

## Research Article

# Energy Yield of Tracking PV Systems in Jordan

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This paper analyzes the energy yield of photovoltaic (PV) modules mounted on fixed tilt, one-axis, and two-axis tracking system towards maximizing the annual energy production. The performance evaluation of the proposed design of the tracking systems is carried via simulating the global radiation averages using METEONORM software and depicting the simulation results in figures using MATLAB software. The one-axis system is simulated by either fixing the azimuth angle while optimizing the inclination angles or fixing the inclination angle while optimizing the azimuth angles; simulation results show an increase in energy yield of 5.87% and 20.12% compared to that of fixed tilt system, respectively. In the two-axis system, optimization of both azimuth and inclination angles is carried out simultaneously which resulted in 30.82% improvement in energy yield. Therefore, 30% improvement in energy yield is directly reflected as saving in PV system cost due to reduction of the PV modules surface area.

## 1. Introduction

The implementation of sun trackers maximizes the energy yield of photovoltaic (PV) systems by keeping the PV modules pointing towards the maximum sun radiation during the entire day [1–3]. The work in [4] validated the accuracy of the METEONORM 5.0 software [5]; thus, we used it here as simulation tool.

METEONORM 5.0 software is a comprehensive meteorological reference, incorporating a catalogue of meteorological data and calculation procedures for solar applications and system design at any desired location in the world. It is based on over 24 years of experience in the development of meteorological databases for energy applications.

In this paper, we calculate the radiation received from the sun using the METEONORM 5.0 software for different azimuth ( $-90^\circ \leq \zeta \leq 90^\circ$ ) (east to west) and inclination ( $-90^\circ \leq \theta \leq 90^\circ$ ) (north to south) angles. A wide range of angles for PV modules are found [6] as shown in Figure 1. The two-axis tracking configuration rotates about two axes maintaining the surface of the PV module always perpendicular to the sun to maximize the collected radiation and thus maximizing the amount of energy production. 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 because on sunny days, the direct sunshine accounts for up to 90% of the total solar energy [1, 7]. The study explores the potential of solar energy generation in the area of the Hashemite University in Jordan. This work is organized as follows: Section 2 introduces the energy yield of fixed ( $\zeta = 0^\circ$ ,  $\theta = 30^\circ$ ) PV modules which was optimized in [8] assuming the efficiency of the PV modules is  $\eta = 10\%$  as a standard value. In Section 3, one-axis tracking system simulation results are presented. In Section 4, the two-axis system results are highlighted. Conclusions are drawn in Section 5.

## 2. Energy Yield of Fixed-Tilt PV System

We utilize with the finding of [9] by fixing the inclination angle at  $\theta = 30^\circ$  and the azimuth angle at  $\zeta = 0^\circ$  (i.e., facing the south) to compute the energy yield of a 10% efficient PV module from 8 Am to 6 Pm for entire year as shown in Figures 2 and 3. The maximum energy yield of the

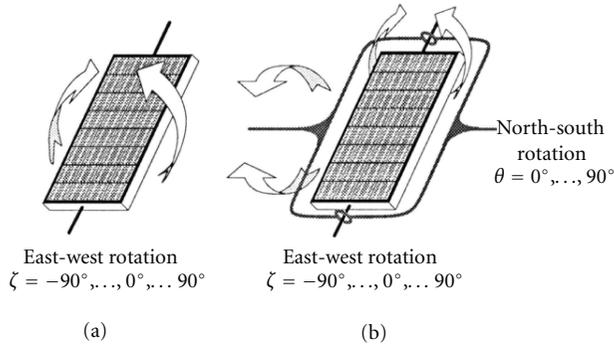


FIGURE 1: One (a) and two-axis (b) tracking configurations where the PV modules rotate about the axes (inclination and azimuth) by a controllable gear.

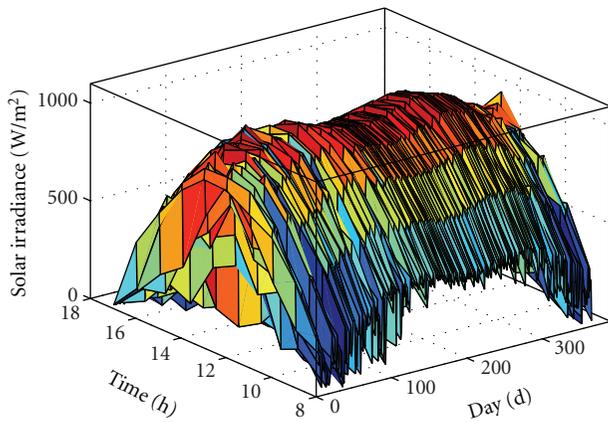


FIGURE 2: Hourly solar irradiance from 8 to 18 O'clock.

PV module occurs at 12 O'clock on 6th of April where the radiation reaches  $1100 \text{ W/m}^2$  and  $227.1 \text{ kW h/m}^2/\text{year}$ .

### 3. Energy Yield of One-Axis Tracking PV System

In this section, simulation results of one-axis tracking system are presented and compared with energy yields of the PV system in previous section.

**3.1. Fixing Azimuth Angle and Varying Inclination Angle.** In this subsection, we fixed the azimuth angle at  $\zeta = 0^\circ$ , while the inclination angle varies from  $\theta = 0^\circ$  to  $\theta = 90^\circ$ . For each step, we calculate the energy yield of the PV system per hour from 8 Am to 6 Pm over a complete year. The optimized inclination angle  $\theta$  results in a global maximum energy yield. Figure 4 shows the optimal inclination angles for each day of the year at different times. Therefore, to maximize the energy generated by PV modules, they have to be inclined at the angles shown in Figure 4.

Figure 5 depicts the energy yields of both fixed and one-axis PV systems. Fixed system is fixed at  $\theta = 30^\circ$ , and one-axis system is inclined to optimal angles. It is obvious that one-axis system outperformed the fixed system by about 5.87%.

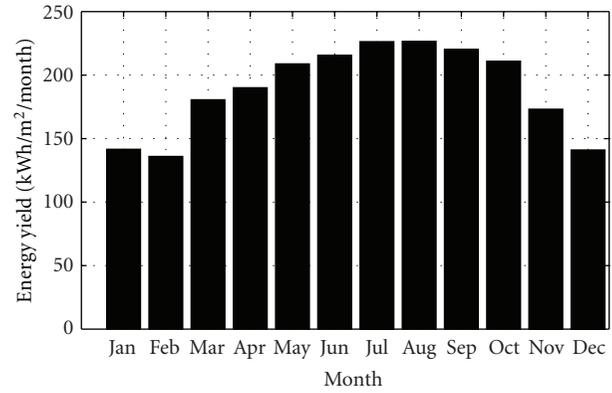


FIGURE 3: Energy yield of the PV systems; the energy yield is  $227.1 \text{ kW h/m}^2/\text{year}$ .

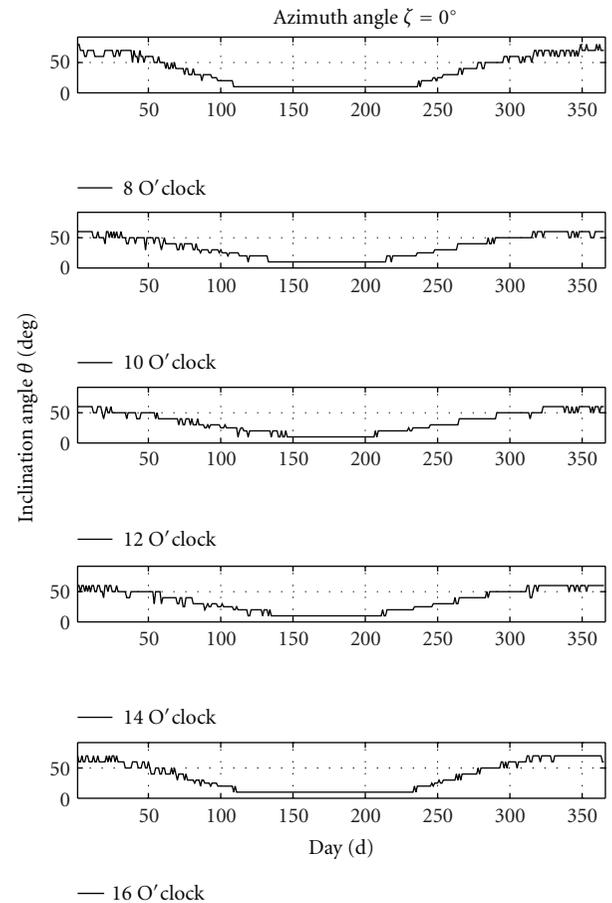


FIGURE 4: Optimal inclination angles  $\theta$  for different times in the day over all the year while the azimuth angle is set to  $\zeta = 0^\circ$ .

The effect of tracking can be measured as “gain”  $g$ , which is defined as the ratio of the energy produced in deflected positions to the energy produced in the fixed position system [10]; therefore, the gain of the one-axis system of fixed azimuth and varying inclination angles is  $g = 5.87\%$  at optimal inclination angles.

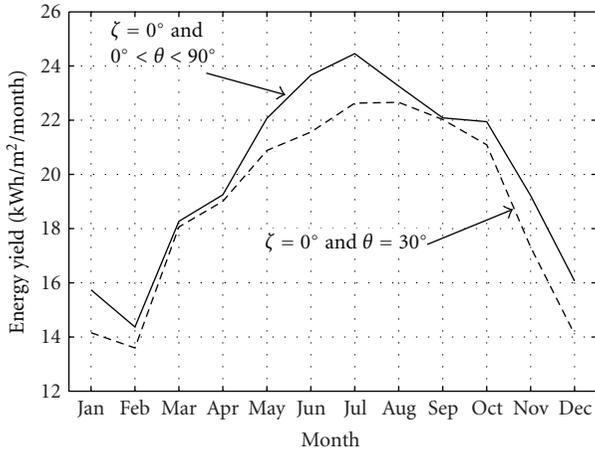


FIGURE 5: Energy yield of fixed (fixing both  $\zeta$  and  $\theta$ ) and one-axis (fixing  $\zeta$  and varying  $\theta$ ) PV systems for each month. The maximum energy yield occurs in July for both lines. The gain of such tracking over the fixed one is 5.87%.

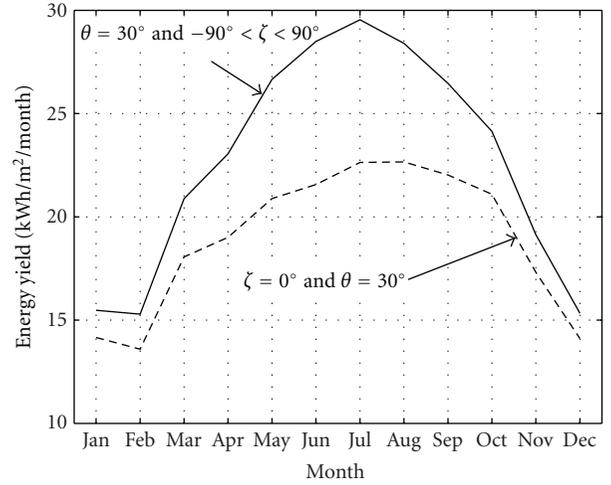


FIGURE 7: Energy yield of fixed (fixing both  $\zeta$  and  $\theta$ ) and one-axis (fixing  $\theta$  and varying  $\zeta$ ) PV systems for each month. The maximum energy yield occurs in also July for both curves. The gain of such tracking over the fixed one is 20.12%.

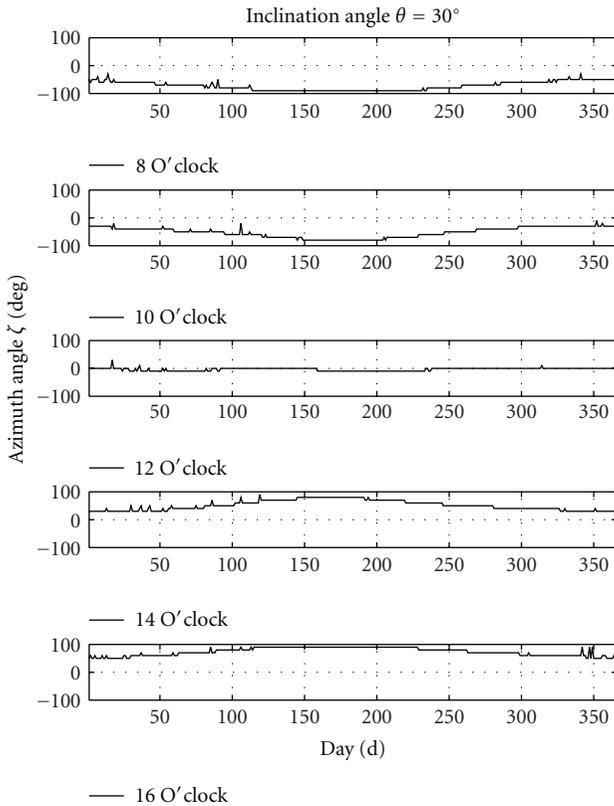


FIGURE 6: Optimal azimuth angles  $\zeta$  for different times in the day over all the year while the inclination angle is set to  $\theta = 30^\circ$ .

3.2. *Fixing Inclination and Varying Azimuth.* A second method of optimizing the one-axis tracking system is by fixing the inclination angle at  $\theta = 30^\circ$ , while the azimuth angle varies from  $\zeta = -90^\circ$  to  $\zeta = 90^\circ$  (i.e., from east to west). The energy yield of this system is calculated on hourly basis during each day of the year. The azimuth angle  $\zeta$  is optimized to result 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 yields of this PV system and that of fixed system are shown in Figure 7. The gain of fixing the inclination and varying azimuth give a  $g = 20.12\%$  at optimal azimuth angles compared to that of fixed system.

#### 4. Energy Yield of Two-Axis Tracking PV System

In this section, we optimize the two-axis tracking system by varying both the azimuth angle  $\zeta = -90^\circ \dots 90^\circ$  and the inclination angle  $\theta = 0^\circ \dots 90^\circ$  simultaneously. The energy yield of the PV systems is maximized for each hour during the day over the entire year by selecting the appropriate angles that maximize the global energy yield. Figure 8 shows the optimal inclination  $\theta$  and azimuth  $\zeta$  angles for every day in the year at the same times used in the last subsections. The energy yield of the two-axis PV system, at optimal azimuth and inclination angles against that of fixed system, is depicted in Figure 9.

The gain of this system is  $g = 30.82\%$  which is superior to both fixed and one-axis systems better than the one discussed before. From those results, one can say that the energy yield of PV systems depends on the effectiveness of the tracking method used. In Figure 10, the energy yield of the three systems considered in this work is plotted on the same graph. From this graph, we notice that the tracking about azimuth or the inclination shows comparable results in the winter months. Table 1 shows a brief comparison between the calculated gains for the energy yields of tracking PV (one- and two-axis) systems.

#### 5. Conclusion

In this paper, we highlighted the potential of the one-axis and two-axis tracking PV systems in improving the energy

TABLE 1: Summary of the improvements for tracking PV systems over fixed systems.

Case	Gain, $g$
Optimal azimuth angle and variable inclination angles	5.87%
Optimal inclination angle and variable azimuth angles	20.12%
Optimal inclination and azimuth angles	30.82%

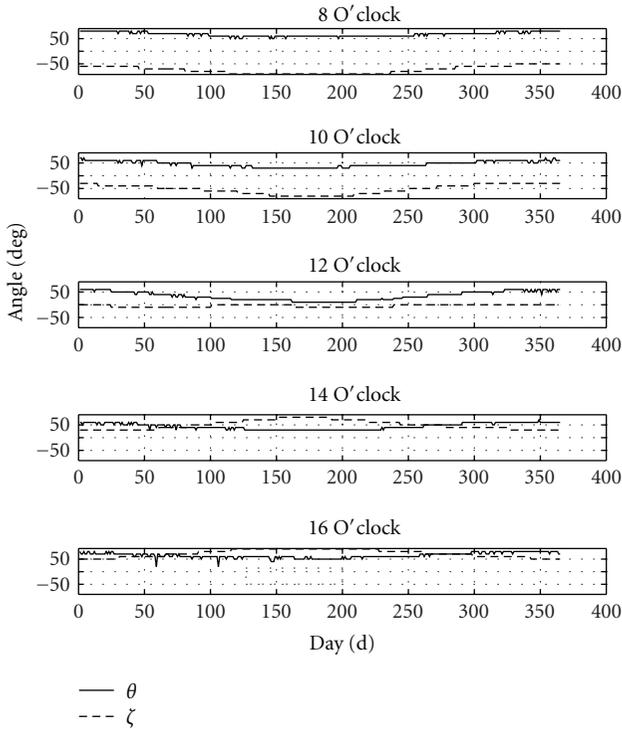


FIGURE 8: Optimal azimuth  $\zeta$  (dashed lines) and inclination  $\theta$  (solid lines) angles are plotted for different times in the day over all the year.

production of solar system 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 could increase the energy produced by more than 30% compared to fixed systems. Therefore, the modules area can be reduced by 30% which cuts cost by the same percentage.

## Nomenclature

$\zeta$ : Azimuth angle  
 $\theta$ : Inclination angle  
 PV: Photovoltaic  
 $g$ : Gain of the tracking system with respect to the fixed  
 $\eta$ : Efficiency of the PV modules.

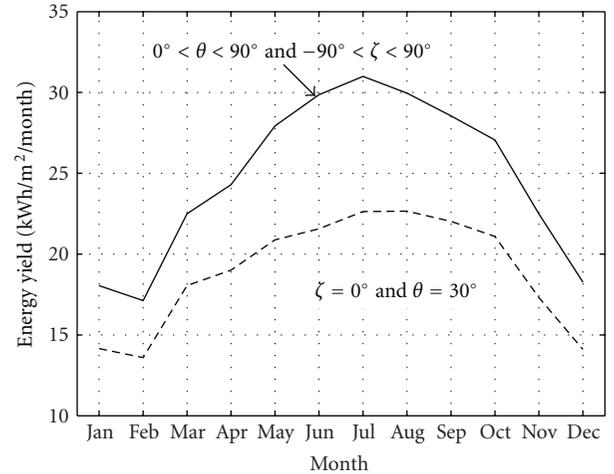


FIGURE 9: Energy yield of fixed (fixing both  $\zeta$  and  $\theta$ ) and two-axis (varying both  $\theta$  and  $\zeta$ ) PV systems for each month. The maximum energy yield occurs in also July for both lines. The gain of such tracking over the fixed one is 30.82%.

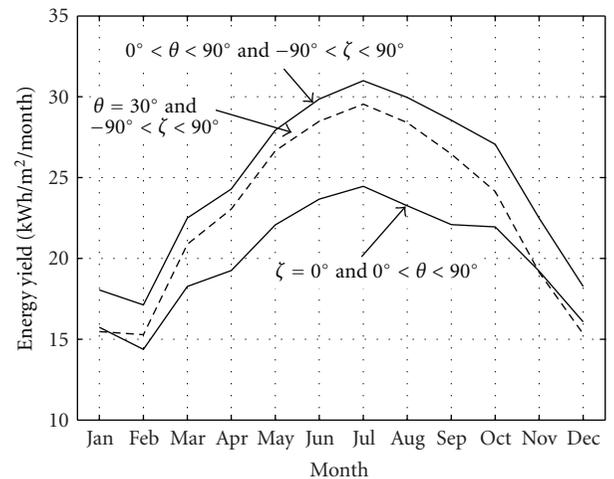


FIGURE 10: Comparison of the energy yield of the two-axis (variable  $\theta$  and  $\zeta$ ) and the one-axis (fixing  $\zeta$  or  $\theta$ ) tracking of PV systems. The tracking about azimuth or the inclination shows comparable results to each other in the winter months.

## Conflict of Interests

There is no conflict of interests in this paper. As a corresponding author for this paper, A. Al Tarabsheh does not have any financial or personal relationships with other people or organizations.

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