A review on dual-axis solar tracking system

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Abstract

PV systems are now thought to be the most effective renewable energy source for producing power. the value of solar energy as an environmentally friendly, sustainable, and cost-free energy source. With an emphasis on solar tracking systems, it talks about the continuous investigation and study into improving solar energy harvesting techniques. An overview of solar PV cells, their building materials, various solar PV system types, and solar tracking systems is given in this article. It highlights the efficiency and benefits of dual-axis tracking solar systems over single-axis and fixed systems by focusing on their design and performance analysis. Through this research, solar energy usage is continuously improved. Dual-axis tracking systems not only increase energy efficiency but also help to decrease the total amount of acreage needed for solar power.

Keywords—Solar energy, Solar tracking, Dual axis, Arduino, *Light* dependent resistors (LDRs), *Servo* motors, Tracker mount, Driver, Efficiency

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1.Introduction

An innovative device called a solar tracking system is made to maximize the effectiveness of solar panels by reorienting them to track the sun's path across the sky during the day. Compared to stationary solar panels, this tracking optimizes the quantity of sunlight captured, increasing energy production. One of the most important technologies in the development of solar energy is solar tracking systems. These systems increase energy output and support the more general objectives of sustainability and energy efficiency by utilizing the sun's full potential. The use of solar tracking systems is anticipated to increase as costs come down and technology advances, contributing to the trend toward renewable energy sources.

These semiconductor-based panels are used in photovoltaic systems to directly convert sunlight into electrical power. A dual axis monitoring system that tracks the sun's movement both vertically and horizontally allows panels to maintain the perfect angle to the light. Panels move from east to west each day to follow the path of the sun across the sky. The panels adjust to the height of the sun as the seasons change. They will constantly be facing the sun thanks to this. These systems are especially effective in areas that receive a lot of sunlight or where the sun's position varies greatly during the year, such those near the equator.

In this work, we These semiconductor-based panels are used in photovoltaic systems to directly turn sunlight into power. In order to keep panels at the best possible angle to the light, a dual axis tracking system monitors the sun's movement both horizontally and vertically. To track the sun's journey across the sky, panels rotate every day from east to west. The height of the sun varies with the seasons, and panels adapt to match it. They will always be angled straight at the sun thanks to this. These systems work particularly well in bright regions or locations, like those close to the equator, where the sun's position fluctuates significantly during the year.

1.1. Requirement of Tracking System

The fact that the sun’s position changes throughout the day and year necessitates the use of a sun-tracking system. Solar panels or solar collectors are used because being installed in one place does not provide enough sunlight to generate maximum energy. By tracking the motion of the sun through the sky, a sun-tracking system can keep solar panels or solar collectors oriented towards the sun, maximizing the amount of sunlight received and thus increasing energy output

Figure1: Single axis solar tracking system

Solar panels on single-axis trackers revolve in a single direction, typically east-west or north-south. Throughout the day, the systems change the panels' angle to track the sun's path across the sky. They are a popular option for large solar farms since they are easier to use, less costly, and use less energy than dual-axis systems. They do not account for seasonal variations in the sun's position, despite the fact that they greatly increase energy output (30–35% more than fixed systems). 25–35% more energy is produced than with fixed panels. less expensive and complicated than dual-axis systems. Ideal for locations that receive steady sunlight all year round. unable to adapt to the sun's seasonal variations in angle (greater in summer, lower in winter). A little less effective

Figure2: Dual axis solar tracking system

Solar panels can follow the sun both vertically (as the sun's height changes over the year) and horizontally (as it moves from east to west) thanks to dual-axis trackers, which offer two degrees of rotation. This maximizes energy absorption guaranteeing that panels are always facing the sun. Dual-axis systems work well in areas with different seasonal patterns of sunshine. When compared to fixed systems, they can enhance energy production by 40–45%. However, because these systems require more sensors, motors, and upkeep, they are more costly and complex. makes sure the panels are always facing the sun in order to maximize the amount of sunlight that is captured. 40–45% more energy is produced than with fixed panels. Perfect for areas that receive different amounts of sunlight throughout the year.

2.Literature Review;

This is the literature survey of those below research papers. which we studied about dual axis of solar tracking system.

Control of Single-Axis and Dual Axis Solar Tracking System [1].	The study focuses on utilizing Dual Axis Solar Tracking (DAST) and Single Axis Solar Tracking (SAST) to increase the stability and efficiency of solar systems. The project's primary control and simulation tools are Arduino and MATLAB/SIMULINK. By measuring the sun's position throughout the day, solar tracking devices assist solar panels in generating the most power possible.
DUAL AXIS SOLAR TRACKING SYSTEM WITH MONITORING [2].	MATLAB/SIMULINK is used in the design and simulation of the solar tracking systems in order to study and analyse their performance. Sensors, motors, and an Arduino microcontroller are used in the development of a dual-axis solar tracking system prototype. The solar panels' position is continuously adjusted by Light Dependent Resistors (LDRs), which sense the strength of the sun. To assess efficiency gains, the dual-axis tracking system's performance is contrasted with that of single-axis and stationary solar systems. To maximize the solar panels' energy output, algorithms such as Maximum Power Point Tracking (MPPT) are used.
Performance Investigation of Low-Cost Dual-Axis Solar Tracker using Light Dependent Resistor [3].	A low-cost dual-axis solar tracker that is installed on a moving platform and maintains the solar panel's perpendicularity to the sun by means of PI-controlled linear actuators and a specially designed sunlight

	sensor. The device increases the efficiency of solar energy generation for cars, boats, and other mobile platforms by achieving a tracking error of roughly 2 degrees.
Dual axis solar tracker with IoT monitoring system using Arduino [4].	It uses Arduino to create a dual-axis solar tracker with an Internet of Things monitoring system that tracks the position of the sun in order to maximize solar panal efficiency. The efficiency increased by 45.11%, according to the results, demonstrating how well the dual-axis design maximizes energy output. A dual-axis solar tracker that optimizes solar energy collecting and offers real-time performance data for analysis was successfully produced by the project by integrating sensor-based control, Arduino programming, IoT monitoring, simulation, and real-world testing.
Performance evaluation of standalone double axis solar tracking system with maximum light detection MLD for tele communication towers in Malaysia [5].	High-efficiency heterojunction intrinsic thin-film (HIT) solar modules with a sophisticated dual-axis MLD solar tracker make up the system. Daily data over a four-month period, including average power output and battery state of charge, is analysed in relation to various weather conditions in order to evaluate the performance. The amount of solar radiation captured, global solar irradiation, and ambient temperature are among the statistics that have been gathered.
Design of Arduino-Based Dual Axis Solar Tracking System [6].	A power output increase of about 20%. The findings demonstrate that by guaranteeing that solar panels receive the most sunshine possible throughout the day, the dual-axis system can greatly increase solar panel efficiency.

	A dual-axis sun tracking system with an Arduino microcontroller is used in the paper. The system employs two linear actuators to modify the position of the solar panel and five light-dependent resistors (LDRs) to measure the intensity of the sunshine. These components are used in the hardware design to build the tracking system, while C++ programming is used in the software development to operate the system.
Real building implementation of a deep reinforcement learning controller to enhance energy efficiency and indoor temperature control [7].	In order to maximize building thermal regulation, this article employs a three-step process. In order to balance speed and transparency, the thermal dynamics of the building are first simulated using a grey-box RC model. The model uses resistors (thermal resistance) and capacitors (thermal mass) to simulate heat flow and storage. Second, to maximize comfort and energy efficiency, a DRL control agent is trained in a simulated environment. Lastly, real-world environments are used to test the operation of both the RBC and DRL controllers.
Simple design and implementation of solar tracking system two axis with four sensors for Baghdad city [8].	The paper demonstrates that the solar tracker produces greater power when compared to a stationary solar panel. The system has two modes of operation: direct sun tracking using LDR sensors and a fallback mode that keeps the system still in bad weather. The findings show that by maintaining photovoltaic (PV) panels' alignment with the sun for maximum power extraction, the solar tracker increases the energy efficiency of these devices.

State-of-the-art in solar water heating (SWH) systems for sustainable solar energy utilization: A comprehensive review [9].	The article examines the latest developments in Solar Water Heating (SWH) systems, emphasizing important parts such as storage tanks and solar collectors (FPC, ETC, and CPC). It also discusses how nanofluids may improve thermal efficiency. It has been demonstrated that nanofluids such MWCNTs, CuO, and AlO_3 greatly enhance collector performance, with efficiency gains of up to 35% in FPCs and 12.4% in ETCs. By lowering heat losses, the addition of Phase Change Materials (PCMs) to collectors and storage tanks improves thermal performance even more.
Dual-Axis Solar Tracker for Using in Photovoltaic System [10].	Compared to a properly aligned static solar panel, the device increases energy output by 9.87%. This illustrates the benefit of continuously monitoring the sun's location in real time. In comparison to a fixed panel setup, the study emphasizes that the dual-axis tracker technology improves solar exposure and boosts the system's total energy efficiency by continuously altering the panel's position.
Analysis and Testing of Dual Axis Solar Tracker for Standalone PV Systems using Worm Gear [11].	The application of automated dual-axis tracking systems that maximize solar energy collecting by combining motorized mechanical systems, solar sensors, and microcontroller-based control units. When compared to fixed solar panels, these systems showed notable increases in energy output, usually between 31-42% higher energy generation. According to the study, dual-axis trackers are a promising way to improve solar energy harvesting since they are significantly more efficient than static systems at reorienting the panel in response to the Sun's location.

Review of dual axis solar tracking and development of its functional model [12].	In order to effectively capture solar energy and lessen the constraints of static solar panels, the research highlights the need of increasing the efficiency of solar tracking systems, especially dual-axis systems. Dual-axis tracking systems are already more effective than stationary systems, according to the analysis of existing technologies, but they can yet be made more effective. Higher energy yields and improved overall performance of solar power technologies may result from the coevolving design approach and the suggested functional model, which provide a means to build more effective systems.
A new two-axis solar tracker based on the online optimization method: Experimental investigation and neural network modeling [13].	This study examines the viability of employing neural network modeling and optimization techniques (such as PSO) to precisely forecast the Sun's location in a two-axis solar tracker system. Without depending on conventional models of solar movement, the system enhances solar energy capture by adjusting the Sun's position-related parameters (azimuth and zenith angles). For solar tracking systems, the combination of ANN modeling with online optimization offers a dynamic and effective solution that improves performance and speeds up response times. The outcomes highlight how this strategy could maximize solar energy harvesting in practical settings, especially in areas with solar data accessible, like Shiraz City.
Artificial intelligent control of solar tracking system [14].	The study shows how well fuzzy logic controllers and artificial neural networks (ANNs) work for regulating a two-axis solar tracker and process identification, respectively.

	The performance of the solar tracker is greatly enhanced by the use of intelligent controllers, especially the fuzzy logic PID controller with self-tuning scaling factors, as opposed to traditional PID controllers. The research demonstrates the possibility of merging artificial intelligence (through ANNs) and advanced control systems (such fuzzy logic) to boost the accuracy and efficiency of solar tracking systems, leading to better solar energy use .
Sun flower mimic robot for dual axis solar tracking system [15].	By constantly modifying the solar panels to follow the sun, this system shows how contemporary technology using cameras, microprocessors, and motors can greatly improve solar power output and result in higher energy efficiency. The potential advantages of such tracking systems in solar power applications are shown by the 2-3% improvement in energy output.
Energy, exergy, economical and environmental analysis of photovoltaic solar panel for fixed, single and dual axis tracking systems: An experimental and theoretical study [16].	In comparison to fixed solar panels, the study finds that solar tracking systems—particularly dual-axis tracking—offer significant gains in energy yield, economic feasibility, and environmental sustainability. Dual-axis tracking systems are especially efficient, delivering notable CO_2 emission reductions and increasing energy output by up to 25.5%. They are more expensive initially, but over time, the economic advantages make them a better choice, particularly in areas like Zakho with ideal climates.

A dual solar tracking system based on a light to frequency converter using a microcontroller [17].	With LTFs for accurate tracking and microcontroller-based control logic, the suggested PILOT-PANEL solar tracking system is incredibly effective, extracting up to 98.36% of the energy while requiring very little energy. The high current consumption and heating difficulties present in conventional LDR-based trackers are resolved by this method. The system offers a sustainable, energy-efficient way to maximize solar energy capture and shows significant gains over traditional solar tracking systems.
Comparative Analysis of Dual and Single Axis Solar Tracker [18].	Single-axis trackers are simpler but less accurate at tracking the Sun because they only require two LDRs and a single servo motor. Conversely, dual-axis trackers provide more accurate tracking with the use of two servo motors and four LDRs, which enable the panel to adjust in both axes, enhancing overall energy capture. Both systems can successfully follow the Sun thanks to the microcontroller used in both tracker designs to interpret LDR data and regulate the servo motors, but the dual-axis system offers a higher level of solar energy efficiency.
Design and Practical Implementation of Dual-Axis Solar Tracking System with Smart Monitoring System [19].	When compared to conventional fixed-position solar panels, the suggested low-cost solar tracking system with dual-axis movement and real-time monitoring delivers notable energy efficiency gains. The system provides useful performance data and efficiently tracks the Sun's location through the use of a microprocessor, servo motors, LDRs, and wireless data transmission. This concept is a viable way to

	increase the efficiency of solar power generation because it is affordable, simple to deploy, and offers real-time insights.
Experimental and numerical study of a linear Fresnel solar collector attached with dual axis tracking system [20].	This study shows that a linear Fresnel solar collector can effectively produce thermal energy, and that using a dual-axis tracking system can significantly increase efficiency. The device can produce significant amounts of useful energy, according to the testing data, particularly those from May 27. Furthermore, the experimental results are further validated by the numerical analysis using CFD, guaranteeing that the collector's performance and design live up to expectations.
An intelligent fuzzy based tracking controller for a dual-axis solar PV system [21].	Solar energy systems can use a very effective solar tracking system that combines fuzzy logic control, dual-axis tracking, and PWM motor control. Because of its accuracy and versatility, the system is a good fit for residential and solar farm systems, where optimizing energy capture is essential to raising system efficiency and lowering energy expenses. Even more effective solar tracking systems may result from future implementations that better optimize the fuzzy controller and sensor placement. Furthermore, based on environmental variables, real-time modifications to the fuzzy logic rules might be implemented to improve system performance in various weather scenarios.
Arduino based Dual Axis Smart Solar Tracker [22].	This research methodology provides a small, affordable, and effective solar tracking device, which makes it appropriate for both practical and educational uses. An outstanding introduction to solar power

	optimization and automation can be obtained by combining an Arduino UNO, solar sensors, and servo motors to construct a straightforward yet incredibly efficient solar tracker that maximizes the power output of solar panels. This kind of system helps guarantee that solar energy stays a viable and affordable energy source, whether it is used for small solar farms or residential purposes.
Designing of dual-axis Solar tracking system with remote monitoring [23].	Using a dual-axis solar tracking system, this research offers a very creative and economical way to improve solar panel performance. The concept is small, effective, and simple to use thanks to the use of servo motors for movement, Beagle Bone Black for control, and LDRs for sunlight detection. Furthermore, the system's internet connectivity enables for remote monitoring, making it a perfect solution for both residential and business applications in places like India, where energy demand is expanding rapidly.
Dual axis solar tracking system [24].	With the use of Arduino-controlled DC motors and LDR-based light detection, the dual-axis solar tracking system effectively positions the solar panel for maximum sunshine exposure, increasing energy efficiency through continuous tracking. The system guarantees maximum solar energy capture and is easy to use and reasonably priced. Light Dependent Resistor (LDR)-based tracking with Arduino driving DC motors for solar panel orientation adjustment is the technique employed in this dual-axis solar tracking system. To ensure that the panel faces the sun for optimal

	energy capture, the system uses PWM signals to move the motors based on LDR inputs.
Implementation of Dual Axis Solar Tracking System [25].	The paragraph concludes by stating that the automated solar tracking system positions the solar panel for optimal sunlight capture using Arduino, LDRs, and stepper motors. This system is an economical way to generate solar energy since it maximizes the panel's vertical and horizontal movement, improving energy efficiency and lowering the number of solar panels required. Furthermore, the expensive price of solar tracking systems is a deterrent, particularly for larger families who might need to install more than one solar panel to meet their energy needs. Optimizing solar panel efficiency while controlling the expenses of the tracking system and the required number of panels is therefore a challenge.
Comparative evaluation of optimal energy efficiency designs for solar tracking systems [26].	According to the study's final review, a one-axis tracking system for photovoltaic (PV) modules driven by a solar-powered Stirling engine greatly increases the efficiency of solar energy gathering when compared to stationary PV systems. The system monitors the Sun's path throughout the day, which causes the module to get a significant increase in solar irradiation and produce more energy. An effective and economical method of solar tracking is offered by the combination of LDR sensors for determining the direction of the sun and a Stirling engine acting as a low-power tracking motor. This strategy is a viable way to improve solar power efficiency in areas with significant solar potential, as evidenced by the modeling and simulation done at

	Giza, Egypt. According to the study's findings, this By increasing the output of each solar panel, a tracking system can significantly improve performance and perhaps eliminate the need for additional panels.
Dual-axis solar tracking system with different control strategies for improved energy efficiency [27].	Precise tracking of the sun is made possible by the combination of motor-driven mechanisms, feedback control, and LDR sensors, which guarantees ideal alignment and maximizes power production. Furthermore, the system is a flexible and efficient solar energy generation tool due to its location-independent operation. The study of wind pressure impacts will help optimize the tracker design for durability, and the device demonstrated improved performance and increased current output. Future development for commercial applications is part of the scope, with the goal of increasing the productivity and efficiency of solar energy.
Performance Evaluation of the Designed Two-Axis Solar Tracking System for Trabzon [28].	In order to compare the power generation of the suggested tracking system with a fixed-tilt solar panel facing south, experimental investigations were carried out during three gloomy days. According to the trial results, the two-axis solar tracking system generates more energy than fixed-tilt systems, especially in areas like Trabzon that receive less sunlight. Optimizing solar energy utilization in cloudy or low-sunlight areas may be made possible by the system's capacity to detect the sun's daily movement and produce more power. The study demonstrates that, especially in foggy areas

	where fixed systems perform poorly, the two-axis STS is an economical and energy-efficient way to maximize solar energy output. In gloomy situations, this solar tracker design can be a perfect substitute for fixed systems, producing 24.7% more energy. Areas with less sunlight that provide significant advancements in solar energy production
Real Time Clock based Energy Efficient Automatic Dual Axis Solar Tracking System [29].	The study comes to the conclusion that the asymmetric solar dish concentrator in conjunction with the RTC-based dual-axis solar tracking system is a very effective solar energy solution. Its ability to enhance solar energy collecting is demonstrated by the 75% increase in thermal power as compared to fixed systems, especially in applications that need for high-temperature generation. For solar power systems in areas with varying solar conditions throughout the year, this design presents a potential option.
Simple design and implementation of solar tracking system two axis with four sensors for Baghdad city [30].	The study's findings show that, with a 35% increase in energy output, the dual-axis tracker is noticeably more efficient than a fixed solar panel. The energy difference between the tracker and fixed panel is negligible at midday since both systems efficiently capture energy when the sun is directly overhead, but the tracker performs best in the morning and evening when the sun is at a lower angle. Relatively speaking, the solar tracker is a cost-effective solution because it is relatively cheap to operate and maintain. Furthermore, unlike fixed systems, which have more limited efficiency, the dual-axis tracker may be mounted anywhere, guaranteeing excellent energy gain and increased mobility. All

	things considered, the dual-axis solar tracking system provides a significant boost in energy gathering and is a viable way to optimize solar energy generation in different geographical areas.
Advancing sustainable cooling: Performance analysis of a solar driven thermos electr2024ic refrigeration system for eco-friendly solutions [31].	The performance of a solar-powered thermoelectric refrigerator (SPTR) that uses solar energy for cooling is examined in the research. To optimize solar energy capture, a dual-axis solar tracking system (STS) is used. Both a fixed solar panel system (WST) and the dual-axis STS were used to evaluate the system in a local climate with an ambient temperature of 25°C. The findings showed that solar irradiance, system input power, panel surface temperature, and cooling rate all had a substantial impact on the SPTR's coefficient of performance (COP). In comparison to the fixed system, the directly coupled SPTR with a WST showed an improvement of 44–75%, with COP values ranging from 0.27 to 1.19 and 0.39 to 2.07 for the STS. The cooling load was directly correlated with the refrigerated space and the thermo-electric characteristics of the thermoelectric modules (TEM), and the cooling rate was highest when the system was running with the STS on a bright, sunny day.
Comparative assessment of different solar tracking systems in the optimal management of PV-operated pumping stations [32].	In contrast, a two-axis solar tracker reduces operating expenses by 4.8% and increases PV production by an additional 3.2% when compared to a single-axis tracker. This benefit, however, is negligible in light of the two-axis system's higher cost and more complicated technical requirements. According to the study's

	findings, a single-axis solar tracker is typically the more sensible and economical option for maximizing the efficiency and lowering the running costs of PV-powered pumping systems, even though a two-axis tracker offers somewhat more advantages. The study emphasizes how crucial it is to choose the best PV tracking system by weighing energy output, operational effectiveness, and financial viability.
Machine learning assisted prediction of solar to liquid fuel production: a case study [33].	In order to forecast power output and formic acid production under various situations, this study combined machine learning (Support Vector Machine) with a two-axis solar tracking system that converts solar energy into formic acid. By using formic acid as a storage medium, the study offers a viable way to get around the technological and financial constraints of two-axis solar tracking systems. This method contributes to more sustainable and profitable solar energy systems by increasing the efficiency of solar energy capture and establishing a financially feasible strategy to use excess solar power.
Methodology for the estimation of cultivable space in photovoltaic installations with dual-axis trackers for their reconversion to agrivoltaics plants [34].	The objective was to locate arable land areas between the solar collectors and the distance between them where the levels of sun irradiation would be enough for agricultural development. Using this simulation, the study suggests the best crop heights and cultivation techniques, calculating the proportion of accessible cultivable land based on crop height. In order to identify and demarcate areas appropriate for agricultural use, this study used a theoretical simulation of solar astronomy and the spatial geometry of a photovoltaic plant with dual-axis trackers.

Two-Axis Solar Tracker Analysis and Control for Maximum Power Generation [35].	According to the simulation results, by making sure the panel is positioned at the ideal angles all day long, such a system can greatly boost the energy yield. The goal of the research is to create a novel method for managing the motion of dual-axis solar trackers, which are intended to maximize solar panel orientation. The emphasis is on developing and putting into practice effective control algorithms that modify the panel's location in elevation (vertical rotation) and azimuth (horizontal rotation).
Novel high precision low-cost dual axis sun tracker based on three light sensors [36].	This paper proposes a revolutionary solar tracking system that does not require costly parts like lenses, motors, or feedback sensors. Instead, it uses common Light Dependent Resistors (LDRs) and 3D-printed components to achieve high-precision sun tracking. In order to follow the sun and focus light on a central LDR, the system moves Fresnel mirrors, keeping the angle between the incoming sun rays and the solar concentrator's target direction less than 0.26°.
Parametric comparison of a CPVT performance evaluation under standard testing procedures-ISO 9806:2017 and IEC62108:2016 foranautomatedandmanual2-axis tracking solar system stand [37].	The study finds that although automated two-axis trackers are best suited for large-scale, high-efficiency applications, manual systems can still be a practical and economical option in some situations, especially when the use of more costly automated systems is restricted by installation size or budgetary considerations. In order to achieve the best possible balance between energy production and financial efficiency, the decision between the two should be made based on project-specific factors including scale, costs, and operational requirements.

Review on sun tracking technology in solar PV system [38].	Greater Efficiency: Because dual-axis solar tracking systems watch the sun in both azimuthal and elevational directions, they are more efficient than single-axis and stationary systems. This ensures that the panels are oriented optimally throughout the day. The capacity to adjust to changing land features allows dual-axis tracking systems to maximize solar energy generation in a variety of geographic regions and topographies. Better Performance: New developments in dual-axis tracking systems have led to better performance, which helps to gather and generate solar energy more effectively. Long-Term Cost-Effectiveness: Although dual-axis tracking systems may initially cost more, their capacity to produce more energy makes them more affordable over time, providing faster returns on investment.
Self-shading of two-axis tracking solar collectors: Impact of field layout, latitude, and aperture shapes [39].	The study found that the form of the collector aperture had a substantial impact on shading losses. Of all the forms examined, square collectors had the most shading losses, whereas rectangular collectors had the lowest. This implies that the shape of the solar panel must be carefully considered in order to maximize solar power capture. The study also looked into the effects of rectangular arrays rotating less optimally. It was demonstrated that improperly oriented collectors led to greater shading losses, which in turn reduced the system's power output. This outcome highlights the importance of precise alignment and tracking in maximizing the efficiency of solar installations.

Techno-economic comparative study of grid-connected PV/reformer/FC hybrid systems with distinct solar tracking systems [40].	According to the study, VSAT is the most effective tracking system in terms of yearly power generation and energy penetration into the grid. The VSAT system performs better than the others in terms of producing the most energy and reaching the most PV penetration, even though HSAT and DAT are equally advantageous in some situations. However, each system's economic viability must be thoroughly evaluated, taking into account both the energy gain and implementation costs. In some situations, fixed tilt systems are typically more economical, while tracking systems—particularly VSAT—can offer notable performance advantages, especially in regions with abundant solar resources.

3.Methodology

3.1Materials

- LDR sensors, Stepper motors, Microcontroller, Solar panels, Voltage regulator, Limit switch, Adaptor, AC motor, PMDC Motor, BLDC Motor

3.2 Steps involved in dual axis solar tracking system

• **Program:** Launch the application, specify variables, and set up the input and output ports.

• **Read sensors:** Examine the light-dependent sensors' (LDRs') values.

• Examine sensors: To ascertain the location of the solar panels, examine the analog values.

• **Verify voltages:** Verify the fixed voltages in the design configuration.

• Tilt panels: Adjust tilting in accordance with voltages

• **Rotate panels:** Depending on the voltage differential between the LDR sensors, rotate the panels either clockwise or counterclockwise.

• **Stepper motor movement:** The microcontroller moves the stepper motors to a new location by turning on driver circuits.

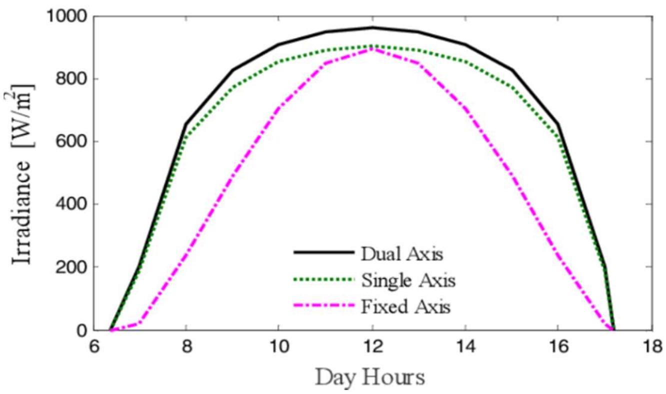

Figure3: daily incident of solar intensity three systems

1. Black Line Dual Axis Tracking

• Justification: This system monitors the sun's position all day long, both vertically and horizontally. Consequently, it keeps the solar panels at the ideal angle to get the most sunlight.

• Finding: Throughout the day, the black line exhibits the maximum irradiance, peaking at midday. In comparison to the other methods, this shows the highest efficiency in capturing solar energy.

2. Green Dotted Line Single Axis Tracking

• Justification: This system allows for a certain amount of alignment with the sun by tracking its movement along a single axis, which can be either vertical or horizontal.

• Finding: The green dotted line is much higher than the fixed-axis system but marginally lower than the black line. When compared to the dual-axis system, it exhibits lower efficiency, but is still superior to a fixed panel in terms of effectiveness.

3. Fixed Axis (Dash-Dot Line in Pink)

• Justification: This system does not track the solar panels; instead, it maintains them at a constant angle. The panels are unable to dynamically adapt to the movement of the sun because they are set to the ideal tilt for a typical day.

• Finding: In the morning and late afternoon, when the sun's angle differs greatly from the fixed panel's orientation, the pink line exhibits the lowest irradiance. When the sun is above around noon, the irradiance peak at that time indicates some efficiency.

An overview of the trends

• Less efficient than dual-axis tracking, but still more efficient than a fixed system, is the single-axis system.

• The dual-axis system performs better than the others in terms of continuously capturing solar energy throughout the day.

4.Applications

- Dual-axis solar tracking systems continuously align solar panels with the position of the sun to optimize energy generation from solar panels. The main applications are as follows:

  4.1 Solar Power Plants at the Utility Scale

  • Goal: To maximize the production of power in huge solar farms.

  • Advantage: Because dual-axis trackers optimize energy production, they are appropriate for high-energy-demanding projects where space efficiency is crucial.

  4.2 Solar Systems for Homes

  • Goal: To help homeowners boost the effectiveness of their ground-mounted or rooftop solar panels.

  • Advantage: Dual-axis tracking might be a wise investment in areas with significant solar energy potential, while being more costly than fixed systems.

  4.3 Systems for Off-Grid Energy

  • Goal: To provide electricity to isolated locations without grid connectivity, including islands, rural settlements, or research outposts.

4.4 Plants Using Concentrated Solar Power (CSP)

• Use: In CSP systems, sunlight is focused onto a small area by mirrors or lenses, producing heat that is used to produce electricity.

• Advantage: The efficiency of the thermal energy generating process is increased by precise alignment with the sun.

4.5 Solar Power

• Goal: Grows crops beneath or next to solar panels, combining agriculture with solar energy production.

• Advantage: Dual-axis trackers maximize sunlight and shade throughout the day, which promotes crop growth and energy production.

4.6 Commercial and Industrial Uses

• Goal: To supply energy to commercial buildings, manufacturers, and warehouses with high energy requirements.

• Advantage: Dual-axis tracking lessens dependency on traditional energy sources by ensuring increased power generation during the hottest parts of the day.

4.7 Projects for Research and Development

• Goal: To investigate cutting-edge solar systems or technologies in practical settings.

• Advantage: Researchers can evaluate the greatest energy potential and advance solar energy technology with dual-axis systems.

4.8 Solar-Powered Plants for Desalination

• Goal: To provide electricity for the desalination of water.

• Advantage: Guarantees that the most solar energy is captured to power the

5.Conclusion

Solar tracking technologies have emerged as a major development in photovoltaic (PV) systems due to notable improvements in energy capture and system efficiency. The relative advantages of several solar tracking schemes are discussed in review articles along with their applications in a range of settings, such as water pumping stations and standalone electricity generation systems. Because dual-axis trackers maintain the optimum possible orientation toward the sun throughout the day and year, they perform better. This method is particularly useful for maximizing energy output in applications where efficiency is critical, such as large-scale power generating. Despite their greater initial costs and maintenance requirements, dual-axis trackers show energy benefits of 15% to 30% over fixed panels and single-axis systems. They are therefore ideal for regions with varying

Single-axis trackers, on the other hand, balance cost, complexity, and performance. They are widely utilized in applications like pumping irrigation water, where a 33% increase in energy production can lead to a significant decrease in operating expenses. Because these systems are simpler to install and operate than dual-axis trackers, they are more affordable for medium-sized businesses. The trials also demonstrate the versatility of solar trackers in integrating renewable energy sources into systems that are already in place. For example, incorporating solar trackers and variable-speed pumps into irrigation systems enhances water resource management, reduces dependency on the electrical grid, and maximizes energy efficiency. Furthermore, tracking systems' enhanced self-consumption ratios promote sustainable energy practices by lowering reliance on external power sources.

Economic and environmental variables have a significant impact on the adoption of solar tracking systems. Given the potential for long-term cost reductions and the reduction in greenhouse gas emissions, solar tracking is positioned as a critical component in the transition to renewable energy. However, the unique project parameters, geographic location, and budgetary constraints will determine whether to use fixed systems, single-axis, or dual-axis trackers.

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