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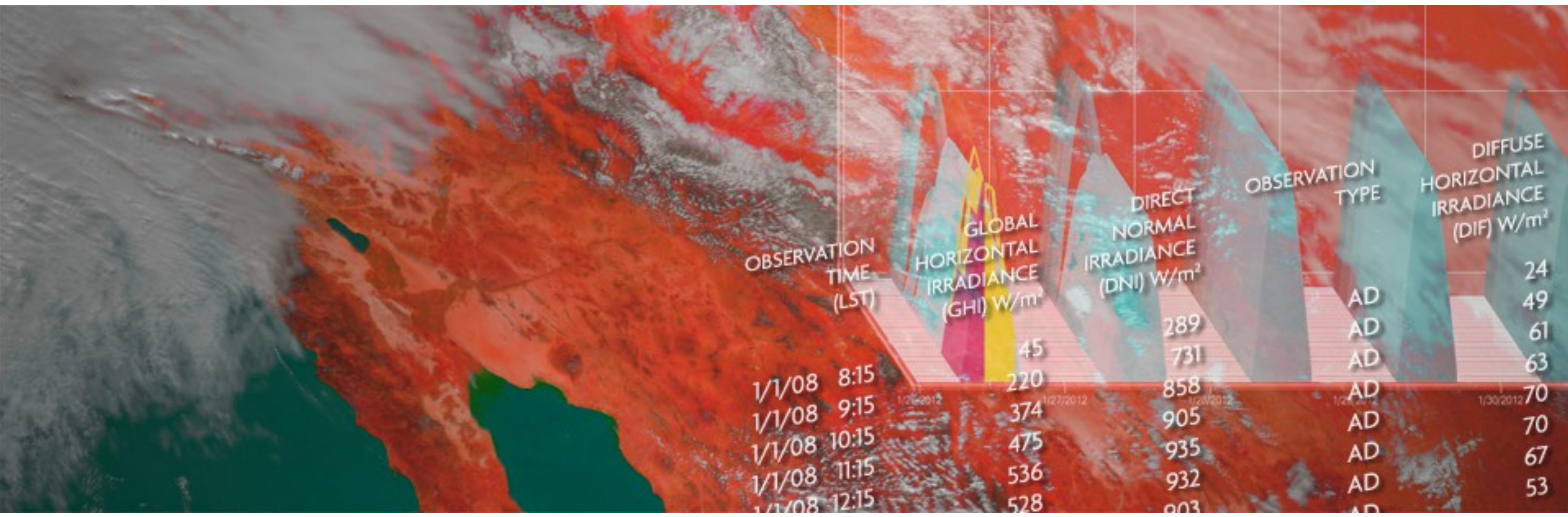
Powering Intelligent Energy Decisions®

Behind-the-Meter Intelligence for Distributed PV Grid Integration



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Executive Summary

As energy generation from distributed photovoltaic (PV) increases, utilities and ISOs are working to understand the impact that high penetration PV has on the electrical power system. While there is no single definition of high penetration PV, it's commonly understood that if additional efforts are required to integrate dispersed generation resources optimally, then that constitutes a high penetration scenario.[1] Of particular concern to utilities and ISOs is the ability to quantify the effects of variability with respect to the reliability and stability of electric power systems.

PV installations can experience rapid changes in power output due to cloud transients. While this variability is typically not a concern for the individual PV system owner, it is for utilities or system operators that may have tens of thousands of grid-connected PV systems within their service territories. Gaining insight into the performance of these PV 'fleets' is important to enable utilities and ISOs to reliably interconnect PV and potentially allow for a higher percentage of PV generation on the grid, while reducing costs for themselves, ratepayers and PV system owners.

This whitepaper outlines the challenges utilities face in integrating high penetration PV into their grid operations, and the difficulty they have in obtaining the quantitative information required to maintain grid reliability. It will also introduce SolarAnywhere FleetView™, a new software service that enables utilities to obtain behind the meter data, calculate power output variability, and understand the implications of grid-connected solar. Ultimately, this software will enable grid operators to better calculate the full economic and operational impact of PV without requiring extensive investments in grid infrastructure.

Contents

[1] R. Brundlinger and C. Mayr: International Energy Agency Photovoltaic Power Systems Programme Task 14. [link]

Challenges of Grid-Connected PV

As the penetration of PV increases, PV production variability is a critical concern for energy providers, both at the planning stage and in day-to-day operations. Intermittency causes utilities and ISOs to be concerned about scheduling reserves and meeting their operational obligations. This is true whether the PV resource is a utility-scale plant or a collection of small residential systems.

Utilities also have concerns about how high levels of PV will impact local distribution feeders. Because electric distribution systems are primarily designed for one-way power flow, introducing a high penetration of distributed PV systems can affect voltage regulation, power flow and system protection. These real and perceived risks to grid operations have led regulatory agencies, including the California Public Utilities Commission (CPUC) and the Federal Energy Regulation Commission (FERC), to set guidelines that limit PV penetration within a particular balancing area to 15 percent or less of peak load. Beyond that threshold, additional studies are required, adding significantly to the cost of installing new PV and creating a barrier to PV growth.[2]

The issue is particularly pressing in light of aggressive state renewable energy targets. For example, to meet California's RPS goal of 33 percent renewables by 2020,[3] industry experts anticipate that the resource mix will include about 5,000 MW of PV in only 10 years. However, the extent to which these resources will require regulation is largely unknown at present. The energy storage industry and grid operators alike will benefit from models and tools that accurately quantify the issue.[4]

Energy providers are in the early stages of understanding the full effects of high-penetration PV on electric power systems, and uniform standards for analyzing PV

[2]SunShot Initiative (2011): Beyond the 15% Rule. U.S. Department of Energy SolarHighPen. [link]

[3] P. Douglas, E. Stoltzfus, A. Gillette and J. Marks (2009): 33% Renewables Portfolio Standard Implementation Analysis Preliminary Results." California Public Utilities Commission. [link]

[4] B. Norris and T. Hoff (2012): Determining Storage Reserves for Regulating Solar Variability." Clean Power Research. [link]

variability have yet to be set. The lack of a standardized approach results in increased costs and barriers to PV growth:

- **Difficulty obtaining behind-the-meter data.** Until now, the primary method of obtaining behind the meter measurements of PV system performance has been to install expensive hardware along with a communications network connection (e.g., Internet, cellular modem, etc.).
- **Additional hardware requirements.** To overcome grid impacts caused by high-penetration PV, utilities may require owners of grid-connected PV systems to install and maintain additional hardware, such as voltage management devices.
- **Cost and time involved to conduct planning studies.** Because of the expense and long time-frames involved in conducting planning studies and their static nature, quantifying the impact of changing variables is difficult.
- **Reserve planning.** Quantifying the impact of distributed generation sources on peak demand can make it possible to properly size spinning and regulation reserves.
- **Forecasting distributed generation.** In order to maintain system balance, load balancing authorities need to forecast the variability of distributed PV in order to dispatch energy reserves.

Given these concerns, utilities and energy agencies recently began directing resources towards researching this problem. Research grants such as the CPUC California Solar Initiative Research, Development, Deployment and Demonstration (CSI RD&D) grants have focused on solving grid integration challenges with the aim of supporting the growth of solar.[5]

[5] Resolution E-4470 of the Public Utilities Commission of the State of California. [link]

Meeting the Challenge: SolarAnywhere FleetView™

Clean Power Research has developed a new approach to obtaining the intelligence needed to address concerns of high penetration PV. The solution, called SolarAnywhere FleetView, employs satellite-derived irradiance data in combination with patented fleet analysis methodologies to provide unprecedented insight into the impact of distributed PV on grid operations. As a hosted software solution, SolarAnywhere FleetView serves as an ongoing platform for analysis, enabling rapid, dynamic and cost-effective intelligence as compared to traditional point-in-time studies.

SolarAnywhere FleetView utilizes satellite-derived irradiance data to generate behind-the-meter PV performance data rather than using expensive ground sensors and communication networks. Using this data, SolarAnywhere FleetView can quantify PV variability to allow grid operators to conduct planning studies and forecast PV fleet output based on the design attributes and locations of individual PV systems. It uses advanced algorithms for calculating PV plant correlation coefficients and quantifying geographic dispersion effects in a manner that is useful at the control area level.

Integral to the solution is the ability to enumerate, specify, catalog, model and simulate fleets of PV systems, including providing PV power output forecasts. These software tools allow utility managers to understand PV system impact at macroscopic or granular levels, with virtual fleets being definable as a few systems on a single feeder or many thousands across an entire service territory. As a result, SolarAnywhere FleetView makes it possible for utilities and ISOs to, in effect, have an ongoing planning study to optimize PV siting while accounting for changes in distributed generation resource availability and other factors; all at a fraction of the cost and time associated with traditional planning studies.

In addition to planning studies, SolarAnywhere FleetView enables utilities and ISOs to cost-effectively forecast PV fleet variability minutes- to days-ahead for planning and scheduling regulation reserves in anticipation of high variability. Accurate quantification of needed regulation helps avoid the extremes of grid instability or over-commitment of resources.

Fig. 1 outlines how SolarAnywhere FleetView functions for both planning and operations, depending on whether SolarAnywhere High Resolution real-time or forecast data is used.

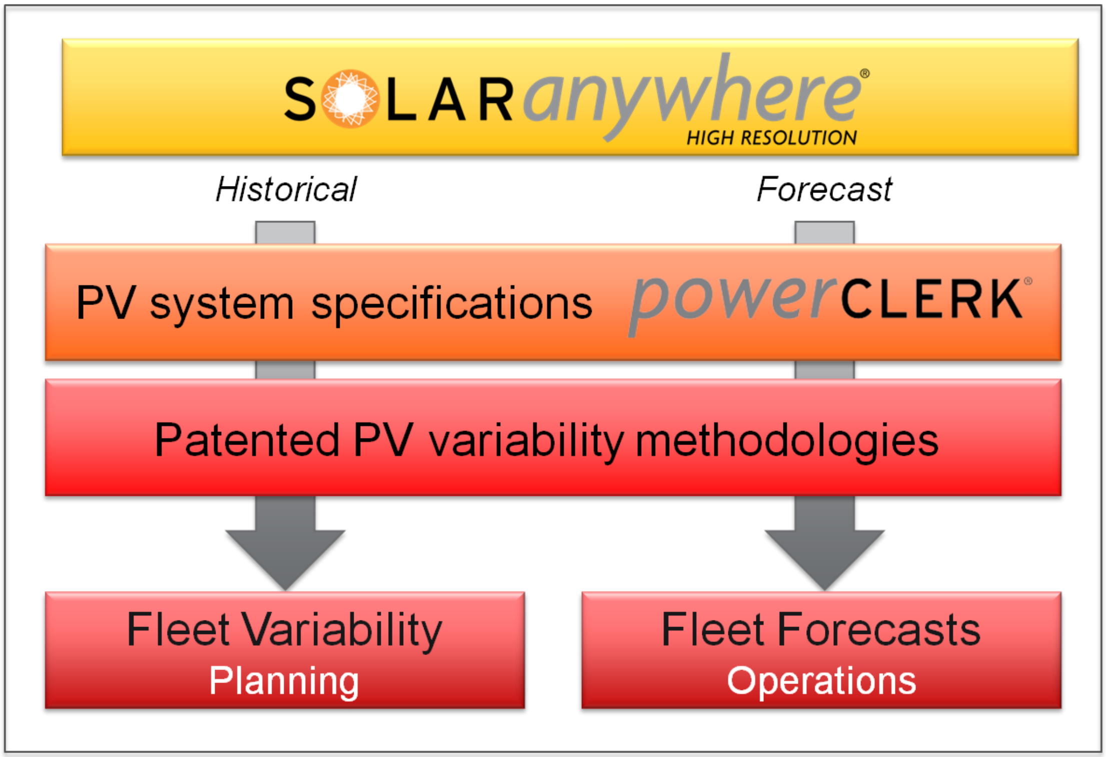

Fig. 1: SolarAnywhere FleetView can be used for planning or operations based on the data input—historical or forecast.

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SolarAnywhere High Resolution Irradiance Data

Measuring short time-scale ramp rates of grid-connected solar is critical to understanding system-wide effects of interconnected PV systems.[6] Clean Power Research is first to market with satellite-derived irradiance data at one-kilometer spatial resolution and one-minute temporal resolution, called SolarAnywhere High Resolution. SolarAnywhere High Resolution data enables SolarAnywhere FleetView to accurately measure the short time-scale ramp rates used to calculate variability across a range of environments, from large balancing areas, or a feeder line down to a single system.

SolarAnywhere High Resolution data is derived from the same robust satellite image processing algorithm that generates SolarAnywhere Standard Resolution and Enhanced Resolution data. However, the High Resolution data uses an added method of temporal interpolation to create minute-by-minute solar irradiance estimates for any tile across the continental United States and Hawaii. The increase in temporal resolution is illustrated in Fig. 2 for a single one-kilometer tile taken in San Francisco, Calif., at SolarAnywhere Enhanced Resolution (one-kilometer, thirty-minute) versus SolarAnywhere High Resolution (one-kilometer, one-minute).

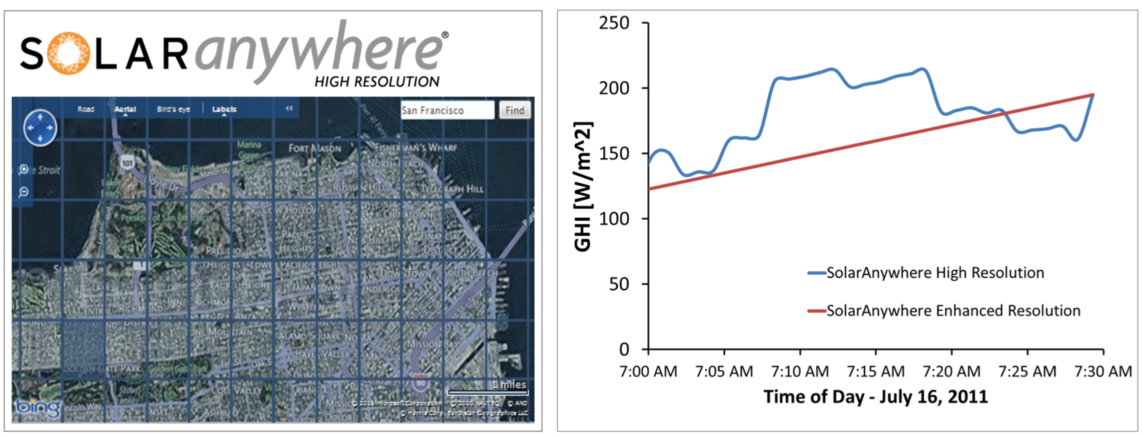

Fig. 2: Comparing SolarAnywhere Enhanced and High Resolution Data

[6] T. Hoff and R. Perez (2012): Predicting Short-Term Variability of High Penetration PV. American Solar Energy Society – Proc. ASES Annual Conference, Raleigh NC. [link]

SolarAnywhere High Resolution data was developed as part of a California Solar Initiative grant. Historical data from August 1, 2010, is available within the United States, Mexico, the Caribbean and parts of Canada. Current SolarAnywhere regional and time domain coverage are depicted in Figure 3.

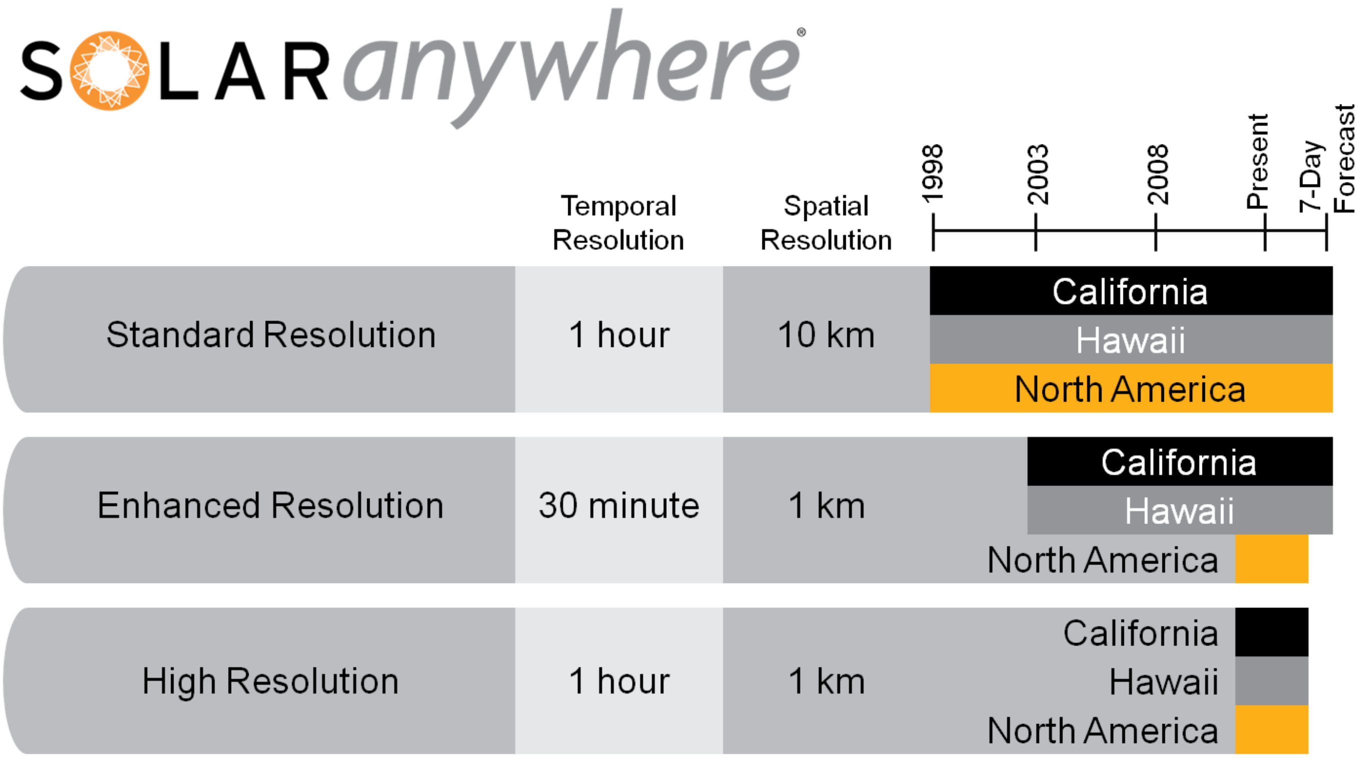

Fig. 3: SolarAnywhere Coverage (North America covers the continental U.S., Mexico, the Caribbean and parts of Canada)

SolarAnywhere High Resolution data is also available in seven-day advance forecasts for use in scheduling. Forecast data is created as a composite of two unique prediction methods. For medium-term estimates between five hours and seven days, National Digital Forecast Database values are used to derive irradiance. For shorter-term forecast horizons of one-minute to five-hours, a cloud directional vector model is applied, projecting irradiance through an interpolation method similar to the one used to create historical High Resolution data.

Patented PV Fleet Variability Methodologies

To address the need for a scalable, standardized approach to quantify and evaluate PV fleet variability, Clean Power Research developed methodologies for accurately estimating the overall system-wide effects of solar, given a non-correlated, distributed fleet of PV systems.[7]

Prior methods for addressing large fleets of grid-connected PV involved cumbersome computations and impractical high-speed data collection networks that would not be feasible in real time operations, and would constantly need to be updated as changes to the fleet occurred. The ability to quickly model fleet power output variability is thus particularly important as grid operators wish to balance power in real time as their distributed resources change. In April 2012, Clean Power Research was granted three patents on the PV fleet variability methodologies used in SolarAnywhere FleetView.

Validation of SolarAnywhere FleetView and Benefits of Geographically Dispersed PV

A recent study, conducted in cooperation with the California ISO, evaluated the ability of SolarAnywhere FleetView to predict ground-based measured irradiance conditions.[8] Results suggest that the performance of satellite-based irradiance approaches that of well-maintained redundant sensors, and that SolarAnywhere High Resolution data is well-suited to provide the basis for data required to perform high-penetration PV studies.

Of note, the study highlighted the fact that even well-maintained ground sensors produce considerably more invalid data points than the satellite (a ratio of 100-to-1), and that satellite data were key in detecting these erroneous data points.
The study also validated previous research that the greater the geographic distribution of a PV fleet, the less variability there is on a fleet-wide basis. A second

[7]T. Hoff, R. Perez (2012): Modeling PV Fleet Output Variability. Manuscript submitted to SolarEnergy. [link]

[8]Hoff and R. Perez (2012): Predicting Short-Term Variability of High Penetration PV. American Solar Energy Society – Proc. ASES Annual Conference, Raleigh NC. [link]

and equally important finding is that geographic dispersion also results in less *prediction* error. This is illustrated by comparing Figure 4, which shows the average MAE of 4 individual locations, to Figure 5, which combines irradiance across all four locations. Fig. 5 shows a clear reduction in error due to combining locations.

These findings are consistent with recent observations that regional solar resource predictions are considerably more accurate than single site predictions. This has important implications for utilities and ISOs as it demonstrates the value of geographically dispersed PV to reliable grid operation.

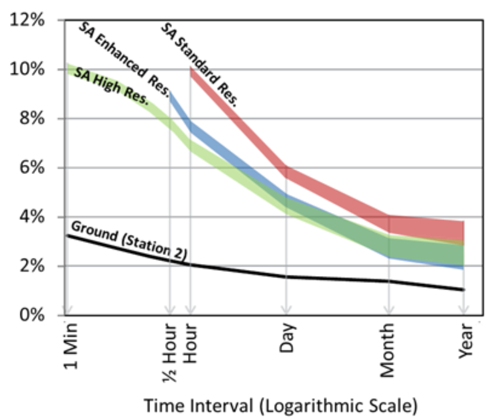

Fig. 4: Average MAE of 4 individual locations

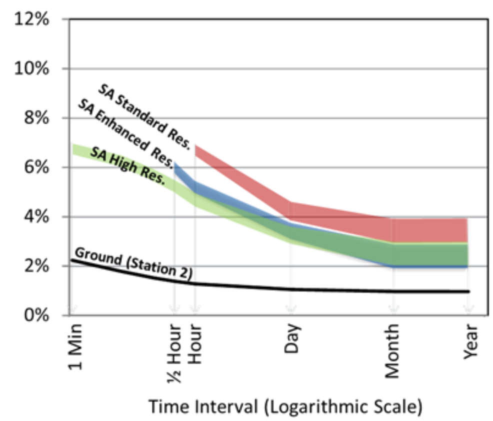

Fig. 5: MAE of 4 locations combined

Empowering High Penetration PV

Clean Power Research is addressing the needs of the solar industry through research and by bringing to market cost-effective, scalable software solutions. With increasing PV capacity, a need is arising for new methods to plan and operate the changing utility grid. Variability is inevitable because of intermittent cloud cover, but with SolarAnywhere FleetView, utilities and ISOs gain the ability to quantify variability effects on an ongoing basis without large infrastructure investments or high-cost planning studies.

By addressing the need for methods to plan and operate the grid, SolarAnywhere FleetView enables utilities and ISOs to cost-effectively and reliably integrate distributed PV, allowing for higher PV penetration and reducing costs for utilities, ratepayers and PV system owners.

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