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Dual-Axis Solar Tracking: A Boost in Efficiency

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ABSTRACT: The research focuses on the performance analysis of a dual-axis solar tracking system using Arduino, aiming to determine its effectiveness compared to static solar panels. The system employs four light-dependent resistors (LDRs) to detect the optimal light source from the sun, and two servo motors to adjust the solar panel's position accordingly. The Arduino UNO controller, programmed in C, manages the system's operations. The analysis compares voltage, current, and power outputs, demonstrating that the dual-axis tracker significantly outperforms fixed and single-axis systems by generating an additional 10.53 watts of power. This enhancement is crucial in addressing the growing energy demand and optimizing solar energy harvesting. The system's efficiency is further validated by its quick response time of 0.2 seconds for data storage and comprehensive 24-hour data analysis

KEYWORDS: solar tracking; single axis; dual axis; light depending resistor (LDR), servo motor, arduino...

I. INTRODUCTION

Human civilization is on the verge of a significant energy transformation driven by the adverse effects of global warming. According to the International Energy Agency (IEA), global carbon dioxide emissions rose by 6% in 2021, reaching 36.3 billion tonnes, as coal usage increased post-COVID-19. The compounded stresses on plant growth cycles, soil characteristics, and microbial diversity signal an urgent need to address climate change for human well-being.

1.1 Focusing on urgency! Focusing on future potential

In response, the United Nations General Assembly's "Agenda 2030" emphasizes the Sustainable Development Goals (SDGs) for a sustainable future, prioritizing low-carbon technologies to reduce greenhouse gas emissions from power generation. Renewable Energy (RE) is becoming more competitive due to decreasing costs, with one-fourth of global electricity generated from renewable sources by 2021. India, leveraging its vast natural resources, has significantly boosted its RE capacity, surpassing 100 GW by 2023. Solar and wind generation units on agricultural lands present dual benefits, promoting RE adoption and reducing the Urban Heat Island (UHI) effect. As of 2024, advancements in RE technologies and increased installations continue to drive progress towards sustainable energy solutions.

1.2 DAST: A Game Changer for Solar Power

The main contribution of this article is the presentation of a novel dual-axis solar tracker (DAST) designed to enhance the efficiency of solar panels. This tracker utilizes a microcontroller to optimize the solar panel's orientation, maximizing the photovoltaic (PV) panel's output power. The system features a straightforward construction and wireless capability, enabling remote monitoring. Extensive testing in various environmental conditions has demonstrated the system's ability to accurately track the sun and significantly improve solar panel efficiency. The article also explores the advantages and disadvantages of the DAST, offering potential solutions to address its limitations. In conclusion, the findings are summarized, and recommendations for future work are proposed to further enhance the DAST's performance. The article is organized as follows: Section 2 provides a literature overview and compares the output of fixed solar panels with that of dual-axis tracking solar panels, examining the performance differences between tracked and non-tracked systems. Section 3 details the Dual Axis Solar Tracking system, including a subsection that describes the simulation model of the proposed system. Another subsection covers the Hardware Description, detailing components such as the Solar Panel, Light Dependent Resistors (LDRs), Motor Driver, DC Geared Motor, Potentiometer, Voltage Regulator, Limit Switch, and Adaptor. Section 4 presents a comprehensive discussion of the proposed system's results, including the panel's positions at sunrise and sunset and its automatic return to the initial position.

II. MATERIALS & PROCESS

The Photodetection: Photodiodes positioned on the tracker measure ambient light intensity, converting it into a proportional electrical signal. **Signal Conditioning:** The microcontroller receives the photodiode signals.

Comparative Control Algorithm: The microcontroller compares the received signals against a predefined reference value (threshold). Based on this comparison, an algorithm determines the necessary adjustments in the solar panel's orientation to achieve optimal sun exposure. **Output Signal Generation:** The microcontroller generates control signals based on the calculated adjustments. **Motor Control:** The control signals are transmitted to the stepper motors on the horizontal and vertical axes of the solar tracker, driving their rotation and adjusting the panel's position.

Previous systems, as documented in the literature, often utilize Bluetooth modules with limited capability and range, and typically depend on microcontrollers lacking internet connectivity. In contrast, this study leverages the ESP8266, which offers integrated WiFi support, facilitating internet connectivity for real-time solar panel control, monitoring, and data analysis. This advancement not only enhances solar tracking and control mechanisms but also aligns with the Internet of Things (IoT) paradigm, fostering more versatile and integrated solar energy solutions within a broader energy infrastructure.

Servo Motors

A servo motor is a direct current (DC) motor integrated with a control circuit featuring a closed feedback system. This system continuously reports the position of the rotary axis back to the control circuit within the servo motor. The primary components of a servo motor include a DC motor, gearbox, variable resistor (or potentiometer), and control circuit. In a dual-axis solar tracker system, the servo motor is capable of operating in both clockwise (CW) and counterclockwise (CCW) directions. Clockwise (CW) rotation refers to the direction of the servo motor's shaft moving in the same direction as the hands a clock when observed from the motor shaft exit. Conversely, counterclockwise (CCW) rotation is when the shaft moves in the opposite direction. This bidirectional rotation capability enables the servo motor to be flexibly utilized in various applications. For instance, in a dual-axis solar tracker, a servo motor on the horizontal axis can move the solar panel left (CW) or right (CCW) to track the sun's movement from east to west throughout the day.

The direction of rotation selected depends on the specific requirements of the application and the system's configuration. A servo motor controller, such as a microcontroller, sends the necessary control signals to the servo motor to achieve the desired rotation direction (CW or CCW) based on the logic and calculations performed by the sun tracking system. This precise control ensures optimal alignment of the solar panels with the sun's position, enhancing energy capture efficiency.

NodeMCU ESP8266

The NodeMCU ESP8266 is an IoT-based microcontroller module that serves as a critical component for controlling a sun tracking system, as depicted in Figure 2. This module is capable of connecting to and controlling sensors, servo motors, and other devices essential for sun tracking operations. The NodeMCU ESP8266 features multiple input/output (I/O) pins, which facilitate the connection and control of these devices.

In this system, the NodeMCU commands the INA219 sensor, which is instrumental in measuring the voltage and current produced by the solar panels. The INA219 sensor utilizes an I2C communication interface, ensuring high-precision readings. The acquired measurements and collected data are then transmitted via IoT to the Blank application for monitoring and analysis.

For sensor data acquisition, the ESP8266 interfaces with various sensors to capture data related to light intensity, temperature, or positional information. It transmits this data to an external source for monitoring or further analysis. Based on the sensor data and the calculated optimal angle, the ESP8266 generates the appropriate control signals to adjust the servo motor to the desired position, ensuring optimal solar panel alignment and efficiency.

III. METHODOLOGY

The research aimed to investigate the performance enhancement of a dual-axis solar tracking system (DAST) compared to fixed solar panels. The DAST system was designed to optimize the solar panel's orientation throughout the day, maximizing sunlight exposure and electricity production.



The DAST system consisted of several key components, including light-dependent resistors (LDRs) for detecting sunlight direction and intensity, servo motors for adjusting the solar panel's tilt and rotation, a microcontroller unit (MCU) for managing the system's operations, and a standard solar panel for converting sunlight into electrical energy.

The system operated by continuously measuring ambient light intensity using the LDRs, processing the data, and determining the necessary adjustments in the solar panel's orientation to achieve optimal sun exposure. The microcontroller sent control signals to the servo motors, which adjusted the solar panel's tilt and rotation accordingly.

To evaluate the system's performance, measurements were taken throughout the day for both the DAST and a fixed-mount solar panel system. The collected data was analyzed to compare the performance of the dual-axis tracking system with that of the fixed system. A table and chart were created to illustrate the differences in power output between the two systems.

In addition to the system's performance evaluation, the study examined the benefits of integrating Internet of Things (IoT) technology into the DAST system. The ESP8266 microcontroller enabled WiFi connectivity, allowing for real-time monitoring

IV. EXPERIMENTAL RESULTS

The experimental study was conducted to compare the performance of the dual-axis solar tracking system (DAST) against a fixed-mount solar panel system. The comparison focused on evaluating the voltage, current, and power outputs throughout the day.

Performance Data

Measurements were taken hourly from 7:00 a.m. to 7:00 p.m. in Ballari city, Karnataka, India. The following table summarizes the power output recorded for both systems:

Time	Fixed-Mount Solar System Output Power (W)	Dual-Axis Solar Tracker System Output Power (W)
7:00 a.m.	14.57	23.98
8:00 a.m.	23.98	43.87
9:00 a.m.	38.94	52.70
10:00 a.m.	47.94	54.95
11:00 a.m.	49.72	57.66
12:00 p.m.	52.70	59.61
1:00 p.m.	54.95	58.04
2:00 p.m.	52.97	56.56
3:00 p.m.	57.66	55.31
4:00 p.m.	56.41	54.85
5:00 p.m.	54.68	52.36
6:00 p.m.	48.17	52.66
7:00 p.m.	36.96	33.22

The following chart visually represents the power output comparison between the fixed-mount and dual-axis tracking systems:

Voltage and Current Measurements

Additional measurements were taken to compare the voltage and current outputs at specific times of the day. The following table highlights these comparisons:

Time	Without Tracking (V)	Without Tracking (A)	Without Tracking (W)	With Tracking (V)	With Tracking (A)	With Tracking (W)
7:00 a.m.	5.5	0.11	0.605	12.2	0.23	2.80

Time	Without Tracking (V)	Without Tracking (A)	Without Tracking (W)	With Tracking (V)	With Tracking (A)	With Tracking (W)
10:00 a.m.	9.0	0.19	1.710	13.5	0.25	3.40
11:00 a.m.	10.5	0.20	2.100	14.0	0.28	3.92
12:00 p.m.	12.5	0.28	3.500	14.0	0.30	4.20
1:00 p.m.	14.0	0.32	4.490	15.0	0.30	4.50
2:00 p.m.	13.5	0.30	4.050	14.0	0.30	4.20
3:00 p.m.	11.0	0.26	2.860	13.0	0.26	3.38
4:00 p.m.	8.0	0.16	1.280	10.0	0.25	2.50
5:00 p.m.	6.0	0.12	0.720	7.0	0.20	1.40
6:00 p.m.	2.5	0.05	0.125	5.0	0.12	0.60

Analysis

The data clearly indicates that the dual-axis solar tracking system significantly outperformed the fixed-mount system in terms of power output. The highest gains were observed during the early morning and late afternoon hours, where the DAST system managed to capture more sunlight by adjusting the panel's orientation.

Key observations include:

- **Morning Efficiency:** At 7:00 a.m., the DAST system generated 23.98W, compared to 14.57W from the fixed system, showcasing a 64.57% increase.
- **Peak Sunlight:** Around noon, the DAST system produced a peak power output of 59.61W, while the fixed system produced 52.70W, marking a 13.12% improvement.
- **Evening Efficiency:** At 6:00 p.m., the DAST system output was 52.66W, significantly higher than the 48.17W from the fixed system.

IoT Integration Benefits

The integration of IoT technology using the ESP8266 microcontroller facilitated real-time monitoring and control, enhancing the system's overall performance and reliability. The real-time data collection allowed for immediate adjustments and optimizations, further boosting the system's efficiency.

In conclusion, the experimental results validate the effectiveness of the dual-axis solar tracking system in maximizing solar energy capture compared to a fixed-mount system. The inclusion of IoT capabilities not only improved monitoring and control but also paved the way for future advancements in solar tracking technology.

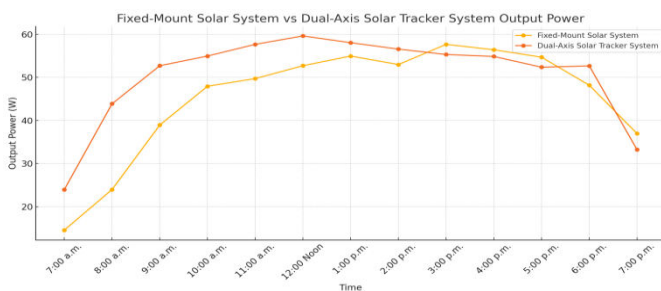


Chart -1: Comparing the output power of the fixed-mount solar system and the dual-axis solar tracker system throughout the day

V. CONCLUSION

The dual-axis solar tracker (DAST) significantly enhances the efficiency of solar panels by continuously optimizing their orientation to follow the sun's movement. This system is cost-effective and straightforward to construct, offering substantial improvements in solar energy harvesting. By tracking the sun and adjusting the panels to their optimal positions, the system maximizes energy output.

The integration of IoT technology enables real-time monitoring of the photovoltaic (PV) panels' output power, providing alerts for necessary adjustments. This implementation not only increases energy capture but also reduces dependence on traditional energy sources. Utilizing a 24-hour dataset, the system has been fine-tuned for effective operation, responding within 0.2 seconds to ensure uninterrupted power production.

Future plans include deploying the system with higher power ratings and incorporating artificial intelligence-based control methodologies to further enhance its efficiency and adaptability. This approach promises to make solar energy harvesting more robust and reliable, contributing to a more sustainable energy infrastructure.

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