PHOTOVOLTAIC POWER PLANTS WITH TRACKER SYSTEMS

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Abstract: This article provides a detailed overview of the operating principle, advantages, disadvantages, and application areas of photovoltaic power plants with tracker systems. Photovoltaic technology and tracker systems are examined separately, highlighting their role and efficiency in the energy sector. Tracker-based photovoltaic power plants represent a modern technology designed to utilize solar energy more efficiently. These systems automatically adjust the position of solar panels in accordance with the movement of the sun, thereby optimizing the energy production process. There are single-axis and dual-axis tracker systems, both of which aim to increase electricity generation by maximizing solar radiation capture.

Keywords: Tracker system, photovoltaic energy, solar panels, electrical energy, solar radiation, efficiency, photovoltaic power plant, single-axis tracker, dual-axis tracker, solar tracking system, photovoltaic conversion, energy efficiency, tracker motors, solar radiation optimization, static and dynamic panels, electricity generation, batteries and accumulators, tracker control system, automated solar tracking, advantages of tracker systems, photonic energy absorption, climate conditions and solar energy, investment and economic efficiency, environmental impact.

Introduction: Maximizing the use of solar energy is one of the key challenges in the modern energy sector. Photovoltaic power plants (solar panels) rely on the angle of solar radiation incidence during the energy generation process, which directly affects their efficiency. Tracker-based photovoltaic systems, however, follow the movement of the sun and ensure that the solar panels are positioned at the most efficient angle. The main advantages of tracker systems include high energy efficiency, stability in electricity generation, and long-term economic benefits. Solar trackers can operate using various methods and mechanisms; however, they all serve the same fundamental purpose: to increase energy production by moving solar panels in such a way that they capture the maximum possible amount of direct sunlight.

Some manufacturers claim that their trackers can increase energy output by up to 45% compared to fixed rooftop systems. Fixed installations—such as those mounted on traditional residential rooftops—only maintain an optimal angle for a limited portion of the day and therefore cannot fully utilize solar radiation. Although fixed systems are generally less efficient than those with solar trackers, each installation type has its own advantages and disadvantages, depending on the project, client, and geographic location. Such systems significantly improve solar exposure, resulting in better performance compared to conventional static solar panels. Moreover, the application of tracker systems enables more efficient use of clean, renewable energy sources and contributes to the reduction of carbon emissions. This study focuses on the development of photovoltaic power plants, the operational principles of solar tracker systems, and their economic and environmental significance. These technologies are expected to play a vital role in the future expansion of renewable energy deployment. Photovoltaic technology is a system that converts solar radiation into electrical energy using solar panels. These panels are made from semiconductor materials, where the impact of solar photons on electrons generates an electric current.

Photovoltaic systems enable the use of solar energy as a clean and renewable energy source. There are three main categories of solar trackers, each with its own strengths and limitations. Understanding these types helps determine which option—if any—is most suitable for a given solar energy requirement. Manual solar trackers, often referred to as portable solar trackers, represent the simplest and most cost-effective type. As the name implies, these systems require manual adjustments throughout the day to follow the sun's position. Either the user or another individual must physically reposition the panels to align them with the sun's path. Although manual trackers are less convenient than automated alternatives, they may serve as a low-cost solution for small-scale installations or for users who are not averse to hands-on operation.

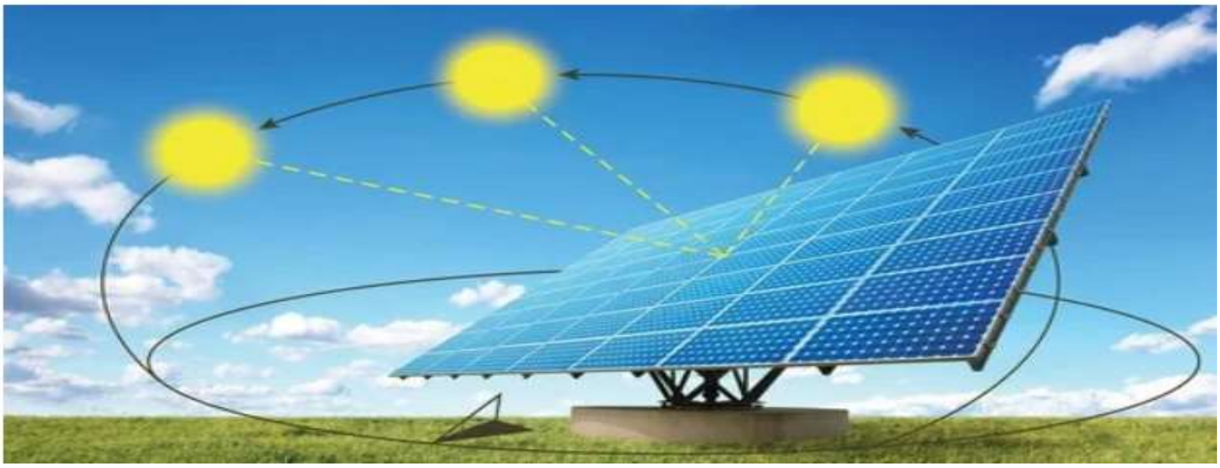
The tracker system is a mechanical mechanism designed to automatically move solar panels in order to maximize solar radiation utilization. It consists of the following key components:

Sensors and control system – determine the position of the sun and adjust the angle of the panels accordingly.

Electric motors and mechanical structures – rotate the panels in the required direction.

Power supply – provides the energy necessary to operate the tracker system.

The tracker system adapts to the optimal tilt angle by accounting for the sun's movement throughout the day and across different seasons. This adjustment increases the efficiency of electricity generation by the solar panels. Photovoltaic systems equipped with trackers are generally classified into two main types based on their range of motion:



Single-Axis Tracker:

This system moves in only one direction—typically along the east-west axis—tracking the sun's movement throughout the day and adjusting the tilt of the panels accordingly. It is widely used in large-scale solar power plants. Single-axis trackers can improve energy output by approximately 20–30%. They are a popular choice due to their effective balance between performance and cost. Although single-axis systems do not adjust for the sun's elevation angle (i.e., how high or low the sun is in the sky), they still capture significantly more sunlight compared to fixed-panel systems. For users seeking a relatively simple and cost-effective way to enhance energy production without investing in complex technology, a single-axis tracker is an ideal solution. It is particularly suitable for large-scale installations such as solar farms, as well as for homeowners who want to increase energy yield without incurring the added costs and maintenance demands of more advanced systems [1-2].

This system tracks the movement of the sun along two directions—both horizontal and vertical planes. It offers the highest efficiency among tracking technologies and can increase energy output by approximately 30–40%. Dual-axis trackers are typically used in small-scale systems or in locations where high performance is essential. These trackers represent the most advanced and efficient option available. They move in two directions—east to west and up and down—enabling the solar panels to follow the sun more precisely throughout the day and across seasons. This improved alignment allows for up to 40% greater energy production compared to fixed systems. However, dual-axis trackers are more expensive and require more maintenance than single-axis systems. Due to their complexity and cost, they are most commonly deployed in large-scale solar farms or commercial installations where maximizing energy output is critical. For residential users, unless there is a specific need to optimize every possible watt of solar energy and a sufficient budget to invest in more advanced infrastructure, dual-axis tracking systems may not be the most practical choice [2-5].

Higher Efficiency: Tracker systems enable solar panels to capture the maximum amount of solar radiation by maintaining optimal alignment with the sun throughout the day.

Maximum Utilization: By continuously adjusting the panel orientation, the system ensures that energy production remains high, particularly during peak sunlight hours.

Stable Energy Production: Compared to fixed systems, tracker-equipped panels produce electricity more consistently throughout the day, resulting in a more uniform power output profile.

Increased Return on Investment: Higher energy generation leads to faster payback periods, making the system economically attractive in the long term.

Advantages and Disadvantages of Tracker Systems

Enhanced Energy Output: The primary advantage of solar trackers is their ability to increase solar energy capture. Depending on the type, they can deliver up to 40% more electricity compared to fixed systems. This means that more energy can be generated with the same number of panels, or fewer panels can be used to meet the same energy demand—particularly beneficial in space-constrained environments [6-9].

Maximum System Performance: With tracking technology, panels are continuously adjusted to maintain the optimal tilt angle relative to the sun, ensuring improved overall efficiency. Unlike fixed-angle installations, the system dynamically responds to solar movement for peak performance across the entire day.

Improved Performance in Specific Climates: Solar trackers are especially effective in regions with high solar irradiance and clear skies, where they can follow the sun's path with minimal obstruction. In such conditions, system performance can be significantly enhanced.

The upfront investment required for solar trackers can be substantial. Even the most basic tracker systems are more expensive than fixed-mount solar panel systems. More advanced models, such as dual-axis trackers, can significantly increase overall system costs. It is essential to carefully evaluate whether the additional energy production justifies the higher capital expenditure [10-14].

Due to the presence of moving parts, tracker systems require more maintenance than stationary systems. Components such as motors, sensors, and actuators are subject to mechanical wear over time. Any malfunction can impair the system's ability to properly track the sun, potentially reducing energy output. This necessitates allocating a budget for periodic inspections, repairs, or replacement of parts.

Installing a tracker system is generally more complex than setting up a fixed solar array. A stable and reinforced foundation is often necessary, and precise alignment with the sun's path is required to ensure proper functionality. This added complexity may also contribute to higher installation costs [15-19].

Applications of Tracker Systems.

Tracker-based photovoltaic power plants are widely used in the following areas:

- Large-scale solar power plants – used for generating electricity in high volumes.
- Industrial enterprises – applied in large industrial facilities to reduce electricity costs.
- Agriculture – utilized to power water pumps and irrigation systems.
- Private households – serve as a high-efficiency solar energy source for residential needs.
- Off-grid systems – used as an independent energy source in areas that are distant from centralized power grids.

Conclusion

Solar panels equipped with tracker systems represent one of the key solutions aimed at enhancing the efficiency of modern photovoltaic technology. By continuously optimizing the tilt angle of the panels, these systems enable maximum absorption of solar radiation. As a result, energy production significantly increases compared to conventional fixed-panel systems. The advantages of tracker systems include high efficiency, stable energy generation, and long-term economic benefits. Particularly in large-scale solar power plants, the use of such technology reduces the cost of electricity generation and expands the potential for utilizing clean and renewable energy sources.Overall, solar panels with tracker systems constitute an important innovation in the field of renewable energy and play a significant role in global sustainable development and the transition to green energy. The further advancement of this technology is expected to contribute to greater energy efficiency and the reduction of carbon emissions in the future.

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