Solar Energy 137 (2016) 201–211

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

A novel prediction algorithm for solar angles using second derivative of the energy for photovoltaic sun tracking purposes

Sebastijan Seme [a,*], Bojan Štumberger [a,b], Miralem Hadžiselimović [a,b]

[a] University of Maribor, Faculty of Energy Technology, Hočevarjev trg 1, SI-8270 Krško, Slovenia
[b] University of Maribor, Faculty of Electrical Engineering and Computer Science, Smetanova ulica 17, SI-2000 Maribor, Slovenia

ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form 27 July 2016
Accepted 2 August 2016

Keywords:
Control model
Sun tracking system
Photovoltaic system
Optimal orientation and tilt
Energy production

ABSTRACT

This work deals with a new analytical control model of single axis and dual axis tracking systems. A new analytical control model of tracking is defined by the second derivative of the energy production of photovoltaic systems. The aim is to maximize energy production of photovoltaic tracking system in a simple analytical way. The method used to determine the tilt and orientation of the modules of the sun tracking system is presented analytically by the second derivative of the energy produced. To evaluate the new analytical control model, the calculation of solar radiation on moving surface is presented. The calculation of the energy produced by a photovoltaic system takes into account the efficiency of solar modules, the efficiency of inverters and area of modules. The results presented in this work show that the new analytical control model increases the yield of energy production of photovoltaic tracking systems. The calculated results are also compared with the measured results from existent photovoltaic systems. These results are important for the future research in control of the sun tracking systems.

1. Introduction

In the last decade, the demand for energy production from renewable sources has increased sharply. In the foreground of renewable sources are in particular photovoltaic (PV) systems, which can be classified according to different criteria. According to the connection they can be classified as stand-alone or grid-connected. Depending on the installed power they can be classified as micro (less than 50 kW), small (less than 1 MW), medium (from 1 MW up to 10 MW) and large (over 10 MW up to 125 MW). Depending on the installation they can be classified as on buildings, integrated and self-standing structures. All PV systems can be either fixed or tracking. In the production of electricity from PV systems the tilt and orientation are the most important parameters, which are already presented in Khoo et al. (2014), Siraki and Pillay (2012), Bakirci (2012), and Mehleri et al. (2010). There is no doubt that the yield of energy production from PV systems can be increased by the sun tracking systems (Huld et al., 2010; Chong and Wong, 2009; Beg et al., 2008; Sarker et al., 2010; Guo et al., 2010). Maximum yield of energy production from PV systems is achieved if the angle between the surface of solar modules and the sunbeams is constantly 90°.

The sun tracking system is a movable mechanical structure for the installation of solar modules, which consists of a mechanical, electrical and information technologies. The sun tracking systems are divided according to the receipt of energy of the sun: the sun tracking systems without concentrators (conventional sun tracking systems) and the sun tracking systems with concentrators. Conventional sun tracking systems, which are most interesting for us, receive energy of the sun directly on solar modules. "The sun tracking systems can be further categorized by the number and orientation of their axes, their actuation architecture and drive type, their intended applications, and their vertical supports and foundation type (Solar Photovoltaic Energy Systems, 2014)". Thus exist single axis tracking systems (Huld et al., 2010; Chong and Wong, 2009; Beg et al., 2008) and dual axis tracking systems (Sarker et al., 2010; Guo et al., 2010). Single axis tracking systems have one degree of freedom that acts as an axis of rotation, mostly from east to west, as shown in Fig. 1a. "Dual axis tracking systems have two degrees of freedom that act as axes of rotation, as shown in Fig. 1b. These axes are typically normal to one another. The axis that is fixed on the ground can be considered the primary axis. The axis that is referenced to the primary axis can be considered the secondary axis (Solar Photovoltaic Energy Systems, 2014)".

Fig. 1a shows several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT), vertical single axis trackers (VSAT), and tilted single axis trackers

* Corresponding author.
E-mail address: sebastijan.seme@um.si (S. Seme).

http://dx.doi.org/10.1016/j.solener.2016.08.001
0038-092X/

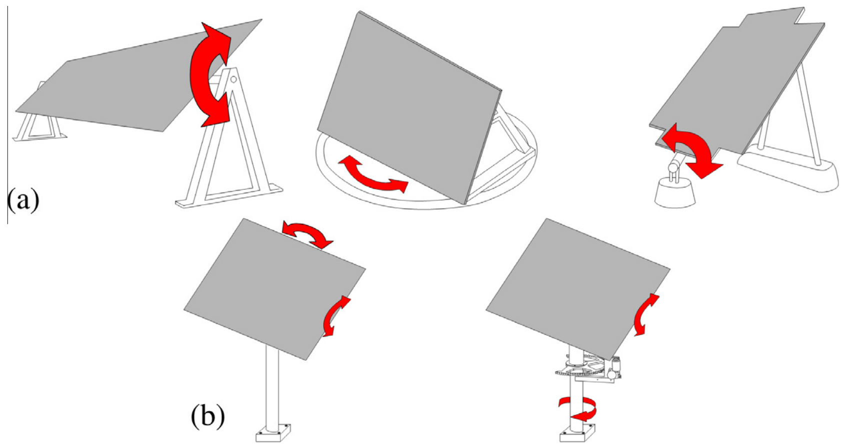

Fig. 1. Solar tracker: (a) single axis and (b) dual axis.

(TSAT). Fig. 1b shows several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are tip-tilt trackers (TTDAT) and azimuth-altitude trackers (AADAT). Adapted from IEC 62817 - photovoltaic systems - Design qualification of solar trackers (Solar Photovoltaic Energy Systems, 2014). In the paper VSAT in AADAT are discussed. There are also other systems for dual axis tracking, such as equatorial and pseudo-equatorial, which are described in detail in Alexandru (2013).

The electric drive is commonly used to create rotational motion for single axis or dual axis tracking system. There exist three types of tracker control: passive control, active control and backtracking. "Active control uses supplied power to drive circuitry and actuators (motors, hydraulics, and others) to position the payload (Solar Photovoltaic Energy Systems, 2014)". There exist two kinds of active control: closed loop control (Karimov et al., 2005) and open loop control (Khatib et al., 2009). The closed loop control uses one or more photo sensors and feedback controllers to position the payload. Open loop control uses a mathematical algorithm that is loaded in the controller and is responsible for controlling the position of the payload. The hybrid control includes the open loop control and closed loop control. Dual axis tracking system with hybrid control is described in Rubio et al. (2007).

The authors in Abdallah and Badran (2008) present their solution for sun tracking system, while the authors in Kacira et al. (2004) deal with the optimal altitude and azimuth for fixed photovoltaic systems. The results presented in Abdallah and Badran (2008) and Kacira et al. (2004) show that the PV tracking system produces up to 30% more energy than the fixed PV system. However, in these cases, the authors do not describe the types of tracker control.

In order to provide the reader with a complete overview of the topic we reviewed many papers, which describe photovoltaic tracking systems and maximization of energy production. Authors in Mi et al. (2016) use the open loop control system with variable tracking frequency for tracking accuracy. As a result, it effectively decreases the moving frequency of the tracking system, which saves the required external energy to drive of the tracking system and improves its reliability. The authors in Yao et al. (2014), on the other hand, deal with a multipurpose dual-axis solar tracker that can be applied to solar power systems. Normal tracking strategy and daily adjustment strategy are developed in this paper. Paper (Katalinic et al., 2014) is about a solar-tracking method for control of photovoltaic panels where tri-positional control strategy is used. Paper (Barker et al., 2013) proposes a low-profile dual axis solar tracker. The proposed tracker is inherently accurate and sturdy due to its large base and unique linkage geometry.

The authors in Chong and Wong (2009) and Guo et al. (2010) present optimal tracking of azimuth sun tracking system. The aim of authors is to maximize the energy production by azimuth sun tracking system with minimum number of moves. Optimization is defined for one day, by comparing the characteristics obtained by different number of moves. The results should give the answer to the question on when and for how many degrees the azimuth should be changed to produce the maximum of energy by a PV system.

The authors in Alexandru and Pozna (2010) deal with the planning and optimization of the sun tracking systems. In this way, they use dynamic (multi-body) models of tracking systems along with dynamic models of electric drives, which are otherwise called virtual models or virtual prototypes. They use already known models for calculation of the solar radiation. Mentioned tools are used for planning and continuous controlling of single axis tracking systems. Optimization is implemented in order to achieve the maximum energy produced in the time interval of a few days, depending on the initial and final position of the tracking system, as well as the return to the starting position. The authors show the energy production of a PV system and the energy consumption by electric drive of the sun tracking system. The authors (Seme and Štumberger, 2011) use the stochastic optimization method called Differential Evolution (DE) to optimize the trajectory of the sun tracking system.

The aim of the new analytical control model is to maximize energy production of a PV tracking system in a simple manner. The essential difference between the model presented in Seme and Štumberger (2011) and the proposed one is that in this case we do not need to know the energy consumption in the tracking system. In the presented simple model, which is based on the second derivative of the energy produced, the energy consumption tracker is deducted at any time from the production and thus affects the second derivative of energy. Stochastic optimization method called Differential Evolution presented in Seme and Štumberger (2011) requires a prediction of electricity production. In the proposed case, current energy production is monitored and the change in position of the tracking system is determined on the basis of the second derivative. The proposed method provides a new approach to the search for maximum energy production of PV tracking systems.

In reviewing the literature, the use of second derivative of the energy produced to optimize the trajectory of the sun tracking system was not detected. This paper proposes a new method for