The Impact of Tilt Angle on Photovoltaic Panel Output

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ABSTRACT

PV (photovoltaic) panels are getting more attentive in our life due to its big advantages. At the same time its efficiency is an important factor to consider. At any location on the earth its output is affected by its tilt and azimuth angles. These angles play an important role in the efficiency of the photovoltaic panel. In this paper, the effect of tilt angle on PV performance determines. The PV module tilt angle changes from 0° to 90° using Arduino Mega 2560 to control it. The values of the PV panel output voltage collects using the Arduino and output power calculates at different tilt angles to know the effect of tilt angle shift on the PV panel output. A mathematical equation derives to calculate the effect of tilt angle on the PV output.

1. INTRODUCTION

Energy requirement increases due to technology improvement every day can never be fulfilled by the generation from fossil fuels. Thus, power generation from renewable energies should be considered. The solar energy attracts large interest out of other renewables, because of its great advantages like it is easy to install, minimum maintenance required and more.

1.1 Solar Angles

The sun's position in the sky as per any location on the earth could be located using the solar angles (Tilt and Azimuth angles). The tilt angle plays important role towards the efficiency of the PV (photovoltaic) panels.

Thus, it is very important to orient the PV panels at tilt angle for any given location to obtain maximum power output. PV panels are most efficient when they are perpendicular to the sun's rays. Figure 1 shows Azimuth and Tilt angles (Weir, 2006).
However, throughout the year the sun’s path and the solar altitude vary. The highest point in the sun path will have largest altitude angle value in summer on June 21\textsuperscript{st} and lowest value in winter on December 21\textsuperscript{st}. The tilt angle is 90\(^o\) from sun-rise and decreases until mid-day which reaches to its lowest value then increases until 90\(^o\) at sun-set (Solar data, 2017).

1.2 Tilt Angle Equations

The tilt angle is time and location dependent, i.e., every location will have different tilt angle for different time of days of a year. To calculate the tilt angle for any location and time over the days of year, equation from 1 to 7 can be used (Weir, 2006).

\[
AST = LST + (4\text{ min/deg})(LSTM - Long) + ET
\]  
Where: AST: Apparent Solar Time, LST: Local standard time, LSTM: Local longitude

\[
LSTM = 15^\circ \times \left(\frac{Long}{15^\circ}\right)_{\text{round to integer}}
\]  
Where: Long: longitude

\[
ET = 9.87 \sin(2D) - 7.53 \cos(D) - 1.5 \sin(D)
\]  

\[
D = \frac{360^\circ(n - 81)}{365}
\]  
Where: \(n\) is number of days until the required date.

The declination angle, \(\delta = 23.45^\circ \sin \left[\frac{n + 284}{365} \times 360^\circ\right]\)  

The hour angle, \(H = \frac{\text{No of mins past midnight} \cdot AST - 720 \text{ mins}}{4\text{ mins/deg}}\)  

Tilt Angle, \(\theta_t = \cos^{-1}(\cos(Lat) \cos(\delta) \cos(H) + \sin(Lat) \sin(\delta))\)  
Where: \(Lat =\) Latitude

1.3 Research Background

Several authors published papers to study the effect of tilt angle on the PV panel output power; Salih (Salih, 2014) studied and simulated the effect of tilt angle on PV performance. The simulation involved a PV module tilted at 0\(^o\), 15\(^o\), 30\(^o\), 45\(^o\), and 60\(^o\). The values of the current, voltage, and power were measured at these positions.

Radhika and Suman (Suman, 2015) calculated the effect of tilt angle and azimuth angle on solar output. Helioscope software used to analysis the data. The optimum values of tilt angle and azimuth angle for selected location have thus been found.

Abdul-wahid and Mahdi (Mahdi, 2010) studied the effect of changing tilt angle and the variations in the incident sunlight effect on the amount of electrical output. Four solar panels in four different tilt angles (20\(^o\), 35\(^o\), 45\(^o\), 55\(^o\)) installed and tested for one year. Optimum tilt angle found.

Yang and Sahib (Sahib, 2007) developed a new mathematical model for calculating the optimum tilt angles and azimuth angles for building-integrated photovoltaic (BIPV) applications in Hong Kong on yearly, seasonal, and monthly bases.
Kumar, Chaurasia and Singh (Saurav Kumar, 2014) did experimental based study that how voltage and current may be affected as the slope of a panel gets changed for a selected location in India. The paper shows that at different position of solar panel has different power & efficiency.

In this research the PV panel's tilt angle will change between 0° to 90° degree in 1° degree step and the five PV panel output voltage readings will read per second. The average of the five output voltage readings is being calculated and analyzed to find the impact of tilt angle on photovoltaic panel output. Then the mathematical model will be concluded.

2. MATERIALS AND METHODS

For the purpose of collecting data accurate system designed and built to change the tilt angle from 0° to 90° degree in 1° degree step as shown in figure 2.

An Arduino MEGA 2560 (figure 3) used to control the system and as data logger also (Smith, 2011). Two servo motors used to rotate the PV panel around tilt angle axes between 0° to 90° degree. The servo motors connected to pins 8 and 9 of the Arduino Mega 2560.

3. RESULT AND DISCUSSION

The specification of the tested solar photovoltaic panel has been shown in the figure 4.

Before collecting the results, we have to find the maximum power point of the PV panel. This can be done by using a variable load resistor as R_L, connecting across the PV panel output terminals, and then measuring both voltage and current across the R_L.
On February 22, 2017 results obtained for the PV panel maximum power point. As per results the maximum power point occurs at voltage of 7.4 volts and current of 0.11 Amperes. At that point the power was 0.814 watts and load resistor was 67.27 ohms. Figure 5 shows collected results.

On April 17, 2017 at 9:20AM the designed system tested in Erbil, Kurdistan region, Iraq with coordinates of latitude of 36.15° and longitude of 44.05°. The tilt angle changed from 0° to 90° automatically by the two servo motors and five PV panel output voltages obtained for each single angle using the Arduino analogue inputs as a data logger each second and the average of collected calculated. Obtained results shown in figure 6.
The output power can be determined knowing the load resistor 67.27 ohms which is connected to the PV panel output terminals and using equation 8. Obtained output power is shown in figure 7.

\[ PV \text{ Panel output power, } P = \frac{(\text{Terminal voltage})^2}{67.27} \]  

(8)

![Figure 7: PV Panel output power per tilt angle](image)

Using equation 1 to 7 for date and time of the test (April 17, 2017 at 9:20AM) the tilt angle can be calculated and is equal to 45°. As seen in figure 5 the maximum output power is obtained when the tilt angle is 45° and it decreased significantly when the tilt angle intercepts from 45° because at 45° tilt angle the sun's ray is perpendicular on the PV panel and it gives maximum output power.

To know exact effect of shift of tilt angle on the PV panel output; the percentage of output power drop from maximum output power calculated and the results are shown in figure 8.

![Figure 8: PV Panel percentage output power drop due to tilt angle shift from 45°](image)

To get the equation of the percentage of output power drop with the change of tilt angle degree the polynomial curve fitting process were used. For that a Matlab Polyfit function
(Gilat, 2011) was used and equation 9 obtained:

\[ D = 1.41669574 \times 10^{-9} A^6 - 3.59548024 \times 10^{-9} A^5 - 5.57767010 \times 10^{-6} A^4 + 1.64493758 \times 10^{-5} A^3 - 1.724028491 \times 10^{-4} A^2 - 7.11435953 \times 10^{-3} A + 99.37322857 \]  

(9)

Where \( D \) is percentage of output power drop and \( A \) is PV panel tilt angle shift in degrees. The equation 9 could be used for to know the power drop for any PV panel for any shift in Panel tilt angle.

Figure 9 shows the percentage of output power drop from maximum output power due to shift of tilt angle and the fitted curve with it. It's obviously seen that how much the tilt angle shift increases the output power drop increases and the output power decrease until it reaches to its minimum in -45° and 45° of tilt angle shift.

![Figure 9: PV Panel percentage output power drop and the fitted curve](image)

4. CONCLUSION

The main conclusion of this research paper can be described as follows:
1. The tilt angle orientation of the PV panel affected its output power.

2. The maximum PV panel output power occurred when the tilt angle was optimum (for this work was 45°) i.e. the sun rays were perpendicular to the PV panel.

3. The PV panel output power decreases significantly when the tilt angle becomes far-off from its optimum value (for this work is 45°) and the output continuously drops how far it away from the optimum angle.

4. The mathematical model the equation of the percentage of PV panel output power drop with the change of tilt angle degree obtained. This equation gives accurate results for calculating the decrease of PV panel power output due to tilt angle shift for any PV panel.

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