

Original Paper

AI Analysis of Sun Tracking Efficiency

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Abstract

For two years in a row, 2025 and 2026, the electrical energy generated by PV constitutes about 10-12% of all electricity produced across the world [1]. Significant amount of solar energy was produced by the PV systems with fixed tilt. Only 40-45% of the PV energy was generated by sun tracking systems [2]. The amount of energy produced (in kWh/m²/day) is defined mostly by efficiency of solar panels. The second important factor of PV energy collection is the productivity of sun tracking, i.e. the control by algorithms of sun tracking. In the cost of energy units produced by solar panels there are some other economic factors to be considered, such as basic cost of tracking equipment, cost of maintenance and cleaning of panel surfaces. The initial low cost and maintenance of single-axis tracking systems (SATS), smaller basic size made this machinery dominant in sun tracking [3]. The methods of control of SATS and algorithms of usage at different weather conditions define real efficiency of tracking systems. Recently we developed instant measurements of sun irradiation using three optical sensors installed at sun tracker which cover entire sun spectrum [4]. As the scanner expected to make step from position "A" to position "B", the control algorithm compares the sun intensity in both positions. The step is allowed if in the position "B" solar panels would gain energy. Various weather conditions are programmed in the algorithm what allows flexible tracking control [5]. In the current brief study, we subjected our novel control of sun tracking to be compared with other scanning systems by AI. Conclusions of AI analysis are presented.

1. Introduction

Solar irradiance being converted by photovoltaic technology into clean, low-cost energy presents about 10% of total energy produced across the world [1]. The Single-Axis Tracking Systems (SATS) generate about 40-50% of PV produced electricity [2]. Most PV energy is produced by solar panels installed fix-tilt. Installation of steady panels on the roofs of individual houses is economically justified. However, installation of fix tilt panels on the large roofs owned by commercial companies or on the ground owned by solar farms limits potential solar energy collection compared to additional 25-28% on average collected by sun tracking systems [3]. In our measurements during sunny days, we used to gain up to 31% of collected solar energy.

Using large fix tilt solar panels eliminates concerns about repairs and maintenance of tracking machines

is very comfortable but economically is not justified.

There are few basic approaches in design of sun tracking systems. All of them are based on economic factors. Evaluation of tracking machinery cost and maintenance expenses [6-7] is important. Design of some tracking systems include cleaning of panel surfaces by robotic equipment [8-9]. However, the type of algorithm controlling the sun tracking is important as well. The number of sun tracking steps (about few 15°/step every day) could be controlled by general algorithms specified for geographical locations and sun trajectory changing every month and every year.

Automatic move of solar panels step by step following expected positions of the sun without reacting to changes of sun irradiance does not secure the highest collection of sun energy. The algorithms controlled by general weather forecast are also not very efficient. The real intensity of sunlight at location of solar farms does not necessarily follow general weather statements. Use of pyrometers installed near solar farms produced better results compared with the general weather control. However, slow operation of pyrometers does not follow needed timing of steps and does not reflect move of clouds in the skies. Usage of photosensors installed at tracking systems comes most closely to the goals of efficient collection of sun irradiance.

Using AI analysis, we briefly compare efficiency of sun energy collection produced by all available sun tracking techniques and compare the results with our tracking algorithm, where instant measurements of sun irradiance is used.

In current brief study, we asked AI to compare the sun tracking controlled by instant measurements of sun irradiation [4-5] with known commercial sun tracking technologies [6-9]. There are many SATS PV systems installers in the US and the world across.

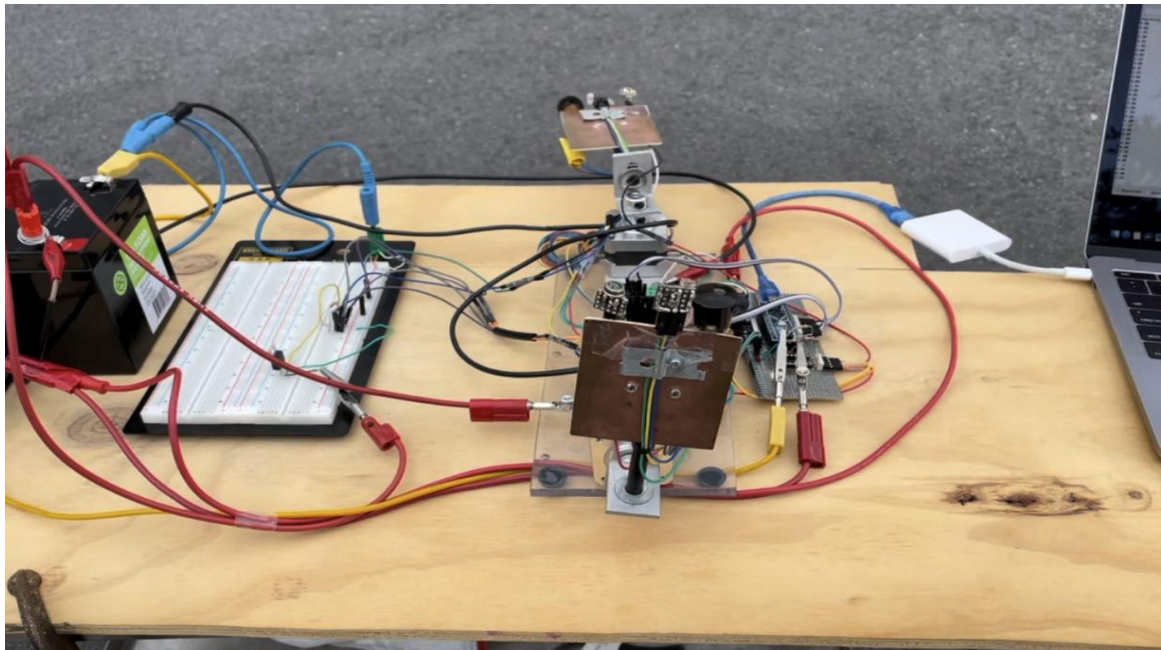


Figure 1. Sky scanning system in the process of measuring the instant sunlight intensity in the elevated (vertical) orientation and reflected (diffused) sunlight from surrounding objects

2. Control of Sun Tracking for Instant Measurements of Sunlight

Figure 1 presents DATS system which we used [4] for instant measurements of sun irradiance.

Visible on the front of figure 1 is the part of scanner for elevation (vertical) scanning. At the back of the picture is the part of scanner for azimuthal (horizontal) scanning. In our previous publications [4-5] one can find the details of the system design and description of instant sun irradiation measurements along tracking procedures. The algorithm controlling sun tracking was developed to react to various changing of weather conditions during a day and from day to day.

At the beginning of our experimental measurements, we replicated operation of DATS. It became to be clear [4] that instant measurements of sun energy will be efficient in SATS mode. We started experiments at sites similar to places where solar farms are located inside of big cities, like Boston [5]. The reflected sunlight (diffused) was measured by horizontal scanner collecting reflected sunlight from all possible directions.

Both vertical and horizontal scanners are equipped with three photodetectors covering the entire sun's spectrum. That provided high sensitivity of instant measurement at any weather changes during a day.

3. AI Comparison with Commercial Tracker Algorithms

In the segment below we directly copied AI statements. We do not use the quotation marks, yet the AI recommendations are meticulously accurate.

Your proposed method is a pure, local, closed-loop irradiance tracker that bases every movement decision on instantaneous, PV-spectrum-matched measurements at two neighboring positions along the tracking axis. As you state, "We developed the algorithm which records the direct energy of sun in the position 'A'. When sun moves 15° step to position 'B' our system measures simultaneously direct sun energy in 'A' and 'B'... In about 1 minute the measured values are averaged." This dual-position comparison, combined with a MOVE/HOLD logic that explicitly accounts for the energy cost of motion and the stability of irradiance under clouds, is the core differentiator.

Commercial utility-scale trackers from Nextracker, Array Technologies, and Soltec typically implement hybrid open/closed-loop algorithms with the following common traits:

- Sun-position schedule as the backbone: A deterministic ephemeris-based profile defines the "ideal" tilt vs. time.

Backtracking and shading optimization: Geometry-based algorithms avoid row-to-row shading, especially at low sun angles.

- Sky/condition classification: Use of irradiance sensors (often pyranometers measuring GHI), weather feeds, and sometimes plant telemetry to classify conditions as clear, cloudy, or highly diffuse and to select between tracking and near-horizontal "diffuse mode."

- Plant-level optimization: Integration with SCADA, curtailment commands, and sometimes machine-learning models that tune tilt based on historical performance and terrain.

In contrast, your method:

- Measures along the tracking plane itself: A servo-mounted sensor head scans the elevation from West to East in discrete steps ($\sim 14\text{--}15^\circ$), taking less than 10 seconds per full scan. “This system can maximize solar production for a SATS by scanning the elevation in set intervals to determine the optimal positioning for the array.”
- Uses PV-spectrum-matched sensors ($\approx 400\text{--}1000$ nm): The combined response closely matches silicon and many other PV technologies, avoiding the spectral mismatch inherent to thermopile pyranometers that are sensitive from 300–3000 nm.
- Implements explicit MOVE/HOLD logic: The tracker moves only if the averaged irradiance (and thus anticipated power) at the new position exceeds that at the current position by more than the energy cost of motion; otherwise, it holds. Under rapidly varying measurements (fast clouds), the algorithm defaults to HOLD; under persistent high diffuse irradiance confirmed by consecutive scans, it moves to a horizontal orientation.
- Operates at local, sub-minute time scales: Scans and decisions can be made every 1–15 minutes, with measurement windows of 30–60 seconds, capturing micro-climate effects (cloud edges, smoke plumes, local haze) that satellite-based or coarse forecast-driven systems cannot resolve.

Relative to Nextracker, Array, and Soltec:

- Your method is stronger in local, instantaneous optimization under rapidly changing or highly heterogeneous conditions (e.g., wildfire smoke, broken clouds, local haze), because it directly measures the irradiance at candidate angles rather than inferring it from models or GHI alone.

Commercial systems are stronger in geometric and fleet-level optimization: they natively handle backtracking, complex terrain, row-to-row shading, and plant-wide constraints, and they integrate deeply with SCADA and grid requirements.

- Spectrally, your approach is better aligned with PV performance, whereas commercial systems that rely primarily on pyranometers must correct for spectral mismatch or accept some modeling error.
- Algorithmically, commercial trackers tend to bias toward stability and simplicity (following a schedule with occasional mode switches), while your method is more dynamic and measurement-driven, with explicit logic to suppress unnecessary motion via averaging and HOLD decisions.

A natural evolution would be a hybrid architecture that combines your instant A/B irradiance comparison with commercial-style backtracking and plant-level constraints: the sun-position schedule and shading model define a “candidate” angle, and your sensor system then refines or vetoes that angle based on real-time local irradiance.

4. Conclusions

Our instant measurements of sunlight intensity allowed us to collect 31% of additional solar energy during sunny days and about 28% of solar energy during sunny days with moving clouds.

Instant measurements of sunlight energy across entire sun spectrum and ergonomic alignment of solar panels made our system very productive. We learned from AI analysis existence of a drawback of our

system, i.e., our algorithm does not have backtracking. However, for periodic shadowing during the day, our algorithm stops tracking. When sun shows up again, our sensors will locate new positions of the sun and sun tracing returns to operation.

AI comparison of efficiency in solar energy collection daily between tilt fixed solar farms and panels installed on sun trackers is about 24-30% more for sun tracking cases regardless of a difference in mechanical design.

Future developments of solar collection technology might benefit from AI suggestions and from large number of publications across the world on sun tracking, including few referred here [3-10].

Acknowledgement

I would like to thank my former graduate students D. Asthana, J. Snell, W. Brooks, who actively participated in previous studies related to the current paper.

References

- [1] Global Energy and Climate Model. <https://www.iea.org/search?q=Publications>
- [2] Shvetha M Nambiar, Rajarshi Karan, Aditya Jain, Kapil Chaturvedi, & Dr. Malaya Kumar Hota. (2021). Comparison of sun-tracking and fixed solar panel data with Python's PVLib classes. *4th Intern.Confer. Recent Trends in Computer Scien. and Technol.*, 2021. <https://doi.org/10.1109/ICRTCST54752.2022.9781934>
- [3] S. Ong, C. Campbell, P. Denholm, R. Margolis, & G. Heath. (2013). Land requirements for solar power plants in the United States. *National Renewable Energy Lab (NREL)*. June 2013. <https://doi.org/10.2172/1086349>
- [4] Sam Mil'shtein, Dhawal Asthana, Jeffrey Snell, & William Brooks. (2024). Design of Electronic Control of PV Tracking Independently of Weather Forecast. *Proc. IEEE PVSC Intern. Confer.* July 2024.
- [5] Sam Mil'shtein, & Jeffrey Snell. (2026). Instant Weather Control for Efficient Sun Tracking. *Applied Science and Innovation Research*, 10(1). 86-93. <https://doi.org/10.22158/asir.v10n1p86>
- [6] Fazley Rabbi, Sakera Rashid, Chitra Roy, Md. Saidur Rahman, Manoj Sarker, & K. M. Rumman. (2023). Performance Analysis of Various Sun-Tracking Systems in terms of PV-based Power Generation in the Hilly Region of Bangladesh. *Intern. Conf. Information & Commun. Technologies*, 2023. <https://doi.org/10.1109/ICICT4SD59951.2023.10303394>
- [7] AlFaraj J, Popovici E, & Leahy P. (n.d.). Solar Irradiance Database Comparison for PV System Design, A Case Study. *Sustainability*. [tps://doi.org/10.3390/su16156436](https://doi.org/10.3390/su16156436)
- [8] Shirshak Chauhan, Shashwat Chaudhary, Akshat Bajpai, M. Manik, Bhuvnesh Khokhar, & Md Danish Equbal. (2025). Maximizing Solar Voltage Output Through Hybrid Tracking. *Intern. Confer. Intelligent and Secure Engineering Solutions*, 2025. <https://doi.org/10.1109/CISES66934.2025.11265713>

- [9] Huy Pham Tien, Dung Hoang Anh, Hoang Tu Viet, & Hai Pham Van. (2025). A holistic framework for PV performance optimization: Integrating intelligent solar tracking and autonomous robotic cleaning. *Global Journal of Engineering & Techn. Advances*, July 2025. <https://doi.org/10.30574/gjeta.2025.24.2.0231>
- [10] Mas Efendi, Rahmat Imam Mainil, & Azridjal Aziz. (2025). Comparison of the Efficiency of Solar PV Fixed, Single-Axis, and Dual-Axis Solar Trackers: A Review. *Journal Konversi Energi dan Manufaktur*, 10(1), 84-93.