Simulation and Prototyping of an Active Dual-Axis Solar Tracker Based on Control Algorithm Using Arduino and Sensors

K. Narayana Rao[1], S. Sampath kumar[2], K. Mohan Kishor[3], P. Lalitha[4], E. Balaram hari[5], K. Vasundhara[6]

[1]*Assistant Professor, EEE, Visakha institute of engineering & technology, Visakhapatnam, Andhra Pradesh, India*
[2,3,4,5,6]*UG Student, EEE, Visakha institute of engineering & technology, Visakhapatnam, Andhra Pradesh, India*

Abstract - *A solar tracking system that is both affordable and easy to implement is detailed in this project. This project has developed a solar tracking system with two axes, allowing for greater energy harvesting from the sun. An arduino Uno has served as the central processing unit (CPU) for this endeavor. Four light-dependent resistors (LDRs) were employed to measure the sun's angular position in the sky, and two servo motors were employed to rotate the solar PV panel's orientation. Everything is in working order with the servo motor and sensors. The PV panel and the servo motor are now mechanically coupled. Everything has been put together and tested to ensure the system is working properly. When this tracker detects that the sun is directly overhead, it will adjust the solar panel's orientation accordingly. A dual-axis solar tracker increases the efficiency of the solar panel by constantly following the sun's movement across the sky.*

Key Words: Arduino, LDRs, Solar PV System, Renewable energy, DC Motor.

1.INTRODUCTION

One of the most widespread and long-term viable energy options now is solar power. Nevertheless, the direction of photovoltaic (PV) panels in relation to the sun determines their efficiency. The fluctuating angles of the sun cause fixed solar panels to capture less energy as the day progresses. A solution to this problem is the development of solar tracking systems, which aim to collect the maximum amount of energy from the sun. By dynamically modifying the panel's azimuth and elevation angles, dual-axis solar trackers offer the maximum efficiency. With an emphasis on control algorithms, sensor integration, and Arduino-based implementations, this literature review delves into previous research on active dual-axis solar trackers that have focused on simulation and prototyping [1].

There are two main categories of solar tracking systems: passive and active. Motors, sensors, and controllers enable active trackers to follow the sun's movement, while mechanical components or thermal expansion are used by passive trackers. When comparing single-axis and dual-axis tracking systems, it is clear that the latter are inferior. The former allow for more accurate PV panel orientation all day long and in all seasons [2]. Several studies have shown that, in comparison to fixed panels, dual-axis trackers can enhance energy capture by 25-40% [3].

The efficiency of a solar tracker largely depends on the control algorithm used to adjust the panel's position. Commonly employed algorithms include: Light-dependent algorithms: These use light sensors such as LDRs to detect sunlight intensity and drive motors accordingly [4]. Mathematical models: Some trackers use preprogrammed solar position equations to predict the sun's trajectory [5]. Hybrid methods: Combining sensors and mathematical models enhances accuracy and system robustness [6]. Arduino microcontrollers are widely used in implementing these algorithms due to their affordability and ease of programming. Accurate tracking relies heavily on sensors. The simplicity and low cost of LDRs make them a common choice. Nevertheless, weather conditions have the potential to impact them, resulting in inaccurate tracking. There are alternative sensors that provide better accuracy, like photodiodes and pyranometers. Improving tilt control using Inertial Measurement Units has been investigated by a few researchers [7].

Because of its open-source status, library availability, and compatibility with a wide range of sensors and motor drivers, Arduino is a favorite among prototyping solar tracking systems. Research by [8] shows that trackers controlled by Arduino can be effectively implemented with servo motors, stepper motors, and DC motors. Wi-Fi and Bluetooth, among other wireless communication modules, allow for remote control and monitoring [9]. Solar tracker performance is typically modeled using simulation tools like PVsyst, MATLAB/Simulink, and Proteus before physical prototyping. Control strategy optimization, energy gain assessment, and tracking accuracy validation are all aided by these simulations [10]. Researchers have recently used neural networks and other AI-based methods to enhance tracking efficiency [11].

This paper is structured as follows: Section 1 introduces the concept of Dual-Axis Solar Tracking Systems and their importance in optimizing solar energy capture. Section 2 provides an overview of solar trackers, differentiating between passive and active systems. Section 3 discusses the methodology, including simulation and hardware setup for the dual-axis solar tracking system. Section 4 presents the results and analysis of system performance. Finally, Section 5 concludes the study and suggests future research directions.

2.SOLAR TRACKER

As shown in Figure 1, Static solar panels are the most common way to collect solar energy. The efficiency of solar energy harvesting can be improved in other ways, though. The efficiency of solar trackers was found to be 30-60% higher than that of static PV panels. In addition, a variable elevation solar tracker can increase annual power production by over 40%. To maintain a nearly constant energy output throughout the day, photovoltaic panels must rotate in a specific way in response to the sun's angular motion in the sky. A solar tracker system is necessary for this to happen.

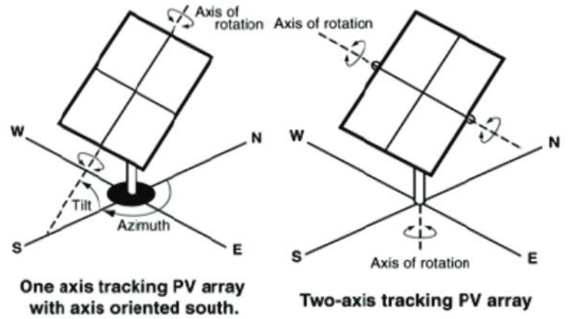

Fig - 1: One and two axis solar tracker [6]

Using an Arduino, this project aims to create a working prototype of a solar time algorithm that is based on a dual-axis solar tracker. Furthermore, the outcomes were compared to the results obtained when considering the performance of the solar energy harvesting dual-axis solar tracking method and static solar panel.

3. METHODOLOGY

3.1 Block diagram

The given block diagram as shown in Figure 2 represents an active dual-axis solar tracking system using a microcontroller, sensors, and motors. Here's a breakdown of its key components are Light Detectors (Sensors), Microcontroller, Motors for Dual-Axis Movement, Power Supply and Solar Panel. There are three light detectors. one for the X-direction, one for the Y-direction, and one as a reference point. These sensors detect sunlight intensity and provide signals to the microcontroller for adjustment. It acts as the brain of the system, processing data from the light sensors.

Based on the sensor inputs, it determines the required movement of the solar panel and controls the motors accordingly. Motor 1 (X-axis rotation) controls the horizontal movement (East-West direction). Motor 2 (Y-axis rotation) controls the vertical movement (North-South direction). Shaft couplers connect the motors to the solar panel, enabling smooth movement. Provides the necessary voltage and current to operate the microcontroller, sensors, and motors. This allows for uploading and modifying the control algorithm in the microcontroller.

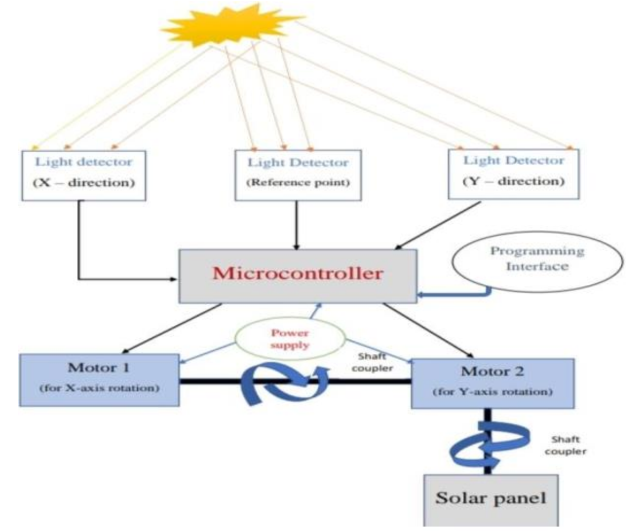

Fig - 2: Block diagram of proposed system [6]

The solar panel is mounted on the tracking system and follows the sun's position throughout the day for maximum energy absorption. The light detectors continuously sense the intensity of sunlight. The microcontroller processes these signals and determines whether the panel needs to move. If movement is required, it activates the appropriate motor to adjust the panel's orientation. This ensures that the solar panel is always facing the sun for optimal energy generation. This system significantly enhances the efficiency of solar panels compared to fixed systems by dynamically tracking the sun.

3.2 Control algorithm

The given flowchart shown in Figure 3, outlines the working algorithm of a solar tracker, particularly for a dual-axis system that adjusts both azimuth (horizontal) and elevation (vertical) angles. Here's a step-by-step breakdown: The algorithm begins execution when the system is powered on. The system initializes key components such as: RTC (Real-Time Clock): Keeps track of time for sun position calculations. LCD Display Used to show system status and parameters. Algorithms Control logic for adjusting panel orientation. The system checks if the elevation angle is greater than 0° (i.e., the sun is above the horizon). If the elevation angle > 0°, The system calculates the required position and moves both the azimuth motor (East-West movement) and elevation motor (up-down tilt) to track the sun accurately. If the elevation angle = 0° or lower, the system sets the motors to a default position (Azimuth = 90° (East), Elevation = 90° (Vertical position)). This ensures that during nighttime or when the sun is below the horizon, the panel is properly aligned for the next sunrise. The system checks the sun's position every minute to ensure real-time adjustments. The system continues tracking and updating the solar panel's orientation in a loop until powered off.

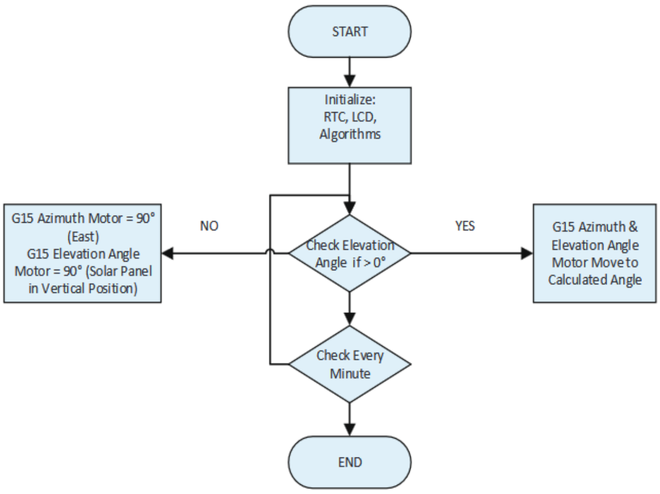

Fig - 3: Flow chart for control algorithm

3.3 Simulation study

Figure 5 shown the simulation diagram of proposed system. The given image represents a solar tracking system simulated in Tinkercad using an Arduino Uno, light sensors (LDRs), servo motors, and a battery power supply. Here's a breakdown of the components and their roles: The main microcontroller, which processes sensor data and controls the movement of the solar panel by sending signals to the servo motors. It receives input from the LDRs and adjusts the panel's orientation accordingly. The circuit contains four LDRs arranged in a voltage divider configuration. These sensors detect sunlight intensity and send signals to the Arduino to determine the sun's position.

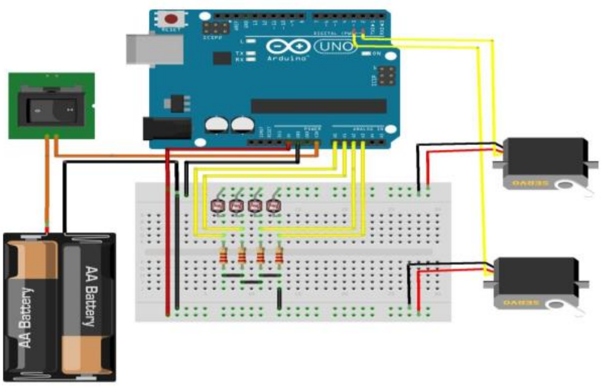

Fig - 4: Simulation diagram of proposed system

Two servo motors are used to provide dual-axis movement: One for horizontal (azimuth) movement (East-West direction). One for vertical (elevation) movement (tilt up-down). The Arduino adjusts the servo angles based on the LDR readings. Breadboard and Resistors The breadboard connects the LDRs to the Arduino with pull-down resistors, ensuring stable readings. The resistors help in balancing the voltage from the LDRs for accurate signal processing. The system is powered by a AA battery pack, supplying energy to both the Arduino and motors. A switch is included to control the circuit's power supply.

3.4 Prototype study

Figure 5 shows the prototype of the project. The solar panel, which is directly linked to a load, is mounted on top. The precise voltage, which is dependent on the amount of light hitting the panel and the tracker's location, may be measured by connecting a voltmeter or an LED to the load. Solar trackers need to be positioned appropriately in order to gather energy from concentrated solar photovoltaics, which have optics that directly absorb sunlight. Concentrated solar systems rely on trackers to ensure proper orientation toward the sun, which is essential for energy production. The solar panel is only a device that accepts light radiation; its control is by means of light-dependent resistor (LDR) sensors, and the load that may be connected to it is determined by the panel's rating.

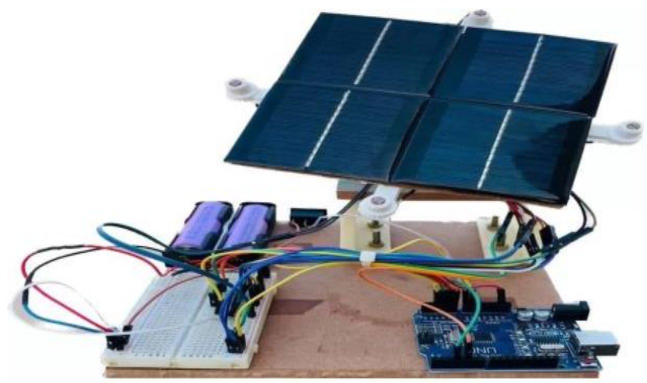

Fig - 5: Prototype of proposed system

Table -1: Hardware specification

Parameters	**Specification**
Operating voltage	11V
Operating current	750mA
Open-circuit voltage	9.2V
Maximum load voltage	10V

A gadget that detects light and moves towards the brightest spot is called a dual axis solar tracker. It can follow light from any direction because to its design. In order to mimic the overall motion of the Sun, the tracker's whole coverage in both directions is taken into account as 120°. The starting point for both the east-west and north-south servo motors is 90°. When the threshold value rises beyond the tolerance limit, the tracker's position will only go up or down.

4. RESULTS AND ANALYSIS

The data collection period for the measurements was a full day, beginning at 7:11 a.m. and ending at 6:54 p.m. The graphs were created using the measured data obtained from the data logger. The solar tracker was programmed to retrieve data by following the algorithms that were defined, while the static solar panel was inclined at a 15-degree angle toward south.

Both the solar tracker and the static panel's output voltage vs time are displayed in Figure 7. At 1.06 p.m., with an azimuth angle of 64.53° and an elevation angle of 166.24°, the solar tracker reported a maximum output voltage of 5.03V. As the output voltage hovered at 8.72V, the static panel recorded it.

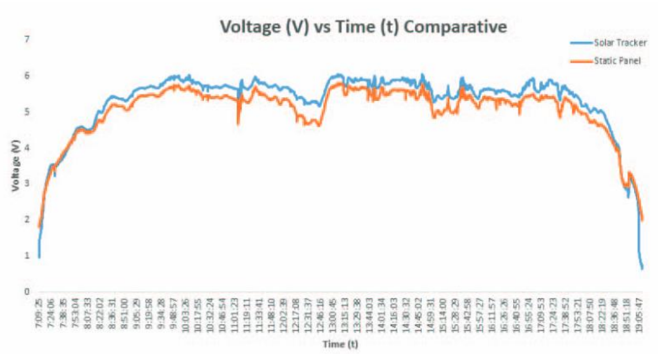

Fig -6 : A look at the power output from both stationary solar panels and solar tracking systems

Solar tracking technologies and a static solar panel's output current vs time are shown in Figure 8. With an azimuth angle of 63.29° and an elevation angle of 218.85°, the solar tracker reached its maximum output current of 93mA at 3.28 p.m. At the same time, the static panel measured an output current of about 101 mA.

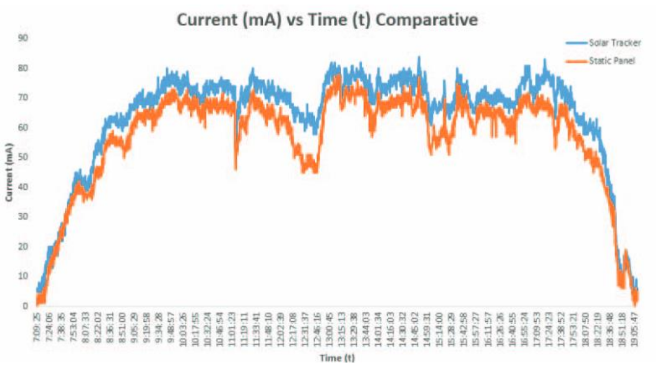

Fig-7: The comparison between solar tracking methods and static solar panels for the output current

5. CONCLUSIONS

Research goal in creating the Dual Axis Solar Tracker prototype was to find the exact spot where the sun's rays are strongest, so that our solar panels could produce the highest possible voltage. We are pleased to have contributed to our community after many failed attempts at completing our project. There are a few kinks in this endeavor, as there are with every experiment.

(i) Panel is sensitive to light within a certain range; outside of this range, it does not provide any feedback.

(ii) It determines the location of the panel by calculating the vector sum of all the light sources, which it does when the panel is illuminated by diffused light. We managed to complete this job with very few resources. Simplicity was maintained in the circuitry,

REFERENCES

[1] K. Achuthan et al., "Remote Triggered Dual-Axis Solar Irradiance Measurement System," in IEEE Transactions on Industry Applications, vol. 56, no. 2, pp. 1742-1751, March-April 2020, doi: 10.1109/TIA.2020.2966156.

[2] S. L. Jurj and R. Rotar, "Increasing the Solar Reliability Factor of a Dual-Axis Solar Tracker Using an Improved Online Built-In Self-Test Architecture," in IEEE Access, vol. 12, pp. 37715-37730, 2024, doi: 10.1109/ACCESS.2024.3375333.

[3] M. Saeedi and R. Effatnejad, "A New Design of Dual-Axis Solar Tracking System With LDR Sensors by Using the Wheatstone Bridge Circuit," in IEEE Sensors Journal, vol. 21, no. 13, pp. 14915-14922, 1 July1, 2021, doi: 10.1109/JSEN.2021.3072876.

[4] H. Fathabadi, "Novel Online Sensorless Dual-Axis Sun Tracker," in IEEE/ASME Transactions on Mechatronics, vol. 22, no. 1, pp. 321-328, Feb. 2017, doi: 10.1109/TMECH.2016.2611564.

[5] S. Asapu, Y. T. R. Palleswari, P. S. Rapaka, M. C. Bade, M. Deenakonda and R. Banothu, "Design and Implementation of High Voltage Gain DC-DC Converter for solar PV Applications," 2024 International Conference on Computational Intelligence for Green and Sustainable Technologies (ICCIGST), Vijayawada, India, 2024, pp. 1-5, doi: 10.1109/ICCIGST60741.2024.10717566.

[6] S. Asapu, N. Chilaka, N. S. Pantham, N. Sakalabattula, K. S. Tejitha and R. Lakkabattula, "High-Gain DC-DC Converter Implemented with an Improved Sliding Mode MPPT Control for Solar PV Applications," 2024 International Conference on Innovation and Novelty in Engineering and Technology (INNOVA), Vijayapura,

India, 2024, pp. 1-6, doi: 10.1109/INNOVA63080.2024.10846995.

[7] T. R. Palleswari Yalla, A. Siva, K. P. Swaroopg, G. Durga Prasad, M. Deenakonda and R. Banothu, "Comprehensive Analysis and Performance Investigation of Non-Isolated DC-DC Converters in Solar Photovoltaic Applications," 2024 International Conference on Computational Intelligence for Green and Sustainable Technologies (ICCIGST), Vijayawada, India, 2024, pp. 1-6, doi: 10.1109/ICCIGST60741.2024.10717523.

[8] S. Asapu, L. Juttiga, D. Bhuvaneswari, S. S. Adabala, P. Apireddi and A. Bale, "Implementation of Seven-Level Asymmetrical Multilevel Inverter for Solar PV Application," 2024 International Conference on Distributed Computing and Optimization Techniques (ICDCOT), Bengaluru, India, 2024, pp. 1-5, doi: 10.1109/ICDCOT61034.2024.10516167.

[9] Y. R. Al-Saadi, M. S. Tapou, A. A. Badi, S. Abdulla and M. Diykh, "Developing Smart Self Orienting Solar Tracker for Mobile PV Power Generation Systems," in IEEE Access, vol. 10, pp. 79090-79099, 2022, doi: 10.1109/ACCESS.2022.3194026.

[10] C. F. Abe, J. Batista Dias, G. Notton, G. -A. Faggianelli, G. Pigelet and D. Ouvrard, "Estimation of the Effective Irradiance and Bifacial Gain for PV Arrays Using the Maximum Power Current," in IEEE Journal of Photovoltaics, vol. 13, no. 3, pp. 432-441, May 2023, doi: 10.1109/JPHOTOV.2023.3242117

[11] A. K. Suria and R. M. Idris, "Dual-axis solar tracker based on predictive control algorithms," 2015 IEEE Conference on Energy Conversion (CENCON), Johor Bahru, Malaysia, 2015, pp. 238-243, doi: 10.1109/CENCON.2015.7409546.