EPIC Solar Forecasting

TASK 2 Final Report

Data Forecasting Accuracy Improvement Report

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Prepared for

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Prepared by

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Clean Power Research®

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Contents

Introduction and Background

The key challenge facing the California ISO (CAISO) and the electric utilities as they integrate higher and higher concentrations of photovolotaics (PV) into the grid is the uncertainty associated with PV generation profiles. PV is inherently an intermittent resource and utilities are charged with maintaining high system reliability at low costs. The uncertainty in PV is reflected in conservative scheduling of regulation and spinning reserves.

Itron, Inc., developed a proposal in June 2014 to the California Energy Commission (CEC) to address this issue by advancing the state of the art in solar energy forecasting as it relates to the operation of the California electric grid. The proposal was submitted under the Electric Program Investment Charge (EPIC) funds, with Clean Power Research, LLC (CPR) identified as a major subcontractor. The Itron/CPR team was awarded the project in February 2015.

The work described in this report covers Task 2 of the project, related to the use of existing real-time data to improve the solar generation forecasts. Forecasts include both forcasts for output of individual utility-scale resources as well as aggregated forecasts of small behind-the-meter (BTM) forecasts.

Before the project was initiated, CPR had an established software system for providing forecasts to grid operators (its SolarAnywhere® FleetView™ software product), but these forecasts solely rely upon knowledge of the installed PV resources and the forecasted irradiance/temperature at grid locations across the state. The PV system hardware specifications—solar panel ratings, tilt and azimuth orientation, inverter specifications and the like—were obtained primarily under the California Solar Initiative (CSI) incentive program for BTM systems. Various public data sources were used for transmission-connected resources. Solar irradiance and temperature forecasts are available through FleetView directly.

This task was undertaken to determine whether real-time data collected could be used to supplement the other two data sources. Two data feeds were of particular interest.

First, the metered systems, i.e., utility-scale PV systems, could collect plane-of-array solar irradiance, and this data could be used in real-time to provide state of the art forecasts for the resources. It was believed that this data could act as calibration source to supplement CPR's data, derived from satellite imagery.

In particular, Aerosol Optical Depth (AOD) and cloud albedo are two physical parameters that govern availability of solar radiaction at ground level. These parameters are not measurable or derivable from the satellite images, collected ouside the atmosphere. Consequently, ground measured sources are required for calibration of satellite-derived irradiance, and these are supplied by ground stations across the U.S. Real-time collected ground irradiance measurements taken at various solar generating sites could potentially be used to obtain local values that could be incorporated into the irradicance forecasts. If this were possible, the measured data could help to calibrate the irradiance data in real time, and the improvement would apply to both metered and BTM forecasts.

Second, maintenance schedules of metered systems could also potentially be used as an input to the forecasts. For example, if an inverter or array was going to be taken out of service, this would reduce the available capacity of the resource, and this could be incorporated into the forecast of solar production by scaling the production forecast to account for the reduced plant capacity.

The intent of the task was to obtain the relevant data fields in real-time and evaluate their use in producing more accurate forecasts. Unfortunately, CPR was not granted access to the real-time data. Security requires that plant-specific data be available only by permission from specific plant operators. CPR could have required getting approvals from solar plant operators, but this would have exceeded the time available under the project. Therefore, this task did not include a demonstration of the use of real time irradiance but rather focused on a description of such a process and an analysis of the approach, should it be implemented in the future.

CPR developed software in preparation for uploading and processing of the real-time data. Development work was carried out on SolarAnywhere infrastructure in order to be ready to accept a real-time feed of data and to incorporate this into the FleetView software. Other sources of data were also identified and incorporated into FleetView forecasts. New numerical weather prediction (NWP) models can now be downloaded from their respective sources and uploaded to CPR servers for use in FleetView with operational reliability.

Forecasting Model

Overview of Forecasting Model

SolarAnywhere® FleetView™

SolarAnywhere FleetView employs satellite-derived irradiance data in combination with patented fleet analysis methodologies to provide insight into the impact of 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 PV performance data rather than using expensive ground sensors and communication networks. Using this data, 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, 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 RTO's/ISO's, such as CAISO, to 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 RTO's/ISO's 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.

To date, simulations of fleets within CAISO have been performed under contracts with the CEC and CPUC. Most of the behind-the-meter resource data was collected from the California Solar Initiative (CSI). Systems have been divided into five geographical territories according to the California ISO designations. The baseline CSI fleet includes 78,025 systems with a total rating of 773 MW-AC. Figure 1shows the mapping of all CSI systems in their respective fleets.

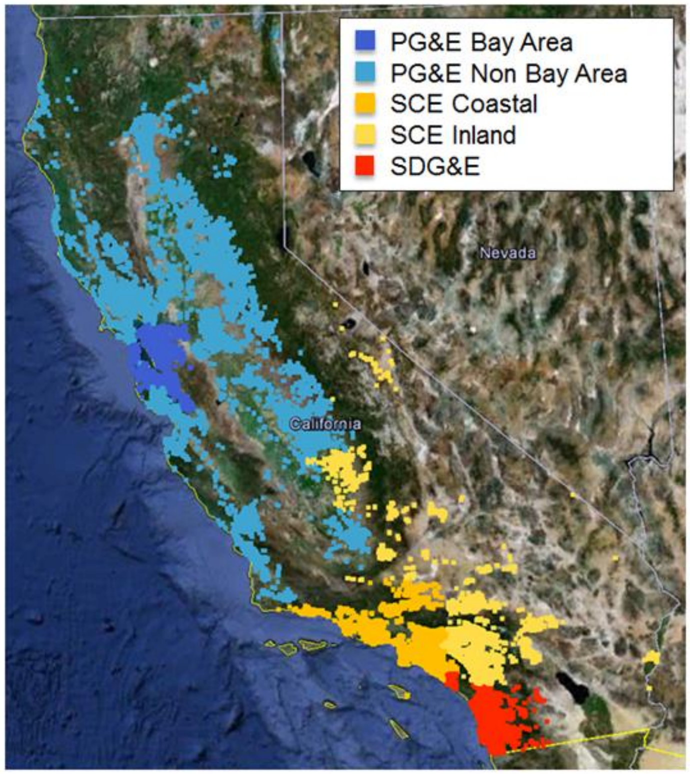

Figure 1.Mapping of all ~78,000 behind-the-meter PV systems in the California ISO

Additionally within the scope of this work with CAISO, the total California impact was forecasted. Important to note, fleet simulation must take into account the change in fleet makeup over time. Figure 2 shows the growth of the fleets. For example, fleet energy production during January 2015 would only include PV systems installed as of January 2015, and not include systems installed at a later date.

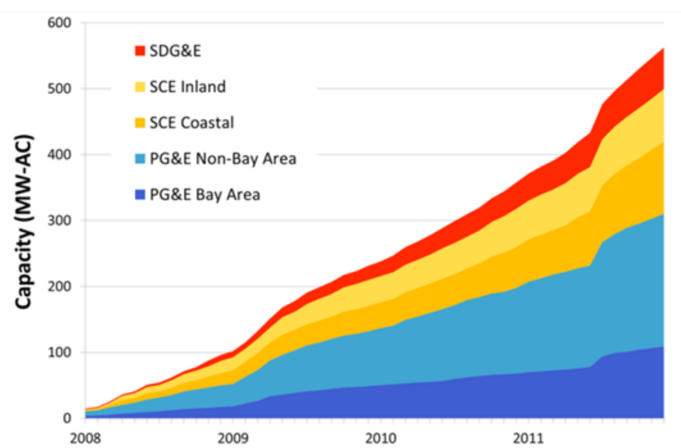

Figure 2. Change in California ISO PV fleet combined capacity over time

In addition to the behind-the-meter resources identified through CSI (and later through GoSolarCalifornia), CAISO's metered systems (utility scale systems) were included. Plant specifications for these systems were collected independently by CPR. Data sources included available public information from the CAISO OASIS site and various public records (e.g. permits, press releases, and maps). These public sources provided the required hardware specifications.

Validation

A team led by Dr. Richard Perez at the University at Albany (SUNY Albany) developed and began implementing an operational satellite-to-solar irradiance model in the mid 1990's for data production in the northeastern United States.[1] The model was refined over the following years, and validated in multiple climatic environments from arid, to humid continental, to subtropical.

Dr. Perez's model was originally verified by the National Renewable Energy Laboratory (NREL) against 31 U.S. locations with varying climates in the early 2000's. It was then selected to create updates of the U.S. National Solar Radiation Data Base (NSRDB 2010 Update). This independent validation found that the average hourly mean bias error of the model was 0.2 W/m^2 for GHI and 16.5 W/m^2 for DNI when compared to ground measurements. Since that time model improvements have further increased relative mean bias (rMBE) accuracy down to about 2% for GHI and 4% for DNI. The latest version of the model is only commercially available through SolarAnywhere and continues to serve as the resource database of choice for major energy companies that are financing and managing solar assets.

Recent validation studies[2] have paired measurements from SolarAnywhere against ground measured data from high-caliber ground sensors. In a recent California study, CPR and project partners evaluated the SolarAnywhere model accuracy against sites with redundant ground sensors, across multiple time periods of comparison.

The results, comparing data over the year 2011, are depicted in Figure 3. As noted, the black line incorporates the measurement error between the two site hardware sensors and the colored lines represent the different resolutions of SolarAnywhere relative to ground.

[1] R. Perez and R. Seals, (1997): Production of Site-Time Specific Irradiances from Satellite and Ground Data. Final report to NYSERDA and NREL. NYSERDA Report No98-3 35 pp., NYSERDA, Albany, NY / NREL Golden, CO
Zelenka, A., Perez R, Seals R. and Renné D., (1999): Effective Accuracy of Satellite-derived irradiance, Theoretical and Applied Climatology, 62, 199-207

[2] A recent example is Perez, et.al., Detecting Calibration Drift at Ground Truth Stations A Demonstration of Satellite Irradiance Models' Accuracy, available at http://go.cleanpower.com/rs/369-HBZ-605/images/DetectingCalibrationDrift_6.2017.pdf.

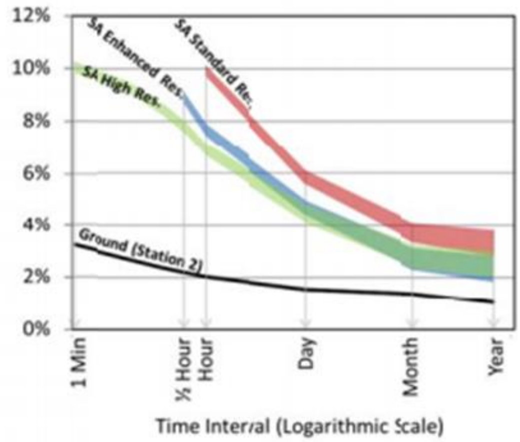

Figure 3. Relative mean absolute error (%MAE) of SolarAnywhere against ground sensors (averaged over four distinct locations within the CAISO service territory)

The satellite-based approach taken by Dr. Perez and his team has numerous advantages over other methods of irradiance measurement for short-term forecasts (i.e., under four hours). On March 1, 2018, NOAA's newest geostationary satellite launched into space from Cape Canaveral, Florida. GOES-S (which will become GOES-17 once it reaches its final orbit) will significantly enhance weather forecasting capabilities across the western United States, Alaska, and Hawaii and provide critical data and imagery of the eastern and central Pacific Ocean extending all the way to New Zealand.

The benefits of the satellite-based approach, as compared to ground sensor networks, include lower costs, faster time to market, and the ability to create forecasts for predicting variability of generation. Additionally, the satellite model uses a consistent feed of inputs, mainly government operated satellite-generated images—data can be captured reliably and consistently across the entire geographic coverage area. Consistency can be problematic for ground sensor networks, as well as numerical weather prediction models because the inputs are either sparse, inconsistent, or missing over relavent time frames. These benefits will be applicable using data from GOES-17, once the data is available.

Ongoing research towards advancements are continuously being incorporated to update the processing model in SolarAnywhere. Recent work addressed winter snow conditions, for example, with Natural Resources Canada licensing data produced with this model. The updates incorporated data from the geostationary satellites' multiple infrared (IR) sensors to increase performance during snow cover conditions.[3]

The model has been validated against five U.S. locations that experience extensive snow cover conditions in winter. One of these locations, Fort Peck, Montana, is very close to the Canadian border

[3] Perez R., S. Kivalov, A. Zelenka, J. Schlemmer and K. Hemker Jr., (2010): Improving the Performance of Satellite-to-Irradiance Models using the Satellite's Infrared Sensors. Proc., ASES Annual Conference, Phoenix, Arizona

and is representative of the sparsely forested environment to be found in Western Canada. This type of environment produces the highest visible surface reflectivities during snow conditions and results in the highest model bias errors. Compared to the older model without IR sensor data, the updated model showed a mean bias error during snow conditions at the five U.S. locations that was reduced by a factor of four down to an absolute value average of 12 W/m^2. The nature of this improvement in the model will also be realized in areas where ground reflectance is just naturally high, independent of season, such as areas with extensive sand coverage.

PV Simulation Methods

PVSimulator is a software service within SolarAnywhere that produces a time series of PV system energy production for use across a broad range of applications. PVSimulator has improved on deficiencies in other PV simulation software products in three ways:

1) PVSimulator is implemented as a supported web service with proven availability. A web service implementation supports interoperable machine-to-machine interaction over a network. This enables software products that are designed with different purposes to access the same simulation code.

2) PVSimulator has a flexible software architecture, providing users with the ability to pick and choose from an assortment of simulation models and weather data sets (like selecting models and data sets from drop down lists). This provides developers with a simple means for adding new models and weather data sets as they are developed while at the same time maintaining past models in order to produce consistent results for historical comparison.

3) PVSimulator supports the function of SolarAnywhere FleetView by producing results for either a “fleet” of PV systems, such as the hundred thousand behind-the-meter PV systems in California or a single PV system. A simulation can range from a single PV module to thousands of distributed PV systems spread across a wide geographic area. This feature allows owners of multiple systems to simulate production in parallel and in real time. Calling production estimates from other simulation engines one-by-one will eventually become latency-prohibitive as the number of systems increases beyond a certain threshold.

The simulation process begins by specifying inputs about how the simulation is to be performed, what is to be simulated, and what results are desired. The definition of how the simulation is to be performed consists of selecting among a variety of different electrical models for PV arrays and inverters as well as different models for shading and obstruction analysis. The specification of what is to be simulated consists of a definition of the PV system configuration and weather data for the time span of interest.

The level of detail in the final simulation results can be configured to return the estimated production as well as a wide range of intermediate results. Figure 4 displays the level of communication between inputs and production output, depending on the level of system specification.

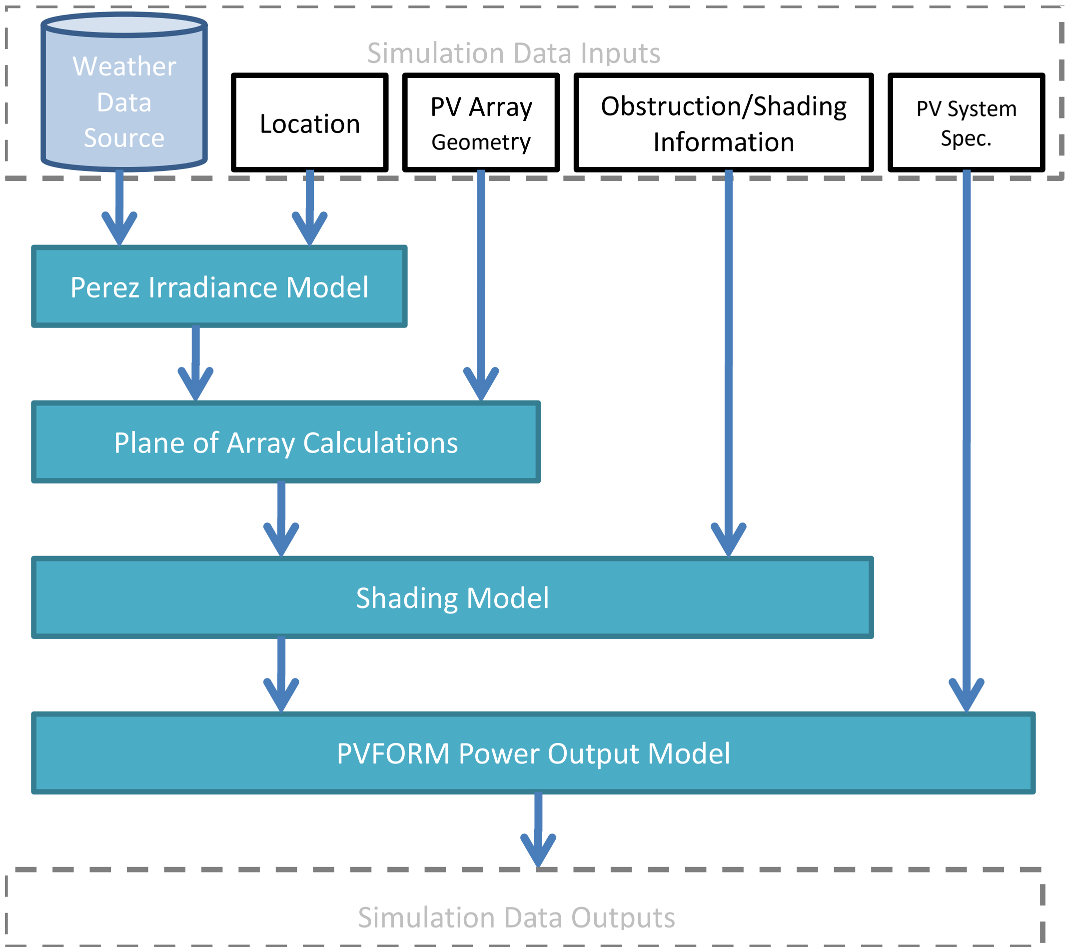

Figure 4. PVSimulator methodology for simulating PV system output

Locational information can be defined by either latitude and longitude or by street address (for residential systems). Less accurate simulations can be performed by just inputing a system zip code to define location, in which case the geographic centroid of the zip code will be used to select the weather data.

PV array geometry includes inputs such as installation azimuth and tilt angle, as well as tracking algorithms (e.g. stationary, single-axis and dual-axis tracking). Solar obstruction information is collected on site and reflects obstructions caused by surrounding objects, including trees or adjacent buildings, or obstructions caused by utility plant intra-row spacing. The specific equipment by manufacturer and model or generic sytem ratings determine the actual hardware efficiency of energy conversion, used in the PVForm power output model. The commissioning (installation) date can be used to estimate year-by-year degradation. Also, modules are identified by a temperature coefficient that describes the reduction in output for higher temperatures (temperature data is also supplied by SolarAnywhere).

Weather Data Selection

The ability to use actual, location-specific, time-correlated weather conditions over the time span of the simulation is a key differentiator for PVSimulator. The necessary weather data consists of irradiance, ambient temperature, and wind speed. The irradiance data can be provided as either Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) or Plane-of-Array (POA) irradiance. In instances when GHI and DNI are provided, POA can be calculated as an intermediate result, given inputs of panel azimuth and tilt angle.

PVSimulator's modular architecture allows for a variety of ways to specify the weather data. Users can explicitly specify the weather data by uploading it along with the simulation request. It is more common, however, for users to specify a date range and extract the weather data from an established weather database. PVSimulator currently supports all resolutions of SolarAnywhere® and NREL TMY3 data (chosen from nearest station). PVSimulator simulates the performance of the system with the desired models specified, the PV system defined, and the weather data provided. The simulation results contain a detailed dataset congruent with the input time series irradiance data, including the expected energy for each hour of the day (kWh per hour).

Power Output Simulation

PVSimulator has been designed to accept multiple models throughout the different stages of simulation, hence making it customizable. The model that is selected impacts the accuracy of the results as well as potentially requires that additional model-specific information be supplied about the PV system. The current PV power output option is an implementation of PVForm, with the Sandia PV Array and Inverter Performance Model under development. The Perez/Hoff shading model can be selected for the obstruction analysis or there is also the option to forgo obstruction analysis in cases where details about the surrounding obstructions are unknown. Other model imputs can be incorporated, depending on the level of specification by the application.

It is necessary to define the PV simulation configuration once the desired models have been identified. PVSimulator can model a diverse range of system configurations. The configuration begins at the smallest scale with the PV array consisting of one or more PV modules having the same orientation. A PV subsystem is composed of one or more PV arrays each of which can have a different orientation, shading, and an arbitrary number of inverters. A PV system consists of one or more PV subsystems all at the same geographic location. A simulation consists of one or more PV systems all of which can be in different locations. In this way, PVSimulator is able to accommodate the needs of any size system from the small residential scale up to a large industrial PV systems or a fleet of PV systems distributed across different geographic locations.

PVSimulator's accuracy depends on the level of detail and accuracy in specifying the PV system configuration and the models and data used to perform the simulation. PVSimulator can be supplied with a minimal amount of configuration information (i.e., location, orientation, and system rating) using a simple model for applications designed to provide a quick economic evaluation. PVSimulator can also be supplied with detailed information (e.g., detailed inverter and module specs, SolarAnywhere time series data, specific shading information) for applications designed to produce performance guarantees where greater accuracy is required.

Sandia PVFORM Power Output Model

The PVForm Power Output Model was originally developed by Sandia National Labs in 1985 and has been implemented by the means outlined in Figure 5. As noted, NREL has implemented the PVForm model through their PVWatts tool. Clean Power Research originally developed PVForm through the Clean Power Estimator tool, which has been built into numerous solar agency and solar manufacturer's websites. CPR has further developed this implementation into PVSimulator.

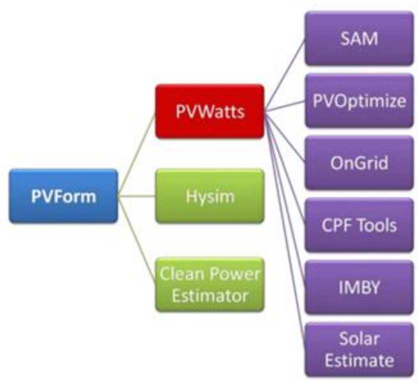

Figure 2. Hierarchy of PV and hybrid system models that use PVForm

Figure 5. Use of the Sandia PVForm model[4]

Data Sources

Functionally, SolarAnywhere is currently retrieving and processing data in real time throughout North America and Hawaii at Standard Resolution (10-km grid, 1-hour measurements) and contains historical measurments back to January 1st 1998. Research improvements have added the ability to capture higher resolution data. SolarAnywhere Enhanced (1-km, 30-minute) and SolarAnywhere High (1-km, 1-min) Resolution can be added geographically to match any current Standard Resolution area. While the underlying satellite images have a resolution of 30 minutes, High Resolution is obtained using cloud motion vector calculations to effectively interpolate irradiance during times between any two images.

[4] Klise GT and Stein JS "Models Used to Assess the Performance of Photovoltaic Systems" Sandia National Laboratories, 2009.

To date, however, only certain regions have been processed at Enhanced and High Resolution, including the states of California and Hawaii.

SolarAnywhere implements the latest satellite-to-solar irradiance model developed by Dr. Richard Perez at SUNY Albany by collecting half-hourly satellite visible and infrared (IR) images from GOES satellites operated by the National Oceanic and Atmospheric Administration (NOAA). NOAA owns and operates the GOES-15, responsible for images in the western half of North America and GOES-13, for images in the eastern half of North America. The Perez algorithm first extracts the cloud indices from the satellite’s visible channel using a self-calibrating feedback process that is capable of adjusting for arbitrary ground surfaces. The cloud indices are then used to modulate physically-based radiative transfer models representative of localized clear sky conditions. Wind and ambient temperature data are incorporated into the database through collection of NOAA weather data on their standard 5-km grid.

Standardized logic in SolarAnywhere calculates typical year data files. First, sub-monthly time series data is summed to compute the total available energy on a monthly basis, specific to each 10-km or 1-km gridded tile location. Global horizontal (GHI) and direct normal (DNI) irradiance are treate*d* as separate irradiance components. For each location, the average GHI or DNI is calculated by selecting the month with total energy closest to mean and concatenating the actual data into a final 12-month, 8760-hour typical irradiance file. Default settings in SolarAnywhere select data based on the most complete months of data (i.e. January 1998 to present complete calendar month), however, alternate settings can be selected to create custom date ranges from which to select typical year energy production.

For this project, several Numerical Weather Prediction (NWP) models were identified and evaluated for their usefulness in improving a solar forecast. Development work went into creating robust systems for downloading this data from their respective sources and then uploading to CPR servers.

Use of Data in Forecasts

Ground Irradiance Measurements

Initial investigation of historical (not real time) data revealed that many of the utility scale PV plants do not report Global Horizontal Irradiance (GHI) but that plane of array (POA) irradiance is available. However, POA is not as clearly related to AOD. Issues such as back tracking can pollute any AOD signal that might be detected. Additionally, there is uncertainty and error associated with any sort of POA to GHI transposition as well, which would also degrade any sort of AOD signal detected.

CPR concluded that GHI data is not available and POA data could not be reliably used to provide real-time improvements in forecasting. It would be possible to install solar instrumentation at selected CAISO locations, but such a demonstration was not included in the project scope.

Plant Availability

CPR developed a procedure that could be used to incorporate plant production as an indicator of availability. This could be an approach where plant availability reporting is not provided. Given the plant technical specifications and recent (e.g., the prior hour) irradiance measurements, it would be possible to compare the expected production with the actual production. If the actual production consistently was less than expected, the plant could be “derated” for a temporary period. A proof-of-concept plant database schema was developed in order to support such an approach, matching plant rating by date. This schema would be used for both ongoing forecasts (during the temporary outage) as well as serving as a record for later analysis using historical data.

Concentrating Solar Power Resources

The project was primarily concerned with forecasting solar PV production using the methods described above. However, concentrating solar power (CSP) resources are also present on the California grid, and the scope of work (SOW) required that CPR develop a description of an approach that could be used to forecast CSP resources.

A conceptual diagram of the “power tower” technology is provided in Figure 6. This technology employs hundreds or thousands of tracking mirrors (heliostats) to concentrate direct normal irradiance onto the receiver at the top of a tower. A heat transfer fluid, such as molten salt, is delivered to the receiver, where it acquires thermal energy at high temperature, and is directed to a feedwater heater to generate steam. Finally, the steam is expanded in a turbine, and the mechanical energy is used to generate electrical power.

Several other variations of CSP technologies are possible, including “trough” and “dish” configurations that differ in the means by which solar radiation is concentrated, the types of heat transfer fluids, and the heat engines used to convert thermal energy into useful electricity. This project was limited to power towers as a proof of concept.

Regardless of technology, CSP requires optical concentration of direct normal irradiance (DNI). Unlike non-concentrating PV, CSP is not able to capture radiant energy from diffuse sky regions. SolarAnywhere includes DNI, so it would be possible to use the SolarAnywhere DNI as a basis for for forcasting, along with SolarAnywhere ambient temperature data, also a factor in CSP performance.

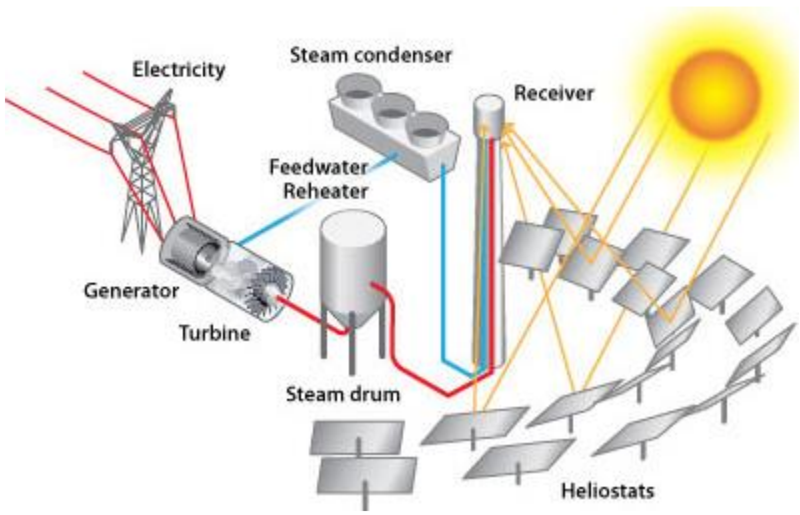

Figure 6. CSP "Power Tower" Plant Concept[5]

CPR developed a method for calculating power output as follows. Optical efficiency is complicated by the complex array of heliostats, each of which accept solar beam radiation at a different angle defined by their location in the field and the time-varying solar vector.

To model each heliostat individually requires knowledge of the heliostat geometrical attributes and the tower/receiver height in order to calculate the solar incidence angle on the receiver. Other plant attributes must also be specified and modeled, such as the heat transfer fluid thermal properties, loss factors, turbine parameters, and so forth. It is not possible to model the plant without these data, and it is not feasible to obtain the plant specifications without significant input from the system designer.

To overcome these difficulties, it may be possible to create a simplified model that correlates plant output with available SolarAnywhere irradiance and ambient temperature data. The approach taken by CPR was to perform this correlation as a function of sun position.

The heliostat field has a different optical efficiency (incident radiation on the received divided by incident radition on the heliostat) for each sun position. For example, at solar noon the heliostats located to the north of the tower will have a small angle between the solar vector and the tower vector, so the incidence angle will be small. These northern heliostats will therefore have a higher efficiency

[5] Figure taken from EIA at https://www.eia.gov/todayinenergy/detail.php?id=530

than heliostats located in, say, the east. However, in the afternoon, the sun is located in the west. Therefore, heliostats located in the east will have higher efficiency than heliostats in the north.

Plant performance is therefore a function of sun position. At a given position, the optical efficiency is determined, and the potential plant output would be a function of the piping losses, turbine efficiency, and ambient temperature.

Also unlike PV, CSP does not respond instantaneously with available irradiance. Instead, a lag time may be observed. This is consistent with the understanding that CSP plants have inherent thermal capacity in the piping, receiver, and other components. Such a thermal lag would lead to both slow startup time at sunrise and extended operation after sundown. The time lag would have to be build into the forecast model.

A final difficulty is that CSP plants can be designed with thermal storage. Molten salt plants, for example, can be designed with storage subsystems which can retain salt at elevated temperatures, providing dispatchability to the plant. In these cases, output is decoupled from solar availability, and knowledge of storage dispatch is required to complete the forecast. It may be possible to forecast dipatch based on available radiation and market prices, i.e., to assume an optimized dispatch to maximize revenue.

In sum, CPR believes that to fully incorporate CSP resources into the forecast, additional study is required. A more expansive study could incorporate data from multiple resources and an investigation into the dispatch of stored energy.

CAISO Real Time Data Feed

Description of Real-time CAISO Data Feed

The SOW also called for CPR to describe the real-time data feed at CAISO, data structure formats, and API. To accomplish this, CPR reviewed publicly available data provided by CAISO's specification documentation. This documentation is avalilable to the public by downloading it from the CAISO website. The following is a summary of the relevant information.

Background

In March 2016, our research indicated that such real-time data was provided by the California ISO through the Participating Intermittent Resource Program (PIRP) Application Programming Interface (API), but this method of access was in the process of being deprecated in favor of the Plant Information Service-Oriented Architecture (PISOA) API.[6]

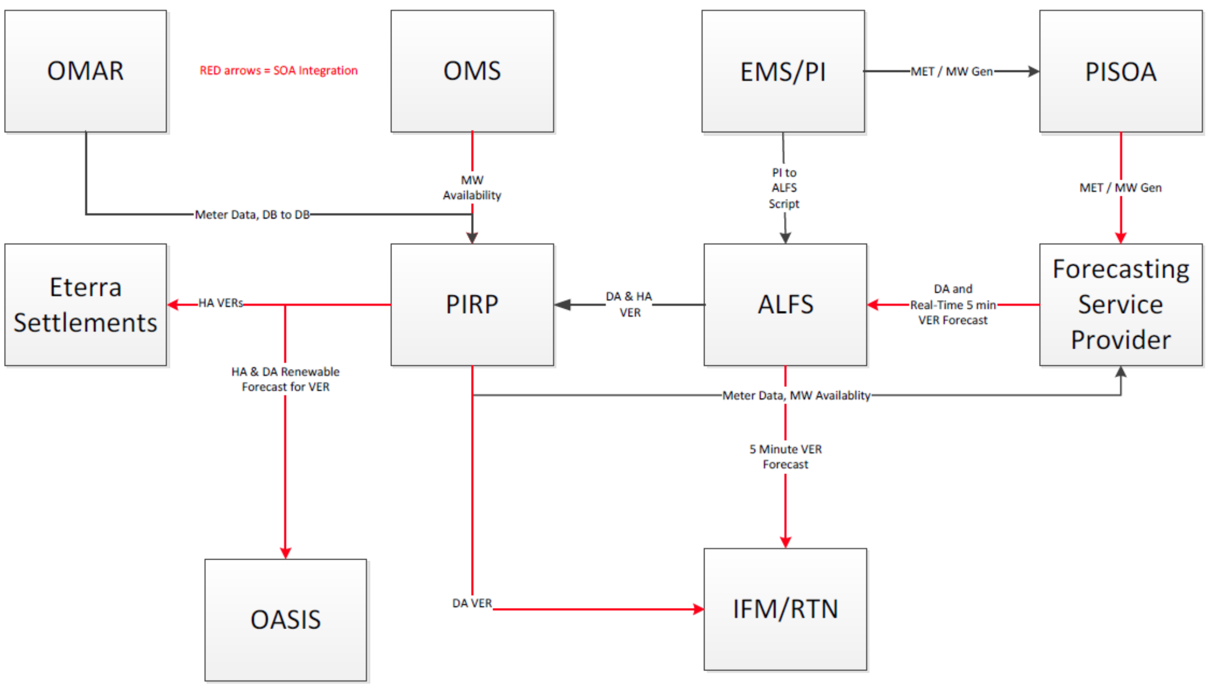

Figure 7. System Diagram

To obtain access to the data provided through PIRP the authorized Point of Contact (POC) submits an Application Access Request Form (AARF) through the California ISO's Customer Inquiry and Dispute

[6] http://www.caiso.com/Documents/BusinessRequirementsSpecification-ForecastingandDataTransparency.pdf

Information (CIDI) system. Applications specify both the resource ID and the Scheduling Coordinator ID (SCID).

Real-time Data Through PISOA

PISOA provides access to near real-time measurements of wind speed, plane of array irradiance, wind direction, MW generated, barometric pressure, ambient air temperature, and back of (PV) panel temperature for the requested Variable Energy Resource (VER).

Access to the service is via HTTP over SSL (HTTPS) using an SSL certificate signed by a CAISO Certificate Signing Authority. The app_pisoa_ver_measurements role must be associated with the certificate used by application retrieving the VER measurements.

CAISO Data API and Structure Formats

The PISOA service has one operation for getting VER measurements with three message types. All input and output messages are in XML format. The operation for making a data request is RetrieveVERMeasurements_PISOAv2_AP.

The input message for the RetrieveVERMeasurements_PISOAv2_AP operation is RequestVERMeasurements_v1. This message can include an optional message header, but it is the message payload that contains the required start and end time to indicate the period that the returned measurements will cover.

The output message for this operation is Meter Measurement Data. Although the PISOA Interface Specification is unclear in this regard, it appears that meter measurement data includes the PI tag associated with the VER, the VER registered name, the type of measurement, the metered value, and the timestamp associated with the end time of the measured value.

If there is an error in processing or in the input message header or payload, a fault type message will be returned. Fault return data is documented in the PISOA Interface Specification.