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Potential of One-Axis and Two-Axis Tracking Photovoltaic Systems

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Abstract

This paper explores the potential of solar energy generation in the area of The Hashemite University in Jordan (32.05_N, 36.06_E) by investigating the optimal inclination and azimuth angles of photovoltaic (PV) modules for every hour, day, month, and of the whole year. The object of this study is to maximize the annual energy production of PV systems by tracking the changes of sun's position in the sky north-to-south and east-to-west. Hourly, daily, monthly, and annually global radiation averages are simulated using the METEONORM comprehensive meteorological software and then analyzed using the MATLAB™ software. This study shows that the one-axis PV tracking system about the inclination axis increases the energy yield of 5.87% compared to the fixed surfaces (azimuth angle=0° and inclination angle=30°) , while the one-axis PV tracking system about the azimuth axis increases the energy yield of 20.12% compared to the fixed surfaces. On the other hand, the two-axis PV tracking system about both the inclination and azimuth axes increases the energy yield of 30.82% compared to the fixed surfaces.

Keywords: One- and Two-axis Tracking, METEONORM, Solar Energy.

1. Introduction

In order to maximize the energy produced by photovoltaic (PV) and solar collector systems, they have to receive maximum solar irradiation by pointing them at the sun at all the times. This is done by the implementation of sun-trackers. Different configurations of sun-trackers are investigated in [1-3]. In this paper, we calculate the radiation received from the sun using the METEONORM 5.0 software (a comprehensive climatological database for solar energy applications at every location of the globe.)[4] for different azimuth $(-90^o \le \zeta \le 90^o)$ and inclination $(0^o \le \theta \le 90^o)$ angles. The integration of PV generators in buildings, presently in many industrialized countries, led to the use of a large range of different orientations and tilt angles. PV module orientations from east to west, and tilt angles from horizontal to vertical are found in practice [5].

Figure 1 shows a two-axis tracking configuration that rotates about two axes maintaining the surface of the PV module always perpendicular to the sun. Hence, it allows collecting the maximum amount of energy possible. The rotation about the azimuth axis ranges from $\zeta = -90^\circ$ (east) to $\zeta = 90^\circ$ (west) while the inclination angles range from $\theta = 0^\circ$ (horizontal) to $\theta = 90^\circ$ (vertical). In this paper, we investigate only the direct radiation meteorological data rather than the diffused radiation and explore the potential of solar energy generation in the area of the Hashemite University since on sunny days, the direct sunshine accounts for up to 90% of the total solar energy [1,6].

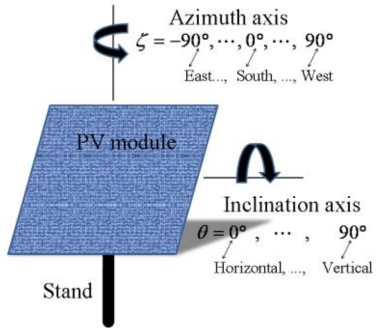

Fig. 1. Two-axis tracking configuration where the PV module rotates about its axes (inclination and azimuth) by a controllable gear.

This work is organized as follows; Section 2 introduces the energy yield of fixed $(\zeta = 0^o, \theta = 30^o)$ PV modules which was optimized in [7] assuming the efficiency of the PV modules is 10% as a standard value. Section 3 compares between the tracking about the inclination and the azimuth axes. Section 4 shows the optimal inclination and azimuth angles and the potential of such two-axis tracking PV system.

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2. Energy yield of fixed PV-modules

In this section, we start with the find outs of the researchers in [7] by fixing the inclination angle at $\theta = 30^o$ and the azimuth angle at $\zeta = 0^o$ (i.e facing the south) and then compute the energy yield of a 10% efficient PV module from 8 O'clock to 17 O'clock for over the year as shown in Figure 2. The maximum energy yield of the PV module occurs at 12 O'clock on 6th April where the radiation reaches 1100 W/m^2.

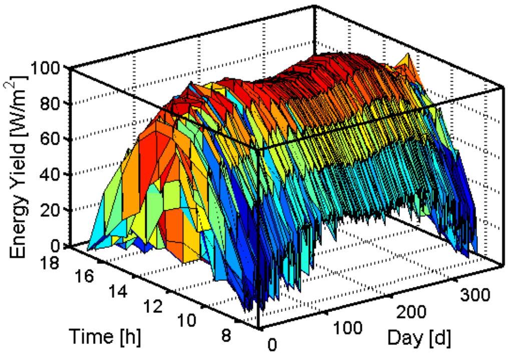

Fig. 2. Hourly energy yield of a 10% efficient PV module from 8 to 18 O'clock

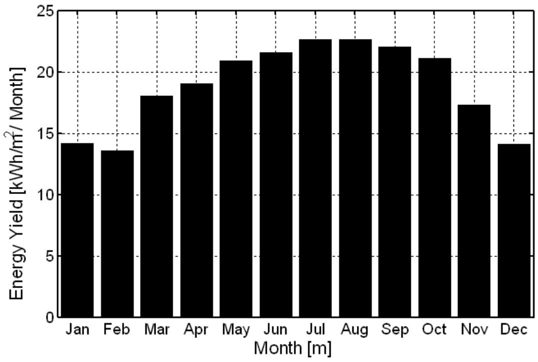

Fig. 3. Energy yield of the PV systems, the energy yield is 227.1 kWh/m^2/ year.

3. Energy yield of one-axis tracking PV-modules

3.1. Fixing azimuth and varying inclination

In this section, we fix the azimuth angle at $\zeta = 0^o$ while the inclination angle varies from $\theta = 0^o$ to $\theta = 90^o$. For each step, we calculate the energy yield of the PV systems for every hour during the day over all the year. The inclination angle θ is optimized by selecting the angle θ which results in a global maximum energy yield. Figure 4 shows the optimal inclination angles for every day in the year at different times. Therefore, to maximize the energy produced from PV modules they have to be inclined at the angles shown in Figure 4.

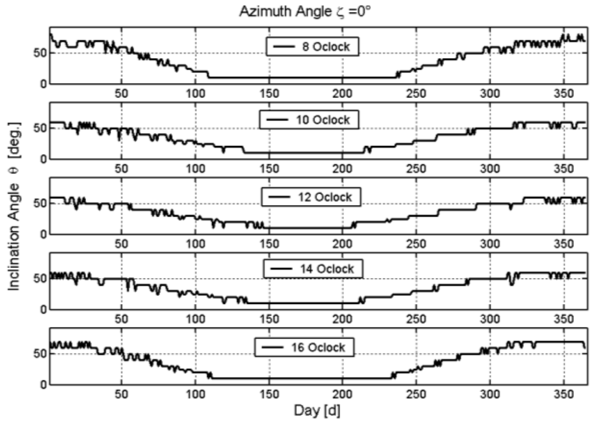

Fig. 4. Optimal inclination angles θ for different times in the day over all the year while the azimuth angle is set to $\zeta = 0^o$.

To prove the effectiveness of such tracking, the energy yield of PV systems fixed at $\theta = 30^o$ and others inclined having the optimal angles is computed and plotted in Figure 5. It is obvious that an increase of energy yield can be obtained by applying this tracking method.

The effect of tracking can be measured as "gain" g that is defined as the ratio of the energy produced in deflected positions to the energy produced in the fixed position system [8]. The gain of fixing the azimuth and varying the inclination angles at optimal ones compared to the fixed angles is $g = 5.87\%$.

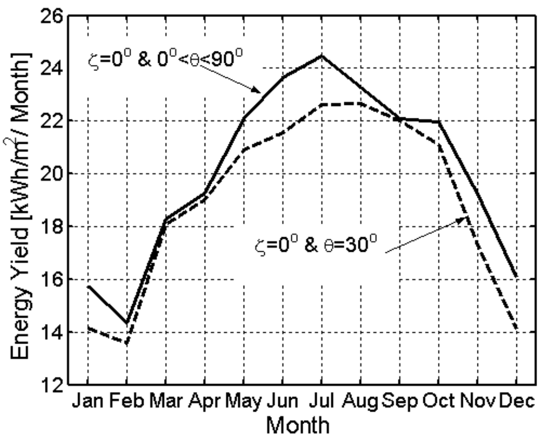

Fig. 5. Energy yield of fixed (fixing both ζ and θ) and one-axis (fixing ζ and varying θ) PV systems for each month. The maximum energy yield occurs in July for both lines. The gain of such tracking over the fixed one is 5.87%.

3.2. Fixing inclination and varying azimuth

A second method of one-axis tracking is to fix the inclination angle at $\theta = 30^o$ while the azimuth angle varies from $\zeta = -90^o$ to $\zeta = 90^o$ (i.e from east to west). The energy yield of the PV systems is also calculated for every hour during the day over all the year then the azimuth angle ζ is optimized by selecting the angle ζ which results in a global maximum energy yield. Figure 6 shows the optimal azimuth angles for every day in the year at the same times used in the last subsection. The energy yield of PV systems fixed at $\theta = 30^o$ and others rotating about the azimuth axis having the optimal angles shown in Figure 6 is computed and plotted in Figure 7. The gain of fixing the inclination and varying azimuth the angles at optimal ones compared to the fixed angles is $g = 20.12\%$ which is better than the one discussed in last subsection.

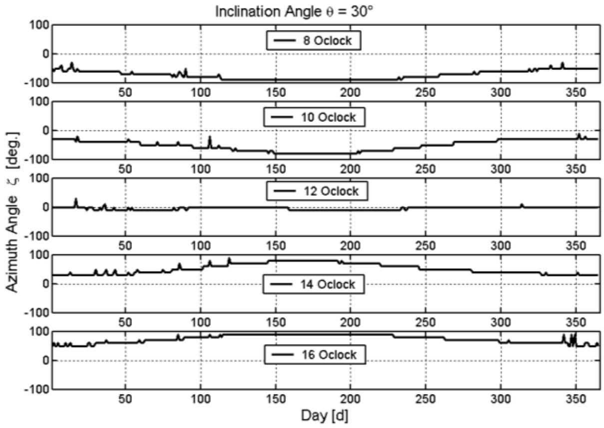

Fig. 6. Optimal azimuth angles ζ for different times in the day over all the year while the inclination angle is set to $\theta = 30^o$.

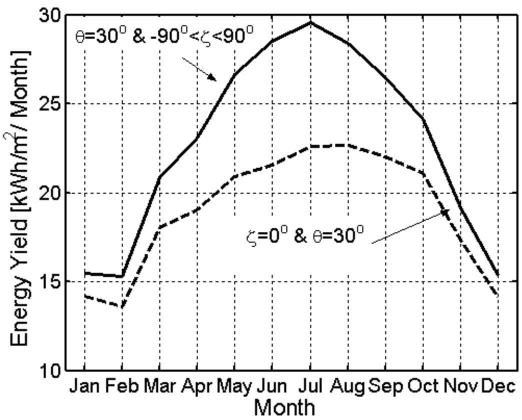

Fig. 7. Energy yield of fixed (fixing both ζ and θ) and one-axis (fixing θ and varying ζ) of PV systems for each month. The maximum energy yield occurs in also July for both curves. The gain of such tracking over the fixed one is 20.12%.

4. Energy yield of two-axis tracking PV-modules

In this section we optimize the azimuth $\zeta = -90^o \cdots 90^o$ and the inclination $\theta = 0^o \cdots 90^o$ angles simultaneously, i.e. two-axis tracking. The energy yield of the PV systems is maximized for every hour during the day over all the year by selecting the appropriate angles which result in a global maximum energy yield. Figure 8 shows the optimal inclination θ and azimuth ζ angles for every day in the year at the same times used in the last subsections. The energy yield of PV systems fixed at $\theta = 30^o$ and others rotating about both the azimuth and inclination axes having the optimal angles shown in Figure 8 is computed and plotted in Figure 9.

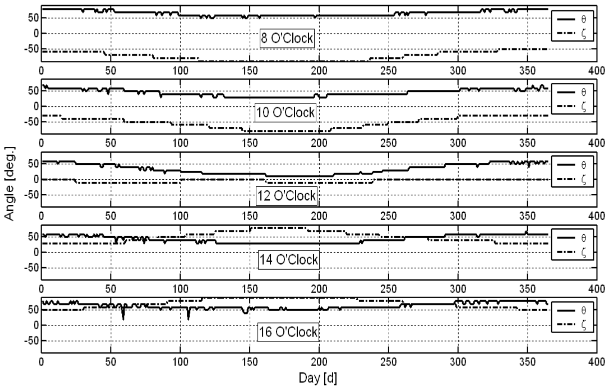

Fig. 8. Optimal azimuth ζ and inclination θ angles for different times in the day over all the year.

The gain of choosing the inclination and varying azimuth the angles at optimal ones compared to the fixed angles is $g = 30.82\%$ which is better than the one discussed before. At the end, we show the energy yield of PV systems depending on the tracking method used. Figure 10 shows this comparison between the one-axis (two types) and the two-axis tracking systems where we notice that the tracking about azimuth or the inclination shows comparable results to each other in the winter months.

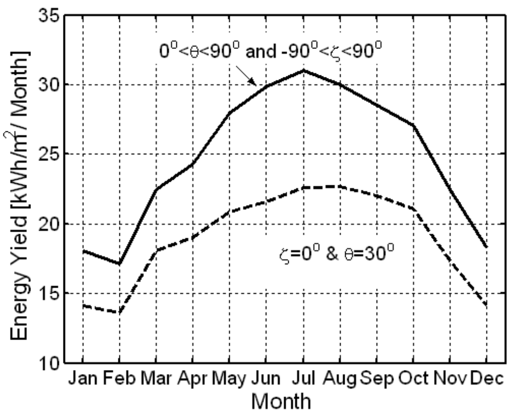

Fig. 9. Energy yield of fixed (fixing both ζ and θ) and two-axis (varying both θ and ζ) of PV systems for each month. The maximum energy yield occurs in also July for both lines. The gain of such tracking over the fixed one is 30.82%.

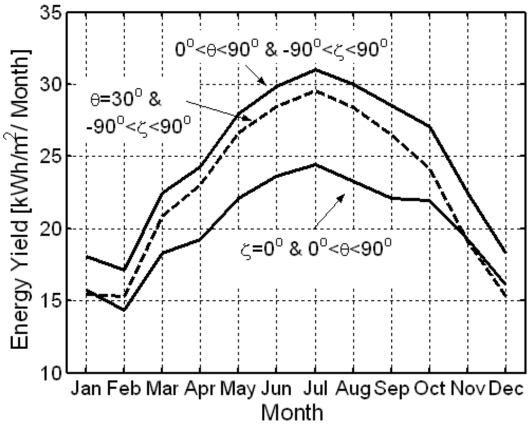

Fig. 10. Comparison of the energy yield of the two-axis (variable θ and ζ) and the one-axis (fixing ζ or θ) tracking of PV systems. The tracking about azimuth or the inclination shows comparable results to each other in the winter months.

5. Conclusion

In this paper we showed the potential of the one-axis and two-axis tracking PV systems in The Hashemite University. The optimized rotation of the PV systems around the inclination axis can increase the energy yield up to 5.87% compared to the fixed systems, while the optimized rotation of the PV systems around the azimuth axis can increase the energy yield up to 20.12% and the optimized rotation about both the inclination and the azimuth axes simultaneously can increases the energy produced by the PV systems more than 30% compared to fixed systems.

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