Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 641-646, 11, 2024
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Araştırma Makalesi

IJANSER

https://as-proceeding.com/index.php/ijanser
ISSN:2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 641-646, 11, 2024
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Research Article

Assessment of Photovoltaic Panel Efficiency at Various Tilt Angles in Mersin Province During the Cooling Season

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(Received: 16 December 2024, Accepted: 20 December 2024)

(4th International Conference on Frontiers in Academic Research ICFAR 2024, December 13-14, 2024)

ATIF/REFERENCE: Ünal, F., Acar, M. Ş. & Demir, B. (2024). Assessment of Photovoltaic Panel Efficiency at Various Tilt Angles in Mersin Province During the Cooling Season. *International Journal of Advanced Natural Sciences and Engineering Researches*, 8(11), 641-646.

***Abstract* –** This study evaluates the efficiency of photovoltaic (PV) panels in Mersin Province during the cooling season by analyzing performance optimization under varying tilt angles. During the summer months, when solar radiation reaches the Earth at higher angles, it is crucial to adjust PV panels to the optimal tilt angles to maximize efficiency. For this purpose, local meteorological data for Mersin Province were analyzed using the EnergyPlus software, and the performance of PV panels under various tilt angles was simulated. The study examines the variations in panel efficiency caused by environmental conditions and evaluates the outcomes achieved at different tilt angles. Through the integration of theoretical calculations and simulation techniques, the impact of tilt angle on the energy production of PV panels was comprehensively assessed. Initial findings indicate that steeper tilt angles during summer months enhance solar radiation capture, thereby increasing efficiency. Furthermore, the research underscores the importance of determining optimal tilt angles specific to each geographical region as a key strategy to improve the efficiency of PV systems. This study contributes to improving energy efficiency by identifying suitable tilt angles to optimize the performance of PV panels in Mersin Province during the cooling season.

Keywords – Photovoltaic Panel Efficiency, Tilt Angle, Cooling Season, Mersin, Solar Radiation.

I. INTRODUCTION

Photovoltaic (PV) panels, a key component of the global energy transition, offer an effective technology for harnessing solar energy with high efficiency. However, the efficiency of PV systems hinges not only on the technology and materials employed but also on the alignment of the panels with the sun. This alignment, which determines the tilt angle of the panel, directly influences how effectively sunlight is absorbed. During the summer months, when solar irradiance reaches the Earth at higher angles, the importance of adjusting the tilt angles of PV panels for optimal performance becomes even more critical. Regions with Mediterranean climates, such as Mersin, Turkey, typically experience hot, sunny summers. These conditions necessitate precise optimization of tilt angles to maximize the efficiency of photovoltaic energy systems. During these months of intense solar radiation, adjusting the panel's tilt angle to match the sun's position directly impacts energy production. Accurate determination of tilt angles plays a crucial role in achieving both energy generation and economic benefits, ultimately enhancing the long-term efficiency of the system.

Recent research underscores the significance of optimizing PV panel tilt angles for efficient solar energy utilization. Studies by Gopinathan [1] and Mehleri [2], analyzing solar irradiance and tilt angles across various geographical regions, have explored how optimal tilt angles can enhance system efficiency. Similarly, Moghadam [3] and Khorasanizadeh [4] have demonstrated how optimizing tilt angles for different climatic conditions can improve the energy efficiency of PV panels. Kazem and Chaichan [5] examined the influence of relative humidity on PV system performance, emphasizing its inverse relationship with solar irradiance, wind speed, and ambient temperature. These studies collectively highlight the importance of adapting PV systems to specific geographical and climatic conditions.

In Mersin, the combination of high temperatures and abundant sunshine during summer allows for efficient solar energy collection with appropriate tilt angles. Therefore, this study aims to investigate the performance of PV panels in Mersin and determine the optimal tilt angles throughout the summer season to optimize energy production. By doing so, solar energy generation in the region will be increased, contributing to the development of more sustainable energy systems. This research seeks to emphasize the importance of selecting appropriate tilt angles to enhance the efficiency of solar energy.

II. MATERIALS AND METHOD

This study was conducted in Mersin, a city located in southern Turkey, specifically on the campus of Mersin University's Faculty of Engineering. The primary objective was to investigate the efficiency of photovoltaic (PV) panels with varying tilt angles during the cooling season, defined as the period between May and September when solar irradiance and temperatures are typically higher. To optimize photovoltaic energy production, five distinct tilt angles (15°, 30°, 45°, 60°, and 75°) were employed. These angles were selected based on the environmental conditions prevalent in Mersin, allowing for the evaluation of panel efficiency under different parameters. The study relied on meteorological data specific to Mersin, encompassing ambient temperature, wind speed, and solar irradiance. This data was crucial for accurately simulating the performance of the photovoltaic panels and understanding the influence of environmental conditions on panel efficiency. Mersin's Mediterranean climate, characterized by significant variations in solar irradiance and temperature, plays a key role in influencing the efficiency of PV panels. To simulate the performance of the photovoltaic panels under different tilt angles, EnergyPlus software was utilized. EnergyPlus is a comprehensive energy simulation tool designed for building energy efficiency analysis and modeling the performance of renewable energy systems. It is particularly well-suited for accurately modeling the effects of solar irradiance on panels at various tilt angles. Using EnergyPlus, the efficiency of the photovoltaic systems was evaluated for each tilt angle, incorporating the collected meteorological data.

The study examined five different tilt angles: 15°, 30°, 45°, 60°, and 75°. These angles were strategically chosen to maximize the utilization of solar irradiance during the cooling season in Mersin, when solar radiation is high. Given the higher angle of solar irradiance during this period, selecting appropriate tilt angles ensures the most efficient collection of sunlight, thereby enhancing energy efficiency. The study meticulously investigated the efficiency of photovoltaic systems across these different tilt angles.

Throughout the study, monthly average DC power output and panel efficiency served as key performance indicators to assess the impact of each tilt angle on the overall performance of the photovoltaic panels. DC power output represents the panel's electricity generation capacity in response to solar irradiance at each tilt angle, while efficiency indicates the effectiveness of this energy conversion. These performance metrics facilitated a comprehensive analysis of the influence of each tilt angle on the efficiency of the PV systems. Ultimately, this study aims to determine the optimal tilt angle for maximizing the efficiency of photovoltaic panels during the cooling season. The monthly average values of the meteorological data for the cooling season in Mersin are presented in Table 1.

Table 1 presents the monthly average values of ambient temperatures and wind speeds for the cooling season in Mersin, aiming to assess the performance of photovoltaic panels. The data reveals a consistent increase in average ambient temperature from May, with an initial measurement of 21.941 °C, through the summer months. June, July, and August recorded temperatures of 25.778 °C, 28.760 °C, and 29.045 °C, respectively, highlighting the impact of increased solar irradiance on temperature elevation during this period. By September, the temperature drops to 25.593 °C, indicating a decreasing trend towards the end of the cooling season. Analysis of wind speeds shows an average speed of 2.299 m/s in May, with minor fluctuations throughout the summer months. Wind speeds remain relatively consistent in June and July at 2.393 m/s and 2.391 m/s, respectively, before decreasing to 2.288 m/s in August and reaching the lowest value of 2.203 m/s in September. These consistently low wind speeds suggest a limited contribution to the natural cooling mechanisms of the panels. Considering that elevated temperatures can negatively impact the efficiency of photovoltaic panels, and that the cooling effect of low wind speeds may be limited, this data emphasizes the significance of temperature as a critical parameter in determining optimal panel tilt angles. Specifically, the peak temperatures observed in August, coupled with the accompanying low wind speeds, create conditions that can potentially hinder panel performance. This table provides a valuable dataset for understanding the external environmental conditions influencing photovoltaic panel performance and informing the selection of appropriate tilt angles in response to these conditions. The radiation values per unit panel area, dependent on panel tilt angles, are provided in Table 2.

Table 1. The monthly averages of meteorological values during the cooling season

Month	Outdoor Air Temperature [°C](Monthly)	Wind Speed [m/s](Monthly)
May	21.941	2.299
June	25.778	2.393
July	28.760	2.391
August	29.045	2.288
September	25.593	2.203

Table 2. The monthly averages of solar radiation per area during the cooling season

Month	Tilt Angle	Solar Radiation Rate per Area [W/m^2](Monthly)
May	15	265.7771
	30	254.7345
	45	231.4061
	60	197.2844
	75	154.4371
June	15	283.8066
	30	266.7109
	45	236.705
	60	195.832
	75	148.0207
July	15	277.4591
	30	262.9876
	45	235.5299
	60	197.0928
	75	151.2212
August	15	291.0615
	30	287.869
	45	268.6136
	60	234.8991
	75	189.3831
September	15	241.9738
	30	252.1178
	45	248.2226
	60	230.5655
	75	200.4395

Table 2 presents the average solar irradiance values (W/m²) per unit area for photovoltaic panels at different tilt angles in Mersin. The data demonstrates that variations in panel tilt angles significantly influence solar irradiance rates. In May, the highest solar irradiance rate of 265.7771 W/m² was observed at a 15° tilt angle, with a decreasing trend as the tilt angle increased. For instance, at a 75° tilt angle, this value dropped to 154.4371 W/m². This pattern was similarly observed in June and July. June recorded the highest solar irradiance at a 15° tilt angle, measuring 283.8066 W/m², which decreased to 148.0207 W/m² at a 75° tilt angle. July also showed a maximum value of 277.4591 W/m² at a 15° tilt angle, falling to 151.2212 W/m² at 75°. August differed slightly, with the highest irradiance rate recorded at a 30° tilt angle (287.869 W/m²). However, the irradiance value at a 15° tilt angle was very close at 291.0615 W/m². This suggests that minor tilt angle variations in August do not significantly impact solar irradiance. Nonetheless, a notable decrease to 189.3831 W/m² was still observed at a 75° tilt angle. In September, the impact of tilt angle variations became more pronounced. A 15° tilt angle resulted in an irradiance rate of 241.9738 W/m², increasing to 248.2226 W/m² at 45°. However, irradiance values dropped to 230.5655 W/m² and 200.4395 W/m² at 60° and 75° tilt angles, respectively.

This data underscores the need to optimize the tilt angle of photovoltaic panels throughout the year to maximize solar energy collection efficiency in Mersin. Generally, lower tilt angles (especially 15° and 30°) yield higher irradiance rates during the summer months, while steeper angles (45°) can also be beneficial in September. These findings highlight the importance of seasonal tilt angle adjustments to enhance panel performance.

III. RESULTS

This study evaluated the performance of photovoltaic (PV) panels in Mersin, Turkey, throughout the cooling season, examining the effects of tilt angle and seasonal variations. The findings of this investigation are presented in Table 3.

Table 3. Results of PV panel performance with different tilt angles during cooling season months

Tilt Angel		**Month**				
		May	**June**	**July**	**August**	**September**
15	Produced DC Electric Power [W](Monthly)	18.293	18.882	18.265	18.975	16.385
	PV Efficiency (Monthly)	6.302	6.304	6.174	5.863	5.557
	PV Cell Temperature [°C](Monthly)	29.337	33.800	36.482	37.273	32.497
30	Produced DC Electric Power [W](Monthly)	17.520	17.745	17.312	18.690	16.960
	PV Efficiency (Monthly)	6.332	6.311	6.206	5.847	5.534
	PV Cell Temperature [°C](Monthly)	29.022	33.306	36.069	37.177	32.784
45	Produced DC Electric Power [W](Monthly)	15.957	15.784	15.539	17.490	16.702
	PV Efficiency (Monthly)	6.345	6.298	6.181	5.830	5.522
	PV Cell Temperature [°C](Monthly)	28.367	32.448	35.296	36.627	32.670
60	Produced DC Electric Power [W](Monthly)	13.592	13.044	12.999	15.332	15.585
	PV Efficiency (Monthly)	6.280	6.248	6.167	5.840	5.518
	PV Cell Temperature [°C](Monthly)	27.413	31.284	34.220	35.668	32.164
75	Produced DC Electric Power [W](Monthly)	10.556	9.708	9.833	12.278	13.567
	PV Efficiency (Monthly)	6.272	6.217	6.109	5.773	5.464
	PV Cell Temperature [°C](Monthly)	26.217	29.927	32.941	34.376	31.301

Table 3 presents an analysis of DC electrical power output, PV efficiency, and cell temperatures for each tilt angle between May and September. At a 15° tilt angle, the panels generated the highest DC electrical power output in most months, peaking at 18.975 W in August. However, PV efficiency showed a gradual decline throughout the season, decreasing from 6.302% in May to 5.557% in September. This reduction correlated with an increase in PV cell temperatures, which reached their highest point in August at 37.273 °C. Steeper tilt angles (45° and 60°) resulted in lower power output during the summer months, but exhibited a slight increase in September as the solar irradiance angle became more favorable. For instance, at a 45° tilt, power generation reached 16.702 W in September, approaching the output observed at a 15° tilt in the same month. Similarly, PV efficiency fluctuated between 6.272% and 6.345% across all tilt angles, with cell temperatures remaining lower at higher tilts. This suggests that lower cell temperatures may help mitigate efficiency losses. The steepest tilt angle of 75° yielded the lowest power output and efficiency values throughout the season. In June, DC power dropped to 9.708 W, while efficiency decreased to 5.464% in September. However, this tilt angle also maintained the lowest cell temperatures, averaging 29.927 °C in June and decreasing further in September. These results highlight the trade-off between selecting optimal tilt angles for energy generation and minimizing efficiency losses by maintaining lower panel temperatures. Overall, shallower tilt angles (15° and 30°) are more favorable for maximizing energy production during the peak cooling season months of May to August. However, a 45° tilt angle may optimize performance in September. These findings underscore the importance of implementing seasonal tilt angle adjustments to enhance the efficiency of PV panels and maximize energy yield.

IV. DISCUSSION

The findings of this study demonstrate that the performance of photovoltaic panels is significantly influenced by tilt angle and seasonal variations. Shallower tilt angles (specifically 15° and 30°) were found to maximize solar irradiance collection and increase energy production during the summer months. However, the rise in cell temperatures emerged as a significant factor limiting PV efficiency. Steeper tilt angles, particularly 45° and 60°, resulted in lower cell temperatures, contributing to more stable efficiency outcomes. This data emphasizes the importance of implementing seasonal tilt angle adjustments to optimize the performance of PV panels in hot climates like Mersin. Adjusting tilt angles to balance solar irradiance capture with temperature mitigation offers an effective strategy for enhancing energy production while minimizing efficiency losses.

V. CONCLUSION

This study conducted a comprehensive evaluation of photovoltaic panel performance in Mersin, Turkey, during the cooling season, examining the impact of tilt angle and seasonal variations. The results underscore the critical importance of tilt angle optimization in hot climates to maximize energy generation and maintain panel efficiency. It was determined that shallower tilt angles (15° and 30°) captured the highest solar irradiance and yielded the greatest power output during the summer months. However, increased cell temperatures at these angles emerged as a significant factor limiting efficiency. Steeper tilt angles (e.g., 45°) demonstrated improved performance, particularly in September as solar irradiance angles shifted, and maintained more consistent efficiency throughout the season due to lower cell temperatures. These findings emphasize the need for adopting seasonally adjusted tilt angle strategies to optimize PV system performance in regions with high solar irradiance and significant temperature fluctuations. Such strategies can enhance energy yield, improve operational efficiency, and promote the sustainability of solar energy systems.

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