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Monthly profile analysis based on a two-axis solar tracker proposal for photovoltaic panels

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ABSTRACT

The concerns due to pollution and depletion of traditional energy sources and increasing consumption motivates the use of renewable energies. Photovoltaic energy presents advantages like low cost for maintenance, installation in remote locations, besides not generating environment impacts during operation. However, the cost of photovoltaic energy sources is greater than traditional ones due to, among other reasons, irradiation losses. The objective of this work is the development of a two-axis solar tracker and performance evaluation of a solar panel, compared to a fixed system. The tracker uses LDRs to identify sun movement direction and engines adjust the panel position, according to the control performed by an electronic device. Each system is composed by a mechanical structure, a solar panel and a resistive load. The electronic device, besides engines controlling, performs the measurement and storage of luminosity and irradiation information over the panel. The evaluation of the two systems occurred for 152 days, between 2016's June and November, in southern Brazil. The panel with tracking system presented average monthly gains varying from 17,20% and 31,1%, indicating that this is an alternative to make photovoltaic energy more attractive.

1. Introduction

Energy has been essential for the development of society over time. The increase of energy consumption since the industrial revolution has led to concerns associated with environmental impacts and resource depletion, particularly because most of the energy originates from fossil fuels such as oil and coal. Fossil fuel depletion and global warming are the two most important concerns for the sustainability of energy systems in the future [1]. Energy dependence, the limitation of fossil energy sources, and the negative environmental impacts of fossil fuels have directed researchers towards renewable energy sources [2]. The efforts to reduce the use of fossil fuels and greenhouse gases emissions, related to electricity generation, have been leading to a fast increase in the development of renewable generation [3].

Nevertheless, the renewable energies account for only 13.20% of the worldwide energy consumption in 2012 [4]. Photovoltaic (PV) energy is an alternative energy source for the future due to the world's limited energy resources [5]. Photovoltaic technologies have been highlighted as an ideal source of energy due to its non-pollution performance in the way it produces electricity by harvesting the energy available from the sun, which is free source of energy, once the facility of has been built [6]. Among the renewable energies, photovoltaic energy has drawn considerable attention for being a renewable, inexhaustible, and nonpolluting source [7]. This energy has positive advantages when compared to hydraulic energy, which is also renewable but criticized in terms of its social and environmental impacts caused by the flooding of lands [8]. However, photovoltaic energy is more expensive than the traditional sources [9] and considerably expensive than hydraulic [8]. Moreover, the photovoltaic panels are typically mounted on fixed holders, i.e., they do not follow the variation of the solar position, resulting in less efficient systems [8]. Therefore, enhancing this energy to be more competitive is an important step to increase its participation in the energy matrices.

A photovoltaic panel receives maximum solar radiation when it is perpendicular to the rays of sunlight, which is a factor of direct relation to the yield of system [10]. As the solar position varies during the day, the solar tracker is considered to be one of the main approaches to increase the energy generation efficiency [11,12]. A

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promising solution to cope with these problems is the use a solar concentrator in conjugation with a solar tracker [13]. The tracking mechanism is expensive because it requires high cost for installation and maintenance of the generation system. Moreover, it consumes energy, which requires the evaluation of the viability of its use [14]. The trackers can be passive, when the panel moves owing to the difference of fluid density, or active, when motors position the panel. The most common active trackers are as follows [11]:

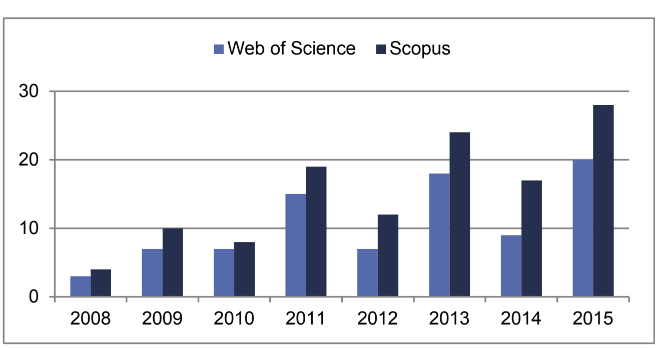
- Trackers based on optical sensors and microprocessor: the trackers have at least two optical sensors with an angle difference. When there is a difference in the received light, the motor is activated using a microprocessor until both of them receive the same light intensity and are electrically balanced, indicating a position perpendicular to the rays of sunlight.
- Trackers based on date and time: a computer calculates the solar position based on date and time, and it controls the motors for achieving the desired position.

In terms of worldwide research in photovoltaic based energy generation, it is possible to observe in last few years (Graph 1) an increase in the number of publications on solar tracking systems, particularly in Asian countries and in the United States. Some of the mechanisms described in publications of journals and congresses are presented in this study [15,16].

The authors in Ref. [10] compared the yield of a system with fixed photovoltaic panel and another panel, which is equipped with single-axis solar tracker. In this study, the systems were evaluated in clear sky days during the summer of the year 2000, from 5:00 to 19:30. The system used two light sensors separated by a barrier, which generates shadow according to its position. The mechanism consisted in the pursuit of balance in the reading of the light sensors. The authors observed that the average increase was higher than 20% when the system was used with the tracker.

A similar study performed in Ref. [9] considered the consumption of the motion mechanism. The tracker panel was positioned on the basis of the measurements of two sensors. The fixed and mobile systems operated simultaneously for 30 days, in 2014, with a data acquisition system recording the data every 15 min, from 8:00 to 19:00. The authors classified the climate conditions as clear sky (15 days), partly cloudy (9 days), and cloudy (6 days). The daily average registered a 12–20% increase in the yield.

The authors in Ref. [8] developed a dual-axis tracker and compared it with a fixed system. The sensor technique was similar to that presented by Ref. [10], however, with three light sensors. Some aspects defined in the algorithm were the correction of the position through the shortest path, the return to vertical and hibernation during the night, and the use of one motor at a time. The experiment was performed on November 18, 19, and 20 and on December 11, 12, and 21 of 2010 in the city of Viçosa, MG, Brazil. Two days had clear skies, two days had cloudy skies, and the other two had clear skies during most of the day, with summer rain. Subtracting the energy consumed by the mechanism, the energy increase ranged from 34% to 56%.



Source: [15][16].

Graph 1. Evolution of the number of studies and reviews on solar tracking systems in the Web of Science and Scopus databases since 2008. Searched terms: Title: ((*solar* or *sun*) and *track**) AND Topic: (*photovoltaic* not MPP* not "*Maximum Power Point Tracking*").

The dual-axis tracking system, developed by Ref. [17], also applies the photosensor balance technique for tracking the solar position. Two are used for the north/south motion, and another two are used for the east/west motion. At the end of the day, the panel is stationary, facing west, and this blocks the photosensors from receiving light in the next morning. To enable the return of the panel to the origin, two east-facing photosensors were added to the fixed structure. The yield increase of the fixed panel ranged from 20% to 28% according to the climatic conditions.

A single-axis tracker was developed in Ref. [12]. The primary axis covers the variation of solar inclination from one day to the other, while the secondary axis, which is perpendicular to the primary, follows the solar motion during the day. In this project, the use of the sensor was dismissed, provided that the axis was fixed for constant rotation of 15°/h. The tests were performed on July 17 and September 12, in the city of Weihai, Shenzhen, China. The data were collected every 10 min, from 8:00 to 19:00. The average increase in power was 31.80%.

Table 1 presents the main points of the related studies. It is possible to note the maximum period of test adopted, varying from 3 days to one season. This work discusses the development and performance of a dual-axis solar tracker, considering its monthly behavior profile along 152 days, comprising winter and spring seasons of southern Brazil. Also, in contrast to the cited references, this work evaluates the movement cost of the PV system, according to the energy generated in periods of reduced irradiation, typically found in winter season. The PV system embedded algorithm considers the minimum luminosity conditions and has the purpose of rationing the motors, by saving energy. In addition to the tracker, an holder was constructed for the fixed panel, which served as a reference. The two sets were compared for six months, including the winter and spring months, to identify the difference in the results of the average irradiation.

To study the alternatives for the enhancement of the photovoltaic energy yield, this paper presents the development of a dual-axis solar tracker. The main contributions of this work are: (i) the conceptual design of the solar tracker, characterized by its movement based on two independent perpendicular axis and (ii) the activation embedded algorithm for the solar tracker engines, with optimizes the movement during the solar tracking process. During a period of 152 days, from June to November 2016, irradiation data were collected about the tracking panel and one fixed panel, which was used as reference. The aim is to obtain the difference between the yields of the systems, considering the consumption of the tracking mechanism.

2. Methodological procedures and application of a proposed solar tracker

2.1. Electronic panel

The electronic panel was developed for reading the signals of the sensors, storing and processing the information, and controlling the movement of the motors. The panel is fed by an external source connected to the electrical grid; therefore, it is independent