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Novel high accurate sensorless dual-axis solar tracking system controlled by maximum power point tracking unit of photovoltaic systems

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HIGHLIGHTS

- Novel high accurate sensorless dual-axis solar tracker.
- It has the advantages of both sensor based and sensorless solar trackers.
- It does not have the disadvantages of sensor based and sensorless solar trackers.
- Tracking error of only 0.11° that is less than the tracking errors of others.
- An increase of 28.8–43.6% depending on the seasons in the energy efficiency.

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ABSTRACT

In this study, a novel high accurate sensorless dual-axis solar tracker controlled by the maximum power point tracking unit available in almost all photovoltaic systems is proposed. The maximum power point tracking controller continuously calculates the maximum output power of the photovoltaic module/panel/array, and uses the altitude and azimuth angles deviations to track the sun direction where the greatest value of the maximum output power is extracted. Unlike all other sensorless solar trackers, the proposed solar tracking system is a closed loop system which means it uses the actual direction of the sun at any time to track the sun direction, and this is the contribution of this work. The proposed solar tracker has the advantages of both sensor based and sensorless dual-axis solar trackers, but it does not have their disadvantages. Other sensorless solar trackers all are open loop, i.e., they use offline estimated data about the sun path in the sky obtained from solar map equations, so low exactness, cloudy sky, and requiring new data for new location are their problems. A photovoltaic system has been built, and it is experimentally verified that the proposed solar tracking system tracks the sun direction with the tracking error of 0.11° which is less than the tracking errors of other both sensor based and sensorless solar trackers. An increase of 28.8–43.6% depending on the seasons in the energy efficiency is the main advantage of utilizing the proposed solar tracking system.

1. Introduction

A maximum power point tracking (MPPT) unit is an essential part of almost all photovoltaic (PV) systems [1]. It adjusts the operating point of the PV module used in the system to the maximum power point (MPP) of the PV module [2]. Thus, a MPPT controller significantly increases the energy conversion efficiency of the PV system by extracting as much as possible instant power from the PV module [3]. Different MPPT methods have been reported in the literature [4]. Some methods are offline or model-based such as short-circuit current (SCC) and open-circuit voltage (OCV) because the PV module is regularly disconnected, and a specific physical parameter such as short-circuit current or open-circuit voltage is measured [5]. Other MPPT techniques such as extremum seeking control (ESC), perturb and observe (P&O), and incremental conductance (IC) use the output voltage or current of the PV module under actual operating condition, so they are online or model-free methods [6]. The OCV technique uses the open-circuit voltage of the PV module to estimate the MPP voltage [7]. The temperature technique is an online version of the OCV method which estimates the open-circuit voltage of the PV module using its temperature under operating condition [8]. The SCC method measures the

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short-circuit current to estimate the MPP current [9,10]. Fuzzy methods first convert the PV module current and voltage into fuzzy parameters [11]. They provide some fuzzy outputs based on the fuzzy roles defined for the system, and then, the fuzzy outputs are converted into real outputs by the defuzzification unit [12]. A modified version of the fuzzy technique is adaptive-fuzzy technique which utilizes a fuzzy unit having an adapted gain [13]. Artificial neural network (ANN) based techniques use different trained neural networks to track the MPP [14,15]. The P&O technique first perturbs the PV module voltage or current, and then, the output power of the PV module is compared with the previous value to determine how to produce the perturbation in next step [16]. A modified version of P&O method which determines the perturbation direction using three points is known as three-point weighted technique [17]. Another improved version of the P&O method employing dynamic perturbations was proposed in [18]. Particle swarm optimization adaptive neuro-fuzzy inference system (PSO-ANFIS) and P&O-ANFIS are the two hybrid online MPPT techniques reported in [19]. The slope of *P–V* characteristic is used to track the MPP in the IC method [20,21]. An improved version of the IC technique having zero oscillation of the maximum output power was reported in [22]. The ESC technique uses a nonlinear closed loop mechanism the dynamic of which has been adapted well to the PV module operating point to find the MPP [23–25]. Ripple-based ESC is a modified version of the ESC technique which can be used in grid-connected PV systems, it uses the DC-link voltage ripple to find the MPP [26]. Some other MPPT techniques such as power management maximum power point tracking (PM-MPPT) [27], Cuckoo Search (CS) [28], and modified genetic algorithm (GA) [29] have been also reported in the literature. The MPPT controller used in this study is implemented based on the high accurate MPPT technique presented in [30] which concurrently uses PV current and voltage deviations to precisely track the MPP.

Solar energy is an important renewable energy source getting popular in many countries day by day. The main defect concerning solar energy conversion systems is their low efficiency, so increasing the energy efficiency of this type of renewable energy systems has been the subject of many research projects. A PV system uses a PV module/panel/array to convert solar energy into electric energy. To extract the maximum output power from the PV module, a solar tracker can be used to track the sun direction, so that, sunbeam strikes the PV module surface perpendicularly. In fact, previous researches showed that about 20–50% more solar energy can be captured depending on the geographic position by adding a solar tracker to a PV system [31]. Solar trackers are divided into two types: single-axis and dual-axis [32]. The sole axis of a single-axis solar tracker is aligned along the local north meridian, it has only one freedom degree, so it can only track the sun in one direction which is the daily path of the sun [33]. Dual-axis type has two freedom degrees, so it can track the sun path in two directions which are daily and seasonal motions of the sun [34]. A single-axis solar tracking system increases the daily output power of the PV module up-to about 20% compared to a fixed PV module [35]. It is clear that a dual-axis solar tracking system is more accurate to track the sun direction compared to a single-axis type [36]. The output power of the PV module can be increased up-to about 33% compared to a fixed PV module by utilizing a dual-axis solar tracker [37]. Dual-axis trackers are classified into two types: sensor based and sensorless solar trackers. A sensor based solar tracker acts as a closed loop system in which photo-sensors are used to provide appropriate feedback signals for tracking the sun direction using a feedback control system [38]. The sensors equipped with the radiance limiting tubes are carried and oriented by a dual-axis mechanical system to find the sun direction such as that shown in Fig. 1, and then, the correct angles of the sun position obtained by the sensors are used by the solar tracker to orient

Fig. 1. Sensor of sensor based dual-axis solar tracker equipped with a radiance limiting tube, and mounted on an independent dual-axis mechanical system [39].

the PV module face toward the sun [39]. In fact, two independent dual-axis mechanical systems are needed; one for carrying the sensors, and another for PV module. It is clear that the reference points of the two mechanical systems should be identical, and this increases the complicacy of the solar tracker. Thus, the advantages and disadvantages of sensor based dual-axis solar trackers can be summarized as follows. They are high accurate, so that, their tracking error is about 0.15° [40], but they need one extra dual-axis mechanical system together with several sensors and radiance limiting tubes that significantly increase the cost and complicacy. A sensorless dual-axis solar tracker acts as an open loop system. It uses the offline estimated geographic data about the sun path in the sky obtained from different sun path charts or solar map equations [41]. Similarly, the advantages and disadvantages of sensorless dual-axis solar trackers can be summarized as follows. They are cheaper but their tracking error is averagely about 0.4°, so they are less accurate compared to the sensor based type because of using a set of offline estimated data rather than the online data indicating the actual position of the sun in the sky at the moment [42]. A new set of data is also needed by changing the geographical latitude and/or longitude of the PV module location. Furthermore, they follow the routine path of the sun in a cloudy sky because as mentioned, they operate as an open loop system, so there is not any feedback signal informing the actual environmental conditions.

In this study, a novel high accurate sensorless dual-axis solar tracking system controlled by the internal MPPT unit is proposed. The MPPT controller continuously calculates the maximum output power of the PV module at any time, and then, it uses the deviations of the altitude and azimuth angles to find the correct direction of the sun where the greatest value of the maximum output power is obtained. In fact, the PV module itself plays the role of a sensor, so the proposed sensorless dual-axis solar tracker operates as a closed loop system which uses the online data indicating the actual position of the sun in the sky at the moment. Thus, it has the advantages of both sensor based and sensorless dual-axis solar