WOA-Based Evaluation of Solar Tracking's Impact on Photovoltaic Efficiency

Vijay Chavda
Lecturer
Mechanical Engineering Department,
RCTI, Ahmedabad, Gujarat, India.

Abstract : Photovoltaic (PV) systems' efficiency is significantly impacted by how the solar panels are oriented in relation to the sun's position. Because the sun's path changes during the day, even simple and low-cost fixed-angle photovoltaic panels often fail to capture the full quantity of solar radiation. This work explores the use of two bio-inspired metaheuristic algorithms, Whale Optimization Algorithm (WOA) and Particle Swarm Optimization (PSO), to improve the tilt and azimuth angles of PV panels for improved solar tracking performance. Using simulated data matching to Maharashtra, India, the algorithms maximize net energy output by optimizing panel angles throughout the day, accounting for both harvested energy and tracking energy usage. According to the results, the WOA-based tracking system generates 1484.25 Wh of energy per day, which is 15% more than the fixed system. The generation of the PSO-based system is 1397.00Wh, which is 8.68% more than that of the fixed-angle system, which is 1285.41 Wh. The study found that intelligent solar tracking significantly boosts PV efficiency and that, in this particular scenario, WOA is a better optimization technique than PSO.

***IndexTerms* – Particle Swarm Optimization, Solar Tracking, Whale Optimization Algorithm.**

I. Introduction

As sustainability issues and energy demands have grown, photovoltaic (PV) systems have emerged as a significant renewable energy source globally. The efficiency of these systems is mostly determined by the incident solar irradiance, which varies with the angle between the surface of the solar panel and the sun's beams. Most commercial PV installations utilize fixed-tilt panels because they are simple to use and need no maintenance. However, energy losses happen because fixed angles do not allow for optimal alignment with the sun during the day.

To overcome these limitations, solar tracking devices have been developed, which continuously adjust the panel orientation to maintain the panel surface perpendicular to incoming sunlight [1, 4]. While one and two axis trackers can significantly increase energy yield, they often lead to increased mechanical complexity and power consumption.

In recent advances, solar tracking angles have been dynamically optimized through the application of computational intelligence. Bioinspired metaheuristic algorithms such as Particle Swarm Optimization (PSO) and Whale Optimization Algorithm (WOA) are gaining popularity for this purpose. PSO mimics the social nature of bird flocks to explore and exploit the search arena for optimal solutions [2], whereas WOA mimics the behavior of whales, offering an efficient balance between exploration and exploitation [3].

Few comparison evaluations have been carried out under the same conditions, despite the fact that these techniques have been the focus of multiple independent research for sun tracking. This research aims to bridge this gap by optimizing the tilt and azimuth angles of PV panels on a typical bright day in Maharashtra, India, and comparing the efficacy of the PSO and WOA algorithms to a fixed angle system.

II. Literature Review

One of the several uses of particle swarm optimization (PSO) in renewable energy is solar panel angle optimization. Kennedy and Eberhart initially introduced PSO as a successful optimization technique that can handle non-linear, multi-dimensional problems [2, 5]. Studies have demonstrated that PSO increases energy yield by optimizing tilt angles based on weather and solar position [5].

In 2016, Seyedali Mirjalili created the Whale Optimization Algorithm (WOA), a nature-inspired metaheuristic optimization method based on the distinctive bubble-net feeding habit of humpback whales. In WOA, random exploration throughout the search space guarantees worldwide search capabilities, whereas whales encircle their prey and move in a spiral or shrinking circle pattern to mimic the exploitation phase of optimization. The method effectively solves complicated, multi-dimensional, and nonlinear optimization problems by striking a balance between exploration and exploitation using a theoretically defined set of behaviors. WOA has been widely used in engineering, image processing, machine learning, and particularly in the optimization of renewable energy systems because of its ease of use, limited number of tunable parameters, and strong convergence ability. For example, it can be used to determine the best operating parameters for solar tracking systems to increase photovoltaic efficiency. In some complex optimization situations, WOA may avoid local optima more successfully than PSO thanks to its encircling hunting mechanism and hierarchical leadership architecture. WOA was successfully used for solar tracking in [6], who reported faster convergence and better energy capture.

In solar angle optimization, comparative studies have shown that WOA often outperforms PSO, particularly when managing several variables and constraints, as several works have shown. However, practical concerns like actuator energy prices and real-time implementation challenges remain important study areas.

This study simulates and compares WOA and PSO for two-axis solar tracking under identical climatic circumstances, and includes tracking energy consumption into the objective function to provide a realistic assessment.

III. Results Analysis And Discussion

The experiment's results show how effective metaheuristic optimization is for sun tracking. It is regarded as the longest day of the summer. Maharashtra, India, is taken into consideration for the latitude 19.663280. For the output power, standard irradiance, panel area, efficiency, and tracking cost are taken into account [7, 8]. There are 100 search agents and 50 iterations for the optimization algorithm. The fixed system's output power is 1285.41Wh. The WOA algorithm beat the fixed-tilt baseline by 15%, with the highest total energy output of 1484.25 Wh. PSO also improved performance, generating 1397.00Wh, 8.68% more than fixed. The advantages of dynamic tracking in better collecting sun irradiance throughout the day are supported by these findings.

WOA outperforms PSO due to its better exploration-exploitation balance, which facilitates the search space in finding a more optimal global solution. The ability of WOA to mimic the whale behavior prevent early convergence, which is a common issue with PSO. The comparison of several optimization techniques with a fixed one is displayed in Fig. 1. Table 1 tabulates the results.

The fixed-angle system performed well in the middle hours half the day but declined in the morning and evening, which is consistent with findings from the literature [8]. This confirms that adaptive tracking is essential in regions with significant variations in solar elevation angle.

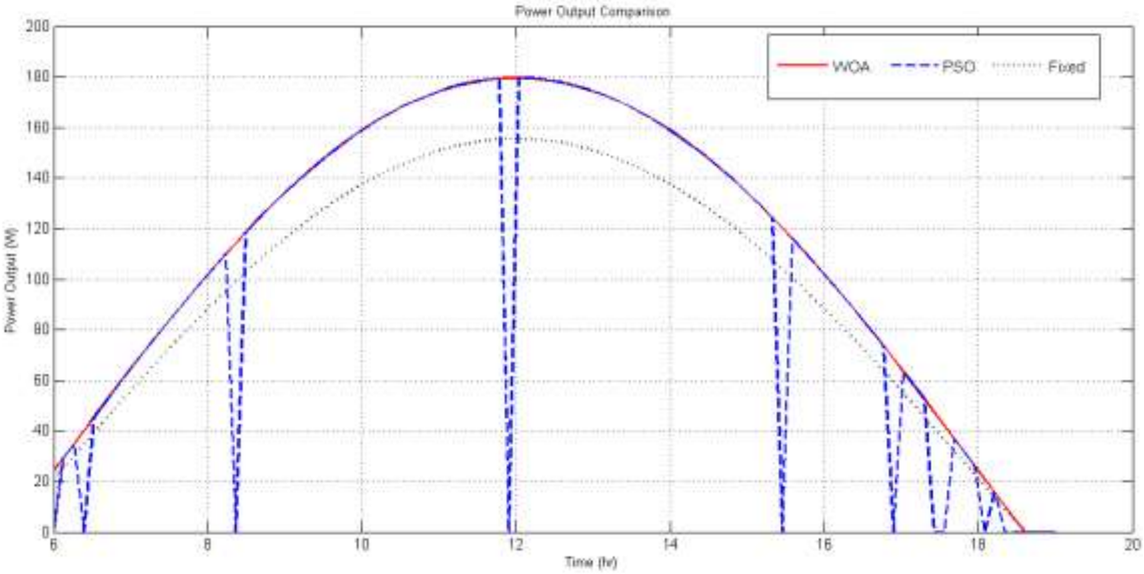

Fig.1 Time V/S Power output for different algorithms

Table 1 Comparison of Results

Parameter	Fixed Angle	PSO	WOA
Total Energy Output (Wh)	1285.41	1397.00	1484.25
Improvement over Fixed (%)	—	8.68 %	15%
Tracking Energy Consumption (Wh)	0 (no tracking)	Included	Included
Convergence Speed	N/A	Moderate	Faster

Monitoring energy use was added to the objective function to ensure that net gains reflect real-world conditions. The effectiveness of these optimization-based tracking devices was confirmed by the fact that the relatively low tracking energy costs did not offset the improvements in gathered solar energy.

Overall, the study demonstrates that by utilizing clever algorithms like WOA and PSO, sun tracking techniques can greatly boost PV system efficiency. WOA in particular exhibits promise for further study and development.

IV. Conclusion

In the solar climate of Maharashtra, this study assessed how well the Particle Swarm Optimization and Whale Optimization Algorithms performed in maximizing the sun tracking angles of photovoltaic panels in comparison to a fixed-angle system. Both metaheuristic algorithms continuously optimized the tilt and azimuth angles, significantly increasing the daily energy output. WOA outperformed PSO with the highest energy gain of 15% over the fixed configuration. The findings show that employing adaptive sun monitoring with advanced optimization algorithms can greatly boost solar efficiency and energy yield.

References

[1] H. Garg and J. Prakash, "Solar Energy: Fundamentals and Applications," New Age International, 2017.
[2]. J. Kennedy and R. Eberhart, "Particle swarm optimization," Proc. IEEE Int. Conf. Neural Netw., 1995, pp. 1942–1948.
[3]. S. Mirjalili and A. Lewis, "The Whale Optimization Algorithm," Advances in Engineering Software, vol. 95, pp. 51–67, 2016.

[4]. A. Yadav and S Chandel, "Tilt angle optimization to maximize incident solar radiation: A review," Renewable and Sustainable Energy Reviews., vol.23, pp. 503-513, 2013.

[5]. Y Chang et al., "Optimal the tilt angles for photovoltaic modules using PSO method with nonlinear time-varying evolution," Energy, vol. 35, pp. 1954-1963, 2010.

[6]. M. Ebrahim, A. Osama, K. Kotb, and F. Bendary, "Whale inspired algorithm based MPPT controllers for grid-connected solar photovoltaic system" Energy Procedia, vol. 162, pp. 77-86, 2019.

[7]. John Duffie and William Beckman, "Solar Heating and Cooling," Renewable Energy, 2011.

[8]. G Tiwari and S Dubey, “Fundamentals of photovoltaic modules and their applications”, 2009.