BEHIND-THE-METER PV FLEET FORECASTING

Thomas E. Hoff, Benjamin L. Norris, John H. Dise
Clean Power Research
Napa, CA
www.cleanpower.com

Richard Perez,
ASRC, University at Albany
Albany, NY
asrc.albany.edu

Jim Blatchford
California Independent System Operator
www.caiso.com

Obadiah Bartholomy, Thomas J. Vargas
Sacramento Municipal Utility District
www.smud.org

ABSTRACT

Grid-connected PV in the U.S. has grown substantially over the past several years and grid operators are increasingly concerned about its impacts in planning and operations. In response, the California Solar Initiative (CSI) and the California Energy Commission (CEC) have funded research to support the development of cost-effective strategies and solutions for integrating large amounts of PV into the power system.

This paper describes preliminary results from the CSI and CEC projects. The paper describes how PV fleet power production is being simulated for all PV systems in the state of California. It then illustrates how these results could be used in balancing area planning and operation. Results suggest that simulating PV fleet power production using satellite irradiance data holds promise as an approach to address some of the challenges associated with integrating PV generation into the utility grid.

1. INTRODUCTION

The amount of PV connected to the U.S. utility grid has grown substantially over the past few years. Many expect that this growth will continue and perhaps even accelerate. As a result, utilities and agencies in charge of the grid have grown increasingly concerned with the potential effects. In response to this concern, the California Solar Initiative (CSI) has funded research to support the development of cost-effective strategies and solutions for integrating large amounts of PV into distribution systems.

Clean Power Research (CPR) and its partners have undertaken the following grid-integration tasks under this program: (1) Create a high resolution solar resource database with one-kilometer geographical resolution and one-minute temporal resolution (designated as "SolarAnywhere High Resolution" [1]); (2) Validate PV fleet simulation methodologies using measured ground data from fleets of PV systems; and (3) Integrate PV fleet simulation methodologies into utility software tools to support activities ranging from distribution planning to balancing area operation.

In addition, the California Energy Commission (CEC) has funded a complementary project to validate satellite-derived solar fleet forecasts for use by the California Independent System Operator (CAISO).

2. OBJECTIVE

This paper presents preliminary results from these projects. In particular, the paper describes how to predict aggregated PV fleet power and then illustrates its use in balancing area planning and operation. The paper uses data from CAISO and the Sacramento Municipal Utility District (SMUD) to illustrate the results within the state of California.

3. APPROACH

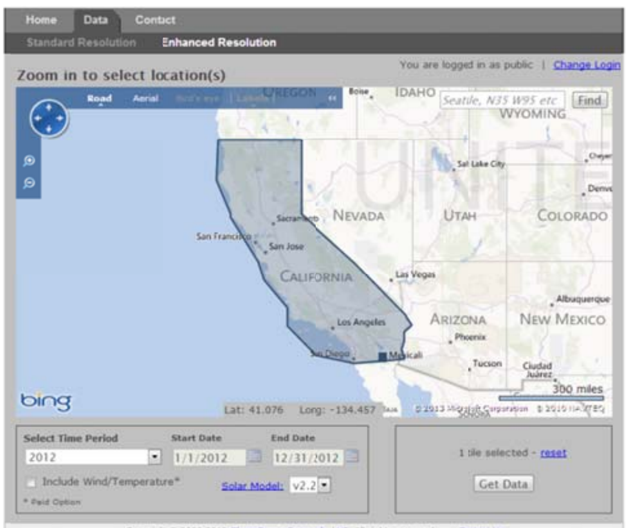
Three critical components are required to predict PV fleet power production: (1) Historical or forecasted solar irradiance; (2) PV system specifications; and (3) a PV power simulation model.

3.1. HISTORICAL OR FORECASTED SOLAR IRRADIANCE

The first critical component required to predict PV fleet power production is historical or forecasted solar irradiance time-series data (i.e., observations every minute, half-hour, hour, etc.) for some given location or region. It can be historical when used for planning purposes or forecasted when used for operational purposes. Solar irradiance data can be obtained from a variety of sources including ground-based irradiance monitoring devices, satellite imagery, and numerical weather prediction (NWP) models.

The SolarAnywhere [1], [2] software service was used for both historical and forecasted applications for this work. Fig. 1 presents the region over which the one-km resolution data was available (a few large systems outside of this area required SolarAnywhere data with a resolution of ten-km).

Fig. 1. SolarAnywhere solar resource data.



3.2. PV SYSTEM SPECIFICATIONS

The second critical component required to predict PV fleet power production is a set of PV system specifications. These specifications include the power rating of the PV system (including the effect of efficiency of the modules, wiring, inverter, and other factors), azimuth and tilt angles, tracking attributes, and row-to-row as well as gross obstruction shading.

In California and other states, this information is typically provided by the PV system owner or operator as a requirement for interconnection. This information can be obtained from a solar program database such as PowerClerk [3], from the utility receiving the power, or from the system owners directly.

3.3. PV POWER SIMULATION MODEL

The third critical component required to predict PV fleet power production is the PV power simulation model that uses a set of mathematical equations to combine solar resource information with PV system specifications to produce power output. The same model can be used for both fleet historical and forecast simulations. Some models (e.g., [5], [6]) are also designed to predict the output from a fleet of PV. Other models address various aspects of output variability ([7] to [10]). SolarAnywhere PV Simulator was used for this work.

4. RESULTS

PV system specifications were obtained for each PV system from a variety of sources, including CSI, CEC incentive programs and the CAISO directly. The number of systems and ratings are summarized in Table 1. These systems were then mapped to the CAISO regions as illustrated in Fig. 2. California PV capacity over time is presented in Fig. 3.

The PV fleet simulation was performed using SolarAnywhere FleetView [11]. This service combines the SolarAnywhere irradiance data, the system specifications database, and the PV Simulator model to provide historical and forecast PV fleet production. Each of the approximately 150,000 systems was simulated individually, and the power output results were aggregated at the fleet level. This sequence ensures that each system correctly corresponds to the local irradiance data.

Table 1. Summary of CAISO PV systems by source.

Source	System Count	Rating (MW-AC)
CAISO Metered Systems	46	1,214
CEC ERP (pre-2005)	11,439	122
CEC ERP (2005 to end)	16,592	83
CEC SB-1 (POUs)	82	18
CEC NSHP	12,541	127
CSI & MASH	90,378	935
SASH	1,791	17
SGIP	831	162
Total	133,700	2,682

Fig. 2. Behind-the-meter PV systems mapped to locations and CAISO regions.

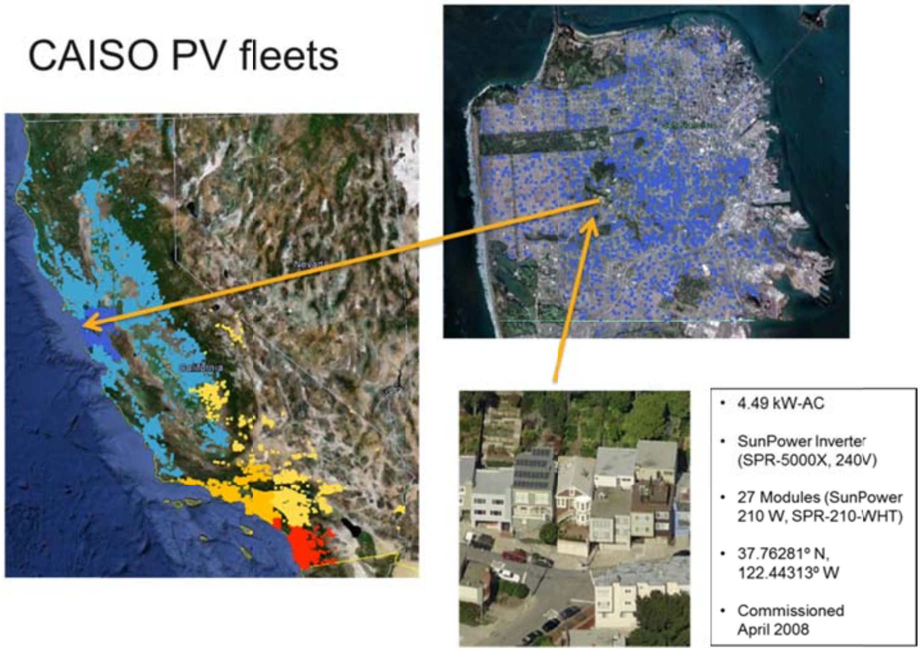
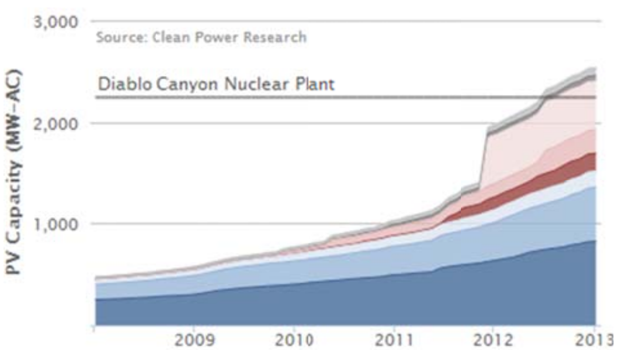


Fig. 3. California PV capacity.



PV fleet simulation results can be used for both planning and operational purposes.

4.1. PLANNING

PV fleet simulation results can be used to assist from a planning perspective. There are two sources of demand when behind-the-meter PV systems exist: (1) demand supplied by the balancing area authority (i.e., CAISO or SMUD) and (2) on-site demand supplied directly by behind-the-meter PV systems. "Total Demand" is the sum of both sources.

A planning exercise that assesses future System Demand is performed as follows:

1. At the current time:
    a. Obtain System Demand
    b. Simulate PV Fleet Production
    c. Calculate Total Demand
2. For some future time:
    a. Estimate Total Demand
    b. Estimate PV Fleet Production
    c. Calculate System Demand

System Demand at the current time can be measured by the balancing area authority and PV Fleet Production can be simulated from existing system specs. Total Demand equals the sum of System Demand and PV Fleet Production.

For some future time, Total Demand can be estimated by scaling current Total Demand and PV Fleet Production, each using different growth factors. Future System Demand then equals Total Demand minus PV Fleet Production.

Consider an example about how PV fleet simulation might be used. The example is not a statement about what CAISO believes will happen in the future but is only meant to be illustrative.

The solid red line in Fig. 4 presents CAISO's System Demand on the 2012 peak day (Aug. 13, 2012). There was approximately 1.3 GW of behind-the-meter PV system capacity available on that date. PV Fleet Production was simulated for the same day and added to the measured System Demand. The result, Total Demand, is represented by the solid gray line.

Future Total Demand was estimated by applying a load growth factor to all hours of current Total Demand. Assume that Total Demand will grow by 1.7 percent per year through 2020. This result is illustrated by the dashed gray line. Behind-the-meter PV Fleet Production can now be scaled up to model potential capacity in 2020. Assume that Governor Gerry Brown's goal of 12 GW of renewable distributed generation power in California by 2020 [12] is met using PV. The scaled PV Fleet Production can be subtracted from the Total Demand to estimate future System Demand. This is illustrated by the dashed red line.

The dashed red line is the demand that the balancing area authority would need to be prepared to satisfy in 2020. As can be seen with this particular day, the result is that the behind-the-meter PV is expected to reduce Total Demand and flatten the load earlier in the day. A full planning study is required to repeat this exercise for all times of the year.

4.2. OPERATION

In addition to planning, PV fleet simulation capabilities may be used for grid operation. Fig. 5 presents the PV power forecast at 13:00 on February 14, 2013. The figure is constructed by simulating half-hour power output for each of the approximately 150,000 PV systems individually and then aggregating the results based on the geographic location of each system. This forecast information can be incorporated into operations by the balancing area authority to more effectively schedule non-solar units.

5. VALIDATION

Validation of numeric results is underway and the following are some preliminary results.

Simulated PV fleet production was validated using one year (9/1/11 to 8/31/12) of measured half-hour PV power production data for a set of 18 large PV systems from CAISO. The data were filtered to eliminate data collection errors (but still reflect PV plant performance issues). Normalized, simulated half-hour PV fleet power is plotted versus measured PV fleet power in Fig. 6. Results suggest that the relative mean absolute error was 6 percent ([13] discusses the calculation methodology).

Another comparison was made with roughly 1,000 residential and commercial distributed generation systems within SMUD's territory as presented in Fig. 7. Fleet system production was compared over a six-month period (4/16/12 – 10/10/12), using hourly measurements from PV production meters and resulted in a 5 percent relative mean absolute error. Expanding the time period to one year may change the results.

6. CONCLUSIONS

This paper described preliminary results from CSI and CEC projects led by CPR to support the development of strategies for integrating large amounts of PV into the power grid. The paper described a demonstration of PV fleet simulation for the state of California and then it illustrated how the results could be used in balancing area planning and operation. Results suggested that simulating PV fleet power production using satellite irradiance data holds promise as an approach to address some of the challenges associated with integrating PV generation into the utility grid.

7. ACKNOWLEDGEMENTS

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Fig. 4. Using PV fleet data for planning purposes.

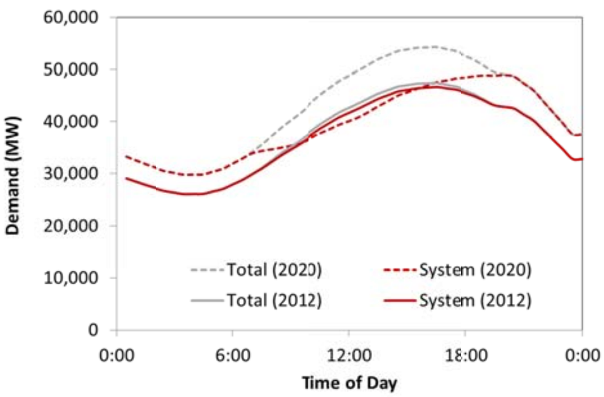


Fig. 5. Using PV fleet data for operational purposes.

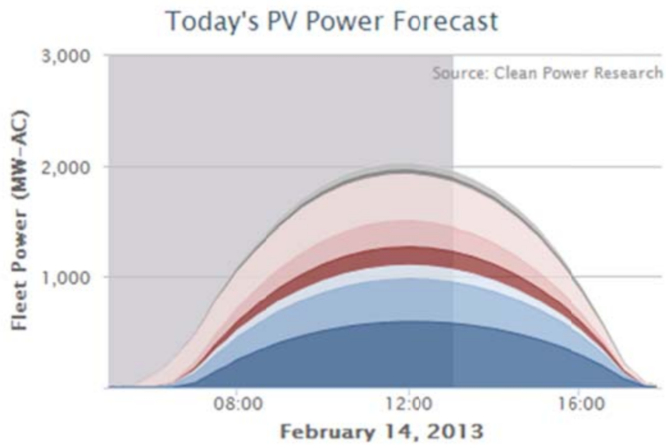


Fig. 6. Simulated vs. measured PV fleet power (18 CAISO metered systems).

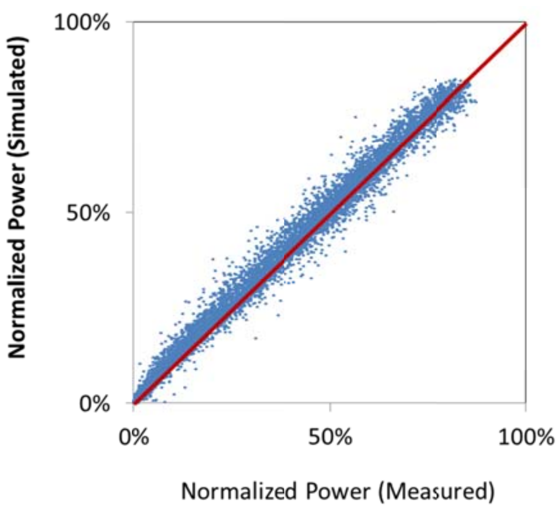
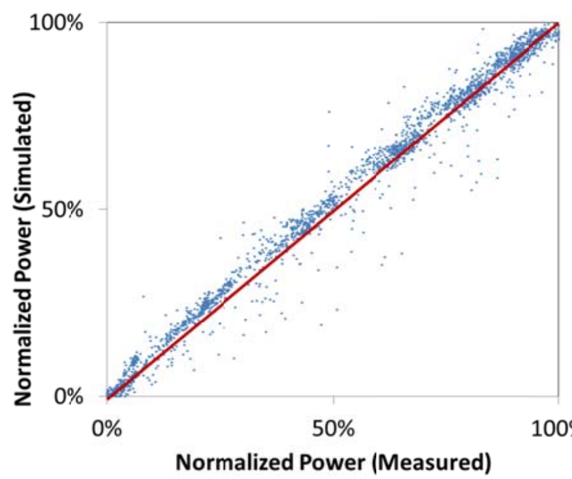


Fig. 7. Simulated vs. measured PV fleet power (1,000 SMUD distributed systems).



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