Dual-Axis Solar Tracking System with Increased Efficiency

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***Abstract* - As non-renewable energy sources deplete, the focus on optimizing renewable energy, particularly solar power, has grown in importance. This paper proposes a solar tracking system designed for domestic use to enhance solar energy efficiency. The system comprises three key components: a solar tracking device utilizing Light-Dependent Resistors (LDRs) and servo motors to detect and align with the sun, a solar panel turning mechanism powered by a stepper motor for two-axis movement, and an algorithm to calculate optimal angles for solar panel adjustment. By improving the alignment of solar panels with the sun's intensity, the system maximizes energy harvesting and boosts overall efficiency.**

Keywords - renewable energy, photo-voltaic, single axis, dual axis, degree of freedom, static

I. INTRODUCTION

The global challenges of climate change and resource depletion emphasize the urgent need for sustainable energy solutions. Among various renewable energy sources, solar energy stands out due to its abundance and ecological benefits. This paper explores solar tracking systems, which enhance the efficiency of photovoltaic (PV) panels by adjusting their orientation to follow the sun's movement. Two primary types of solar tracking systems are discussed: single-axis, which tracks the sun along one direction, and dual-axis, which tracks both horizontal and vertical sun angles. The paper also outlines modern methods, such as GPS-based, machine learning-based, and cloud-based tracking, that further optimize solar energy harvesting. These systems, while more complex and costly than static solar panels, offer increased energy efficiency, making them a promising solution for both industrial and domestic applications. The proposal introduces an innovative dual-axis solar tracker with a cost-efficient design suitable for household use, addressing the challenges of affordability and maintenance in residential settings. Single-axis solar tracking systems, while simpler, struggle to adjust for seasonal changes in the sun's position, leading to reduced energy efficiency. Dual-axis tracking systems, though more effective at capturing solar energy year-round, are typically more expensive due to the need for two motors and a complex design, making them less feasible for home use. Current research focuses on dual-axis tracking with two motors, leaving a gap for innovation in developing a more affordable single-motor system. This would balance efficiency and cost, making solar tracking more accessible for a broader range of applications.

In the face of global warming and climate change, the transition to renewable energy sources, such as solar power, has become imperative. Solar energy is one of the most abundant and ecologically sustainable resources available. Photovoltaic (PV) solar panels are widely used to convert solar energy into electricity. To enhance the efficiency of solar energy capture, solar tracking systems are employed to adjust the panels' orientation according to the sun's movement. However, most systems either rely on costly dual-axis tracking or are less efficient single-axis systems.

Problem Statement

Single-axis solar tracking systems struggle to capture solar energy efficiently throughout the year due to their inability to adjust for the sun's seasonal changes. While dual-axis systems provide optimal energy capture, they are expensive and impractical for widespread use. Therefore, there is a need for a more cost-effective system that combines the efficiency of dual-axis tracking with the affordability of single-motor systems.

Objectives

1. Designing a Mechanical System – Develop a system that uses one motor to provide two degrees of freedom (2-DoF) for solar panel tracking without sacrificing energy efficiency.
2. Developing a Solar Tracking Device – Create a device that can autonomously track the sun's position, optimizing solar panel orientation to capture maximum energy.
3. Establishing Communication Between Devices – Ensure seamless communication between the solar tracking device and the mechanical system to enable automatic adjustments in the panel's position for optimal energy capture.

Background search

Solar energy, a critical renewable resource, has evolved since the creation of silicon photovoltaic cells in 1954 [1]. To enhance efficiency, solar tracking systems were introduced, adjusting panels to follow the sun's movement. Early methods, like manual adjustments and passive systems using low boiling point fluids, have given way to modern active systems powered by motors.

Globally, both single-axis and dual-axis tracking systems are used, with single-axis being more common but less efficient, especially in regions with significant seasonal solar variations. Dual-axis systems, while costlier due to their reliance on two motors, offer superior efficiency by tracking the sun horizontally and vertically. Recent innovations aim to reduce costs by using a single motor for dual-axis tracking.[2]
In Sri Lanka, where sunlight is abundant, solar tracking adoption is hindered by complexity and cost. LDR sensors, a more accessible alternative to sun sensors, are practical in this context. Single-motor dual-axis systems are seen as a cost-effective and energy-efficient solution for residential and commercial applications [3].

Assumptions

- Stable solar conditions in Sri Lanka.
- LDR sensors provide reliable data.
- Motor performance deviations are negligible.

Limitations

- Precision issues with the gear mechanism due to the screw type.
- Scalability challenges for larger solar systems are not addressed.

II. METHODOLOGY

The Solar Tracking project aims to develop a cost-efficient system to enhance solar energy harvesting at the domestic level. The project is divided into two main segments:

Solar Tracking Section
The solar tracking device optimizes solar panel efficiency by dynamically adjusting its orientation to follow the sun. It utilizes Light-Dependent Resistors (LDRs) to detect solar intensity and a single motor to achieve two degrees of freedom (2-DoF) for precise adjustments.[4]

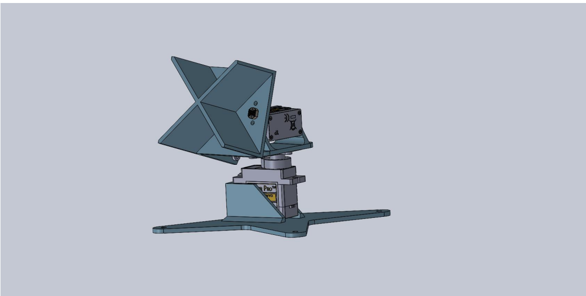


Fig 01 - Solar tracking device

Steps in Operation:

LDR Detection: LDRs measure solar intensity and provide resistance values.
Algorithm Processing: The system identifies LDRs with the lowest resistance, indicating the highest solar intensity.
Motor Adjustment: The algorithm directs the motor to align the panel with the maximum solar intensity. [5]
Optimization: The device continues adjusting until all LDRs show equal resistance, indicating optimal solar alignment.

Components:
Arduino Uno Microcontroller: Controls motors based on LDR data.

Mechanical device

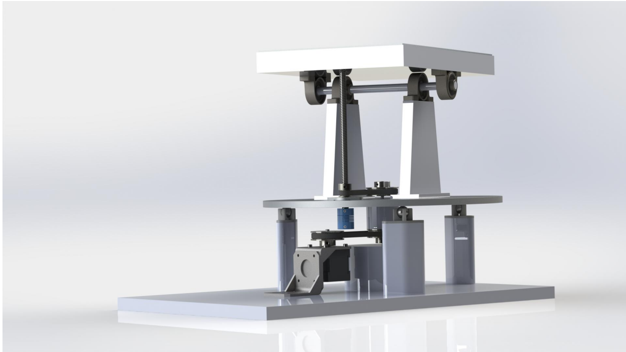


Fig 02 - Design for mechanical device

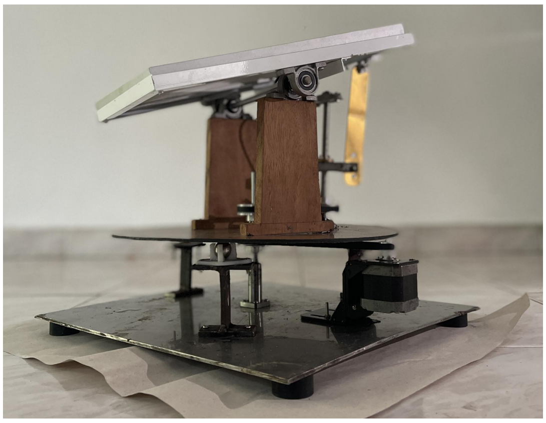


Fig 03 - Final implementation

Fig 04 - Voltage reading

Includes a gear mechanism that uses belts, gears and thread bars to adjust the solar panel in horizontal and vertical planes with the use of one motor.
With the use of this gear mechanism, we can turn the solar panel in both degrees with one movement of the stepper motor. The second degree of freedom is achieved with respect to the first degree of freedom. Therefore, when compared to dual axis solar tracking devices with two motors, the above design will not be able to achieve an infinite number of points on the hemisphere of movement in a dual axis solar tracking device. The design we have designed is only able to achieve 2200 points in the hemisphere of points. Therefore, a certain error percentage will be available when testing our solar tracking device.

Likewise, the error percentage can be decreased exponentially with the use of a thread bar with a higher number of pitches. As the bar we used consists of a pitch of 8mm the maximum number of points we could achieve was 2200.

As a stepper motor moves one step at a time which when taken in degrees can be said to be 1.8 degrees, we use the angles of the servo motors as variables to derive the number of steps the stepper motor has to turn in order to turn the solar tracking device towards the direction of the highest solar intensity present. As our design gives the stepper motor only 2200 steps to move, we derive the number of steps the stepper motor should move to the closest possible whole number and is therefore used to turn the solar panel.

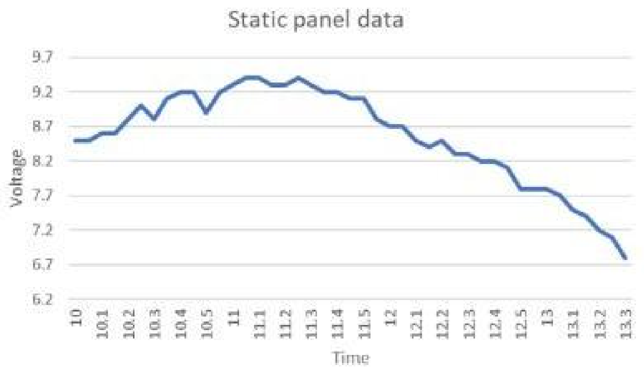
Control Unit: Communicates with a Raspberry Pi for motor position control.

III. RESULTS

Data Collection: Over 18 days, voltage measurements were recorded every 5 minutes from 10 am to 6 pm for both static and solar tracking panels.

Static Solar Panel:

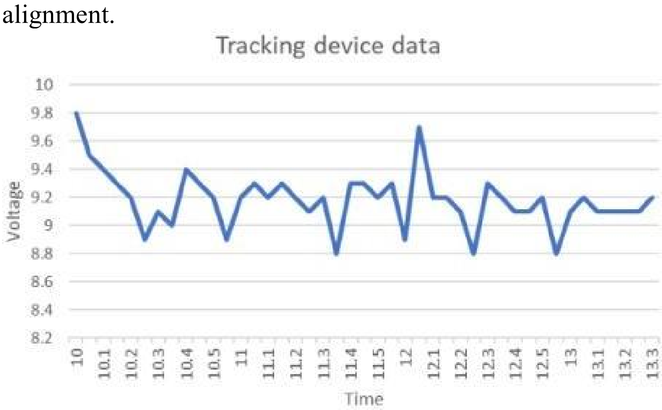
Performance: The static panel shows decreased efficiency as it cannot dynamically adjust to the sun's position, leading to a gradual drop in energy harvest.



Graph 1 : Voltage vs. Time shows a decreasing trend in energy collection.

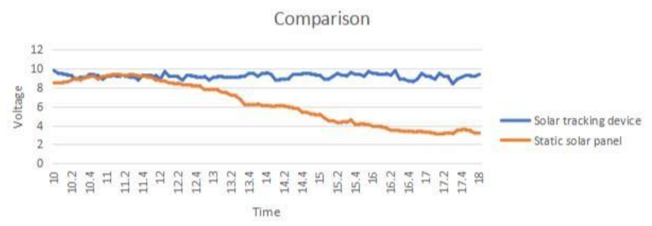
Solar Tracking Device:

Performance: The tracking panel maintains a more consistent energy collection pattern, with intermittent drops due to real-time adjustments for optimal solar alignment.



Graph 2 : Voltage vs. Time shows a consistent pattern with occasional dips

Comparison:



Graph 3 : The tracking device's curve demonstrates superior performance compared to the static panel, highlighting the advantages of solar tracking in maximizing energy generation.

Mean Values and Cost Analysis:

Tracking Device:
Daily Voltage: 893.4 V
Current Output: 0.57 A
Energy Output: 4.08 kWh
Monetary Gain: Rs. 175.44
Break-even Time: ~284 days

Static Panel:
Daily Voltage: 606.2 V
Current Output: 0.57 A
Energy Output: 2.61 kWh
Monetary Gain: Rs. 112.23
Break-even Time: ~178.2 days

IV. CONCLUSION

Harnessing solar energy is crucial for a sustainable future, offering virtually limitless power with minimal environmental impact and reducing reliance on fossil fuels. Solar energy's role in addressing climate change and promoting clean power generation is increasingly significant, driven by advancements in technology and decreasing costs.

Comparative Analysis:

- Solar Tracking Systems: These systems improve energy capture by adjusting to the sun's position, enhancing efficiency. However, they involve higher initial costs and require more maintenance.
- Static Solar Panels: While less efficient compared to tracking systems, static panels are more affordable and simpler to maintain.

Findings:

- The single motor dual-axis solar tracking system is more cost-effective compared to the dual motor system but still not as cost-efficient as static panels.
- Static panels remain a better option for budget-conscious projects, especially in areas with consistent sunlight or limited financial resources.

Ultimately, the choice between solar tracking systems and static panels should be guided by project goals, budget, and local solar conditions. Tracking systems are ideal for locations with varying sun angles and where budget allows, while static panels are suitable for consistent sunlight areas or constrained budgets.

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