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Performance of Bi-Facial Modules on a Dual-Axis Tracker in a High-Latitude, High-Albedo Environment

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***Abstract* — Bifacial modules installed on a dual-axis tracker in Vermont delivered significantly more energy than adjacent mono-facial modules installed on the same tracker, with peak energy gains occurring in winter months attributable to the high reflectivity of surrounding snow. Data from the winter of 2018 reveal monthly bifacial gains to be as high as 91 percent and gains in non-snowy months as high as 13 percent. The authors will include data from the winter of 2019 in the final paper, resulting in two years of performance data and one year of reliability data.**

I. Introduction

Bifacial modules are rapidly gaining market share, a trend driven by lower costs and multiple studies quantifying the energy gain of bifacial modules relative to monofacial modules (known as bifacial gain.) Estimates for bifacial gain range from as much as 30 percent for a fixed-tilt photovoltaic (PV) system to 50 percent for single-axis trackers (not taking into account a system optimized for all the variables that contribute to bifacial gain, including azimuth, height, tilt angle, cell type, albedo, etc.) [1]

As a result, LCOE calculations have given the edge to the bifacial tracker systems, which are one of the fastest growing segments of the bifacial market. Many tracker manufacturers are redesigning their trackers to reduce backside shading from torque tubes and mounting structures, further increasing bifacial gain. High-albedo environments, such white commercial rooftops, deserts, and snow-covered terrain, are an especially attractive market for bifacial PV systems because albedo is a primary contributor to bifacial gain. [2] Furthermore, placing bifacial PV on trackers typically increases the distance between the PV module and the ground. This height increase also improves the energy gain of bifacial PV relative to monofacial PV.

Despite the importance of albedo, limited research has been conducted on the production advantages of installing bifacial systems in snowy environments. Even less well understood is the performance of bifacial modules mounted on dual-axis trackers. [3] Yet—as our research shows—bifacial dual-tracker systems in northern latitudes have the potential to outperform other designs, thereby offsetting their greater installation and maintenance costs. Higher performance can be attributed to four factors: 1) the ability of two-axis trackers to minimize the angle of incidence, thus maximizing the amount of direct normal irradiance striking the front of the array; 2) the reflectivity and high-albedo of snow, which may be present from three to four months each year in northern regions of the continental US; 3) cooler year-round operating temperatures; and 4) the height of the modules relative to the ground, which increases the amount of light reaching the modules' backside.

In order to quantify the performance potential of dual-axis bifacial systems in snowy climates, Sandia National Laboratories is collecting data from two tracker systems installed at the US Department of Energy's Regional Test Center for Photovoltaic Technologies in Williston, Vermont. [1]This effort is part of a larger, three-year project that aims to increase the performance and resilience of PV systems deployed in regions of the US that regularly experience below-freezing precipitation, thus aiding in the adoption, integration and optimal operation of the nation's solar resources.

This paper describes the results from data collected in 2018 but will be expanded by the final submission date to include both 2019 performance data and our reliability analysis.

II. EXPERIMENTAL METHODOLOGY

We collected data from two dual-axis tracker systems, which were installed in late 2017, and populated with equal numbers of mono-facial and bifacial modules as follows:

<u>Tracker System One</u>

- Ten (10) 60-cell 290W monocrystalline, monofacial modules
- Ten (10) 60-cell 290W *frameless* monocrystalline bifacial modules (frontside flash-test results at STC)

<u>Tracker System Two</u>

- Ten (10) 72-cell 325W monocrystalline monofacial modules
- Ten (10) 72-cell 325W monocrystalline bifacial modules

[1] The Vermont Regional Test Center (RTC) is one of five US Department of Energy funded RTCs, four of which are managed by Sandia National Laboratories. These RTCs validate the long-term performance of PV components and systems across different climates, collecting high quality, high fidelity data from fielded equipment. Manufacturers, also known as RTC industry partners, who wish to have their equipment studied at one or more sites, are selected via a competitive process and work closely with Sandia on a set of technical objectives, which Sandia then executes.

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We instrumented each tracker as follows:

- Four Omega Type T thermocouples (two per string), distributed across the back of the array.
- Two EETs reference cell irradiance sensors (one for frontside plane-of-array; the other for backside.
- Two tracking error monitors, one with a 120-degree field-of-view (MEMS ISS-D60); the other with a 30-degree field-of-view, which provides greater accuracy (MEMS ISS-D15). The sensors are mounted on the lower edge of the tracker array to facilitate cleaning.
- One string-level DC monitoring box containing Empro current shunts and resistive voltage dividers (both calibrated to an accuracy of 0.1 percent.)
- Campbell datalogger configured with an RS485 communications backbone and set to collect data every 5-seconds, averaged at one-minute intervals.
- Campbell outdoor observation auto-focus camera set at maximum view angle

Figure 1 EETS reference cells mounted in the plane of array on both front and back of the tracker systems. The cells are cleaned twice a week.

Data collected from both systems is transmitted via cellular modem to Sandia, where it is monitored daily for anomalies that might indicate sensor or system failure. In addition, the EETS reference cells are cleaned twice a week, and the MEMS tracking sensors twice a year; we also conduct monthly visual inspections for physical changes in the modules.

III. Results

In analyzing the results of our performance analysis, the inherent bifaciality of a module, which reflects cell type, must be considered. The bifaciality is the ratio of the power measured during a flash test on the rear-side of the module to a flash on the front-side of the module. System one is populated with modules that have a bifaciality of about 92 percent; system two modules have a bifaciality of only 62 percent. Also, in order to fully assess performance, one must monitor the tracking accuracy of the tracker itself. In addition, the impact of any backside shading of the bifacial modules created by the tracker frame and pedestal must be determined. Finally, we assessed the impact of snow load on module reliability, with the results of our electroluminescence analysis provided below.

A. Bifacial Energy Gains

We measured bifacial gain as a percentage of total energy output, calculated according to the following equation:

Bifacial Gain in Energy (BG_E)

$$BG_E = 100\% \times \left(\frac{\sum_{1\,month} P_{bifacial} \;/\; Pmp_{bifacial}}{\sum_{1\,month} P_{monofacial} \;/\; Pmp_{monofacial}} \right) \quad (1)$$

As expected, bifacial modules outperform monofacial modules throughout the year, but the gains are greatest in winter when snow cover creates a high albedo. During December of 2017, for example, systems one and two had bifacial gains of 34 and 91 percent, respectively (see Figure 2), although it should be noted that overall energy generation at that time of year is low. The large bifacial gain documented in December for system two, which underperforms system one on an annual basis, is likely attributable to snow cover on the front side that blocks light entering the front side.

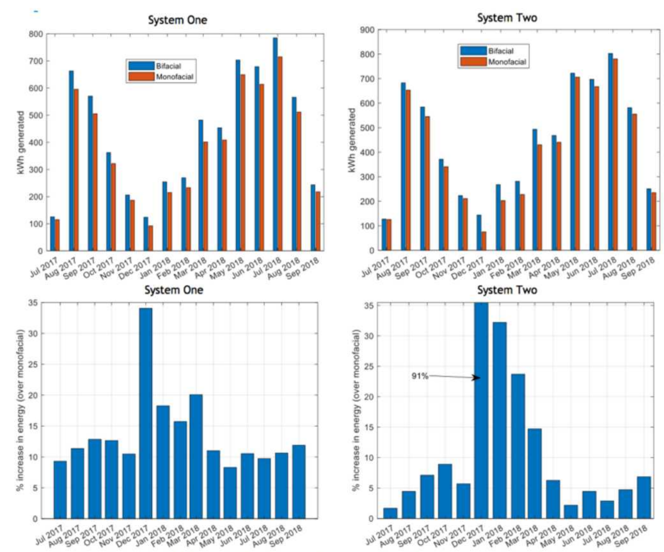

Figure 2. Energy yields and bifacial gain for dual-axis tracker systems one and two. Note that bifacial gain is greatest in winter when there is high albedo from snow.

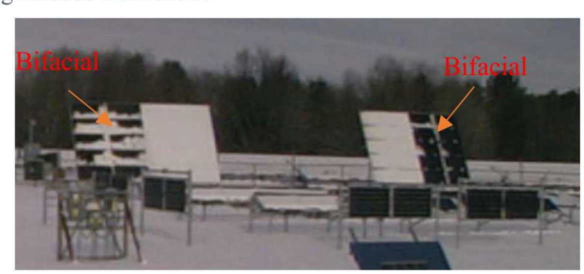

Figure 3. Time-stamped images of systems one and two demonstrate that the bifacial modules shed snow more quickly than the monofacial modules. System two (*left*) has framed bifacial modules mounted on system one (*right*) are unframed.

B. Backside Shading from Tracker Frame

The dual-axis trackers chosen for this study were not specifically designed for bifacial modules and thus have a large H-shaped frame and pedestal that shade the backside. We analyzed both structures and found that "soft" shading (the offset design of the H frame allows some light to reach the modules' backside) reduced overall power output by only 1.2 percent for system one and had an even smaller impact on system two, attributable to the latter's reduced bifaciality. In contrast, the "U" channel racking creates "hard" shading, that is, full blockage of the module behind it, although the amount of area involved is small. We estimate the resulting power loss due to back-of-the-module shading by the U-channel to be 0.4 percent or less. Combining those losses, we calculate that the total energy lost from backside shading for system one is about 1.6 percent and about 1.1 percent for system two, which has lower inherent bifaciality.

Figure 2. Backside of system one, with DC monitoring box and datalogger mounted on the pedestal. Monofacial modules are on the left side; bifacials on the right. Backside shading proved to have minimal impact on the bifacial gain for this system.

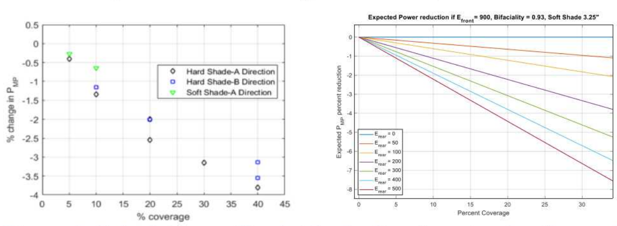

Figure 4. Calculations of backside shading from tracker frame show shading from the "H" frame (*left*) and "U" channel (*right*). Total shading losses for both systems are less than 1.6 percent.

C. Tracker-Error Monitoring

We determined tracking performance of both systems by measuring the error of the trackers' elevation and cross-elevation axes. Cross-elevation is defined as the axis in the plane of the tracker face, orthogonal to the elevation axis. In-plane tracking-error monitors usually measure both elevation- and cross-elevation error. Azimuth error is defined as:

$$AzimuthError = \frac{CrossElevationError}{cos(Elevation)} \qquad (2)$$

Our analysis shows consistent tracking between September 2017 and August 2018, with errors of less than 5 degrees.

D. Reliability Analysis

To identify reliability issues, such as the susceptibility of unframed glass-glass bifacial modules to cell cracking caused by snow load or mechanical stress across the tracker, we will subject both the monofacial and bifacial modules to *in situ* electroluminescent (EL) imaging and compare the results with EL images of spare modules kept in storage. [Editors: please note that these results are incomplete but will be included in the final submission.]

IV. Conclusions

Our research demonstrates that year-round gains from bifacial dual-axis trackers are an under-recognized opportunity to lower levelized cost-of-energy projections for northern latitude, high-albedo environments.

We found that bifacial panels consistently outperformed their monofacial counterparts, although the percentage gained was smallest in summer when grass reduces the albedo to ~ .25 from a high of .80 or more when snow is present in winter.

Overall, the productivity of bifacial dual-axis systems can be attributed several factors:

- High albedo (.80) in winter
- Array height, which allows for more light to reach the backside of modules, especially at low sun angles
- Accelerated snow shedding enabled by 1) backside irradiance that increases module temperature and 2) frameless modules
- Cooler operating temperatures

In conclusion, our work suggests there is an under-recognized opportunity to lower levelized cost-of-energy projections for PV systems installed in northern latitude, high-albedo environments and also to identify climate-specific operating and design parameters that will lead to a new generation of PV systems optimized for the climates in which they will operate.

References

[1] J. Stein, D. Riley, M. Lave, C. Deline, F. Toor and C. Hansen, "Outdoor field performance from bifacial photovoltaic modules and systems," Sandia report. SAND2017-10254C

[2] M. Lewis, C. Valdivia, C. Tu Li, A. Russell, H. Schriemer and K. Hinzer. "Bifacial photovoltaic module energy yield in northern Canada," BiFiPV 2018 Workshop, Denver, CO

[3] Y. Taomoto, K. Hosokawa, M. Yagami, H. Hanzawa, T. Ohkawa and K. Iwamoto. "Bifacial tracking system in snowy region," BiFiPV 2016 Workshop, Miyazaki, Japan