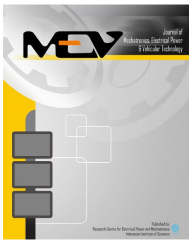
Journal of Mechatronics, Electrical Power, and Vehicular Technology 15 (2024) 23-31

Journal of Mechatronics, Electrical Power, and Vehicular Technology

e-ISSN: 2088-6985
p-ISSN: 2087-3379

mev.brin.go.id



Comparative performance evaluation of dual-axis solar trackers: Enhancing solar harvesting efficiency

Saman Sarkawt Jaafar *, Hiwa Abdlla Maarof, Hardi Bahman Hamasalh,
Kardo Muhammed Ahmed

Department of Physics, College of Science, University of Halabja
Halabja, Kurdistan Region, Iraq

Abstract

Nowadays, renewable energy is a much discussable topic because of its important specifications such as pollution and un end sources. This paper emphasizes the importance and capabilities of the dual axis solar tracking system (DASTS) of solar cell technologies. The study carried out a practical process of a dual-axis system design, which practically demonstrates the influence of dual-axis solar trackers, including their operational principles, advantages, and associated challenges. Furthermore, it has been shown that dual-axis solar trackers can significantly increase solar energy yield by capturing maximum sunlight, making them an important advancement in improving the efficiency and effectiveness of solar energy generation. The paper also presents a performance evaluation of a solar tracker system that improved energy output by 45 % compared to the fixed solar panel (FSP) while also reducing the numerical calculation (NC) efficiency of DASTS by 3.16 %. Based on these findings, solar tracker systems can provide sustainable and environmentally friendly energy solutions that are both feasible and substantial.

Keywords: DASTS; PV system; Uno board; solar panel efficiency; sustainable energy; maximum power point tracking (MPPT); energy harvesting; environmental monitoring.

I. Introduction

To address climate change and promote sustainable development, the adoption of sustainable energy solutions is critical [1][2]. Solar power has emerged as a leading source of sustainable and efficient energy. Solar panels offer immense potential for capturing the sun’s energy, but optimizing their performance has been a continuous area of innovation. A solar tracking system (STS) ensures that solar panels are aligned with the sun's trajectory to maximize their efficiency. An overview of the evolution, benefits, and applications of solar tracking technology is presented in this compilation of research findings. A pivotal study [3][4] demonstrates an impressive +25.62 % increase in average power gain from solar panels thanks to a hybrid solar tracker. A system like this enhances both the production of energy as well as the use of thermal systems. It is designed for both fixed solar panels (FSP) and continuous tracking (TC) systems. Another ground-breaking study focuses on innovative sensor technology, where the traditional light dependent resistors (LDRs) are replaced with ultra violet (UV) sensors. This novel approach results in superior sun-tracking accuracy, ultimately leading to increased power generation [5].

Comparative assessments [6] emphasize the advantages of automatic solar tracker systems over

---

* Corresponding Author. saman.jaafar@uoh.edu.iq (S. S. Jaafar)

https://doi.org/10.55981/j.mev.2024.808

Received 22 January 2024; revision 17 April 2024; accepted 22 April 2024; available online 19 July 2024; published 31 July 2024

How to Cite: S. S. Jaafar *et al.*, “Comparative performance evaluation of dual-axis solar trackers: Enhancing solar harvesting efficiency,” *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 15, no. 1, pp. 23-31, July, 2024.

fixed solar systems. Notably, these systems are not only cost-effective but also highly adaptable, with many applications benefiting from Arduino microcontroller-based control. This paper introduces the concept of an internet-of-things (IoT)-based setup, enhancing data monitoring and storage in the cloud, making solar tracking not only efficient but also technologically advanced. A particularly compelling study presents dual axis solar tracker technology utilizing LDRs with Arduino UNO, showcasing its ability to generate substantially more energy than fixed solar panels or single-axis trackers. Efficiency gains of around 30-40 % compared to fixed panels and 6-7 % compared to single-axis trackers underscore its potential.

In Iraq, real-world prototypes of STSs have been implemented using Arduino-based controllers, delivering practical results [7][8]. Energy gains of approximately 26.83 % were achieved by these prototypes, which demonstrated their ability to control costs and enable efficient energy production. Furthermore, they provide empirical evidence to support the use of solar energy for a wider range of applications.

Using a microcontroller Arduino, a dual axis solar tracking system (DASTS) is explored for its versatility and ease of use [9]. A particular emphasis is placed on the two-axis movement, the high response to sunlight, and the programmability of the device. The advantage of this approach is that it achieves a 20 % efficiency increase compared to fixed panels, although it is slightly more costly than single-axis systems.

The proposed system has the advantage of being compatible with smartphone monitoring, simplifying the data collection, particularly in regions such as North Iraq, where sunlight data collection can be challenging. Furthermore, this system offers the potential for further development, such as the implementation of maximum power point tracking (MPPT)-based battery charging systems [9]. A comparison of dual-axis solar trackers and fixed tilted panels suggests that there is an intriguing balance between efficiency and cost [10]. The increased cost of the former offers significantly greater energy collection, especially on clear days. As a result of this study, it has been concluded that dual-axis solar trackers, which are controlled by Arduino boards, are capable of optimizing solar energy. Researchers have concluded that dual-axis tracking systems offer a distinct advantage over single-axis tracking systems [11]. Using solar trackers, you can expect an approximately 20 % increase in power production due to the substantial difference in voltage output and the choice of materials and components.

In another research, dual-axis solar trackers are being designed and implemented [12]. by utilizing Arduino controllers, LDRs, and motors; these trackers were able to achieve maximum efficiency by controlling the solar panel both horizontally and vertically. Efforts to harness solar energy even in low-light conditions are evident [13], where a low-cost microcontroller-based scaled-down solar tracker, guided by Arduino, successfully tracks various light sources. This low-cost, dependable solution is well-suited for rural areas. A comprehensive analysis of solar panel performance under different conditions is conducted in Brasov, Romania [14].

This study compares five types of photovoltaic (PV) modules on fixed and dual-axis solar-tracked platforms, demonstrating significant energy gains with the tracked platform. The research underscores the consistent effectiveness of DASTS [15]. The adoption of solar trackers yields substantial efficiency improvements [16][17], especially when solar tracking is integrated into prototypes that concentrate sunlight [18] or during multi-day experiments [19][20].

In addition to improving energy output, dual-axis solar trackers are environmentally friendly and cost-effective, reducing electricity expenses [21]. Researchers continue to innovate with new Arduino-based systems [22]. Furthermore, the advantages of solar tracking strategies are evident [23], as they were able to maximize irradiance capture throughout the tracking process, eliminate shading, and optimize energy conversion, even under cloudy conditions. These strategies employ simple algorithms, reducing computing time. Exploring different tilt angles [24] and the impact of single-axis solar trackers [25] The understanding of STSs is further enhanced by focusing on energy output. Even artificial light sources have been used in research to study the effect of dual-axis solar trackers on PV energy production [26].

The versatility of solar tracking solutions is further highlighted with the development of Arduino Uno-based systems [27] and IoT-based dual-axis solar trackers [28]. Solar energy utilization continues to expand as a result of these innovations. The compilation of research presented here demonstrates the significant advancements in solar tracking technology, as well as the variety of features it can be used.

This research contributes to the ongoing development and implementation of solar tracking solutions in the quest for renewable energy sources in several ways, including increasing energy efficiency, reducing costs, and increasing adaptability.

II. Materials and Methods

A. Numerical concept

A dynamic and intriguing feature of the sun is its daily movement, which follows an apparent path called the solar ecliptic as it rotates around the earth. Azimuth (the position of the sun along the horizon) and altitude angle (its height above the horizon) are used to describe the sun's position in the sky. A change in these parameters occurs as the sun rises from the east, reaches its zenith at solar noon, and sets in the west. This has a significant impact on daily sunlight patterns as well as influencing fields such as astronomy, navigation, and solar energy. It is important to note that solar radiation is composed of direct beam irradiance (sunlight that reaches PV surfaces directly) and reflected beam irradiance (sunlight that reflects off PV surfaces without causing any energy production). To maximize the amount of energy captured by solar panels, it is imperative to optimize the angle and orientation of the panels, as shown in Figure 1.

In addition to aligning solar panels with the sun throughout the day, a DASTS maximizes the amount of energy produced. In this case, the angle between the vertical line on Earth's surface and the solar zenith will be used as the reference. If the solar zenith angle is minimal, the panels should be oriented perpendicular to the incoming sunlight. The equation relating solar zenith angle, panel tilt angle, and panel orientation angle can be expressed as equation (1)

$$sin(\theta) = cos(\beta)cos(\alpha) \quad (1)$$

where θ is solar zenith angle (degree), β is Panel tilt angle (degree), α is Panel orientation angle (degree).

As the solar zenith angle changes, a DASTS continuously adjusts the panel's orientation. Different mechanisms can be used to achieve tracking, including single-axis tracking (rotating around one axis) and dual-axis tracking (rotating around both the horizontal and the vertical axes). Optimizing energy conversion efficiency requires aligning the panel precisely with the sun.

In essence, the effectiveness of the DASTS in harnessing solar energy depends on its ability to accurately calculate and respond to the dynamic solar zenith angle, ensuring that the solar panel maintains optimal positioning to capture maximum sunlight.

The efficiency of the solar panel can be determined using equation (2)

$$\eta = \frac{Ppeak}{A \times E} \times 100\% \quad (2)$$

where η is efficiency, P_{peak} is peak power of solar panel (W), A is area of solar panel (m^2) and E is irradiance of sun (W/ m^2).

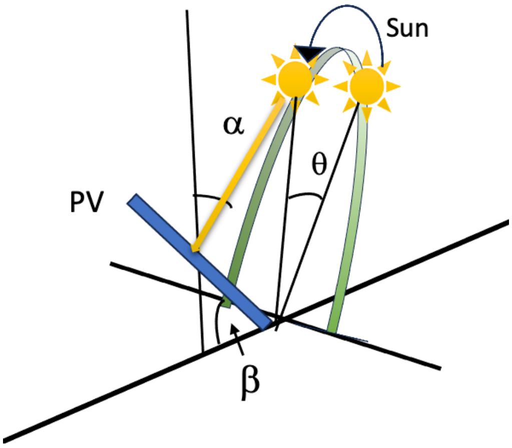


Figure 1. Geometrical representation of sun motion.

B. Appurtenances

Arduino UNO R3 in solar tracking: the Arduino UNO R3 is a versatile open-source platform used in electronics projects. It combines a programmable circuit board and software. With digital and analog pins for input and output, it connects to computers via USB and operates at 5 V.

Servo motors for solar tracking: servo motors offer precise control based on controller input. In this project, two servos are used: one with a 180 degree rotation capacity for horizontal movement and another with a 45 degree rotation for vertical movement. They respond to signals from the Arduino.

LDRs are light-sensitive resistors whose resistance changes with light intensity. Four LDRs, each representing a direction (north, south, east, west), help track light changes. The Arduino monitors LDR resistance imbalances and controls servo motors accordingly.

Solar cells/PV: Solar cells transform light into electrical energy, with their effectiveness contingent on direct sunlight. An Arduino-controlled servo motor repositions the solar cells to track the sun's movement during the day, enhancing energy production.

The compacted system has been shown in Figure 2 in both photographs and illustrative versions of the detailed parts.

C. Tracking system flowchart

Based on Figure 3, the formal workflow commences at the "Start" point, marking the commencement of the process dedicated to the monitoring of LDRs within a tracking system. In the subsequent step, a comprehensive assessment is conducted to ascertain whether the LDRs exhibit uniform irradiance. Should they indeed demonstrate congruent irradiance levels, the workflow proceeds seamlessly to the phase of data

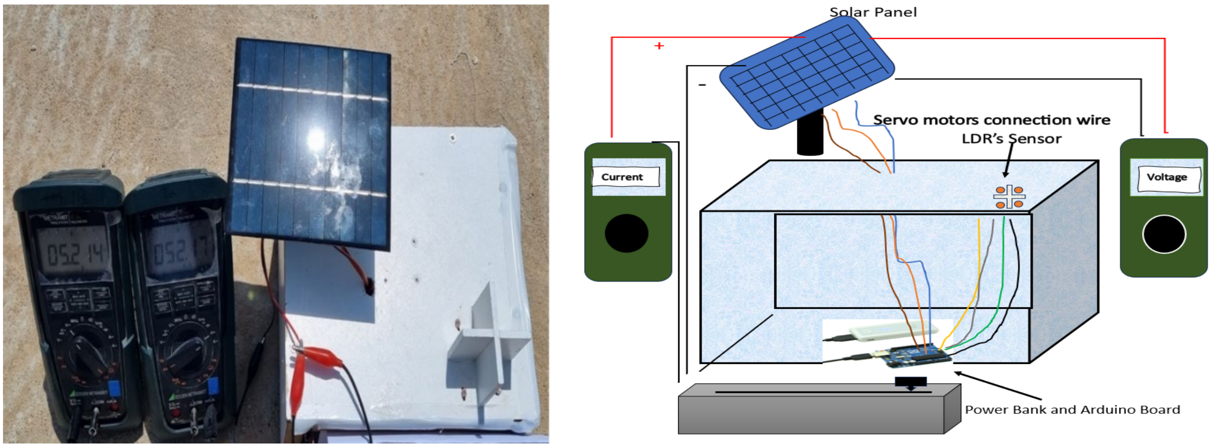


Figure 2. Experimental setup.

acquisition, followed by a predetermined time delay. Conversely, in instances where the LDRs do not present uniform irradiance, the workflow transitions to the task of identifying the specific LDR characterized by the highest irradiance. Subsequently, the ensuing step mandates the precise adjustment of the PV system's orientation towards the LDR characterized by superior irradiance.

The process subsequently reverts to the previous step that addresses the uniformity of irradiance levels, necessitating the continuous acquisition of data. This iterative cycle persists until parity in irradiance among the LDRs is attained. At this juncture, the system prompts an additional data acquisition phase before reinitiating the comparison steps. This iterative and perpetual monitoring process ensures optimal performance within the tracking system, maintaining continuous vigilance over the irradiance status of the LDRs.

III. Results

This experiment was conducted during July and August, chosen for their favorable conditions of enhanced sunlight and reduced dust levels. These conditions collectively improve the performance of the system. As sunlight reaches the LDRs, each responsible for a specific cardinal direction, changes in resistance occur. Through computer code stored on the Arduino UNO R3, the system interprets the optimal direction of sunlight for the solar panel by analyzing the variations in resistance. Subsequently, signals are sent to the servo motors, facilitating the accurate rotation of the solar panel to maintain its alignment with the sun's position.

Data were meticulously collected during this experiment for both the active DASTS and the FSP system, allowing for a comprehensive comparison of their respective performance and highlighting the advantages of solar tracking in maximizing electricity generation throughout the day.

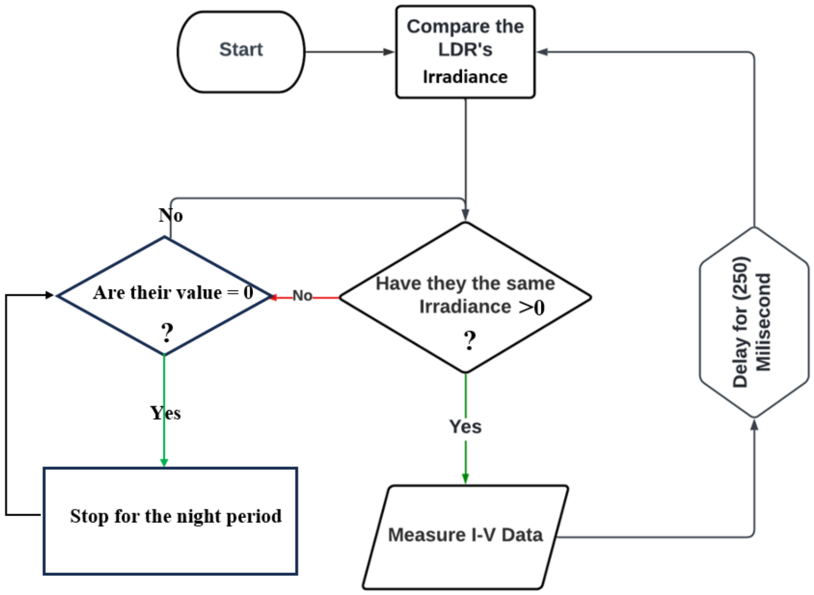


Figure 3. Flowchart of the system.

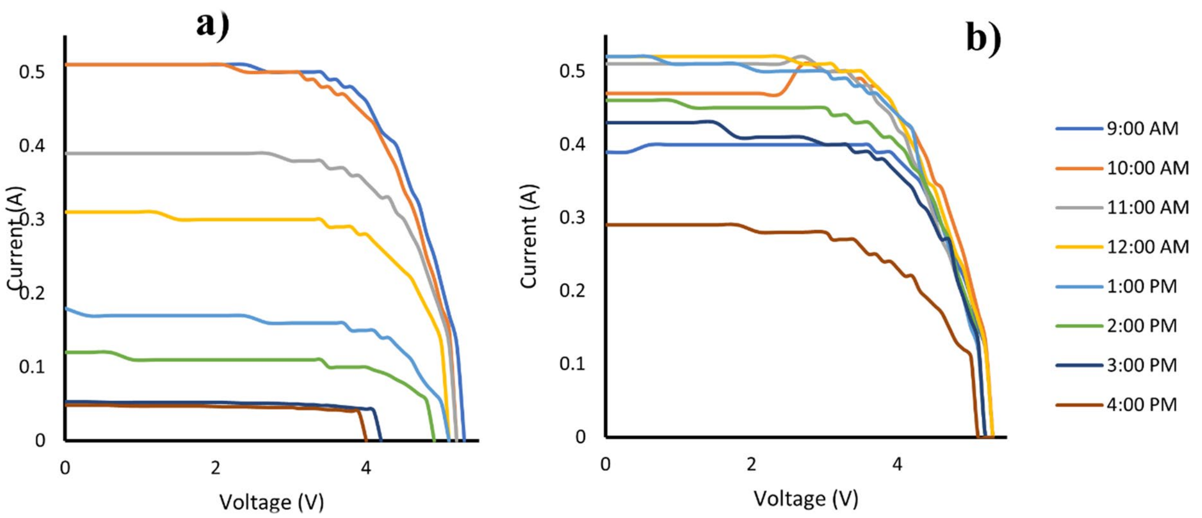


Figure 4. V-I curve for a) FSP case; b) DASTS.

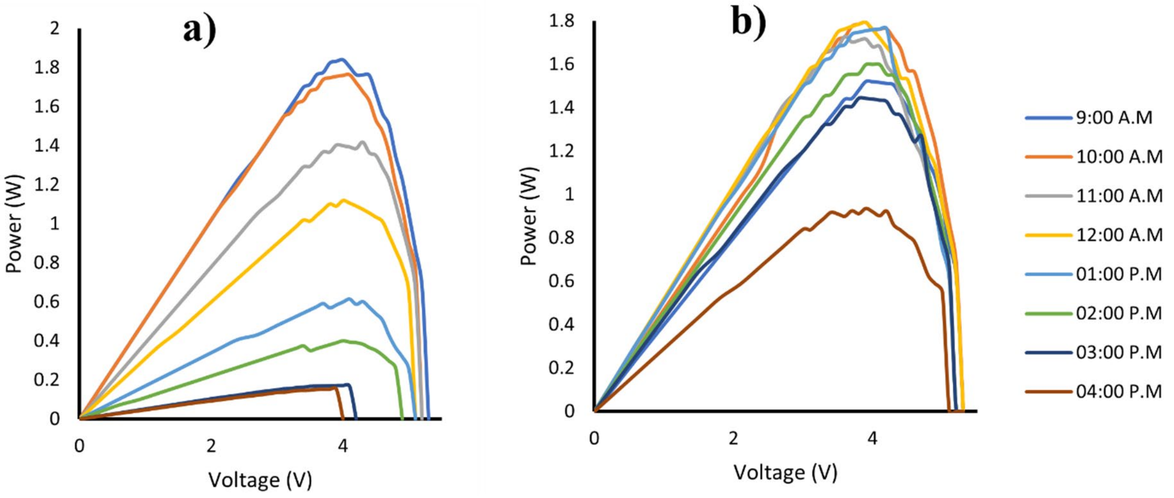


Figure 5. V-P curve for a) FSP case; b) DASTS.

Figure 4 and Figure 5 provide a comprehensive snapshot of the real-world performance of my solar PV system based on meticulously gathered and analyzed data from my solar PV system. This graph illustrates the complex relationship between voltage and current, as well as voltage and power, shedding light on how my system responds to constantly changing environmental conditions. V-I graphs, in particular, provide valuable insights into the system's behavior under different conditions of irradiance and temperature, where open-circuit voltages (Voc = 5.2 V) and short-circuit currents (Isc = 0.51 A) can be seen. As well as providing a deeper understanding of the system's maximum power points (MPP), the V-P graph provides further information about the voltage at which the solar PV system generates its maximum output power. Figure 4 and Figure 5 show the plot between current (A) and power (W) concerning solar panel voltage (V) in both FSP and DASTS cases.

The data were taken for eight-hour periods and clearly show that the current and power in Figure 4(a) and Figure 5(a) decreased respectively due to the change in the sun irradiance deflection angle on the fixed solar panel surface. Instantly, for the case of DASTS that is shown in both Figure 4(b) and Figure 5 (b) for the current and power, respectively, the decreasing or fluctuation of the current and power is not more like part (a) in both figures, and this stability is due to the influence of the DASTS system that is used. In the case of the DASTS system nearly we have satisfied the maximum power point tracking (MPPT) because for all hours of data measurements, the maximum power and maximum current remain constant. Furthermore, our investigation delved into both hourly temperature and irradiance, as depicted in Figure 6. In Figure 6(a), the temperature of the solar panel was measured during the time of data collection. It changes for each hour at the beginning of the morning its lowest and rising near noon, and after that hour, it decreases to 43 °C, and again increases by the evening. Figure 6(b) shows the sun irradiance for different hours of the day. The highest irradiance can

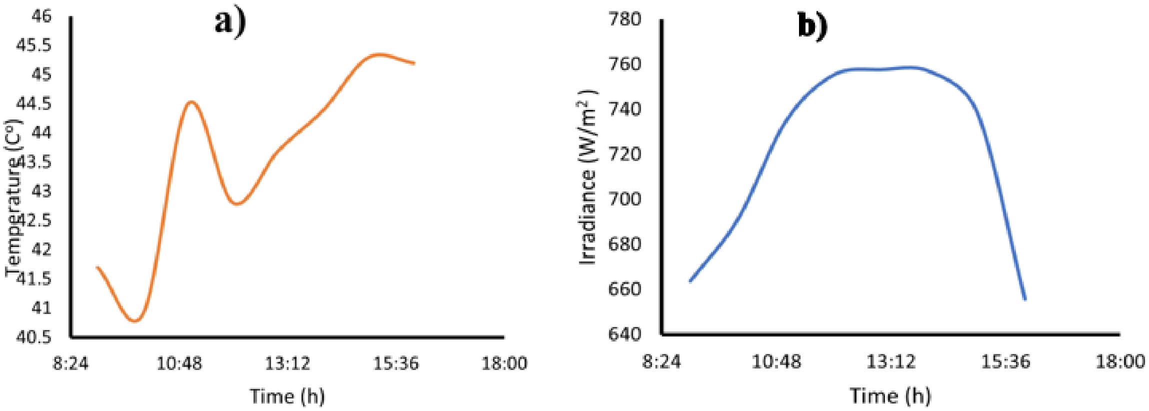


Figure 6. a) Variation of temperature with respect to the time for both cases; b) Variation of sun radiation to the time for both cases.

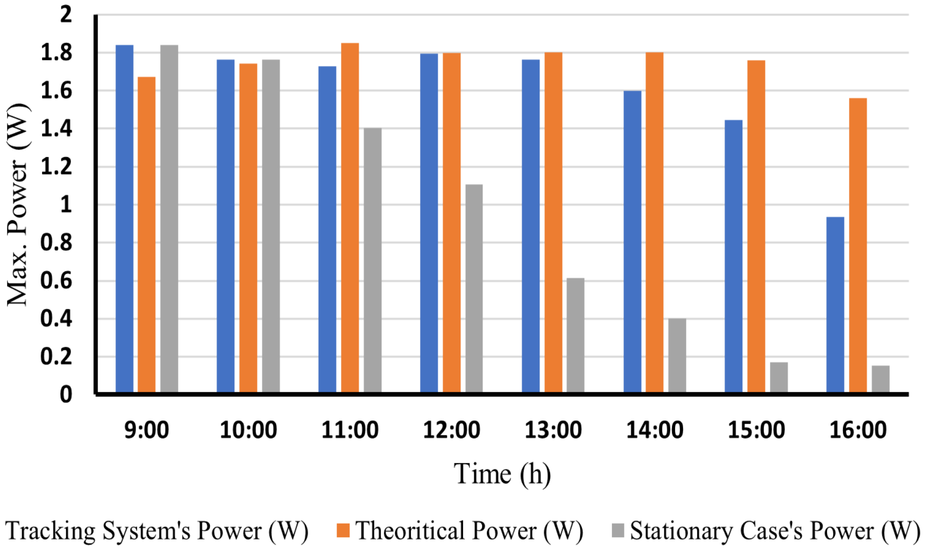


Figure 7. Variation of the MPP to the time for each: stationary case, theoretical and practical solar tracking system.

be achieved from 11:00 a.m. to 02:00 p.m. Meanwhile, before and after those times, the irradiance level is going to vanish gradually. Subsequently, we determined the maximum points for each of the three distinct scenarios and illustrated these points Figure 7 for comparison.

The variation in solar irradiance throughout the day follows a distinct pattern for the solar tracker system, and this phenomenon can be mathematically described using the equation (3) when irradiance ∝ cos(θ)

$$E = E_D \cos(\theta) \tag{3}$$

where E is Irradiance of the Sun (W/m2), ED is direct irradiance (W/m^2), and θ is solar zenith angle (degree).

In this equation (3), Irradiance represents the solar energy received by the PV, and θ denotes the solar zenith angle, which is the angle between the Sun and the vertical line perpendicular to the Earth's surface. The mathematical relationship illustrates that irradiance is lowest during early morning and late evening when the solar zenith angle is at its peak, indicating oblique sunlight. As the day progresses, the solar zenith angle decreases, reaching its minimum at solar noon when the Sun is directly overhead. This results in maximum irradiance around midday. Subsequently, after solar noon, as the solar zenith angle increases once more, irradiance decreases, following a similar pattern in the late afternoon and evening hours, and the main taken data are plotted in Figure 7 and clearly shown in Table 1. The solar panel's efficiency, as determined numerically by the equation (2), stands at approximately 16.5 %. However, in the case of an FSP setup, irradiance is highest in the early morning because the panel is fixed at an angle equal to the solar zenith angle.

This mathematical expression quantifies the observed phenomenon of daily irradiance variations based on the changing angle of the Sun in the sky. To easily assess the efficiency of energy harvesting, one can adopt the following approach: First, to facilitate comparison and gain a clear understanding of how closely the solar tracker's performance aligns with ideal numerical calculations (NCs), one can employ the following equation (4)

Table 1.
Evaluate MPP hourly across three cases, accounting for DASTS's energy harvesting compared to NC (reference power of PV) and FSP setups.

Time (h)	DASTS's power (W)	NC power (W)	FSP power (W)
09:00	1.84	1.53	1.84
10:00	1.763	1.60	1.763
11:00	1.728	1.70	1.404
12:00	1.794	1.74	1.107
13:00	1.764	1.75	0.615
14:00	1.6	1.75	0.4
15:00	1.444	1.71	0.172
16:00	0.936	1.51	0.1521
∑MPP	12.869	13.29	7.4531
Energy harvesting equation (4) and equation (5)		-3.16 %	+42.08 %

$$\text{Energy Comparison of DASTS with NC} = \frac{\sum_{\mathrm{h}} \mathrm{P}_{NC} - \sum_{\mathrm{h}} \mathrm{P}_{\mathrm{DASTS}}}{\sum_{\mathrm{h}} \mathrm{P}_{\mathrm{NC}}} \mathrm{x}100\% \quad (4)$$

where PDASTS is Power of DASTS (W), PNC is obtained power from numerical calculation (W) and secondly, to compare the DASTS to the FSP scenario.

$$\text{Energy harvesting of DASTS compared to FSP} = \frac{\sum_{\mathrm{h}} \mathrm{P}_{DASTS} - \sum_{\mathrm{h}} \mathrm{P}_{\mathrm{FSP}}}{\sum_{\mathrm{h}} \mathrm{P}_{DASTS}} \mathrm{x}100\% \quad (5)$$

where PDASTS is Power of DASTS (W) and PFSP is obtained power from FSP (W)

IV. Discussions

Implementing dual-axis solar DASTS significantly enhances the performance of PV systems by dynamically aligning solar panels with the sun's path. This optimization maximizes sunlight capture, ensuring consistent achievement of the MPP throughout the day, as illustrated in Figure 4 solar tracking is especially beneficial in regions with variable sunlight angles and high solar variability, enhancing overall PV system efficiency. Based on Figure 7 and Table 1, the main goal of this study can be extracted. In this figure, the maximum power in each case of DASTS, FSP, and theoretical (NC) can be sensed. Both DASTS and NC are very close, which means that the DASTS system will mostly achieve the possible power of the used PV. However, the DASTS is significantly different from FSP because of its capability rather than the fixed case of the PV.

Temperature and irradiance levels profoundly impact MPP. Temperature-induced changes in electrical resistance within PV cells can shift the MPP voltage, affecting power output. Higher irradiance levels increase output current and shift MPP towards higher power, as shown in Figure 5 and Figure 6. Engineers must consider these factors to design efficient PV systems that operate close to their MPP under varying environmental conditions.

Daily temperature fluctuations are the result of factors like solar radiation, sunlight angle, geographic location, and altitude. Figure 7 graphically illustrates the DASTS's pivotal role in maintaining consistent power output throughout the day, outperforming static configurations. This performance closely aligns with NCs, with minor deviations attributable to temperature and irradiance, detailed in Figure 6.

V. Conclusion

The performance evaluation of the solar tracker system has yielded highly promising results. Our analysis indicates that the solar tracker system operated at an impressive efficiency rate, closely approximating 45 % of the ideal energy levels derived from NCs. Furthermore, in direct comparison to the FSP case, the solar tracker system demonstrated its efficacy by significantly improving the output energy, achieving a remarkable enhancement of -3.16 %. These findings underscore the practical effectiveness of the solar tracker system in harnessing solar energy efficiently, making it a valuable asset in the realm of renewable energy technology. With such substantial improvements in energy capture and utilization, the solar tracker system represents a pivotal advancement in the pursuit of sustainable and eco-friendly energy solutions.

Declarations

Author contribution

Saman Jaafar carried out system building, data analysis, and interpretation experiments Hardi Hamasalh and Kardo Ahmed cooperated as a partner in data analysis. Hiwa Maarof cooperated in paraphrasing and rewriting the draft version. All authors have read and agreed to the published version of the manuscript.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Additional information

References

[1] V. M. Avargani, H. A. Maarof, S. Zendehboudi, "Multiphysics CFD modeling to assess performance of a perforated multi-plate indirect solar dryer with a V-corrugated absorber surface," *Appl Therm Eng.*, 227:120387, 2023.

[2] A. S. Isah, H. B. Takaijudin, B. S. M Singh, T. O. Abimbola, M. M. Muhammad, S. B. Sani, "Photovoltaic-integrated advancements for sustainable water production: Developing and evaluating an enhanced hybrid solar desalination system," *Desalination*, 579, 2024.

[3] R. A. Ferdaus, M. A. Mohammed, S. Rahman, S. Salehin, M. A. Mannan, "Energy Efficient Hybrid Dual Axis Solar Tracking System," *Journal of Renewable Energy* 1–12, 2014.

[4] H. Abdlla, V. Madadi, Eqqab I, "CFD modeling of a tubular three-pass solar air heater with phase change material: Investigating heat transfer enhancement and energy efficiency," *J Energy Storage,* 87:111522, 2024.

[5] C. Jamroen, C. Fongkerd, W. Krongpha, P. Komkum, "A novel UV sensor-based dual-axis solar tracking system: Implementation and performance analysis," *Appl Energy.*, 299:117295, 2021.

[6] V. Mohanapriya, V. Manimegalai, V. Praveenkumar, P. Sakthivel, "Implementation of Dual Axis Solar Tracking System," *IOP Conf Ser Mater Sci Eng,* 1084, 2021.

[7] M. J. Fadhil, R. A. Fayadh, M. K. Wali, "Design and implementation of smart electronic solar tracker based on Arduino," *Telkomnika (Telecommunication Computing Electronics and Control),* 17:2486–96, 2019.

[8] A. Mohamad, M. T. A. Rahman, K. Phasinam, M. S. bin Mohamad, M. A. M. Saad, S. Y. Chionh, "Analysis of an Arduino based solar tracking system," *J Phys Conf Ser,* vol. 2051, 2021.

[9] B.A. Hamad, A. M. T. Ibraheem, A. G. Abdullah, "Design and practical implementation of dual-axis solar tracking system with smart monitoring system," *Przeglad Elektrotechniczny*, 96:151–5, 2020.

[10] S. Ahmad, A. N. Razali, M. I. Misrun, "Effective and Low-Cost Arduino based Dual-Axis Solar Tracker," *J Phys Conf Ser,* 1878, 2021.

[11] Y.H. Naif, "A New Design Arduino-Based Dual Axis Solar Tracking System," *JAREE (Journal on Advanced Research in Electrical Engineering),* 4:129–33, 2020.

[12] M. N. A. Mohd Said, S. A. Jumaat, C. R. A. Jawa, "Dual axis solar tracker with iot monitoring system using arduino," *International Journal of Power Electronics and Drive Systems,* 11, 2020.

[13] H. Anderias, H. Amzal, Algiranto, S. Merta, "Solar Tracker Design Based on Arduino Nano to Improve Solar Energy Efficiency," *Technium: Romanian Journal of Applied Sciences and Technology,* 16, 2023.

[14] M. Moldovan, B. G. Burduhos, I. Visa, "Efficiency Assessment of Five Types of Photovoltaic Modules Installed on a Fixed and on a Dual-Axis Solar-Tracked Platform," *Energies (Basel),* 16, 2023.

[15] M. S. Rana, R. S. Prodhan, M. N. Hasan, "Self Powered Automatic Dual Axis Tracking and Positioning System Design," *IEEE Region 10 Symposium*, *TENSYMP*, 2020.

[16] B. Abhishek, C. B. Kumar, P. Pavaneswar, M. Sindhwani, "Dual Axis Solar Tracking *System,"1st International Conference on Sustainable Technology for Power and Energy Systems (STPES),* 2198–202, 2022.

[17] Koppada, H. Mehar, A. Katta, K. Teja, A. A. Chilakamarthi, M. Kosuru, R. R. Rokkala, "Self-Powered Dual Axis Solar Tracking System," In *2nd Indian International Conference on Industrial Engineering and Operations Management*, 2022.

[18] K. G. Ghalem, M. I. Ziane, A. Hamoul, R. Gheni, "Maxi dual axis solar tracker system," *Journal of Renewable Energies,* vol. 1, no. 1, pp. 43, Sep., 2023.

[19] F. M. Mahmood, S. S. Jaafar, R. W. Mustafa, "Designing and programming a microcontroller based on a solar tracking system," *NTU-JRE*, vol. 3, no. 1, pp. 51–59, Oct., 2022.

[20] Asnil, Krismadinata, I. Husnaini, E. Astrid, "design and performance of dual axis solar tracker based on light sensors to maximize the photovoltaic energy output," *J Theor Appl Inf Technol,* 100, 2022.

[21] P. Okae, O. M. Raji, J. Lade, "Integrated dual axis solar tracker using a single tracking motor," *Science World Journal,* 18, 2023.

[22] Hamad B, Al-Naib AMTI, "Design and Implementation of a Dual-Axis Solar Tracking System STS," *NTU-JET,* vol. 1, no. 1, pp. 35-43, Oct., 2021.

[23] L. M. Fernández-ahumada, J. Ramírez-faz, R. López-luque, M. Varo-martínez, "Influence of the design variables of photovoltaic plants with two-axis solar tracking on the optimization of the tracking and backtracking trajectory," *Solar Energy,* 208:89–100, 2020.

[24] J. M. Wang, C. L. Lu, "Design and implementation of a sun tracker with a dual-axis single motor for an optical sensor-based photovoltaic system," *Sensors (Switzerland),* 13, 2013.

[25] S. S. Jaafar, H. A. Maarof, "Influence of micro-controller-based single axis solar tracker system on solar panel's performance: Case study," *NTU Journal of Renewable Energy,* vol. 3, no. 1, pp. 33–43, Sep., 2022.

[26] K. S. Gaeid, M. N. Uddin, M. K. Mohamed, O. N. Mohmmoud, "Design and implement of dual axis solar tracker system based Arduino," *Tikrit Journal of Engineering Sciences,* 27, 2020.

[27] Syafaruddin, Gassing, F. A. Samman, N. Umniyah, F. Febriyana, "Arduino Uno Avr Atmega328 microcontroller based dual axis solar tracker design," *ICIC Express Letters*, *Part B: Applications*, 13:337–45, 2022.

[28] O. O. Apeh, E. L. Meyer, O. K. Overen, "Contributions of solar photovoltaic systems to environmental and socioeconomic aspects of national development-a review," *Energies (Basel)* 15, 2022.