An Experimental comparison study between Single-Axis Tracking and Fixed Photovoltaic Solar Panel Efficiency and Power Output: Case Study in East Coast Malaysia

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ABSTRACT

A sustainable energy supply is required in Malaysia to meet the increasing electricity demand with rapid growing in population and economy. Photovoltaic solar panel is most suitable alternative way to generate electricity in Malaysia where most of its location receives large number of solar radiation throughout the year. However, fixed solar panel is more preferred than tracking panel because it is cost effective. In present work, the power output and efficiency of single-axis tracking solar panel is compared with fixed solar panel by experimentally in East Coast Malaysia. A single-axis tracking panel produces higher power output than fixed panel up to 28W. During this time, the average efficiency of tracking panel was about 66.70% and fixed panel was 39.96%. Hence, the percentage increment on average power output using tracking panel reached up to 66.92% compare to fixed panel during this period. The tracking panel module efficiency was higher than fixed panel for the same period and can reach up to 28.9% at 6.00p.m. In conclusion, single-axis tracking panel is more efficient than fixed panel in premeridian and postmeridian. Thus, it produces higher power output than fixed panel which means it utilize the most of available solar radiation effectively and this will reduce payback period of the initial investment cost.

Keywords: Single-Axis, Solar Tracking, Solar radiation.

INTRODUCTION

A sustainable energy supply is required in Malaysia to meet the increasing electricity demand with rapid growing in population and economy. Solar energy is the most potential renewable energy in Malaysia, whereby most of its location receives abundant solar radiation yearly [1]. The photovoltaic (PV) solar panel is an alternative way to generate green electricity and becoming one of popular technology in Malaysia. Typically in Malaysia, stationary PV solar panel is installed at fixed position at rooftop of a building to harness energy from solar irradiation during daytime throughout the year. Conversely, Bari [2] noticed that not all Malaysian domestic consumers installed their PV solar panels at an optimum orientation and tilt angle. Eventually, it reduces the incoming solar irradiation onto panel to 10-35% less than properly installed solar panel. Thus, an optimum orientation and tilt angle can increase the yearly gains for installed fixed solar panel.

However, the properly installed fixed panel is also operating less efficient at some point compared to tracking panel due to sun's motion on daily and yearly basis. Therefore, employing a tracking panel will generate higher electricity and more efficient as compared to fixed panel [3-5]. The performance of passive tracker using mechanical system has been found to be comparable to active tracking system. Even so, passive tracker system has not yet been widely accepted by the consumer even though the cost is often less expensive [6]. Abdallah [7] perform an experiment to investigate the performance of vertical axis tracking system and horizontal south-north single-axis tracking system. He found that the performance of vertical axis was better than horizontal axis solar tracking system. A simple single-axis tracking solar panel was designed using PIC microcontroller for controlling the mechanical movement based on the predetermined position of sun [8-10]. The result shows that more than 20% daily power output is generated by tracking system in comparison to a fixed panel. The increment of power output of a solar tracking system was about 20 to 40% as compared to fixed solar panel. However, an external energy such as electrical and mechanical equipment is required to keep the solar panel position always perpendicular to the sun irradiation and transfer it into useful form of energy.

A horizontal single-axis tracking system was developed for this project. The purpose of this paper is to perform an experimental comparison study between single-axis tracking and fixed PV solar panel efficiency and power output in East Coast, Malaysia. The experimental study on a clear sky and partly cloudy day at this part of Malaysia has not been done yet. Furthermore, the module efficiency comparison between tracking and fixed panel has never been done yet.

METHODOLOGY

Experiment set-up and procedure

The experiment was conducted on a clear sky and partly cloudy day at 3.5˚N, 103.42˚E Pekan Campus, University Malaysia Pahang by using two units of PV monocrystalline solar panel with specification as shown in Table 1. The horizontal global solar irradiation was measured using calibrated pyranometer with maximum irradiance measurement up to 2000 W/m^2 and sensitivity of 5 to 20 $\mu V/W/m^2$. The both panels were installed side by side with an adequate space and tilting towards due south at angle of 10˚ as shown in Fig. 1. The voltage, ampere, power, and energy output from PV solar panel were measured using digital watt meter with maximum measurement up to 6554W and 0.1W resolution. Both PV solar panels have connected to digital watt meter separately and all the readings were taken simultaneously are recorded in an interval of 15 minutes from 9.00a.m until 6.00p.m.

Table1: Specification of PV Panel

Type	Value
Dimensions (mm)	980 x 445 x 35
Type	Monocrystalline
Weight (kg)	6.1
Number of cells	36 (12 x 3)
Max Power Output (W)	50
Power Tolerance (%)	±3
Module Efficiency (%)	10
Normal Operating Cell Temperature (˚C)	44.4±2

Development of Single-Axis Tracking system

The analysis of structural and selection of material for test rig were done using autodesk algor simulation. The CAD drawing in Figure 2 shows PV solar panel was attached to a hollow shaft that allows the panel to rotate at vertical axis. The hollow shaft was fixed to the bearing at base structural. A 12V DC motor with worm gears was used this project. The worm gears able to hold the PV solar panel in same position even though the motor is offline or no power supplied. A reduction gear chain system used to increase the torque output on shaft. The gear ratio was 40:12 or 3.33.

An active tracker type of single-axis tracking system was used to track the position of sunlight which includes a PIC microcontroller and electro-optical sensor. The single-axis tracking system was designed to track the sun position by comparing the analog signal from Light Dependent Resistor (LDR). The both LDRs were separated by acrylic board and its height adjusted to required sensitivity for the tracking system. Motor rotate clockwise if analog signal from LDR 1 is greater than LDR 2 and anticlockwise if vice versa. The motor keep rotates until the both LDRs analog signal are equal and then stop as shown in Figure 3. The solar tracking system follow the instantaneously sun motion at all the time and reset to its original position at 7.00p.m.

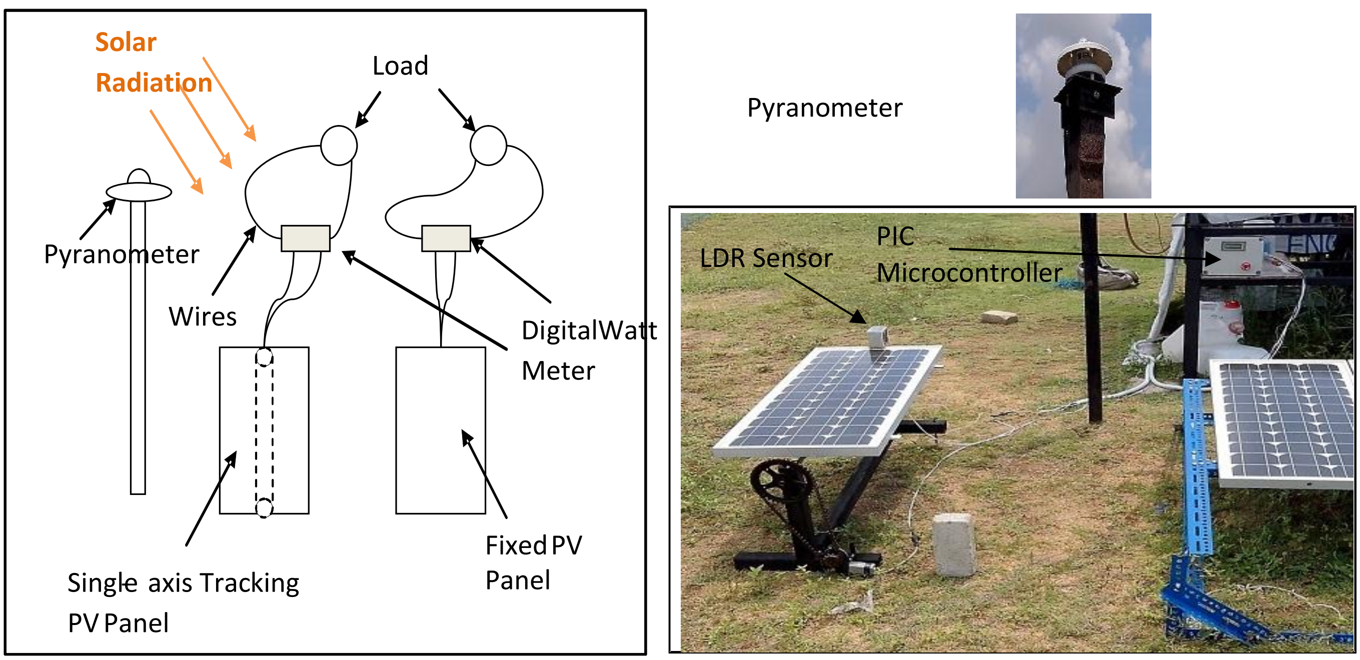

Figure 1. Schematic diagram and actual photograph of PV Solar Panels

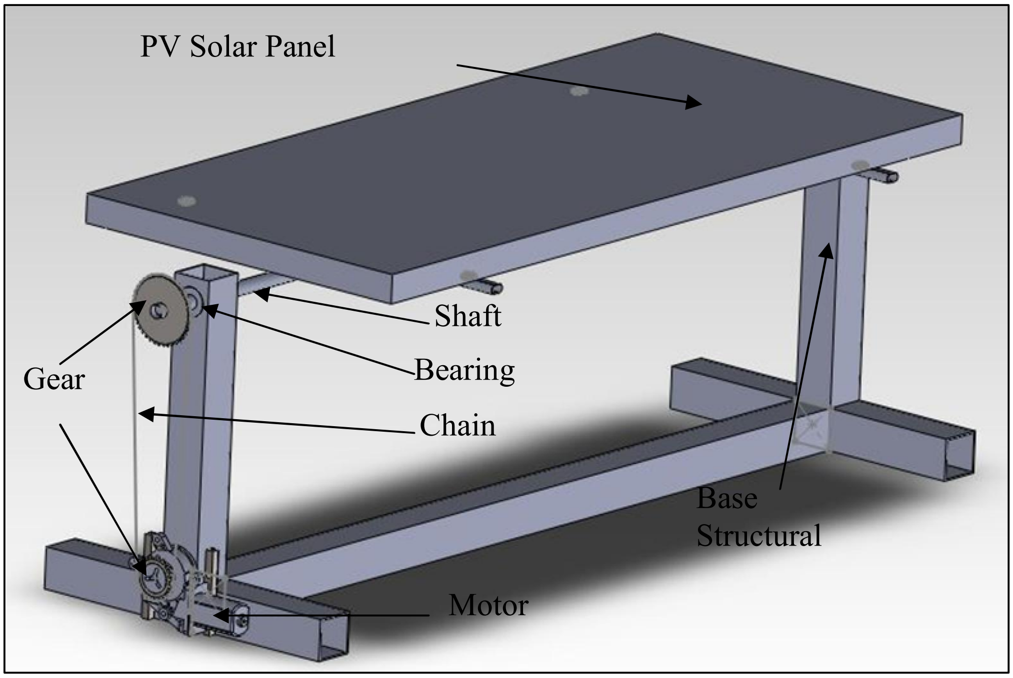

Figure 2. CAD drawing of Single-axis tracking PV

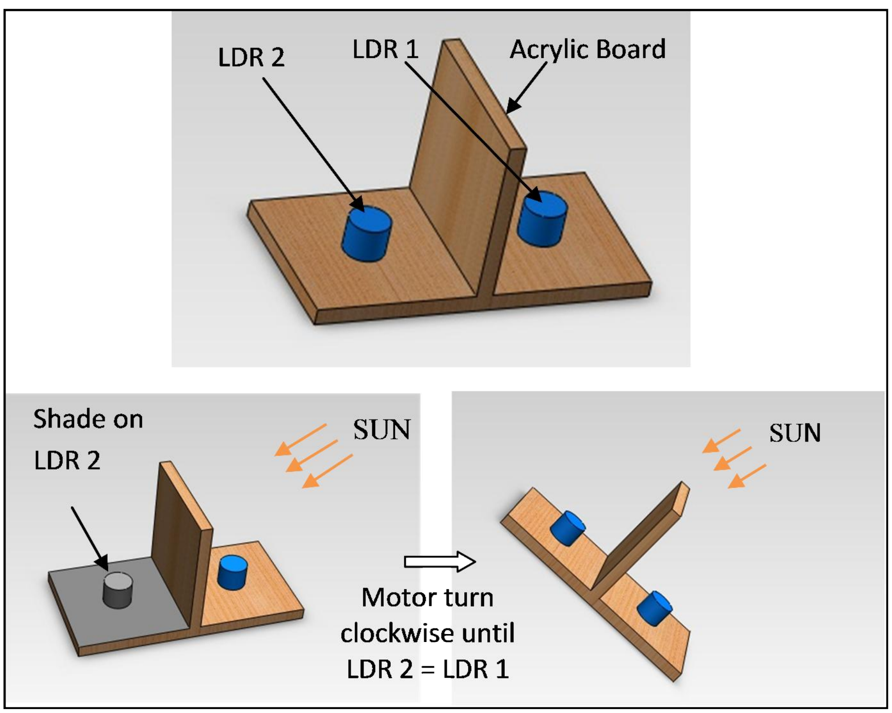

Figure 3. Tracking system working principle using LDR

Efficiency Calculation
The solar panel efficiency was calculated using Eq. 1[11];

$$\eta_p = \left(\frac{P_o}{P_{\max}} \right) \tag{1}$$

Where, η_p is PV solar panel efficiency, P_o is power output from panel and $P_{\max}$ is maximum power output of the panel.

The module efficiency of PV was evaluated using Eq. 2 [11];

$$\eta_m = \left(\frac{P_o}{A_c \cdot G} \right) \tag{2}$$

Where, η_m is module efficiency, P_o is power output from panel, A_c is area of PV solar panel and G is horizontal global solar radiation.

RESULTS AND DISCUSSION

On a Clear sky day
Experiment was conducted on a clear sky day and partly cloudy day. These two diurnal patterns were commonly observed in Pekan, Malaysia throughout the year. On a clear sky day, it was observed the solar irradiation increase steadily until it reaches its maximum intensity about 950W/m^2 by midday and gradually decreases after 3.00p.m and reached about 215W/m^2 at 6.00p.m as shown in Fig. 4. Meanwhile, the power output from single-axis tracking and fixed PV solar panel are also plotted in the Fig. 4. The single-axis tracking panel produce a steady power output approximately 30-35W throughout day from 9.00am until 6.00pm. This is because the tracking sensor always locates the maximum solar irradiation and point the panel towards its direction. In contrast, the fixed panel power output follows quadratic pattern as distribution of solar irradiation for the entire day. It was observed that before 11.00a.m and after 3.00p.m, the power output produced by fixed panel was uneven and comparatively smaller amount than tracking panel.

Nevertheless, fixed panel is also able to produce equal power output as single-axis tracking panel when sun position perpendicular panel during the midday. This is clearly shown in Figure 5 that during the midday additional power gain from single-axis tracking panel is less than 2.5W and nearly to zero. Furthermore, it was observed the additional power gain from tracking panel during morning and evening can reach up to 28W. Thus, the tracking solar panel is able to produce steady power output throughout the day whereas fixed panel is highly dependent on solar irradiation and its sun's position.

The total energy output for a clear sky day from single-axis tracking was 280Wh is shown in Figure 6. The tracking panel has produced about 32.7% higher energy output compared to fixed panel on the particular day. This finding is comparable with investigator discussed in literature earlier.

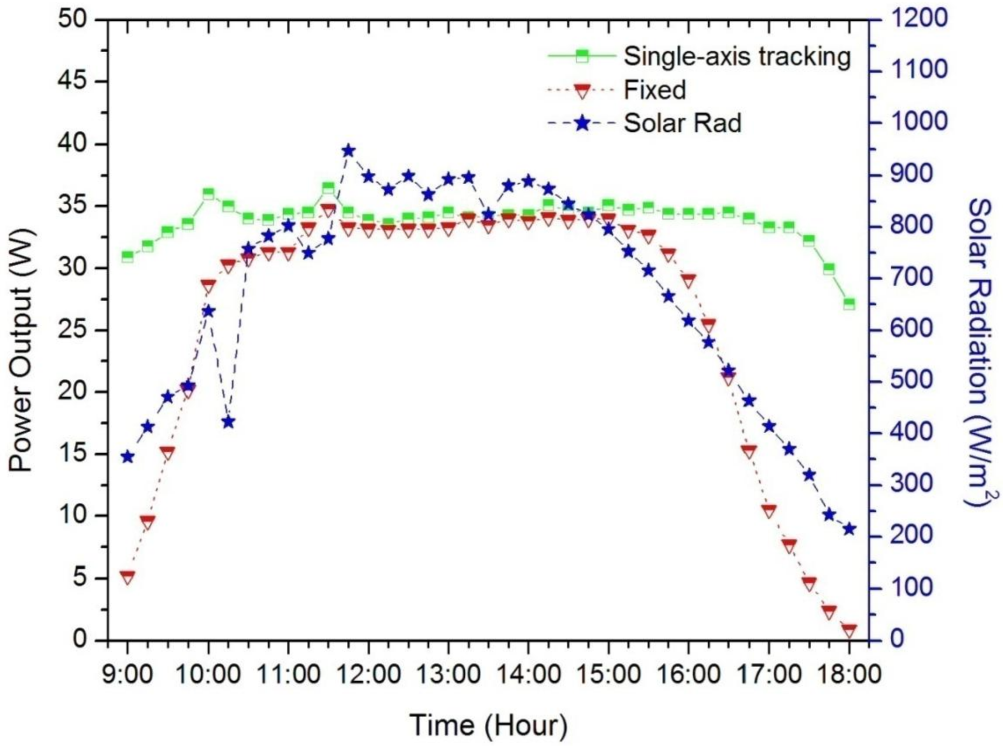

Figure 4. Power output comparison between single-axis tracking and fixed solar panel on a clear sky day

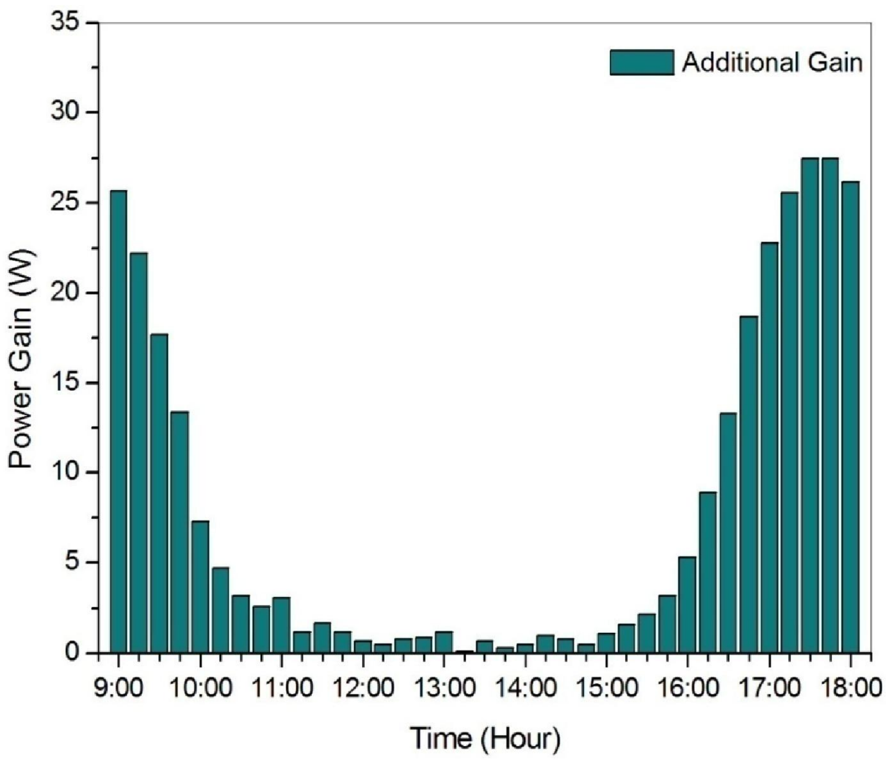

Figure 5. Additional power gain from single-axis tracking solar panel on a clear sky day

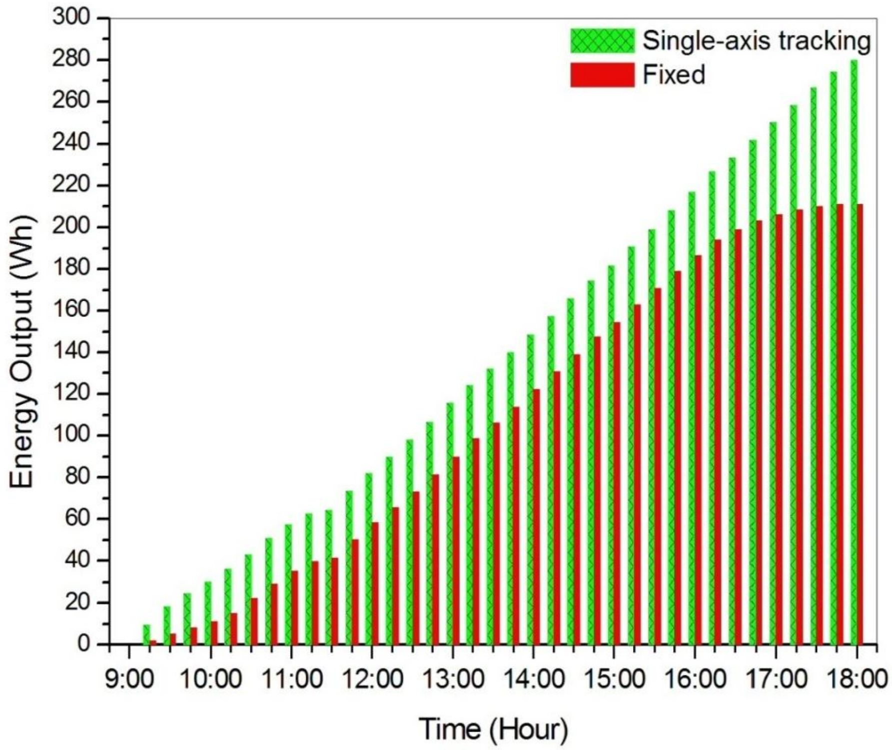

Figure 6. Total energy output from single-axis tracking and fixed solar panel on a clear sky day

On a Partly cloudy day

On the contrary, the solar irradiation on a partly cloudy has irregular pattern due to large number of passing clouds in morning and evening time. However, it reaches its maximum intensity about 1050W/m^2 by midday as shown in Figure 7. The solar irradiation pattern on this day is not predictable as it depends on degree of cloudiness at the time.

Hence, both tracking and fixed panel are not able to produce a stable power output before noontime. Nonetheless, tracking panel produces a stable power output during midday and evening about 35-37W. The power output was higher than clear sky day due to direct incoming solar irradiation after the clouds cleared. The fixed panel power output follows exact pattern as distribution of solar irradiation for whole day.

The most additional power gain from single-axis tracking panel on this day was after 3.00p.m to 28W 6.00p.m as seen from Figure 8. The total energy output for partly cloudy day from single-axis tracking was 242Wh is shown in Figure 9. The tracking panel has produced about 28.0% higher energy output compared to fixed panel on the day.

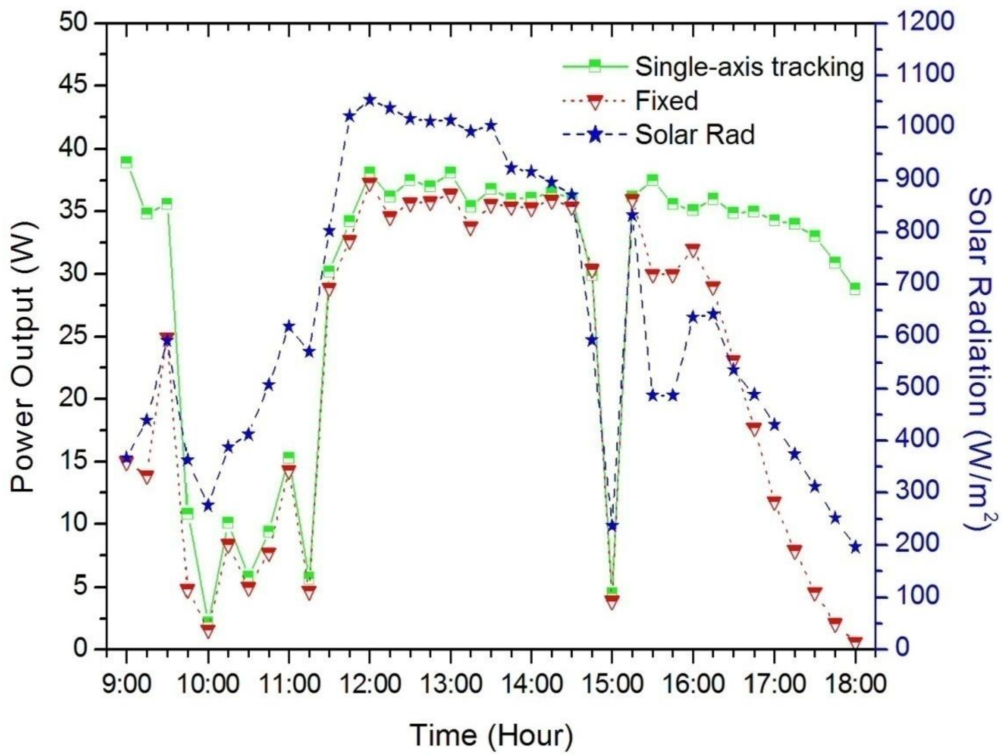

Figure 7. Power output comparison between single-axis tracking and fixed solar panel on a partly cloudy day

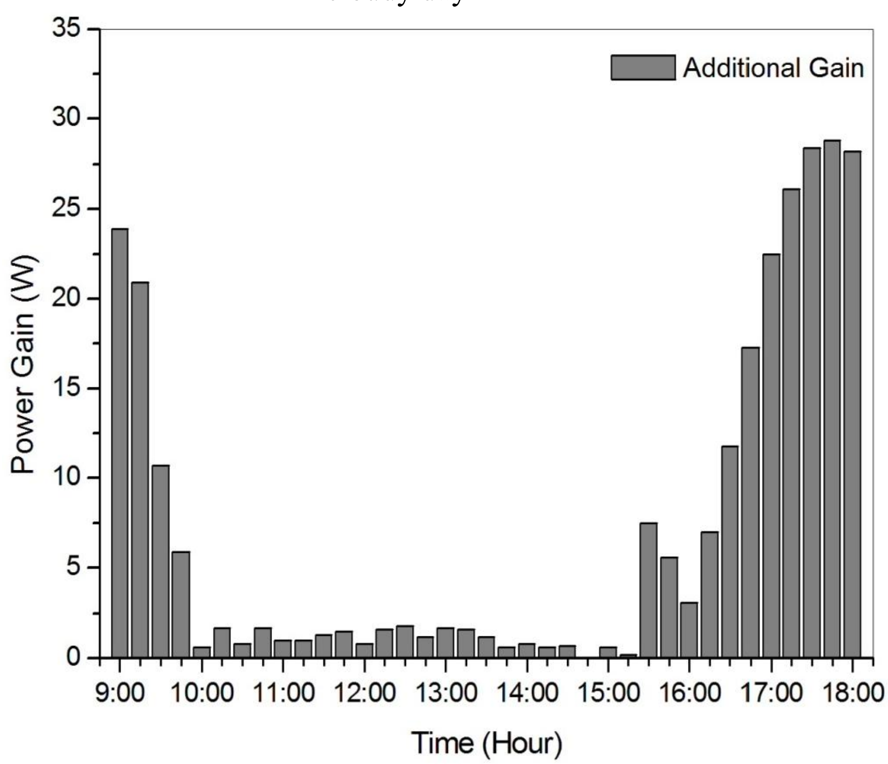

Figure 8. Additional power gain from single-axis tracking solar panel on a partly cloudy day

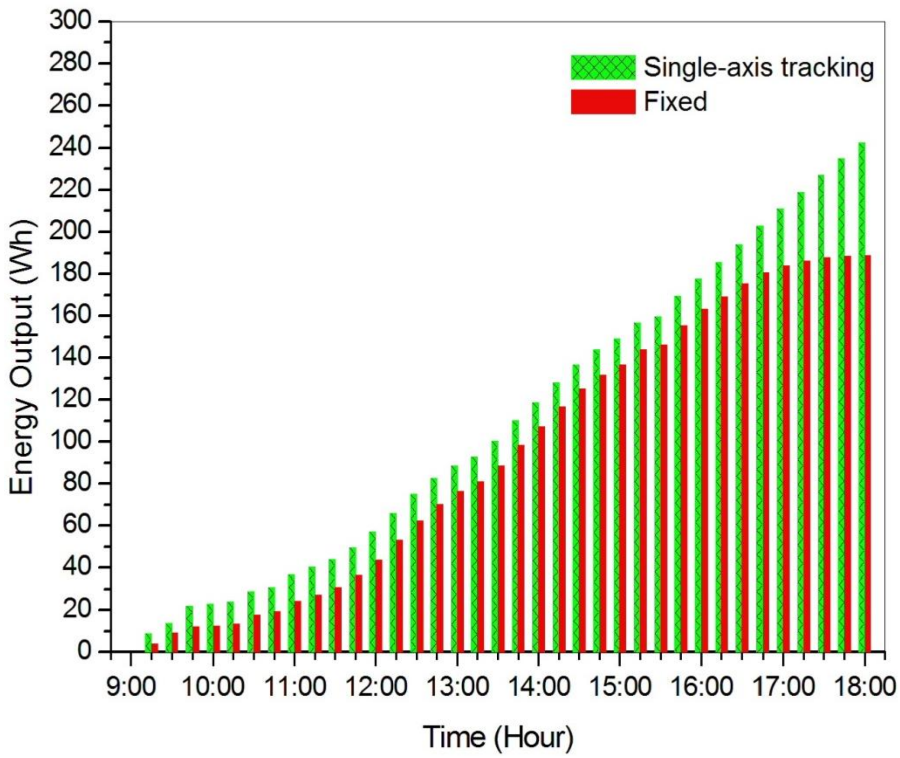

Figure 9. Total energy output from single-axis tracking and fixed solar panel on a clear sky day

Efficiency of PV solar panel

On a clear sky day, average panel efficiency for the single-axis tracking panel was about 67.65% for the entire day as shown in Table 2. Meanwhile, fixed panel was only about 51.65% for the same day. The percentage increase on average power output by the tracking panel over the fixed panel was 30.12%. However, tracking panel produce higher power output than fixed panel is before 11.00a.m and after 3.00p.m. During this time, the average efficiency of tracking panel was about 66.70% and fixed panel was 39.96%. Hence, the percentage increment on average power output using tracking panel reached up to 66.92% compare to fixed panel during this period. Similarly, the tracking panel module efficiency was higher than fixed panel at same period and can be reaching up to 28.9% at 6.00p.m as seen from Table 3. In addition, module efficiency of both panels were relatively equal during midday with maximum difference was only about 0.3%. This is because the both panels received equal amount solar irradiation from the sun and its direction was perpendicular to the panels. For partly cloudy day, average panel efficiency for the single-axis tracking panel was about 61.22% and fixed panel was only about 46.61% for the whole day. Thus, percentage increment on average power output was about 31.37% and it is comparable with clear sky day which was only 1% in difference. Even so, before 11.00a.m and after 3.00p.m the average efficiency of tracking panel was about 56.80% and fixed panel was 32.67%. Therefore, the percentage increment on average power output using tracking panel reached up to 73.81% compare to fixed panel during this time. Likewise, the tracking panel module efficiency was higher than fixed panel at sunset and reached about 33.7% at 6.00p.m. Besides, it was noticed that module efficiency both panels were follow the solar irradiation during midday and the maximum difference was only about 0.6%.

Table 2: PV Solar Panel Efficiency

Day Condition	Panel	Average of Entire day		Average before 11.00am and after 3.00pm	
		Average Power Output (W)	Average Panel Efficiency (%)	Average Power Output (W)	Average Panel Efficiency (%)
Clear Sky	Tracking	33.82	67.65	33.35	66.70
	Fixed	25.83	51.65	19.98	39.96
Partly Cloudy	Tracking	30.61	61.22	28.40	56.80
	Fixed	23.30	46.61	16.34	32.67

Table 3: Module Efficiency

Day Condition	Panel	Time									
		9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm
Clear Sky	Tracking	20.0%	13.0%	9.8%	8.7%	8.9%	8.8%	10.1%	12.7%	18.4%	28.9%
	Fixed	3.4%	10.3%	8.9%	8.5%	8.6%	8.7%	9.8%	10.8%	5.8%	1.0%
Partly Cloudy	Tracking	24.3%	1.8%	5.7%	8.3%	8.6%	9.0%	4.4%	12.6%	18.2%	33.7%
	Fixed	9.4%	1.3%	5.3%	8.1%	8.2%	8.8%	3.8%	11.5%	6.3%	0.7%

CONCLUSION

The efficiency of single-axis tracking and fixed solar panel was investigated. Few exceptional conclusions can be drawn in this study as follow:

i. Single-axis tracking panel is more efficient than fixed panel only in premeridian and postmeridian.
ii. At noontime or midday, both panels were producing comparable equal amount of power output.
iii. Single-axis tracking produces higher power output than fixed panel throughout the day which means it is utilizing the most of available solar radiation effectively and this will reduce payback period for the initial investment cost of this technology.

An experimental investigation with double-axis tracking system compared to single-axis tracking system should be considered in future work in this part Malaysia.

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