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Design and Performance Analysis of a Low-Cost Dual Axis Solar Tracking System Using LDR Sensors for Developing Countries

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Abstract— The performance of a photovoltaic (PV) system mainly depends on the position of the solar panel with respect to sunlight. Fixed solar panels cannot receive maximum sunlight throughout the day because the position of the sun changes continuously. To solve this problem, this study presents the design and performance analysis of a low-cost dual-axis solar tracking system using Light Dependent Resistor (LDR) sensors and a PIC16F690 microcontroller-based control system. The proposed system automatically adjusts both the horizontal (azimuth) and vertical (elevation) angles of the solar panel to receive maximum solar radiation. A prototype of the system was developed and tested under outdoor environmental conditions in Bangladesh. Experimental results show that the tracking system achieved around 18.29% higher daily energy output compared to a fixed solar panel system. The proposed system provides a good balance among low cost, simple design, and improved performance, which makes it suitable for small-scale and rural solar energy applications, especially in developing countries such as Bangladesh.

Keywords: Solar tracking system, Dual-axis system, LDR sensor, Photovoltaic efficiency, Embedded control, Renewable energy, Maximum Power Point (MPP).

I. INTRODUCTION

Solar photovoltaic (PV) systems are the most promising renewable energy sources to fulfill the ever-increasing energy demand. Energy demand is escalating significantly in developing countries such as Bangladesh due to population explosion, industrial growth, and urbanization. Although the country's national power grid has improved remarkably, rural areas, especially in remote regions, are still plagued by load-shedding and electricity access issues. In these situations, decentralized solar PV system is an economical and sustainable option to generate electricity for lighting, communication, education, irrigation, farming, and small businesses.

A PV system's efficiency is directly related to the amount of solar radiation striking on the panel. Here, the angle of incident radiation is of great importance. Bangladesh is primarily using fixed-type PV panels, which are simple in operation, relatively inexpensive, and require low maintenance. Fixed-type PV panels can't track the continuous change in position of sun throughout the day. Therefore, a significant energy loss can occur, as the PV panel does not receive optimal incident radiation.

Solar trackers are designed to orient the panel towards the sun to capture maximum solar energy. There are two types of solar trackers: single-axis and dual-axis. Dual-axis solar trackers, which adjust the vertical and horizontal movement of the panel to face the sun, are more accurate than single-axis types and the energy output can increase up to 20% than that of fixed position panel. This energy output increase can be very effective in developing countries like Bangladesh, where the solar panel size and space should be optimized. [1]

But most of the solar tracking systems are expensive and complex, so difficult to install and maintain in rural and low-income regions. In most of these cases, tracking of the sun is achieved through a series of sensors (LDR, UV, inclinometer, etc.), a navigation system (GPS, etc.), and other control circuits. Systems like that of [2] are accurate and efficient for tracking the position of the sun, but costly, and difficult to maintain and repair.

Thus, many researchers are proposing sensor-based tracking systems. Light-dependent resistor (LDR) sensor is inexpensive, available, and easy to get, so very common in sensor-based trackers. By sensing different amounts of light, a solar panel can be tracked toward the sun. [3] proposed an improved LDR-based solar tracking system using a wheatstone bridge configuration. [4] presented a dual-axis solar tracker using LDR and RTC, improved solar energy collection with low cost of the system.

Microcontroller-based solar trackers are also gaining much attention, due to the simple controller structure and low cost. At present, mostly Arduino microcontrollers are used. An Arduino-based solar tracking system proposed by [5], improves solar energy absorption. The hardware-based dual-axis solar tracker presented in [6] utilizes feedback control, which is efficient. But [7] stated that the sensitivity of the sensor and the time delay may limit the performance of tracker.

To overcome the problems of cloudy conditions, in some tracker systems, a hybrid control system, i.e., a combination of LDR based and time or GPS-based systems are presented [8, 9]. However, these systems are complex and costly for rural areas.

Recently, techniques like IoT, fuzzy logic, artificial intelligence, and machine learning are applied in solar tracking systems. An IoT-based solar tracker has been developed in Bangladesh for real-time monitoring and remote control [10]. Some researchers use fuzzy logic controller or other intelligent control schemes to improve tracker precision and efficiency [11-13]. These advanced control system generally requires higher computational capability, complex programming skills, and expert knowledge.

The mechanical structure of the tracker is also a crucial parameter for the reliable performance over time. Solar trackers contain mechanical part that is exposed to the outdoor environmental conditions like humidity, dust, rain, and wind. So, difficulty in repair may reduce the system performance over time in a developing country like Bangladesh [14-16]. Therefore, not only tracking accuracy, but the structural designing aspect should also be given consideration while designing a solar tracker, so that maintenance and complexity of the mechanical parts are reduced.

Cost-effectiveness is another major concern for practical implementation. Although dual-axis tracking systems can improve energy generation by nearly 20–30%, the overall implementation cost must remain affordable for low-income users. Several studies have analyzed the economic feasibility of solar tracking systems and concluded that low-cost and simplified designs are more suitable for residential and rural photovoltaic applications [17]–[20].

From the existing literature, it can be observed that many solar tracking systems either provide high performance with high cost or offer simple implementation with limited efficiency. Therefore, there is still a need for a solar tracking system that is affordable, reliable, easy to implement, and capable of improving energy output under real environmental conditions.

In this work, a low-cost dual-axis solar tracking system based on LDR sensors and a simple embedded control technique using a PIC16F690 microcontroller is proposed. The system is designed using easily available components to reduce implementation cost while maintaining satisfactory tracking performance. The proposed design mainly focuses on simplicity, affordability, and practical usability for rural and off-grid applications in developing countries such as Bangladesh. Experimental analysis was

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carried out under outdoor environmental conditions to evaluate the effectiveness of the proposed tracking system in comparison with a conventional fixed-panel setup.

II. SYSTEM DESIGN AND METHODOLOGY

1. System Overview

The work to be carried out concerns the design and implementation of a cheap and simple dual-axis solar tracking control system in order to maximize the energy gain of a PV panel by keeping it closest to the direction of the incident solar radiation at any time of the day.

This system is divided in 3 units that perform a particular function: sensing unit, control unit, and actuation unit. The sensing unit detects the variation of the solar irradiance, the control unit is where the information is processed, where the decision making occurs, and actuation unit physically moves the solar panel position. These units work in a closed-loop system, making sure that the solar panel always tracks the sun.

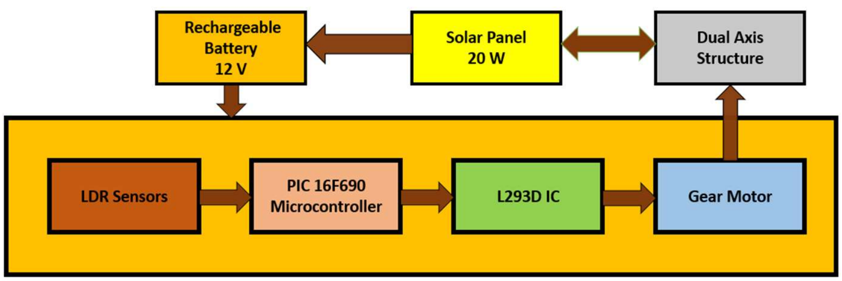

Fig. 1. Block diagram of the solar tracker control system circuit

2. The Sensing Unit

The operation of the system is based on the principle that maximum solar energy is received when sunlight falls perpendicularly on the panel surface. The relationship between received power and the angle of incidence can be expressed as:

$$P = P_{max} cos(\theta)$$

where P represents the actual received power, P_{max} is the maximum possible power, and θ is the angle between the sunlight and the normal to the panel surface. From this relationship, it is evident that the received power is maximized when θ=0∘. Therefore, the tracking system continuously adjusts the panel orientation to minimize this angle.

The sensing unit consists of four Light Dependent Resistor (LDR) sensors placed in the east, west, north, and south directions. These sensors detect the relative intensity of sunlight from different directions.

The resistance of an LDR varies inversely with light intensity, which can be approximated as:

$$R_{LDR} \propto \frac{1}{I}$$

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where I denote the incident light intensity.

Each LDR is connected in a voltage divider configuration to convert resistance variations into measurable voltage signals:

$$\text{Vout} = Vcc \times \frac{R}{R + R_{LDR}}$$

These voltage signals serve as inputs to the control unit for further processing.

3. The Control Unit

The control unit evaluates the relative light intensity by comparing voltage outputs from opposite sensors. The horizontal and vertical differences are defined as:

$$\Delta\text{H} = V_E - V_W, \qquad \Delta V = V_N - V_S$$

where V_E, V_W, ,V_N, and V_S represent the voltages from the respective LDR sensors.

The sign and magnitude of these differences indicate the direction of maximum sunlight. Positive or negative values correspond to directional imbalance along the respective axes.

To prevent unnecessary movement due to minor fluctuations or sensor noise, a threshold value ϵ (epsilon) is introduced. The control conditions are defined as:

$|\ \Delta H\ | < \epsilon$; no horizontal movement

$|\ \Delta V\ | < \epsilon$; no vertical movement

By using this thresholding value, this can improve the stability of the system and the power consumption. Due to the limited range of the operation for the motor.

A PIC16F690 microcontroller is used as the central unit of control. Analog values read by the LDRs sensors were been converted to digital values by the built-in ADC function. The calculation to find the directional difference was done by the PIC16F690 microcontroller with the defined decision algorithm, and a suitable output signal was generated for the actuators. All this is carried out in the endless loop in order to be able to respond in real-time.

The control system follows a simple repetitive loop process. Initially, the voltage from the sensors is being taken. Secondly, horizontal difference (ΔH) and vertical difference (ΔV) is calculated. Decision on how the panel needs to turn is then being made depending on the calculated value compared to the threshold defined (ϵ). If the horizontal difference (ΔH) value is larger than threshold (ϵ), then turning eastern or western would be executed depending on the sign of the difference. And if the vertical difference (ΔV) is larger than the threshold (ϵ), the panel will turn up or down. If both the horizontal and vertical differences are within the range, the motor will stop.

4. The Actuation Unit

This actuator system uses two DC gear motors controlled by an L293D motor driver IC. The L293D is the interface between the microcontroller and the motors; the drivers provide sufficient current and bidirectionality to control them. One motor will be responsible for horizontal (azimuth) position control, and one will be responsible for vertical (elevation) control. Gear motors were chosen for their large torque and steady performance, which is necessary for stable control of the solar panel position.

The orientation of the solar panel can be represented by two angles: azimuth (ϕ) and elevation (θ). The panel surface can be described by a normal vector N, which depends on these angles:

$$\mathbf{N} = \mathbf{f}(\boldsymbol{\theta}, \boldsymbol{\phi})$$

The tracking objective is to align this normal vector with the direction of incoming sunlight S. The alignment error can be expressed as:

$$\textbf{Error} = |\, \boldsymbol{N} - \boldsymbol{S} \,|$$

By minimizing this error, the system maintains optimal panel orientation.

The power consumption of the motors can be expressed as:

$$P_{motor} = V \times I$$

To ensure efficient operation, the motors are activated only when necessary. The threshold-based control significantly reduces unnecessary movements, resulting in a net positive energy gain.

5. System Operation

The system as a whole works on a continuous feedback loop. Solar radiation is sensed by the sensors, transformed to electrical signals, and then processed by the microcontroller. The calculated differences result in the generation of control signals that are passed onto the motor driver, which drives the motors in such a way that the panel faces the sun.

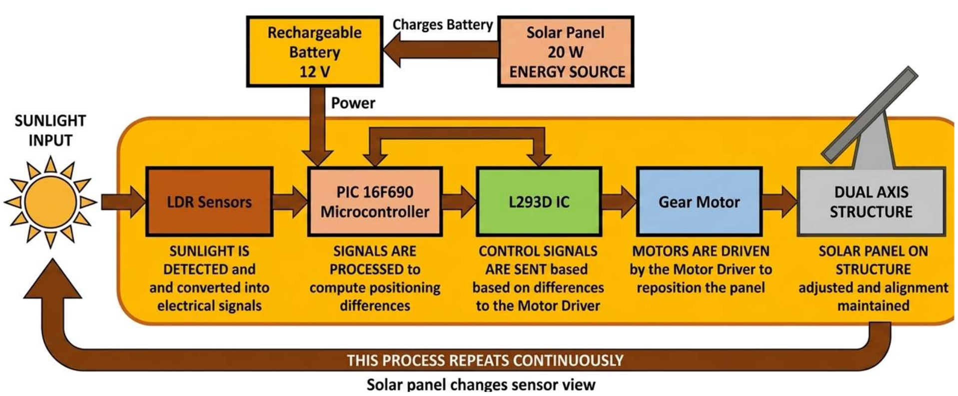

Fig. 2. System Operation Flowchart: Continuous Feedback Loop

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6. Experimental Setup and Data Collection

To compare our fixed-axis and dual-axis solar tracking systems, we tested both setups outdoors using the same 20W solar panels (Model: SNG-20M).

TABLE I. SNG-20M PHOTOVOLTAIC MODULE ELECTRICAL SPECIFICATIONS (AT STC: 1000 W/M², 25°C, AM 1.5)

Parameter Description	Symbol	Value	Unit
Maximum Power	P_{max}	20	Watts (W)
Voltage at Maximum Power	V_{mp}	18.0	Volts (V)
Current at Maximum Power	I_{mp}	1.11	Amperes (A)
Open-Circuit Voltage	V_{oc}	21.2	Volts (V)
Short-Circuit Current	I_{sc}	1.22	Amperes (A)
Maximum System Voltage	V_{sys}	1000	Volts (V)

The panel was directly wired to the ceramic wire-wound rheostat, which was used as the load. No battery was included, as was no charge controller. This was because we wanted to record the raw output power from the panel, not be affected by the changing state of charge of a battery, or limited by a charge controller. The electrical output was recorded by wiring in parallel to the panel a digital voltmeter to measure the voltage (V), and wiring in series a digital ammeter to measure the current (I).

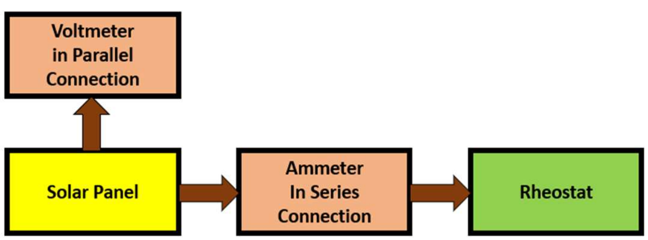

Fig. 3. Experimental Setup for Data Collection

To capture the true Maximum Power Point (MPP), we manually adjusted the rheostat dial at every testing mark. By slowly turning the dial, we found the exact sweet spot where the panel produced its highest possible wattage. This manual tuning mimicked an automatic MPPT controller, keeping our operating voltage high and stable (approx 15.0 V - 15.5 V) instead of letting it drop as the sun went down.

Experimental measurements were carried out during peak solar hours from 11:00 am to 4:00 pm for 10 days randomly, where solar irradiance is relatively stable and near maximum. Outdoor conditions like moving clouds and shifting sunlight can cause sudden, temporary spikes or drops in data. To smooth out this environmental noise, we recorded four separate readings of both voltage (V1, V2, V3, V4) and current (I1, I2, I3, I4) every hour, spaced exactly 15 minutes apart.

At the end of each hour, we calculated the average voltage (V_{avg}) and average current (I_{avg}) from those four raw readings:

$$V_{avg} = \frac{V1 + V2 + V3 + V4}{4}$$

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$$I_{avg} = \frac{I1 + I2 + I3 + I4}{4}$$

Then the data of 10 days are averaged for each time period and noted down for the final performance calculation.

Once we had these stable hourly averages, we calculated the total hourly power (P) by multiplying them together:

$$\mathrm{P} = V_{avg} \times I_{avg}$$

This step-by-step mathematical approach gave us a reliable baseline to calculate and compare the cumulative energy yield (in Watt-hours) for both systems over the testing period.

7. Energy Yield Estimation

The total energy generated over the observation period was determined using discrete summation of the measured power values:

$$\mathrm{E} = \sum P_k \, \Delta t$$

where E represents the total energy **(**Wh), P_k is the power at each time step, and Δt is the sampling interval.

In this study, Δt=1 hour, therefore the energy contribution at each interval is numerically equal to the power value in watt-hours (Wh).

8. Comparative Energy Analysis

The total energy generated by both systems is computed as:

$$E_{fixed} = \sum P_{fixed} \,; \qquad E_{tracking} = \sum P_{tracking}$$

The percentage improvement in energy yield due to tracking is calculated as:

$$\eta_{gain} = \frac{E_{tracking} - E_{fixed}}{E_{fixed}} \times 100$$

9. Project Architecture and Circuit Board

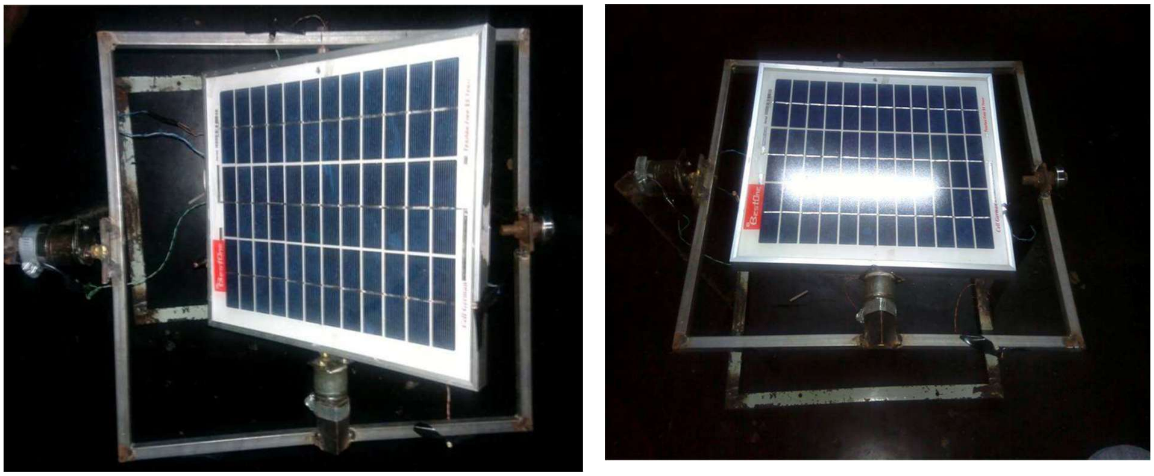

Fig. 4. Dual Axis Solar Tracking System

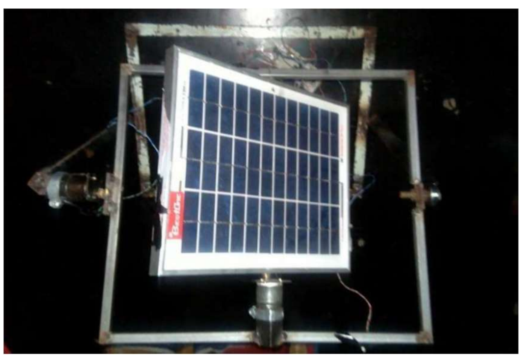

Fig. 5. Dual Axis Solar Tracking System

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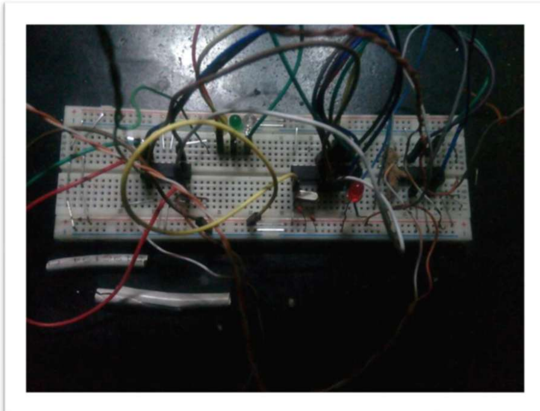

Fig. 6. Circuit Connection in Breadboard

III. RESULTS AND DISCUSSION

1. Data Table

The designed system was tested in an experiment of 20 W photovoltaic panel under the same weather conditions with the other fixed panel to see whether the LDR-tracking mechanism and the threshold-actuated method designed were practical to implement. The data was measured between 11:00 to 16:00 (11:00 am to 4:00 PM) when the sunlight is at its peak. The data are taken for 10 days randomly and the average value for each time period for final calculation. All experimental average data and calculations are shown in Table 1 below.

TABLE II. PERFORMANCE ANALYSIS OF FIXED AND TRACKING SYSTEM (20 W PANEL)

Time	V_{fixed} (V)	I_{fixed} (A)	P_{fixed} (W)	V_{track} (V)	I_{track} (A)	P_{track} (W)	E_{fixed} (Wh)	E_{track} (Wh)
11:00	15.1	0.61	9.21	15.3	0.73	11.17	9.21	11.17
12:00	15.3	0.95	14.54	15.5	1.06	16.43	14.54	16.43
13:00	15.3	0.89	13.62	15.5	1.04	16.12	13.62	16.12
14:00	15.2	0.75	11.40	15.4	0.87	13.40	11.40	13.40
15:00	15.0	0.55	8.25	15.2	0.67	10.18	8.25	10.18
16:00	15.0	0.42	6.30	15.2	0.50	7.60	6.30	7.60
Total	--	--	--	--	--	--	63.32 Wh	74.90 Wh

2. Energy Yield Comparison

From Table 1, the total energy generated by the fixed system is:

E_{fixed}=63.32 Wh

and for the tracking system:

$E_{tracking}$=74.90 Wh

The percentage improvement is calculated as:

$$\eta_{gain} = \frac{E_{tracking} - E_{fixed}}{E_{fixed}} \times 100$$
$$= \frac{74.90 - 63.32}{63.32} \times 100 \ \approx 18.29\%$$

This result clearly demonstrates that the proposed tracking system significantly enhances energy harvesting efficiency even at the prototype scale.

3. Power Variation with Time

We can also see from the power profile that the tracking system has a higher power output over the fixed system during the entire duration of the observation. The difference is largest at solar noon (12 pm to 1 pm), when the angle of incidence changes quickest for the fixed system. This result directly verifies our theoretical model:

$$\mathrm{P} = P_{max} cos(\theta)$$

As the tracking system continuously minimizes θ, it maintains near-optimal alignment with the sun, resulting in higher power output.

4. Effectiveness of Control Strategy

The LDR based sensing with threshold-based actuation control mechanism has been successful in decreasing redundant motor activation, thereby causing a) increased system stability, b) saving energy of the motors, c) increasing the overall system efficiency. The overall energy benefit remains clearly positive, indicating that the energy required for the actuation system is almost nil.

5. Cost–Performance Analysis

The economic feasibility of the proposed system is analysed using the cost estimation presented in Table 2**.**

Table 2: Cost Estimation of Proposed System (10 W Prototype)

Component	Specification	Quantity	Unit Price (BDT)	Total Cost (BDT)
Solar Panel	20 W PV Panel	1	1,400	1,400
LDR Sensors	Standard LDR	4	40	160
Microcontroller	PIC16F690	1	700	700
Motor Driver	L293D Module	1	350	350
DC Gear Motors	12V Low RPM	2	350	700
Power Supply	12V Battery 9 AH	1	2,750	2,750
Mechanical Frame	Mount Structure	1	1,200	1,200
Miscellaneous	Wires, PCB, etc.	--	--	1,000
Total Estimated Cost	--	--	--	7,010 BDT

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The dual-axis solar tracking system, as presented herein, demonstrates a continuous enhancement in terms of the energy generated when compared to the fixed system. The energy gain produced by the dual-axis solar tracking system is in the range of 18.29%, which is considered reasonable for LDR based tracking systems of small power consumption.

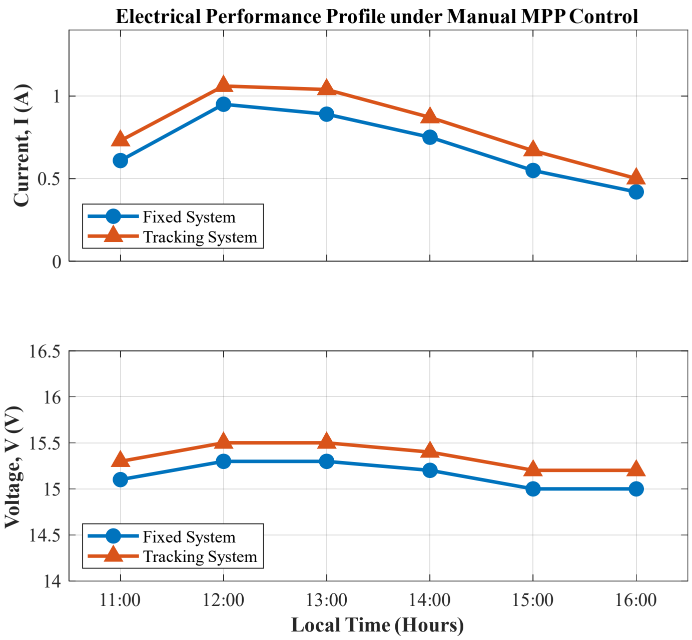

Fig. 7. Current and Voltage Profiles at 12 PM

In order to analyze how both systems performed under the true sun conditions over a whole day, the operation values were measured every hour from 11 am to 4 pm. Fig. 7 shows the operation characteristic, namely, I and V of the dual-axis solar tracker and the fixed panel system.

The operation current (I) throughout the whole day is given in the upper chart of Figure 7. As it can be seen from the operation current, the daily characteristic shows a typical bell shape similar to solar irradiance. From 11 am to 4 pm, the dual-axis solar tracker system always showed a higher operation current than the fixed panel system. The differences between the two operation currents peaked at about 12 pm, with 1.06A from the solar tracker system and 0.95A from the fixed panel system. It shows that the solar tracker system indeed got more direct solar irradiation than the fixed panel system.

The operation voltage under the load is described in the lower chart of Fig. 7. The operation voltages are almost unchanged throughout the day and are within about 15.0 V to 15.5 V. But there was a little decrease in voltage during the hottest noon time between 12 pm and 2 pm, which is due to the high temperature and solar irradiance made the solar cell output voltage to decrease. The operating voltage from the dual axis solar tracker system was always 0.2 V higher than the one from the fixed panel system which means the dual-axis solar tracker system also has better electrical performance at work.

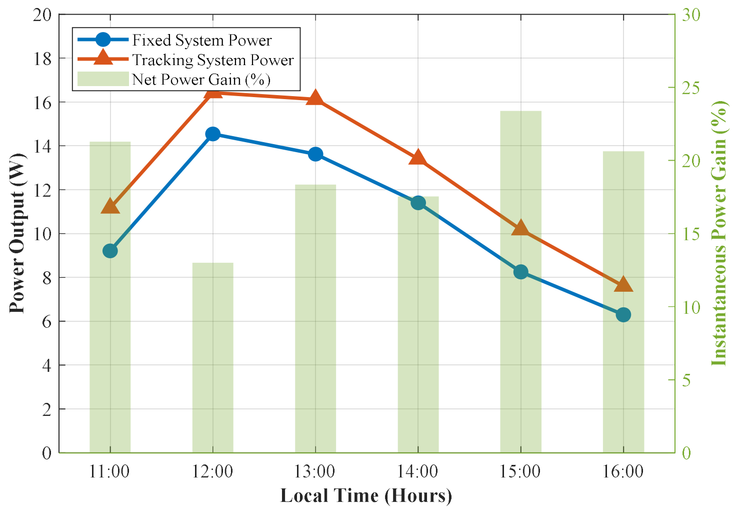

Fig. 8. Power Output and Instantaneous Net Gain

Figure 8 combines the operating current and voltage characteristics to analyze the total power output (left axis) and the instantaneous percentage power gain achieved by the tracking system (right axis). The power curves show that both systems reached their maximum power generation at around 12:00 PM. At this time, the dual-axis tracking system produced a peak power of 16.43 W, while the fixed-panel system generated 14.54 W. After midday, the power output of both systems gradually decreased due to the lower position of the sun in the sky during the afternoon hours.

The green shaded bars represent the percentage power improvement achieved by the tracking system compared to the fixed system at different times of the day. The results reveal an interesting relationship between solar position and tracking effectiveness. Around midday, the tracking system provided the smallest relative improvement of approximately 13.0% because the sun was already nearly aligned with the fixed panel orientation. However, during the morning and afternoon periods, the fixed panel experienced significant geometric losses as sunlight reached the panel surface at larger angles. In contrast, the dual-axis tracking system continuously adjusted its orientation to face the sun more directly. As a result, the relative performance advantage of the tracking system increased significantly, reaching approximately 21.3% at 11:00 AM and about 23.4% at 3:00 PM.

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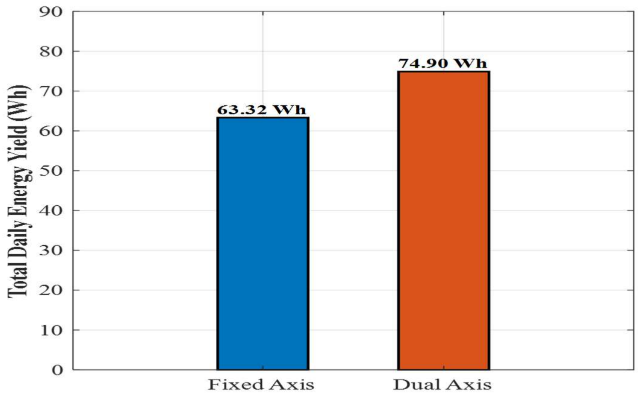

Fig. 9. Total Daily Energy Yield Comparison

Combined with the current and voltage curves of each system operating state, Figure 8 shows the curves of overall power generation (left y axis) and the instantaneous power increase (as percentage) of the tracking system to the fixed panel (right y axis) over time. Both systems have the same maximum generation power around noon, 16.43 W of the two-axis tracking system and 14.54 W of the fixed system. Afternoon, the two power curves decline steadily as the sun's angle declines.

Green shaded bars show the percentage increase in power achieved by the tracking system over the fixed system at a specific time of the day. The results provide interesting information about the dependence of tracking performance on sun location. The minimal power increase (about 13.0%) occurs at noon where the fixed panel already has a nearly optimum angle relative to the sun and tracking effect has least advantage, however when it is morning and afternoon, there is big geometrical losses occurred on the fixed panel due to the increasing angle of the sunlight relative to the panel, while the dual-axis tracking system follows the direction of the sun, therefore it brings great benefit in tracking performance which achieved 21.3% increase in the power generation at 11:00 a.m. And 23.4% at 3:00 p.m.

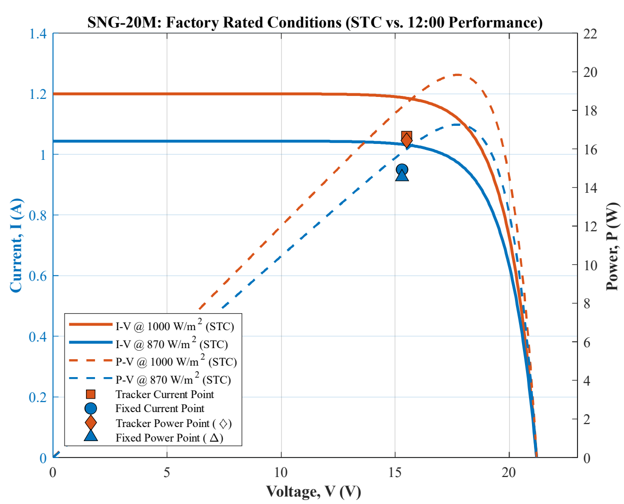

Fig. 10. Performance at 12 PM Relative to Factory Rated Conditions (STC)

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The measured electrical performance compared to ideal STC (1000 W/m, 870 W/m at 25 °C) for the SNG-20M solar panel is illustrated in Figure 10 for both a dual-axis tracked panel and a fixed panel. The solid lines show the Ideal Current-Voltage (I-V) characteristic and the dashed lines shows the Ideal Power-Voltage (P-V) characteristic for each panel, where the operating points of the dual-axis tracked panel and the fixed panel have been plotted on each graph. The tracked and fixed panels are operating at

12:00pm generated outputs of 1.06A and 0.95A respectively, and operated at 15.5V and 15.3V, producing respective power of 16.43W and 14.54W. The measured operating points are evidently below the ideal STC maxima, highlighting that real-world operating losses are unavoidable and influenced by a range of factors including atmosphere, dust on panels, but most significantly, heat on solar cells.

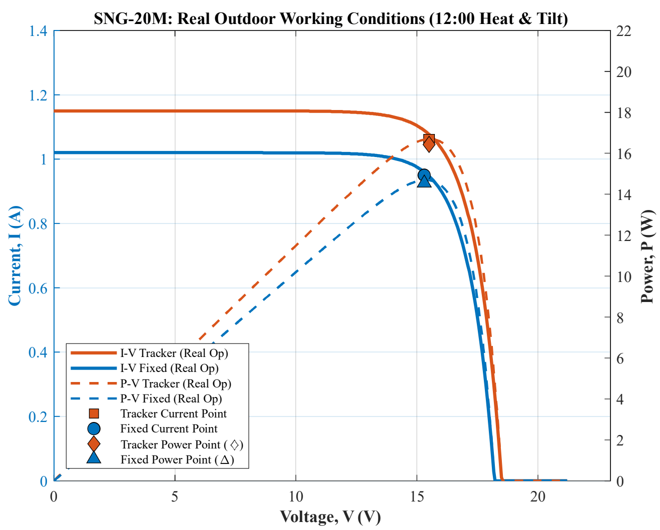

Fig. 11. System Performance Under Real Outdoor Working Conditions

To observe the tracking efficiency on a scale not influenced by environmental losses, the same 12:00 PM data is plotted on mathematically manipulated outdoor operating curves that take thermal and tilt factors into account. The voltage output of the modules fell significantly from the rated 21.2 V to around 18.2-18.5 V in the outdoor scenario because the intense heat of the sun under outdoor conditions reduces the open circuit voltage (Voc) of the solar modules in proportion to the temperature negative voltage coefficient that silicon solar cells have. Comparing with these realistic outdoor curves, the measured operating points fall within very good agreement with the system characteristics: the current operating points lie within the knee region of the operating I-V curves, whereas the power operating points lie within the peak region of the P-V curves, meaning that both systems were nearly operating at their respective maximum power points during midday. So it can be pointed out that;

a) The measurements support that the control hardware as well as the mechanism of MPPT, worked well, so that the panels provided as much power as possible at the operating temperature.

b) The marked difference between the curves for tracking systems and fixed panels illustrates the benefit in geometry for solar tracking systems, for which at noon, the higher effective solar irradiance of 1000 W/m2 compared to the value of 870 W/m2 for the fixed panel resulted in higher generated power.

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IV. CONCLUSION

The objective of this project was to determine the performance of the SNG-20M solar panel in practical real conditions by taking an hourly comparison between a dual-axis tracking system and a fixed solar panel on the roof in outdoor conditions. From this experimental investigation, it has been clearly observed that there are significant discrepancies between the performance of solar panels under real operating conditions and STC, and what it should ideally be. Various environmental conditions influence the behavior of solar panels in real operating conditions and temperature increase is one of the major ones. Due to the negative temperature coefficient of silicon solar cell, an increase in panel temperature at noon reduces the open circuit voltage from the nominal 21.2V to 18.2-18.5V at noon, thus limiting the power output for both of the systems.

Even though thermal loss is unavoidable, it can be concluded that the developed tracking system is working properly from experimental results that at about noon, operating voltage and current points for both of the systems are close to knees on the respective I-V curves and at the peaks of the P-V curves, indicating that manual MPPT is working and it is always possible to extract the maximum possible power out of the modules in real operating conditions, given the temperature losses are accounted for.

It is observed from the hourly data that the tracking system provides greater improvement at times other than around noon, as the position of the sun and the fixed panel at noon closely align, resulting in a smaller instantaneous gain of about 13.0%. In the morning hours, the fixed panel had a large geometric loss because the sun's rays would impinge on the panel at an acute angle, while with proper tracking, it is possible to always get parallel rays, which accounts for an increase in gain up to 23.4% in late afternoon and also at morning hours (e.g., 23.4% at 3:00 PM).

It is found from the data that the dual-axis tracking system yields 74.90 Wh of energy while the fixed panel system yields only 63.32 Wh of energy from 11:00 AM to 4:00 PM, yielding a gain of about 18.29% by the tracker.

Thus, it is confirmed that while fixed panel system can provide satisfactory performance at noon it does not do so effectively for morning and late afternoon hours compared to a dual axis system due to loss from incidence of solar rays and it is indeed beneficial for energy harvest in morning and late afternoon hours, and an overall gain of 18.29% has been observed for a dual axis tracking system which would increase energy generation efficiency of photovoltaic system and hence it is cost-effective at small scale installations like rural Bangladesh.

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