Energy Conversion and Management 149 (2017) 543–552

Contents lists available at ScienceDirect

Energy Conversion and Management

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

A novel algorithm for single-axis maximum power generation sun trackers

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ARTICLE INFO

Keywords:
PV system
Electric energy production
Direct-search method
1A-3P
1A-MPG

ABSTRACT

The purpose of this study is to develop a novel algorithm for a single-axis maximum power generation sun tracker in order to identify the optimal stopping angle for generating the maximum amount of daily electric energy. First, the photovoltaic modules of the single-axis maximum power generation sun tracker are automatically rotated from 50° east to 50° west. During the rotation, the instantaneous power generated at different angles is recorded and compared, meaning that the optimal angle for generating the maximum power can be determined. Once the rotation (detection) is completed, the photovoltaic modules are then rotated to the resulting angle for generating the maximum power. The photovoltaic module is rotated once per hour in an attempt to detect the maximum irradiation and overcome the impact of environmental effects such as shading from cloud cover, other photovoltaic modules and surrounding buildings. Furthermore, the detection range is halved so as to reduce the energy consumption from the rotation operations and to improve the reliability of the sun tracker. The results indicate that electric energy production is increased by 3.4% in spring and autumn, 5.4% in summer, and 8.3% in winter, compared with that of the same sun tracker with three fixed angles of 50° east in the morning, 0° at noon and 50° west in the afternoon.

1. Introduction

It is well known that a photovoltaic (PV) system can convert solar energy into electric energy by using PV modules. However, the major disadvantage of the PV system is the low efficiency, which is strongly dependent on the azimuth and tilt angles of the PV modules [1]. Both azimuth and tilt angles are mainly varied with geographic latitude, climate, and the atmospheric composition [2]. Therefore, the azimuth and tilt angles can be optimized by the methods of the fixed tilt angles, single-axis trackers and dual-axis trackers [3]. Because the tilt angle needs to be optimized to obtain higher power output at different latitudes, there are many techniques developed to determine the optimum tilt angles for different latitudes and surface azimuth angles around the world. For example, Soulayman and Hammoud presented a modified general algorithm to optimize the tilt angle for mid-latitude zone [4]. Stanci and Stanci proposed an equation to optimize the tilt angle at latitudes from 0° to 80° [5]. Benghanem proposed a method to calculate the optimum tilt angle in Madinah, Saudi Arabia [6]. The results indicated that the collected energy by using the yearly average fixed angle which is nearly corresponding to the latitude of Madinah site is around 8% lower than that by using the optimum tilt angles for each month [6]. Yan et al. determined the optimum tilt angle and orientation in Brisbane, Australia [1]. Gong reported that the yearly energy output at optimum tilt angle of 30° is 2% higher than that of the current angle of 42° in Carbondale, Illinois [7]. Kacira determined that the amount of solar radiation throughout a year by using monthly optimum tilt angles between 13° and 61° is 1.1% and 3.9% higher than those by using seasonal optimum tilt angles and the fixed tilt angle equal to the latitude of Sanliurfa, Turkey, respectively [8]. Chang demonstrated that the yearly conversion efficiency of a fixed module in Taipei, Taiwan is 10.2%, 9.2% and 8.3% for the extraterrestrial, predicted and observed radiation, respectively [2]; the irradiation ratio of the single-axis sun tracker to the fixed PV module is about 1.5 for latitudes below 65° [9]. Miguel determined that the optimum tilt angles for Burgos, Spain are between 7° and 80°, 7° in June, 70° in January and 80° in December [10]. However, the fixed PV system has relatively lower efficiency. In order to increase the power output, a sun-tracking system which can orient the PV modules facing the sun is developed to receive the maximum irradiation and then generate the maximum power output. The sun-tracking system can be classified into a single-axis sun tracker and a dual-axis sun tracker. The single-axis sun tracker only tracks the sun in one direction, from east to west, which is azimuth direction. Consequently, the tilt angle with respect to the horizontal is constant and optimized for the local latitude. The dual-axis sun tracker can track the

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http://dx.doi.org/10.1016/j.enconman.2017.07.041
Received 11 April 2017; Received in revised form 15 July 2017; Accepted 20 July 2017

Nomenclature

1A-3P	one-axis three positions
1A-MPG	one-axis maximum power generation
BIPV	building-integrated photovoltaic
H_T	daily-total solar irradiation (MJ/am^2 day)
I_A	instantaneous current of PV module (A)
Impp	maximum power current (A)
Isc	short circuit current (A)
MPP	maximum power point
MPPT	maximum power point tracking
NOCT	nominal operating cell temperature (°C)
nMPPO	near maximum power point operation
Pmax	maximum power (Wp)
PV	photovoltaic
P&O	perturb & observe method for MPPT
Vmpp	maximum power voltage (V)
Voc	open circuit voltage (V)

sun in azimuth and south-north (altitude) directions, which ensures the PV modules precisely follow the motions of the sun. The control algorithm of the sun tracking system can be classified into an open-loop strategy and a closed-loop strategy [3]. Chang demonstrated that yearly gains of a single-axis sun tracker with the yearly optimal tilt angle from the extraterrestrial, predicted and observed radiation are 51.4%, 28.5% and 18.7%, respectively [2]. Lazaroiu et al. presented that a single-axis sun tracker using a closed-loop operation and two photo sensors increases 12–20% of the produced energy [11]. Lubitz presented that a single-axis sun tracker and a dual-axis sun tracker increase annual solar irradiation incident by an average of 29% and 34% relative to the fixed tilt angle, respectively [12]. Fathabadi reported that the sensorless closed-loop dual-axis tracker increases the energy efficiency by 28.8–43.6%, depending on the seasons [13]. Quesada et al. developed the tracking strategy for dual-axis sun trackers in Montreal, Canada and in other high latitudes [14]. Sinha and Chandel demonstrated that a two-axis sun tracker generates 4.88–26.29% more energy per year than the fixed PV system [15]. Bahrami et al. reported the effect of latitude on the performance of different sun trackers, including dual-axis, East-West (EW), North-South (NS), Inclined East-West (IEW), and Vertical-axis (V) trackers. The results indicated that the performance of the IEW tracker is close to that of the dual-axis tracker and better than those of other single-axis trackers [16]. In addition, Bahrami et al. analyzed the energy gain of the various sun trackers in 21 low latitude countries and then reported that the ranking for the efficiency of the dual-axis, inclined east–west tracker at its yearly optimal angle (IEWO), and inclined east–west tracker at the yearly optimal angle of a fixed south-facing panel (IEW) sun trackers, from high to low, is the dual-axis, IEWO and IEW trackers [17].

Though the efficiency of the dual-axis sun tracker is higher than those of the single-axis sun tracker and the fixed PV system [13], the design of a dual-axis sun tracker is more complex [14]. In addition, the dual-axis sun tracker is more expensive and has higher energy consumption [18]. Therefore, Skouri et al. proposed a relatively simple and cheap two-axis sun tracker [19]. Despotovic and Nedic proposed that PV modules with yearly, seasonal and monthly optimum tilt angles increase annual energy by 5.98%, 13.55% and 15.42% respectively, compared with the PV modules on the roof with the fixed angles [20].

In an attempt to solve the issue related to low power output, Huang et al. developed a one-axis three-position sun tracker (1A-3P) [21], which is a type of building-integrated photovoltaic system (BIPV) that can be architecturally integrated into the design of a building to enhance the technology, efficiency and visual effects on the appearance of the building [22]. Lu reported that the annual energy output generated by the roof-mounted BIPV system with the optimal tilt angle of 30° in Hong Kong is higher than those generated by the same BIPV system with the tilt angles of 22.5° and 90°, respectively [23].

The algorithm for the 1A-3P sun tracker is to rotate the PV modules at three fixed positions: 50° east in the morning, 0° at noon, and 50° west in the afternoon, regardless of the level of electric energy generated by the PV modules. The 1A-3P sun tracker with low concentration ratio reflector increases the total PV power generation by 56%, compared with the fixed PV modules; 24.5% of the PV power generation is contributed by the 1A-3P tracking algorithm and about 23% of the PV power generation is contributed by the low concentration (2X) reflectors [21]. Consequently, Huang et al. reported that the 1A-3P tracking PV module increases electricity by 35.8%, compared with the fixed PV module in a partly-cloudy weather with daily-total solar irradiation H_T = 11.7 MJ/m^2 day, or 35.6% in clear weather with daily-total solar irradiation of 18.5 MJ/m^2 day [24]. Furthermore, the results indicated that the energy generation of the single day can be increased by 39% in clear days [25]; the overall energy generation is increased by 24.2% in Taipei, Taiwan [25]; the overall energy generation is increased by 37.5% in high solar radiation areas with yearly-average solar irradiation greater than 17 MJ/m^2 day [24]. In addition, the control algorithm of 1A-3P sun tracker is similar to that of the IEW sun tracker and the performance of the 1A-3P sun tracker is close to that of the dual-axis sun tracker [17]. It indicates that a series of 1A-3P sun tracker research is very important to the research of the single-axis sun tracker. However, the efficiency of the 1A-3P sun tracker installed in an urban area is affected by the location of the sun, irradiation, and shadows from surrounding buildings and cloud cover since the PV modules are fixed at three different angles.

Therefore, this present study is in an advanced stage in the research of the 1A-3P sun tracker. The goal of this study is to further improve the efficiency of the 1A-3P sun tracker. Consequently, a novel algorithm for a single-axis maximum power generation (1A-MPG) sun tracker based on the 1A-3P sun tracker is developed to automatically identify the optimal stopping angle for the PV modules, avoiding any shading, and then increase the amount of generated electric energy.

The novelty of the 1A-MPG sun tracker is that the PV modules are automatically rotated from east to west once per hour during daylight hours in order to identify the optimal angle that produces the maximum amount of electric energy. The rotation frequency is nine times per day, and the range for each rotation is from 50° east to 50° west. A good quality timer IC is used to achieve precise timing for the rotation. The proposed algorithm is called the "direct-search method." In this study, the impact on electric energy production by using the direct-search method is compared with that of the previous 1A-3P approach.

A disadvantage of the direct-search method, however, is that the wide rotation range will reduce the lifetime of the components and increase the cost of maintenance. In order to solve these problems, the detection range is reduced, and then the influence on electric energy production of the reduced detection range is also investigated.

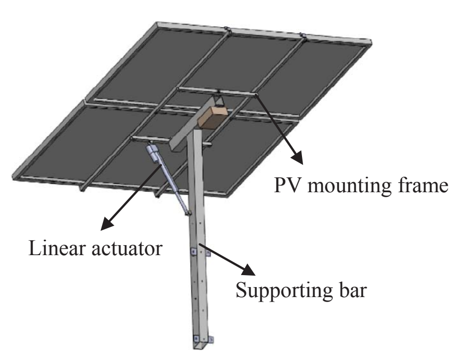

Fig. 1. The 1A-MPG sun tracker.