Voltage	Vr 35.8V	Vr 45.0V
Short Circuit Current	Isc 5.30A	Isc 3.34A
Rated Current	Ir 4.89A	Ir 5A
Power Specs at STC:	1000W/m^2 25^{o}C A.M 1.5	

The experiment is sorted into four groups which comprise of

i. The Sharp PV modules whose surface is always clean (CS)
ii. The Sharp PV modules whose surface is not clean throughout the experiment (DS)
iii. The Poly SolarWorld modules whose surface is always clean (CSW)
iv. The Poly SolarWorld modules whose surface is not clean throughout the experiment (DSW)

The voltage form is measured directly from the PV module i.e. using a multi-meter set to direct current DC voltage. A manual data logger was used to obtain readings. The readings were collected every ten minutes for six equal duration (30 minutes) between the hours of twelve noon and three in the afternoon (3 pm) when the sun is believed to be at its peak.

4. Results and Discussion

The effect of climate change can be observed from the solar environmental factors (shown in figure 2 a-c) considered i.e. solar irradiance and sunshine hour. One of the challenges of the coastal tropical region is the total precipitation (P). Hence, the three factors for 2011-2013 were considered in the simulation to ascertain the effect of global change on solar outcomes. At higher precipitation (200≤P), the linearity of solar irradiance and sunshine hour is uniform. When the precipitation was at about 150mm, the plateau shape consistently emerge for 2011(figure 2a), 2012(figure 2b) and 2013 (figure 2c). This shows a sharp increase in the solar irradiance and sunshine hour.

When 80 ≤ P ≤ 150 i.e. between the red and blue line, the consistency of the solar irradiance and sunshine hour varies adversely. 2013 was more stable than 2012 and 2011. 2011 was more perturbed than 2012. When P≤80, all the parameter with 2011-2013 were perturbed. More significant is its reduction with respect to the succeeding years. This are evidences of global change in the tropical coastal region.

The voltage-time graph of the four PV thin film module groups and Temperature- Time graph from the Davis weather station for each active days of December is shown below. The first day (see fig 3a & b) is characterized by a sudden-linear rise in the voltage-time graph of the sharp PV modules in the first eighteen minutes (18min) and stabilizes i.e. maintaining a sinusoidal pattern.

At maximum temperature of the day (see figure 3b), voltage of the Sharp PV thin film module-drops and maintains a moderate sinusoidal form. The dusty Sharp PV thin film module mimics the clean Sharp PV thin film module. Unlike the Sharp PV thin film module, the SolarWorld PV poly module seems to operate at lower but stable voltages. Like the dusty Sharp PV thin film module, the dusty SolarWorld PV thin film module mimics the clean SolarWorld PV thin film module. These factors shown in figure 3a &b are affirmation of global change on the PV output.

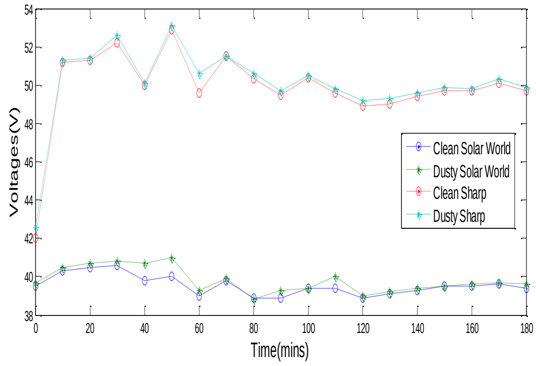

Fig. 3a. Voltage-time on day one

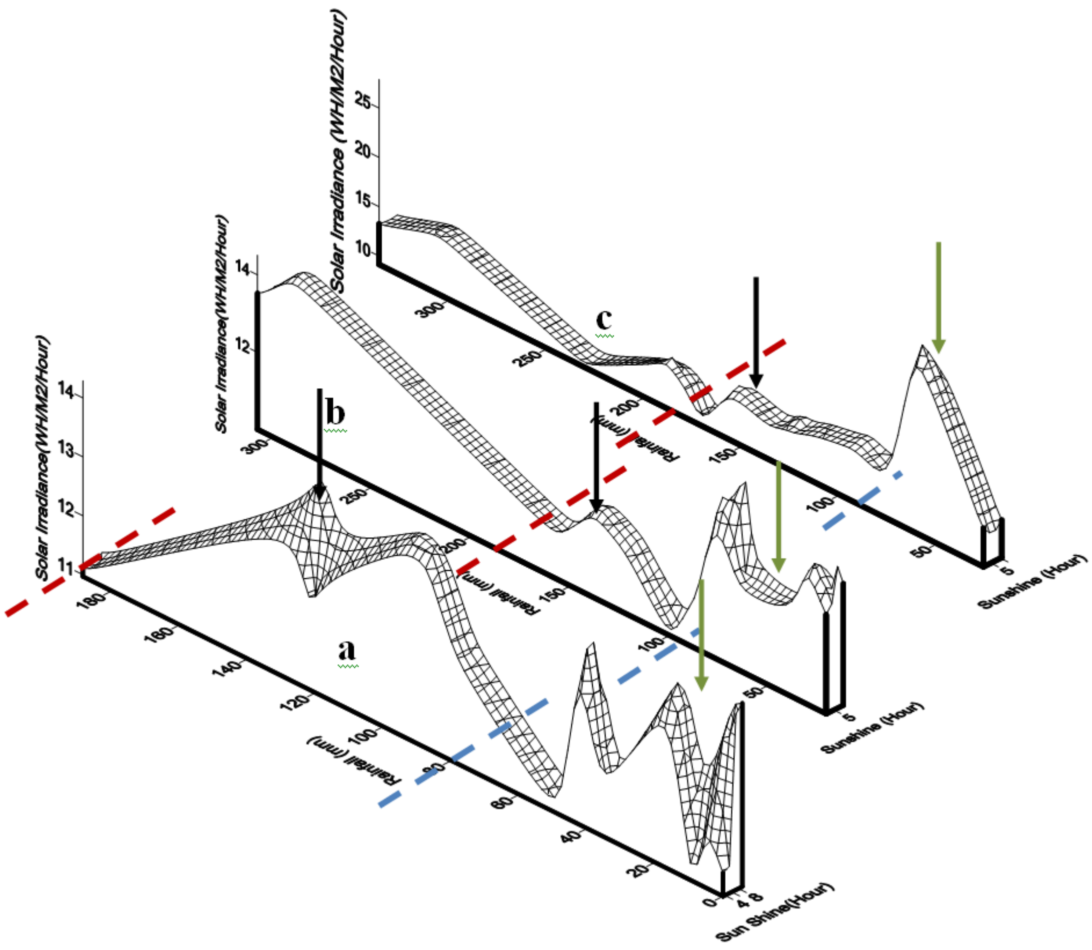

Fig. 2. Climate change solar environmental factors

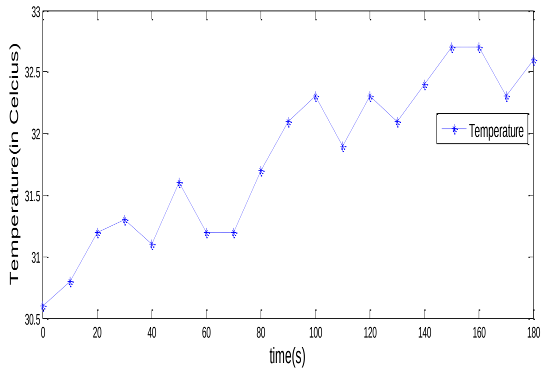

Fig. 3b. Temperature-time on day one

The meteorological effect (ME) on the performance of the PV module has been established in the previous section. The varying solar radiation in figures 3a & b are clear evidence of the ME in coastal areas. We propose that the coastal regions are characterized by solar sectional shading (SSS). We illustrate a pictorial model to further explain the SSS effect in figure 4a-d below. We assumed a square coastal area which is further divided into four sub-sections i.e. A, B, C and D. We gave a mathematical representation of the SSS within each or all sub-sections. The assumption is that the SSS switch perfectly fits into each square area. Though in reality, it carries the shape of the cloud form.

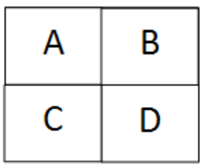

Fig. 4a. Representation of first term of equation (4)

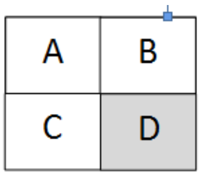

Fig. 4b. Representation of second term of equation (4) when SSS appears in all subsections at a time

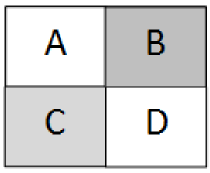

Fig. 4c. Representation of Third term of equation (4) when SSS appears in any two subsections at a time

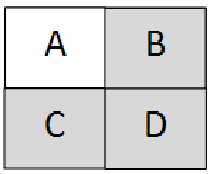

Fig. 4d. Representation of fourth term of equation (4) when SSS appears in any three subsections at a time

The theory of the SSS was tested by inserting equation [5] into [4]. The graphical interpretation is shown in figure 5 below. The none-SSS (Figure 4a) shows a moderate take – off and consistence solar radiation for larger area. This is a rare occurrence in the coastal area. The one-SSS (figure 4b) is characterized by a moderate solar radiational take-off. However, its lower solar radiational effect along larger area gives the maximum performance expected in coastal regions. The two-SSS (figure 4c) had an initial high solar radiational take-off but dies-away along large area. This occurrence is very common in coastal areas (Noor et al.,2011;Akbari et al., 2001;Loonar et al., 2004) as shown in figures 3a & b. The three-SSS (figure 4c) had the highest solar radiation at take-off (figure 5). However, it possesses the lowest sustenance along larger area. We did not discuss the results of equation [3] because its results are almost synonymous to the one discussed here.

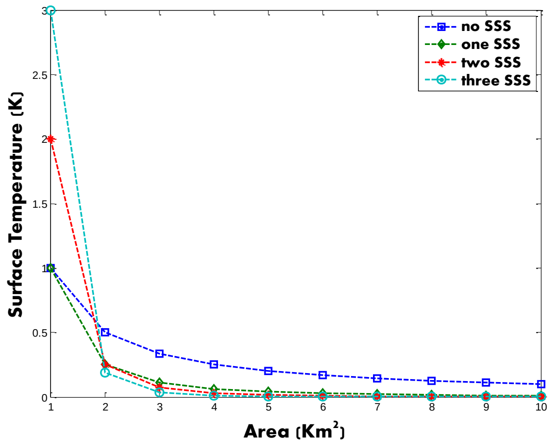

Fig. 5. Effect of solar shading on surface temperature and surface area

5. Conclusion

The climatic factors influence solar radiation in coastal regions. The experiment performed in this study is a day-to-day solar radiation pattern in the tropical coastal areas. The solar radiation pattern is characterized by undulating features which connotes the vast influence of climatic change in the prediction of solar activities in coastal region. The danger of the irregular solar radiation features can be seen to mitigate-individual performance of the solar cells despite the use of bypass diode. The solar sectional shading is prevalent in the coastal region and it triggers the type of solar pattern for the day/month/year. The SSS is an atmospheric event which occurs due to cloud movements and formation over coastal area. This event leads to the existence of physical shades over a region. The mathematical model propounded explains the collective solar radiation over a massive area. The surface temperature or the solar intensity is inversely proportional to the area. This result was related to the experiments performed in the previous section. The pictorial and operational model was adequately explained.

Acknowledgements

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