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Research paper

# Single axis automatic tracking system based on PILOT scheme to control the solar panel to optimize solar energy extraction

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## HIGHLIGHTS

- Solar energy is maximized by exposing the panel to irradiation for maximum time.
- Energy consumption by the drive is kept to its minimal.
- Technique could help in designing future optimized panel.
- A considerable improvement in solar efficiency is feasible.

## ARTICLE INFO

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## ABSTRACT

Two types of solar panels are currently in use. Fixed panels; where they are placed at a convenient angle depending on the geographical location with a fixed tilt angle. But irradiation time merely exceeds six hours/day. The second type is rotating panels, either by continuously tracking the sun or through a preprogrammed angle at preprogrammed time. Unfortunately, both schemes, continuous tracking or pre-programmed are inefficient. In the first one, motor running at a very low speed requires a high torque which requires high current, leading to more driving power. In the second scheme, the system rotates at predetermined small angles independently whether the new position contributes to extra energy or not. In fact, it may have the opposite effect where all the extracted energy could be consumed by the driving system. This paper presents a new technique where those two draw backs have been addressed. The design uses a microcontroller-based control mechanism to maximize solar energy extraction. This is done by the design of a tracking system known as the PILOT and cells rotating system known as PANEL. First the system is oriented towards the east waiting for sun to rise. When this happens, the PILOT keeps tracking the sun. This is done with the aid of a light to frequency converter (LTF) mounted on a miniature electric motor. This converter always lines the PILOT with the sun. Two identical light dependent resistors (LDR) are mounted, one on the PILOT and the other on the PANEL. After each positioning of the PILOT, a comparison process takes over. If the voltage induced by the PILOT LDR is greater than that induced by the PANEL LDR plus a preset offset, the PANEL aligns itself with the PILOT, otherwise, it stays at its current position, and waits for the PILOT to move to new position, and the process repeats itself. By doing so, the PANEL only moves to the new location when the latter produces higher energy. At the end of the day, after sun set, the system returns to its initial position and waits for the following day.



## 1. Introduction

With the scarcity of fossil fuel as well as its warming effect on the environment, and the great danger posed by nuclear energy, such that suffered by Chernobyl nuclear disaster in 1986 and Fukushima nuclear disaster after the 15 m tsunami that hit Japan's coast, on March the 11th, 2011, and despite being rated to be highly safe, researchers have been looking for safe and cost effective alternative ways. They returned their attention towards renewable energy such as wind, waves, heat, solar just to name a few. But amongst them all, probably solar energy has become more popular and has more chance to survive due to its abundance and decreasing cost and availability of its technology. But solar energy suffers from several drawbacks; up to recently its efficiency is considerably low. The cost was considerably high and most of the panels were stationary, so the extraction times is only limited to few hours a day. But with technology development, efficiency is climbing rapidly where it has been reported to be on the verge of 50% [Wesoff (2016) 24.1%, Green et al. (2016) 38.8%, King et al.

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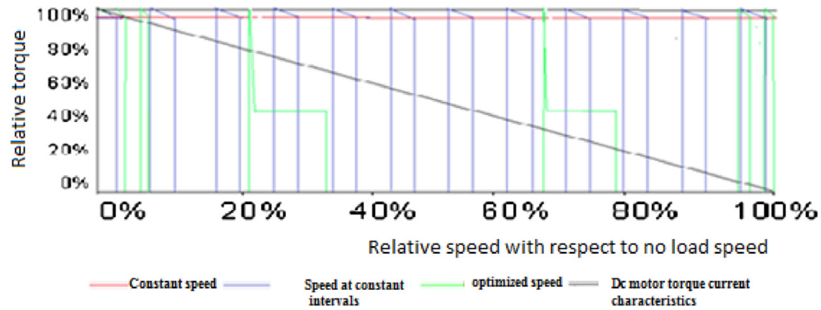


**Fig. 1.** Different scenarios of motor speed control. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(2012), Solar cell (2012) 40%, Fraunhofer ISE (2016) 43.3%, Dimroth (2013) 44.7%, Hossain et al. (2016) 47.2%].

If the solar panels are fixed midway between east and west, the extraction time is roughly between 10 O'clock and 15 O'clock in the afternoon on av**erage**. In fact, Salman et al. (Sections-Clouds, 0000) have shown that solar irradiation in Bahrain, reaches more than 80% approximately between 10 O'clock and 15 O'clock. The experiment was conducted in the middle of summer on June the 26th. Thus, the extracted energy is very limited. If the cleaning cost is added to this, especially in dusty areas like ours, it is quite a difficult challenge to be competitive vis a vis the classical energy produced from fossil fuels. For solar energy to be competitive, at least two issues have to be addressed. One on the cell side, where scientists have to come up with cells with high efficiency and on the engineering side, engineers have to find the optimum positioning of the cells. In the past, people used solar energy with fixed panels midway between the geographical east and west with approximately 26.8° tilt angle towards the south (in Bahrain). Studies have shown that this is not ideal positioning for maximizing energy extraction. A better way is to orient the panels continuously towards the sun, using single axis or double axis. Single axis was chosen for the following reason. As it was mentioned before tilt angle is about 26.8° south (Georgantopoulou and Vasilikos, 2017). That means, it is not very far from the equator. This means that tilt angle needs to be adjusted only twice or three times per year. This could be done offline and may not require automation. In fact, Jafarkazemi and Saadabadi (2013) recommended that tilt angle could be a least changed twice every year in Abu Dhabi which has almost the same tilt angle as Bahrain. Determining the tilt angle requires another motor which requires extra energy consumption, but this is not significant because the tilt angle could be probably adjusted at most four times per year. Many researchers have published their work on the subject. Hession and Bonwick (1984) designed a sun tracker where the sun position is sensed using photo transistors connected to a 2.34-m$^2$ cylindrical parabolic collector mounted on a simple structure. Cliford and Eastwood (2004) reported that computer modelling predicted an increase in efficiency of up to 23% over fixed panels. They also claimed that experimental testing showed excellent agreement with computer model. Huang et al. (2011) developed a 1 axis 3 position sun tracking PV to measure the daily and term power generation of the solar PV system. Chin et al. (2011) designed a compact solar tracker mounted on a wall. This system was operated at different modes to accommodate for weather conditions. To increase still the efficiency of energy extraction, many two axes systems were developed. Al-Soud et al. (2010) have designed a parabolic solar cooker using two axes tracking system. They showed that the temperature inside the heating tube, reached 90 degrees Celsius. Even better, Abu-Malouh et al. (2011) reported that they constructed a solar cooking system, with a dish built to concentrate solar radiation on a pan that was fixed at the focus of the dish and they showed that the temperature inside the pan reached 93 degrees Celsius. Batayneh et al. (2013) followed different approach by designing a fuzzy based two axis tracking system. Though, the system looks to be promising from simulation point of view, it needs to be tested experimentally. Bentahar et al. (2014) developed a solar tracking system based on LDRs using electro-optical tracking. They reported that acceptable results were obtained. Yao et al. (2014) presented a study dealing with multipurpose dual-axis solar tracker. The tracker uses a declination clock mounting system to locate the primary axis east–west direction. The secondary rotates at a constant speed of 15° /h. Ahmed et al. (2013) developed a hardware and software for sun tracking mechanism. The system has two axes tracking with accuracy of 1° controlled by a programmable logic controller. Sidek et al. (2017) presented a study on an automated positioning open-loop dual-axis solar tracking system.

## 2. Background

Despite the intensive research to maximize energy extraction by orienting the panels towards the sun, by continuously rotating the solar panels in order to track the sun, a major problem still remains. That is: to rotate thousands of panels, electric motors are required. Those motors draw very high currents to produce high starting torque especially at the start of rotation in order to overcome the panel's inertia. It is well known that in a DC motor, the torque is proportional to the armature current provided the excitation field is kept constant, according to Eq. (1)

$$T = K\phi Ia \quad (1)$$

where T is the torque in N m, K is constant depending on the coil geometry, $\phi$ is the flux in Weber, and $I_a$ is the armature current in Amperes. It could also be noticed that to reduce the torque, hence the armature current, one needs to increase the speed. By referring to Fig. 1, the Torque is governed by:

$$T = -\frac{W}{W_s}T_s + T_s \quad (2)$$

where T is the torque in N m, W is the rotational speed in Radians/s, $W_n$ is the rotational no load speed in Radians/s and $T_s$ is the stall torque in N m (Collins 2015).

There are three different possible scenarios for motor drive. The first scenario is to drive the panels continuously at a very low speed (Ghassoul, 2010). This could result in feeding back the converted energy into the drive to overcome the torque without extracting additional energy if not more energy is fed back from the storage. On top of that, is the heating effect on the motors due to high torque hence high current. So this option is not feasible. This is shown in Fig. 1 in red where the motors draw high current continuously. The second scenario is to rotate the motors through a fixed angle at fixed periods of time (Ghassoul, 2001). This is shown in Fig. 1 in blue. Though the energy extraction efficiency has been improved because the driving motors rotate faster hence