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Design of two axes sun tracking controller with analytically solar radiation calculations

Saban Yilmaz [a,*], Hasan Riza Ozcalik [b], Osman Dogmus [a], Furkan Dincer [c], Oguzhan Akgol [d], Muharrem Karaaslan [d]

[a] Kahramanmaras Sutcu Imam University, Vocational School of Kahramanmaras, 46000 Kahramanmaras, Turkey
[b] Kahramanmaras Sutcu Imam University, Department of Electrical and Electronics Engineering, 46000 Kahramanmaras, Turkey
[c] Mustafa Kemal University, Department of Computer Engineering, 31200 Hatay, Turkey
[d] Mustafa Kemal University, Department of Electrical and Electronics Engineering, 31200 Hatay, Turkey

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ABSTRACT

Photovoltaic systems have gained a great deal of interest in the world and these studies performed on this subject have been gaining more and more importance. In order to design new PV systems that will be installed to operate in more efficient and more feasible way, it is necessary to analyze parameters like solar radiation values, the angle of incidence of the genus, temperature etc. Therefore, in this study, theoretical works have been performed for solar radiation and angle of incidence values of any location, plus an experimental study was carried out on a system tracking the sun in two axes and in a fixed system. The performed prototype is also adapted into a PV system with 4.6 kW power. Theoretical data are consistent with the data obtained from the PV system with 4.6 kW power. This study will be an important guide for the future PV power stations.

Contents

1. Introduction

The increasing needs of the energy can be supplied by solar energy. Besides, solar energy also provides environmental protection and sustainability. The superiority of the solar energy is mentioned by many researches. Solar energy can be transformed into electricity and heat by many ways for industrial or commercial applications such as photovoltaic (PV) panels [1–7]. Energy generated from PV panels is related with temperature, irradiance and incident angle of the solar radiation and so on. The efficiency of a PV panel can easily be increased by sun tracking systems which are investigated by many researches [8,9].

One way of sun tracking is flat PV system. Two axis tracking PV theoretically propose 41% energy entrance improvement in a mid-latitude region with respect to the fixed PV panel. Besides, the improvement for a one-axis tracking system is 36%. Captured solar energy by sun tracking system is related with region and meteorological conditions [10].

Many times, the improvement of a solar system is achieved using tracking controller structures by increasing the collected solar energy ratio. The tracking systems include microprocessors or other control mechanisms to determine the best position.

* Corresponding author. Tel.: +90 344 280 25 05.
E-mail address: sabanyilmaz@ksu.edu.tr (S. Yilmaz).

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Nomenclature

γ_s	azimuthal angle
ϕ	latitude
β	surface slope from the horizontal
δ	declination, radian
θ_z	zenith angle and the sun's position relative to the north–south axis,
ω_r	sunrise hour angle
ω_s	sunset hour angle
f	extraterrestrial solar radiation
R_b	ratio of average daily beam radiation incident on an inclined surface to that on a horizontal surface
H	daily global radiation incident on a horizontal surface
H_b	daily beam radiation incident on an inclined surface
H_T	daily global radiation on a tilted surface
$H_{d,p}$	daily ground reflected radiation incident on an inclined surface
H_{gr}	daily sky-diffuse radiation incident on an inclined surface
n	nth day of the year
k_y	ground albedo

The widespread samples of tracking systems are dual and single axis tracking [10] which cannot exactly determine the best position for efficient collection of the solar energy. Two-axis tracking systems need two motors to follow the sun in the azimuth and tilt angles. Although they are more expensive, they propose better performance with respect to the single-axis systems even in the morning and evening [11,12].

The generated power is directly proportional with the collected solar radiation in a solar system. Maximum sun power collection is possible by adjusting solar system position with respect to the sun's location. This adjustment can be realized more easily with two axes sun tracking systems than single ones which is cheaper and simpler to design. Beside this, using two axes sun tracking system is inevitable in some solar system and it can be adapted to all solar systems to improve collection of solar radiation [13]. The tracking systems include closed and open loop control mechanisms. The PV panels are positioned by the help of photo sensors and feedback controllers. The disadvantage of the closed loop system is that the system spends more energy than the generated one in the case of quick weather changes. The open loop one is based on calculations of the seasonal weather and the sun position. The hybrid control is made up of both closed and open loop tracking systems [12].

A sun tracking system with microprocessors does not need sensors since it estimates the best location via the written algorithm. It moves to the best location by step motors or optical encoders. The systems with microcontrollers can be used to direct arrays of sun tracking systems [14]. The self-calibration of the microprocessor controlled trackers is possible by electro-optic sensors [15] or a search routine without a sensor [16]. Although the microprocessor based trackers provide good sun light collection, it is hard to realize the detailed installation conditions.

The performance of the electro-optical tracking systems such as sun sensor composed of four photo resistors with cylindrical shades is better depending on good weather conditions [17]. This system is controlled by differential amplifiers, comparators and output components. Another electro-optical system with fixed and moving sensors is suggested better accuracy and reliability [18].

Moreover, there are many studies on sun tracking systems in literature such as Rustemli et al. [19], Abu-Khader et al. [20], Abdallah and Nijmeh [21], Kivrak et al. [22], Kivrak [23]. However, unlike the other studies, this paper presents a control strategy for a two axes sun tracker system executed in a microprocessor. In addition, solar radiation calculations are theoretically realized and used to obtain more electrical energy with the proposed sun tracking system that controls PV panel in two axes. As is known, generated electrical energy is directly related with incident solar radiation. Therefore, optimum angle has crucial importance. The most proper position can be determined from the generated electrical energy from the line. The control strategy we have used in the paper includes a dynamic controller and it can be divided into two sections, open loop and closed loop tracking strategies. Former one includes the microprocessor controller while the latter one corresponds to the electro-optical controller section [24–26].

Moreover, there are some studies on solar energy resources in literature. However, in Turkey, these studies started to get researchers' attentions recently and the studies performed on PV systems are even quite recent. Our study mainly focuses on the analysis of PV systems in climate conditions of Gaziantep, which is its main contribution. While the other studies which have been conducted so far depend on outsourcing, this study was carried out by using only domestic sources. In addition, this study also provides information about the differences between fixed systems and double-axis sun tracking systems. The procedure to find optimum solar radiation angle include some calculations. Moreover, the performed and realized application is compared with the other studies in the literature.

2. Solar irradiance incident with a tilted surface for solar radiation calculations

The measurements will be made for a geographical point which is established for the position of the sun. There are two important angles for solar radiation which are the altitude and the azimuth angles [27]. There are many models developed recently to calculate solar irradiance incident to a tilted surface from a known direct (normal) and a diffuse (horizontal) solar irradiance. Main difference between them is in the concept of whether or not the diffuse solar irradiance is isotropically distributed over the sky [28]. Zenith, azimuthal, and hour angles for solar radiation calculations are shown in Fig. 1.

Variation of solar radiation values depending on the day, month and the season mandates the calculation of the angle of solar radiation values. As known, electrical energy produced by a PV panel is directly proportional with the solar radiation amount it is exposed. In order to make maximum use of solar radiation, it is also required to know the angle of solar radiation very well. Commonly used terms are as follows:

Elevation angle (α_s): It is the angle between the solar radiation and the horizon. According to the definition; $\alpha_s = 90 - \theta_z$.
Solar azimuth angle (γ_s): It is the angle showing the tilt of sun's rays to the north in the clockwise direction.
Surface azimuth angle (γ): It is the angle showing the deviation of the vertical surface to the local longitude. $\gamma = 0^\circ$ for the surfaces facing south. It takes positive values for the surface facing to the east. It has negative values for the westward surface.
Declination angle (δ): It is the angle between equatorial plane and sun's rays at 12 o'clock.
Incidence angle (θ): Angle between the normal of the surface and the sun's rays.