Updated Trial of Meteorological Station Using PV Reference Cell Array

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***Abstract* — We report on an updated field trial of a new meteorological station concept for resource assessment at the site of a prospective utility-scale photovoltaic (PV) power plant to be developed by 7X Energy. Cost savings are achieved by substituting Atonometrics PV reference cells for thermopile pyranometers in a unique multi-reference-cell array configuration that allows accurate determination of global horizontal irradiance (GHI) and by using advanced remote diagnostics to minimize the need for on-site visits for sensor cleaning. Reference data are also obtained from a second station at the site employing thermopile pyranometers and maintained through weekly site visits for pyranometer cleaning. Data from both stations are compared to industry-leading SolarAnywhere® satellite-derived irradiance measurements from Clean Power Research and are used for tuning of the satellite model for long-term irradiance prediction and site resource assessment. Predicted long-term average annual irradiance using either the reference cell array or pyranometer ground station for satellite model tuning differed by only 0.6%.**

***Index Terms* — photovoltaic systems, solar energy, resource assessment, pyranometer, reference cell**

I. Introduction

Meteorological ("met") stations play a key role in the development and operations of utility-scale photovoltaic (PV) solar projects for both pre-construction resource assessment campaigns and operational performance monitoring.

Pre-construction resource assessment is performed to qualify a prospective site and evaluate its long-term expected energy in support of project financing. A widely used approach to irradiance assessment for utility-scale PV combines satellite-based irradiance measurements, which provide long-term history and inter-annual variability data, with typically 12 months of ground-based global horizontal irradiance (GHI) data for site-specific high accuracy measurements and tuning of the satellite model [1][2].

Acquisition of ground data represents a material expense for projects both during preconstruction development and long-term operation, for both met station hardware and ongoing maintenance. Typical resource assessment met stations employ thermopile pyranometers for GHI measurement with weekly visits for pyranometer cleaning.

Here we report on an updated field trial of a new met station concept by Atonometrics that achieves cost savings by employing an array of multiple photovoltaic (PV) reference cells for GHI measurement, in place of thermopile pyranometers, and remote diagnostics to minimize site visits for sensor cleaning. The unique station concept solves several important issues typically associated with using PV reference cells to measure GHI, including minimizing the impact of soiling and correcting for incidence-angle dependence.

The field trial has been conducted at a prospective 7X Energy site over an 8-month period, during which comparison data were also collected at the site by a traditional station using thermopile pyranometers with weekly maintenance. Data obtained from the two ground stations are used with SolarAnywhere® satellite irradiance data from Clean Power Research to perform site tuning of the satellite irradiance model.

We previously reported on a 10-month field trial of an earlier version of the reference cell array concept [3][4]. In the current work, we have updated the array design by optimizing the orientation of the reference cells and have updated the analysis with a new algorithm calibrated against traditional thermopile pyranometers [5].

II. EXPERIMENTAL

A. *Reference cell array*

Field data were obtained between July 2020 and February 2021 from the pre-construction site in Texas that is under consideration for construction of a utility-scale PV power plant.

The experimental met station measures GHI, albedo, and soiling, and data were transmitted from the site via cell modem. For this work we are specifically concerned with the instrumentation for measuring GHI and soiling.

Three PV reference cells (Atonometrics, RC18) are mounted at 25° tilt facing different compass directions, nominally north,



Fig. 1: Reference cell array, with 3 cells facing nominally north, southeast, and southwest, with another cell facing down (not shown, on extension arm).

southeast, and southwest, as shown in Fig. 1. A fourth reference cell (not shown) faces down to measure ground-reflected light (reflected horizontal irradiance, RHI). This arrangement has been updated since our previously reported study [3][4]. The tilt angle helps minimize soiling as compared to a horizontal orientation [6], while the use of a multiple reference cell array allows determination of direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI) components [5][7][8] and therefore calculation of GHI and correction for incidence angle dependence [3][4][5]. The precise azimuthal orientations of the PV reference cells were determined after installation by analysis of their daily irradiance profiles under clear-sky conditions.

Data from all four reference cells are analyzed at each time point by a two-stage process, in which an isotropic sky model is solved to determine estimates of GHI, DNI, DHI, and RHI which best fit the data from the multiple cells, taking into account the incidence angle response of the cells, and then a neural network model adjusts the estimates to final values [5]. The neural network was pre-trained on a set of data acquired at other locations on other similar cell arrays. The training uses thermopile pyranometers (Hukseflux, SR30) as a reference for GHI. In the current work we are interested only in the GHI results and use the DNI, DHI, and RHI data only as intermediate values to support the GHI calculations; further use of the DNI and DHI data is the subject of ongoing study [5].

For this work the analysis was carried out by post-processing; for future deployments, the analysis could be performed on-site in real time by an embedded processor.

B. *Remote diagnostics*

We employ remote diagnostics to determine the reference cell array sensor cleanliness and thereby reduce the expense of weekly cleaning visits associated with traditional stations.

Soiling measurement is performed with a maintenance-free optical soiling sensor (Atonometrics, Mars™) mounted at the same tilt angle as the reference cells. The soiling sensor, which has a flat glass window similar to a PV device, has been shown to be a good measure of the soiling of PV reference cells due to atmospheric dust deposition [9] and is especially sensitive to low soiling levels. In addition, we could detect occasional fouling of individual PV reference cells by inter-comparison of the three up-facing cells, for which the cell redundancy is an advantage, and by comparison of the PV reference cell data to clear-sky models during clear-sky conditions as in [10].

Data from the soiling sensor and the clear-sky models were used to determine a daily soiling ratio for each PV reference cell, and the measured irradiance data were corrected, if needed, to account for soiling. These remote diagnostics showed typically low soiling and therefore the data collection was completed without performing any site visits for sensor cleaning during the entire reported data collection period.

C. *Pyranometer station*

A second more traditional met station was also present at the site. This station included two horizontally mounted thermopile pyranometers (Hukseflux, SR30) for GHI measurement, as well as other meteorological instruments. Data from this station were used for comparison to the experimental reference cell array station.

D. *Sensor calibration*

The RC18 PV reference cells were calibrated at Atonometrics per IEC 60904-2 and using a reference PV device calibrated at the National Renewable Energy Laboratory (NREL), while the SR30 thermopile pyranometers were calibrated by Hukseflux prior to shipment according to ISO 9847. Both sets of calibrations are traceable to the World Radiometric Reference, although via different instrument paths and procedures applicable to each instrument type.

The neural network model discussed above serves as a post-calibration to adjust the reference cell array readings to better match those of the SR30 pyranometers, via work carried out at another site [5] on separate but identical reference cells following the same initial calibration procedure.

E. *Satellite-derived irradiance*

Satellite-derived irradiance values for the site were generated using SolarAnywhere, an industry-leading data product from Clean Power Research.

Data from both the reference cell and pyranometer ground stations were used to tune the long-term satellite model, comprising over 20 years of data, as described in [1][2]. An overlapping data period of July 1, 2020 to February 28, 2021 was used from both ground stations.

The tuned satellite models allow a comparison of the typical year annual GHI and long-term average annual GHI using either the pyranometer or reference cell array data, and therefore a comparison of the energy estimates and financial impact of using either type of ground station as reported in our previous study [3][4].

III. Results

Results are shown in Table I, which quantifies the satellite model irradiance predictions and inter-annual statistical variations using tuning from both ground stations.

The typical year annual GHI prediction is constructed using data from actual months corresponding to the ground station campaign. The long-term average annual GHI represents the average irradiance that will be exceeded with 50% probability. The coefficient of variation is the standard deviation of annual irradiances divided by the mean, and the normalized range of annual irradiance is the difference between the maximum and minimum year, divided by the mean.

TABLE I: ANNUAL RESOURCE ASSESSMENT FROM SOLARANYWHERE® SATELLITE DATA TUNED WITH EACH GROUND STATION.

	Pyranometer	Ref. Cell Array	Difference
Typical Year Annual GHI (kWh/m^2)	1742	1749	0.4%
Long Term Average Annual GHI (kWh/m^2)	1744	1754	0.6%
Coefficient of Variation	3.3%	3.2%	
Normalized Range of Annual Irradiance	14.4%	14.0%	

Average predicted irradiance using satellite tuning based on either the pyranometer or reference cell array ground stations produced almost identical results. The 0.6% difference in long-term average annual GHI is small compared to instrument uncertainties. NREL has estimated the expanded uncertainty of a field pyranometer to be 3-5% [11].

In a previous study at another site we reported a larger difference in predicted long-term average annual GHI using an earlier version of the reference cell array compared to the same model pyranometer [3], and identified sensor calibration differences as the most likely primary factor [4]. In the present study, as discussed above, we have added the neural-network analysis stage which, among other benefits, serves to match the reference cell array calibration to that of same-model thermopile pyranometers used in the pyranometer ground station.

IV. CONCLUSIONS

Results of the 8-month field test for this site suggest that the reference cell array may be a viable alternative to a traditional pyranometer for ground measurement campaigns used for solar resource assessment. Use of the reference cell array, coupled with greatly reduced site visits enabled by remote monitoring and correction for sensor soiling, could enable significant cost reductions in ground measurement campaigns, while producing equivalent quality data. Testing at additional sites is in progress.

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