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Using Solar Tracking Technologies to Enhance the Efficiency of Solar Panels

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Abstract
This paper analyzes energy yield increases from prototype solar tracking roof-mounted panels. A measuring stand tracked solar radiation and directed the panel using a microprocessor-controlled energy monitoring device for automatic operation. Sensors detected the sun's position, with adjustments by electric servo motors. Results showed solar tracking can enhance energy yield by about 35.6% over fixed panels on sloped roofs, offering quick returns on investment. Solar technologies are categorized into solar thermal, capturing heat, and solar photovoltaic, generating electricity, further divided by collector surface area: concentrated systems with fewer, larger surfaces focus sunlight, while non-concentrated systems feature larger areas with integrated conversion devices. This research emphasizes enhancing flat plate solar photovoltaic efficiency through two-axis solar tracking for better sunlight capture. Many systems face issues since optimal exposure occurs only at solar noon, as around 80% of solar energy is reflected outside this time. Therefore, panel orientation must adjust throughout the day. Proposed two-axis trackers use servo motors to change the panel's inclination on both azimuthal and elevation axes, suggesting diverse designs for solar trackers, including mechanical and microcontroller-based systems.

keywords : axis tracker system; azimuthal axes; elevation axes; microcontroller system; panel orientation.

1. Introduction

Solar panel efficiency is defined as the ratio of electrical power output to incoming solar energy, based on voltage and current. The output is measured against solar energy received through collector area and solar radiation. Evaluations happen at 1000W/m², with data collected every half hour from 0900 to 1600 hours. The dual-axis solar tracking (DOST) system employs algorithms to track the Sun, creating an angle matrix based on temperature and humidity, enabling efficiency assessments between DOST and stationary systems at the University of Malaya and Perlis, with weather data updated every 15 seconds.

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In Turkey, the benefits of solar trackers versus stationary panels are debated due to abundant sunlight. While stationary panels are common, solar tracker use is growing, especially on large farms, despite misconceptions about their function. This overview examines a basic solar tracker project to enhance understanding for researchers and the public. Trackers are categorized into active and passive. Active systems include single-axis for one-plane and dual-axis for two-plane movements, using sun-position algorithms. Efficiency improvements vary based on location, solar intensity, and weather. Single-axis trackers can enhance efficiency by 20% to 40% in high insolation areas, while dual-axis trackers might offer greater benefits, although cost-effectiveness depends on location due to higher material costs.[1][2][3]

A solar panel's efficiency measures the energy produced from solar input power. It's determined by measuring voltage and current, leading to the equation: Efficiency (%) = (Vo*Io)/(Pin) * 100. Here, Vo is open circuit voltage, Io is short circuit current, and Pin is solar radiation in W/m^2. Measurements are obtained from the data acquisition (DAQ) system and analyzed to calculate efficiency.

Once efficiency for a solar panel is calculated, it's important to measure Performance Ratio (PR), not just conversion efficiency.

PR indicates how well the system performs relative to ideal solar conditions and is dimensionless, ranging from 0 to 1. It benchmarks panel performance using the equation PR = (Eyield)/(Eexpected). Accurate assessment involves comparing kWh produced against total solar irradiance and modeling sunny day output against ideal conditions. [4]

paper structure : this paper is structured as follows: first, we will discuss the principles of solar tracking technologies and their mechanisms. Next, we will analyze various types of tracking systems and their impact on solar panel efficiency. Finally, the paper will conclude with a discussion on the future prospects and potential advancements in solar tracking technologies.

2. Types of Solar Tracking Systems

The activity tracker app is a prototype for a larger project that employs a GPT model to monitor sun activity. While rooftop solar panels are less efficient than tracking systems, this project focuses on creating an automated dual-axis sun tracker for photovoltaic (PV) arrays. It emphasizes the construction with LDR sensors and an Arduino microcontroller. The sun tracker consists of the sensor and control system and the mechanical system. A basic sensor model was developed to evaluate capture efficiency and slew time. Analysis provided insights for development. A solar tracking system with a light sensing module, microcontroller, and motor can track the sun's position, optimizing solar panel orientation and enhancing sunlight exposure. [1]

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2.1. Single-Axis Trackers

Single-axis trackers enhance the efficiency and cost-effectiveness of photovoltaic panels by adjusting their tilt to follow the sun. They come in two types: vertical, which rotate east-west, and horizontal, which rotate north-south. Unlike fixed solar installations that rely on specific radiation and tilt angles throughout the year, single-axis trackers continuously adapt to the sun's movement. A simple tracker system, using a microcontroller and light-dependent resistors, detects shadows and employs DC motors to optimize panel positions for power generation. It operates in two modes: light mode for shadow tracking and dark mode reacting to light intensity. Automatic trackers use photo-resistors for light detection and motor activation, showing high voltage outputs reaching 27.5 volts in sunny conditions. They provide a 9.35% energy gain in the evenings compared to fixed tilt panels. [1] [5][6]

2.2. Dual-Axis Trackers

In solar energy systems, a dual-axis solar tracker optimally orients panels toward the sun by tracking both latitude and azimuth. This setup achieves around 30% more solar gain than static systems, making it popular in stationary latitudes. New trackers must be cost-effective, simple, low maintenance, and reproducible. A simplified design with fewer moving parts eases maintenance and matches output better. Parallel dual-axis systems minimize lateral motion but have unequal motion ratios. An offset arm crank-rod mechanism promises more affordable trackers, enhanced by advancements in materials and CAD technology. Active tracking systems led by microprocessors are being developed in areas with extensive solar installations. Exploring various tracker types reveals valuable innovative design insights. [7][1]

A single axis tracker rotates solar panels horizontally or vertically, while a dual axis tracker utilizes both movements for enhanced sun tracking. Dual-axis systems capture 30-50% more solar power by keeping panels perpendicular to sunlight. An active dual-axis tracker features a microcontroller, sensors, and actuators, with components like Arduino Uno, dual gear DC motors, and light-dependent resistors (LDRs). LDRs detect sunlight, and Arduino manages operations, adjusting panel position based on sunlight distribution for optimal tracking. [1][8]

The efficiency of solar photovoltaic (PV) systems is enhanced by advanced tracking systems that better concentrate sunlight. These systems improve PV cell efficiency without altering optics and use diverse tracking methods. Current systems rely on electrical controls, which can impede energy use. Economically designed earth-moving trackers can maximize solar energy and battery generation. Research continues to improve productivity and efficiency in the PV sector, though issues like reduced PM and string temperature losses remain. Numerous trials aim to enhance energy production feasibility. Advanced tracking systems significantly boost PV performance, making solar PV a crucial electricity source beyond fossil fuels. Efficient tracking technologies outperform fixed systems, with dual and single variable rotation plane

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solar trackers being popular for cost-effectiveness and adaptability. The single-axis system captures solar energy better at lower angles, providing reliable performance for east-west tracking in flat installations. Studies on dew-blocking variable angle panels focus on maximizing light capture in the morning and evening, suitable for both ground and rooftop use. Various climatic zones are investigated to optimize axis angles, potentially increasing fixed solar panel efficiency further. [9][1]. Figure 1 illustrates the layout and working components of a dual-axis tracker system. The setup includes LDR sensors for sunlight detection, an Arduino for processing, and motors for precise panel alignment.

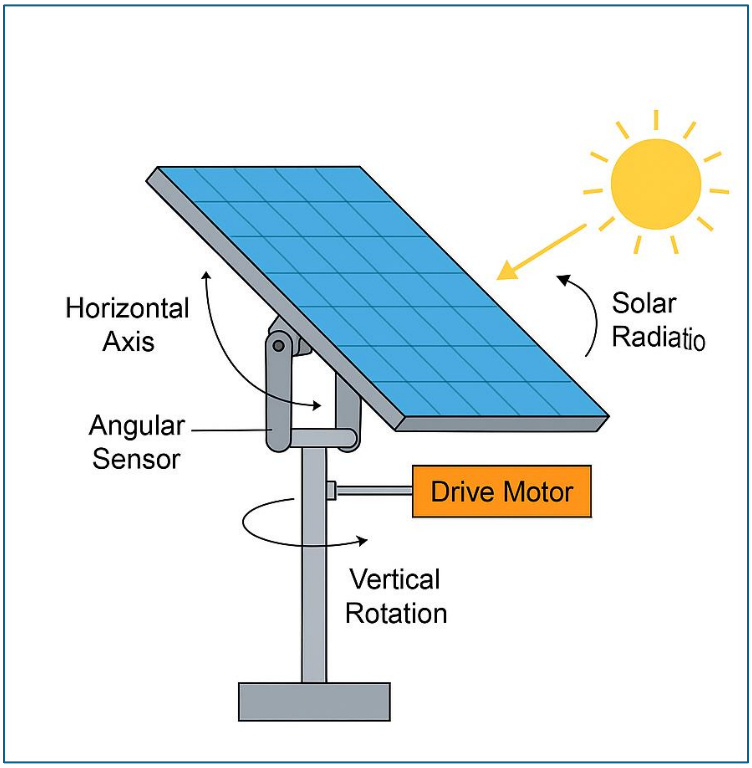

Figure 1: Schematic of a dual-axis solar tracking system.

2.3. Passive Tracking Systems

The simplest solar tracking systems are Passive solar trackers, which don't need motors or controllers. They enable panels to tilt and follow the sun using mechanical or bi-metallic designs. Bi-metallic trackers rely on different thermal expansions of two metal strips. When heated, one strip curls towards the metal with less expansion, creating east-west tracking. However, the panel returns to its original position as fast as it tracked, which may result in a loss of morning sun rays and decreased efficiency. [10]

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A passive dual-axis bimetallic tracker is designed to return to its original position before sunrise using mass gravity, effectively minimizing the return mechanism's volume and ensuring tracking capability. Some components are glued, affecting reusability. This study details the design and prototype using accessible components. The bi-metallic solar tracker faced challenges tracking the panel's return, leading to a system with a two-pivot arrangement. The first pivot tilts for y-axis rotation, while the second elevates for z-axis rotation through a pyramidal tilt mechanism. [1] As shown in Figure 2, solar tracking systems are categorized into fixed, single-axis, dual-axis, and passive types. Each type presents a different level of complexity and energy gain potential.

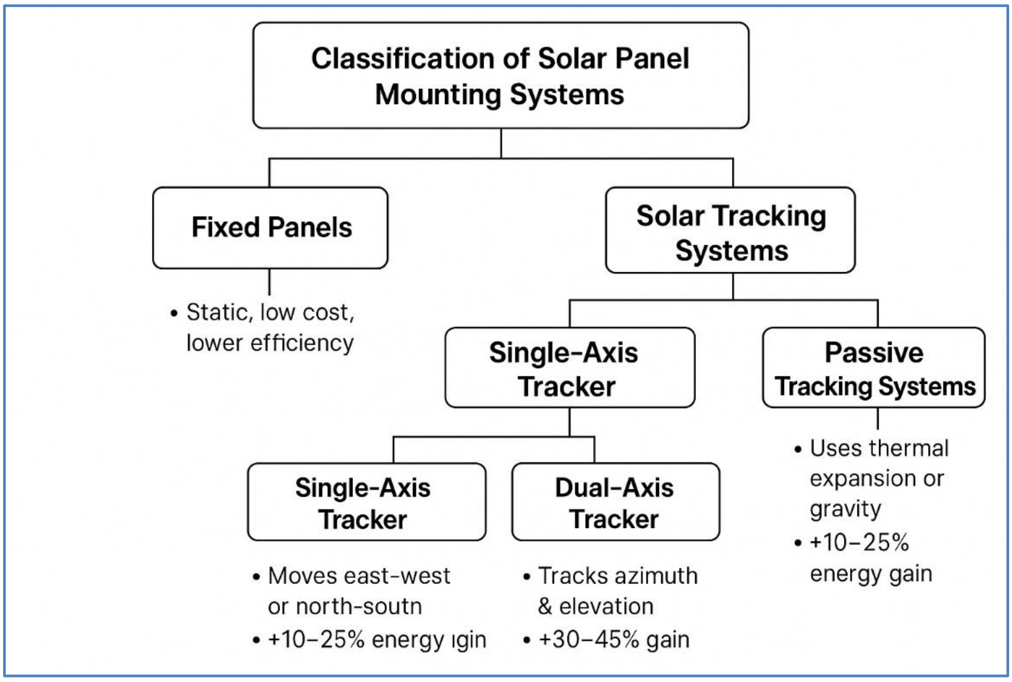

Figure 2: Classification of solar tracking systems.

3. Benefits of Solar Tracking

Solar tracking enables solar panels to follow the sun using motors and gears, enhancing their efficiency compared to stationary panels. The angle of a panel relative to Earth's latitude is vital for performance, as fixed panels lose energy due to their immobility. Solar trackers rotate on multiple axes to align with the sun, boosting efficiency significantly—by over 30% on clear days in latitudes under 30°. One-axis horizontal trackers are popular for being cost-effective and minimizing soil disturbance. Fixed setups can face maintenance issues and may require additional materials and fences to mitigate tracker challenges. [1][8] ust meet specific criteria for optimal performance, including stability and the ability to tilt and follow natural movements. It should be sturdy yet use accessible materials for easy reproduction. A flatter design requires minimal maintenance and tolerates off-focus construction while incorporating rigid elements to prevent accidental dislocation. [11]

Increased Energy Output

The shift to renewable energy has led to efficient solar energy systems. Solar tracking technology enhances photovoltaic output by aligning panels with the sun, increasing production by 20 to 40% depending on location and weather. However, solar trackers are complex and costly, making them impractical for small applications like rooftop panels. Motorized trackers are typical, but simpler hydraulic options exist. Dual-axis trackers offer precise alignment, while fixed panels underperform due to shadowing. Future designs should prioritize portability, remote operation, and cost efficiency, with automatic adjustments to optimize output. [8][1]

Mounting solar panels correctly enhances energy output, making the evaluation of solar tracking technology's economic feasibility essential. A cost-benefit analysis quantifies the costs and benefits for informed decision-making among alternatives. Identifying actions is vital, yet benefits assessment is challenging due to uncertainties in verifying solar tracking advantages. This analysis uses a fixed rooftop solar panel as a reference. The scenario for solar tracking in Umeå, Sweden, from 2020 to 2024, estimates a 200,000 SEK investment based on literature and weather data. It anticipates rising electricity prices sold to the grid, despite historical fluctuations. Sensitivity analyses further enrich the assessment. A user-friendly spreadsheet facilitates annual cost-benefit comparisons between solar tracking and fixed PV mounting in Umeå, assessing various costs, benefits, and uncertainties while highlighting solar tracking's potential benefits. [5]

4. Challenges in Implementing Solar Tracking

Implementing solar tracking systems presents challenges. In commercial plants, the cost of tracking structures is higher than static ones. For small-scale plants, solar trackers may hinder performance due to slower movements. Solar battery banks help but require larger components without cutting costs. Additional issues arise from needing power adapters and connections. Rural plants generating 2 to 50 kW may need to increase size with solar tracking systems, necessitating different electrical devices. A solution could be starting with a smaller system of 5 to 8 panels while accurately assessing power needs. [1][12]

Today, various technologies enhance solar tracking systems beyond fixed installations, with traditional systems relying on light sensors for optimal sun following. These trackers greatly outperform fixed-angle systems. Ideal locations are often rooftops, though roof pitches, gables, and chimneys present challenges. Tilted solar panel structures, known as facades, require more research. A new roof-mounted solar tracking design features an automated mechanism, using localization data for azimuth control and a rigid mechanism with a linear actuator for panel

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tilting. This innovative system integrates technologies like a worm gear with a rotation-driven actuator, plus a slip ring and dual collar shaft, ensuring precision and low maintenance. Specifications indicate a tracking angle accuracy of one eighth of the tracker diameter (±7.5 deg and ±4 deg) for roof-mounted models, integrated with smart grid, load, and meteorological data through a 3-phase smart meter for real-time output. A prototype has been constructed and tested using commercial components. Long-term performance analyses of the solar tracker and fixed panels employed analogue tracking and geographic detection, providing insights into energy output discrepancies, tracking algorithms, hardware selection, and cost optimization. Additionally, photovoltaic panel design impacts on performance were examined. [1][12]

Economic Considerations

Solar trackers adjust photovoltaic (PV) panels or mirrors to follow the sun, available in single-axis or dual-axis designs, each influencing complexity and cost. Evaluating their economic efficiency is vital for maximizing solar performance. Comparisons show trackers enhance energy output by 23.1% compared to fixed systems, with lower costs overall. Within the first month post-installation, the output power exceeded the initial investment for the tracker. A simple tracking system made with local materials was successfully tested in developing countries facing energy challenges. Future advancements aim to test these systems in diverse locations and refine designs for better assembly and performance. Innovations in sun-nozzle types for hybrid solar concentrators promise enhanced efficiency without heavy modeling or testing. While solar trackers provide increased energy production with reduced shading, their complexity and costs remain barriers to wider adoption. [10][12]

A major issue with solar tracking systems is the frequent accumulation of dust, requiring cleaning two to five times weekly, unlike fixed PV panels which need maintenance every four to six months. This regular cleaning is crucial, as contamination can drop efficiency by 10% to 20%. Many PV owners can't afford this, leading to dirty trackers needing specialized cleaning. Tracking algorithms are complex, risking failures from sensor issues or outdated data. Precise motor coordination is essential, as any signal error can affect performance. Additionally, algorithms may develop fixed-point errors without maintenance, leading to inaccuracies over time. Despite these obstacles, a balance has been found between power output and CPU efficiency, using varying parameters to enhance performance. [8][2]

5. Case Studies of Solar Tracking Implementations

A solar tracking system was implemented at a power plant in Perlis, Malaysia, using a low-cost active dual-axis tracker that outperformed fixed solar panels in most conditions. Performance evaluations showed that during cloudy weather, the solar tracker produced twice the output of fixed panels. On tracking days, fixed installations generated no output, highlighting the need for further evaluations. Initial deviations from the nominal tilt angle

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improved photovoltaic energy output, indicating that fixed installations are optimal only at certain times, regardless of weather. Additionally, a study compared the efficiency of static photovoltaic systems and solar trackers. The tracker used two servo motors to adjust tilt and swiveling, guided by four light-dependent resistors detecting light intensity. The motors were programmed for adjustments based on light conditions, with control logic developed via a flow chart. An Arduino microcontroller managed calculations and control signals for servo adjustments, with data collected and compared every 10 minutes for performance analysis. [1][2]. Figure 3 highlights the difference in power output between fixed panels and dual-axis tracking panels, with tracking systems maintaining higher output during morning and late afternoon hours.

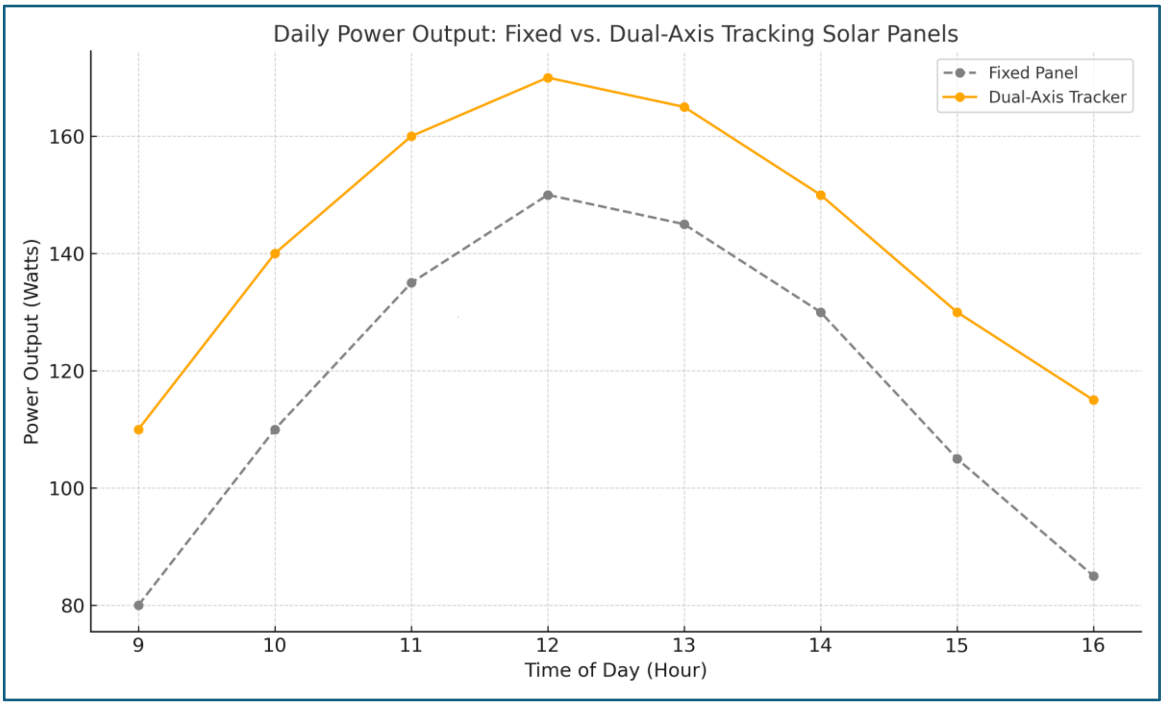

Figure 3: Daily power output profiles of fixed and dual-axis tracking solar panels during typical daylight hours.

5.1. Residential Applications

In the quest to refine the motor and chassis design, various crucial aspects came into focus. The dimensions of the chosen chassis and its accompanying plate elements were thoroughly examined to ensure compatibility and efficiency. Detailed CAD visualizations were created to illustrate the gear system that would adeptly drive both motors, showcasing the intricate mechanics at play. The placement of the motors alongside the internal components was carefully strategized to maximize performance while maintaining a compact structure. A well-thought-out design for the electronics container was also developed to house all necessary

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components securely.

A notable application emerged to enhance roof-mounted solar panel systems through a novel tracking method. Prior analyses showed that solar energy output could vary by 80%, but no simulations had been done for these installations. To address this, a resource-intensive yet feasible physical demonstration of the system's capabilities was proposed, offering practical insights and elevating public understanding of solar technology.

Adapting the tracking system for roof-mounted solar panels posed unique challenges compared to free-standing ones. Several factors required careful consideration to maintain the integrity of the fixed mounting. The dimensions of the tracking system had to fit within the solar panel's footprint, necessitating thoughtful planning. Additionally, a simpler design was needed, leading to a shift towards innovative, cost-effective solutions instead of expensive mechanical milling for the base plate. [12][13]

It is proposed to construct the base plate by gluing multiple cut plywood sheets, resulting in simpler production than mechanically milled pieces, and allowing for greater tolerance in assembly. The current plate construction lacks a guide ring, which could improve the central axis's flexibility and robustness, but such modifications can be made easily and are not crucial for demonstration. Since the equipment for driving motors and the belt system is similar to the previous generation, it is advisable to maintain the same tracking device drive technique. This method has proven efficient in transferring rotational motion to the belt system, facilitating the central axis's movement with minimal effort and high quality. Servos rated for indoors are appropriate, given the prototype won't face weather issues. However, attic space temperatures must be considered for component enclosure selection, as seen in the previous model. The construction should remain unchanged. [8]

5.2. Commercial Applications

The solar tracker system enhances solar panel output, commonly employing single-axis trackers for cost-efficiency. To capture more energy than stationary panels, double-axis trackers with advanced controls are recommended. Sun-tracking systems may be active, using electrical components, or passive, relying on heat transfer fluids. This work presents a software solution on a PC network for managing multiple autonomous active solar trackers that can adjust to the sun's position in both bi-axial and mono-axial modes. It monitors data from active trackers in photovoltaic plants. Test results of a PWM-controlled stepper motor tracker are included. Introducing a biomass gasification cycle may improve efficiency, transforming thermal plants into combined gasification-gas turbine systems, enhancing overall performance. The economic analysis looks at costs and profitability of biomass gasification technologies,

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with reliable thermal efficiency estimates aiding future assessments of plant size and installation costs. [14][8]

5.3. Utility-Scale Projects

Utility-scale solar power plants (over 50 MW) can have over 100K solar modules and cover more than 200 acres. Traditional monitoring methods are costly. Evaluations of existing techniques revealed that recent deep learning advances could enable automatic monitoring. The YOLOv3 deep learning model is demonstrated as a fast and reliable alternative for classifying and locating faulty modules in aerial images, saving power and time while being applicable to drone footage from other large plants. [15]

A comprehensive analysis of public data on utility-scale solar power plants revealed that countries generating over 4 terawatt-hours of electricity annually are either constructing or planning solar facilities with capacities above 10 megawatts. These plants can reach sizes of up to 500 megawatts, featuring more than 100,000 solar panels. However, such scale poses challenges in maintenance and monitoring, as stationary cameras can only capture limited areas, complicating the analysis of numerous panels over extensive recorded footage. [2]

Drone footage scanning the plant weekly or biweekly provides a comprehensive health overview. A powerful solution is needed to analyze this footage for faulty solar panels. Aerial survey images of a utility-scale solar plant were captured by a drone and filtered to focus on individual panels, reducing image size for efficiency. A dataset of images of healthy and faulty panels was created. A deep learning model, YOLOv3, was trained to classify and locate faulty panels in the filtered footage, accurately identifying faults in seconds during exhaustive testing on unseen footage. [6]

6. Future Trends in Solar Tracking Technologies

Solar tracking technologies improve solar panel efficiency and are increasingly being adopted in the energy sector. Advancements in these technologies have garnered attention from researchers. Solar photovoltaic (PV) systems now significantly contribute to electricity production in various economies. The rising costs of fossil fuels and the push to reduce reliance on conventional energy sources have accelerated the global transition to renewable energy, particularly solar and wind power. Recently, solar power has gained favor among users, developers, and researchers. Utilities have constructed large-scale PV systems, providing electricity to numerous homes and businesses. Diverse PV technologies, such as crystalline, thin-film, organic, and perovskite, have emerged. Research continues to focus on boosting productivity and efficiency within the PV industry, exploring operational structures alongside the economic, social, and environmental impacts of renewable energy.

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The development of effective PV tracking systems has enhanced the efficiency of photovoltaic systems. A key feature is their ability to track the sun's movement through a self-control system, categorized into single-axis and dual-axis systems. Fixed tilted PV panels with less than 90° inclination may fail to follow the sun's seasonal path, reducing energy production. Costs and suitability concerns hinder wider adoption. A precise PV tracking system using shape memory alloy strips has been designed and verified through numerical and experimental methods, examining how operational tilt angles and boundary conditions affect SMA actuators' amplification ratio.

PV-tracking mechanisms align panels perpendicular to the sun using sensor and azimuth-based methods. A novel, cost-effective mechanism utilizing cables over a drum was introduced, contrasting the complex, high-cost electronic systems. Various dual-axis and azimuth parallel trackers were presented, all based on rotational designs. Tracking PV panels differ significantly in design and actuation, categorized as one-axis or two-axis, and utilizing motors, shape memory alloys, or hydraulic systems. Motor-activated trackers are low-maintenance and less sensitive to environmental factors but are expensive due to reliance on electronic components, leading to inefficiency during heavy rain, cooling requirements, or dust interruptions. [16]

6.1. Innovations in Tracking Systems

Dual-axis tracking systems for photovoltaics are favored over stationary modules due to lower costs and competitive energy generation. They can achieve outputs similar to more expensive systems using just two servomotors, although they might not surpass higher-end carport models. Sun-tracking systems enhance efficiency by adjusting toward the sun, and many utilize servo motors for movement. A cost-effective one-dimensional approach can improve speed and flexibility in commercial applications. Larger arrays see greater benefits from tracking in cooler climates, needing no additional cooling. Solar irradiance plays a crucial role in performance estimates, with tracking systems showing varying outputs in overcast conditions. Low-cost light-dependent resistors can enhance research and reduce costs. [8][1]

6.2. Integration with Smart Grids

Solar panels produce electricity constantly, though their efficiency depends on the sun's position. Solar tracking systems enhance alignment by rotating panels with servomotors, often using encoders for precise tracking. Conventional systems track about 15 minutes ahead, potentially wasting energy. Smart panels boost efficiency by sensing temperature changes to optimize motor activation for better rotation. This method uses temperature data and amplifier signals to maximize solar energy use, but further improvements in tracking technology are still needed. [17]

One significant benefit of solar energy is its lack of greenhouse gas emissions, which improves urban air quality. Unlike fossil fuels, solar energy reduces harmful pollutants and helps mitigate

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climate change. Solar installations over 100 MW can often pause operations during risks like shading, eliminating the need for extensive contingency studies. It is vital to evaluate the ecological impact of solar projects as this influences investment and planning. Collaborating with agronomists helps pinpoint the best land for solar systems. Fixed solar mounts allow for grazing or farming underneath, while solar trackers require more open land, with ground stability essential in windy areas. Ground-mounted systems peak in energy output around noon, though cloud cover can impact this. Shading may cause thermal runaway, but tracking technologies can improve lifespan by redistributing current. Lightweight cantilever tracker designs allow for cost-effective manufacturing, beneficial for regions needing temperature control for vaccine storage. Enhanced designs may utilize solar-powered motors for increased efficiency. Solar power is crucial for both ecosystems and humanity due to its renewable, non-polluting nature. Tracking systems are necessary for optimal panel operation, but spherical systems for artificial biospheres remain impractical. Common panel designs vary, and innovative polymer methods are being explored to create flexible light concentrators. A computer model simulating energy tracking across biomes has been developed. Many artificial biospheres strive to maintain species diversity while focusing on environmental changes, integrating interests in biospheres with computational biology to enhance productivity, including optimizing sugar harvests in productive ecosystems. [8][12]

Solar photovoltaic energy generation is becoming a key source of clean energy, with efficiency affected by location, panel orientation, angle, shadowing, and dust. Innovations such as fixed, manual, or automatic tracking systems can enhance energy collection by optimizing exposure to sunlight. This paper assesses tracking panels against stationary ones, noting that tracking systems significantly increase efficiency in cloudy weather during mornings and evenings, although their higher costs hinder their adoption since fixed panels are cheaper to maintain. In Poland, stationary systems commonly lack tracking. A test rig with motors allowed panel adjustments using a lightweight frame to minimize stress. A cost-effective motor with a two-phase driver regulates rotation, with analysis through video using EV3 software and Python for daily angles, azimuths, and energy output. The study compares tracking and non-tracking panels, revealing differences in power efficiency and presenting challenges. Insights on construction and performance testing indicate potential for replication in projects. Initial costs and returns of solar systems are crucial, with a tracked roof system costing around 3250, including 2556 for tracking alone. A single panel is approximately 393, while fixed panels cost less than 300. Three fixed panels yield 160–180 kW-h monthly, totaling 2000–2200 kW-h annually, while tracking may improve output by 23%, adding 800–1000 kW-h, leading to payback periods of 10–11 years. Weather variability and energy rates also impact returns, with passive panels using bimetallic activators around 100. Profitability evaluation of solar tracking is critical, with dual-axis designs enhancing adaptability. Engineers strive to improve solar panel performance, using Lidar sensors, though this increases complexity. Flat trackers employ

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LDRs for alignment. Efforts continue to create cost-effective tracking systems utilizing actuators, microcontrollers, and sensors, focusing on advancements in control units and sensor research. Solar trackers use lightweight materials for durability and ease of adjustment, necessitating protective enclosures for sensitive components, with innovative designs like dual-axis systems with servo motors and LDRs confirming tracking benefits for optimal panel output. [12][1]

7. Reflections and Conclusions

Solar tracking technologies enhance the efficiency of solar panels by maximizing sunlight exposure throughout the day. These systems adjust their angles to follow the sun's trajectory, thereby optimizing energy production and electricity generation. They can be categorized into single-axis or dual-axis systems, with single-axis tracking facilitating movement from west to east, while dual-axis tracking provides more precise alignment with the sun's path. As a result, these tracking systems require fewer panels to achieve the same energy output compared to fixed systems. Essential components of these technologies encompass solar photovoltaic panels, controllers, actuators, H-bridges, drift sensors, and microcontrollers. The demand for solar tracking technologies continues to rise due to their numerous advantages.

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