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Experimental Effect of the Impact of Stagnant Water on Solar Modules

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Abstract— ***In this research, an experimental study of the impact of stagnant water on solar modules is investigated. Two different experiments using two identical photovoltaic (PV) modules S1 and S2 were used for the study. In the first experiment, the PV module S1 was covered with stagnant water and the second PV module was unshielded with water. In the second experiment, the PV modules were swapped with S2 covered with stagnant water and S1 unshielded with water. The experiments were carried out under normal operating temperature of PV cells at the Department of Electrical Engineering, University of Nigeria, Nsukka on latitude 6:52 degrees north, longitude 7:23 degrees. Results obtained from the first experiment show that the efficiency and power output of S1 PV module decreased by 9.3% and 8.0% respectively when compared with that of S2 PV module. In the case of output voltage and current, it was found that shielding of PV module S1 with stagnant water caused an increase in the output voltage by 1.93% and a decrease in the output current by 10.26%. In the second experiment, the efficiency and Output power of PV module S2 decreased by 9.21% and 8.18% respectively when compared with the unshielded PV module S1. In the case of voltage and current, it was found that shielding of PV module S2 with stagnant water caused an increase in the Output voltage by 1.63% and decrease in the output current by 10.91%.***

Index Terms— ***Output Current/Voltage, PV Module, Renewable Energy, Solar Radiation.***

I. INTRODUCTION

There are many sources of renewable energy like solar, wind, biomass, etc., for distributed generation but solar PV system is the most simple and reliable way to produce electricity from the sun [1-2]. The technological sustenance of PV systems depends on many factors, such as improvement in technology, reliability and quality of PV components and locations where these PV systems are deployed [3]. The latter point determines the performances of PV modules under exposure like the tilt angle and positioning of the modules. Climatic conditions like pollution, fog, stagnant water, etc., can reduce the energy output of the solar modules by more than 60%, owing to dust, leaves, fog, stagnant water, birds acting as a shield to the PV module [2, 4]. Also, higher temperature more than the working temperature of solar cells reduces the efficiency of the cells [5].

Tilt angle of solar modules varies from one location to the other. Countries such as Burundi, Ecuador, Malaysia, Maldives, Rwanda, Tanzania, Uganda, Nigeria, South Sudan etc. with tilt angles close to the equator are likely to have low output efficiency owing to the presence of stagnant water, fog and snow on the module surfaces [6].

Furthermore, for PV module distributed generation which is within the range of tens of watts, kilowatts to a few megawatts, it is necessary to design an optimum tilt angle which will have easy run off of water and fog that falls on the PV modules.

Optimal module tilt angles are suggested as solution of minimal irradiance loses as it eliminates waste of insolation and improve PV module performance, hence; increases electrical yield of the PV module [6 - 12]. In this regard, for ground mounted solar modules and roof mounted solar modules an optimal tilt angle can be chosen to optimize the performance of the solar module.

Although this paper suggests the effect of stagnant water on solar modules, several other studies have analyzed the efficiency improvement of PV module by cooling. Krauter [1], investigated "Increased electrical yield via water flow over the front of PV panels" at a conventional temperature rise from 22 to 60 degree Celsius. Results show power and efficiency improvement of 10.3%. Mehrotra [13], evaluated performance of a solar panel with water immersion cooling technique. Finding from the study shows that electrical performance of the experimental cell increased to 17.8% at a depth equal to 1cm. Bahaidarah [14], conducted an experiment to evaluate the performance of a PV module with water cooling. The experimental results showed that the water cooling dropped the module PV temperature significantly to about 20% leading to an increase in panel efficiency of approximately 9%. This result was obtained when the conventional temperature of the PV module was 45 degree Celsius. Other studies that show power and efficiency improvement using water cooling on PV modules can be found in literature [15 -20].

In all of these studies, the cooling was done by splashing and running of water on the surface of PV modules. These studies were applied to achieve improved PV module output power and efficiency. [21 – 23].

In this paper, the authors investigated the performance of a small-sized (3W) polycrystalline PV modules when stagnant water is used on them. In order to achieve reliable power supply from PVS,

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there is need to see how the yield of PV modules installed closer to the equator can be maximize. This study will benefit solar designers to know the appropriate designs to be incorporated into solar modules. It will help solar installers to obtain the right position for installing solar modules for the purpose of obtaining optimal yield for the benefit of the end users (power consumers).

This paper is organized as follows: sections 1and 2 presented the introduction and research methodologies respectively; while sections 3 and 4 presented the results and conclusion respectively.

II. METHODOLOGY

The method employed in this research is an experimental analysis using two identical solar PV modules S1 and S2 with name plate parameters shown in Table 1. The experiment was done at no load condition and measurements were limited to short circuit current (I_{SC}) and open circuit voltage (V_{OC}).

Table1: Manufacturer specification of PV modules

Parameters	Module 1 (S1)	Module 2 (S2)
Model	DP--Li21	DP--Li21
Type	Polycrystalline Silicon	Polycrystalline Silicon
Dimension	14 x 23 cm	14 x 23 cm
Power	3W + - 5%	3W + - 5%
Open Circuit Voltage (V)	DC 7.2V	DC 7.2V
Short Circuit current (A)	DC 568mA	DC 568mA
Working Voltage	DC 6V	DC 6V
Working Current	DC 500mA	DC 500mA

The experiments were conducted for a period of two months. The first one was from 17th February to 17th March, 2019 and the second experiment was from 26th March to 26th April, 2019 at the department of Electrical Engineering, University of Nigeria, Nsukka. The modules with stagnant water were sealed at the edges with adhesive gum to avoid water seepage from the modules. Before the experiment commenced the surface of the PV modules were covered in order to prevent generation of power and allow for connections of the measuring instruments. The PV modules S1 and S2 were placed side by side in an open field with no nearby buildings and tall trees. PV module S1 was shielded with 5 centiliter volume of water, which formed a thickness of 2.8mm on the surface of the panel. The thickness of the stagnant water varies with respect to PV modules depending on the physical structure of the PV module frame. The greater the thickness of the stagnant water, the lesser the light absorption and vice versa. The unshielded PV module S2 served as reference module. Since evaporation occurs at any temperature, this study focuses on investigating the impact of stagnant water as the water evaporates. The modules were kept on a flat board at 0^{o} inclination. Two digital multimeters were connected to modules S1 and S2 in order to take voltage and current readings. A digital solarimeter was used to take the reading of the direct irradiance incident to the PV modules; digital thermometer was used to measure the ambient temperature of the environment while solar camera (Seek thermal) was used to measure the thermal temperature of PV modules S1 and S2. The experimental setup is as shown in Fig. 1.

The experiment commenced each day by 8:00am and ends by 2:00 pm when all the stagnant water on the panel evaporated. An optimal time was reached when the stagnant water on PV module S1 dried up at 2:00pm as a result of evaporation and the contaminants like dust forms a shield on the surface of the PV module. Readings of voltage, current, irradiance and temperature were taken at 2 minutes intervals for analysis. The measured values were used to calculate the output power and efficiency of each module.

In order to test if similar results would be obtained, the two identical panels were swapped and S2 was shielded with stagnant water while S1 was unshielded. The experiment was conducted again following the same methodology and processes.

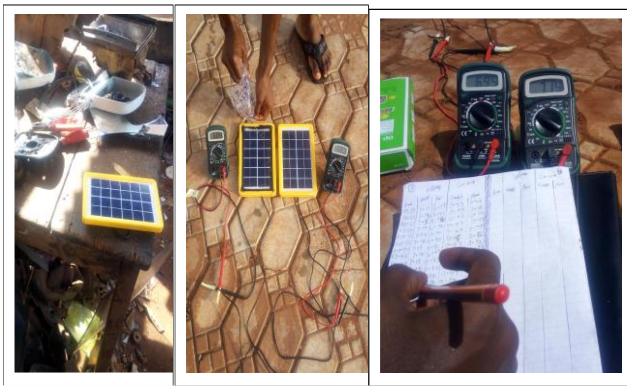

Fig. 1. Picture of the experimental setup

Equation (5) is used for calculation of output power

$$P_{pv} = I_{pv} \times V_{pv} \quad (5)$$

Equation (6) is used for calculation of efficiency

$$\eta = \frac{P_{pv}}{G \times A} \times 100 \quad (6)$$

Where, P_{pv} is the output power of the PV module in Watt,
G is the solar irradiance in W/m^2 and
A is the area of the solar panel in m^2.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. *Situation when S1 was shield with water and S2 Unshielded*

The performance of PV Module is a function of several environmental and climatic factors such as solar irradiance, ambient temperature, shield etc. in the event of this experiment, values of voltage, current, temperature and irradiance were taken at two minutes interval but for ease of analysis and discussion a scale of 30 munities interval was considered. As seen in Fig. 2, maximum ambient temperature was 30^0C at 1:00pm. The average ambient temperature throughout the month of the experiment was 25.23^0C. As time increases, the hourly ambient temperature increased until a maximum 30^0C was reached at 1:00pm. The maximum conventional temperature (for S2) was 36^0C at 1:00pm and the average conventional temperature was 31^0C while the maximum temperature of the shielded panel (S1) was 33^0C at 1:00pm average temperature was 28^0C.

The average measured temperature of modules S1 and S2 are 28^0C and 31^0C, respectively as shown in Fig. 2.

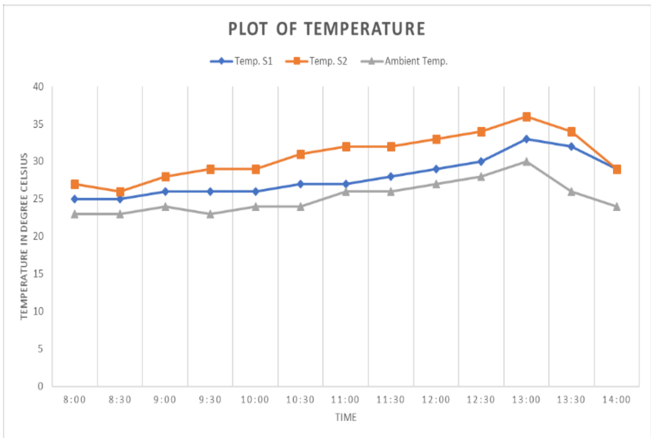

Fig. 2. Comparison of cell temperature during the month.

At 1:00pm, maximum value of irradiance was recorded with a value of 1180W/m^2 and the average irradiance throughout the period of experiment per day was 716.15W/m^2 as seen in Fig. 3. The irradiance started decreasing after 1:00pm.

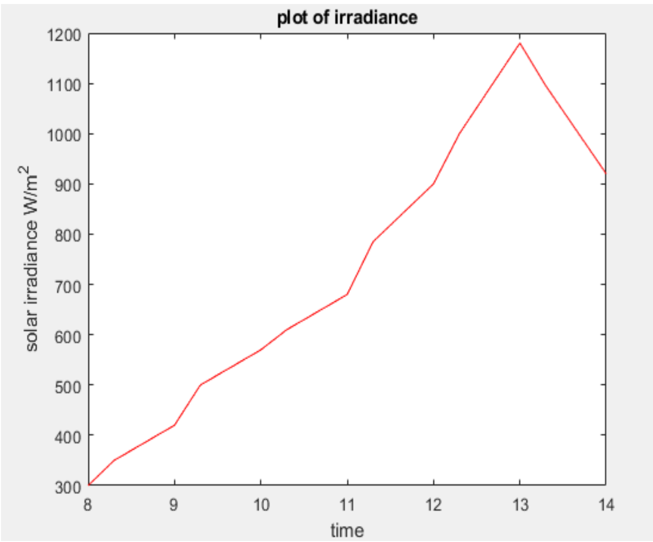

Fig. 3. Plot of irradiance with time.

The difference in temperature between modules S1and S2 was within the range of 3^0C - 6^0C throughout the day. This temperature reduction resulted in a noticeable decrease in electrical efficiency of PV module S1 as shown in Fig. 4. The maximum efficiency of module S1 was 0.1470 (value in percentage was 14.70%) at 11:30am and average efficiency of 0.1172 (value in percentage is 11.72%) while maximum efficiency of module S2 was 0.1574 (value in percentage is 15.74%) at 11:30am and average efficiency was 0.134 (value in percentage was 12.81%). The average reduction in the electrical efficiency is 9.3%. This reduction in electrical efficiency was due to the fact that the PV module with stagnant water has reduction in output current. This reduction in output current was due to low performance of the panel with stagnant water. This low performance was as a result of low spectra irradiance the cell of the panel gained.

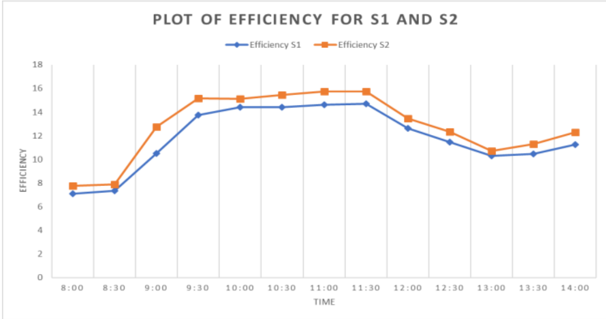

Fig. 4. Plot of efficiency for S1 and S2

With module S1 shielded with water, its maximum voltage was 7.24V (at temperature of 30^0C) and it occurred at 1:00pm with average value of 6.87V; while the maximum voltage of the unshielded panel was 7.15V at 1:00pm with average value of 6.74V. Stagnant water on panel S1 caused a slight increase in the average electrical voltage by 1.93% as shown in Fig. 5. This slight increase in the average voltage resulted from the less irradiance value received on the PV cell. The water acted as a heat absorber at the topmost surface while the bottom most surface remained cooled.

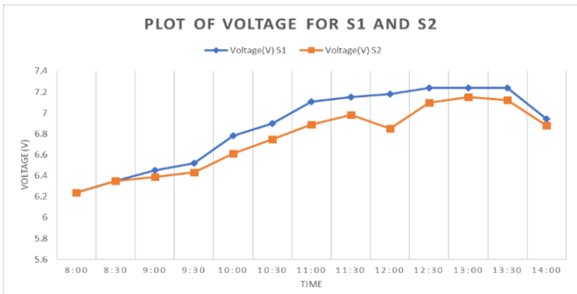

Fig. 5. Plot of voltage for S1 and S2 with time.

The maximum output current with S1 shielded with stagnant water is 0.54A (at temperature of 30^0C) and it occurred at 1:00pm with an average value of 0.39A while the maximum current of the conventional panel (S2) is 0.57A (at temperature of 35^0C) at 1:00pm with an average of 0.43A. Shielding of PV module S1 with stagnant water caused a noticeable decrease in the average electrical current by 10.26% as shown in Fig. 6. This reduction in the average output current was as a result of shield from stagnant water. The shield from stagnant water led to low performance of the panel. This low performance was as a result of low spectra irradiance the cell of the panel received

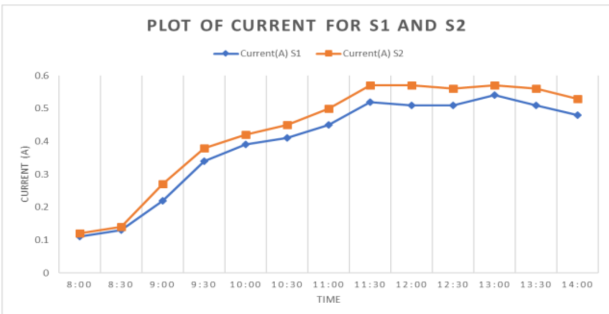

Fig. 6. Plot of current for S1 and S2 with time.

With active stagnant water shielding, the reduction in the electrical power per day was 8%. The maximum value of power output of the unshielded module was 4.08 W at 1:00pm with an average of 2.97W whereas the maximum power output for water shielded panel (S1) was 3.91 W at 1:00pm with average of 2.75W as shown in Fig. 7. This reduction in electrical power was as a result of reduction in the output current.

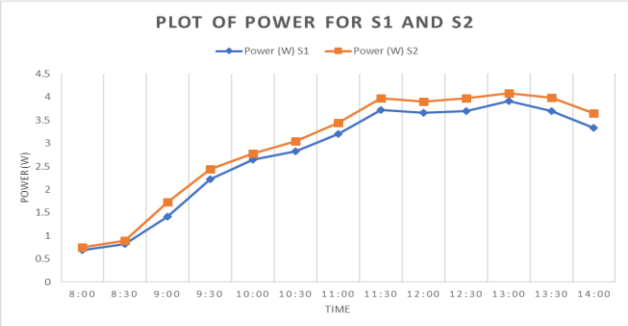

Fig. 7. Plot of power for S1 and S2 with time.

*B. **Situation when S1 was unshielded while S2 was shielded with stagnant water.***

In order to test if similar results would be obtained, the two identical panels were swapped and S2 was shielded with stagnant water. The experiment was conducted again following the same methodology and processes. It can be observed that when module S2 was shielded with stagnant water, the cell temperature and irradiance plots shown in Fig. 8 and Fig. 9 respectively followed similar behavior as when module panel S1 was shielded with stagnant water.

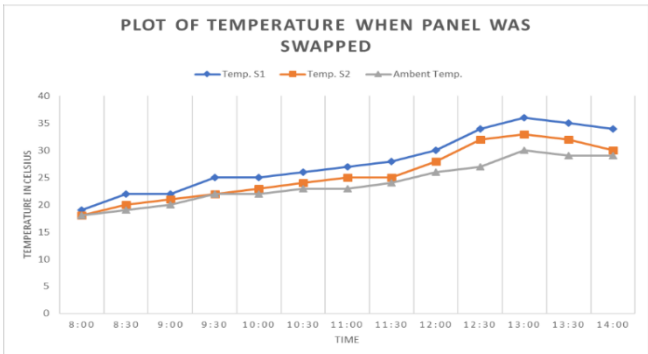

Fig. 8. Comparison of cell temperature during the month.

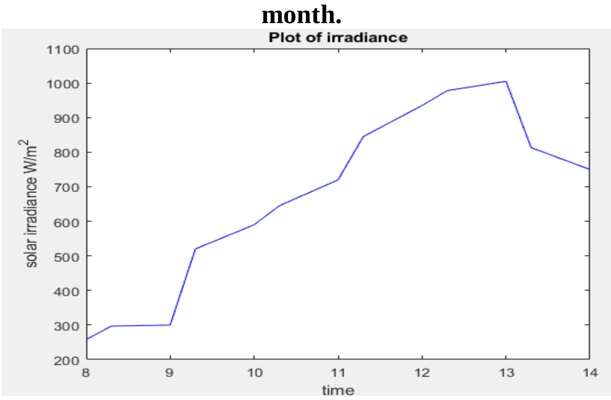

Fig. 9. Plot of irradiance with time.

Stagnant water on module panel S2 resulted in the reduction of the electrical efficiency by 9.21% as shown in Fig. 10. This reduction in electrical efficiency is as a result of reduction in output current of the panel. This reduction in output current was due to low performance of the panel with stagnant water. This low performance was as a result of low spectra irradiance the cell of the panel gained.

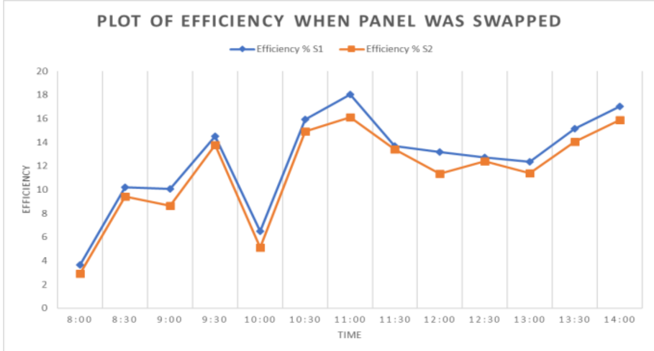

Fig. 10. Plot of efficiency for S1 and S2 with time.

Stagnant water on panel S2 caused a slight increase in the electrical voltage by 1.63% as shown in Fig. 11. This slight increase in the average voltage resulted from the less irradiance value received on the PV cell. The water acted as a heat absorber at the topmost surface while the bottom most surface remained cooled.

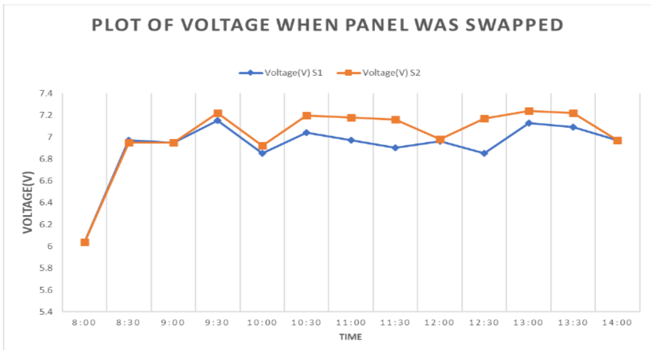

Fig. 11. Plot of Voltage of S1 and S2 with time (Swapped)

Shielding of PV module S2 with stagnant water caused decrease in the electrical current by 10.91% as shown in Fig. 12. This reduction in the average output current was as a result of shield from stagnant water. The shield from stagnant water led to low performance of the panel. This low performance was as a result of low spectra irradiance the cell of the panel received.

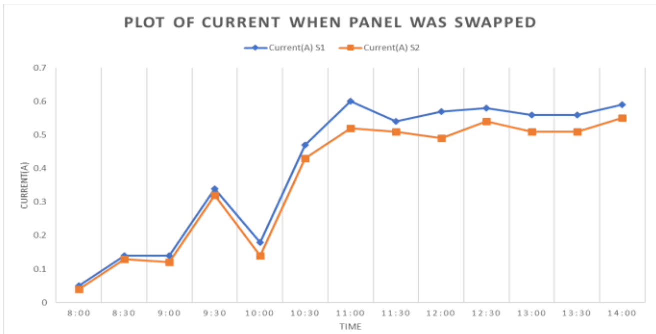

Fig. 12. Plot of current of S1 and S2. (Swapped)

As shown in Fig. 13, with active stagnant water shielding, the reduction in the electrical power per day was 8.18%.

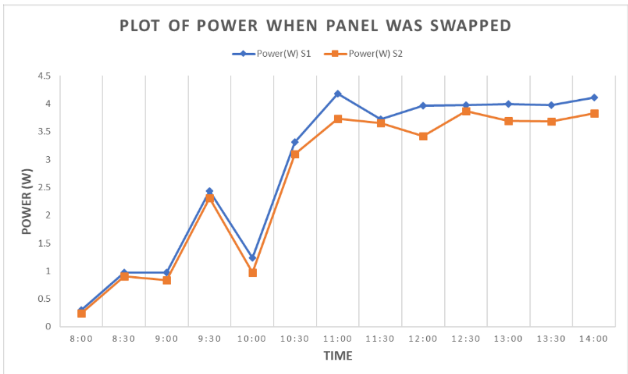

Fig. 13. Plot of power of S1 and S2. (Swapped).

This reduction in electrical power was as a result of reduction in the output current of panel S2.

IV. CONCLUSION

This paper discusses experimental study of impact of stagnant water on solar panel module. Two identical solar panel modules were used for this study. Two experiments were conducted – with PV module S1 shielded with stagnant water while PV module S2 was unshielded and PV module S2 shielded with stagnant water while PV module S1 was unshielded. The two experiments were carried out under PV normal working temperature. Based on the first experiment conducted, that is for PV Module S1 shielded with stagnant water and PV module S2 was unshielded, the efficiency and power output of the PV module decreased by 9.3% and 8% respectively as compared to the unshielded PV module S2. In the case of voltage and current, it was found that shielding of PV module S1 with stagnant water caused a slight increase in the electrical voltage by 1.93% and a noticeable decrease in the electrical current by 10.26%. For the second experiment, that is when PV Module S2 was shielded with stagnant water and PV module S1 was unshielded, the efficiency and power output of the PV module decreased by 9.21% and 8.18% respectively as compared to the unshielded PV module S1. In the case of voltage and current, it was found that shielding of PV module S2 with stagnant water caused an increase in the electrical voltage by 1.63% and decrease in the electrical current by 10.91%.

Although these experiments were conducted using 3W solar modules, this result is applicable to larger solar modules. This is because an increment in surface area of a solar module will result to a corresponding increase in the quantity of stagnant water on it. From these findings, it is obvious that stagnant water on a PV module acts as a shield and thus, reduces the efficiency and power output of the solar panel module under normal working condition. Furthermore, dust particles on the surface of the PV module after evaporation acts as a shield which also reduces the electrical yield of the PV module.

We recommend that the PV module designers consider these two options to eliminate stagnant water on modules – by the use of super hydrophilic, super hydrophobic coatings or frames designed for water drainage

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