An Investigation of Partial Shading Effects on Solar Photovoltaic Module Performance Using Infrared Thermography

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ABSTRACT

Partial shading is detrimental to the performance of a solar PV module. This is because it not only reduces the current and voltage of the module which leads to power loss in the module but may also lead to the formation of hotspots. This work presents an investigation carried out on the cross-comparison of two different PV modules subjected to the same ambient conditions in a tropical hot climatic region, to observe the effects of partial shading on them and if hotspots are formed, determine if they are heightened by the climatic condition of the environment. Different shading patterns and shading due to partial obstruction of direct radiation were considered. Shading was achieved using opaque shading sheets. The results of the experiment showed that the efficiency or performance of these modules is dependent on the type and direction of shading. This implies that as the percentage of shading increases, there is a decrease in power output and ultimately its efficiency. Also, thermal images obtained showed that asides temperature difference between the modules, hotspots formed on the test modules were not magnified by climatic conditions. The Infrared image indicated the likelihood of an internal defect in the control module. Considering the emergence of new solar technologies to improve its efficiency, it's recommended that a similar investigation under real outdoor conditions be carried out on Perovskite solar cells. Results of the outcome of the findings should be compared to those of the silicon crystalline modules, to determine which solar technologies perform better.

Keywords: ***Infrared, Partial Shading, PV Module, Solar***

1 INTRODUCTION

The use of renewable energy (solar energy precisely) is increasing globally as it promises a clean, green and healthy environment unlike non-renewable energy sources which when harnessed result in pollution of air, land and water bodies. The source of electricity in most Nigerian residential buildings is through the national grid. Less than 45% of the country's population is connected to the national grid and more than 60% of about 200 million people live in 80% of Nigeria's landmass which is not connected to the national grid. In a bid to get an alternative means of generating power to carry out day to day activities whilst maintaining a cleaner environment and cutting down on cost incurred during the extraction and processing of fossil fuels, the use of solar electricity (photovoltaic) has proven to be a popular alternative as it is sustainable and equitable as much as it is renewable.

The French Physicist Edmond Becquerel was the first to experimentally demonstrate the photovoltaic effect in the year 1839. But it was not until photovoltaic effect (i.e. the creation of voltage and electric current in a material by exposing them to light). The semiconductor device that converts solar radiation into direct electricity is called a solar cell. Cells are made from silicon which is the second most abundant element on earth. One solar cell can produce several watts of power which could run a calculator or charge a phone but is not sufficient enough to run high power consuming devices providing electricity for homes, businesses or com- munities. Hence, a series of cells are grouped together to form a module and an array of modules produces the required amount of power necessary to run large wattage devices.

According to [1], "the global solar photovoltaic market has experienced a vibrant growth for more than a decade since the year 2000, sporting an average annual growth rate of 40% with continued significant potential for long term growth.

The basic components of a photovoltaic system include the solar panels, wiring, batteries, switches, inverters, battery charger and a mounting system. When installing a solar photovoltaic system, the positioning of the solar panels is of utmost importance. The panels should be oriented in such a way that they face the sun at the time of the day when it is at its peak. Another important consideration in the installation of PV panels is shading which affects the efficiency and power output of the system. The detrimental effects of shading on the total output of the system is as a result of the wiring together of the cells into a series circuit. Hence, the shading of any part affects the entire system. Therefore, the aim of this investigation is to comparatively investigate the effects of partial shading on the performances of monocrystalline and polycrystalline PV module types which are subjected to similar shading patterns and ambient conditions. Hence, the objectives were: (i) to determine the power outputs of the two PV module types when subjected to several standardized shading patterns; (ii) to determine the changes in the efficiency of the modules due to the partial shading imposed; (iii) to obtain the thermal responses of the Photovoltaic modules to the imposed shadings using infrared thermography to evaluate the severity of any occurring thermal problems (e.g. hotspots); (iv) to cross compare the detrimental effects of the imposed shading patterns on the different PV module types.

Additionally, the statement of problem is Shading is a factor that detrimentally affects the performance of solar PV systems. This is because it not only causes a drop in the power output and current of the system but also could lead to permanent damage of the PV system as a result of the formation of hotspots. It is naturally expected that the decrease in power production is proportionalto the shaded area and reduction in solar irradiance. While this concept might be true for a shaded single cell but at an array or module level the decrease in power is far from being linear with the shaded portion. It has been noted that the type, pattern or object of shade determines the level of risk it poses to reliability and long-term performance of the system. Hence, the effect of shading a PV module or panel is one that needs to be investigated and considered thoroughly before a module or panel is to be installed. This work will focus on how shading affects the behavior of two of the most common solar PV module types.

This work is important as it helped to determine if the ambient conditions of the environment magnifies the damaging effects of the hotspot. Also, it helped to ascertain which PV module type performed better under the subjected conditions and furthermore, give advice to homeowners on measures to take to minimize the effects of shading prior to installation.

Renewable energy is the energy that in a sense never runs out. It is inexhaustible and naturally available. There are many definitions of renewable energy, but it has been observed that of all these definitions, sustainable, replenished, inexhaustible are words that encompass them all. According to [2] renewable energy was defined as “the energy collected from renewable resources which are naturally replenished on a human timescale”.

Solar PV is preferred to other sources of renewable energy because it is simple, it is more predictable, it requires no fuel, it is noiseless, produces no greenhouse emissions, it requires minimal maintenance, it is available all over the world, it is abundant, it builds energy security, it reduces peak loads and other listless benefits [3]. According to the IEA, the development of solar energy will have a long term benefits as it will enhance sustainability, keep the price of fossil fuel lower than otherwise and lower the cost of alleviating climate change [4]. Global data shows that more solar photovoltaic (PV) capacity is being installed than any other electricity generation technology [5].

The history of photovoltaic is dated back to 1839 when a 19-year-old French physicist Edmond Becquerel first discovered the photovoltaic effect. He was experimenting with electrolytic cells when he generated electricity by placing silver chloride in an acidic solution and exposing it to sunlight [6, 7]. Thirty-seven years later, a London professor William and his student Richard discovered selenium’s photoconductivity.

Several studies have the carried out on the effects of shading on the performance of different PV module types [9, 10], some on the analysis of mismatch and shading effects in photovoltaic array using technologies [11] or the detection of faults and hotspots in solar cells [12]. Some researches went further to analyses the effects of shaded solar module using different computing environment, models and array configuration such as MATLAB, SimPower, shadow analyzer, shadows, Bishop model, heuristic model [13, 14, 15]. [8] reported that for objective shading with low irradiance caused heavy cloudy day for instance, a PV array may still generate a high voltage even if the current is extremely low or zero. Also, bypass diodes are important in minimizing the effects of hotspots in crystalline silicon modules. With regards to partial shading, results from their study showed that as the cell becomes partially shaded, the unshaded portion remains operational with little or no change in voltage and the cell/module continues generating power but at a reduced current. Hence, even if the output current is extremely low or zero, the PV array may still generate a high voltage. Also, it was observed that as partial shading increased, it got to a threshold point at which it changed to whole shading and the cell voltage collapsed. [16] experimented on the effect of full shading of a solar

PV module using 30W of monocrystalline PV module with different numbers of bypass diode and15profitest PV analyzer. Their experiment was aimed at determining which of these bypass diodes performed better when subjected to the same shading pattern. Full shading conditions was achieved using cardboard sheets and different configurations of full shading was obtained. The shade covered 1 cell, 2 cells, 3 cells and 4 cells. They observed that 4 bypass diodes save more power compared to 2 bypass diodes. Hence, increasing the number of bypass diodes improves the performance of PV panel under fully shaded conditions. Also, they found out that the drop in short circuit current (Isc) and power of the module is dependent on the number and position of the shaded cells.

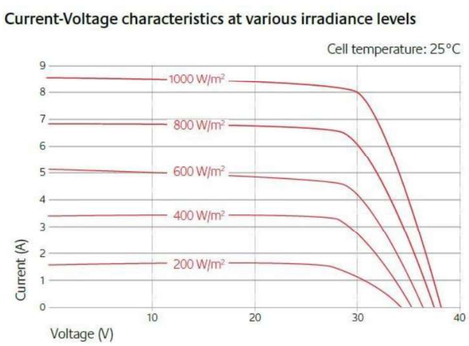

Figure 1: Objective Shading effect on I-V characteristics

2 METHODOLOGY

Two PV module types (monocrystalline and polycrystalline silicon) were tested in this study. During the tests, two of each module types were tested simultaneously. One served as a control module while the other was the experimental module.

The following experimental materials were used:

- Monocrystalline module
- Polycrystalline module
- Shading sheets i.e. 3mm cardboard paper
- Digital Thermometer
- TES 1333R Solarimeter
- Seek thermal imager
- Anemometer
- Android Phone
- USB Cord

Table 1: Specification of test PV Modules

Specification	Monocrystalline	Polycrystalline
Manufacturer	Rubitec Solar	Rubitec Solar
Model Type	HU 40	PV40P
Quantity	2	2
maximum Power, P_{max} (W)	40W (± 5%)	40W(± 3%)
Current at P_{max}, I_{max}(A)	2.22	2.25
Voltage at P_{max}, V_{max}(V)	18.0	17.8
Short circuit current, I_{sc}(A)	2.43	2.39
Open circuit voltage, V_{oc}(A)V	22.1	21.7
No. of cells	68	36

2.1 EXPERIMENTAL METHOD

The shading experiments was performed according to the following procedure:

1. **Setup and Installation**: Two modules (one for control and the other experimental) were mounted on the stand. The panels faced South at an angle 22º to the horizontal as shown in Fig 2.

2. **Shading of the modules:** The modules were shaded uniformly in percentages varying from 20% to 80% and the effects of partial shading under diffuse and global radiation was studied. The sheets were cut into varying sizes and shapes to obtain the various percentages and patterns of shading. The shading was done vertically, horizontally, diagonally and randomly (see Fig 3).

3. **Measurement of module output**: Current and voltage was measured using the digital multimeter when a certain percentage of the module was shaded. Also, Solar radiation, ambient temperature and wind speed were recorded. The parameters stated above were measured for both the control and test modules. Each test lasted for a period of 20 -30 minutes. The measurements were recorded at an interval of on minute. Thermal images were also obtained from the back- side of the module using the infrared thermal imager.

Figure 2: Apparatus Setup for experiment

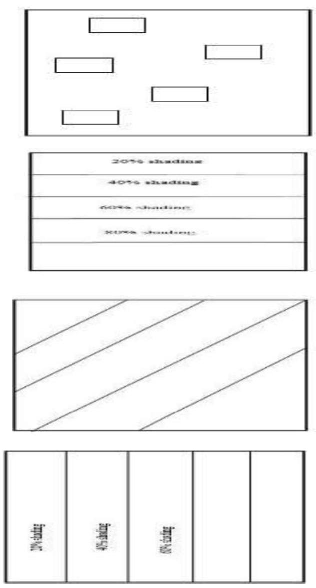

Figure 3: Shading Patterns

2.2 DETERMINATION OF MODULE PERFORMANCE

The module performance which is characterized by the current and voltage was determined using the performance quantifying parameters below:

$$\eta = \frac{\text{Power Output}}{\text{Power Input}} = \frac{V_{mp}I_{mp}}{IA} \quad (1)$$

$$\text{Fill Factor (FF)} = \frac{V_{mp}I_{mp}}{V_{oc}I_{sc}} \quad (2)$$

$$\text{Maximum Power Output } P_{mp}\text{ (W)} = \frac{V_{mp}}{I_{mp}} \quad (3)$$

Where:

I = Isolation or Irradiance (W/m^2)

A = Area of Panel (m^2)

I_{sc} = Short circuit current

A = Area of Panel (m^2)

I_{sc} = Short circuit current

V_{oc} = Open circuit Voltage

V_{mp} = voltage at maximum power (V)

I_{mp} = current at maximum power (A)

3 RESULTS AND DISCUSSION

Data collected during the experiments were analyzed and plotted using the OriginPro graphing and data analysis software.

3.1 EFFECT DUE TO HORIZONTAL SHADING OF MO-NOCRYSTALLINE PV MODULE

Figure 4 show plots of power, efficiency, irradiance and ambient temperature against time for the PV modules that were shaded 20% horizontally. From Fig. 4, the maximum power produced by the 20% shaded module was 4.7W while that of the unshaded module was 32W respectively and this occurred at an irradiance of 1151W/m^2. Also, it can be seen from the graph that the maximum amount of sunlight that was converted into usable electricity by the unshaded

module was about 16.89% while that of the shaded module
was 2.47%. The percentage drop in efficiency
of the module was 85.3%. Also, the plot shows the power generated is mainly dependent on irradiance.

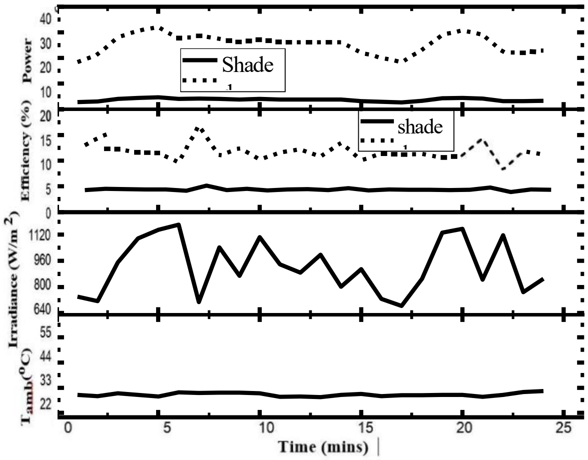

Figure 4: Impact of 20% horizontal shading on the Monocrystalline PV module

3.2 EFFECT DUE TO HORIZONTAL SHADING OF POLYCRYSTALLINE PV MODULE

Figure 5 depicts the impact of partially shading 40W of a polycrystalline PV module 20% horizontally taking into consideration the irradiance and the ambient temperature. From Fig.4, the maximum power generated by the shaded and unshaded modules was about 8.69W and 42.8W respectively at an irradiance of 866.2W/m^2. Also, the influence of insolation on the power generated is clearly seen in Fig. 5. The maximum usable energy converted from the sun's irradiance for the shaded module was 4.72% while that of the unshaded module was 22.94%. Therefore, the drop-in efficiency was 79.5%.

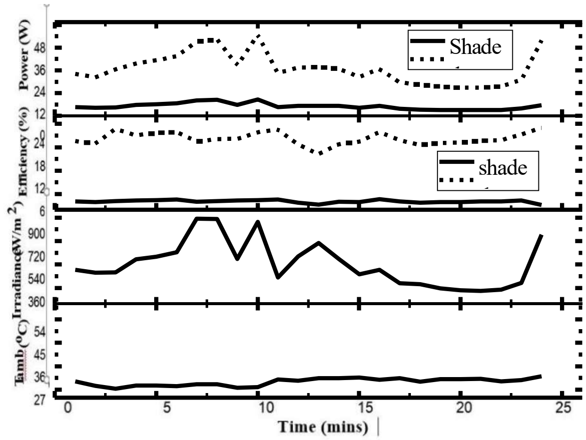

Figure 5: Impact of 20% horizontal shading on the polycrystalline PV Module

3.3 IR ASSESSMENT FOR THE MONOCRYSTALLINE MODULE SHADED HORIZONTALLY

Figures 6 and 7 are the normal and thermal images respectively of the 40W monocrystalline modules shaded 20% horizontally. As seen in Fig. 6, no hotspot was detected but temperature gradient was observed in the modules. This may have effects on the module's integrity due to thermal stress.

Figure 6: Normal image of 20% horizontal shading

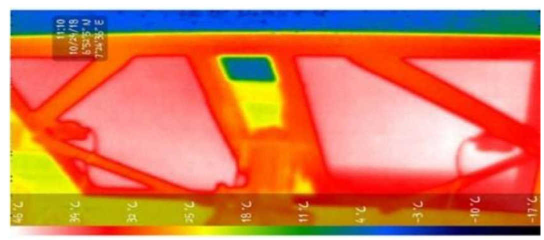

Figure 7: IR (Infrared) image of a functioning modules subjected 20% horizontal shading

3.3 IR ASSESSMENT FOR POLYCRYSTALLINE PV MODULE SHADED HORIZONTALLY

Figures 8 and 9 shows normal and IR (Infrared) image of 40W polycrystalline module shaded 20% horizontally. No hotspot was detected in the test module as seen from Fig. 4.48, but it can be seen that the temperature of the modules was higher than the frame.

Figure 8: Normal image of 40W Polycrystalline module subjected to 20% horizontal shading.

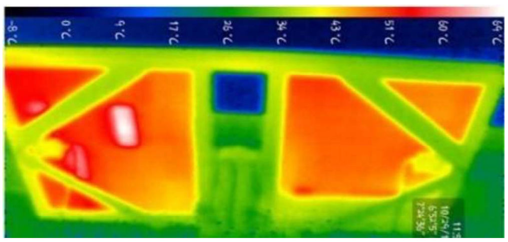

Figure 9: IR mage of 40W Polycrystalline module subjected to 20% horizontal shading

4 CONCLUSION

Although during the experiments, 20%, 40%, 60%, 80% Partial Horizontal, Vertical and diagonal was done on both Monocrystalline and Polycrystalline PV Modules and results were gotten, but for the purpose of this paper, only 20% horizontal shading for both PV Module is discussed.

Also, below conclusion discussed is based on all results gotten from all shadings done.

Experiments were carried out to determine the effects of partial shading on solar PV modules using two different topologies of modules and exposing them to global and diffuse radiation. Also, the damaging effects of hotspots and its severity considering the climatic conditions of the environment was studied. Also, cross comparison between both PV topologies was carried to determine which modules performs better under the various shading conditions.

Results of the experiment showed that the power output and hence, the efficiencies of the different PV modules are dependent on the type of shading. This implies that as the amount/percentage of shading increases, there is a decrease in power output and ultimately its efficiency. Additionally, the study confirms the findings of Bulanyi and Zhang [8] that at low irradiance, a PV array will still generate a high potential difference even if the current is extremely low or zero.

Furthermore, the bar charts comparing the effects of shading on the power and efficiency of the modules showed that for shading parallel to the long side, the monocrystalline modules performed better than the polycrystalline modules to an extent, while for other types of shading the polycrystalline modules performed better by a slight amount.

The results also showed that there were more losses in the PV modules when objects were directly placed on them than when the modules were partially obstructed from direct radiation. In as much as the modules generated a considerable amount of power when there was diffuse radiation, the efficiency of the module will be greatly reduced.

Finally, the IR images showed that modules with random shading were more susceptible to hotspot formation.

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