Integrating PV into Utility Planning and Operation Tools

Final Presentation
March 11, 2014

Project Partners
Primary Funders
Power Industry

Project Lead
Clean Power Research®
Current Work is Result of Multiple Projects

- **CSI Phase 3**
  *Address cost-effective strategies for integrating large amounts of PV into distribution systems by integrating PV modeling into utility planning and operation tools*

- **CEC Forecasting (Completed)**
  *Validate ability of satellite-derived solar data to forecast PV fleet output with CAISO and integrate into planning processes*

- **DOE Sunrise (In Progress)**
  *Demonstrate improved net utility load forecast by incorporating behind-the-meter PV forecast for CAISO and all PV in California*
Objective: Accomplish Three Grid-integration Tasks

1. Extend the SolarAnywhere Enhanced Resolution solar resource database, create high resolution (1-km, 1-minute resolution) solar resource data, and benchmark data accuracy.

2. Validate previously developed PV fleet simulation methodologies using measured ground data from fleets of PV systems connected to California’s grid.

3. Integrate PV fleet simulation methodologies into utility software tools for use in activities ranging from distribution planning to balancing area operation using CAISO as a test case.
Benefits to California

- **Solar Resource Data**
  - State-of-the-art high spatial resolution 1-km data freely available for duration of grant; developers obtaining lower financing rates because of lower risk
  - High temporal resolution 1-min data (for variability studies)

- **PV Fleet Simulation Validation**
  - Validation results indicate ~5% MAE (relative to energy, not capacity)
  - Grid operators gaining confidence in models prior to their use

- **PV Fleet Simulation Integration Into Utility Software Tools**
  - CAISO receiving forecasts for 175,000 behind-the-meter PV systems every 30 minutes; system in operation for one year
  - Behind-the-meter fleet forecasting available for all CA utilities
  - PV fleet simulation available for distribution planning
Task 1 Description: Irradiance Data

Extend the SolarAnywhere Enhanced Resolution solar resource database, create high resolution (1-km, 1-minute resolution) solar resource data, and benchmark data accuracy.
Task 1: Accomplishments

- Extended freely available SolarAnywhere Enhanced Resolution solar resource database (1-km, 30-minute resolution)
- Created high resolution (1-km, 1-minute resolution) data
- Benchmarked data accuracy
Freely Available Enhanced Resolution Data

Visit SolarAnywhere.com

Select 1 km Location

Download ½ Hour Data

Analysis Results

Clean Power Research®
Produced High Resolution (1 km, 1 min) Data (Useful for Grid Integration Studies)

July 4, 2011, CAISO Site A

[Graph showing solar data with lines labeled 'Ground' and 'SA, High Res.' and a dashed line labeled 'Clear Sky']
Example Using SMUD’s Solar Data Network on Highly Variable Day (Nov. 18, 2011)
Validated SolarAnywhere Enhanced Resolution Data (UCSD)

Calibrated SolarAnywhere performance, with 30-min time step, versus CSI measured output (averaged over two 15-min time steps), for 86 PV sites in 2009 in San Diego, CA

Source: Jan Kleissl, UCSD
Questions
Task 2 Description: PV Fleet Simulation

Validate previously developed PV fleet simulation methodologies using measured ground data from fleets of PV systems connected to California’s grid
Task 2 Accomplishments

- Validated fleet simulation using CAISO data
- Validated fleet simulation using SMUD behind-the-meter data
45 PV Plants Connected to CAISO

PV on commercial buildings (SCE service area – Google Maps)

Large central station PV (Copper Mountain, NV, pv-magazine.com)
How to Validate Forecast Accuracy When Historical Data is Unavailable?

- Validate accuracy using measured PV production
  - Use backcasting to:
    - Validate PV performance model
    - Identify PV performance issues
    - Quantify forecast accuracy

- Gain confidence in behind-the-meter fleet forecast
CAISO Fleet Results

Measured Data
- 18 PV systems
- Half-hour data
- Capacity normalized to eliminate effect of PV size
- Presented on scale of 0 to 100%
Short-Term Forecast Validation for 45 Systems (Clear Day) March 24, 2013

Time Horizon (Relative to Forecast Delivery)

0 – ¼ Hours

1 – 1¼ Hours

2 – 2¼ Hours

Add 45 minutes to obtain time horizon relative to image creation time
Short-term forecasts are available after visible, daylight satellite images are obtained
Short-Term Forecast Validation for 45 Systems (Cloudy Day) March 20, 2013

Time Horizon (Relative to Forecast Delivery)

0 – ¼ Hours

1 – 1¼ Hours

2 – 2¼ Hours
2,000+ Behind-The-Meter PV Systems at SMUD

Premier Gardens Zero Energy Home Community
Challenges of Behind-The-Meter PV Simulations

SMUD area PV system examples

- Object shading
- Module azimuth rotation
- Multiple module layouts
Quality Control Measures

Measured Data Time Shifts

- Measured power is individually checked for spurious time shifts for each production system in the SMUD PV fleet.

Simulation Tuning

- Simulated power is uniquely tuned (down in this case) for each production system in the SMUD PV fleet.
Well-Characterized PV Simulations

Example simulated (red line) and measured (blue line) production

17 Enphase inverter system – well matched!
Well-Characterized PV Simulation

Single 5.2 kW-AC PV System
(4/16/2012 – 10/10/2012)

<table>
<thead>
<tr>
<th></th>
<th>Clear Days</th>
<th>Cloudy Days</th>
<th>All Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>rMAE</td>
<td>3.3%</td>
<td>13.6%</td>
<td>4.9%</td>
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<tr>
<td>Ave Daily Energy</td>
<td>34.5 kWh</td>
<td>28.1 kWh</td>
<td>33.3 kWh</td>
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<tr>
<td>Number of Days</td>
<td>145 days</td>
<td>32 days</td>
<td>177 days</td>
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Fleet of Well-Behaved PV Systems

Fleet of 1,102 PV Systems
(4/16/2012 – 10/10/2012)

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<tbody>
<tr>
<td>rMAE</td>
<td>3.5%</td>
<td>10.0%</td>
<td>4.5%</td>
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<tr>
<td>Ave Daily Energy</td>
<td>112.8 MWh</td>
<td>88.3 MWh</td>
<td>108.4 MWh</td>
</tr>
<tr>
<td>Number of Days</td>
<td>145 days</td>
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</table>
Validate Variability Results Using SMUD's 66 Sensor Network

Results based on most variable days in SMUD's network from July 1, 2011 to December 31, 2011
Questions
Task 3 Description: Integrate Into Utility Tools

Integrate PV fleet simulation methodologies into utility software tools for use in activities ranging from distribution planning to balancing area operation using CAISO as a test case.
Task 3 Accomplishments

- Original grant proposal was to test fleet forecasting in variety of applications
- CASIO was focused on for this work
- Behind-the-meter fleet forecasting for all of California has been operational for about a year
- CAISO has initiated testing to determine the benefit derived from forecasts
Simulate Fleet Output Using SolarAnywhere® FleetView™

Historical

PV Specifications from PowerClerk® and Other Sources

FleetView Simulation Methods

Capacity Planning

System Operations

Forecast
CA Behind-the-Meter PV Mapping

- 4.49 kW-AC
- SunPower Inverter (SPR-5000X, 240V)
- 27 Modules (SunPower 210 W, SPR-210-WHT)
- 37.76281° N, 122.44313° W
- Commissioned April 2008
Using FleetView for Capacity Planning

- **Demand (MW)**
  - 0:00
  - 6:00
  - 12:00
  - 18:00
  - 0:00
- **Time of Day**
- **1.7%/yr. growth**

- **System Demand**
  - **2020 Peak (w/12 GW PV)**
  - **2012 Peak (w/1.3 GW PV)**

- **Total Demand**

**Peak Day:** August 13, 2012

[Clean Power Research logo]
Using FleetView for Capacity Planning

Peak Day: August 13, 2012

- 2012 Peak System Demand (w/1.3 GW PV)
- 2020 Peak System Demand (w/12 GW PV)
California PV Capacity by ISO Areas

Note: Utility-sited systems include intertie systems in NV and AZ
SolarAnywhere – 1 km data

*Web-accessible solar irradiance data & analytical tools*

**Irradiance data**
- Historical satellite-derived time-series data from 1998 through latest hour
- Forecasts up to 7-days in advance by combining cloud motion vector and NWP approaches

**Analytical tools**
- PV system modeling (FleetView)
- PV benchmarking (DataCheck)
- PV fleet variability

Clean Power Research®
Using FleetView for Net Load Forecasting

Note: Utility Sited systems include intertie systems in NV and AZ
Technology Transfer/Outreach

- 8 conferences/journals (ASES, SEPA USC, SEPA, SPI, UVIG)

- State-of-the art solar resource database for all of California

- 6 patent applications

- Upcoming: SEPA Webinar (w/ Jim Blatchford, CAISO) March 20
Conclusions

- **Solar Resource Data**
  - State-of-the-art high spatial resolution 1-km data freely available for duration of grant
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  - Validation results indicate ~5% MAE (relative to energy, not capacity)
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- **PV Fleet Simulation Integration Into Utility Software Tools**
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Questions
Work in Progress Under DOE Sunrise

- Move from static to dynamic accuracy validation
- Implement improved techniques to reduce forecast error
- Implement and test rapid fleet simulation method
- Incorporate uncertainty and ramp rate forecasting
Transition From Static To Dynamic Validation

Time Horizon (Relative to Forecast Delivery)

0 – ¼ Hours

1 – 1¼ Hours

2 – 2¼ Hours
Improve Forecasts Using WRF Modeling (Dr. Kleissl - UCSD)

2/15/2014 Hourly GHI Animation

4 km x 4 km
15-minute resolution
60-hour horizon
Improve Forecasts Using Ensemble Methods (Dr. Perez - SUNY)
Improve Forecasts Using Machine Learning (Dr. Coimbra - UCSD)

Past measurements
Satellite forecasts
Actual measurements

Re-forecast models
Ensemble re-forecast

Forecast residuals minimized?

Residuals
Learning algorithm

Real-Time Smart Re-forecasting
Concern

- Much effort has been devoted to developing a state wide database of all PV systems in California.

- More systems are starting to be installed outside of incentive process.

- California has started to lose easily accessible and possible more detailed information about the installed PV base.
Need for New Method to Collect Specs

Current Capacity

Projected Behind-the-Meter Capacity

Source: Clean Power Research

28% Annual Growth Rate
PowerClerk for Interconnection

- CPR background was incentive and program *design*
- Customer pain point was prog. *operations*
- Customers asked us to build PowerClerk Incentives
- SunShot Incubator award: commercialization of next PowerClerk platform – interconnection, incentives ...
Questions
Thank you

Please feel free to contact us for any details or clarification related to presentation

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