Influence of Orientation and Tilt on Solar Panel Performance

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ABSTRACT

This comprehensive study explores the impact of solar panel orientation and tilt on their efficiency in photovoltaic energy generation. By analyzing the results of three distinct experiments, it highlights the two-axis solar tracker as the most effective method for optimizing solar irradiance reception throughout the day over an extended period. However, it is essential to note that the optimal orientation of solar panels depends on the specific geographic location, while a 60-degree tilt proved particularly effective for a specific day. This research provides crucial insights for designing more efficient and sustainable solar systems and contributes significantly to the ongoing shift toward clean and renewable energy sources.

Key Words: Solar Energy, Optimum Tilt Angle, Orientation Angle, Solar Radiation, Photovoltaic.

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Introduction

Photovoltaic (PV) solar energy plays a pivotal role in the transition to clean and sustainable energy sources, offering a critical alternative to fossil fuels. This innovative technology enables the capture of solar light and its conversion into a valuable source of renewable electricity, contributing to a reduction in our carbon footprint. To maximize the performance of PV installations, understanding key parameters, such as solar panel orientation and tilt, is imperative. Orientation, defining the angle relative to true north, and tilt, determining the angle relative to the horizontal, are critical factors that can either enhance or hinder the performance of PV systems (Fouad, 2017). These parameters are flexible and vary by geographic location, highlighting the importance of regional considerations. Due to the sun's ever-changing position, evaluating these parameters carefully is crucial for optimal energy production. In this context, this study aims to thoroughly examine the influence of solar panel orientation and tilt on energy production. Through rigorous methodology and in-depth analysis, our research contributes significantly to our understanding of the optimal configuration of solar panels to maximize energy yield.

Literature Review

The study of the impact of solar panel orientation and tilt on energy production is a crucial research area in the realm of solar energy. Researchers worldwide have made significant contributions over the years, profoundly affecting our understanding of key parameters influencing solar system performance.

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Orientation, representing the angle relative to geographic north, and the tilt of solar panels, determining the angle relative to the horizontal, are decisive factors that can either optimize or

compromise the performance of photovoltaic installations (Jäger, 2014). These choices directly affect the amount of solar energy captured and converted into electricity and vary by geographic location.

The orientation of solar panels plays a pivotal role in maximizing photovoltaic energy production. Researchers such as Siraki et al. have conducted a comprehensive analysis of tilt and azimuth angles for photovoltaic systems, emphasizing the importance of considering local characteristics when planning solar panel orientation (Siraki, 2012). Guo et al. have demonstrated that it is widely recognized that facing south in the northern hemisphere or north in the southern hemisphere maximizes solar light capture throughout the day, thereby increasing energy production (Guo, 2017). However, in specific situations where electricity demand varies throughout the day, other orientations may be justified (Mondol, 2007).

Other researchers have used experimental approaches to determine the optimal tilt angle for photovoltaic panels. Chang examined the apparent position of the Sun and the optimal tilt angle of a solar sensor in the northern hemisphere, highlighting the importance of geographic orientation (Chang, 2009). Kaldellis conducted a meticulous study on the optimal tilt angle of solar panels during the summer period, emphasizing crucial seasonal variations (Kaldellis, 2012). Le Roux provided valuable data by determining the optimal tilt and azimuth angles for fixed solar sensors in South Africa, based on real measurements. The importance of considering geographical specifics is a key concept (Le Roux, 2016). Kaddoura proposed specific recommendations to maximize the energy efficiency of photovoltaic solar energy in Saudi Arabia, taking into account the particular conditions of the region (Kaddoura, 2016). Hussein and Salih presented results claiming that for every location on Earth with varying radiation characteristics, it is possible to find an optimal tilt angle for the best reception of solar energy (Hussein, 2004; Salih, 2014).

In general, an inclination angle equal to the geographical latitude can be a first approximation to maximize annual energy production. However, finer adjustments based on seasons can further enhance performance (Benghanem, 2011). Stanciu and Hafez conducted research to precisely determine the optimal maximum tilt angle for photovoltaic panels for any country in the world (Stanciu, 2014; Hafez, 2017). These considerations extend beyond solar panel orientation. Kamali quantified the impact of azimuth angle variations on annual photovoltaic energy production, emphasizing the importance of accurate orientation. Furthermore, solar panel efficiency is also influenced by aspects related to the electrical system (Kamali, 2006). Hartner examined the optimal tilt and orientation angles of photovoltaic panels from the perspective of the electrical grid, exploring the benefits for grid integration(Hartner, 2015). Mishra developed an intelligent dual-axis solar tracker based on Arduino, providing an innovative solution for optimizing solar panel orientation (Mishra, 2017).

Studies have also extended to regional variations. Rowlands studied the optimal tilt and orientation angles of photovoltaic thermal systems for use in the Ontario region, Canada (Rowlands, 2011). Yadav conducted experimental and mathematical research on the optimal tilt angle and the effects of reflectors on photovoltaic energy production. Finally, global assessments have been proposed (Yadav, 2013). Dubey provided global estimates of optimal PV tilt angles, as well as insolation ratios for tilted and tracking panels compared to horizontal panels (Dubey, 2013).

Further studies have also provided recommendations regarding fixed tilt and azimuth angles for specific locations, such as South Africa (Le Roux 2016), India (Yadav, 2014), Iran (Jafarkazemi, 2012), the United States(Lave, 2011), Turkey (Bakirci, 2012), Indonesia

(Kurnianto, 2017), China (Tang, 2004), Nigeria (Udoakah, 2015), and the United Arab Emirates (Jafarkazemi, 2013). This research emphasizes the importance of considering these previous works when planning and designing photovoltaic systems, especially based on specific geographic locations, with the goal of optimizing solar energy production.

Despite significant advancements, gaps remain in the literature. Region-specific studies are necessary due to climate variations, sunlight hours, and energy demand differences. Furthermore, while existing studies have mainly focused on fixed photovoltaic installations, there is a growing interest in one or two-axis solar tracking systems, which could significantly improve solar panel efficiency (Ghosh, 2010). Further research is needed to assess the benefits of these systems in various geographic and climatic contexts.

Experiment 1: Impact of Solar Panel Tilt

In this experiment, we assessed the impact of solar panel tilt on their performance using three solar panel kits with tilts of 30°, 45°, and 60°, all oriented towards the south (figure 1). The goal was to determine the optimal tilt angle that would yield the best solar irradiance.

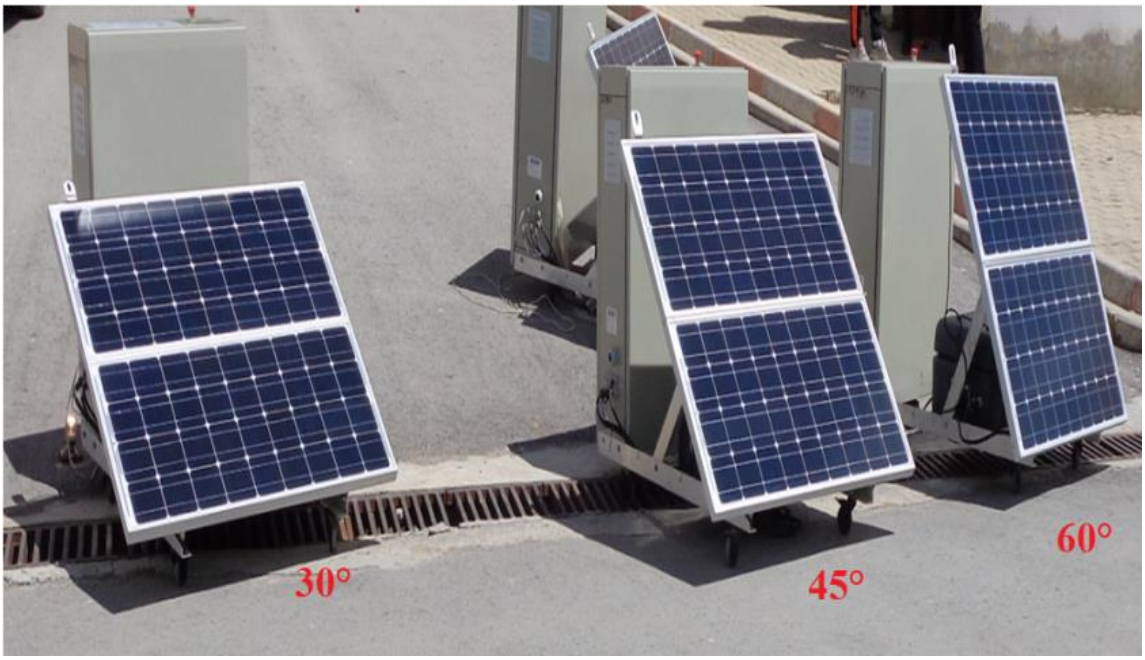

Figure 1. The image of the three solar panel kits with tilts of 30°, 45° and 60°

Methodology

- Three solar panel kits were installed with tilts of 30°, 45°, and 60°, all fixed in a southward orientation.
- Solar irradiance data were collected every hour during the period from 09:00 to 15:00.
- The average solar irradiance values for each kit were recorded and compared.

Results

The results of the experiment, depicted in Figure 2, indicate that the kit with a 60° tilt achieved the highest and most consistent performance throughout the day. This is particularly noticeable when compared to the other two kits, which exhibited a noticeable deviation at each measurement hour.

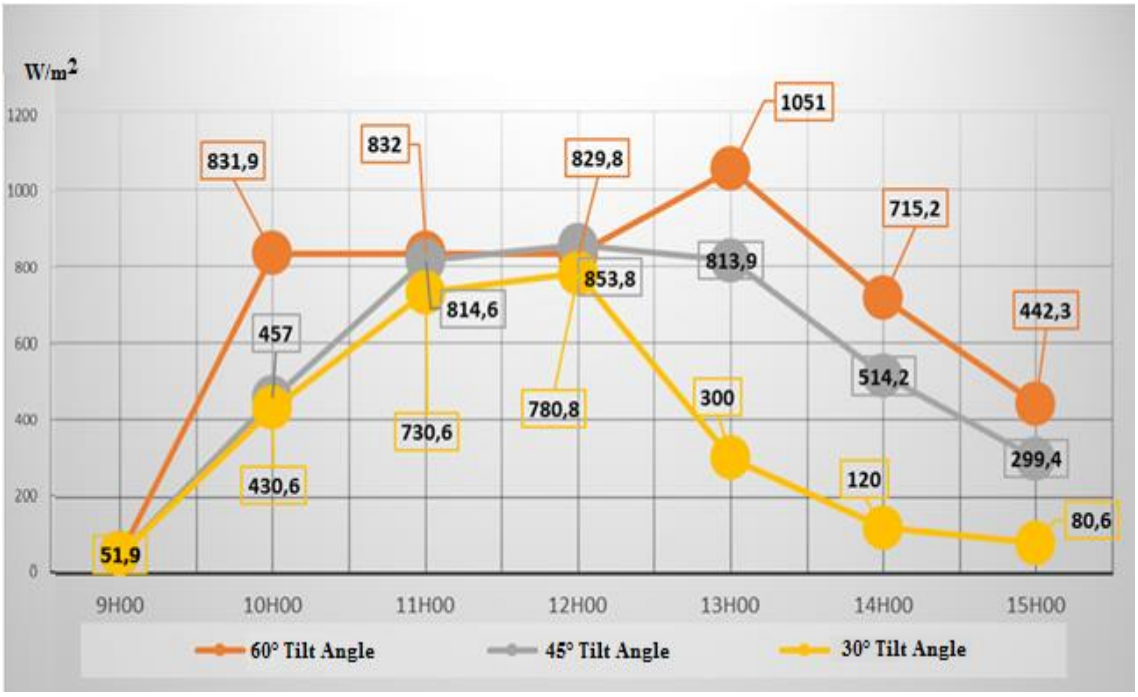

Figure 2. Comparison of the impact of solar panel tilt

To confirm these observations, we calculated the optimal hourly and daily angles for this measurement day using the "Motions of the Sun Simulator" software. The results are summarized in Table 1.

The analysis of the theoretical results confirms that the optimal angle for this measurement day was 60°, which corresponds to the tilt of the kit that achieved the highest performance.

Table 1. Optimal hourly and daily tilt angles

Time	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h
Hourly optimal tilt angle	84.7	72.6	60.6	48.9	38.4	30.2	26.9	30.1	38.2	48.7	60.3	72.3	84.4	90.0
Daily optimal tilt angle	56.16													

Conclusion

This experiment demonstrates that the tilt of solar panels has a significant impact on their performance. In this specific case, a tilt of 60° yielded the most favorable results in terms of solar irradiance. This information can be valuable for the optimization of solar panel installations to maximize solar energy production.

Experiment 2: Comparison Between a Fixed Solar Kit and a Single-Axis Tracking Kit

In this second experiment, our goal is to analyze the impact of the orientation of photovoltaic solar panels on solar energy production. We deliberately chose an inclination angle of 30° for our solar panels. We set up two configurations of solar kits, all inclined at this fixed angle but with different orientations. The first kit is fixedly oriented toward the south, while the second kit has been specially configured as a single-axis solar tracking system, with manual azimuth adjustments made every half-hour to follow the sun's trajectory.

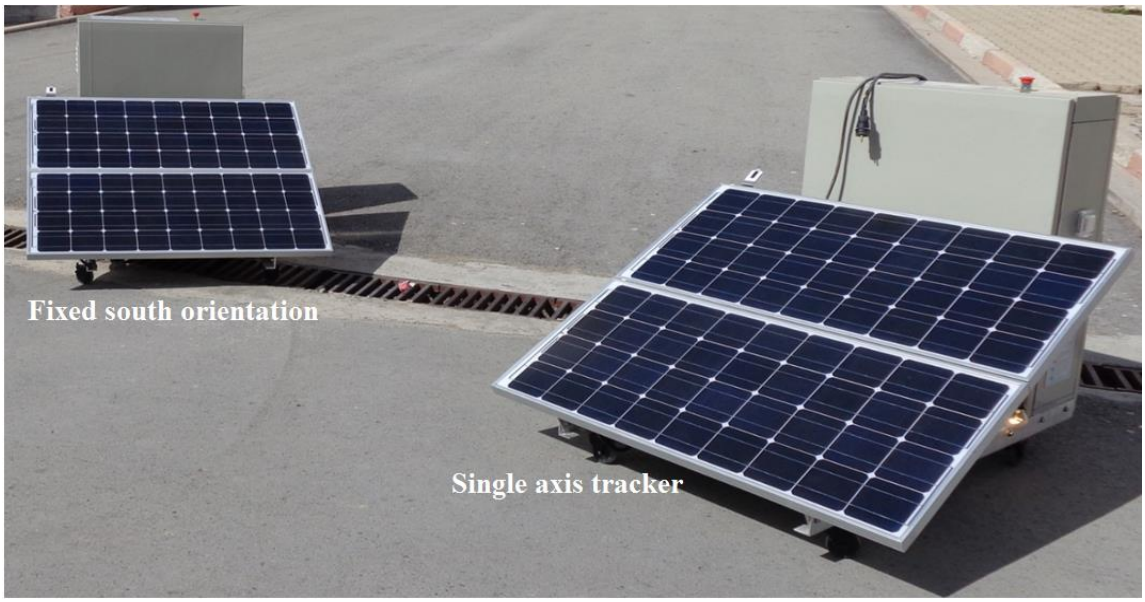

Figure 3. The image of a single-axis tracking kit and the fixed south-facing kit

Methodology

- Two identical solar panel kits with a 30° tilt were installed.
- The first kit was set up as a single-axis solar tracker with manual azimuth adjustments every half-hour.
- The second kit was consistently oriented towards the south.
- Solar irradiance data was collected every hour during the period from 09:00 to 14:00.

Figure 4. Comparison of the performance between the single-axis tracking kit and the fixed south-facing kit

Results

Figure 4 presents the results of the experiment, comparing the average solar irradiance values for each hour between the two kits.

The analysis of the results reveals that both configurations of solar panel kits produced nearly identical solar irradiance values during the early hours of the experiment, from 9 a.m. to 11 a.m. However, starting at 11 a.m., the solar kit equipped with a single-axis solar tracker began to maintain maximum irradiance intensity, while the fixed south-facing kit showed a gradual decline in irradiance. The gap continues to widen until the end of the experiment. The irradiance intensity of the single-axis tracking kit even reaches double that of the south-facing kit. These observations clearly indicate the advantage of single-axis solar tracking for maximizing solar energy production.

Conclusion

The results of this experiment highlight the significant advantage of single-axis solar tracking for maximizing solar energy production. This configuration allows for the maintenance of maximum solar irradiance intensity for a longer duration throughout the day, resulting in a significant increase in energy production.

Experiment 3: Two-Axis Solar Tracker for Optimal Angle

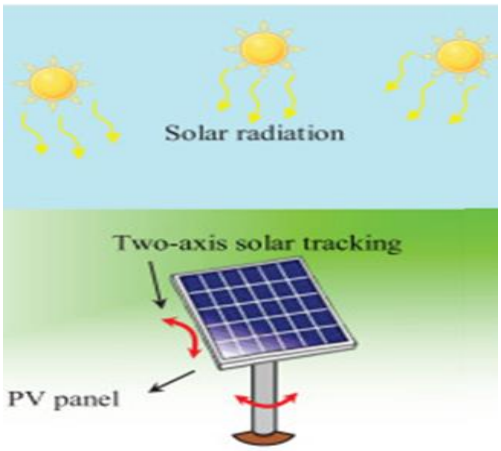

Figure 5. Two-axis solar tracker: tilt and azimuth angles

In this third experiment, our goal was to determine the effectiveness of a two-axis solar tracker in maintaining an optimal angle for each measurement hour, compared to the previous configurations. To achieve this, a single solar panel kit was used with manual orientation capability, capable of tracking the solar path by adjusting its tilt and azimuth angles (figure 5).

Methodology

- A single solar panel kit was installed with a two-axis solar tracking mechanism, allowing manual adjustment of the tilt and azimuth angle to track the solar path.
- Solar irradiance data was collected every hour throughout the day to assess the performance of the two-axis solar tracker.

Results

The results of the experiment are presented in Figure 6, summarizing the average hourly irradiance throughout the day.

The measurements from the reference cell revealed that the solar panel kit equipped with a two-axis solar tracker displayed maximum irradiance values exceeding 1000 W/m² for over 9 hours during the day. These results further support the theory that PV systems with a two-axis tracker ensure significantly higher solar irradiance reception throughout the sunlight hours.

Conclusion

The results of this experiment confirm the efficiency of a two-axis solar tracker in maximizing solar irradiance reception. This configuration allows for maintaining an optimal angle at each measurement hour, ensuring high irradiance values throughout the day.

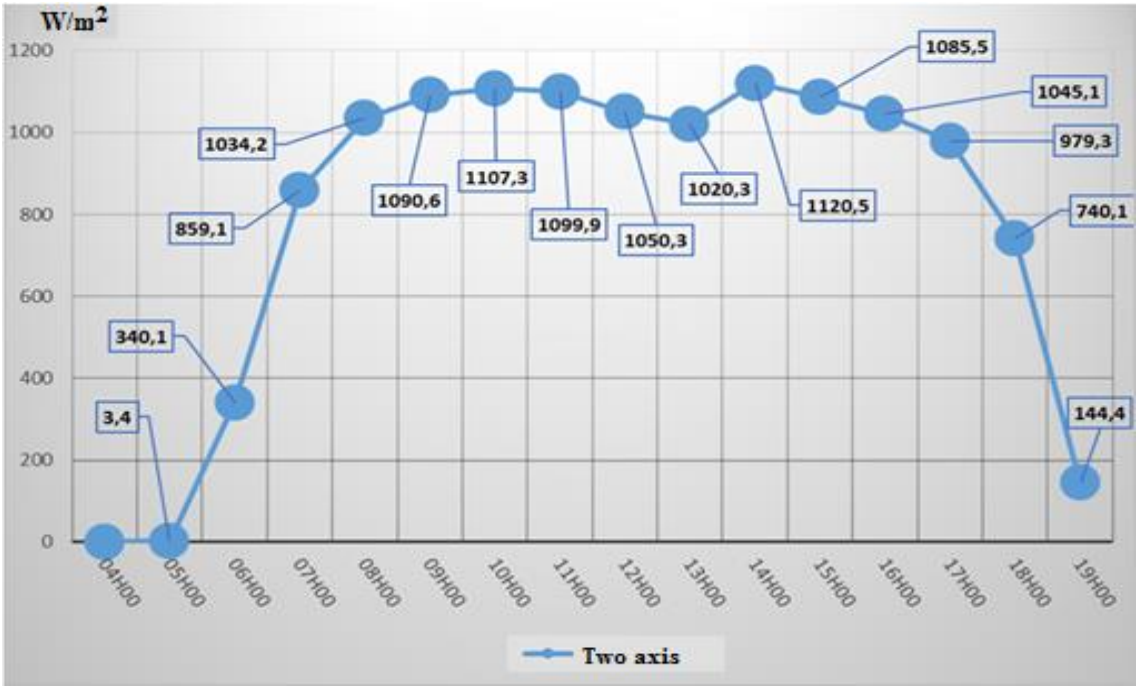

Figure 6. Average hourly irradiance profile over the course of the day

Comparison of Results from the Three Experiments

To determine the most effective method for maximizing photovoltaic energy production, we compared the results from the three experiments. These experiments allowed us to assess the performance of different solar panel configurations in real-world conditions.

The first curve in Figure 7 represents the results of the experiment using a two-axis solar tracker. It displays the best solar irradiance results, exceeding 1000 W/m² for an extended period, notably up to 9 hours. This curve highlights the two-axis solar tracker's ability to maintain maximum solar irradiance reception, making it a promising option increasing energy production.

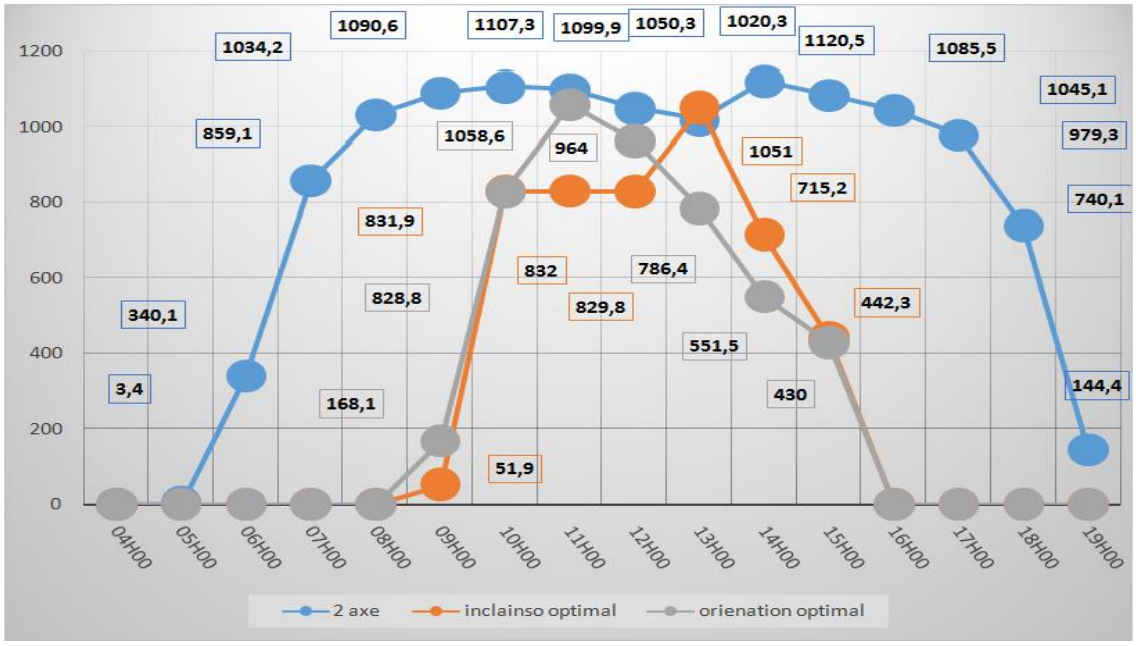

Figure 7. Results from the three experiments

In order to gain a better understanding of the performance and production of the two-axis method, four consecutive days of production were recorded. The system was isolated, meaning it was not connected to a charger, allowing for an assessment of its behavior under normal operating conditions. The results of these four days of production are presented in Figure 8

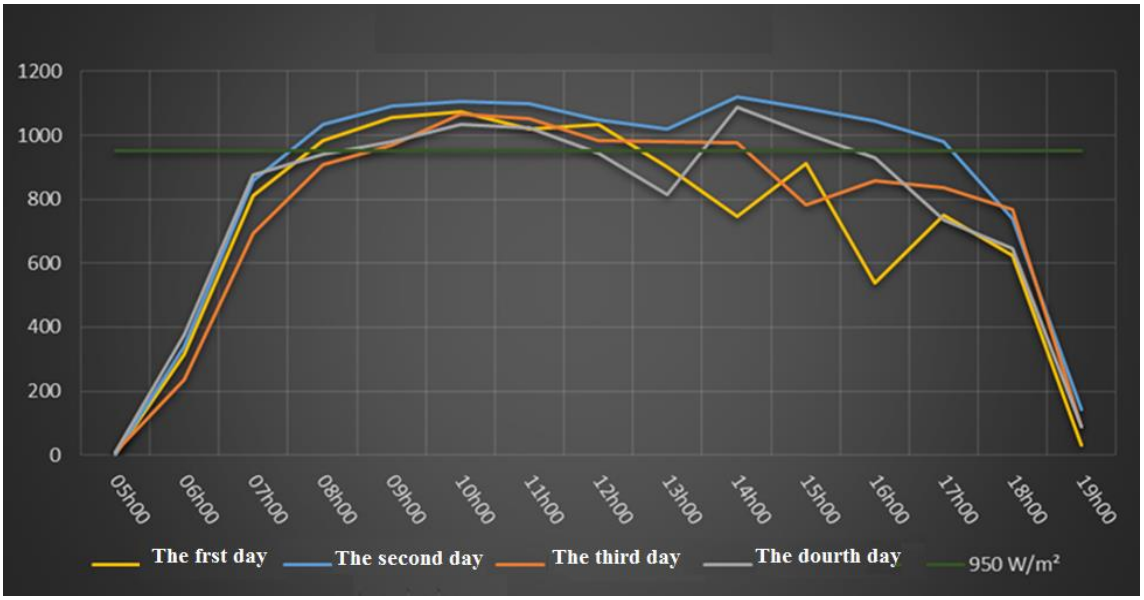

Figure 8. The results of the four days of production

Upon observing these cumulative results, it becomes evident that the two-axis solar tracker is the most effective method for maximizing solar irradiance reception and increasing photovoltaic energy production. This configuration stands out for its ability to maintain a high irradiance intensity for a significant portion of the day. Therefore, in selecting the best condition for our kit and ensuring maximum photovoltaic energy production, the two-axis solar tracker method emerges as the optimal solution. This conclusion is supported by empirical data and tangible results, affirming the effectiveness of this configuration.

General Conclusion

The entirety of these three experiments has provided valuable insights into the impact of orientation, tilt, and solar tracking on the performance of photovoltaic solar panels. These experiments have highlighted key elements for maximizing solar energy production under various conditions.

The first experiment underscored the significance of the tilt of solar panels, with a 60° tilt proving optimal for a specific day. The second experiment showcased the advantages of single-axis solar tracking in maintaining maximum irradiance intensity for an extended duration compared to a fixed installation. The third experiment confirmed that dual-axis solar tracking enables the maintenance of an optimal angle at every measurement hour, guaranteeing high irradiance values throughout the day. Comparing the results of the three experiments has identified the dual-axis solar tracker as the most promising method for maximizing photovoltaic energy production. This configuration offers superior performance, ensuring high solar irradiance reception over extended periods.

The knowledge gained from these experiments can contribute to the design of more efficient and economically viable solar systems and aid in the transition toward a more sustainable energy future.

References

Bakirci K, General models for optimum tilt angles of solar panels: Turkey case study, Renewable and Sustainable Energy Reviews (2012), 16(8), 6149–6159. doi:10.1016/j.rser.2012.07.009

Benghanem M, Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia. Applied Energy (2011), 88(4), 1427–1433. doi: 10.1016/j.apenergy.2010.10.001.

Chang TP, The Sun's apparent position and the optimal tilt angle of a solar collector in the northern hemisphere. Solar Energy, (2009), 83(8), 1274-1284. doi:org/10.1016/j.solener.2009.02.009

Dubey S, Sarvaiya JN and Seshadri B, Temperature dependent photovoltaic (PV) efficiency and its effect on PV Production in the World – A Review. Energy Procedia (2013) 33, 311–321. doi.org/10.1016/j.egypro.2013.05.072

Fouad M, Shihata LA and Morgan EI, An integrated review of factors influencing the performance of photovoltaic panels. Renewable and Sustainable Energy Reviews (2017), 80, 1499–1511. doi: 10.1016/j.rser.2017.05.141.

Ghosh HR, Bhowmik NC and Hussain M, Determining seasonal optimum tilt angles, solar radiations on variously oriented, single and double axis tracking surfaces at Dhaka. Renewable Energy (2010), 35(6), 1292–1297. doi:10.1016/j.renene.2009.11.041.

Guo M, Zang H, Gao S, Chen T, Xiao J, Cheng L and Sun G, Optimal Tilt Angle and Orientation of Photovoltaic Modules Using HS Algorithm in Different Climates of China. Applied Sciences, (2017), 7(10), 1028.

Hafez, A.Z.; Soliman, A.; El-Metwally, I.M.; Ismail, I.M. Tilt and Azimuth Angles in Solar Energy Applications—A Review. Renewable and Sustainable Energy Reviews (2017), 77, 147–168. doi.org/10.1016/j.rser.2017.03.131

Hartner M, Ortner A, Hiesl A and Haas R, East to west The optimal tilt angle and orientation of photovoltaic panels from an electricity system perspective. Applied Energy (2015), 160, 94–107.

Hussein HMS, Ahmad GE, Elghetany HH, Performance evaluation of photovoltaic modules at different tilt angles and orientations. Energy Conversion and Management, (2004), 45(15), 2441–2452. doi.org/10.1016/j.enconman.2003.11.013

Jafarkazemi F, Ali Saadabadi S and Pasdarshahri H, The optimum tilt angle for flat-plate solar collectors in Iran, Journal of Renewable and Sustainable Energy, (2012), 4(1), 013118. doi:10.1063/1.3688024

Jafarkazemi F, Saadabadi SA. Optimum tilt angle and orientation of solar surfaces in Abu Dhabi. UAE. Renewable energy (2013), 56(C), 44–49. doi:10.1016/j.renene.2012.10.036

Jäger K, Isabella O, Smets AHM, Swaaij RAC and Zeman M Solar Energy: Fundamentals, Technology and Systems, Netherland Delft University of Technology, (2014).

Kaddoura TO, Ramli MAM, Al-Turki YA, On the estimation of the optimum tilt angle of PV panel in Saudi Arabia, Renewable and Sustainable Energy Reviews (2016), 65 ,626-634. doi.org/10.1016/j.rser.2016.07.032

Kaldellis J and Zafirakis D, Experimental investigation of the optimum photovoltaic panels' tilt angle during the summer period. Energy, (2012), 38(1), 305-314. doi:org/10.1016/j.energy.2011.11.058

Kamali G, Moradi I and Khalili A, Estimating solar radiation on tilted surfaces with various orientations: a study case in Karaj (Iran). Theoretical and Applied Climatology (2006), 84, 235–241. doi.org/10.1007/s00704-005-0171-y

Kamali G, Moradi I and Khalili A, Estimating solar radiation on tilted surfaces with various orientations: a study case in Karaj (Iran). Theoretical and Applied Climatology (2006), 84, 235–241. doi.org/10.1007/s00704-005-0171-y

Kurnianto R, Hiendro A and Ismail Yusuf HM, Optimum orientation angles for photovoltaic arrays to maximize energy gain at near equator location in Indonesia. International Review of Automatic Control (I.RE.A.CO.) (2017), 10(1), 86–91. doi:10.15866/ireaco.v10i1.11017

Lave M and Kleissl J. Optimum fixed orientations and benefits of tracking for capturing solar radiation in the continental United States. Renewable Energy (2011), 36(3), 1145–1152. doi:10.1016/j.renene.2010.07.032

Le Roux WG, Optimum tilt and azimuth angles for fixed solar collectors in South Africa using measured data. Renewable Energy, (2016), 96, 603-612. doi:org/10.1016/j.renene.2016.05.003

Mishra J, Thakur R and Deep A, Arduino based Dual Axis Smart Solar Tracker. International Journal of Advanced Engineering, Management and Science (2017), 3(5), 532–535. doi:10.24001/ijaems.3.5.20

Mondol JD, Yohanis YG and Norton B. The impact of array inclination and orientation on the performance of a grid-connected photovoltaic system. Renewable Energy, (2007), 32(1), 118-140.

Rowlands IH, Kemery BP and Beausoleil-Morrison I, Optimal Solar PV Tilt Angle and Azimuth : An Ontario (Canada) Case-Study. Energy Policy (2011), 39(3), 1397–1409. doi.org/10.1016/j.enpol.2010.12.012

Salih SM and Kadim LA, Effect of tilt angle orientation on photovoltaic module performance. Journal of Science and Technology (2014), 10(17), 19–25.

Siraki AG and Pillay P, Study of Optimum Tilts Angles for Solar Panels in Different Latitudes for Urban Applications, Solar Energy, (2012), 86(6),1920-1928. doi:org/10.1016/j.solener.2012.02.030

Stanciu C, and Stanciu D, Optimum tilt angle for flat plate collectors all over the World – A declination dependence formula and comparisons of three solar radiation models. Energy Conversion and Management, (2014), 81, 133-143. doi.org/10.1016/j.enconman.2014.02.016

Tang R and Wu T, Optimal tilt-angles for solar collectors used in China, Applied Energy (2004), 79(3), 239-248. doi:10.1016/j.apenergy.2004.01.003.

Udoakah Y and Okpura N, Determination of optimal tilt angle for maximum solar insolation for PV systems in enugu-southern Nigeria. Nigerian Journal of Technology (2015), 34(4), 838–843. doi:10.4314/njt.v34i4.24

Yadav P and Chandel SS, Tilt angle optimization to maximize incident solar radiation: a review. Renewable and Sustainable Energy Reviews (2013), 23, 503–513. doi.org/10.1016/j.rser.2013.02.027

Yadav P and Chandel SS, Comparative analysis of diffused solar radiation models for optimum tilt angle determination for Indian locations. Applied Solar Energy, (2014), 50(1), 53–59. doi:10.3103/S0003701X14010137