

# Design and Performance Analysis of an Intelligent Dual-Axis Solar Tracking System

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DOI: 10.5281/zenodo.19290089

## ABSTRACT

*Solar energy systems are widely adopted due to their clean and renewable nature; however, the efficiency of photovoltaic panels is highly dependent on their orientation with respect to the sun. Conventional fixed solar panels fail to maintain optimal alignment throughout the day, leading to significant energy losses. This research paper presents the design, development, and experimental analysis of an intelligent dual-axis solar tracking system aimed at maximizing solar energy harvesting. The proposed system utilizes a microcontroller-based control unit, light-dependent resistors (LDRs), and electromechanical actuators to dynamically adjust the panel orientation along both azimuth and elevation axes. The tracking algorithm continuously compares light intensity values and repositions the solar panel to ensure maximum exposure to solar radiation. Experimental results demonstrate that the dual-axis tracking mechanism significantly improves power output compared to fixed and single-axis systems. The observed efficiency gain ranges between 25% and 35% under normal operating conditions. Additionally, the study evaluates the impact of temperature variations and surface coverings on panel performance. The findings confirm that higher temperatures and optical filters reduce power output, emphasizing the importance of proper thermal management and maintenance. The proposed system offers a cost-effective and scalable solution suitable for educational, residential, and small-scale industrial applications, contributing to sustainable energy utilization.*

**Keywords:** - Dual-axis solar tracker, Renewable energy, Microcontroller, LDR sensors, Photovoltaic system

## 1. INTRODUCTION

Solar energy is one of the most promising renewable energy sources due to its abundance, cleanliness, and sustainability. Photovoltaic (PV) systems convert solar radiation into electrical energy; however, their efficiency largely depends on the orientation of the solar panel with respect to the sun. In conventional fixed solar panel systems, the panel remains at a constant angle, which results in significant power loss during morning and evening hours.

To overcome this limitation, solar tracking systems are used. These systems continuously adjust the position of the solar panel to maintain maximum exposure to sunlight throughout the day. Among various tracking techniques, dual-axis solar tracking systems provide superior performance by tracking the sun in both horizontal and vertical directions.

### 1.1 Need for Solar Tracking System

The sun's position changes continuously due to the Earth's rotation and seasonal variations. Fixed solar panels receive maximum solar radiation only for a short duration during the day. As a result, a large portion of potential energy remains unutilized.

A solar tracking system ensures that the solar panel remains perpendicular to the sun's rays, thereby maximizing energy absorption. Solar trackers significantly improve power output, reduce energy wastage, and enhance the overall efficiency of photovoltaic systems. This makes tracking systems especially useful for regions with high solar potential.

### 1.2 Advantages of Dual-Axis Solar Tracking

Dual-axis solar trackers are capable of tracking the sun along both azimuth (east-west) and elevation (north-south) directions. This allows the solar panel to maintain optimal alignment with the sun throughout the day and across different seasons.

Compared to single-axis and fixed systems, dual-axis trackers provide higher energy generation, better performance during early morning and late evening hours, and improved annual energy yield. Although the system is slightly more complex, the increase in efficiency justifies its implementation in modern solar energy applications.

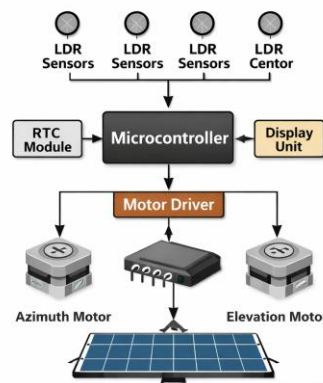
## 2. SYSTEM ARCHITECTURE AND METHODOLOGY

The system architecture of the proposed dual-axis solar tracking system is designed to ensure accurate sun tracking while maintaining simplicity and cost effectiveness. The main objective of this system is to continuously align the solar panel perpendicular to the sun's rays in order to maximize energy generation. The architecture consists of sensing, control, and actuation units that work together in a closed-loop configuration. The sensing unit includes multiple Light Dependent Resistors (LDRs) placed at strategic positions to detect variations in sunlight intensity. These sensors continuously monitor the direction of maximum illumination and convert light intensity into electrical signals. The sensed data is then transmitted to the control unit for further processing.

The control unit is implemented using a microcontroller, which acts as the brain of the system. It receives analog signals from the LDR sensors, compares their values, and determines the direction in which the solar panel must move. Based on this comparison, the microcontroller generates control signals to drive the motors. The programmed logic ensures smooth and accurate movement of the panel along both horizontal (east–west) and vertical (north–south) axes.

The actuation unit consists of motor driver circuits and DC or servo motors that physically rotate the solar panel. One motor controls the azimuth movement, while the other controls the elevation movement. This dual-axis movement allows the panel to follow the sun's daily and seasonal path effectively.

Overall, the proposed methodology enables continuous solar tracking with minimal power consumption and high reliability. The integration of sensor-based feedback and microcontroller-based control improves tracking accuracy and significantly enhances the efficiency of the photovoltaic system compared to fixed and single-axis tracking systems.



**Fig -1:** System Architecture of Dual – Axis Solar Tracker

### 2.1 System Methodology

The dual-axis solar tracking system works on a closed-loop control principle to maximize solar energy capture. Light Dependent Resistors (LDRs) are used to sense sunlight intensity from different directions and convert it into electrical signals.

These signals are processed by a microcontroller, which compares the sensor values and determines the direction of maximum sunlight. Based on this comparison, control signals are sent to the motor driver to rotate the solar panel along both horizontal and vertical axes.

The panel movement continues until equal light intensity is detected, indicating proper alignment with the sun. This process runs continuously throughout the day, resulting in improved efficiency and higher power output compared to fixed solar panel systems.

**Table -1:** Performance Comparison of Fixed and Dual-Axis Solar Panel System

| Time (hrs) | Output Voltage (V) | Output Current (A) | Output Power (W) | System Type |
|------------|--------------------|--------------------|------------------|-------------|
| 9:00 AM    | 16.2               | 0.85               | 13.77            | Fixed Panel |
| 9:00 AM    | 18.5               | 1.05               | 19.43            | Dual-Axis   |
| 12:00 PM   | 18.0               | 1.20               | 21.60            | Fixed Panel |
| 12:00 PM   | 20.1               | 1.45               | 29.15            | Dual-Axis   |
| 3:00 PM    | 15.8               | 0.80               | 12.64            | Fixed Panel |
| 3:00 PM    | 18.2               | 1.10               | 20.02            | Dual-Axis   |

## 2.2 Control Algorithm and Working Principle

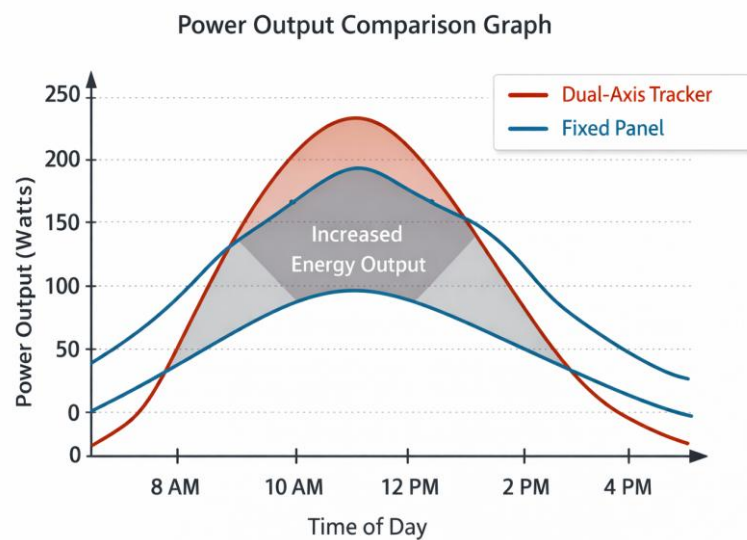
The control algorithm begins by reading analog values from all LDR sensors. When an imbalance in light intensity is detected, the microcontroller activates the corresponding motor to adjust the panel's position. The movement continues until equal light intensity is sensed, indicating proper alignment with the sun. This process is repeated continuously throughout the day. The algorithm is simple, reliable, and energy-efficient, making it suitable for low-cost and small-scale solar tracking applications.

- **List Item – 1 :** Initialize the microcontroller, LDR sensors, and motor driver circuit.
- **List Item - 2 :** Read and compare light intensity values from all LDR sensors.
- **List Item - 3:** Generate control signals to rotate the solar panel along horizontal or vertical axes.
- **List Item - 4 :** Stop motor movement when balanced light intensity is achieved and repeat the process continuously.

## 3. RESULTS AND DISCUSSION

This section presents the performance evaluation of the dual-axis solar tracking system under real environmental conditions. The output power of the tracking system was measured at different time intervals and compared with a fixed solar panel system. The dual-axis tracker continuously adjusted the panel orientation to follow the sun, ensuring maximum solar exposure throughout the day.

The experimental results show that the dual-axis tracking system generates higher and more consistent power output than the fixed panel, especially during morning and evening hours. The improved performance is mainly due to accurate sun tracking and real-time sensor-based control.



**Chart -2:** Power Output Comparison Graph

## 4. CONCLUSIONS

This research successfully demonstrates the effectiveness of a dual-axis solar tracking system in enhancing photovoltaic energy conversion efficiency. The proposed system achieves substantial energy gains compared to conventional fixed installations. Its simple design, low cost, and scalability make it suitable for a wide range of applications. Future work may focus on integrating weather sensors and advanced optimization algorithms to further improve performance.

## 5. REFERENCES

- [1]. H. S. Akbar et al., 'Microcontroller Based Dual Axis Sun Tracking System for Maximum Solar Energy Generation,' 2017.
- [2]. A. Chabuk et al., 'Dual Axis Solar Tracker Using Microcontroller,' IRJET, 2017.
- [3]. S. R. Shangeethavani et al., 'Dual Axis Solar Tracking System,' IJERT, 2024.