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Investigating the effect of solar trackers on solar energy harnessing in the Tropics

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Abstract. Solar panels produce higher output power when the solar radiation reaching it is perpendicular to its surface. Trackers are used to orient the solar panels perpendicular to the incident irradiation for maximum power output. In the temperate region, there is low irradiation compared to the Tropical region, thereby necessitating the use of solar trackers in order to harness as much energy as possible. This research seeks to investigate the effect of using trackers in the Tropical region by making a comparative analysis of the power and voltage output between a static solar panel and a panel mounted on a solar tracker. A cost-benefit analysis is also carried out. The results showed that there was an increase in output power with the use of a solar tracker, relative to a static photovoltaic module by 23.87%. It was concluded that use of trackers in the tropical region could be beneficial if it is used for a large generating solar plant or during the raining season, when there is more cloud cover.

1. Introduction

Photovoltaic solar energy is being explored as an alternative and renewable energy source due to depletion of fossil fuels and for reasons of environmental concern. However, generation of electricity using this technology is still considered undeveloped in comparison with fossil fuels due to the low conversion efficiency and production costs of photovoltaic modules. Research has shown that solar trackers have the ability to cause an increase in the efficiency of Solar Photovoltaic Systems [1, 2, 3]. The benefit of using a solar tracking system is that the output power and energy yield can be increased as the photovoltaic module is always oriented perpendicular to the incoming solar radiation even as the sun's location changes throughout the day.

There are two major factors which affect the increase in efficiency using solar trackers; the mode of operation of the tracking system and the geographical location of the installation of the photovoltaic system. Based on the geographical location, varying temperature, changes in climate and the geographical coordinates (longitude and latitude) affect the energy yield of the photovoltaic modules. For instance, using trackers in places like Europe which is in the temperate region can cause a 50% increase in energy gain when compared a fixed system [4]. In tropical regions, the increase in output power from the photovoltaic system is not as high as that of the temperate region, although it has been reported that the energy gain could be as high as 30% in some places like Tunisia [5], Taiwan [6], and Malaysia [7].

Despite these reports, there is a bit of uncertainty regarding the need for the trackers since the irradiation per day is quite high when compared to temperate regions. Also, a tracking system might



be unnecessary for tropical regions due to the overheating of the solar panels, from excessive exposure to solar irradiance in a hot climate, which consequently affects the performance of the modules. The aim of this research is to ascertain whether or not solar tracking is needed in the tropical region by showing the effect of solar tracking on the output of a PV cell in the tropics. We make a comparative study between a static photovoltaic solar panel and a one-axis mobility panel installed in Covenant University, Ogun state, Nigeria.

1.1. Study area

The study was carried out in Covenant University, Ogun state, the southwestern part of Nigeria (6.6718° N, 3.1581° E). This area is immensely influenced by the tropical savannah climate with distinct wet and dry seasons. The dry period lasts for about 130 days and runs through November till February, while the rainy season lasts for seven and eight months, between April and October with a short dry season in August. The rain in this area is defined by trade winds and its seasonal shift. The mean annual rainfall and temperatures are about 1,270 mm and 28 °C respectively, while the estimated mean annual potential evaporation is 1,100 mm. The daytime lasts from 10 to 13.5 hours, because the zones on both sides of the equator that are shaped by higher daily temporal (time of day climate) and smaller seasonal variations in temperature (25 °C annual averages) and due to that, there is a high irradiation all year around.

2. Methodology

2.1. Description of panels

Technical data at standard test conditions of the photovoltaic modules used are listed below:

Output Tolerance = $\pm 5\%$

Current at $P_{\max}(I_{mp}) = 0.57A$

Voltage at $P_{\max}(V_{mp}) = 17.5V$

Short-Circuit Current (I_{sc}) = 0.63A

Open-Circuit Voltage (V_{oc}) = 22.05V

Mass = 1.2kg

Dimension = 360mm x 245mm x 23mm

2.2. Position of Photovoltaic (PV) modules

The PV modules for the control (stationary) and variable (tracking) systems were placed on the Terrace of the College of Science and Technology (CST) building, Covenant University, Ogun state, Nigeria. The location is suitable as it has a very wide-open air space and allows maximum exposure of the PV module with no shading. The solar panels were oriented towards 22.5° SW, horizontally. While the stationary panel was inclined at an angle of 45° vertically, the tracking panel was left to vary over the x-axis (horizontally).

2.3. Data acquisition

The photovoltaic module was mounted on the solar tracker in order to follow the sun's radiation over the angles of -40 to 530 on the x-axis each day for a period of 10 days, corresponding to time range of about 10.00-18:00 Hrs. Two pairs of an Ammeter and a Voltmeter were connected to the output of the panels (a pair for each panel). The solar tracker passes through each angle and stops at the point where the Ammeter and Voltmeter display the highest values of current and voltage, respectively, at a particular time. The angle at the point of maximum values of current and voltage is the angle where the incident irradiation of the sun is perpendicular to the panel. The values at this point for the both panels were recorded.

3. Results

Recorded in Table 1, are the average values of the measurements for short-circuit current (I_{sc}), open-circuit voltage (V_{oc}) and the power output (P) for the period of 10 days, between 10:00 to 18:00 Hrs, daily.

Table 1: Average Values of I_{sc} , V_{oc} and P .

	NO TRACKER			TRACKER			
Time (Hrs)	$V_{oc}(V)$	$I_{sc}(A)$	$P(W)$	$V_{oc}(V)$	$I_{sc}(A)$	$P(W)$	Angle(o)
10:00	18.40	0.33	4.36	19.32	0.55	7.66	-4
12:00	18.55	0.36	4.84	19.04	0.54	7.45	-3
14:00	18.95	0.49	6.68	19.13	0.55	7.51	20.8
16:00	19.03	0.53	7.29	19.02	0.54	7.42	38.5
18:00	18.23	0.51	6.62	18.26	0.52	6.84	52.1

It is seen that the output power for the mobile systems is significantly higher than that of the static system, although the power output of both systems increases as the sun rises and decreases as the sun sets. There is an increase in efficiency by 23.87% which denotes an improvement in power yield. The performance of open circuit voltage, short circuit current and power for both systems can be seen in figures 3, 4 and 5 respectively. In the three figures, the photovoltaic module which is mounted on the tracker performs better than the static panel. However, in the evening when the incoming solar radiation is minimal, they both exhibit a low performance which is typical at low radiation.

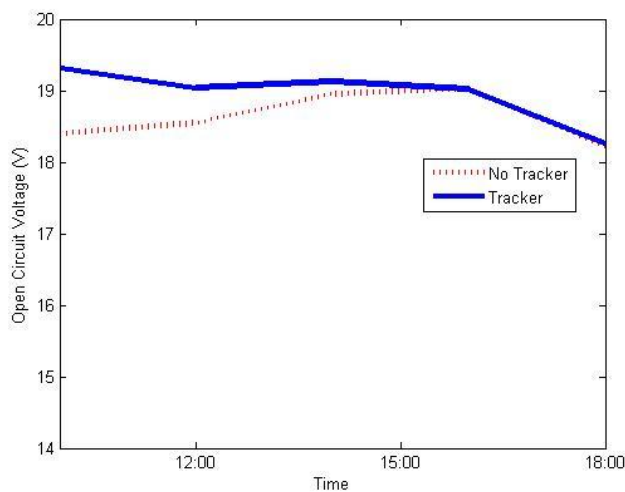


Figure 1: V_{oc} (Non-Tracked [NT] and Tracked [T])

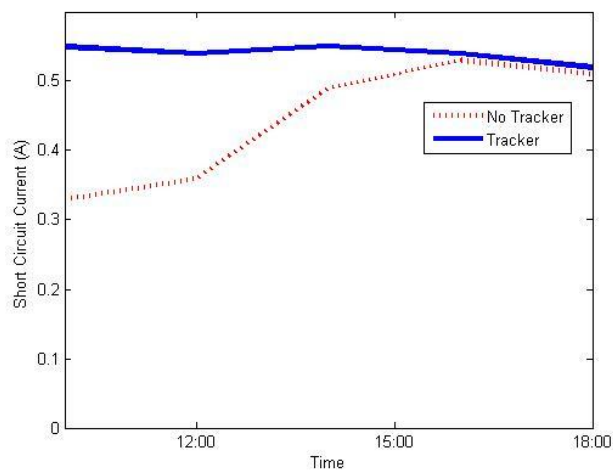
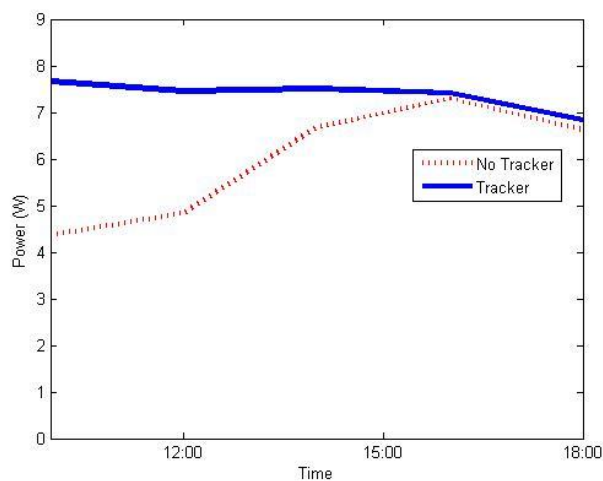
Figure 2: I_{SC} (Non-Tracked [NT] and Tracked [T])

Figure 3: Power (Non-Tracked [NT] and Tracked [T])

It is shown in Table 2, the average results of I_{sc} , V_{oc} and P on a daily basis for both systems. From the analysis of the averaged values, we see again that the mobile system performs better than the static system. The variation in the daily power output is due to atmospheric conditions and other factors which affect the efficiency of the module such as cell temperature.

Table 2: Average Results for each day

	No Tracker			Tracker		
	$V_{oc}(V)$	$I_{sc}(A)$	$P(W)$	$V_{oc}(V)$	$I_{sc}(A)$	$P(W)$
Day 1	18.65	0.45	6.09	19.08	0.54	7.47
Day 2	18.87	0.41	5.63	19.22	0.55	7.59
Day 3	18.77	0.40	5.33	19.13	0.55	7.51
Day 4	18.95	0.50	6.79	19.25	0.55	7.61
Day 5	18.61	0.44	5.90	18.89	0.54	7.32
Day 6	19.07	0.50	6.88	19.31	0.55	7.66
Day 7	18.51	0.47	6.21	18.71	0.53	7.19
Day 8	18.49	0.46	6.16	18.75	0.53	7.22
Day 9	18.23	0.41	5.30	18.51	0.53	7.04
Day 10	18.17	0.40	5.25	18.69	0.53	7.18

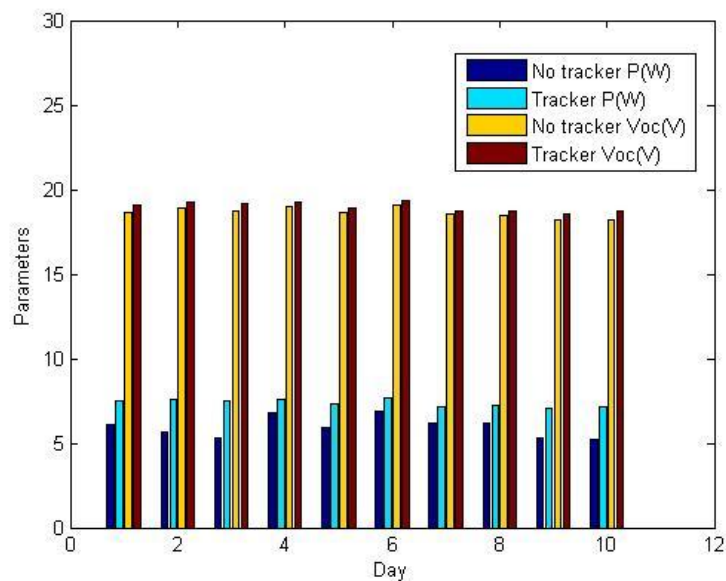


Figure 4: Average value of each parameter over 10 days

3.1. Cost-benefit analysis

3.1.1. *Production cost/ Capital expenditure.* The list of parts or components of the system needed for the implementation of the tracker is shown in Table 3.

Table 3: Capital expenditure

S/N	Parts/Components	Quantity	Cost
1	Frame/Stand	1	₦7,000
2	LDR	2	₦20
3	Resistor	7	₦70
4	AT Mega 16 MC	1	₦1000
5	LM 328	1	₦100
6	L293D	1	₦200
7	Variable Resistors	2	₦20
8	Stepper Motor	1	₦2000
9	Battery	1	₦1300
	TOTAL		₦11,710

3.1.2. *Operational Cost/ Maintenance Expenditure.* The average cost of maintenance is so small that it is negligible.

3.1.3. *Cost Effect.* Average increase in power= 23.87%

Average power generated= 5.96W (Non tracked)/7.38W(Tracked)

Average electricity cost in Nigeria= ₦29.04/KWhr

Total net time for the experiment = 8hrs each day x 10 days => 80hrs

The Gain in power generation over the time of the experiment (80hrs) is equivalent to:

$\text{₦}14.72/\text{KWhr} \times 5.96\text{W} \times 80\text{hrs} \times 23.87\% \Rightarrow \text{₦}3.31 \Rightarrow \sim \text{₦}0.0413/\text{hr}$.

Note: The cost of the panel was not discussed, because in this research, it is a constant and does not change anything if included.

3.1.4. Cost versus benefit. From the Cost effect analysis, it is seen that the use of a solar tracker saves about ₦0.0413 per hour. This means it will take about 33 years to break even (this value is for this research and its specifications alone). The exact tracker used in this project could be used for a 20W solar panel and higher; this implies that the number of years can be reduced, depending on the power efficiency of the Tracker.

The highest energy increase (Table 4) was recorded on cloudy days. This is because the rays from the sun are refracted randomly through the clouds dependent on the arrangement of the clouds. Thus, the incident angle of irradiation is altered with respect to the cloud arrangement. This ascertains the fact that the implementation solar trackers are significant especially during the rainy season.

Table 4: Highest energy increase recorded

	Time (Hrs)	Voc(V)	Isc(A)	P(W)	Voc(V)	Isc(A)	P(W)	Angle(°)	Difference
Day 2	10:00	18.80	0.09	1.21	20.10	0.57	8.29	-36	7.08
Day 3	10:00	18.60	0.09	1.18	19.80	0.57	8.04	-36	6.86
Day 10	10:00	17.85	0.10	1.26	19.85	0.57	8.08	-35	6.82
Day 3	12:00	18.60	0.31	4.16	19.00	0.54	7.41	-10	3.25
Day 9	12:00	18.44	0.31	4.10	18.88	0.54	7.31	-10	3.22

4. Conclusion and Recommendation

The power generated in the photovoltaic module mounted on the tracker yields a higher power output of 23.87% in comparison to the static PV module. The use of a solar tracker also saves ₦0.0413 per hour. Thus, we have in view, a plausibility of relevance of trackers in the tropical region, but it must be noted that the relevance increases directly with the size of the generating plant and power efficiency of the Trackers.

With respect to the results of the analyses carried out, we commend that the use of solar trackers in the tropical region would be very utilitarian in the following cases:

- Large Generating Plants: Use of trackers in the tropical region could have greater relevance when it is used in a large generating plant. This is because the bigger the tracking system (in singular size or quantity), the more cost effective it would be. The amount of time taken to break even is also taken into consideration. Thus, a small scale generating plant would not efficiently express the potentials of Trackers in the tropical region.
- Rainy season: When the atmosphere is cloudy, the irradiation of the sun is randomly reflected and refracted through the clouds. This makes the angle of highest irradiation intensity to vary randomly; thus, a tracker is needed.

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