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Basic Development of Solar Tracking Systems

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Abstract: This review paper comprehensively examines solar tracking systems and associated techniques for optimizing renewable energy capture. It discusses two primary types: single-axis and dual-axis trackers. Single-axis trackers follow the sun's daily east-to-west movement, significantly boosting energy generation. Dual-axis trackers offer even greater adaptability, tracking both daily and seasonal sun position changes, resulting in substantial energy gains. The paper also explores crucial tracking techniques used in concentrated solar power, ensuring precise sunlight alignment for maximal energy conversion in power plants and research facilities. Overall, this paper contributes to renewable energy advancement, underscoring their vital role in sustainable and eco-friendly energy solutions.

Index Terms: Solar Energy, Solar Tracking, Passive Solar Tracking, Active Solar Tracking, Single-Axis Trackers, Dual-Axis Trackers

1 Introduction

Solar energy is rapidly advancing as an important means of renewable energy resource in many applications like thermal energy storage systems and electric power generation systems. Such systems use collectors in the form of optical reflectors or photovoltaic (PV) modules to collect solar energy. The average solar energy intercepted by a fixed collector during the whole day is less than the maximum attainable. This is due to the static placement of the collector, which limits their area of exposure to direct solar radiation. More energy can be extracted in a day if the solar collector is installed on a tracker with an actuator that follows the sun [1].

Solar tracking systems by design and principle of operation are mainly divided into two types: single-axis and dual-axis solar trackers. A single-axis solar tracker continues to follow the movement of the sun either horizontally or vertically. As the name recommends, this sort of tracker has just one axis for rotary motion. The horizontal variety of solar tracker is utilized in tropical regions where the sun will receive very way up at midday, except the days are going to be short. On the other hand, the upright kind of solar tracker is employed in regions with elevations where the sun doesn't have to get high, but summer days are often lengthy. In concentrated solar power processes, single-axis trackers are going to be used with flat-surface solar modules [2]. However, such solar tracking systems cannot fully track the trajectory of the sun during the day. Dual-axis trackers have two rotation axes. Such trackers have some advantages over single-axis trackers, although they are more complex to implement and require more costs. Developed dual-axis solar trackers that produced 30.79% and 13–15% more energy than a fixed solar panel, respectively, making them a promising solution for maximizing solar energy capture and utilization [3]. This paper focused on the technologies that are used in solar tracking systems and different types of trackers basically.

2 Solar Tracker Fundamentals

A solar tracker is a device designed to orient a daylight reflector, solar photovoltaic panel, or concentrating solar reflector or lens toward the sun. The sun's position in the sky varies with the seasons (elevation) and throughout the day as it moves across the sky. Solar-powered devices perform most efficiently when they are aligned with the sun, and using a solar tracker can significantly improve their effectiveness, albeit at the cost of increased system complexity. There are various types of solar trackers available, differing in cost, quality, and performance. The most well-known type is the heliostat, a movable mirror that redirects the sun's position to a fixed location. However, there are also alternative techniques in use. The efficiency of a solar tracker depends on its specific application. For example, concentrators in solar cell processes require precise alignment to ensure that concentrated sunlight is accurately directed at or near the focal point of the reflector [4]. Typically, concentrator systems require tracking, with single-axis tracking being the minimum requirement. In cases of large-scale power plants or high-temperature research facilities utilizing multiple ground-mounted mirrors along with an absorptive surface, a high level of tracking accuracy is essential, like what is utilized in solar telescopes [5].

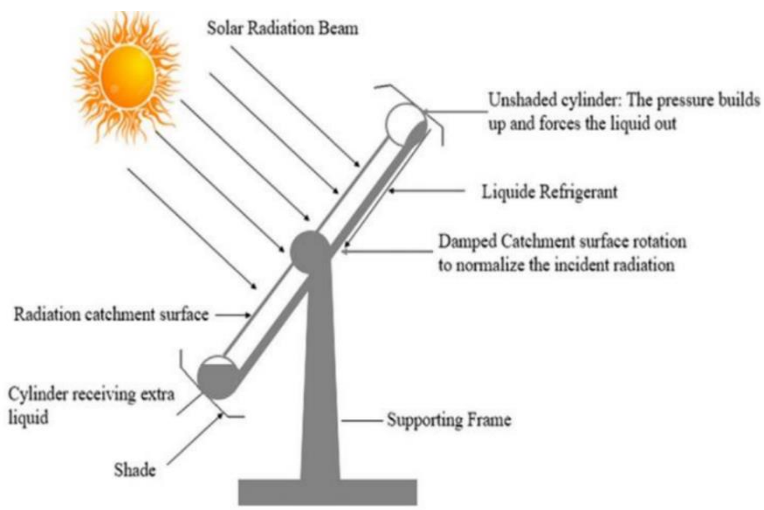

Fig.1. Basic design of Solar Tracker

3 Types of Solar Trackers

The classification of the solar tracking system is based on the extent of its rotational movement. Depending on the degrees of rotation, trackers can be divided into two main categories.

- Single-Axis Solar Trackers
- Dual-Axis Solar Trackers

3.1 Single-Axis Solar Trackers

The single-axis solar trackers depicted in Fig.2 can follow the sun's movement as it traverses from east to west during the day. It's important to emphasize that a single axis refers to the tracker's adjustment along one dimension to track the sun's path. The single-axis tracker does not account for the sun's varying position across seasons. Notably, a single-axis tracker can significantly enhance energy generation compared to a fixed-axis system. In general, single-axis solar trackers can boost their energy output by as much as 20% when compared to stationary flat photovoltaic (PV) systems.[6].

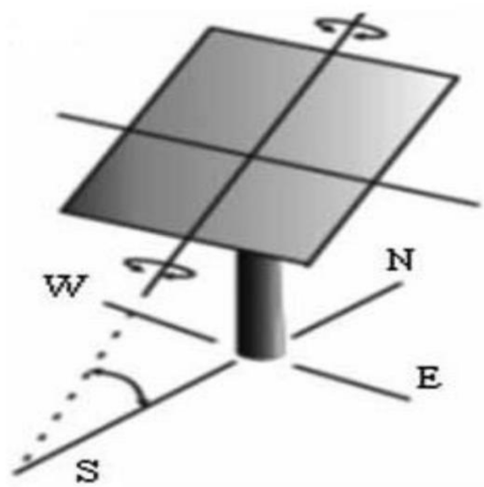

Fig.2. Single-Axis Solar Tracker

3.2 Dual-Axis Solar Trackers

The dual-axis tracker can track the sun's movement not only throughout the day but also over the course of a year. Fig.3 illustrates a dual-axis solar tracker. Unlike the daily east-to-west motion, the sun's position changes both from north to south and east to west as the seasons shift. The dual-axis tracker effectively follows the sun's two-dimensional movement to ensure that the angle between the sun's rays and the panel remains minimized. This ensures maximum sunlight absorption, resulting in the potential for higher energy production compared to single-axis and fixed-axis trackers. Dual-axis trackers deliver excellent performance, achieving greater efficiencies with energy gains ranging from 20% to 50% when compared to stationary flat PV panels [7].

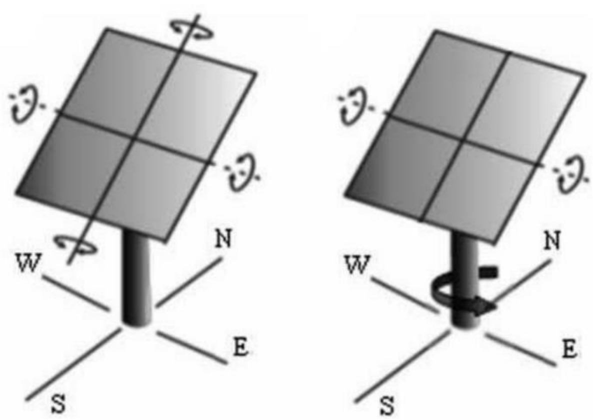

Fig.3. Dual-Axis Solar Tracker

4 Methods of Solar Tracking

There are three main methods of solar tracking techniques.

- Active Tracking
- Passive Tracking
- Chronological Tracking

4.1 Active Tracking

An active solar tracking system determines the position of the sun during the day with existing sensors continuously [8]. The sensor will trigger the motor or actuator to move its fixture following the solar radiation. If the sunlight is not perpendicular to the tracker, then there will be a different illumination on one light sensor compared to another. This difference can be used to determine the direction in which the tracker has to be directed to be perpendicular to the sun [9]. Active solar trackers are further categorized into four categories based on their tracking strategies. There are microprocessors and electro-optical sensors based on date and time, based on auxiliary bifacial PV cells, as well as the combination of the three types above [10].

4.2 Passive Tracking

Passive solar trackers can orient their sensing units towards the direction of the solar radiation beam without using any mechanical drives [11]. Most of these trackers consist of a pair of actuators filled with expansible gas or an on-shape memory alloy. This system utilizes the concept of thermal expansion or an imbalance in pressure between two points at both ends of the tracker. When the PV panel is perpendicular to the sun, the two sides are at equilibrium. Once the sun moves, one side is heated, causing one side to expand and the other to contact, causing the PV panel to rotate [12].

The first commercial passive solar tracking system was introduced by Zomeworks Corporation in 1969. In Zomeworks Track Racks, the PV panel with a tracking system can increase their electrical production output by 25% when compared with the fixed PV panel. Track Racks systems are highly cost-effective components for water pumping systems, industrial power systems, utility applications and cathodic protection systems [13]. In other work, Clifford and Eastwood introduced an economic passive solar tracker model mounted on a wooden frame, symmetrically on either side of a central horizontal axis. The movements of the system were activated by both aluminium/steel bimetallic strips and controlled by a viscous damper. Simulation results and real-time measurements stated that more than 23% energy gain by the proposed solar tracker when compared to a fixed PV panel [14].

Using the passive solar tracker system, the operation is less complex; most of them have a pair of actuators filled with expansible gas or an on-shape memory alloy, working against each other and balanced by equal illumination [15]. However, this method of sun tracking needs to be improved in accuracy and relies mainly on the weather conditions of the site location. The selected location for solar tracker installation is crucial because the location must attain adequate continuous sunlight for an efficient heating process. The type of active solar tracker system can solve the problem of using passive solar trackers.

4.3 Chronological Tracking

A chronological tracker is a timer-based tracking system. The structure is moved at a fixed rate throughout the day since the sun moves across the sky at a fixed rate of about 15 degrees per hour. This method is better suited for single-axis tracking without sensors. For dual-axis tracking, a modified version can be implemented. The position of the sun throughout the day can be calculated and set by the program implemented on the controller module. The solar tracker rotates according to data sent from the control unit's memory of pre-stored data or calculated from a given formula. This method of sun-tracking is accurate and reliable. However, data storage, calculation, and continuous data transmission are power-consuming and unnecessary rotation when sunlight is too low can never be avoided. All three methods are applicable to single-axis and dual-axis tracking systems. Which method is best suitable is determined by the location of installation, purpose of generation and demand for solar power. Modern trackers combine both the sensor-controlled method and sensorless control method at the same time to increase efficiency [2].
Table 1 conclude the advantages and disadvantages of each type of technology for solar tracking system.

Table.1. Advantages and disadvantages of active, passive, and chronological solar trackers

Technology	**Description**	**Advantages**	**Disadvantages**
Active	Use sensors and motors	-More accurate - Efficient in tracking the position of the sun	- Require the extra power consumption - Not very accurate under a cloudy day
Passive	Thermal expansion in material or imbalance in pressure between two points at both ends of the tracker	-Work without using motors or actuators - Easy installation - Low maintenance cost	-Strong dependence on weather conditions - Low inaccuracy
Chronological	-Timed-based tracking system and it rotates at 15° per hour.	-No energy losses - Low tracking error	- Continuous rotation requires more energy - Unnecessary work on a cloudy day

5 Conclusion

In conclusion, this review paper has provided a comprehensive overview of various types of solar tracking systems and the techniques employed to optimize solar energy capture. We have explored single-axis and dual-axis solar trackers, each offering unique advantages and trade-offs. Single-axis trackers excel in following the sun's daily east-to-west movement, significantly enhancing energy generation by up to 20% compared to fixed systems. On the other hand, dual-axis trackers exhibit even greater versatility by tracking the sun's two-dimensional movement, adapting to both daily and seasonal variations. This results in remarkable energy gains, often ranging from 20% to an impressive 50% when compared to fixed flat PV panels. Furthermore, we have delved into the critical role of tracking techniques in concentrated solar power processes, emphasizing the need for precise alignment to ensure optimal sunlight concentration and energy conversion. These techniques are essential for maximizing energy output in power plants and high-temperature research facilities. In an era where renewable energy sources are paramount for sustainable development, the knowledge and understanding of solar tracking systems and techniques are of utmost importance. As technology continues to advance, it is evident that solar tracking systems will play a pivotal role in harnessing the full potential of solar energy, contributing significantly to a greener and more sustainable future.

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