Photovoltaic Panels Tilt Angle Optimization

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The tilt angle of solar panels is significant for capturing solar radiation that reaches the surface of the panel. Photovoltaic (PV) performance and efficiency are highly affected by its angle of tilt with respect to the horizontal plane. The amount of radiation reaching the surface of a PV panel changes with the changes in its tilt angle, hence adding a solar tracking system will maximize the amount of solar radiation reaching the surface of a PV panel at any time during the day, however, integrating solar tracking system will increase the total cost and maintenance of any PV system. Thus, using an optimized fixed tilt angle is the solution to element the initial, maintenance, and operation costs of a solar tracking system. Yet, the fixed angle is location-specific because it depends on the daily, monthly, and yearly location of the sun. In this study; daily, monthly and seasonally angles are calculated mathematically and the amount of incident radiation on the surface of the PV panel is measured along with its voltage. By comparing the practical measurements of the output voltage of PV panels, an optimized tilt angle is decided.

Introduction

The new modern world is currently moving from conventional energy sources to the clean and renewable ones. Solar energy has been known as one of the most promising and reliable renewable energy sources, since it is sustainable and accessible almost everywhere around the world. One promising application of solar energy is Photovoltaic (PV) technology which has developed rapidly. Solar PV technology is one of the best methods to harness solar power [1]. The annual solar energy reaching on the surface of the earth is 1.5×1018 kWh [2], about 30% of the incoming energy is reflected back to space while the rest is absorbed by oceans, land masses and clouds. Iraq is located in the Middle East between latitudes 29° 5' and 37° 22' N and longitudes 38° 45' and 48° 45' E. The highest solar radiation is estimated at 6790kWh/m2 in September while the lowest is 1660 kWh/m2 in December [3]. Therefore, Iraq is well located in terms of solar energy potential. The performance of PV panels is highly affected by its orientation and tilting angle. The tilt angle and orientation can change the amount of solar radiation captured by the panel. Maximum daily energy can be collected by using solar tracking systems also some fixed systems based on the daily, weekly monthly and seasonally optimized tilt angle at particular geographical locations. The radiation level reaching the panels depends on the latitude and longitude of the location where PV panels are located. While sun beams fall with the steep angle at noon, they fall with a narrow angle in the mornings and afternoon. Hence PV tilt angles varies depending on the location, and they differ monthly, seasonally and yearly [4]. Monthly and seasonal changes of tilt angles of panels should be considered by mathematical calculations and supported by experimental results. Many studies showed that the optimum tilt angle depends on latitude angle (λ), solar declination angle or days of the year [5].

TILT ANGLES AND PV PANELS

A. PV tilt Angle

Solar PV tilt angle is defined as the number of degrees from the horizontal plane [10], another definition it is slope angle at which solar panels are mounted to face the sun. The fixed angle is location specific because it depends on the daily, monthly and yearly location of the sun [11]. [12] Showed that daily changes in tilt angles to their optimum value in Egypt can reach a total annual gain in solar radiation of 29.2% more than a fixed collector with a tilt angle equal to its geographic latitude. Yet, daily adjustment of tilt angles is not a practical solutions, due to frequent changes of the angle and composite structure of frames which support solar panels.

B. PV panels

PV panels are semiconductor devices that directly convert the sunlight falling on them to electrical energy [13]. The efficiency and performance of PV systems are affected by many factors, such as solar tracking system, shading or partial shading, solar angle, dust, and cell operating temperature. To achieve maximum output power from PV systems, PV panels must be installed with a specific orientation and tilt angle with the horizontal plane. The PV modules are placed facing south in the northern hemisphere as a general rule. A simple equivalent circuit model for a photovoltaic cell consists of a real diode in parallel with an ideal current source as shown in Fig. 1. The ideal current source delivers current in proportion to the solar flux to which it is exposed [14].

MATHEMATICAL CALCULATION OF TILT ANGLE

Declination angle is calculated by the following equation.

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$\delta = 23.45° \sin[\frac{360}{365}(n - 81)]$ (1)

The altitude angle is calculated as:

$\beta N = 90° - L + \delta$ (2)

where L is the latitude of the site. The tilt angle that is given by:

Tilt $(\emptyset) = 90° - \beta N$ (3)

Equations (1-3) are used to calculate the declination angle and tilt angle for solar PV modules for each day of the year [15]. Using equation (1-3), the tilt angle of the first day of each month in a year for Duhok city written in the Matlab program using the formulas about solar angles is shown in Fig.3.

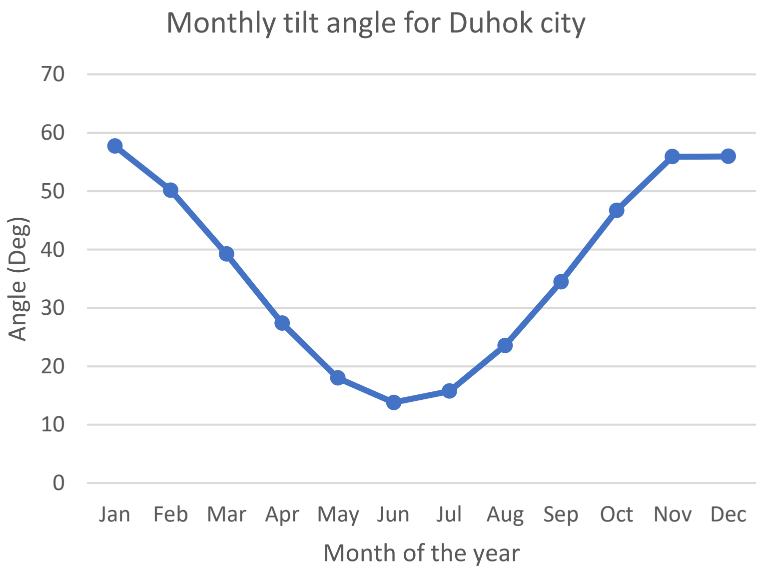

Fig. 3 Monthly tilt angle for Duhok city

EXPERIMENTAL METHODOLOGY

In this study, three identical 100 W monocrystalline PV panels are used. Each panel is able to produce maximum power (Pmax) of 100 watts at standard conditions (STC) (i.e. temperature 25° C, 1000 watts/m^2 of solar insolation and air mass of 1.5). However, in Iraq the operating temperatures during the summer are usually higher than STC. PV panels operating at temperatures higher than 25° C produce less than their rated power. Thus, the efficiency of PV panels drops below the rated values. These modules can produce a voltage (Vmp) and current (Imp) of 16.7 volts and 3.0 amps with an efficiency of 13.5 % at STC. The open circuit voltage (Voc) and short-circuit current (Isc) of each module are 21.1 V and 3.20 A respectively. Three different tilt angles are calculated mathematically using (1-3):

1. **14.8°:** optimum tilt angle of the 1st day of June.
2. **13.78**°: average angle for the month of June.
3. **22**°: average angle for 4 months (June, July, August, and September).

The panels are tilted with tilt angles of 14.8°, 13.78°, and 22°, a digital Multimeter is connected to each panel to record the open circuit voltage of each panel. An Arduino mega microcontroller is programmed to record the voltage produced by each panel over a period of 15 hours, the micro controller is connected to the panels through a voltage sensor, and the voltage of each panel is recorded in a micro SD card. Different values of PV output voltage are recorded, the values are shown in Fig. 4. The values of output voltage are recorded for each tilt angle and for different hours of the day. It is shown that the best tilt angle to get maximum output voltage is 14.8°.

CONCLUSION

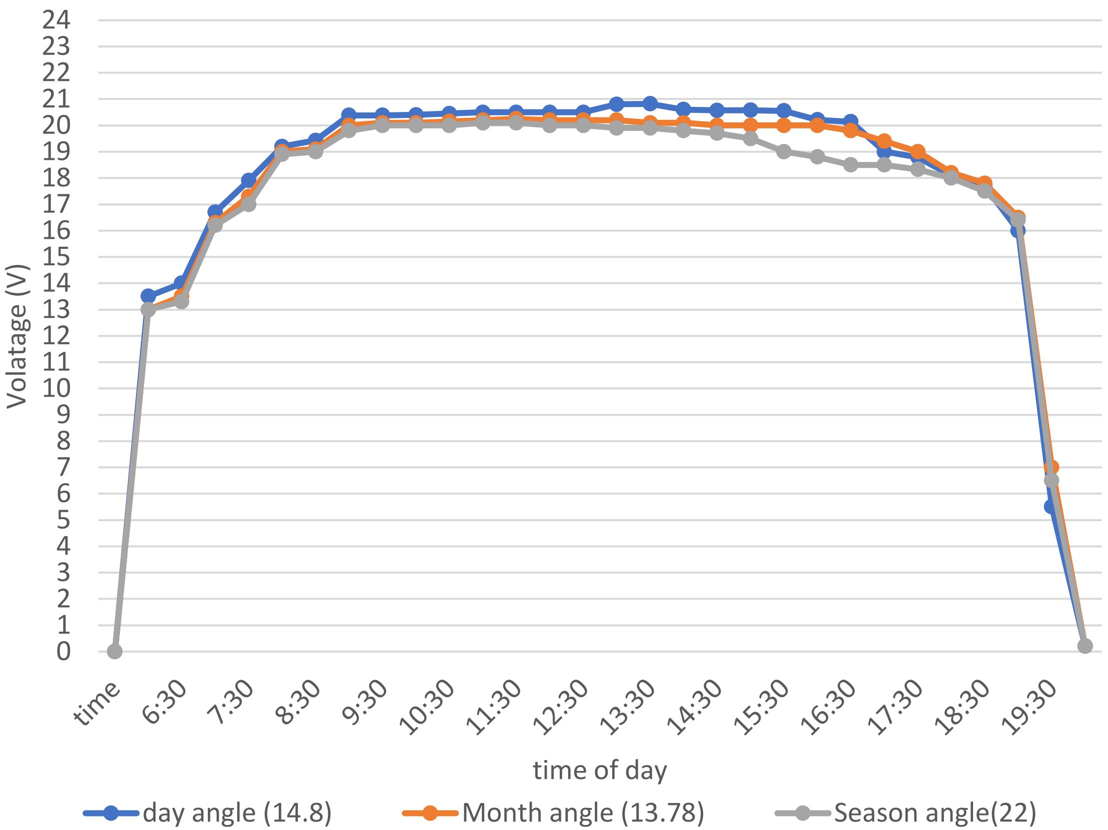

Fig. 4 PV open circuit voltage for different tilt angles

The fixed tilt angle of photovoltaic panels affects directly on the amount of generated electricity by the panels, therefore the angles must be identified correctly and accurately to increase the amount of incident solar radiation on the surface of PV panels. When calculating the optimized fixed tilt angle, the results show that the experimental results differ from the mathematical results by approximately 8º. The difference is caused by some environmental factors such as temperature, dust, and dirt. The increase in temperature decreases the voltage of PV panels and so decreases the efficiency of the panels.