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# The efficacy of a dual-axis solar tracking device in tropical climate

# Eficácia de um dispositivo de rastreamento solar com eixo duplo em clima tropical

# Efectividad de un dispositivo de seguimiento solar a doble eje en clima tropical

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## Abstract

The demand for energy and the pressure for reducing environmental impacts is increasing in developing countries, mainly in agricultural areas. The generation of electricity from photovoltaic panels can be economically and environmentally advantageous as a source of renewable energy and the ability to reach remote consumers. The present study aimed to evaluate the performance of a photovoltaic system equipped with a sun-tracking device, comparing to a fixed panel. The test compared two panels of a photovoltaic cell system, one used a rotation module in two-axis, and the other a fixed one (control), for capturing solar energy throughout the day in a tropical region of Brazil. Solar energy data were obtained in the two photovoltaic panels with data continuously recorded six months, with a weather characteristic of high cloudiness and rainfall indexes. The commissioning of the tested photovoltaic panels was done on bright days. Power results indicated that the two-axis tracker system was useful during the test, presenting an increase of 26% when compared to the fixed panel. It was found that when the cloudiness and the rain index are very high, the sun tracking system might not be as efficient as foreseen. Rainfall and cloudiness index are essential factors for determining the feasibility of using a tracker device in tropical regions.

**Keywords:** Renewable energy; Rain index; Irradiation; Solar energy; Solar tracking system.

## Resumo

A demanda por energia e a pressão para reduzir os impactos ambientais estão aumentando nos países em desenvolvimento, principalmente nas áreas agrícolas. A geração de eletricidade a partir de painéis fotovoltaicos pode ser econômica e ambientalmente vantajosa como fonte de energia renovável, além da capacidade de alcançar consumidores em locais remotos. O presente estudo teve como objetivo avaliar o desempenho de um sistema fotovoltaico equipado com um dispositivo de rastreamento solar em comparação com o painel fixo. O teste comparou dois painéis de um sistema de células fotovoltaicas, sendo que um utilizou um módulo de rotação em dois eixos e outro era fixo (controle), para captar energia solar ao longo do dia em uma região tropical do Brasil. Os dados de energia solar foram obtidos nos dois painéis fotovoltaicos, com gravação constante por seis meses, o que demonstrou uma característica climática de altos índices de nebulosidade e precipitação para o período. O comissionamento dos painéis fotovoltaicos testados foi realizado em dias claros. Os resultados de potência indicaram que o sistema rastreador com dois eixos foi eficaz durante o teste, apresentando um aumento de 26% quando comparado ao painel fixo. Verificou-se que, quando a nebulosidade e o índice de chuva são muito altos, o sistema de rastreamento solar pode não ser tão eficiente quanto o previsto. As chuvas e o índice de nebulosidade são fatores essenciais para determinar a viabilidade do uso de um dispositivo rastreador em regiões tropicais.

**Palavras-chave:** Energia renovável; Índice de chuva; Irradiação; Energia solar; Sistema de rastreamento solar.

**Resumen**

La demanda de energía y la presión para reducir los impactos ambientales están aumentando en los países en desarrollo, especialmente en las áreas agrícolas. La generación de electricidad a partir de paneles solares fotovoltaicos puede ser ventajosa económica y ambientalmente como fuente de energía renovable, además de la capacidad de llegar a consumidores en ubicaciones remotas. El presente estudio tuvo como objetivo evaluar el rendimiento de un sistema fotovoltaico equipado con un dispositivo de seguimiento solar en comparación con el panel fijo. Se han implementado dos sistemas fotovoltaicos, uno de los cuales usaba un módulo de rotación de dos ejes y el otro era fijo (control), para capturar energía solar durante todo el día en una región tropical de Brasil. Los datos de energía solar se obtuvieron de los dos paneles fotovoltaicos, con registro constante durante seis meses, lo que demostró una característica climática de altos niveles de nubosidad y precipitación para el período. La puesta en marcha de los paneles fotovoltaicos analizados se realizó en días claros. Los resultados de potencia indicaron que el sistema de seguimiento con dos ejes fue efectivo durante la prueba, mostrando un aumento del 26% en comparación con el panel fijo. Se confirmó que, cuando la nubosidad y el índice de lluvia son muy altas, es posible que el sistema de seguimiento solar no sea tan eficiente como se predijo. La lluvia y la nubosidad son factores esenciales para determinar la viabilidad de utilizar un dispositivo de rastreo en las regiones tropicales.

**Palabras clave:** Energía renovable; Índice de lluvia; Irradiación; Energía solar; Sistema de seguimiento solar.

## 1. Introduction

The demand for energy is increasing in developing countries, mainly in agricultural areas. Solar power generation might be an adequate solution for the lack of energy in remote areas; however, solar energy is not steady throughout the day, and the performance of solar panels is highly prejudiced by a large number of environmental factors such as sunshine intensity, cloudiness and wind speed (Kannan & Vakeesan, 2016). Nevertheless, the generation of electricity from photovoltaic panels can be economically and environmentally advantageous as a source of renewable and sustainable energy (Branker et al., 2011; Parida et al., 2011; Sampaio & Aguirre González, 2017).

Solar energy is one of the clean, renewable energy with great potential for use in developing areas (Panwar et al., 2011; Singh et al., 2018). Brazil is one of the top countries in the world capable of producing solar energy, with a high potential for the use of this energy source, since it has solar radiation indexes higher than those found in most European countries. The energy potential ranges from 1,500 kWh/m2/year to 2,200 kWh/m2/year (ANEEL, 2016). The country's solar power generation potential exceeds 10,000 GW, while the hydroelectric potential is 280 GW and 300 GW (Pereira et al., 2017). Still, the current challenges in generating solar energy are the initial costs (such as a raw material acquisition), and the national taxes, since the material for building up the panels are imported (ANEEL, 2016).

Increasing the use of renewable energy even on a small scale promotes sustainable technological development in rural areas and results in a lower load for the grid (Kabir et al., 2018). The design of a system of electric energy generation from photovoltaic panels must provide the maximum efficiency in the capture of the irradiation (Poulek & Libra, 2000; Tharamuttam & Ng, 2017). However, the solar rays are not perpendicular to the ground, with that they lose efficiency and solar power. The efficiency in the capture of solar energy can vary between 20 and 50% in photovoltaic panels that have a capacity of adjustment per movement about fixed systems (Parida at al., 2011; Carvalho et al., 2013). Nevertheless, this advantage varies depending on local climatic conditions and latitude (Sharaf Eldin et al., 2016).

The importance of positioning the panels always perpendicular to the sun aims to obtain the average incidence of irradiation superior to the panels without rotation. For this reason, several studies have been carried out to determine the best solar tracking systems (Abdallah, 2004; Mousazadeh et al., 2009). Yao et al. (2014) presented a multipurpose dual-axis solar tracker that can be applied to solar power systems employing a declination-clock mounting system that locates the primary axis in east-west, and drives the secondary axis to rotate at a constant speed. Batayneh et al. (2019) proposed a single-axis solar tracking system that only triggers three times a day in the azimuthal plane to follow the sun. The presented tracking angles are based on simulation using weather data to find optimum angles of tracking. Moreover, Tharamuttam & Ng (2017) suggested an automatic solar tracker using a hybrid algorithm for locating the sun position, and the results shown significant improvement when compared to traditional tracker systems.

A key disadvantage with solar tracking systems is that the power used by the driving mechanism is often taken away from the output power of the solar panel, decreasing the net energy gain (Rambhowan & Oree, 2014). Therefore, the present study aimed to propose a solar tracker that could be efficiently used in rural areas. To achive that we compared two panels of photovoltaic cells system under tropical conditions, one of them had a two-axis sun-tracking engine turned towards a higher capture of solar radiation, and the other panel was fixed.

## 2. Materials and Methods

### 2.1 Photovoltaic panel characteristics

Two 20 W monocrystalline solar panels for solar power generation was used, with stationary battery and charge controller. The panels had 36 photovoltaic cells. The technical characteristics were maximum power (MaxP) of 20 W; maximum tension (MaxPT) of 17.3 V; maximum power current (maxPC) of 1.16 A; open-circuit voltage (OcV) equal to 21.24V; short circuit current (ScC) of 1.31A; maximum system voltage of 600V; cell efficiency equal to 14.65%; and module efficiency equal to 10.95%. The cells were made of monocrystalline silicon with a size of 62.5 x 62.5 mm2. The panels were made with high-transmission glass, with lightweight hardware, which directs more light onto the cells, resulting in higher energy efficiency. The dimensions of both photovoltaic panels were 630 x 290 x 25 mm.

### 2.2 Prototype development

The two-axis system was based on a digital timer-driven engine that makes the panel rotate throughout the day, following the sun, in which the engine is driven throughout the day and one last time to return to the starting position. Figure 1a presents the lateral view of the fixed photovoltaic panel, while Figure 1b shows the lateral view of the photovoltaic system with rotational structure, with alignment detail of the rotational axis.

**Figure 1.** Front (a) and lateral view (b) of the fixed photovoltaic panel with a rotational structure.

(a) (b)

Source: Authors.

The rotated photovoltaic panel had a structural system for moving the photovoltaic panels in two axes with an angular amplitude of up to 70º. The rotation had the function of monitoring the solar movement correcting the angle of the photovoltaic plate, keeping it perpendicular to the solar radius, as a function of the time of day and the season of the year. The system was built with two main parts the mechanical part and the control. The mechanical part of the system moves both in vertical and horizontal axes. Equation 1 was used to define the ideal slope of the photovoltaic plate.

$$\delta = 23.45º . sen\ [360\ \times (\frac{J-80}{365})] \qquad (1);$$

where δ is the value of the solar declination in degrees, the J the order number of the days. It also calculates the angle of declination of the earth concerning the solar angles Zenith and Azimuth. The solar azimuth angle is calculated by Equation 2.

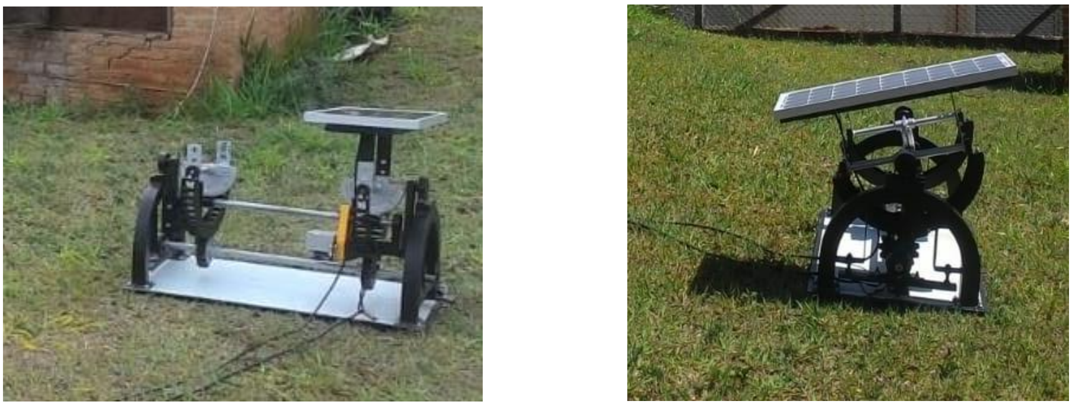
$$\cos \Psi = \frac{-\, sen\ \alpha . sen\ \Phi + sen\ \ \delta}{\cos \alpha . \cos \Phi} \qquad (2);$$

where Ψ is the azimuth angle, α (solar altitude), and Φ Z is the zenith angle. Note that Φ Z = 90° – α. The value of the Zenith angle (Φ Z) might also be calculated using the angle of terrestrial latitude (Φ) decreased from the solar declination solar (δ) for a particular day of the year (Φ z = Φ – δ ). The angle Φ z is the ideal angle for the photovoltaic panel elevation to get the most efficiency of the sunlight intensity, which was used in the experimental trial.

**2.3 Prototype testing**

The prototype was tested in the experimental area of the College of Agricultural Engineering at the State University of Campinas (22° 54' 25.6" S and 47° 3' 47.6" W). The test was carried out from August 17th, 2018 to February 20th, 2019. Two photovoltaic panels were used, one fixed (PFP) and the other with a tracker system (PTP) connected in a steel structure developed for the panel to rotate, using a stepper motor and driver, with supporting metallic servo bracket (Figure 2). The electromechanical system consists of two drivers with an engine: one is for rotating about north and south, and the other for east and west directions. During the experimental period, the values of the generated electric current were continuously recorded using an Arduino microcontroller connected to the panels and recorded into a computer.

**Figure 2.** Front (a) and lateral (b) views of the prototype using the two-axis tracker photovoltaic panel.



(a) (b)

Source: Authors.

### 2.4 Data analysis

Data were recorded using an Excel® sheet containing the values of power current (A) every 60s for each photovoltaic panel. The environmental data (dry-bulb temperature, °C; relative humidity, %; wind speed, m/s; solar radiation, kJ m-$^2$; and rain index) was also recorded every hour in a weather station 50 m from the experimental area. Solar irradiation was adopted as suggested by Viana et al. (2011) for the region.

The power current overall values were analyzed, applying a t-test employing 95% significance (Lowry, 2018). A graph was built to visualize the potential power of each tested panel using the data of the brighter day (rain index=0.0 and no clouds). Mean values of energy recorder were compared by the Tukey test, and results were considered significant at 95%.

## 3. Results

The mean values of solar power, dry bulb temperature, relative humidity, wind speed, solar radiation, and rain index are shown in Table 1. Data from the days shown are those that could be used for commissioning the prototype since the rain index during the period was rather high.

The results of the comparison between the two photovoltaic systems, rotated and fixed, using the daily average solar power did not differ (Table 2; p= 0.219).

**Table 1.** Mean values of solar power (of the two sources of photovoltaic panels), dry-bulb temperature, relative humidity, wind speed, solar radiation, and rain index for the duration of the test (September 2018 to February 2019).

| | Mean value | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | PTP power (A)/day | PFP power (A)/day | Dry-bulb temperature (°C) | Relative humidity (%) | Wind speed ($m\ s^{-1}$) | Solar radiation ($kJ\ m^{-2}$) | Rain index (mm) |
| Sept | 0.90 | 0.74 | 25.03 | 63.05 | 1.84 | 1724.99 | 2.35 |
| Oct | 0.74 | 0.64 | 26.51 | 48.52 | 2.585 | 1536.07 | 3.45 |
| Nov | 0.56 | 0.48 | 22.55 | 65.155 | 2.295 | 1253.60 | 3.01 |
| Dec | 0.64 | 0.56 | 28.76 | 77.43 | 1.89 | 1251.17 | 11.65 |
| Jan | 0.55 | 0.52 | 22.7 | 83.31 | 1.925 | 923.05 | 5.03 |
| Feb | 0.39 | 0.35 | 22.93 | 83.75 | 1.72 | 734.63 | 14.12 |

Source: Authors.

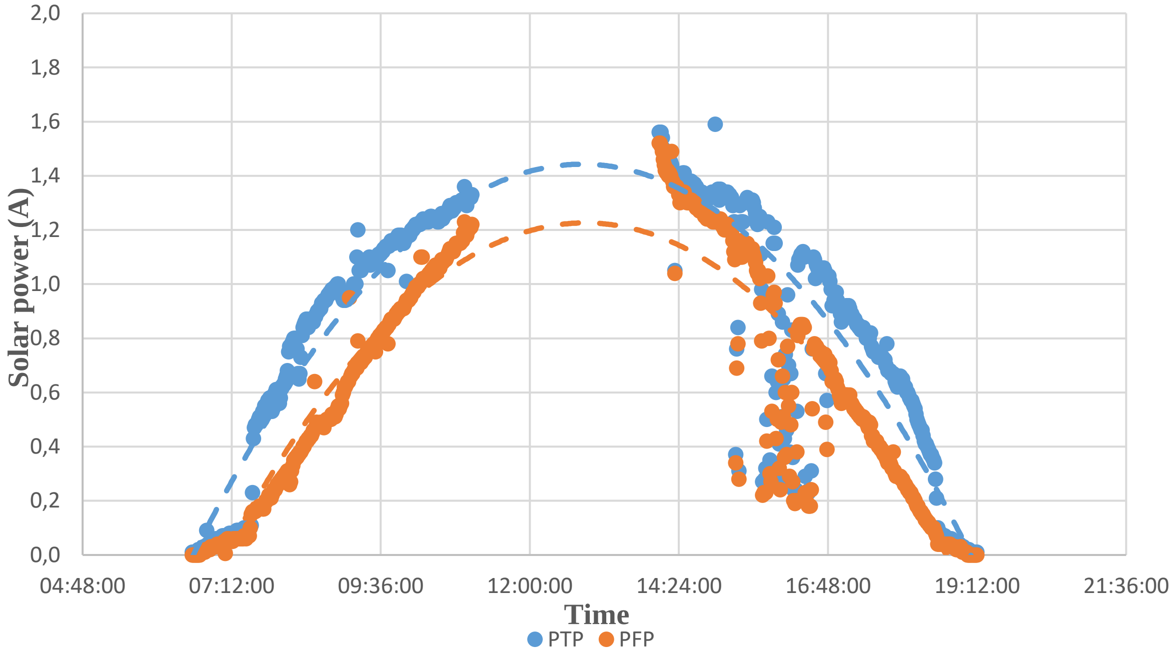
**Table 2.** Data summary of the t-test comparing the fixed photovoltaic panel (PFP) and the tracker panel (PTP) using 95% of confidence.

| | PFP | PTP | Total |
|---|---|---|---|
| n (number of sample) | 7,410 | 7,712 | 15,122 |
| $\sum X$ | 7.13 | 6.23 | 13.36 |
| $\sum X^2$ | 5.33 | 3.99 | 9.33 |
| SS (sum of the squared deviations) | 0.71 | 0.47 | 1.22 |
| Mean | 0.65 | 0.57 | 0.61 |

Source: Authors.

The commissioning of the photovoltaic panels was done on the bright days, with the rain index was near to zero. Figure 3 shows the performance of both tested photovoltaic panels (PFP and PTP). On bright days, the tracker photovoltaic panel showed 26% more gain in electrical energy from tracking the sun than the fixed panel. Such a scenario was found on days in two Southern hemisphere spring months when the solar declination was not at its full (−8.72 in mid-October, and −18.37 in mid-December).

**Figure 3.** Mean values of power of the fixed photovoltaic panel and the photovoltaic tracker panel on bright days, from 6h:34min until 19h:10min (mean number of recorded samples/days=578). (Solar power PFP= $-20.93(\text{time})^2 + 21914(\text{time}) - 6E^{06}$; R² = 0.851); (Solar power PTP = $-21.22(\text{time})^2 + 22221(\text{time}) - 6E^{06}$; R² = 0.812).



Source: Authors.

## 4. Discussion

When the rain index was below 2 mm/ accumulated day, the bright days showed a prevalence of 26% of more energy in the sun-tracking panel. With high cloudiness and rain, the advantage of the tracking photovoltaic panel is not fully optimized, and the results of solar energy were similar (p>0.05). Similar results were found by Sharaf Eldin et al. (2016) when comparing the performance of a photovoltaic panel as a function of tracking the sun and the operating conditions. The authors indicate that the gain in electrical energy from tracking the sun is higher in cold countries than in hot countries. Since solar power technology is highly dependent on regional environmental characteristics (Kannan & Vakeesan, 2016), the extra energy expenditure in the tracking device might be taken into consideration when dimensioning the solar energy application.

On the other hand, Carvalho et al. (2013) tested photovoltaic tracking panels near the summer solstice in southeastern Brazil and found an increase in total energy generation near 53% in the tracking panels compared to the fixed panels, nearly twice as much than the findings of the present study. Serhan & El-Chaar (2010), Bentaher et al., 2014, and Lazaroiu et al. (2015) indicate the use of a tracker system since sun-tracking evidenced a significant growth of power production in both morning and evening. Kelly & Gibson (2009) found that a horizontal module orientation increases solar energy capture by nearly 50% in cloudy periods when compared to a two-axis solar tracking during the same period. When studying different tracking systems and under a range of environmental conditions, Koussa et al. (2011) found that in a clear day, the highest obtained energy is that related to the two-axis sun-tracking system, and in the cloudy days, the efficiency of the tracker systems rely on the clearness index. For a completely cloudy day, the authors indicate that the studied systems produced almost the same electrical energy while the horizontal photovoltaic panel presented the best performance. Such results are quite like those of the present study.

In tropical countries, during the rainy season, showers increase and might lead to the deposit of leaves and soil on the panels carried by the wind. Maghami et al. (2016), studying the decrease in efficiency of soiled photovoltaic panels, found that the amount of accumulated dust on the surface of the panels affects the overall energy collected on a daily, monthly, seasonal, and annual basis. Therefore, although the use of photovoltaic panels is a critical issue in future energy investments (Sampaio & Aguirre González, 2017; Kabir et al., 2018), the use of the tracking device might not be economically viable in tropical countries with high rainfall index. In the present study, in several days, we had to clean up the panels since leaves were deposited on them after the rain, brought by the wind.

Even though the solar industry has many barriers in the technological development, many forms of research are being carried out to remove the barriers to the suitable limit for better efficiency (Panwar et al., 2011; Kannan & Vakeesan, 2016). The results of the current study showed that the potential of the use of trackers associated with photovoltaic panels should be focused on the economic aspect of the investment. In tropical regions with high rain index or cloudiness, the tracking system might not be as efficient as foreseen (Rambhowan & Oree, 2014). More in-depth studies with much more extended duration are necessary in order to be further specific in recommending the proper panels to be used in rural areas of tropical countries.

## 5. Conclusion

Although the results of the daily average solar power did not differ on the tested tracking systems, on bright days, the proposed tracker photovoltaic panel indicated 26% more gain in electrical energy from tracking the sun than the fixed panel, indicating the benefit of using the tracking device.

The use of a photovoltaic panel can be a sustainable solution for regions without access to electricity in rural areas. However, its design and the possibility of a sun-tracking engine to capture more solar radiation is significantly associated with the characteristics of the region. In tropical areas, with a high rain index and a high number of cloudy days with little or no direct sunshine the use of the two-axis tracking device might not be as beneficial as expected.

For a future study we suggest that the tests should be carried out over a period of one full year, to close an evaluation cycle, in this case the solar radiation, even with the presence of rain.

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## Percentage of the contribution of each author in the manuscript

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