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Technologies and classification of solar trackers: a technical *review*

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Summary

Solar tracking is a fundamental technology for maximizing the efficiency of photovoltaic energy conversion, allowing modules to follow the sun's path and optimize the angle of incidence of irradiation. This article presents a technical review of the operation and classifications of solar trackers. It discusses the theoretical basis that mathematically proves the productivity gains, which can reach up to 57% under ideal conditions. Furthermore, the work details the classifications according to mechanism (single and dual axis), control systems (open and closed loop), and steering systems (active, passive, and manual), analyzing the advantages and limitations of each technology.

Keywords: Solar Tracking. Photovoltaic Efficiency. Single Axis. Dual Axis. Systems of Control.

Abstract

Solar tracking is a fundamental technology for maximizing photovoltaic energy conversion efficiency, allowing modules to follow the Sun's path and optimize the irradiation incidence angle.
This paper presents a technical review on the operation and classification of solar trackers. It discusses the theoretical basis mathematically proving productivity gains, which can reach 57% under ideal conditions. Furthermore, the work details classifications regarding mechanism (single and dual axis), control systems (open and closed loop), and drive systems (active, passive, and manual), analyzing the advantages and limitations of each technology.
Keywords: Solar Tracking. Photovoltaic Efficiency. Single Axis. Dual Axis. Control Systems.

1. INTRODUCTION

The search for greater efficiency in solar energy generation has driven the development of robust auxiliary technologies. Among them, solar tracking stands out, a A system designed to track the relative movement of the Sun with respect to the Earth. The main The purpose of this technology is to reduce the angle of incidence between the line normal to the equipment and the Direct solar irradiation ensures that the modules operate close to their capacity. maximum for most of the day.

Rhiff (2014) points out that solar tracking is not used exclusively for panels. photovoltaics, but also for other equipment such as reflectors, lenses and other optical services. Although implementing axes of motion, whether single or dual, adds complexity and cost. According to the project (SUNGUR, 2009), the substantial increase in radiation absorption justifies its application. in various scenarios. This article aims to define how these systems work, to demonstrate theoretically, their gains and classify the technologies available in the current market.

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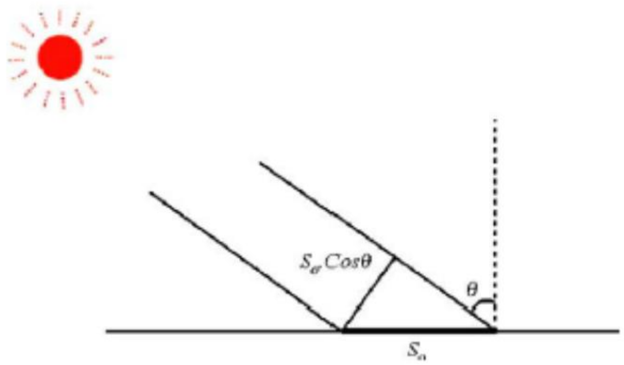
2. THEORETICAL FRAMEWORK

2.1 DEFINITION AND OPERATION

The tracker allows the module to constantly follow the sun's path, increasing the direct irradiance received throughout the day (RECA-CARDEÑA and LÓPEZ-LUQUE, (2018). Productivity gains from using trackers can average between 30 and 40%. per year (RACHARLAA and RAJANB, 2017).

To illustrate this gain theoretically, the calculations presented in Mousazadeh et al. are used. al. (2009). Consider ÿ the angle of incidence of the sun's rays with respect to the normal to the surface. (as illustrated in Figure 1), and assume that the maximum direct irradiance ( ) is 1000 W/m². It is also considered that the solar day length is 12 hours (43200 seconds) and that the solar tracker always Direct the photovoltaic panel so that its face remains perpendicular to the sun's rays. Name this... if the panel area and the effective panel area are perpendicular to the sun's rays.

Figure 1 – Direct incidence of solar rays on a horizontal surface



Source: MOUSAZADEH et al. (2009).

For a fixed photovoltaic panel, the effective area is = , where ÿ varies from ÿ ÿ2 ÿ2 throughout the day. The angular velocity of the Sun moving across the sky is = 2 ÿ = 7.27 × 10ÿ5 ÿ (ÿ =) and the infinitesimal energy produced is = Disregarding the Considering the influence of the atmosphere on the calculations, the daily energy per unit area is:

$$o = ÿ \int_{-21600}^{+21600} = 3.03 \times 10^7 \frac{}{2} = 8.41 \frac{h}{2}$$

For a photovoltaic panel with a solar tracker, disregarding the effect of the atmosphere, the area The effective energy is equal to the area of the panel (=), the energy per unit area for the entire day is:

$$o = 4.75 \times 10^7 \frac{}{2} = 13.2 \frac{h}{2}$$

It is therefore observed that, under ideal conditions and for a direct incident irradiance of With a capacity of 1000 W/m², the use of trackers in photovoltaic panels increases daily production by

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approximately 57%. In practice, when compared to the irradiance on the horizontal surface, in On summer days, the gains are around 50%, and on winter days, 300% or more (DGS, 2008).

On sunny days, that is, with few clouds and a high level of direct radiation, the Solar tracking systems allow for substantial harnessing of energy from the sun. According to DGS (2008), summer is the period in which there are the greatest energy gains, due to higher irradiance rate and due to the fact that there are fewer clouds in the sky.

3. MATERIALS AND METHODS

This study is characterized as a descriptive, bibliographical research. The methodology adopted consisted of the analysis and synthesis of specialized technical literature on systems. solar tracking. Reference works in the field of solar energy engineering were consulted. technical standards and scientific articles that address the mechanics, electronics, and physics involved in Solar tracking. The classification of the systems was structured based on the components. fundamental elements identified by Reca-Cardeña and López-Luque (2018): mechanisms, systems of Control and steering systems.

4. RESULTS AND DISCUSSION

Analyzing the available technologies allows us to classify solar trackers into... distinct categories, each with specific applications and efficiencies.

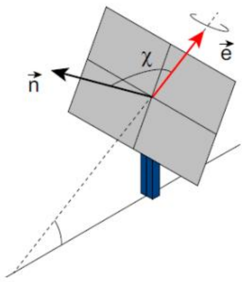
4.1 CLASSIFICATION ACCORDING TO MECHANISM

The mechanism is the part responsible for moving the system, built to support adverse weather conditions and have a lifespan compatible with the modules.

4.1.2 Single Axle

Single-axis systems have only one degree of rotational freedom. The axis can can be horizontal, vertical, or inclined. Figure 2 shows a general diagram where the angle between the axis The rotation and the axis normal to the collector plane remain constant.

Figure 2 – Unit axis of rotation and the axis normal to a single-axis tracker



Source: *RECA-CARDEÑA and LÓPEZ-LUQUE (2018).*

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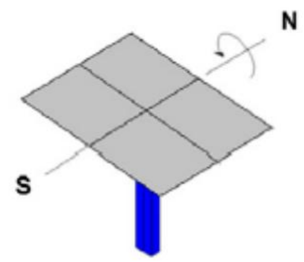
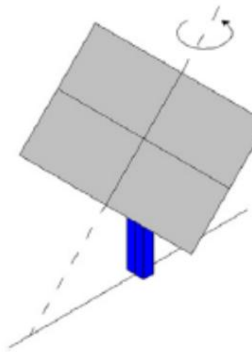
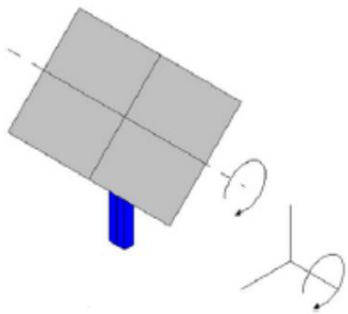
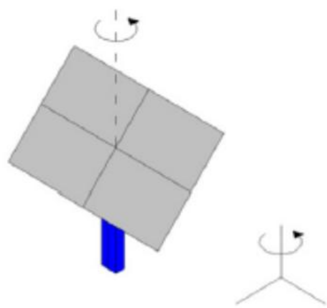
Table 1 presents the most common types of single-axis trackers.

Table 1 — Most Common Types of Single-Axis Trackers

Single Axis Tracker Type	Image
North-South horizontal axis tracker The axis is horizontal and lies in the North-South direction, with ÿ = 90°.	
Polar Tracker: North-South polar axis tilted at an angle equal to the local latitude. The rotation is adjusted to follow the Earth's meridian that contains the Sun. The angular velocity is 15°/h. With this configuration, the solar tracker can be used in northern latitudes and in places near the equator.	
East-West Horizontal Axis Tracker In this configuration, the axis of rotation is in the East-West direction.	
Azimuthal Tracker The tilt angle of the module is constant and equal to the local latitude, tracking the azimuth angle of the Sun. The simple and robust mechanism of azimuthal trackers allows for significant cost-effectiveness compared to dual-axis trackers, making them the most widely used in practice.	

Source: RECA-CARDEÑA and LÓPEZ-LUQUE (2018)

According to the DGS (2008), the advantages of the single axle include lower complexity and consumption.

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energy. The disadvantages are tracking only one movement of the Sun (daily or annually) and Inefficiency on cloudy days.

4.1.2 Dual Shaft

They exhibit two degrees of freedom, following the daily and annual solar movement. They are essential in power concentration systems (HAFEZ et al., 2018). Compounds generally powered by LDR sensors, two motors, and a controller.

The main types are:

1. **Tip inclination (Equatoric):** Uses equatorial coordinates. Axes in the plane of Modules prevent shading (Figures 3 and 4).
2. **Azimuth-height:** These systems use horizontal coordinates. They vary azimuth and height using rings. Support (Figures 3 and 5).

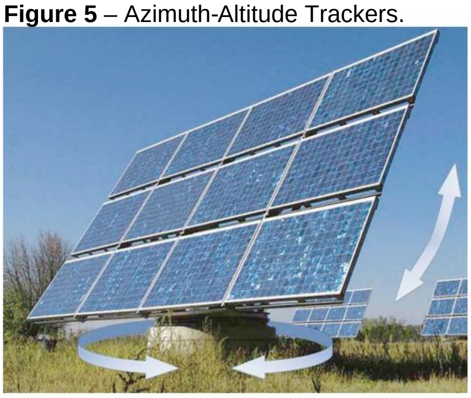
Figure 3 – Tip Tilt and Azimuth-Altitude Trackers and their axes of rotation.

Source: *HONG et al. (2016).*

Figure 4 – Tip Tilt Trackers

Source: *SEI (2016).*

Figure 5 – Azimuth-Altitude Trackers.



Source: *SEI (2016).*

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4.2 CLASSIFICATION ACCORDING TO CONTROL SYSTEMS

Closed-loop systems: They use direct feedback from photosensors (e.g., LDRs) to track the sun. They can suffer from...

Disorientation on cloudy days, requiring auxiliary systems (CHONG and WONG, 2009).

Open Loop: They use astronomical calculations based on date, time, and location. Independent.

of external weather conditions.

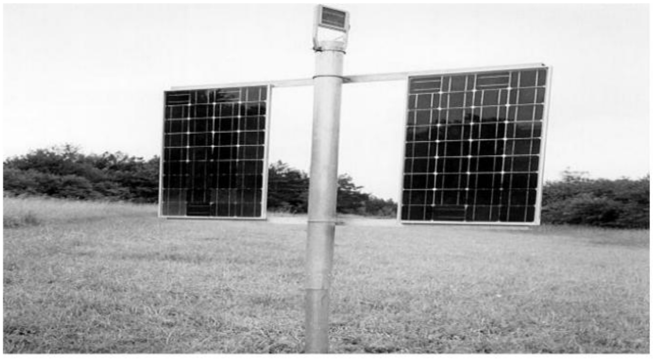
4.3 CLASSIFICATION ACCORDING TO STEERING SYSTEMS

4.3.1 Assets

They use electric motors. The main types are (MOUSAZADEH et al., 2009):

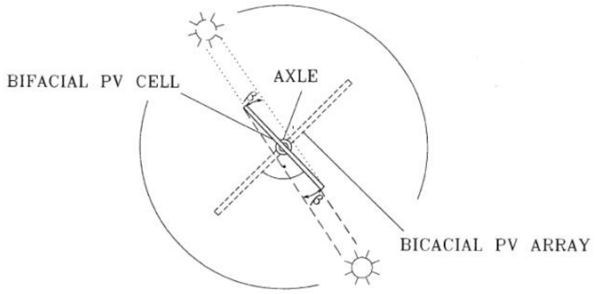
- Microprocessor and Optical Electrical Sensors: The most common. Uses pairs of sensors in antiparallel regions. The controller seeks to equalize the received radiation.
- Bifacial Auxiliary Solar Cell: A bifacial cell directly powers a DC electromagnetic motor. It does not use batteries or complex electronics, increasing reliability (Figures 6 and 7).
- Chronological: Open-loop system based on astronomical algorithms (RACHARLAA and RAJANB, 2017). High efficiency because it does not expend energy searching for the sun, but requires precise location data.

Figure 6 – Trackers based on a bifacial auxiliary solar cell.



Source: POULEK and LIBRA (2000).

Figure 7 – Basic diagram of a tracker based on a bifacial auxiliary solar cell.



Source: POULEK and LIBRA (2000).

4.3.2 Liabilities

They function through the balance of volatile fluids or shape memory alloys. When there is

Due to differences in lighting, thermal imbalance generates mechanical forces that move the system.

Advantage: low complexity. Disadvantage: low efficiency and problems at low temperatures.

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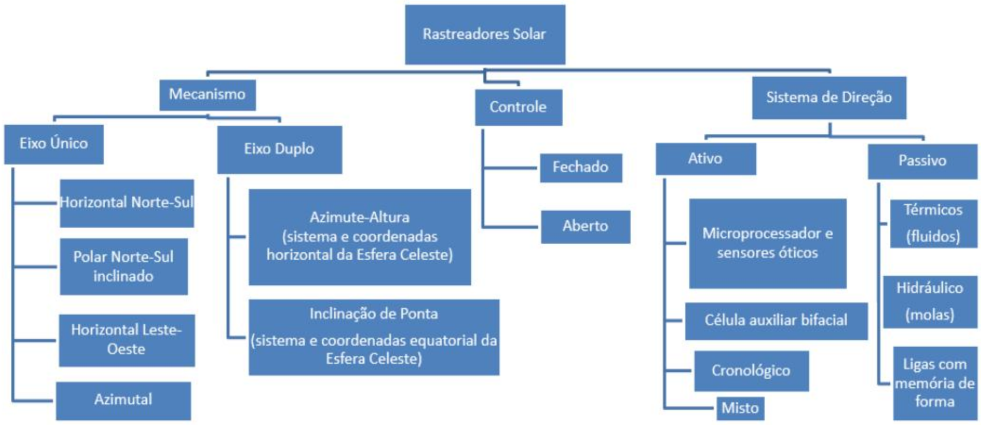
4.3.3 Manual

It utilizes human labor for seasonal adjustments. It reduces complexity and maintenance, being used in simple applications such as solar dryers (HAFEZ et al., 2018).

Figure 8 presents a schematic summary of the classifications discussed.

Figure 8 – Classification Scheme for Solar Trackers.



Source: Author's own.

FINAL CONSIDERATIONS

The study demonstrated that the use of solar trackers is an effective strategy for...

Increased power generation, with significant theoretical gains. Although dual-axis systems

While they offer the highest precision, their complexity and cost often favor the use of trackers.

Single-axis, especially azimuthal, in large power plants. The choice between active and passive systems.

Whether or not to schedule a timeline depends on the specifics of the project, balancing the need for precision with...

Reliability and maintenance costs.

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