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Analytic Comparison of Dual Axis Tracking System and Fixed Mount Solar Panels

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ABSTRACT
Fixed mounted solar panels come with a drawback of lowered efficiency as a result of not being able to harness the sun rays in a perpendicular direction for most hours of the day. One of the solutions to this problem is using a tracking device to focus the solar panel in the right direction. In this paper, an analytic comparison was carried out on the performance of a dual axis solar tracking device implemented in this work and a fixed mounted solar panel of the same rating. Reading from both solar panels were taken during the sunny hours of the day between 7am and 5pm. It was concluded that the dual axis tracking device performed more efficiently as it produced 25.76% more power than the fixed system.

Keywords: Solar, Dual axis tracking, Arduino,Analytic comparison.

I. INTRODUCTION

Solar energy is one of the renewable energy sources which is gaining so much relevance, credits to its attributes which includes cleanliness and inexhaustibility (Yantidewi, Hadid & Dzulkiflih, 2020). Photovoltaic (PV) solar panels are used to convert energy gotten from the sun into electricity. PV solar panel is made up of large number of solar cells composed of silicon-like semiconductors (Mustafa & Ahmed, 2017). It works by transferring the energy of photons from sunlight that strikes the solar cells to silicon electrons, which then flow through electrodes and the external circuit and generate an electric current.

Despite the desirable features possessed by solar as a source of energy, solar PV technology still has a lot of improvement to undergo in order to be able to replace the conventional sources of energy in use. It still faces the challenge of maximizingefficiency for systems in areas without large amount of solar irradiation.

One way of improving the power output of solar panels is incorporating a tracking system in order for the panel to be aimed at the direction having the maximum irradiation per time (Robert et al., 2024). The most obtainable PV panel mounting method is roof mounting. Roof mounts are commonly used in residential andsmallcommercial applications. Althoughroofmounted solar panels possess advantages such as space economy and ability to withstand adverse weather conditions such as strong winds and heavy rain, its drawback is that panel orientation is fixed which implies that it must be out of position of maximum irradiation at most times of the day.

Compared to fixed solar panels, solar panels with tracking systems that can track the positionof the sun have higher solar energycollection capability. This work focuses on comparing the performance a fixed mount solar panel to that which is enhanced with dual axis tracking system.

1.2 Problem statement

The fixed method of mounting solar panels comes with a disadvantage being that most times of the day the sun hits the solar panel at an angle that is not perpendicular to the panel. This does not provide maximum efficiency as some irradiance coming from the sun is not harnessed by the solar panel. This gives rise to the need for a system that tracks the intensity of the sun and faces the solar panel to a direction perpendicular to the sun,thus the system proposed in this paper.

1.3 Aim and objectives

The aim of this work is to compare a dual axis solar tracking system with fixed mounted solar system.

1) To design and construct a dual axis solar tracking system.

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2) To collect readings gotten from a solar panel mounted with the tracking system and another solar panel of equal rating that is fixed mounted.
3) To conduct an analytic comparison on their performance with the two sets of readings.

II. LITERATURE REVIEW

(Noor, Mohamad&Muhammad, 2023) did an overview of a low-cost active dual-axis solar tracking system based on Arduino. The study aimed atimproving the solar tracker efficiency and reducing its development. This solar tracking device is intended to optimize the power generation compared to a fixed solar panel installation. The hardware design was implemented with solar panels, light dependence resistors as sensors, Arduino as the main controller and servo motors. Their study showed that the solar tracker can be built with a minimal cost, and it significantly works efficiently for about 4.45% better than the fixed solar panel.

(Chao et al, 2017) in their paper titled Design of Novel Hybrid Control Solar Tracking Systemdescribes a hybrid controlled solar tracking system consisting of sunlight gathering platforms, mechanical structure and MCU controller system which is mainly based on time and light dependent resistors module. They proposed an operating algorithm with an adaptive calibration to solve accumulated error from inaccurate sun positioning model and servo system error of single axis solar tracking system.

(Wenda & Putra, 2020) conducted researchto optimizes the absorption of solar energy in solar panels by designing mechanical systems that can move solar panels in the direction of incoming sunlight. Light-sensitive sensors were used to track the sun. They designed a solar tracking system using two axes, namely rotation axis and the tilt axis. Both axes are driven by servo motors based on light-sensitive sensors.Their test results claimed that by using solar tracking the amount of energy produced was greater than static solar panelsby 55.2%.

III. MATERIALS AND METHODS

3.1.1 Materials

The materials used for this work includes Solar PV panels, light dependent resistors (LDR), current limiting resistors, arduino nano development board, battery, charge controller, servo motors, wires and a welded iron stand.

3.1.2 Methods

The work was approached in two phases. Firstly, the dual axis tracking system was designed and constructed. After the construction of the tracking system the analytic comparison was carried out between a solar panel mounted on the tracking system and an identical solar panel mounted on a fixed surface. The following section articulates the design and construction of the dual axis tracking system. The block diagram of the dual axis tracking system is given in figure 1 below.

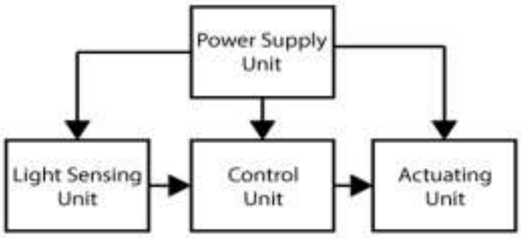

Figure 1 Block diagram of the solar tracking system

The power supply unit is made up of solar panel, a battery and a charge controller which regulates the charging and discharging of the batter. The light sensing unit is made up of four light dependent resistors (LDR) which is connected to four analog pins of the microcontroller. The four LDRs are arranged in a way that at every moment,one is used to sense light coming from the top right side, another one to sense light coming from the top left side, another one to sense light coming from the bottom right side and another one to sense the light coming from the bottom left side respectively.

IV. DESIGN ANALYSIS AND CONSTRUCTION

The system derives its power from a 12V 7.2Ah battery which is charged from the solar panel through a charge controller. Table 1 gives specifications of the solar panel used in this project. It should be noted that these values were derived by the manufacturer under standard test conditions of 1000W/m^2 irradiance and 25℃ temperature.

Table 1 Specifications of the solar panel

Parameters	values
Maximum Power Output (P_{max})	30W
Power Output Tolerance (ΔP_{max})	±3%
Module Efficiency (ηm)	17.2%
Voltage at Pmax (V_{mpp})	17.5V
Current at Pmax (I_{mpp})	1.71A
Open-circuit Voltage (V_{oc})	22.5V
Short-circuit current (I_{sc})	1.92A

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The following equation to calculate the output of the PV array for each time step:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G_T}{G_{T,STC}}\right) [1 + \alpha_P (T_C - T_{C,STC})] \quad \ldots\ldots (1)$$

Y_{PV} = The rated capacity of the PV array under standard test conditions (kW)
f_{PV} = The PV derating factor (%)
G_T = The solar radiation incident on the PV array in the current time step (kW/m^2)
$G_{T,STC}$ = The incident radiation at standard test conditions (1kW/m^2)
α_P = The temperature coefficient of power (%/°C)
T_C = The PV cell temperature in the current time step (°C)
$T_{C,STC}$ = The PV cell temperature under standard test conditions (25°C) (HOMER, 2017).
Two identical servo motors were used for the purpose of rotating the solar panel to the position of the sun. One of the servo motors control the vertical axis rotation or tilt while the other is used for the horizontal movement or azimuth respectively. The specifications of the servo motor are shown in table 2 below.

Table 2 Specifications of the servo motor

Parameter	Values
Operating voltage	5-8.4V
Maximum current	2.3A
Speed	60degrees/0.11sec at 8.4V
Torque	35kg.cm at 8.4V and 2.3A

Calculations were done after fixing the bracket for mounting the solar panel to the servo motors in order to ensure that the motors will be able to comfortably move the panel. This was derived as follows:

$$T = wd \quad \ldots\ldots (2)$$

Where w = weight of object; d = moment arm of the object. (distance from object to servo motor shaft). For this project, weight of the solar panel and bracket assembly = 3.4kg and distance from the bracket to the shaft of the servo motor = 9.8cm. Therefore, the required servo rating can be approximated as $3.4 \times 9.8 = 33.32 kg.cm$. The closest rating to the actual value is a 35kg.cm servo motor which is used in this project.

Four light dependent resistors were used for this project. the specifications of the LDRs are given in table 3 below.

Table 3 Specification of the light dependent resistors

Parameters	Values
Model	5528
Withstand voltage	150V
Maximum power	90MW
Ambient temperature	$-30°C\ to\ 70°C$
Bright resistance	$8K\Omega - 20k\Omega$
Dark resistance	1MΩ
Response time	30ms
Central wavelength	540NM

Each LDR was connected with a 10kΩ resistor to form a voltage divider in order for the microcontroller to be able to read the brightness value. The microcontroller interprets the readings as voltage. The following formular is used to calculate the voltage read by the microcontroller.

$$V_{out} = V_{in}\left(\frac{R_2}{R_1 + R_2}\right) \quad \ldots\ldots (3)$$

Where R_2 is the value of the resistance of the light dependent resistor, R_1 is the value of the voltage dividing resistor, V_{in} is the input voltage from the microcontroller which is 5V and V_{out} is the read voltage from the voltage divider which is sent to the analog pin of the microcontroller.
From the specified value of the of the LDRs, maximum value of V_{out} will be:

$$V_{out}\,max = V_{in}\frac{R_{2\,dark}}{R_1 + R_{2\,dark}} \quad \ldots\ldots (4)$$

$$V_{out}\,min = V_{in}\frac{R_{2\,bright}}{R_1 + R_{2\,bright}} \quad \ldots\ldots (5)$$

$$V_{out}\,max = 5 \times \frac{1 \times 10^6}{(1 \times 10^3) + (1 \times 10^6)} = 4.99V$$

$$V_{out}\,min = 5 \times \frac{20 \times 10^3}{(1 \times 10^3) + (20 \times 10^3)} = 3.33V$$

The arduino development board has a 10bit analog to digital converter therefore it resolves the input voltage as a 10bit number. This means that it will map input voltages between 0 and 5 volts into integer values between 0 and 1023. The $V_{out}\,max$ and the $V_{out}\,min$ will be resolved into 10bit number as follows:

$$max\,resolution = \frac{4.99}{5} \times 1024 = 1022$$

$$min\, resolution = \frac{3.33}{5} \times 1024 = 682$$

Figure 2 gives the algorithm flowchart for the device operation.

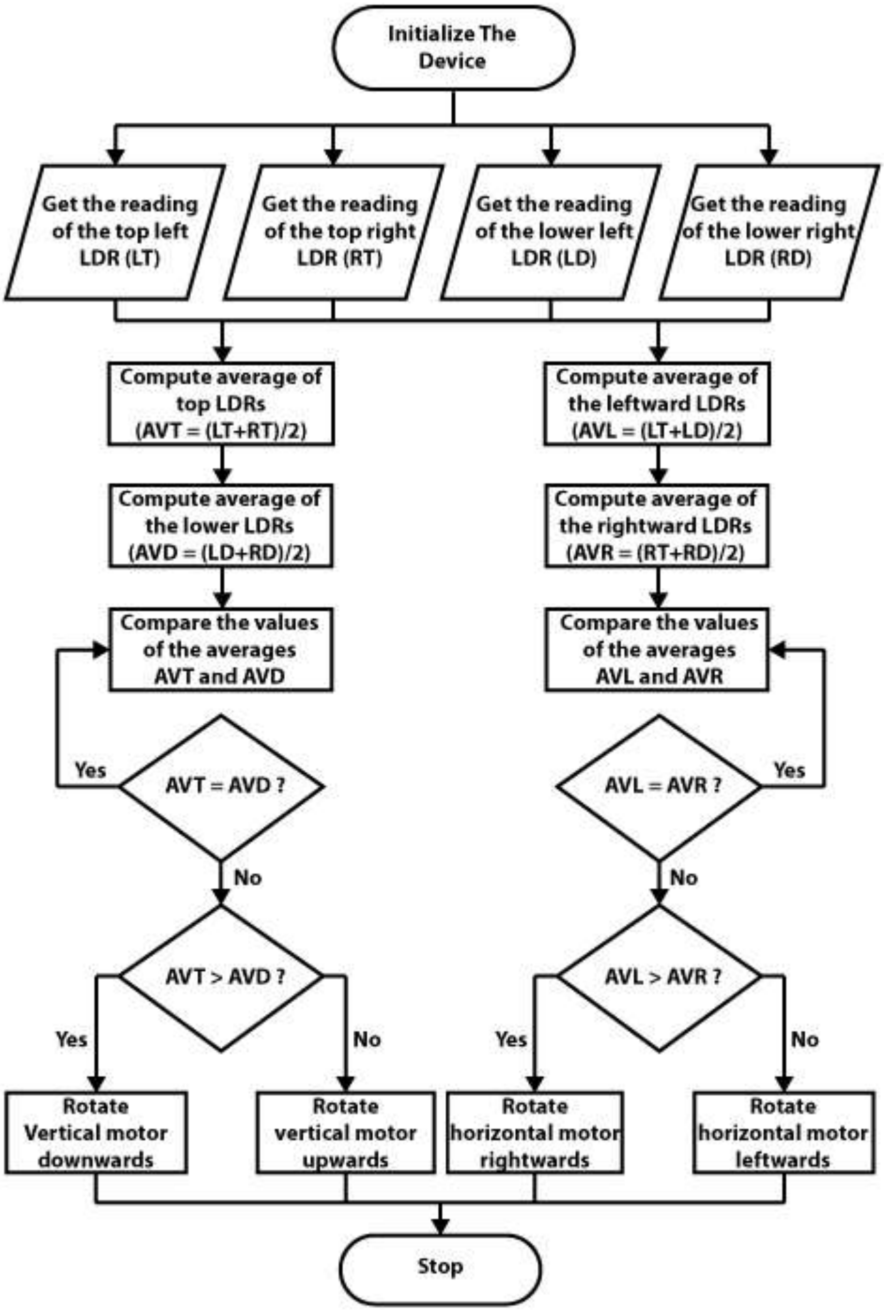

Figure 2 Flowchart for the operating process of the device

The solar panel is connected to the charge controller which charges the battery. Control pins of the horizontal and vertical servo motors were connected to digital pin 9 and 10 of the arduino nano board respectfully. The Vcc pins and the GND pins of the of the servo motor is connected to the positive terminal of the battery and the negative terminal of the battery respectively. The four LDRs are connected in voltage divider format with four 10k resistors. One of the terminals each LDR is connected to the 5V pin of the arduino board, then the other end which is a terminal from the 10k

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resistor is connected to GND pin of the arduino board. The junction connecting each LDR and resistor is connected to an analog pin. Analog pins A0, A1, A2 and A3 were used for the connection of the junctions respectively. The circuit diagram of the work is given in figure 2 below.

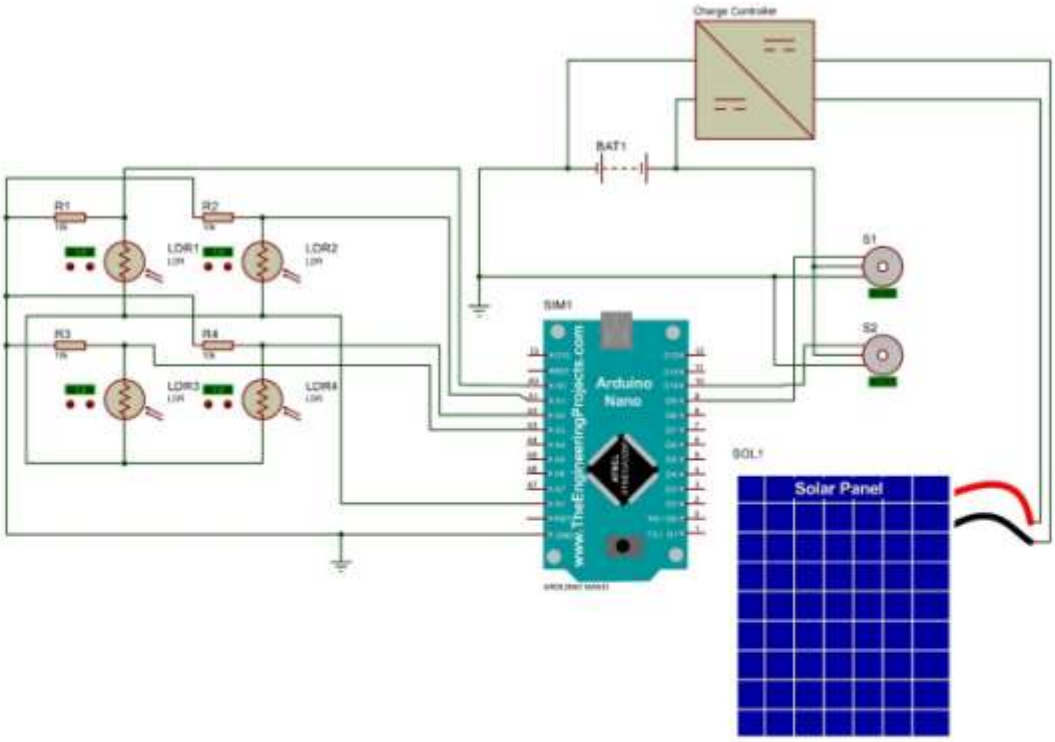

Figure 3 Circuit diagram of the solar tracking system

A printed circuit board was used to solder components of the circuit permanently.The microcontroller unit was placed ina 6in X 3in plastic casing which adequate holes were opened for the peripheral deviceconnections. The entire device and the solar panel were mounted on a metal pole with a heavy base for stability purpose.Figures 4 below shows the completed product.

Figure 4 The complete assembly of the dual axis tracking device

V. TESTING AND RESULT

5.1.1 Testing of the dual axis solar tracking device

Firstly, a basic test was carried out in the dark using a flashlight. The flashlight was pointed towards the device but at different angles per time. The solar panel was seen to rotate and face the direction of the light form the flashlight which indicates that the light sensing unit, the control unit and the actuating unit of the device is properly functioning.

5.1.2 Analytic comparison of the fixed solar panel and the tracking system

The next test was carried out outdoors on a sunny day. The information on the weather was gotten from the NASA weather forecast website. The test was carried out in Unwana, which is a community located in Ebonyi state in the South-East geo-political zone of Nigeria. The coordinates according to GPS are Latitude 5.524°N and Longitude 7.567°E (Onojo, Nkwachukwu & Njoku, 2018). Its climate condition is the tropical savannah type, known as tropical wet and dry climate. Areas with this climate type have almost equal durations of rainy and dry weathers (Richter, M. 2014). The average solar irradiance of the area is 4.71kWh/m2/day and the average annual temperature is 24.91℃.Table 4 shows the monthly average irradiance and temperature of the study location while Figure5is a chart representing the data in the table.

Table 4 The average monthly irradiance, clearance index and temperature of Unwana community (NASA, 2021)

Month	Daily Radiation ($kWh/m^2/day$)	Clearness index	Temperature (℃)
January	5.530	0.588	25.350
February	5.590	0.562	25.760
March	5.532	0.512	25.680
April	5.090	0.488	25.770
May	4.720	0.466	25.650
June	4.310	0.435	24.770
July	3.850	0.386	24.050
August	3.770	0.368	23.940
September	3.940	0.381	24.150
October	4.270	0.426	24.450
November	4.840	0.510	24.680
December	5.290	0.576	24.710
Average	4.71	0.476	24.91

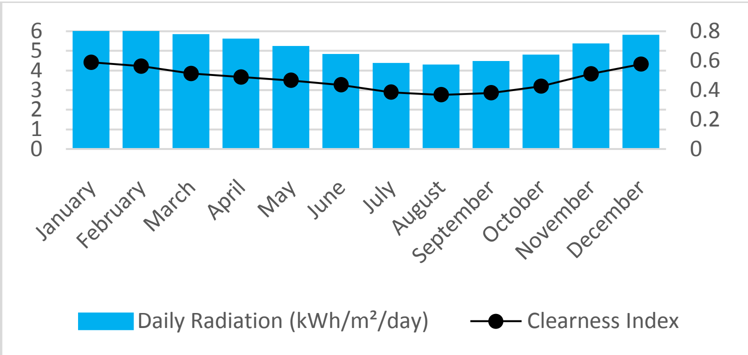

Figure 5 Chart showing the monthly average irradiance and clearness index of Unwana

The test was carried out on 14th of November 2023 in time ranging from 7am to 5pm. From the data retrieved from NASA, it shows that the location has an average irradiance of 4.84kWh/m^2/day during the period of the year the test was conducted. The fixed mount solar panel and the solar panel with the dual axis tracking system were simultaneously exposed to sunlight for the period the test was conducted. It was ensured that the test was carried out in an open spacethat had no objects around that will cast shadow or shade the panels.

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The fixed mounted solar panel was faced true south which corresponds to an azimuth of 180° and the tilt angle was positioned at30°.The first noticeable incident of sunrays was in the direction of approximately 84° east measured from a digital compass. The tracking device was noticed to follow the direction of the sun accurately. Throughout the test period, it was observed that the device tracked the sun by rotating according to change in direction of the sun. The readings of the open circuit voltage and the short circuit current from the fixed solar panel is given in the table 5 while readings for the tracked system is given in table 6 below. Their calculated power outputs in watts are also given in the tables. The power output at the hour mark was calculated with the following formular:

$P = V_{OC} \times I_{SC}$ (watts)

Table 5 Test readings from the fixed solar panel

Time	**Open-circuit voltage** (V_{OC})	**Short circuit current** (I_{SC})	**Calculated power(P)**
7am	8.6	0.48	4.13
8am	9.9	0.52	5.15
9am	10.3	0.64	6.59
10am	13.8	0.87	12.0
11am	14.3	1.08	15.44
12pm	20.6	1.73	35.63
1pm	21.8	1.84	40.11
2pm	21.5	1.79	38.49
3pm	20.9	1.76	36.78
4pm	19.8	1.69	33.46
5pm	17.6	1.53	26.93

Table 6 Test readings from the tracked solar panel

Time	**Open-circuit voltage** (V_{OC})	**Short circuit current** (I_{SC})	**Calculated power (P)**
7am	14.3	0.76	10.87
8am	15.5	0.96	14.88
9am	16.4	1.22	20.01
10am	18.4	1.54	28.34
11am	18.6	1.60	29.76
12pm	21.4	1.86	39.80
1pm	22.1	1.90	41.99
2pm	21.8	1.88	40.98
3pm	21.4	1.86	39.80
4pm	21.2	1.84	39.01
5pm	20.8	1.81	37.65

Plots of the open circuit voltage for the fixed system and the tracked system and the short circuit current for the fixed and tracked systems are given in figure 6 and figure 7 respectively.

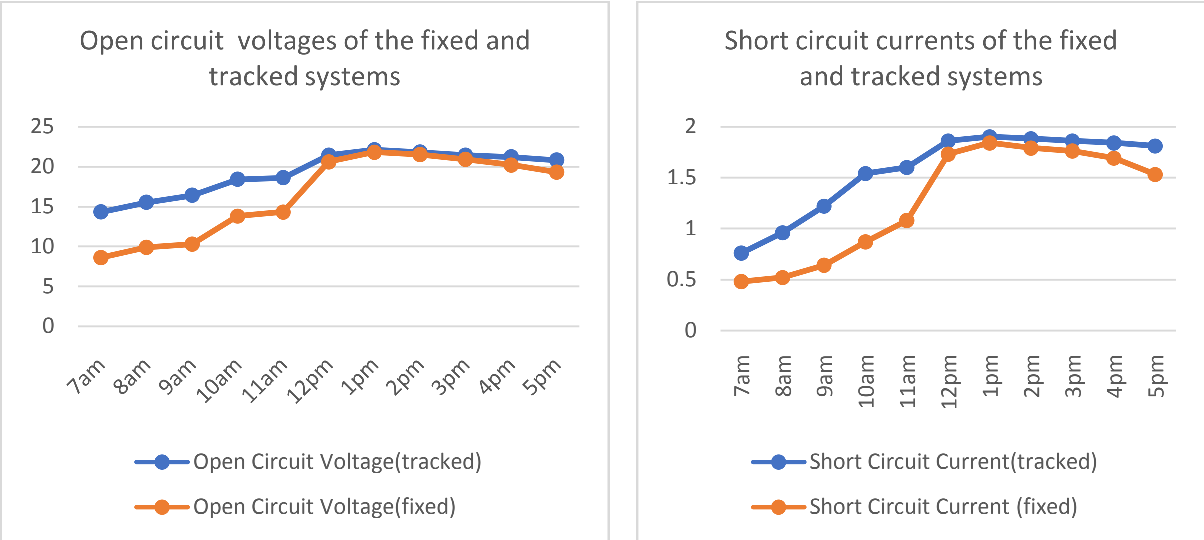

Figure 6 Plots of open circuit voltage and short circuit current for both fixed and trackedsystems

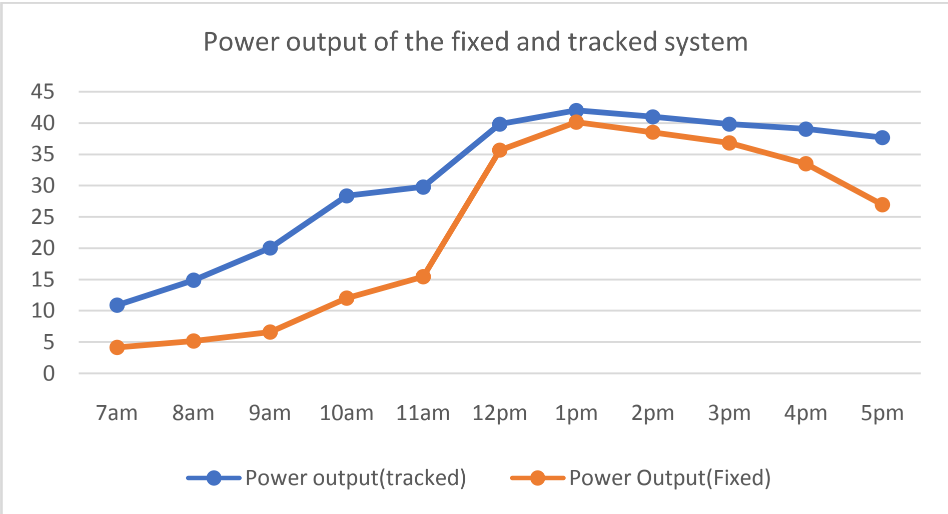

Figure 7 Plots of the power outputs for both the fixed and tracked systems

From the plots above, it can be noticed that the only time the fixed system seems to perform nearly as good as the tracked system is hours of the day when irradiation is at its peak. At other times it can be seen that the output value of the tracked system exceeds that of the fixed system. The calculation to determine the actual figure in percent of the performance difference of both systems based on their recorded power outputs is given in the segment below.

The percentage difference is calculated as follows:

$$\frac{\sum P_{\text{tracked}} - \sum P_{\text{fixed}}}{\sum P_{\text{tracked}}} \times 100\%$$

Where:

$\sum P_{\text{tracked}}$
$=$ sum of the power output of the tracked system
$\sum P_{\text{fixed}}$
$=$ sum of the power output of the tracked system

$$\frac{343.09 - 254.71}{343.09} \times 100\% = 25.76\%$$

From the calculation, it can be seen that the tracked system gives approximately 25.76% percent more power than the fixed system.

VI. CONCLUSION

A dual axis solar system tracking device was designed and successfully constructed and the performance was compared to that of the fixed solar panel system. Output values of both systems were taken and calculations were done. After the process it was conclude that the performance of the system with the dual axis tracking device superseded the fixed system by approximately 25 to 26 percent. The only drawback is that the dual axis tracking device comes with a considerable high-cost implications.

VII. RECOMMENDATION

This viability of this project can be justified in places that require higher efficiency from their solar panels such as industries and manufacturing factories etc.Considering the importance of this work, further development is advised to enhance itsfeature, thus the following recommendations.

1) Larger capacity solar panels should be used in order to obtain more power from the system.
2) The system should employ an MPPT charge controller to further increase the power output.

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