International Journal of Computer Sciences and Engineering
Vol.11, Special Issue.1, pp.236-242, November 2023
ISSN: 2347-2693 (Online)
Available online at: www.ijcseonline.org

Research Paper

Sun Trailing Solar Panel System for Improving Energy Efficiency

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Abstract: This study delves further into the design and analysis of an Automatic Sun Tracking Solar Panel based on the open loop concept. The primary goal of this project is to maximise solar energy utilisation by effectively capturing sunlight and converting it into electrical energy for a variety of purposes. The method increases power output by putting the solar panel perpendicular to the sun's rays, which maximises sunlight absorption. Moreover, this tracking system operates independently of the intensity of the sunrays, accurately determining the sun's coordinates and automatically adjusting its position accordingly. This method ensures the solar panel's excellent efficiency and dependability.
This project's main advantage is its capacity to provide access to a sustainable and ecologically favourable source of energy. This solar tracking system can be integrated into local communities and, when connected to large-scale battery banks, can cater to their energy requirements independently. Overall, this research advances renewable energy technologies, allowing for the broad deployment of solar power systems.

Keywords: Sun tracking, Solar panel, Solar energy, Electricity generation, Environment friendly, Battery, Open loop, Everlasting, Decentralized

1. Introduction

Energy exists in various forms, including thermal, chemical, mechanical, and electrical, among others. Among these forms, electrical energy stands out as the most widely used due to its ease of transfer and high efficiency. The demand for electrical energy continues to rise steadily, prompting a need for sustainable and efficient energy sources.

Traditionally, electrical energy has been generated predominantly from conventional sources such as fossil fuels and nuclear fuels. However, these sources are limited in supply and pose significant environmental challenges, including pollution and eventual depletion. To address these problems, there is a worldwide shift towards solar, wind, tidal and geothermal energy sources which are non-traditional and renewable energy.

Solar energy, in particular, represents an abundant and fundamental form of energy. It serves as the primary source for various other energy forms, such as wind energy derived from air currents generated by solar heating and the formation of fossil fuels through organic matter that depends on photosynthesis driven by solar energy. Therefore, harnessing solar energy directly for electricity generation offers a promising solution.

Photovoltaic/Solar cells are designed to get electrical energy from solar radiation. However, the challenge lies in efficiently harnessing and utilizing the vast potential of solar energy. Traditional fixed solar panels are limited in their ability to maximise energy conversion because they cannot always maintain an optimal angle of incidence with respect to the beams of the sun.

The efficiency of fixed solar panels decreases if they fail to achieve the maximum output that can be obtained when the incident rays strike the panel perpendicularly at a 90-degree angle. Consequently, there is a need for innovative approaches to enhance the performance of solar panels and improve overall energy conversion efficiency.

This paper focuses on the design and analysis of an open-loop Automatic Sun Tracking Solar Panel. The primary goal of this project is to maximise solar energy utilisation by effectively capturing sunlight and converting it into electrical energy for a variety of purposes by positioning the photovoltaic cells perpendicular of the rays of the Sun. This innovative approach eliminates the dependency on fixed positioning and mitigates the efficiency limitations observed in traditional solar panels.
We can considerably improve the utilisation of solar energy for electrical power generation by exploring the potential of this autonomous sun tracking technology. This study advances renewable energy technology, helping the shift to a more sustainable and ecologically friendly energy landscape.

2. Aim and Objective

The goal of this project is to design and analyse an open-loop-based Automatic Sun Tracking Solar Panel. The primary goal is to maximise solar energy utilisation by continuously keeping the solar panel/photovoltaic panel perpendicular to the rays of the Sun which ensurs maximum absorption of sunlight and more efficient production of electrical energy. By implementing an automated tracking mechanism, the project aims to overcome the limitations of fixed solar panels and improve their overall performance and energy conversion efficiency.

The specific goals of the project include:

i. Creating a comprehensive and dependable sun tracking system capable of precisely determining the position of the sun on the basis of its coordinates.
ii. Creating a control mechanism based of the sun's location, which will automatically modify the angle of the solar panel, ensuring that it remains perpendicular to the incident sunlight.
iii. Comparing the performance of the fixed solar panels to our Automatic Sun Tracking Solar Panels in terms of efficiency, dependability, and energy output.
iv. Assessing the system's ability to operate independently of sunray intensity, allowing for consistent and optimized energy conversion regardless of varying solar conditions.
v. Investigating the feasibility of integrating the automatic sun tracking system with decentralized energy generation, enabling its utilization in local areas and facilitating self-sufficiency in energy supply when coupled with large battery banks.

By achieving these goals, this initiative hopes to enhance solar energy technologies and encourage the widespread adoption of renewable energy sources. The successful implementation of an Automatic Sun Tracking Solar Panel can enhance energy generation efficiency, reduce reliance on conventional energy sources, and provide access to a sustainable and pollution-free energy solution.

3. Proposed Work

3.1. Solar Angles and Geometry

Various solar angles and reference frames are evaluated to precisely identify the sun's location and position and optimise the solar panel's alignment. The following subsection explains the solar angles and their relevance in the proposed work:

i. Declination Angle (δ): It represents the location of the sun with relation to the equator of the Earth. It is the resulting angle between the position of the sun and the plane of the Equator. The tilt of the axis of the Earth and the plane of its Sun's orbit is roughly 23.44 degrees. As a result, throughout the earth's rotation around the sun, throughout the year the declination angle varies from 23.45 degrees South on Jun 21 to 23.45 degrees south on December 21. [1]
ii. Elevation Angle or Altitude Angle (α): It is the angle of the Sun's vertical position in the sky in relation to the surface observer on Earth. It calculates the angle between the observer's horizon and an imaginary line drawn between the Sun and the surface observer. If the altitude angle is negative, this means the Sun is below the horizon.
iii. Solar Azimuth Angle (γ_s): It represents the sun's horizontal direction in relation to a reference direction. It is the angle formed between the projection of the line of sight of the sun onto the ground and due south. A position East of South is indicated by a positive azimuth angle, while a position West of South is indicated by a positive azimuth angle.
iv. Latitude (Φ): Latitude is a distance from the equator to the poles in degress. At the Equator, it is 0 degrees and at the poles, it is 90 degrees. The intersection of the latitude angle and the longitude angle is used to precisely and uniquely define a location on the Earth's surface. [1]

The suggested project seeks to properly calculate the Sun's position and alter the orientation of the photovoltaic panel/solar panel to obtain optimal sunlight absorption by taking these solar angles into account and including the latitude of the installation site. The exact computation and use of these angles will aid in the efficient tracking of the sun and the optimisation of solar energy conversion into electrical energy.

3.2. Types of Systems

There are two primary types of systems in solar energy applications: fixed systems and tracking systems. This subsection provides an overview of these system types and their characteristics in the proposed work:

i. **Fixed Systems:** Fixed solar systems are stationary and remain in a fixed position and orientation throughout the day. Once installed, they maintain a constant angle relative to the ground or mounting structure. Fixed systems are relatively simple to install since they do not require any moving parts or mechanisms. However, their efficiency is limited as they are unable to actively track the sun's movement.
ii. **Tracking Systems:** Tracking solar systems are designed to monitor the movement of the Sun by dynamically changing the angle and position of the photovoltaic panel throughout the day. These systems employ a variety of tracking algorithms and techniques to stay perpendicular to the rays of the Sun. Tracking systems are typically more complex to install and require additional components, such as sensors and motors, to facilitate the automated movement of the solar panel.

By incorporating an automated tracking mechanism, the project aims to overcome the limitations of fixed systems and maximize the absorption of sunlight, leading to improved efficiency and energy generation capabilities.

3.2.1. Types of Tracking Systems

There are three main types of tracking systems: active trackers, passive trackers, and open-loop trackers. This subsection discusses these tracking systems along with their respective drawbacks in the context of the proposed work:

i. **Active Tracker:** Active tracking systems detect the intensity of sunlight using sensors such as Light Detecting Resistors (LDRs) or ambient light sensors. A matrix is created to determine the location of the Sun on the basis of the data of the Sun's intensity, and the solar panel is rotated accordingly.

However, a drawback of active trackers is that they primarily track intensity rather than the actual position of the sun. This means that when clouds obstruct the sun, the tracker may mistakenly move towards an area with better intensity, leading to unnecessary and frequent rotations. These constant rotations driven by motors can reduce the system's efficiency and result in higher power consumption. Additionally, the process of creating the matrix for positioning the tracker can be complex. [2]

ii. **Passive Tracker:** Passive tracking systems rely on the use of a low boiling point fluid of a compressed gas. A gas pressure imbalance is created due to solar heat and the tracker moves in reaction to it. However, passive trackers have some disadvantages. For starters, their precision may be less precise, making them less suited for photovoltaic (PV) cells that require perfect alignment. Additionally, passive trackers are sensitive to changes in temperature, and variations in temperature without a corresponding movement of the sun can affect their performance. The mechanical nature of passive trackers also introduces the possibility of friction, which can reduce accuracy over time. [2]

iii. **Open Loop Tracker:** Open-loop tracking systems can be further classified into two subtypes: time-based and altitude-based trackers.

a. **Time-based Tracker:** Time-based trackers rotate the solar panel at fixed intervals. However, a drawback of this approach is that the length of daytime varies throughout the year due to seasonal changes. Consequently, the positioning accuracy of time-based trackers may not be optimal since the fixed time intervals may not align precisely with the sun's position. [2]

b. **Altitude-based Tracker:** Altitude-based trackers fully track the sun's movement and utilize satellite positioning to accurately position the solar panel. These trackers offer high positioning accuracy even in the presence of clouds. If a cloud obscures the sun's location, the tracker will continue to track it, and it will adjust itself to be perpendicular to the sun as soon as the cloud moves. However, it is important to note that altitude-based trackers may require additional infrastructure and reliance on satellite data, potentially increasing the complexity and cost of the system. [2]

By addressing the limitations of existing tracking systems, the project aims to develop an optimized solution that combines accurate tracking, efficient power consumption, and improved positioning for maximum solar energy absorption.

Based on the axis of rotation, there are two types of solar tracking systems: single-axis trackers and dual-axis trackers. Each type offers different capabilities and complexities in terms of tracking the sun's position. This subsection also provides a brief description of these tracker types:

i. **Single-Axis Trackers:** Single-axis trackers allow the solar panel to move along a single axis, either horizontally (left and right) or vertically (up and down), depending on the specific mechanism employed. When compared to dual-axis trackers, these trackers are easier to construct and operate. While single-axis trackers can monitor the sun to some extent, their movement is limited to only one direction. Consequently, throughout the day, they may not be able to fully track the precise position of the Sun. [3]

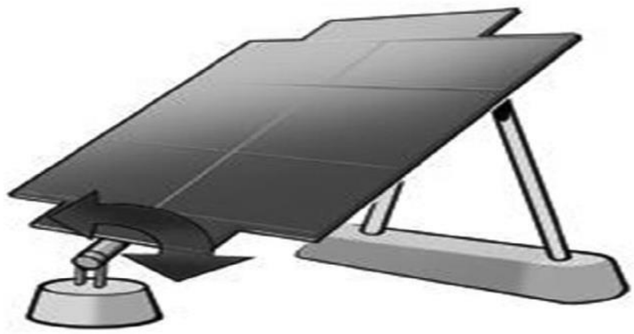

Figure 1. Single-Axis Tracker.

ii. **Dual-Axis Trackers:** Dual-axis trackers let the solar panel to move along both the horizontal and vertical axes, allowing for more mobility and tracking the position of the Sun more precisely. These trackers are more sophisticated in design and necessitate extra control devices to correctly alter the orientation of the panel. Dual-axis trackers can orient the photovoltaic panels perpendicular to the the rays of the Sun by moving in multiple directions during the day. [3]

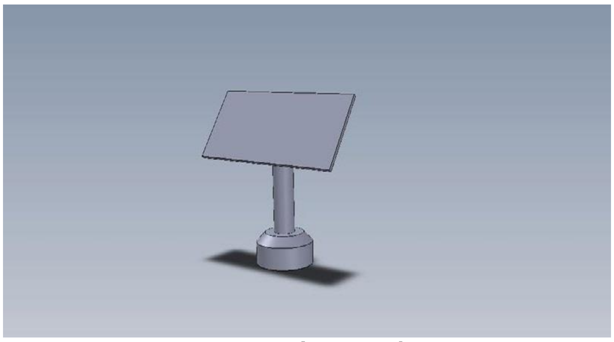

Figure 2. Dual-Axis Tracker.

An Altitude-based Open Loop Tracking System, which falls under the category of single-axis tracking systems, is used in the proposed project. This system uses a solar position calculator to calculate the sun's position and then uses altitude-based tracking to optimise solar panel alignment. A Programmable Logic Controller (PLC) that stores the sun's location over time facilitates the entire tracking procedure. The PLC then transmits the signals to the relays attached to the motors in the mechanism. Each axis of rotation is controlled by two relays, allowing for both movements: forward and backward. The power sent to the motors by the relays can be either DC or AC based on the signals transmitted to the relays. [3]

The paper intends to improve the efficiency of solar panel alignment and maximise solar energy absorption throughout the day by utilising an Altitude-based Open Loop Tracking System with single-axis tracking based on the concept of Open-loop.

3.3. Parts of the Project

The proposed work consists of three essential parts that contribute to the functionality and performance of the Automatic Sun Tracking Solar Panel system:

i. **Solar Tower:** The solar tower comprises the mechanism responsible for the photovoltaic panel's rotation. Depending on the unique design requirements, the solar tower can be designed as a single-axis or dual-axis tracking system. Based on the specifications of the inverter, the solar panels are connected in various configurations such as series and parallel. The rotating mechanism is linked to motors that allow the solar panel to move precisely. These motors are controlled by a dedicated control panel, which includes components such as a Programmable Logic Controller (PLC), relays, and power supplies. The control panel ensures that the solar panel is accurately positioned based on the sun's altitude, maximising solar energy absorption.

ii. **Battery Bank:** The battery bank is a crucial component of the system, responsible for storing the harvested solar energy. It is made up of a group of lead-acid batteries or battery cells, with specialised properties. The capacity of the battery bank determines the ability of the system to store energy for later use. Depending on the capacity and configuration of the battery bank, the system can operate independently or in conjunction with other energy sources. The battery bank ensures a continuous and reliable power supply even during periods of low solar intensity or at night when the solar panel is not generating electricity.

iii. **Inverter:** The inverter is critical to the project because it is responsible for the conversion of the DC produced by the solar panels into AC, which may be used to run electrical equipment and connect to the grid if necessary. The inverter consists of circuits and components designed to efficiently convert the harvested solar energy. High-quality thyristors are typically used in the inverter circuitry to ensure robust and continuous operation. The inverter's reliability and performance are crucial for effectively utilizing the solar energy generated by the system and making it compatible with various electrical loads and applications.[4]

By integrating these three essential parts—solar tower, battery bank, and inverter—the proposed Automatic Sun Tracking Solar Panel system aims to harness maximum solar energy, store it efficiently, and convert it into usable electrical power.

4. Result and Discussions

4.1. Solar Position Calculator

To determine the precise coordinates of the sun based on the project's specific location, the US site of NASA is utilized. This site provides access to the NOAA Solar Position Calculator, a reliable tool for calculating the sun's position at a given time and geographical coordinates.

The NOAA Solar Position Calculator enables the input of latitude and longitude coordinates corresponding to the project site. These coordinates are critical for estimating the position of the Sun in the sky. The device can get crucial information such as the sun's azimuth angle, altitude angle, and declination angle by entering particular coordinates into the calculator. [5] The use of the NOAA Solar Position Calculator ensures the project's solar tracking system operates based on precise and up-to-date sun position data. This information is critical for optimising the solar panel's orientation perpendicular to the rays of the Sun, hence maximising solar energy absorption. [1]

Throughout the day, the project can successfully track the movement of the Sun by leveraging the trustworthy and accurate calculations provided by the NOAA Solar Position Calculator, allowing the solar panel to maintain optimal orientation and maximise the conversion of sunlight into electricity.

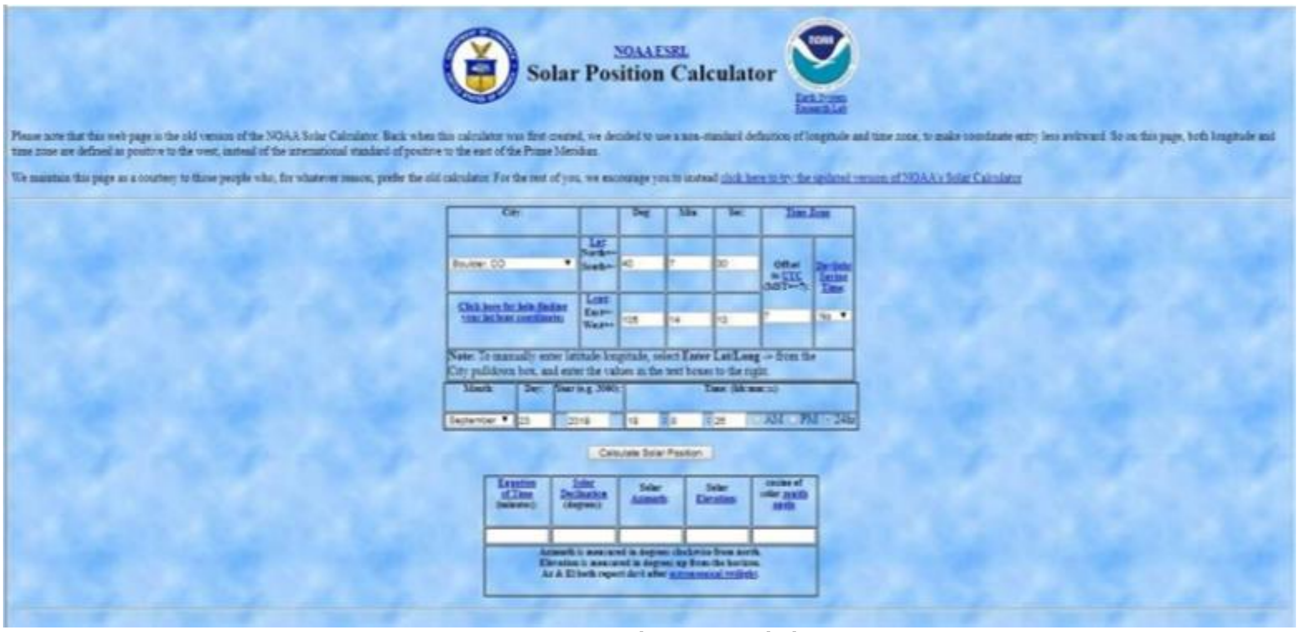

Figure 3. NOAA Solar Position Calculator

4.2. Block Diagram

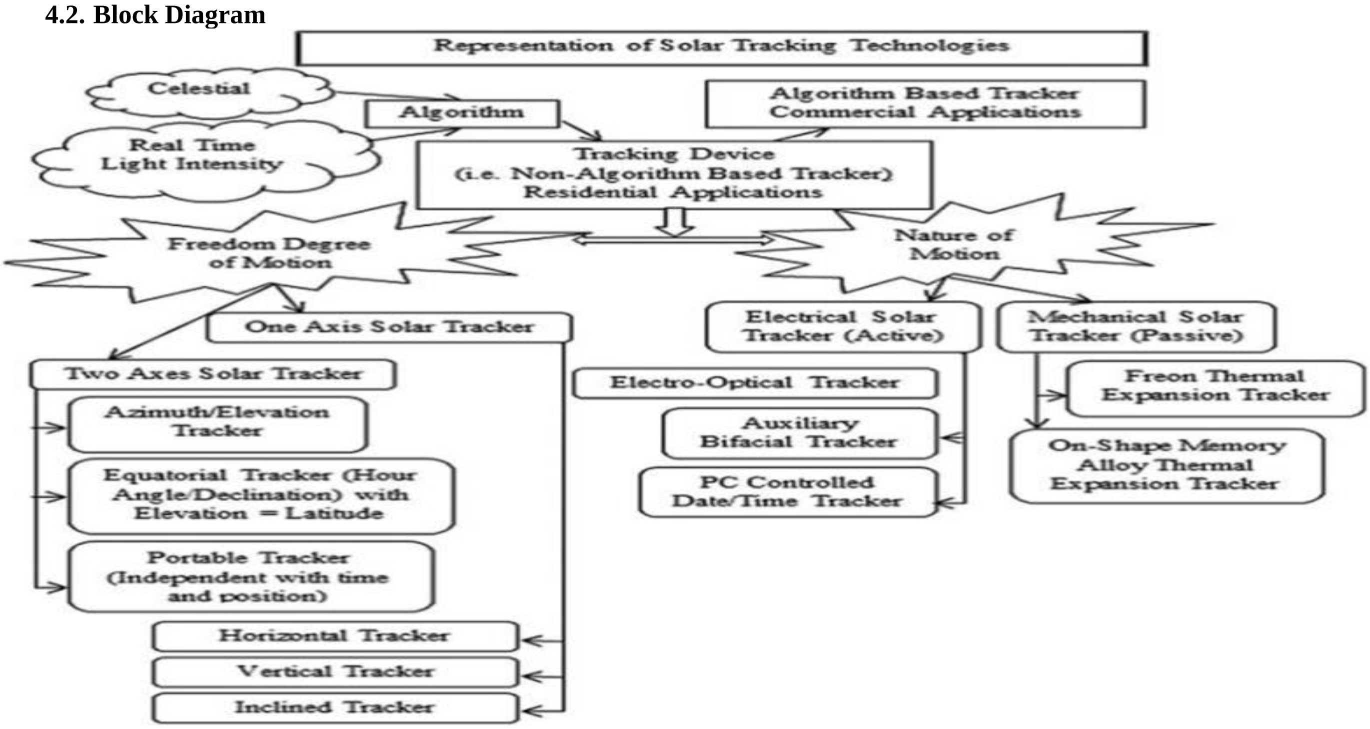

Figure 4. Block Diagram

4.3. Comparison between Different Solar Tracking Systems

Table 1. Different Solar Tracking Systems Comparison Table.

Types of Solar System		Performance	Capabilities	No. of Axis	Technical Restrictions
Single axis solar tracking system	Horizontal Single Axis Tracker (HSAT)	68% compared to fixed panel.	Less complicated, less expensive, rigid and stable, less likely to be damaged during storms.	1	Occupy a lot of space because there are to be arranged horizontally.
	Vertical Single Axis Tracker (VSAT)	62% compared to fixed panel when loss due to wind force taken into account.	Less complicated, less expensive.	1	Easily affected by wind force. So support should be taken care.
	Tilted Single Axis Tracker (TSAT)	69% compared to fixed panel.	More suitable for smaller latitudes, i.e., places which are close to the equator.	1	The inclination should be calculated very accurately to avoid shading and wind loss.
	Polar Aligned Single Axis Tracker (PASAT)	Still experiments are going on.	More suitable for larger latitudes, i.e., places which are far the equator.	1	Still experiments are going on this. Pros and cons has to be studied.
Dual axis solar tracking system	Tip-Tilt Dual Axis Tracker (TTDAT)	78% compared to fixed panel without considering the extra manufacturing cost of dual axis.	Able to track the sun in both directions (East-West as well as North-South) and able to minimize the up-sun shading.	2	Should be attached on a long pole so wind forces will be very high.
	Azimuth-Altitude Dual Axis Tracker (AADAT)	82% compared to fixed panel without considering the extra manufacturing cost of dual axis.	More suitable for greater latitude where substantial seasonal variation in sun's height and arc, and the weight of the array is distributed over a portion of the ring.	2	Its pivoting mechanism rests on the ground so occupies a large space and these are not suitable for northern climates with snow build up.
Passive tracking system		40% compared to fixed panel.	With the help of passive materials like SMA (shape memory alloy), the additional parts can be eliminated.	-	The cost of the material for an actuator will be very high and availability of some materials will be difficult. Its also sluggish in moving cold temperature.

4.4. Project Pictures

Figure 5. Front Image

Figure 6. Top Image

5. Conclusion

The Automatic Sun Tracking Solar Panel system's design and implementation have showed substantial breakthroughs in solar thermal and photovoltaic (PV) systems. The difference between single-axis and dual-axis sun trackers, along with active and passive tracking systems, has provided important insights into the efficiency and performance of such systems.

Based on the results obtained, it is evident that the Altitude-based Dual Axis Solar tracker configuration exhibits superior efficiency compared to other tracking systems. Through experimental analysis, it has been determined that the solar panel's electricity generation efficiency can be increased by a minimum of 5-8% when employing the proposed tracking system. This percentage increase accounts for the tracking system's and accompanying mechanisms' energy usage.

The application of this innovative technology holds great potential, particularly in areas lacking access to electricity, such as rural villages. The decentralized generation provided by the Automatic Sun Tracking Solar Panel system offers a cost-effective alternative to connecting these communities to the national grid. This approach enhances reliability and reduces fault clearing time, as the system operates independently of complex centralized grids.

In summary, the implementation of the Automatic Sun Tracking Solar Panel system presents a promising solution for harnessing solar energy efficiently. The increased electricity generation and reliability achieved through this system contribute to sustainable energy practices and pave the way for improved access to clean and affordable electricity in underserved communities.

Conflict of Interest
Authors do not have any conflict of interest.

Funding Source
None.

Acknowledgement
We would like to express our sincere gratitude to Dr. Dharmpal Singh, Head of the Department of Computer Science and Engineering at JIS University, for his invaluable guidance and support throughout the course of this project. His insights, expertise, and encouragement have been instrumental in shaping the direction of our research. His constructive feedback and thoughtful suggestions have played a pivotal role in refining the project and enhancing its quality.
We would like to acknowledge the support and resources provided by the institution and the faculty members, which have been indispensable in the successful completion of this project.

Lastly, we also extend our appreciation to all our peers and colleagues who provided their insights and assistance during various stages of this project. Their diverse perspectives and discussions have contributed significantly to the development of this work.

We are truly thankful for the collective efforts and contributions that have enabled us to bring this project to fruition.

Author' Contribution
The authors confirm contribution to the paper as follows: study conception, model design and analysis: Pronoy Roy, Ankit Das, Argha Simlai and Indranil Mondol; First draft manuscript preparation by: Pronoy Roy, Ankit Das, Argha Simlai, Indranil Mondol, Tirthajyoti Nag and Jayasree Ghosh; Final draft manuscript preparation by: Tirthajyoti Nag and Jayasree Ghosh. All authors reviewed the results and approved the final version of the manuscript.

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