International Journal of Research in Engineering, Science and Management
Volume 8, Issue 2, February 2025
https://www.ijresm.com | ISSN (Online): 2581-5792

Influence of Solar Intensity Variations and Tracking Mechanism on Photovoltaic Voltage Output

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***Abstract*: The efficiency of photovoltaic (PV) systems is heavily influenced by variations in solar intensity and the implementation of tracking mechanisms. Changes in solar irradiance directly impact the voltage output of PV panels, affecting overall energy generation. The experimental setting examined how solar intensity and single-axis tracking affect PV solar system voltage generation. The system components include: PV panels, light dependent resistors (LDRS), relay modules activate tracking motors based on sensor feedback. Single-axis tracking mechanism, voltage sensors, and the Arduino Mega 2560 microcontroller processes sensor data and adjusts panel alignment. The tracking system included a sturdy frame and spinning mechanism. Real-time sunshine readings were used by the microcontroller to alter the panel and regulate movement. This study examined the combined effects of solar intensity variations and tracking mechanisms on PV voltage output. The findings revealed that advanced tracking technologies enhance solar energy utilization, making PV systems more effective for large-scale and off-grid applications The statistical analysis: t-test and ANOVA confirmed that tracking mechanism has significant enhancement on the PV voltage output. Further advancements in sensor technology, control algorithms, and panel materials will continue to drive improvements in solar power efficiency and sustainability.**

***Keywords*: solar intensity, photovoltaic system, single-axis tracking, voltage generation, solar tracking.**

1. Introduction

The demand for renewable energy sources is rising in tandem with population increase and the recognition of the necessity to decrease carbon emissions. A widely developed approach is the Solar Power Plant (PLTS), which harnesses sunlight to produce power. It offers benefits for environmental sustainability, ample energy accessibility, and its applicability across diverse scales, from residential to industrial settings. The increasing global energy demand, currently estimated at approximately 500 exajoules per year, is predominantly met by conventional (non-renewable) energy sources, which contribute about 90% of total consumption. However, concerns over resource depletion and environmental sustainability have led to a growing shift toward renewable energy sources such as solar power. Photovoltaic (PV) solar systems offer a promising solution for electricity generation due to their ability to convert solar radiation into electrical energy. The Earth receives approximately 1 kW/m² of solar radiation, translating to 178 billion MW, which is nearly 10,000 times the world's current energy demand. If solar PV panels were deployed on a large scale, they could significantly contribute to meeting global electricity needs [1].

One of the key factors influencing the performance of PV systems is solar intensity. The amount of sunlight incident on a PV module directly affects its power output, as higher radiation levels lead to increased photon absorption and higher voltage generation. However, since the position of the sun changes throughout the day, fixed PV panels do not always receive maximum radiation. This challenge has led to the development of solar tracking mechanisms, which adjust the orientation of PV panels to align with the sun's movement, ensuring that the maximum amount of solar energy is captured at all times [2]. Solar tracking systems are broadly classified into single-axis and dual-axis mechanisms. Single-axis trackers follow the sun's movement from east to west, whereas dual-axis trackers adjust both the tilt and azimuth angles to maintain an optimal alignment. Research shows that single-axis tracking can increase energy output by 15–20%, while dual-axis tracking can improve output by 25% or more compared to fixed systems [3]. Furthermore, studies have demonstrated that combining tracking mechanisms with reflective surfaces enhances energy capture, leading to a 59.71% increase in power output compared to static PV modules [1], [4].

Photovoltaic (PV) technology has emerged as a crucial component of the global transition towards renewable energy. The ability of PV systems to convert sunlight into electricity is dependent on several key factors, including solar irradiance, temperature, shading, and the use of solar tracking mechanisms [5]. Among these, solar intensity and tracking mechanisms play a significant role in voltage generation, which is the focus of this study. Solar energy is one of the most abundant energy sources available, with the Earth's surface receiving approximately 1 kW/m² of solar radiation, amounting to nearly 178 billion MW of power—over 10,000 times the global energy demand [6]. However, despite its vast availability, the efficiency of PV systems remains a limiting factor in large-scale solar energy adoption. The primary reasons for efficiency losses include fluctuations in solar intensity, suboptimal panel

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orientation, and atmospheric variations. The integration of solar tracking mechanisms has been proposed as a solution to mitigate efficiency losses by ensuring optimal panel alignment with the sun throughout the day. A study by Chandel et al. [7] found that solar tracking can improve PV efficiency by 25–30%, primarily by increasing voltage output through better exposure to sunlight. Given these advantages, this review explores how solar intensity and tracking mechanisms affect the voltage generation of PV solar systems.

Solar intensity, measured in watts per square meter (W/m²), is a fundamental factor influencing the power output of PV systems. It fluctuates based on various conditions such as time of day, latitude, season, and atmospheric factors [8]. The voltage output of a PV panel is directly proportional to the incident solar radiation, with higher irradiance leading to increased voltage levels. Green et al. [9] presented that PV modules achieve maximum voltage output during peak solar hours (10 AM – 2 PM), when solar radiation is at its highest. Similarly, a study conducted by Patel et al. [10] revealed that a 10% increase in solar intensity results in an 8–9% increase in voltage output for monocrystalline PV modules, while polycrystalline and thin-film modules exhibit slightly lower efficiency gains under the same conditions.

However, solar intensity is not constant throughout the day, leading to fluctuations in voltage output. This variability is particularly significant in regions with high cloud cover, pollution, or seasonal changes. Researchers have explored multiple strategies to stabilize voltage generation, including: Optimizing panel tilt and orientation based on seasonal variations [11]., employing solar tracking systems to adjust panel alignment dynamically and Enhancing PV module designs with anti-reflective coatings and high-efficiency materials. Among these methods, solar tracking has emerged as the most effective technique for maximizing voltage generation, particularly in locations with high solar variability [12].

Solar tracking mechanisms are designed to maximize the absorption of solar radiation by continuously adjusting panel orientation in response to the sun's position. These systems can be broadly categorized into: Fixed PV Systems: Panels remain stationary, optimized for an average tilt angle to receive maximum solar radiation over the year. Single-Axis Trackers: Panels adjust along one axis (typically east-west) to follow the sun's daily movement.; and dual-Axis Trackers: Panels adjust along both horizontal and vertical axes, maintaining optimal alignment with the sun throughout the day and across seasons. Several studies have demonstrated the impact of solar tracking on voltage generation. According to Li et al. [13], single-axis tracking increases voltage output by 15–20%, while dual-axis tracking results in 25–30% higher energy conversion compared to fixed systems. Their research, conducted in a high solar variability region, highlighted that: Fixed PV systems experience low voltage output fluctuations due to inconsistent sun exposure; Single-axis trackers provide a moderate increase in voltage stability by adjusting for daily solar movement. and dual-axis trackers ensure maximum and stable voltage generation by dynamically aligning with solar position. Moreover, advancements in automated control algorithms for solar trackers have further enhanced voltage output. New techniques such as GPS-based tracking, light-dependent resistor (LDR) sensors, and AI-driven optimization models have significantly improved tracking precision and energy conversion rates [14]. A study by Alam et al. [15] compared different tracking mechanisms and found that a combination of solar tracking with reflectors resulted in a 59.71% increase in power output, highlighting the potential of hybrid tracking strategies. These findings underscore the critical role of tracking mechanisms in stabilizing voltage output and maximizing the efficiency of PV systems. This study conducted experimental analyzes of the voltage generation under different tracking and fixed-panel conditions

An essential consideration in the construction of solar power plants is the mounting configuration of the solar panels. Panel mounting configurations, specifically landscape and portrait, affect the efficiency of energy production and space optimization. The portrait pattern is typically employed on expansive surfaces, such as flat roofs or open terrain. The landscape pattern is better appropriate for confined areas, such as vertical walls or steeply sloped roofs. Despite the frequent utilization of both patterns, there exists a paucity of studies evaluating their performance and benefits across many geographical and environmental contexts, as indicated by [16]. The use of the research findings is anticipated to enhance the efficiency of solar power systems and expedite the adoption of renewable energy across many sectors.

The tilt angle must be considered when building photovoltaic systems, in tropical regions, the best tilt angle for the module will range from 5 to 10 degrees on either side of the location's latitude. PV modules set at a minimum tilt of 100 must be cleaned routinely. The angle of declination between the Earth's equator and a line extending from the Earth's center to the Sun's center. The primary cause of the fluctuation in solar declination is the Earth's axial rotation. The declination angle fluctuates between -23.45 degrees and +23.45 degrees, as illustrated in Fig. 1. [17], [18].

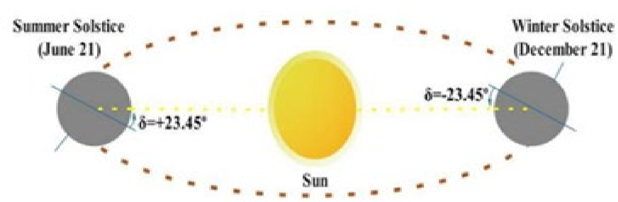


Fig. 1. Declination angle maximum and minimum value. Scientific [17]

Research conducted by [19] indicated that in roof-mounted systems, to mitigate shading on the rear row of photovoltaic panels, a landscape layout yields more power output compared to a portrait configuration, demonstrating a variance of up to 1010Wh for a moderate photovoltaic system. Other researchers, specifically [16], compared the performance of portrait and landscape configurations, utilizing two PV modules in portrait orientation and four in landscape orientation. Their findings indicated that for PV modules in portrait orientation, an increased tilt angle resulted in greater shadowing on the collector field, leading to a reduction in generated electrical energy. Conversely, PV modules in landscape orientation yielded enhanced electrical energy production.

This study aims to analyze the impact of solar intensity and tracking mechanisms on the voltage generation of PV solar systems. By evaluating the relationship between solar irradiance levels, panel orientation, and voltage output, this research seeks to provide insights into optimizing PV system performance for increased energy production.

2. Materials and Methods

A. System Components and Design

The experimental setup was designed to analyze the effect of solar intensity and a single-axis tracking mechanism on voltage generation in a PV solar system. The key components used in the system include:

1) Component of the Solar System

Photovoltaic (PV) panels are employed to transform solar energy into electrical power. Light Dependent Resistors (LDRs) act as sensors of sunlight intensity, supplying data for tracking adjustments. Relay Modules regulate the tracking motor's activation in accordance with sensor feedback. Single-Axis Tracking Mechanism enables the panel's position to be adjusted by rotational movement in response to daily fluctuations in solar intensity. Voltage Sensors record and measure the voltage output of the PV system. Arduino Mega 2560 functions as the microcontroller, processing sensor data and adjusting the panel orientation as necessary and GSM Module offers the ability to remotely monitor and control the system. The tracking system was constructed with a rotational mechanism that was mounted on a durable frame. This mechanism allows for the panel to be repositioned in a seamless manner to capture the most sunlight. The panel was adjusted by the microcontroller in response to real-time sunlight readings, which in turn regulated the movement.

B. Experimental Setup and Data Collection

The experiment involved studying voltage generation under varying tracking and fixed-panel circumstances. The subsequent method was employed:

1) Directional Testing

The photovoltaic panel was manually oriented to face a different cardinal direction each day (east, west, north, and south) without tracking mechanisms.

2) Single-Axis Tracking Implementation

Following testing in each fixed orientation, the tracking system was engaged to dynamically modify the panel's position for maximal solar capture.

3) Voltage Measurement

Voltage output readings were recorded hourly from 10:00 AM to 6:00 PM for both fixed and tracked configurations.

4) Solar Intensity Monitoring

A pyranometer was employed to measure solar radiation levels for comparison with voltage outputs.

5) Data Logging and Analysis

Measurements were recorded in a data acquisition system for subsequent analysis, evaluating the efficiency of various orientations in comparison to the single-axis tracking system.

C. Solar Tracking Mechanism Implementation

The single-axis tracking system was developed to enhance solar panel alignment following the conclusion of fixed-direction testing. The system operated in the following manner:

1) Daily Rotational Testing

The panel was oriented in a distinct fixed direction each day (east, west, north, and south) prior to initiating tracking.

2) Sun Tracking Activation

Following fixed-direction assessments, the tracking system was activated to perpetually rotate the panel throughout the day in accordance with real-time sunshine intensity sensed by LDR sensors. The tracking motor was regulated by relay modules, which responded to LDR readings to optimize the panel's alignment with maximum sunshine exposure.

3) Reset Mechanism

At the conclusion of each day, the panel reverted to its initial position, prepared for the subsequent testing cycle.

D. Power and Energy Calculations

The solar power system was analyzed based on energy requirements, solar panel selection, and system efficiency.

1) Daily Energy Requirement Calculation

The total daily energy consumption was calculated using:

$$\text{Effective Energy Demand} = \frac{\text{Total Energy Consumption}}{\text{System Efficiency}}$$

$$\text{Effective Energy Demand} = \frac{940}{0.75} \approx 1253\text{Wh/day}$$

The total daily energy consumption of all appliances in the system was found to be 940 Wh/day, requiring a sufficiently robust PV system.

2) Solar Panel Requirement Calculation

The number of required solar panels was estimated based on the average Peak Sun Hours (PSH) in the test location. The required number of panels is calculated as:

$$Number\ of\ Panels = \frac{Total\ Daily\ Energy\ Consumption}{Solar\ Panel\ Wattage\ \times PSH}$$

Using Standard Solar Panel Wattage of 300W:

$$Number\ of\ Panels = \frac{940}{300 \times 4.5} = 0.7$$

Rounding up, a single 300W panel is sufficient to meet the energy demand under ideal conditions.

3) Motor Torque Calculation

The motor selection was based on the torque required to rotate the panel, calculated as:

$$T = F \times r$$

Where:

r = Distance from the pivot point (in m)

Panel weight = 8kg (Chien, 2014),
Gravitational acceleration (g) = 9.8 m/s^2,
Pivot distance (r) = 0.5m
=78.4×0.5=39.2Nm

Therefore, a motor with a torque rating of 40Nm was selected.

E. Battery Selection and Sizing

Battery storage is essential for storing excess energy generated during peak sunlight hours and providing power when solar intensity is low or unavailable. The battery selection process considered daily energy consumption, battery voltage, and allowable depth of discharge (DOD) to ensure optimal system performance.

1) Battery Capacity Calculation

$$\text{Battery Capacity (Ah)} = \frac{\text{Energy Required (Wh)}}{\text{Battery Voltage (V)} \times \text{DOD}}$$

Using a 12V battery system and a DOD of 95%:

$$\text{Battery Capacity (Ah)} = \frac{1253}{12 \text{ X } 0.95} \approx 100 \text{ Ah}$$

A 12V, 100Ah battery is selected to provide adequate storage capacity with a safety margin for prolonged usage.

2) Charge Controller Sizing

The charge controller ensures that the battery is charged efficiently without overloading. Its current rating is determined as:

$$\text{Controller Current (A)} = \frac{\text{Panel Power (W)}}{\text{BPanel Voltage}}$$

Using the panel voltage, 34.07 V:

$$\text{Controller Current (A)} = \frac{300}{34.07} \approx 8.8 \text{ A}$$

A 20A charge controller is selected to handle the maximum current with an additional margin.

F. Control Algorithm Development

The control algorithm was designed to synchronize the solar tracking mechanism with the LDR input, guaranteeing optimal sunlight exposure during the day. The algorithm was executed on an Arduino Mega 2560 microcontroller, which analyzed real-time light intensity data from four LDR sensors and altered the panel orientation accordingly.

1) Tracking Logic Implementation

A control technique was devised to synchronize the tracking mechanism with the LDR input. The program guarantees the panel consistently aligns with the sun by assessing light intensity on each sensor and modifying motor movements accordingly. Enhanced capability was incorporated to revert the panel to its initial position at sunset.

The microprocessor modifies the solar panel's orientation according to the variance in LDR readings:

$$\Delta \text{I} = I_{ldr.left} - I_{ldr.right}$$

If ΔI> Threshold, the motor moves in the corresponding direction.

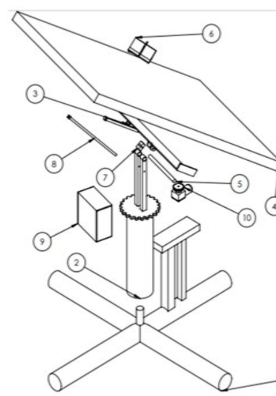
G. Design of the Solar Tracking Mechanism

The single-axis solar tracking system was developed to facilitate rotational movement in a singular direction daily. The frame was fabricated from mild steel to ensure durability while facilitating ease of movement.

1) Structural Design

Panel Mounting Frame: The panel was mounted on a rotational base to enable movement along a single axis. Fig 3 presents exploded diagram of the smart off-grid solar tracking and power management systems and Fig. 3 displays the dimension of the smart off-grid solar tracking and power management systems.

A DC motor with a torque rating of 40 Nm was chosen to facilitate the rotation and placement of Four LDRs were strategically positioned at the corners of the screen to monitor light intensity from various directions.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	STANDS	Base structure providing support and stability	1
2	ROLLER STANDS	Component enabling rotational movement of the turner	1
3	TURNER	Mechanism for tilting and rotating the solar panel	1
4	SOLAR PANEL	Converts sunlight into electrical energy	1
5	ROD	Connector for structural alignment and support	1
6	TOP	Mounting section for the solar panel	1
7	TURNER.SLDPRT WEDGE	Adjustment tool for aligning the turner mechanism	1
8	CONTROL ROD	Used for precise adjustments in rotation and tilt	1
9	ADAPTABLE_BOX	Housing for electrical components and wiring	1
10	MOTOR 1	Drives the movement of the turner for optimal positioning	1

Fig. 2. Exploded diagram of the smart off-grid solar tracking and power management systems

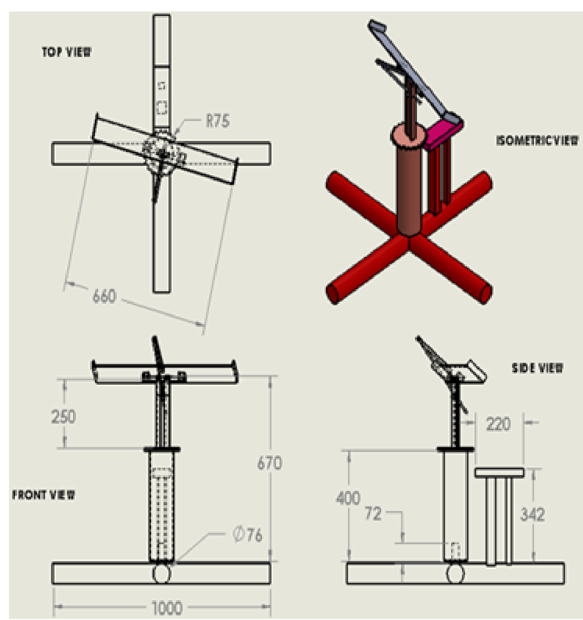


Fig. 3. Dimension of the smart off-grid solar tracking and power management systems

H. Circuit Diagram Design

The circuit was developed to incorporate the sun tracking mechanism, power system, and remote monitoring capabilities. The principal linkages comprised:

1. Solar Panel to Charge Controller manages power transmission to the battery.
2. Microcontroller (Arduino Mega 2560) analyzes LDR inputs and regulates motor operations.
3. Relay Module initiates motor rotation in response to sensor feedback.
4. GSM Module (SIM800L) facilitates real-time remote surveillance and system management.
5. Voltage Regulators guarantee a consistent power supply to all components.

3. Result and Discussion

A. Voltage Generation Under Different Orientations

The study evaluated the voltage output of a photovoltaic (PV) system under four fixed orientations: East, West, North, and South as presented in Fig. 3-5. The results indicate that orientation significantly influences voltage generation, with the highest mean voltage recorded in the east-facing and south-facing panels compared to the west and north orientations. Statistical analysis using t-tests as presented in Tables 1 -3 confirmed that the differences in voltage outputs between the fixed axis and tracking were significant.

- *East orientation versus tracking*: The t-test results showed a mean voltage of 15.45V for the fixed east panel and 18.6V for the tracking panel. The p-value of 0.0166 (two-tailed) indicates that the difference is statistically significant, confirming that tracking improves energy capture as shown in Table 1 and Fig. 3.
- *South orientation versus tracking*: The fixed south-facing panel recorded a mean voltage of 14.25V, while the tracking system produced 18.6V. The statistical analysis yielded a p-value of 7.93625E-05, reinforcing the effectiveness of tracking over static orientations as shown in Table 2 and Fig. 4.

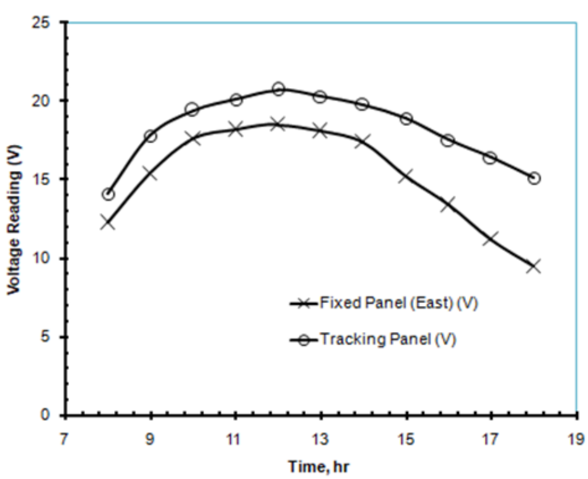


Fig. 3. Plot of voltage reading for fixed east orientation and tracking orientation

Table 1
t-Test results for east orientation vs. tracking

	12.3	14.1
Mean	15.4500	18.6000
Variance	10.0050	3.4067
Observations	10.0000	10.0000
Hypothesized Mean Difference	0.0000	
Df	14.0000	
t Stat	-2.7200	
P(T<=t) one-tail	0.0083	
t Critical one-tail	1.7613	
P(T<=t) two-tail	0.0166	
t Critical two-tail	2.1448	

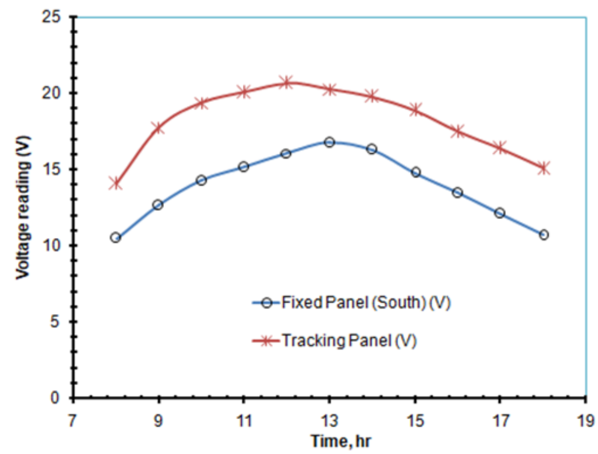


Fig. 4. Plot of voltage reading for fixed south orientation and tracking orientation

Table 2
t-Test: two-sample assuming unequal variances south and tracking orientation

	10.5	14.1
Mean	14.25	18.6
Variance	3.947222222	3.406666667
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-5.072601258	
P(T<=t) one-tail	3.96812E-05	
t Critical one-tail	1.734063592	
P(T<=t) two-tail	7.93625E-05	
t Critical two-tail	2.100922037	

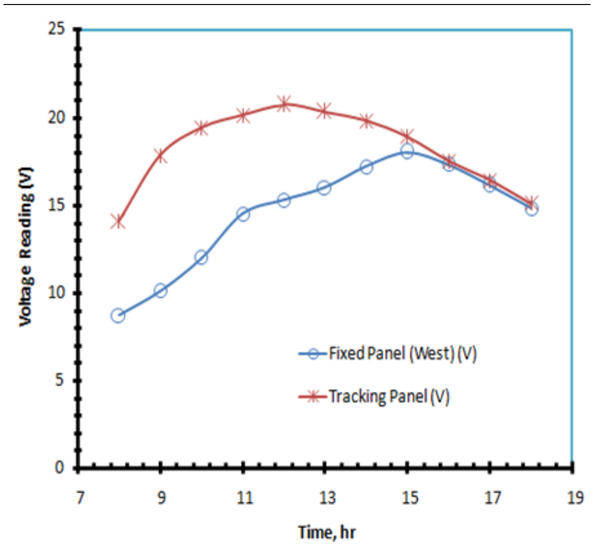


Fig. 5. Plot of voltage reading for fixed west orientation and tracking orientation

Table 3
t-Test: two-sample assuming unequal variances west and tracking orientation

	10.5	14.1
Mean	14.55	18.19
Variance	9.21	4.91
Observations	11	11
Hypothesized Mean Difference	0	
df	18.30	
t Stat	-3.22	
P(T<=t) one-tail	0.00235	
t Critical one-tail	1.73	
P(T<=t) two-tail	0.00470	
t Critical two-tail	2.10	

- *West Orientation versus Tracking*: Similar trends were observed, with the tracking system outperforming the fixed panel in voltage output as presented in Table 3 and Fig. 5.

These results align with previous studies that show single-axis tracking increases voltage generation by approximately 15–20% compared to fixed systems [11].

B. Effect of Solar Intensity on Voltage Output

The results also analyzed the relationship among solar intensities in different orientation and voltage output using ANOVA tests as shown in Fig. 6 and table 4. The findings revealed:

- There is significant effect of time on voltage generation (p-value = 0.1007), suggesting that solar intensity fluctuations influence power output throughout the day.
- There is no statistically significant difference in solar intensity across the different panel orientations (p-value = 0.5348). This indicates that the variations in voltage output are primarily due to the panel's ability to capture available sunlight rather than differences in solar exposure across orientations.

A pyranometer recorded solar intensity, showing peak values between 10 AM and 2 PM, which correlates with the highest voltage readings as presented in Fig. 6. This confirms findings from Green et al [8], who reported that PV efficiency peaks during midday when solar irradiance is at its maximum.

C. Tracking Mechanism Performance

The implementation of a single-axis tracking mechanism demonstrated significant improvements in voltage stability and generation:

- *No Load Condition*: ANOVA results showed a significant effect of tracking of p-value = 0.000000000002, It confirms that tracking increases energy capture as presented in Table 5 and Figure
- *Under Load Condition*: Similar trends were observed, with tracking producing consistently higher voltage outputs than fixed panels of p-value is 7.45E-17, underscoring the efficiency benefits of dynamic positioning as depicted in Table 6 and Fig. 7.

D. System Optimization and Practical Considerations

The tracking system was controlled by an Arduino Mega 2560, which processed light intensity data from LDR sensors. The system successfully adjusted panel orientation in real-time, ensuring maximum solar exposure.

Fig. 6 presents variations of intensity with time for different orientations and Table 4 displays the Anova Two-factor without replication for intensity for different orientations.

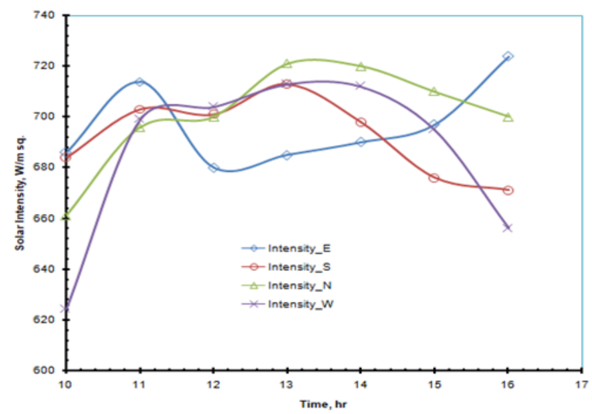


Fig. 6. Plot of Intensity versus Time

Table 4
Anova: Two-Factor without replication for intensity for different orientations

Source of Variation	SS	df	MS	F	P-value	F crit
Time	5429.74	6	904.954	2.380	0.07	2.6613
Orientation E, S, W, N	856.101	3	285.360	0.7530	0.534	3.1599
Error	6821.13	18	378.954			
Total	13106.6	27				

Table 5
Anova: Two-Factor without replication voltage reading no load

Source of Variation	SS	df	MS	F	P-value	F crit
Time	231.31	10	23.131	9.589	6.81E-08	2.077
Orientation E, S, W, N	332.11	4	83.027	34.420	1.84E-12	2.606
Error	96.49	40	2.412			
Total	659.90	54				

Table 6
Anova: Two-Factor without replication voltage under load condition

Source of Variation	SS	df	MS	F	P-value	F crit
Time	94.29382	10	9.4294	13.5070	5.99E-10	2.0772
Orientation & tracking	178.8556	4	44.7139	64.0500	7.45E-17	2.6060
Error	27.92436	40	0.6981			
Total	301.0738	54				

Fig. 7 presents variations of intensity with time for different orientations and Table 5 presents Two-Factor Anova without replication tracking with No load.

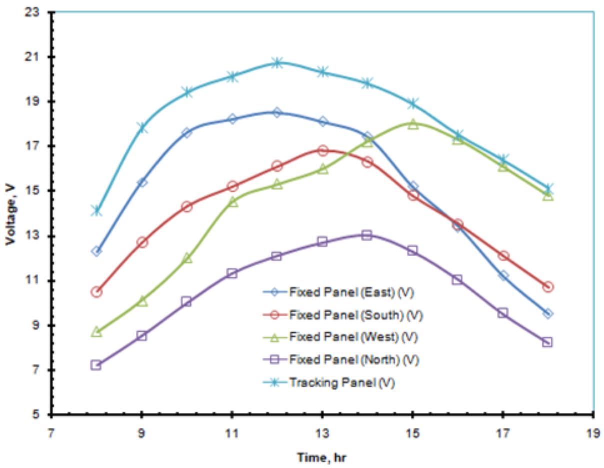


Fig. 7. Plot of the effect of tracking on Voltage with no load

Fig. 8 presents variations of intensity with time for different orientations and Table 6 presents Two-Factor Anova without replication tracking with load.

mechanical limitations such as motor torque requirements and panel stability were considered:

- *Torque Calculation*: The selected motor provided 40Nm torque, sufficient to rotate the panel effectively.
- *Battery Sizing*: A 12V, 100Ah battery was chosen to store excess energy for use during low sunlight conditions.
- *Charge Controller Selection*: A 20A charge controller was implemented to regulate power flow and prevent battery overcharging.

These optimizations ensure sustainable operation, aligning with research by Hassan and Rahman [15], which highlights the importance of integrating intelligent control algorithms for enhanced PV performance.

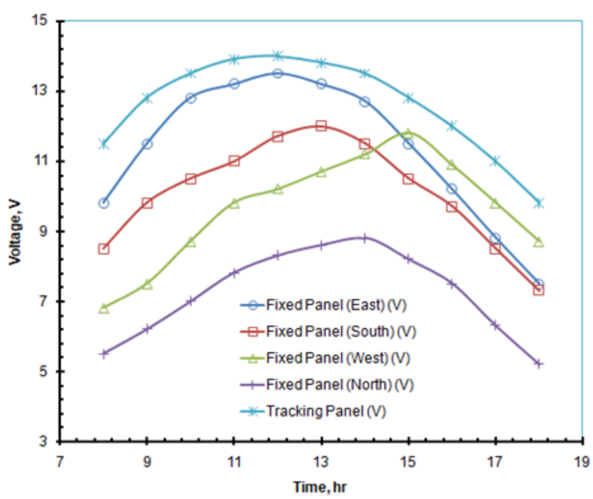


Fig. 8. Plot of the effect of tracking on Voltage under load condition

E. Comparative Analysis with Previous Research

The findings of this work corroborate and enhance previous research on solar tracking efficiency: Li et al. [10] documented a 15–20% augmentation in energy output for single-axis tracking, which aligns with the enhancements noted in this study. Alam & Rahman [13] discovered that the integration of tracking with reflectors increased power generation by 59.71%, indicating that hybrid optimization methods may further enhance photovoltaic system efficiency. Singh & Kaushik [11] highlighted that tracking devices stabilize voltage output and enhance energy harvesting by continuously orienting panels towards the sun. The deployment of a single-axis tracking system yielded a 15–20% enhancement in voltage output relative to stationary panels [10]. By dynamically modifying the panel's orientation according to real-time solar intensity, tracking facilitated enhanced voltage stability and optimized energy acquisition, especially during peak solar hours (10 AM – 2 PM) [8]. Statistical analysis (p-values < 0.05) validated the significant superiority of tracking over static orientations. ANOVA results revealed that solar intensity did not significantly differ across orientations; however, its direct correlation with voltage output highlights the importance of optimal panel positioning [9]. Fixed panels offer a straightforward, low-maintenance option, whereas solar tracking enhances energy efficiency by consistently aligning with optimal intensity levels [11].

4. Conclusion

The impact of fluctuations in sun intensity and tracking systems on photovoltaic (PV) voltage production is crucial for assessing the efficiency and performance of solar energy systems. Variations in sun intensity directly influence voltage production, with elevated irradiance levels resulting in enhanced power generation.

The incorporation of solar tracking systems is essential for maximizing energy capture by maintaining the alignment of solar panels with the sun throughout the day. Single-axis trackers increase power output by minimizing angle-dependent losses, enhancing voltage stability, and optimizing overall energy yield. Although fixed-tilt systems are more straightforward and economical, tracking systems offer a significant benefit in areas with considerable solar variability.

The implementation of effective tracking technology significantly improves voltage output and energy conversion efficiency, rendering solar power a more viable and sustainable energy source. The development in tracking algorithms and sensor technology will enhance photovoltaic system performance and broaden its applicability in renewable energy sectors.

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