Solar Photovoltaic Tracking Systems

Subjects: Automation & Control Systems

Contributor: Abdulwaheed Musa , Emmanuel Alozie , Suleiman A. Suleiman , John Adedapo Ojo , Agbotiname Lucky Imoize

Maximum solar power can be generated only when the Sun is perpendicular to the solar panel, which can be achieved only for a few hours when using a fixed solar panel system, hence the development of an automatic solar tracking system. Over the years, different solar tracking systems have been proposed and developed.

solar tracker single-axis tracker dual-axis tracker active tracker passive tracker

1. Introduction

Renewable energy sources are energies that come from the Sun directly, such as thermal, photochemical, and photoelectric energy, or indirectly, such as wind, hydropower, and photosynthetic energy stored in biomass, as well as other climate regulation and natural motions, such as geothermal and tidal energy; these are then converted into usable forms of energy, such as electricity, heat, and fuels [1]. The most abundant renewable energy that is directly obtained from the Sun is solar energy, which also serves as a regulator of the hydrological cycle and a source of wind energy because the Sun's heating effect on the atmosphere causes air to move [2][3].

Solar power, also known as solar energy, can be generated by a solar panel, which largely depends on the amount of sunlight it is exposed to. Solar photovoltaic energy has a much higher installed capacity than other renewable energy concepts and technologies due to its abundance, versatility, and ease of implementation with minimal negative environmental impact in terms of land use [4][5]. Maximum solar power can be obtained only when the Sun is directly on the panel. Due to the variation of the position of the Sun throughout the day, there is a need to adjust the solar panel so that it is always aimed precisely at the Sun. A solar tracker is a device employed to operate a solar photovoltaic panel, particularly in solar cell applications, and requires a high level of precision to ensure that sunlight is directed accurately onto the power device [6]. Solar tracking systems also play an important role in the advancement of solar concentration applications such as solar-pumped lasers and parabolic concentrators [7][8]. These trackers can improve the efficiency of the overall solar photovoltaic system, reducing the size and the cost per kilowatt hour (kWh).

To increase the efficiency of photovoltaic (PV) systems, several solar tracking systems have been developed over the years.

2. Solar Photovoltaic Tracking Systems

The amount of sunlight received varies throughout the year as a result of the motions of the Earth; however, the amount of solar energy received over a certain period on a surface that is perpendicular to the radiation’s path of propagation outside of the atmosphere at the mean earth–sun distance is known as the solar constant [9] and can be expressed mathematically as given in Equation (1):

$$G_{sc} = \sigma \cdot T^4 \cdot \left(\frac{4\pi R}{4\pi D}\right)^2 = 1367\ W/m^2 \tag{1}$$

where σ denotes the Stefan–Boltzmann constant (5.67×10−8 Wm−2K−45.67×10−8 Wm−2K−4), RR is the radius of the Earth (6371 km), and DD denotes the average distance between the Sun and Earth (148.72×109 km148.72×109 km).

According to [10], the substantial amount of daily solar irradiation has led to the use of solar energy for power generation in a variety of applications, such as water pumping, telecommunication, and lighting. This has resulted in the design and implementation of solar photovoltaic panels, which can collect solar energy and convert it to other forms of energy, such as electrical energy. However, the amount of energy that may be produced is directly proportional to the intensity of the sunlight that falls on the panel. As a result, the necessity to build a system that can follow the position of the Sun over time has emerged, hence the solar tracking system. A solar tracking system can track the Sun’s movement and location over time to increase solar energy output, which in turn boosts electrical energy. **Figure 1** shows the difference and limitations of the fixed solar tracking system compared to a simple solar tracking system.

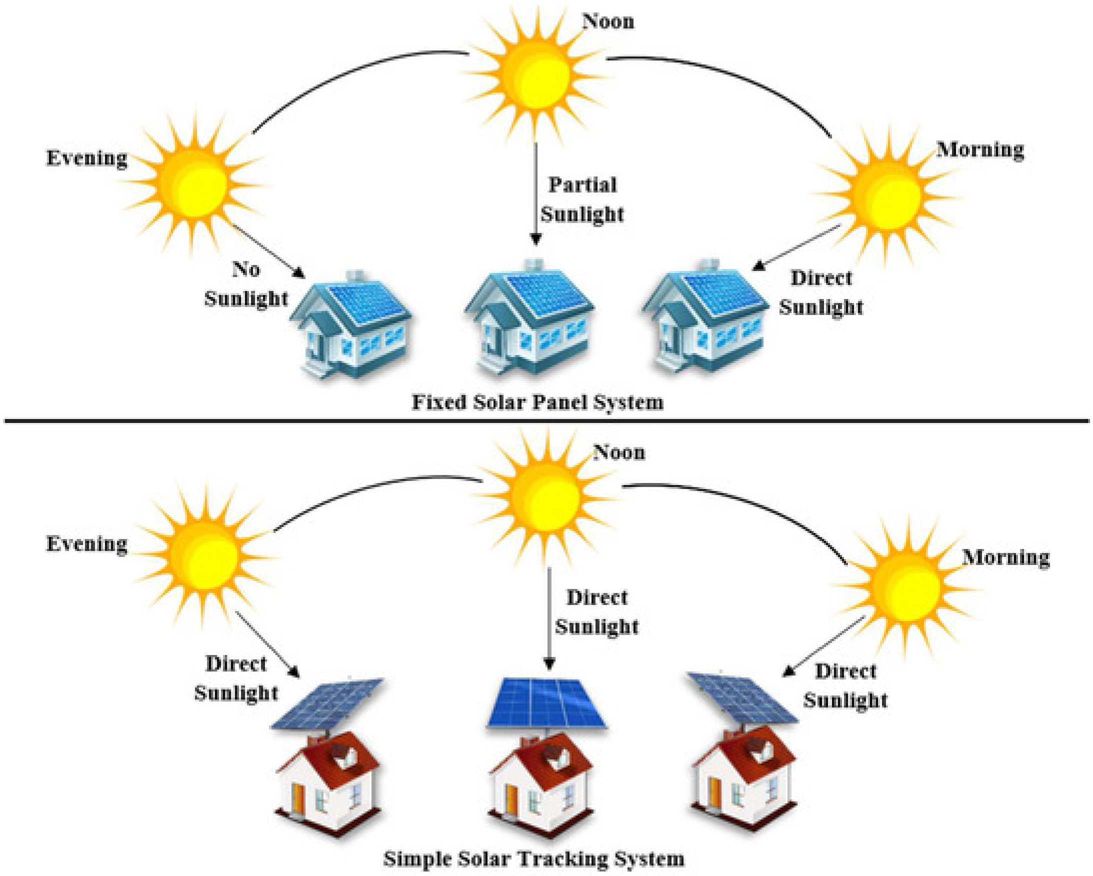

Figure 1. Comparison between Fixed and Simple Solar Tracking Systems.

For the accurate design, implementation, and installation of a solar tracking system, several parameters must be considered, such as the latitude, angle of incidence, solar irradiance, tilt angle, declination angle, elevation angle, zenith angle, orientation angle, solar azimuth angle, and inclination angle.

Latitude is a measure used to calculate the angular distance (south or north) of the equator in any location on Earth. The latitude angle can be measured in degrees. The angle of incidence is the most critical factor to consider when installing solar tracking systems. It is the angle formed by the Sun's rays falling on the surface and the rays perpendicular to that surface.

Solar irradiance is another important parameter to consider, and it can be calculated by measuring the power of the light source or the luminous flux. The angle formed by the solar tracking system and the horizontal axis is known as the tilt angle. The angle of incidence is a variety of tilt angles. The declination angle is the angle formed between the equator and a line drawn from the center of the Sun to the center of the Earth. It can be expressed mathematically as given in Equation (2):

$$\delta = -23.45 \times \cos\left(\frac{360}{365} \times (n + 10)\right) \quad (2)$$

The elevation and zenith angles are similar to the declination angle: the elevation angle is the angle between the Sun's center and the horizon, while the zenith angle is the angle formed by the center of the Sun and the vertical. They are both measured in degrees and expressed mathematically as shown in Equations (3) and (4), respectively:

$$\alpha = 90^{\circ} - \theta_z \tag{3}$$

$$\theta_z = \cos^{-1} \sin L_{st} \sin \delta + \cos L_{st} \cos \delta \cos \mathrm{ST} \tag{4}$$

where α is the elevation angle, θz is the zenith angle, Lst is the standard longitude that is positive for the east region and negative for the west, δ is the declination angle, and STST is the standard time.

The orientation angle can be used to adjust a solar tracking system to keep the solar photovoltaic module perpendicular to the Sun and generate the maximum power. The solar azimuth angle is defined as the angle formed by projecting the Sun's center onto the horizontal plane and pointing due south. It is represented with a positive sign for the position east of south, and the position west of south is represented with a negative sign. It can be represented mathematically as given in Equation (5):

$$\gamma_s = \sin^{-1}\left(\frac{\sin h \cos \delta}{\sin \theta_z}\right) \tag{5}$$

where γs is the solar azimuth angle, δ is the declination angle, θz is the zenith angle, and h*h* is the hour angle expressed as given in Equation (6):

$$h = 15^{\circ}(\mathrm{solartime} - 12) \tag{6}$$

The inclination angle is the angle between a photovoltaic module and the positive x-axis, measured in degrees. As shown in **Figure 2**, these variables can be used to determine the optimal location for installing a solar tracking system or to establish the best orientation for such systems to obtain the maximum solar power.

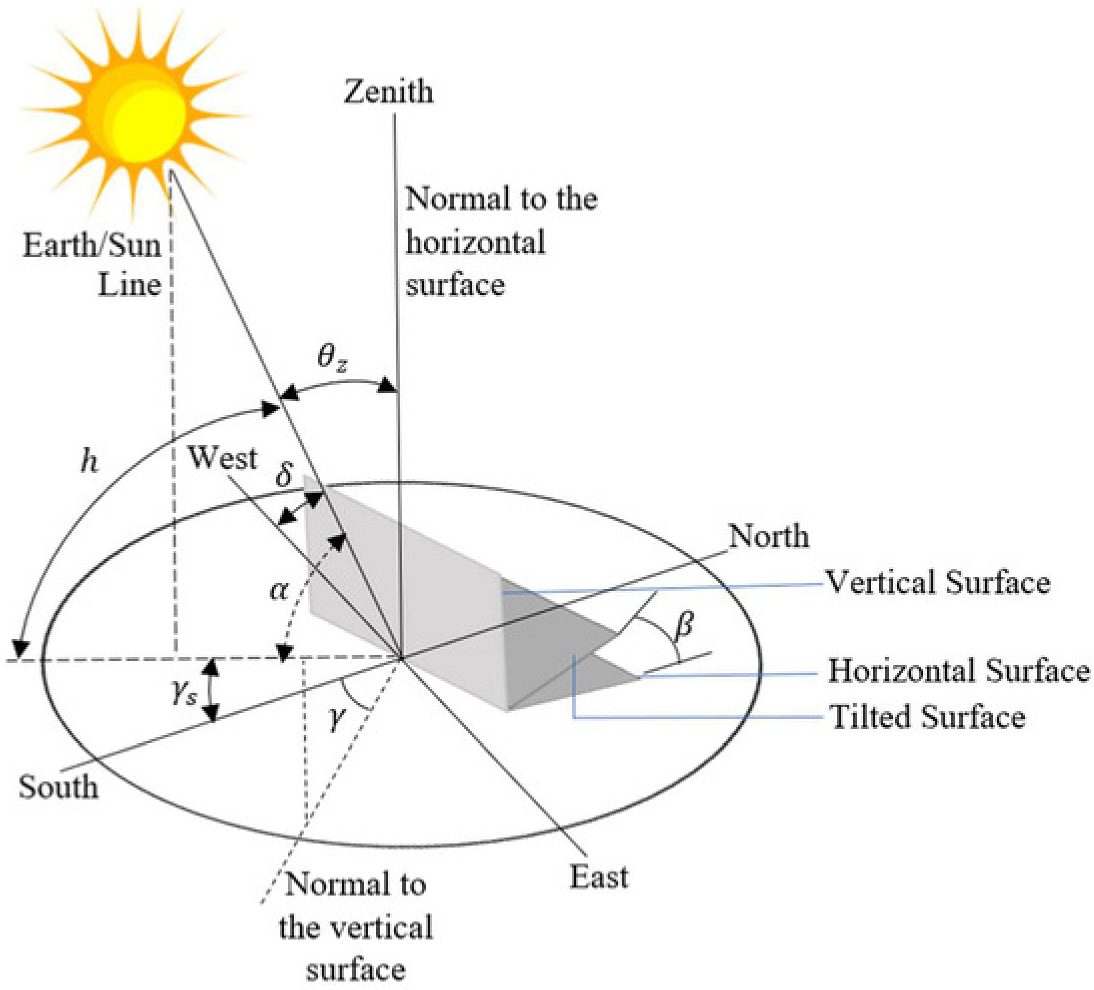

Figure 2. Solar Angles.

Although a solar tracking system can be used to maximize solar power, designing and implementing one is complex for a variety of reasons, including the need for intensive mathematical computations and detailed measurement of numerous solar parameters. It is also more expensive and sophisticated than a fixed-angle solar tracking system. The complexity, however, is determined by the number of axes utilized to move the solar panels horizontally or vertically.

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