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Performance Comparison of Three PV Technologies under the Effect of Partial Shading and Varying Tilt Angles

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Abstract **– Photovoltaics is widely used in industries as well as in households. Accordingly, the efficiency of the system should be assessed under various conditions to minimize energy wastage. This paper aims to present the experimental performance of three different PV technologies under the effect of partial shading and varying tilt angles using a MOSFET based current-voltage (I-V) tracing method. PV technologies: Polycrystalline, Amorphous Silicon and Copper Indium Selenide were used on small scale to perform the experiments. Various shading scenarios were utilized to represent distinct shading conditions. During the second test the impact on the output power of the three PV technologies was determined using varying tilts. The three parameters which were measured during the tests were: current, voltage and temperature. The voltage was measured through the direct connection method and the current was measured using a Hall-Effect current sensor. The temperature was measured using the LM35 sensor. All the data from the I-V tracer and the sensor were acquired using National Instrument myDAQ and the LabVIEW platform was used for display. For partial shading, the results showed that the output current is more affected than the voltage under the surrounding conditions which were irradiance and temperature. Moreover, it was observed that non-uniform shading of solar cells cause significant power output degradation in comparison to uniform shading. To distinguish between the technologies, it was deduced that thin film modules operate more efficiently than crystalline modules under shading condition. In addition, all technologies produced maximum power at a tilt angle of 20° optimal. Finally, the results showed that there was less power loss from the crystalline modules as compared to the thin film modules from angles other than the optimum one.**

Keywords-Solar module, Crystalline technologies, Thin film technologies, Data acquisition, Partial Shading, Tilt Angle

I. INTRODUCTION

Natural gas, coal, oil and nuclear energy have been used for many decades by nations with the intention of inflating their economies. Concurrently, the demand for energy kept on increasing each year. On top of that, the volume of oil in the world is decreasing without being replaced. This alarming situation has compelled many countries to start working in the direction of renewable energy [1]. Besides, fossil fuels release more pollutants when they are used to produce electricity as compared to renewable energy. The density of greenhouse gases such as nitrogen oxides and sulfur dioxide which contributes to the development of acid rain are reduced in the air while using green energy. The utilization of fossil fuel causes particulates to merge with ozone at ground state to form smog in sunshine. Hence, this is poisonous for both animals and men [2]. Out of most forms of green energy, solar energy is said to be the most affordable and predominant one. For example, the generation of wind energy is formed when the atmospheric temperature changes while the sun rotates. Therefore, solar energy is regarded as an important factor in the concept of renewable energy [3].

Mauritius is located in the Indian Ocean and as a tropical island, it gets plenty of sunshine for the whole year. Every day it acquires about 8 to 10 hours of sunlight. Besides, around 6 kWh/m^2 of irradiance is achieved per annum [1]. To help poor people in reducing their electricity bills, the government of Mauritius is working on a project to setup photovoltaic kits on the rooftops of 10,000 beneficiaries. 2,000 kits are being installed annually and the project is expected to end by 2024. Alongside, the Mauritian's government has decided that the use of renewable energy be extended up to 35% by 2025. Consequently, a decline in cost of around USD 35 million is foreseen with regards to the importation of fossil fuel [4] [5].

Nevertheless, it should be known that various weather and environmental conditions influence the optimal functioning of a PV system once it has been installed. As a result of which the total output of the system is lowered. One of the factors which needs to be considered is partial shading. The power output of PV modules is extremely sensitive to partial shading. If for instance a section of a solar module is partially covered by tree leaves or other shading sources, a notable degradation in the power output will be seen. Since solar cells are connected in series, the entire shading of a single solar cell will decrease the total power output to zero [6]. Tilt angle is one more factor which affects the power output of PV modules. The highest amount of sunlight can only be absorbed if the solar modules are at the right orientation and angle with respect to sunrays. Depending on the location, the optimum tilt angle will change in order to achieve the maximum power. The time of the year is also a determining factor [7]. Thus, it is important to quantify how these two conditions impact the performance of different PV technologies such as crystalline and thin films. Hence, the aim of this work is to come up with the above-mentioned tests and results.

The structure of the rest of the paper is as follows. Section II presents the existing works relating to this paper. Section III highlights the methodology used for testing. Section IV details the experimental results and discussions. Lastly, section V concludes the paper and states the future works which can be performed.

II. RELATED WORK

The current-voltage (I-V) curve gives a graphical representation which indicates the performance characteristic of a solar module. Different methods can be used to obtain the I-V curve. Basically, the curve is traced when the current flowing through the PV module is varied between the open circuit voltage and the short circuit current [8]. H. Belmili et al. [9] proposed a technique based on a MOSFET load to measure the I-V curves of solar modules. This transistor was very useful to them since it has many advantages. For example, as compared to bipolar transistors, it is easier to control and does not have characteristic such as rapid change in temperature. The results achieved had acceptable precision and was of good quality. A study conducted by S. Sarikh et al. [8] shows a MOSFET based electronic circuit which was used to trace the I-V curves of PV modules under the prevailing temperature and irradiance conditions. The I-V tracer circuit was controlled by a microcontroller. The outputs of the circuit were acquired by the microcontroller itself and then the I-V curves were traced. The circuit was cost-efficient and it produced results of good accuracy. In their paper, Y. Kuai and S. Yuvarajan [10] show another MOSFET circuit with which PV panels were tested. Using this design, they acquired the voltage, current and the corresponding power output of the panels. They concluded that this technique is suitable for in field experiment as well.

Data acquisition system (DAS) is essential in the area of photovoltaics. H. Rezk et al. [11] describe the design of an economical DAS incorporated with LabVIEW. The system was used to acquire, process and save data from photovoltaic systems. They deduced that this platform worked efficiently in gaining dynamic data in real-time and then concurrently giving a graphical display. W. Wangju [12] used myDAQ to establish a sound processing system. The DAQ device was used to obtain an audio signal. The signal was then sent to LabVIEW and the latter was used to create a graphic analyzer. Afterwards, the processed signal was sent to myDAQ again before it could be heard through a headphone. It was seen that NI myDAQ works perfectly fine with LabVIEW to gain the required results.

The electrical current flowing through a PV module should be measured using a reliable method so that the I-V curve which is traced is as accurate as possible. A. Chouder et al. [13] designed a system which was based on LabVIEW to obtain the current-voltage curves of solar photovoltaics connected to the grid. The Hall-Effect current sensor was used to measure current. All the data acquired from the sensor were transferred to LabVIEW for processing. The parameters measured using this current sensor were good since the results acquired were almost the same as the simulated values.

The increase in temperature of a solar module causes a direct impact on its performance. To measure the modules' temperature Ozemoya et al. [14] stated that the sensor used should give precise values. The aim of their investigation was to determine the factors which cause the temperature of solar panels to change. They used the LM35 temperature sensor for their study. They deduced that a rise in temperature of the panel above 25°C decreased the power output.

The performance of a solar module is greatly reduced when it is under the influence of partial shading. R.S Magdaleno et al. [15] seek to demonstrate the effect of partial shading on PV cells and modules. They set up a scenario which was similar to a real shading circumstance. The results showed that the total power output is lowered by 90% if one of two series connected cell is covered fully. The work presented by E.E Ekpenyoung and F.I Anyasi [16] inquire the impact of partial shading on PV cells. Significant power loss was noticed when all cells which were connected in series were equally shaded. D. Pera et al. [17] presented a paper to show how the total output of a PV module can change if only one cell is shaded. A single cell was partially shaded from 10% to 100%. The results showed that current is the main parameter which is affected. The work of S.M Salih [6] also focuses on the effect of shading on solar modules. The simulation software which was used for his investigation was MATLAB. It was revealed that electrical current is the most impacted factor of shading.

The tilt of a PV module also determines the amount of irradiance which the module can absorb. S.J.M Shareef [18] analyzed the impact of various tilt angles on the output power of a solar panel. Arduino was used to vary the angle from 0° to 90° and it was found that the amount of power produced changes with tilt. The aim of the research of T.O Kaddoura, M.A Ramli and Y.A Al-Turki [19] was to find the most effective tilt of PV panels with regard to locations, geographical aspects and the sun’s position. The irradiance values used were from NASA. MATLAB was utilized as the simulation software. The outcome showed that 99.5% of solar irradiance would be obtained by the daily adjustment of a solar panel if the panel is altered only six times in a year.

III. METHODOLOGY

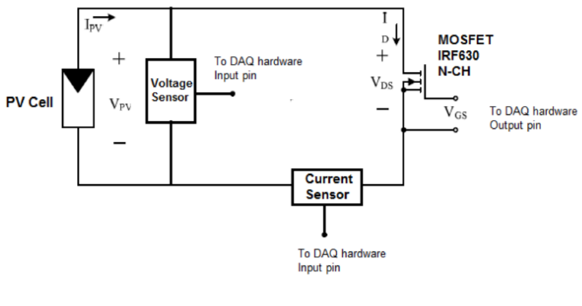
A. PV Module

Small-scale PV modules are extensively utilised for research since they are affordable. The three different PV technologies which were used for the two tests are Polycrystalline, Amorphous Silicon (a-Si) and Copper Indium Selenide (CIS). The datasheet of the Polycrystalline module specifies a current at maximum power point (Impp) of 0.21 A, a voltage at maximum power point (Vmpp) of 3.85 V, a maximum power rating (Pmax) of 800 mW, a short circuit current (Isc) of 0.23 A and finally an open circuit voltage (Voc) of 4.80 V [20]. For the Amorphous Silicon modules, the values specified by the supplier are: Impp of 41.2 mA, Vmpp of 4.6 V and Pmax of 190 mW at standard conditions (STC) [21]. Lastly, the CIS modules have a Voc of 4.5 V, an Isc of 100 mA and a Pmax of 190 mW [22]. Nevertheless, the supplier of the Polycrystalline modules did not specify whether the parameters were acquired at STC. However, due to the fact that two modules of each technology were used for the tests, the exact module parameters were not necessary. During the investigations, one module was always used for the test and the other one as a reference. Then, a percentage was calculated using the two power outputs of the modules. Moreover, before carrying the tests each module was placed outside so that they get adapted to the environment and reached thermal equilibrium.

B. *I-V Tracer Circuit*

The IRF 630 MOSFET was used as an electronic load in the I-V tracer circuit illustrated in Fig. 1. The whole operation of the circuit is explained in [10]. The voltage across the PV modules was measured via a direct connection to the analog input of the NI myDAQ. For the current measurement, the LEM Current Transducer (CT) CTRS 0.3-P was utilized. This current sensor can measure up to 300 mA, therefore a good resolution was obtained for all the PV technologies. On top of that, there was no direct connection between the CT and the circuit since it uses the Hall effect. As a result of which, the characteristic of the circuit was not influenced. The current sensors used were calibrated in the laboratory before implementing the tracer circuit. A varying current was allowed to flow through the CT and then the output voltage was measured. Consequently, the relationship between the input current and the output voltage of the sensor was determined. This result was inserted in the LabVIEW platform for further calculations.

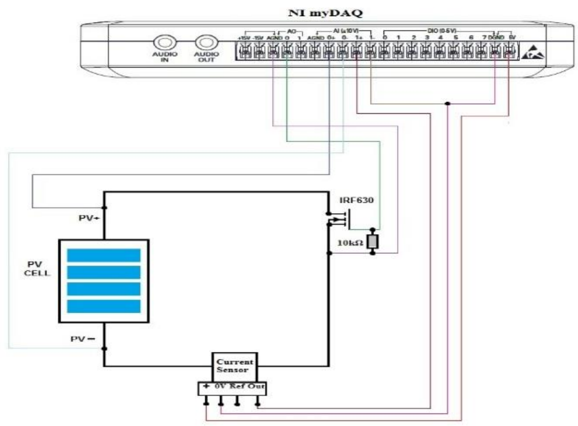
Figure 1. I-V Tracer Circuit



C. *Data Acquisition System*

Tests should be carried out in parallel when comparing two PV modules of the same technology. Therefore, two I-V tracer circuits were mounted, one for each module. One module was used for testing and the other one as a reference. The assembly of one such circuit and the NI myDAQ is shown in Fig. 2. In the beginning, both modules were tested to find any power difference between them when they were placed in the same temperature and irradiance. This power difference is represented by error bars in the results' graphs of section V. In addition, the temperature difference between each module was measured for a duration of 500 S under the same prevailing conditions. This was accomplished using the LM35 precision temperature sensor. The latter was fixed at the back of each module using glue and thermal paste. For each technology, it was seen that the modules' temperatures are quite accurate and close. There is a limited number of input ports in the NI myDAQ. Thus, only the ambient temperature and the temperature of the module under test were taken. The temperature of the reference module was not measured.

Figure 2. I-V tracer circuit and NI myDAQ

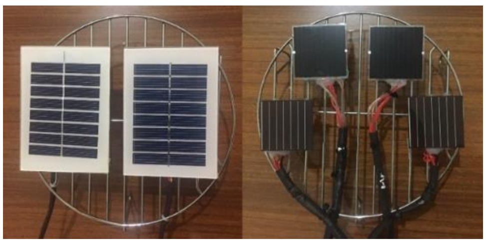


The LabVIEW platform was used to obtain the current and voltage from the I-V tracer circuits and also to vary the gate to source voltage (V_{GS}) of the MOSFET. A Virtual Instrument (VI) was built in LabVIEW to calculate the power of the modules using the acquired parameters. The VI was set so as to sample the voltage and current at a frequency of 1000 Hz. I-V curves were acquired at a rate of 1 Hz. Lastly, the temperatures of the modules were collected at a frequency of 0.5 Hz.

D. *Partial Shading Setup*

The setup used to conduct the partial shading experiment is described in this part. Two different shading scenarios were used. Two modules were utilized from each technology. One of them was chosen to be the reference module and the latter was left unshaded during the whole experiment. Both modules were placed on a metal grill at an angle of 0° as shown in Fig. 3. This stand was used to permit the circulation of air beneath the PV modules. As a result of which, the background temperature would not cause much effect on the modules' temperature.

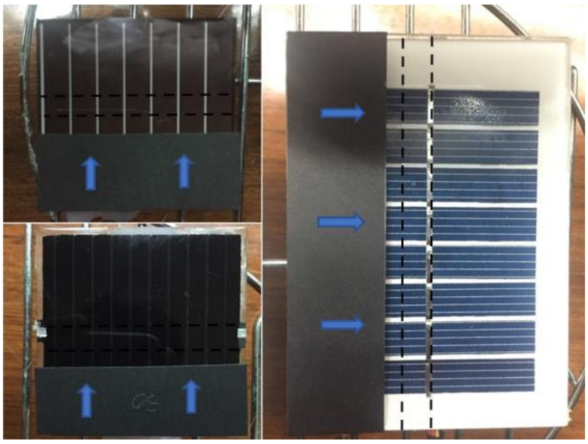
Figure 3. PV modules on metal grill



1) Scenario 1

For the Polycrystalline technology, the module under test was vertically shaded from 0% to 90% in step of 10% using black cardboard. The Amorphous Silicon and CIS modules were horizontally shaded from 0% to 50% in step of 10% as well. The shading patterns are displayed in Fig. 4.

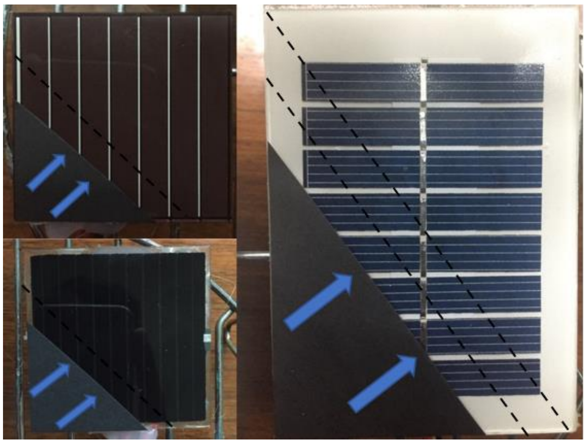
Figure 4. Partial Shading Scenario 1



2) Scenario 2

The modules under test for each technology were diagonally shaded from 0% to 50% in step of 10% as shown in Fig. 5.

Figure 5. Partial Shading Scenario 2

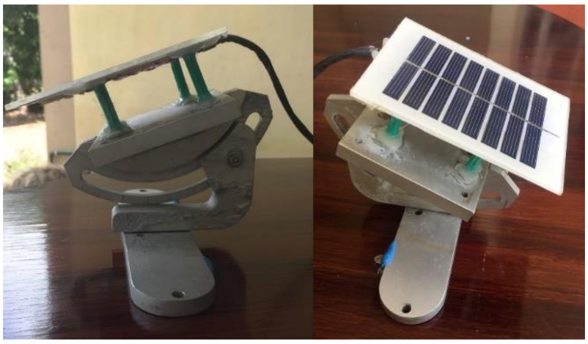


For every pattern, measurements were taken for a time span of 180 S. One I-V curve contained 1000 samples per second. Thus, 180 I-V and P-V curves were obtained for each shading percentage to increase the accuracy. Afterwards, calculations were made so as to obtain the maximum power points of the unshaded and shaded PV modules. The average maximum powers of both modules were calculated for the duration of 180 S. A ratio of shaded to unshaded average maximum powers was determined for each shading percentage. Then the ratio was converted into percentage by multiplying it with 100. Lastly, a graph of percentage maximum power (Pmax) was plotted vs. the varying shading percentages as shown in section IV.

E. Setup for Varying the Tilt Angle of the PV Modules

This part describes the technique used to acquire the Pmax percentage at different tilt angles. The experiment was conducted in Triolet, Mauritius with a Global Positioning System (GPS) coordinates of -20.061876°, 57.556415° during the month of March. To perform this test, the reference module was placed at an angle of 0° and the module under test was placed on a stand whose angle was adjusted from 0° to 90° in step of 10°. The setup is shown in Fig. 6. Moreover, the modules were oriented towards the north direction during the experiment. Readings were taken for a duration of 180 S. Then, a ratio of power was calculated based on the outputs obtained from the tilted module and the flat module. Thereafter, the percentage Pmax was calculated using the same method mentioned in partial shading. The Results of section IV consists of graphs in which Pmax % is plotted against different tilt angles.

Figure 6. Stand



IV. RESULTS AND DISCUSSIONS

A. Partial Shading Analysis

This part reveals the results acquired from the two scenarios of partial shading using the three different technologies.

1) Polycrystalline – Scenario 1

Fig. 7 illustrates the percentage Pmax plotted against the different shading percentages. The graph also includes the module and ambient temperatures recorded during the experiment. It can be seen that as the shading percentage was increased from 0% to 90% the maximum powers reduced almost linearly. From Fig. 4 it is known that all the cells were uniformly shaded in this scenario. Consequently, they gained the same amount of insolation and hence resulting in this linear decrease.

For a deeper investigation, the Isc and Voc were considered. A ratio of Isc shaded module to Isc unshaded module was determined to cancel the effect of solar irradiance. This was plotted against all the shading percentages. The same was done for Voc as displayed in Fig. 8.

Figure 7. Scenario 1 – Polycrystalline results

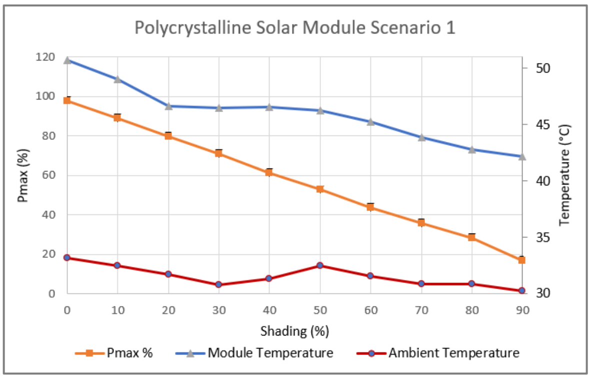
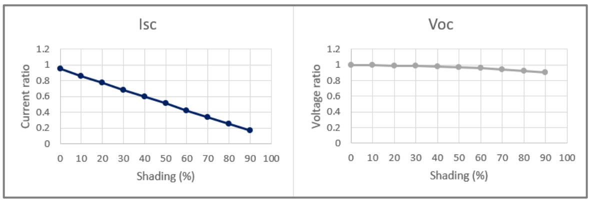


Figure 8. Isc and Voc for Polycrystalline Scenario 1



It can be observed that the Isc decreased by 0.8 when the shading percentages were incremented from 0% to 90%. However, the Voc merely reduced by 0.1. Therefore, the deduction in power output produced by the Polycrystalline module was primarily due to the drop in current. The reason is that an increase in the shading percentage reduced the amount of light striking the PV module. Furthermore, the linear decrease in current ratio was because short circuit current is directly proportional to the amount solar irradiance absorbed by the PV cells. The slight reduction in the Voc was as a result of the logarithmic relationship which exists between solar irradiance and the open circuit voltage.

Considering the temperatures, Fig. 7 shows that from 0% to 20% shaded area, the module temperature lowered by 4.09°C and the ambient temperature dropped by 1.47°C. But, from 50% to 90% shaded area, while the ambient temperature fell by 2.23°C, the module's temperature was reduced by 4.08°C only. This is probably because the second range covered a larger area of the entire module. Therefore, the amount of air circulating over the module was diminished. Besides, the amount of heat transferred from the module to the surrounding was less.

2) Polycrystalline – Scenario 2

In the second scenario, it can be seen that the maximum powers of the module under test decreased at an increasing rate when the shading percentage was increased from 0% to 50%. When a comparison is made with scenario 1, it can be observed that the Pmax was 52.68% at 50% shaded area. Whereas in scenario 2, the Pmax was 18.91% for the same shading percentage as shown in Fig. 9. For further comparison, the Isc and Voc have been taken into account. Referring to figure 10, it is observed that at 50% shading the Isc has decreased by a value of 0.8 whereas the Voc has just reduced by 0.1. Thus, the determining factor is the current in scenario 2 also.

Figure 9. Scenario 2 - Polycrystalline results

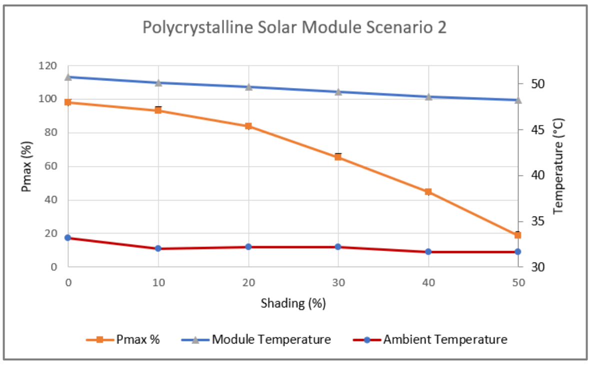
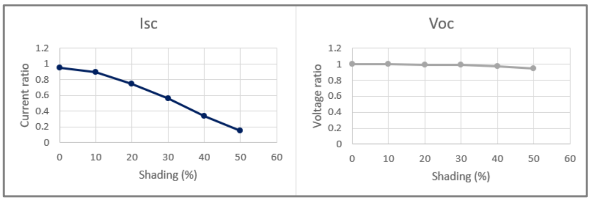


Figure 10. Isc and Voc for Polycrystalline Scenario 2



As a deeper analysis, from Fig. 8 and Fig. 10 it can be observed that at 50% shading, the Isc for scenario 1 has decreased to 0.5 whereas that of scenario 2 has decreased to 0.2. Therefore, the loss in power was much more in the second scenario for the same shading percentage. This is because in this scenario the cells of the module were not equally shaded and hence, they did not get the same amount of sunlight. Ultimately, the module's output current became the current which was being produced by the solar cell receiving the lowest irradiance.

Regarding the temperatures for scenario 2, it can be viewed from Fig. 9 that from 10% to 50% shading the module temperature was decreasing linearly whereas the surrounding temperature was relatively constant. Besides, it is known that light intensity is proportional to the short circuit current. The expansion of the shaded area caused a reduction in the amount of sunlight striking the PV module. As a consequence, the module's temperature was reduced.

Figures 11 to 18 show the results obtained from Amorphous silicon and CIS technologies for partial shading.

3) Amorphous Silicon - Scenario 1

Figure 11. Scenario 1 - Amorphous Silicon results

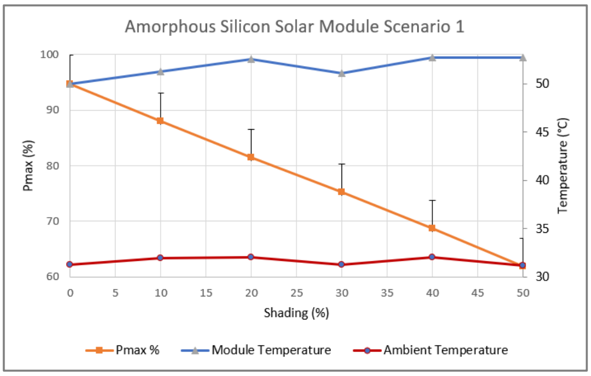
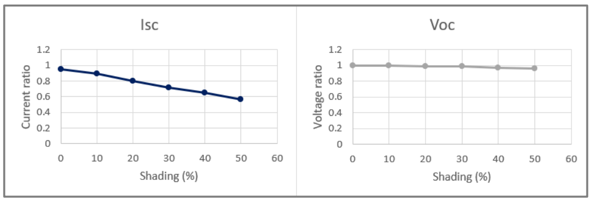


Figure 12. Isc and Voc for Amorphous Silicon Scenario 1



4) *Amorphous Silicon - Scenario 2*

Figure 13. Scenario 2 - Amorphous Silicon results

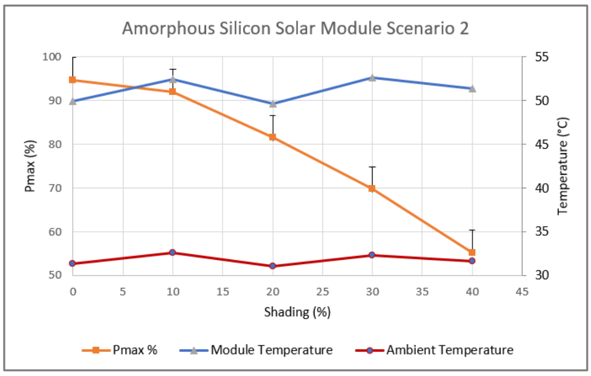
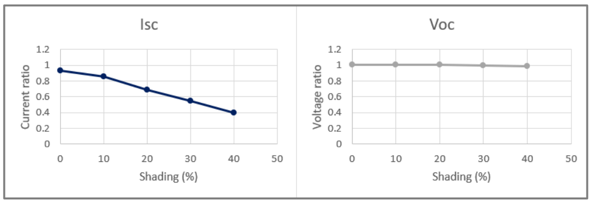


Figure 14. Isc and Voc for Amorphous Silicon Scenario 2



5) *Copper Indium Selenide - Scenario 1*

Figure 15. Scenario 1 - CIS results

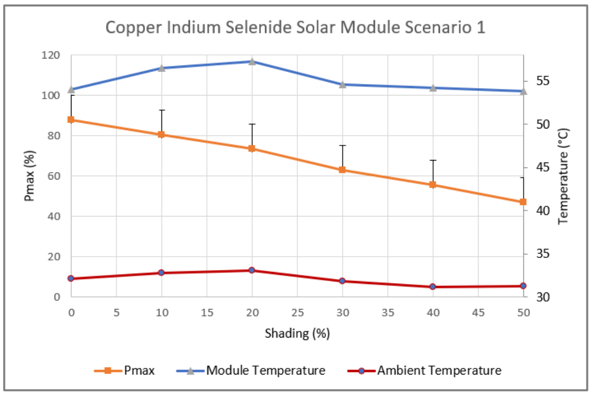
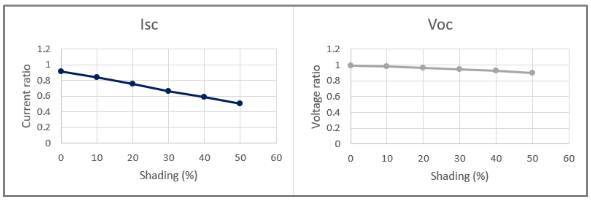


Figure 16. Isc and Voc for CIS Scenario 1



6) *Copper Indium Selenide – Scenario 2*

Figure 17. Scenario 2 - CIS results

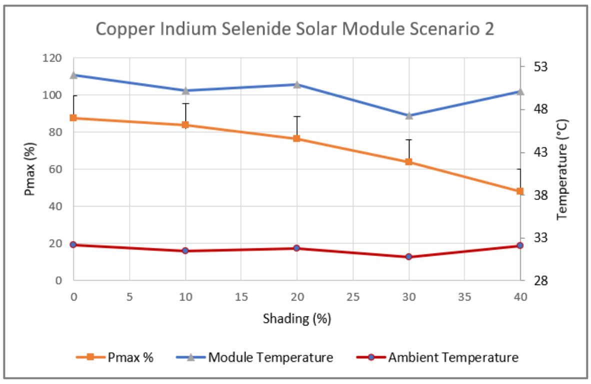
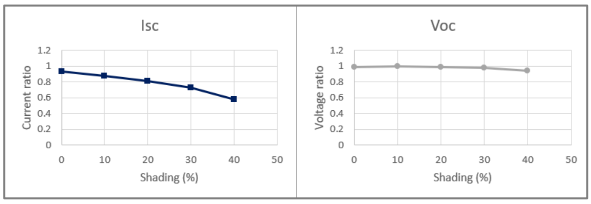


Figure 18. Isc and Voc for CIS Scenario 2



For figures 11, 13, 15 and 17, it can be observed that for 0% shading, the power is not 100%. This is because two PV modules were used each time during the tests to eliminate the effect of irradiance and to calculate the percentage Pmax as explained in section III. Owing to the fact that two PV modules are not exactly identical, they do not produce the same output power when they are placed under the same conditions.

7) *Comparing the three PV technologies*

TABLE I. COMPARISON OF POWERS AT 40% SHADED AREA

	Comparison of Percentage Power Loss at 40% of Shaded Area	
Technology	***Scenario 1***	***Scenario 2***
Polycrystalline	36.70%	53.29%
Amorphous Silicon	26.09%	39.52%
CIS	32.06%	39.48%

Table 1 reveals that most energy was lost by the polycrystalline technology for both scenarios at 40% shading. Comparatively, the two thin film technologies have lost less power. If the two thin film technologies are considered in the first scenario, it can be seen that CIS has lost a greater amount of power as compared to amorphous silicon. Nevertheless, in the second scenario the two thin film modules have lost mostly the same amount of power.

When comparing Fig. 12 and Fig. 16 (Scenario 1), at 40% shading, the current seems to decrease by around 40% for a-Si and by around 50% for CIS. Moreover, the Voc for CIS seems to drop as well, while that for a-Si stays almost the same. This causes the power of the CIS to drop a lot compared to a-Si. When comparing Fig. 14 and Fig. 18 (Scenario 2), at 40% shading, the current seems to decrease by around 60% for a-Si and by around 40% for CIS. The CIS voltage appears to decrease slightly as well. So, it appears that the short-circuit current for the CIS was not so much affected by the shading scenarios, compared to the a-Si.

The individual cells of thin-film modules were shaded differently by the way shading was carried out in scenario 2. The numbers of cells in the a-Si and CIS are different. The percentage shading does not mean that the cells are covered by the same area in both modules. The power of the module depends on which cell drives the current flow when shading occurs in scenario 2, hence the discrepancies between scenarios 1 and 2.

It can be stated that amorphous silicon performs better than CIS and polycrystalline. This result is mostly obtained from scenario 1. This scenario was better than scenario 2 because it caused a linear drop in the percentage Pmax. In fact, all the cells in each module were shaded almost equally, so that there was no discrepancy in terms of which specific cell drives the current flow.

Moreover, it can be deduced that the two thin film technologies sustain partial shading more than the crystalline technology. The reason behind this is that thin film technologies absorb a wider spectral range along the electromagnetic spectrum as compared to crystalline technologies which absorb mostly long wavelength infrared radiation [23].

B. *Effect of Tilt angle on the PV modules' output*

1) *Pollycrystalline PV module*

Fig. 19 denotes that the maximum power was not produced when the PV module was placed horizontally at an angle of 0°. Instead, the Pmax percentage rose from a tilt angle of 0° until 20° and then it started to decrease. Thus, the maximum power output of the PV module was attained at an optimum tilt of 20°.

Figure 19. Polycrystalline module's outputs for various tilts

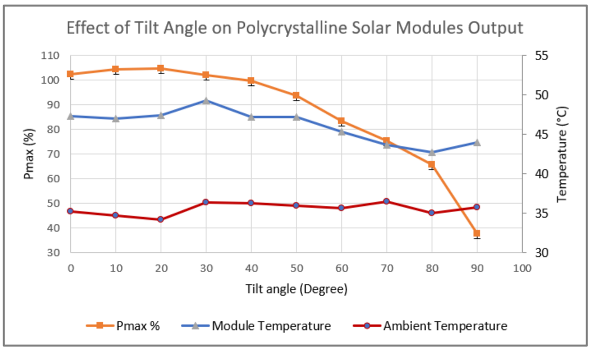
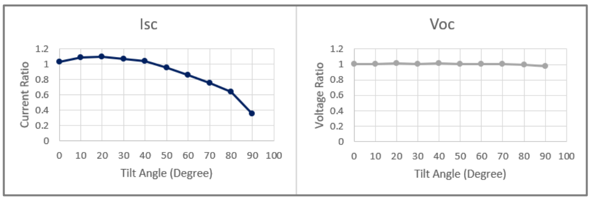


Figure 20. Isc and Voc at different tilt angles



Isc and Voc have been considered in Fig. 20 to find out the determining factor causing the Pmax variation. It can be observed that the trend followed by the Isc is mostly the same as that of the Pmax percentage. In contrast, the Voc remained approximately the same when the tilt angles were changing. Hence, it is noted that the maximum current is obtained at a tilt of 20°. At this angle, the sunrays were almost perpendicular to the surface of the module. Ultimately, the maximum amount of solar irradiance was absorbed by the PV module and maximum power was generated. However, at angles higher or lower than the optimum tilt, sunrays were making angles which were much less than 90° with respect to the module's surface. As a result of which less sunlight was captured and less power was produced. With regards to temperature, Fig. 19 depicts that the module's temperature was changing with reference to the ambient temperature for lower tilt angles. But, as from 50° to 80° tilt a drop of 4.47°C was noted in the module's temperature while the ambient temperature only decreased by 1°C. The reason for this is that at higher tilts less sunrays was striking the surface of the module and hence reducing its temperature. Figures 21 to 24 illustrate the results for the other two technologies.

2) *Amorphous Silicon PV module*

Figure 21. Amorphous Silicon module's outputs for various tilts

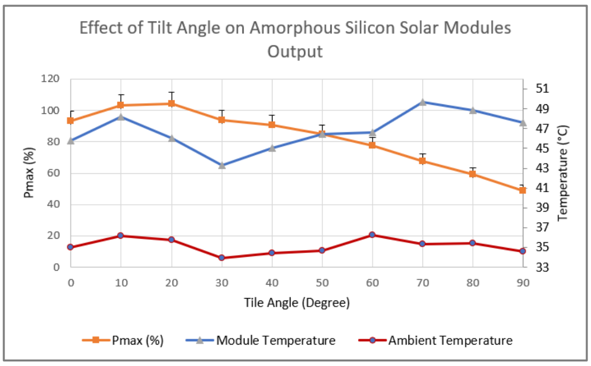
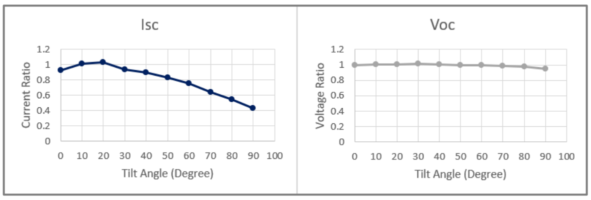


Figure 22. Isc and Voc at different tilt angles



3) CIS PV module

Figure 23. CIS module's outputs for various tilts

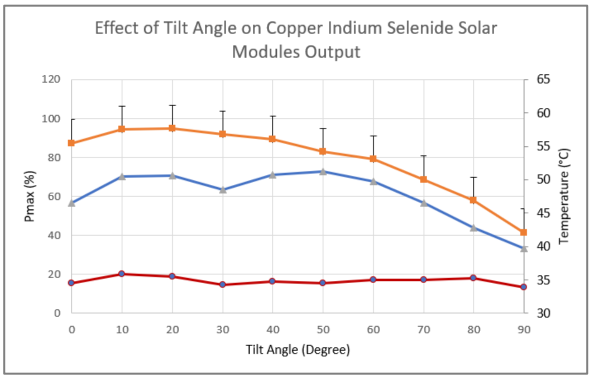
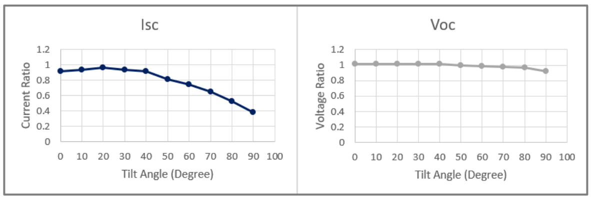


Figure 24. Isc and Voc at different tilt angles



It should be noted that the optimum tilt for all the three PV technologies was 20°. To support this result, it can be seen in paper [24] that the optimum tilt for the month of March in Mauritius is 17.9°. This value is closest to the optimum tilt obtained in this paper as compared to the other angles tested.

4) Comparing the three PV technologies

TABLE 2: POWER LOSS AT 0° FOR THE THREE TECHNOLOGIES

Technology	Power Loss (%) at 0°
Polycrystalline	2.22
Amorphous Silicon	11.19
CIS	7.54

Lastly, the results achieved from the three PV technologies should be compared. Table 2 displays the results obtained when the modules of the three technologies were set at 0° instead of the optimum tilt. It shows that most power was lost by the Amorphous Silicon module. The latter was followed by CIS and Polycrystalline. Therefore, the crystalline technology is more effective than the thin film technologies when the angle was deviated by 20° from the optimum tilt.

V. CONCLUSION

After investigating all the results, the following conclusions were drawn:

- When two modules of the same technology are under the same conditions, their temperature are quite accurate and close. However, a power difference exists between them.
- There is a linear decrease in power for all the technologies when they are evenly shaded. Nevertheless, the power reduction is much more for non-uniform shading when the same percentage area is shaded.
- The effect of partial shading influences the temperature of the crystalline module much more as compared to the thin film modules.
- It is noted that the thin film technologies can withstand shading better than the crystalline technologies. Amorphous Silicon has proven to be the most tolerant one.
- Under the effect of different tilt angle, a maximum output power was produced at an optimum tilt of 20° by all the technologies whilst facing the north direction.
- Ultimately, the least amount of power was lost by the Polycrystalline technology as compared to the other technologies when it was placed at an angle of 0° instead of the optimum tilt angle.
- Finally, from the tests we have seen that both partial shading and tilt angles impact the performance of a PV system. As a recommendation, Polycrystalline can be chosen if the PV module is placed at 0°. But the effect of shading needs to be catered. This is because polycrystalline will give the best output and also it has a better efficiency as compared to the thin film technologies. Proper planning should be done prior to the installation of a PV system. Partial Shading can be caused by buildings, trees and many other factors. In addition, shades can alter over time. For instance, if a tree grows or if a new building is erected. As a result of which, proper design should be done to minimize any source of shade. Daily and yearly shadow path can be simulated to find the best location of PV modules.

Future Work

To make more and better comparisons between the three technologies, the below recommendations can be implemented:

- Other tests such as water cooling, soiling and fan cooling can be performed for more comparisons.
- Using solar panels consisting of bypass diodes to carry out the partial shading analysis.
- Shading different percentages of a single solar cell to see how the output power varies.
- Use a pyranometer to measure the solar irradiance while conducting the tests.

Thus, the relationship between irradiance and the tests performed will be known.

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