Best Practices for the Optimization of Bifacial Photovoltaic Tracking Systems

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Executive Summary

Bifacial photovoltaic (PV) tracking systems, where bifacial PV modules are mounted to moveable racks that rotate the modules to follow the Sun, are the main utility-scale PV system configuration being currently deployed across the world. Today, over 90% of modules sold use bifacial cells and over 60% of the market share for PV systems utilize single-axis trackers. The popularity of such system designs can be traced to the financial benefits of such systems. Typical tracker gains of 15-20% and bifacial gains of 2-10% are additive and these systems provide the lowest levelized cost of electricity in about 90% of the world.

This report provides an overview of current best practices to optimize the performance of such systems. The authors are international experts on these topics and have reviewed recent literature and industry standards for this report. In addition, 16 tracker companies (>87% of global market share from 2012-2021) and owners/operators of more than 13 GW of PV systems around the world were surveyed to learn about real world experience. Additionally, a blind modeling round robin exercise was run to evaluate the state of the art in simulating bifacial tracking system performance.

The different types of single-axis trackers and their components and features, including figures showing the complexity and variety of designs are outlined and design principles for matching the system layout to the site are presented. Several different tracking algorithms have been developed to increase energy yield per land area, including backtracking, which avoids row-to-row shading. Tracker companies are innovating to make their solutions applicable to a wide range of site conditions, including sloping topography. Recent innovations in tracking have focused on active protection of modules from wind, hail, snow and even flooding. By integrating with local sensors and weather forecasts, the trackers move to safer positions during these events. Tracker companies are also experimenting with novel ways to collect more energy during cloudy conditions with diffuse stow strategies, and new backtracking methods that are customized for different module technologies (e.g., thin film, half-cell modules). Recent research has focused on developing backtracking strategies for complex terrains to minimize row-to-row shading and maximize light collection.

The practice of albedo enhancement using reflective engineered materials is reviewed. An important factor is the durability of these materials; many have been shown to not last for more than a few years or less. Current studies have shown that strategic placement of these materials can increase yields while minimizing material usage, but long-term durability will need to be demonstrated for albedo enhancement to be commercially viable.

Agrivoltaic systems (PV along with agricultural crops or livestock) offer an interesting application for bifacial tracking systems due to their ability to control the array tilt and adjust light reaching the ground. These systems also allow the farmers to move the trackers to accommodate farm equipment and activities. Increasing the height of the system leads to potential cost increases due to increased wind loads and stronger foundations. Several studies have shown that agricultural yields beneath the array can increase for some crops in some climates but decrease for many other crops.

Best practices for monitoring the performance of bifacial tracked systems are reviewed. Guidelines for measuring front and rear plane-of-array irradiance are discussed, including the required number of sensors and sensor placement to accurately measure these quantities. Recommendations for measuring back-of-module temperatures, wind speed and direction within the array, tracking angle (inclination), and surface albedo under the array are also given.

Three types of performance models used to simulate bifacial PV performance: view factor, raytracing, and GPU based 3D view factors are summarized and compared including selected commercial and open-source software that implement these methods. Finally, the results of a blind modeling comparison in which nine experts were asked to simulate six hypothetical bifacial PV tracked system designs using the same site and weather data are presented. This comparison demonstrated that simulation models do not yet agree, especially regarding rear side irradiance, module temperature, and tracking angles. More work is needed to generate high quality validation datasets for model developers to improve their models.

Tracker reliability considerations and failures are divided into intrinsic and extrinsic causes. Such failures can result in catastrophic system failures that damage other parts of the system (e.g., module damage from torsional galloping due to excessive wind loads and design flaws). Simulations of annual energy losses are presented for different scenarios where failures only result in tracker stalling.

Finally, topics related to the technical and financial optimization of bifacial tracking systems from the perspective of a project developer or investor are discussed. The LCOE metric, which is useful for comparing different sites and technologies is defined. Once a site and design are chosen, the yield assessment allows estimation of revenue streams throughout the project lifetime. CAPEX and OPEX are very important parameters for evaluating project viability and care should be taken to reduce uncertainty in these values by obtaining reliable quotes from local suppliers. Optimization of a project involves generating scenarios that vary technical and financial inputs to calculate internal rate of return for the project considering uncertainties.

The details in this report are intended to help companies and developers of PV projects to design and build PV systems that consider all the factors that might influence the future performance of the system and result in higher quality systems. Key areas where improvements are needed include:

- **Tracking algorithms**: Tracking companies avoid sharing details about how their specialized tracking algorithms work and therefore it is difficult to evaluate their performance and assess whether they add sufficient value to the bifacial technology or to a particular project. Developers interested in new tracking algorithms are encouraged to deploy multiple sets of trackers each running different algorithms at a site for a test period to help decide which one to use for the life of the plant. Side-by-side comparisons at the same site are necessary to validate industry claims of potential yield increases.

- **Albedo enhancement**: It is not yet clear whether the use of albedo enhancers, such as geosynthetics, will ever be economically feasible, but early studies have shown some promising results. Continuing research into low-cost, durable materials and optimal placement strategies will help determine if albedo enhancement becomes standard practice.
- **Response to extreme weather**: The ability of trackers to respond to rare, extreme weather conditions should be standardized. According to our owner/operator survey, there is a significant risk that a tracker will not respond appropriately to such an event. While these events are rare, their consequences are very impactful.
- **Capacity tests**: While the standardization of monitoring for bifacial tracked PV systems has improved significantly in recent years, there are still serious challenges for completing capacity tests on these systems due to factors such as high dc/ac ratios, periods of cloudy weather, and uncertainty in row-to-row shading and yield predictions.
- **PV performance models**: Yield prediction (performance) models for bifacial tracked systems need to be improved. Our round robin model comparison carried out on six scenarios demonstrated up to ~100% difference between rear side irradiance predictions between different models and participants. Also, predictions for module temperatures and even tracking angles were alarmingly variable between different participants. More high-quality, validated datasets are needed for model developers to ensure that models are more consistent.
- **Reliability**: There is very little literature on the reliability and durability of single-axis tracker systems. Longitudinal studies of different tracker technologies across different climates need to be supported. Such studies are important for optimizing the design and operation of tracked PV plants.

The use of bifacial modules and trackers for agrivoltaic systems is especially exciting because if it can be shown to be feasible, it could make available a vast amount of land for renewable energy generation and help many smaller countries benefit from PV energy without sacrificing land for agriculture. A major challenge will be how to reduce the design complexity and variations for such applications to take advantage of standardization, high throughput manufacturing, and global supply chains to lower the cost.