White Paper

3 Steps to Understanding the Performance of your Distributed Solar Assets

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Shareables

1. Limited budgets and tight timelines make efficient means of analyzing system performance critical to stakeholders in large solar distributed generation (DG) portfolios.
2. Automated and graphical processes can be used to efficiently identify underperforming systems while simultaneously characterizing the overall performance of the portfolio.
3. It is critical that a balanced analysis is performed, such that the portfolio is reviewed in sufficient detail to accurately identify underperforming systems, while sticking to budgets and timelines.

Executive Summary

As distributed solar photovoltaic (PV) portfolios begin to age, the challenge of measuring performance becomes more relevant. Such an analysis can help financial stakeholders identify performance short-falls and potential warranty items, adjust operational procedures, and evaluate the future value of assets' performance projections. However, in depth analysis of all, or a large portion, of the operational/performance data (performance data) for individual systems is often not practical from a timing or budgetary perspective. Therefore, a high-level review of all systems in the portfolio should be performed to identify systems that warrant additional review. It is critical that the portfolio is reviewed with sufficient detail to accurately identify underperforming projects, but such an analysis must also be efficient and practical.

We describe a method of performing analysis of solar DG portfolios that we have found to achieve the necessary balance between detail and efficiency.

To develop a meaningful, cost-effective performance analysis we propose a method to:

1. Evaluate the historical, weather-corrected performance.
2. Characterize the overall portfolio's performance.
3. Identify projects that may warrant additional, in-depth review due to underperformance.

This method has successfully been implemented in the analysis of DG PV portfolios ranging from tens to thousands of projects, representing 100's of MW of capacity. It has proven to be an effective, and efficient method. However, it is important to note, that no analysis is one size fits all. The methods presented herein must be tuned to meet the specific needs of the analysis and the nuances of the specific portfolio.

ICF's method requires an understanding of the following: **1)** high-level project design specifications and initial estimates; **2)** the regional distribution of projects in the portfolio; and **3)** historical weather and performance data. Understanding that each portfolio is unique, we do not attempt to describe a detailed step-by-step analysis, but instead describe the process flow for portfolio review.

Initial Generation Estimates

Initial estimates of generation are typically developed prior to investment and operation of a portfolio. However, because they are theoretical in nature, they can be developed at any point. If initial estimates are not available for the projects, they can be developed based on as-built design information prior to the onset performance data analysis. It isn't necessary to utilized the appropriate generation modeling methods because the implementation of robust and consistent modeling methods is critical to the development of initial estimates, and ultimately the quality of the analysis; however, the appropriate level of detail must be considered in producing the initial estimates.

Regional Historic Weather Data

To increase efficiency of the analysis, projects are organized into regions. A single weather dataset is selected to represent the relative resource fluctuation for all projects in the region. An approach for verifying reasonable demarcation of regions and an appropriate representative dataset is available upon request. It is critical that the Representative Dataset for each region accurately demonstrate the relative variation in resource of all the projects within the region for the operational lifetime of those projects. Datasets developed via satellite-based imagery algorithms[1] are often used because of their demonstrated accuracy,[2] area coverage, and near real-time availability.

[1] Perez, et. al., Sengupta et. al.

[2] Gustafson et. al., Perez et. al.

Historic Irradiance and Weather Correction

Upon selection of the representative dataset for each region, the initial estimates can be adjusted to reflect the expected generation of the projects accounting for the relative variation in solar resource and weather. As a result, actual performance data can be analyzed independent from natural fluctuations in resource; ultimately allowing the analysis to demonstrate if the systems are performing as expected. We have found that weather corrections can be expedited by considering carefully weigthed monthly averages of hourly weather data, rather than the hourly data as applied to each individual project.

To correct the initial estimates for actual solar resource and weather corrections, we recommend the following considerations:

1. Plane of array ("POA") irradiance should be calculated, and used for correcting the solar resource, based on the orientation of modules in each project
2. Soiling and snow losses used in the initial estimates should be modified based on historical precipitation reported for each region
3. Irradiance weighted module temperature, estimated based on the representative dataset and POA irradiance, should be used to adjust estimated module efficiencies
4. Remove periods of underperformance resulting from known system outages

Reflecting these 4 considerations, we develop project specific energy correction factors, which are applied to initial estimates to develop weather corrected estimates of expected energy generation for each project ("Corrected Estimates"). The ratio of the actual energy generation to the Corrected Estimates ("AvE Ratio") can then be used as a metric for evaluating project- and portfolio-level performance.

Result Analysis

Ultimately, the goal is to identify the projects that are most critically impacting the overall portfolio and characterize the overall performance of the portfolio relative to expected. A detailed analysis needs to be performed on all projects with an AvE Ratio below a set limit to determine possible causes and remedies for project underperformance, and to establish revised generation estimates. However, to increase analysis efficiency, it may be acceptable to identify a project capacity threshold ("Threshold"). The Threshold should be established so that projects with capacities below the Threshold should have a minimal impact on the overall performance of the portfolio, such that underperformance of these projects typically does not warrant in-depth analysis. The Threshold is not a fixed value, but may be dependent on the results of the analysis and evaluation of the metrics relevant to the distribution, and may also be dependent on the magnitude of individual project underperformance.

Significant insight to the historical performance of the portfolio can be completed using efficient automated and graphical means of statistical analysis of the AvE Ratio.

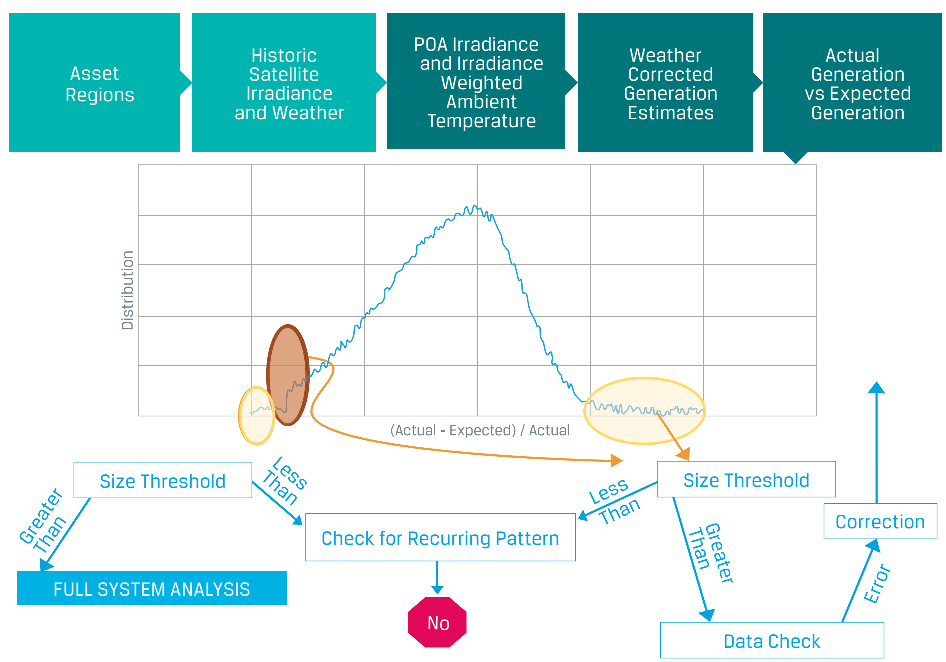
Specifically:

1. Often, the median and mean of the distribution of the AvE Ratios can effectively demonstrate the overall performance of the portfolio.
2. The shape and spread of the distribution of the AvE Ratios can be statistically and graphically analyzed to gain an understanding of the quality of the data and uncertainty of the analysis.
3. Similarly, outliers can be identified through both graphical and statistical measures.

While not discussed in detail herein, we note that the performance of PV generation systems have been shown to degrade over time, which may significantly impact the lifetime value of projects. Therefore, consideration of long term system degradation may also play a critical role in the analysis of a portfolio. Typically, the rate of performance degradation is relatively low and may take many years of operation before the impact of degradation is apparent or easily measurable. Unless the period spans many years or rates of degradation are very high, the analysis may not readily identify projects with accelerated rates of degradation. However, effective methods for estimating the degradation rates of projects, given appropriate levels of data resolution, have been previously described. The analysis detailed herein can be easily modified to perform a high level degradation analysis that can effectively bound the expected limits of long term degradation rates.

A suggested process for performing this analysis and analyzing the results of the distribution and efficiently identifying the projects most critical for detailed analysis is illustrated in a decision matrix (see Figure 3). We have found that this method of analysis is effective, efficient and accurate.

GRAPHICAL REPRESENTATION OF ANALYSIS :



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About the Authors

Mark Reusser specializes in solar photovoltaics with over about five years of experience in the field. He supports solar energy project owners and investors with due diligence and owners engineering services. He applies knowledge gained serving as an owner's engineering representative and independent engineering representative for over 2 Gigawatts of solar photovoltaic projects. Mark developed expertise in solar technology by supporting the independent engineering reviews of numerous utility scale and distributed PV projects. He specializes in performance modeling, performance testing and technology reviews for all scales of photovoltaic projects in support of non-recourse financing, sale-lease back and buy-side transactions.

Heidi Marie Larson is a licensed professional engineer experienced in technical and financial aspects of solar assets, and broader renewable generation. She has proven communication and project management skills that contribute to achieving objectives and creating value across organizationally diverse teams. She has supported more than 3.5 GW-AC of renewable generation assets through development, financing, construction/commissioning, and operation. Ms. Larson also has a strong knowledge base in renewable energy system performance, contracting and project execution, and commissioning and operation.

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