Advanced Modeling and Verification for High Penetration PV: Final Report

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President, Research and Consulting
April 10, 2012

Acknowledgements

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- Special thanks to Smita Gupta, Project Manager

Funding Approver	California Public Utilities Commission
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Program Manager	Itron

Project Participants

Companies, Agencies & Organizations

- Clean Power Research®
- University at Albany, State University of New York
- NREL, National Renewable Energy Laboratory
- nyserda, Energy. Innovation. Solutions.
- SEPA, solar electric power association

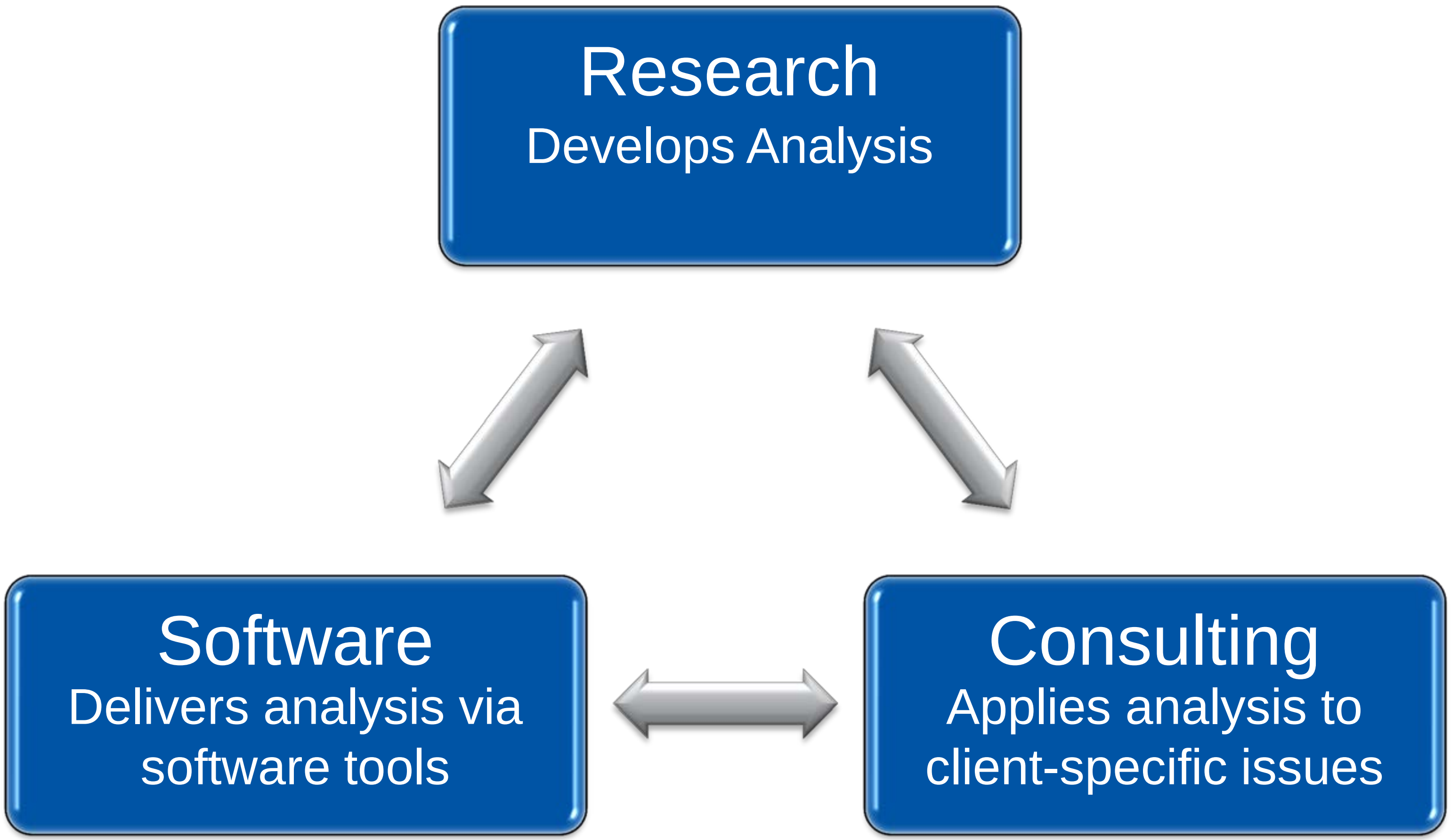
Utilities

- SMUD, Sacramento Municipal Utility District, The Power To Do More.®
- LIPA, Long Island Power Authority
- SRP®
- New York Power Authority

Clean Power Research

- Founded by Dr. Thomas E. Hoff in 1998
- Pioneers in economic analysis of PV and clean energy
- Software services powered by research and industry-leading data
- Research and consulting in Napa, CA
  Software development in Kirkland, WA

Company Structure



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CLEAN POWER RESEARCH PRODUCTS & SERVICES

DATA SOURCES

- SolarAnywhere®
- PowerTariffs™
- Incentives
- TMY (NREL)

SOLAR PREDICTION

Forecast, real-time and historical time-series irradiance data and power simulation for planning, developing and operating solar installations

- SolarAnywhere®

ECONOMIC VALUATION

Embeddable energy, economic and environmental analysis for streamlining sales of renewable energy, EV and energy efficiency projects.

- CleanPower Estimator®
- QuickQuotes™
- PowerBill®

PROGRAM OPTIMIZATION

Automated incentive management and optimization services for renewable energy programs

- PowerClerk®

RESEARCH AND CONSULTING

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Project Overview

PlannedTasks	Actual Accomplishments
• Enhance spatial and temporal resolution of SolarAnywhere® for ***selected*** CA locations	• Enhanced spatial and temporal resolution of SolarAnywhere® for ***the entire state*** of CA
• Enhance PVSimulator to include ***output variability*** and validate	• Developed, validated, and patented approach to simulate ***both output variability and output***
• Integrate PV modeling capabilities into a distribution system engineering and analysis tool	• Developed web services to integrate PV modeling capabilities into distribution system tools
• Create ***initial Excel tool*** to calculate economic value of a specific PV fleet configuration	• Created ***full web-based*** tool to calculate economic value of a specific PV fleet configuration

Task 1

Enhanced Spatial and Temporal Resolution of SolarAnywhere for the Entire State of CA

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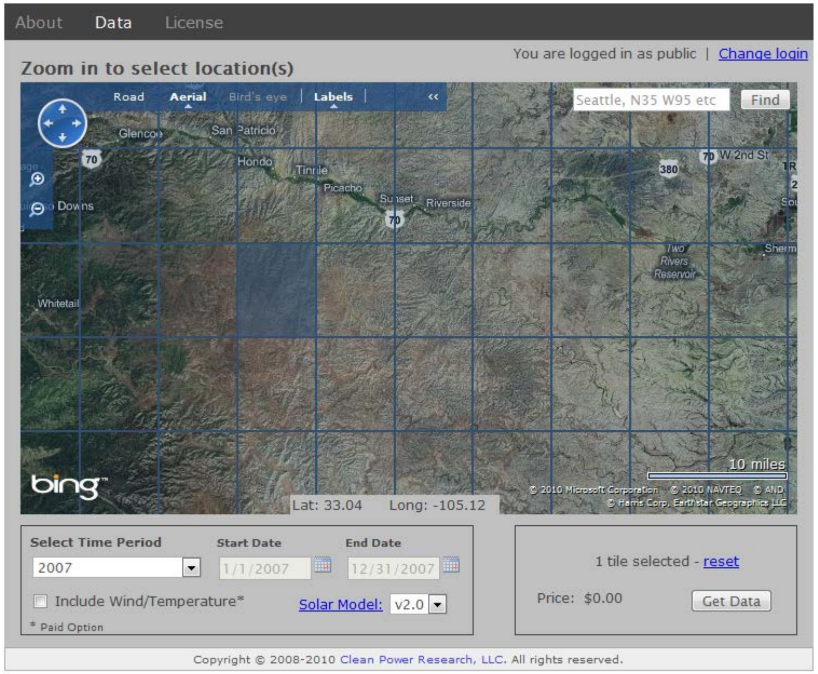
What is SolarAnywhere?

Web-accessible solar irradiance data service

- Innovative
  - Historical values from 1998 through latest hour
  - Hour-by-hour forecasts up to a week in advance
- Accessible
  - Select locations via web-based map
  - Programmatically accessible web service
  - Integrate with system operation tools

SOLARanywhere®



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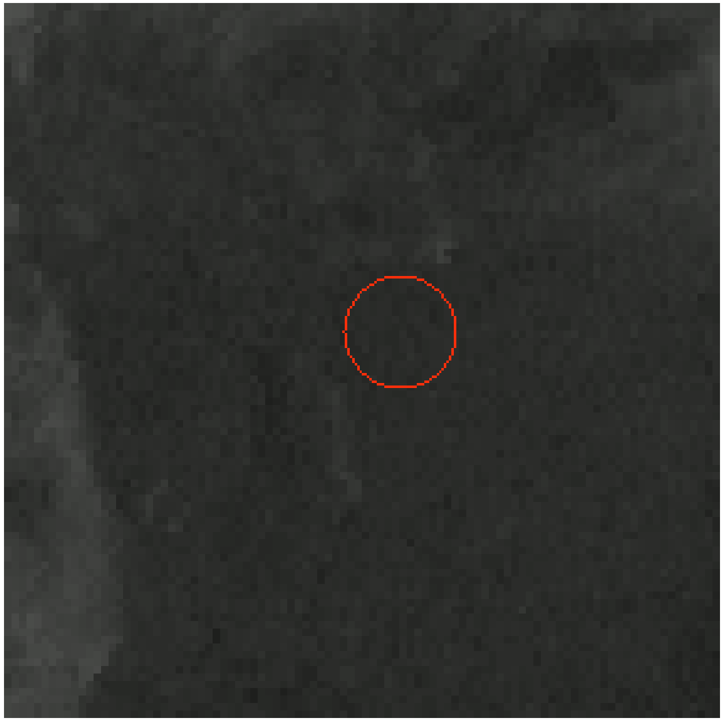
Convert Satellite Images to Irradiance



8 AM 12 PM 4 PM

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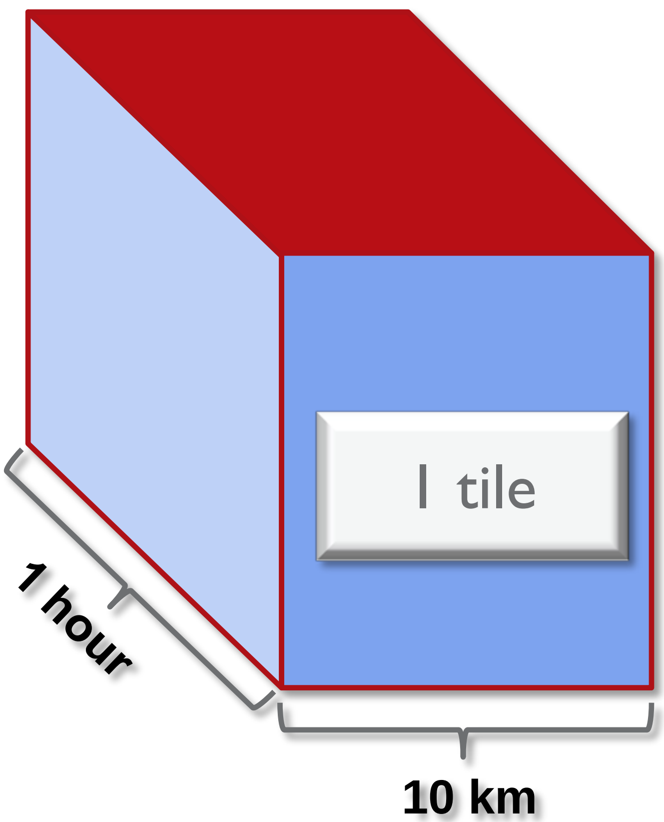
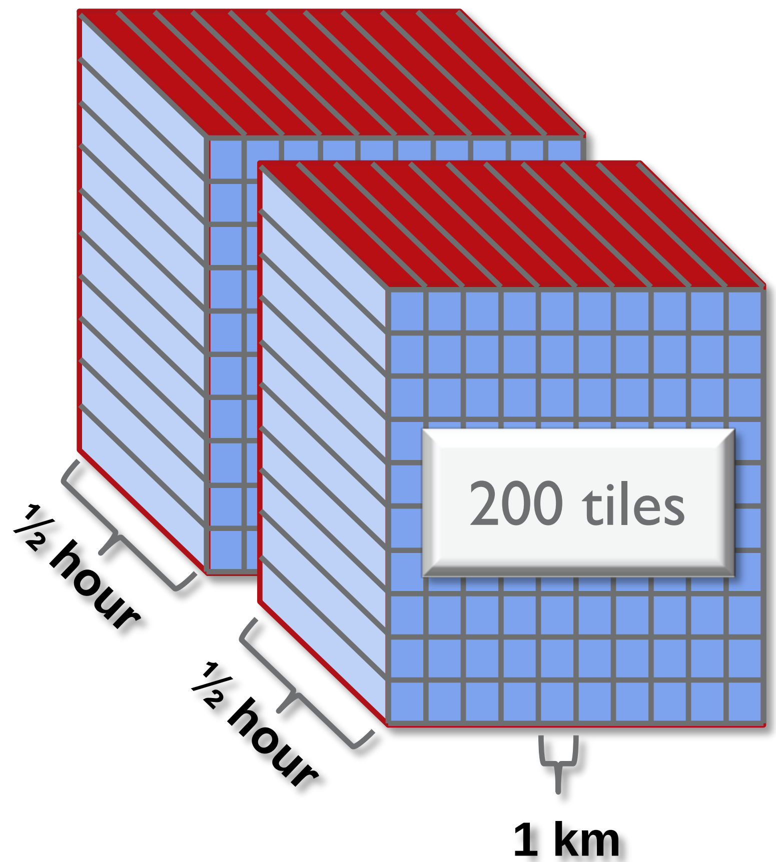
SolarAnywhere Enhanced Resolution

SOLARanywhere STANDARD RESOLUTION → SOLARanywhere ENHANCED RESOLUTION

10 km grid, 1 hour data

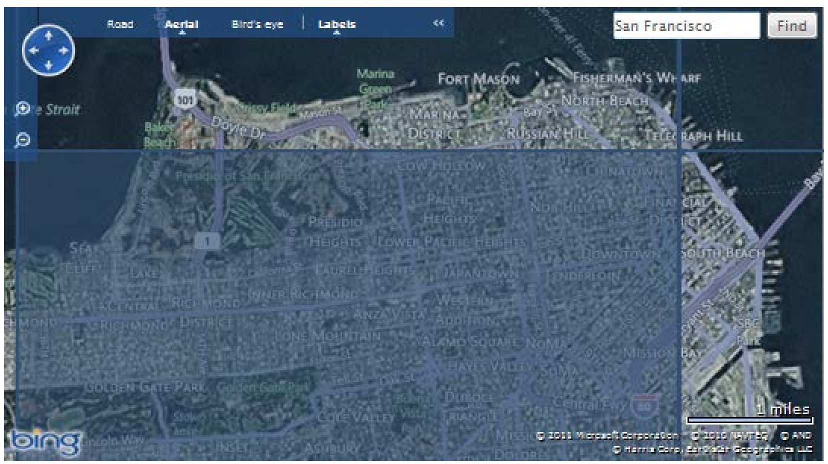
1 km grid, 1/2 hour data



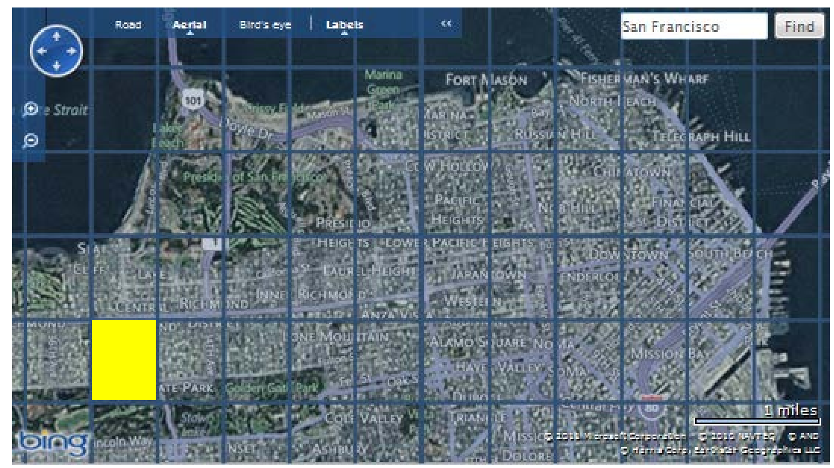


Example: San Francisco, CA

SOLARanywhere® STANDARD RESOLUTION



SOLARanywhere® ENHANCED RESOLUTION



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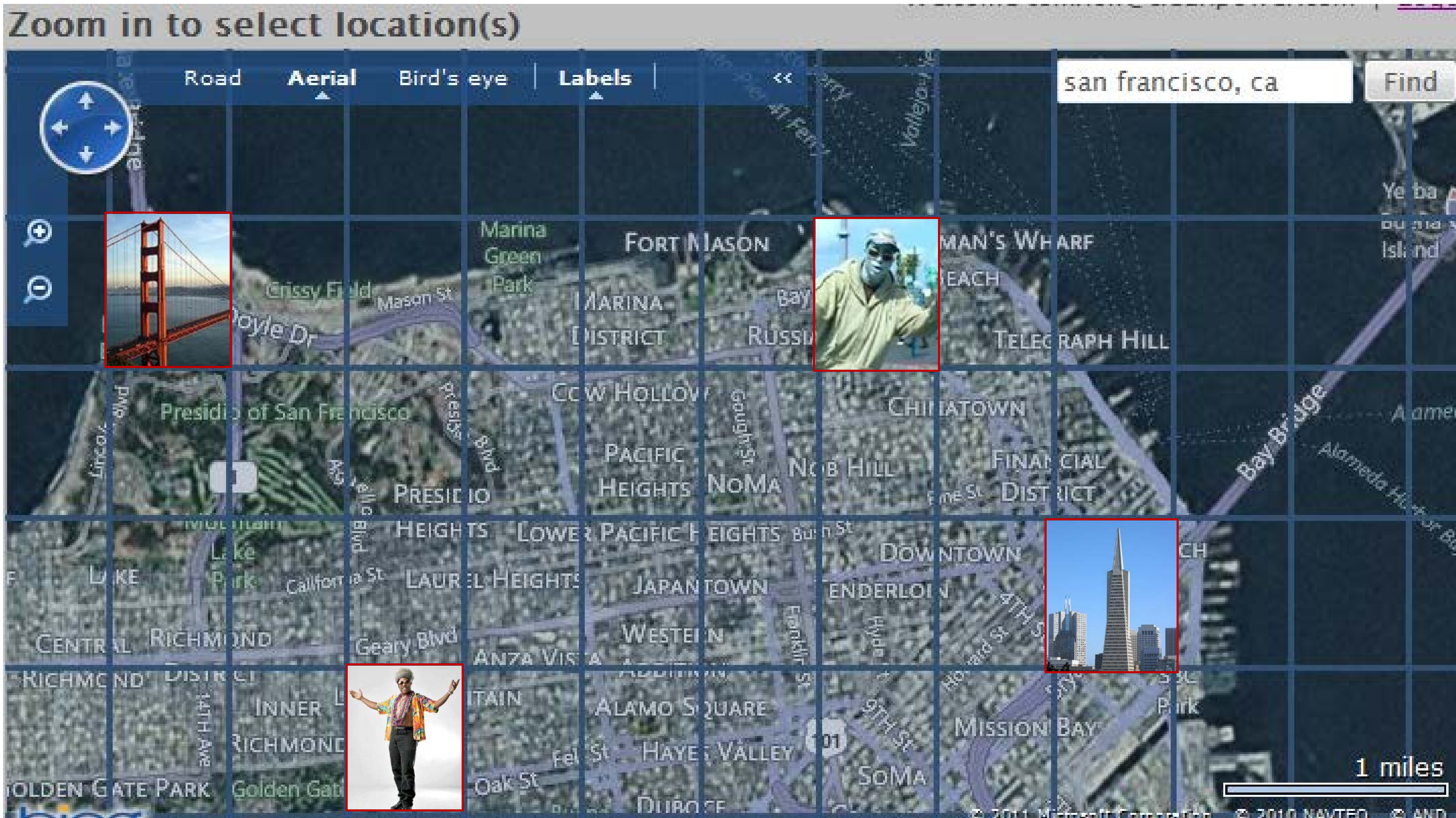
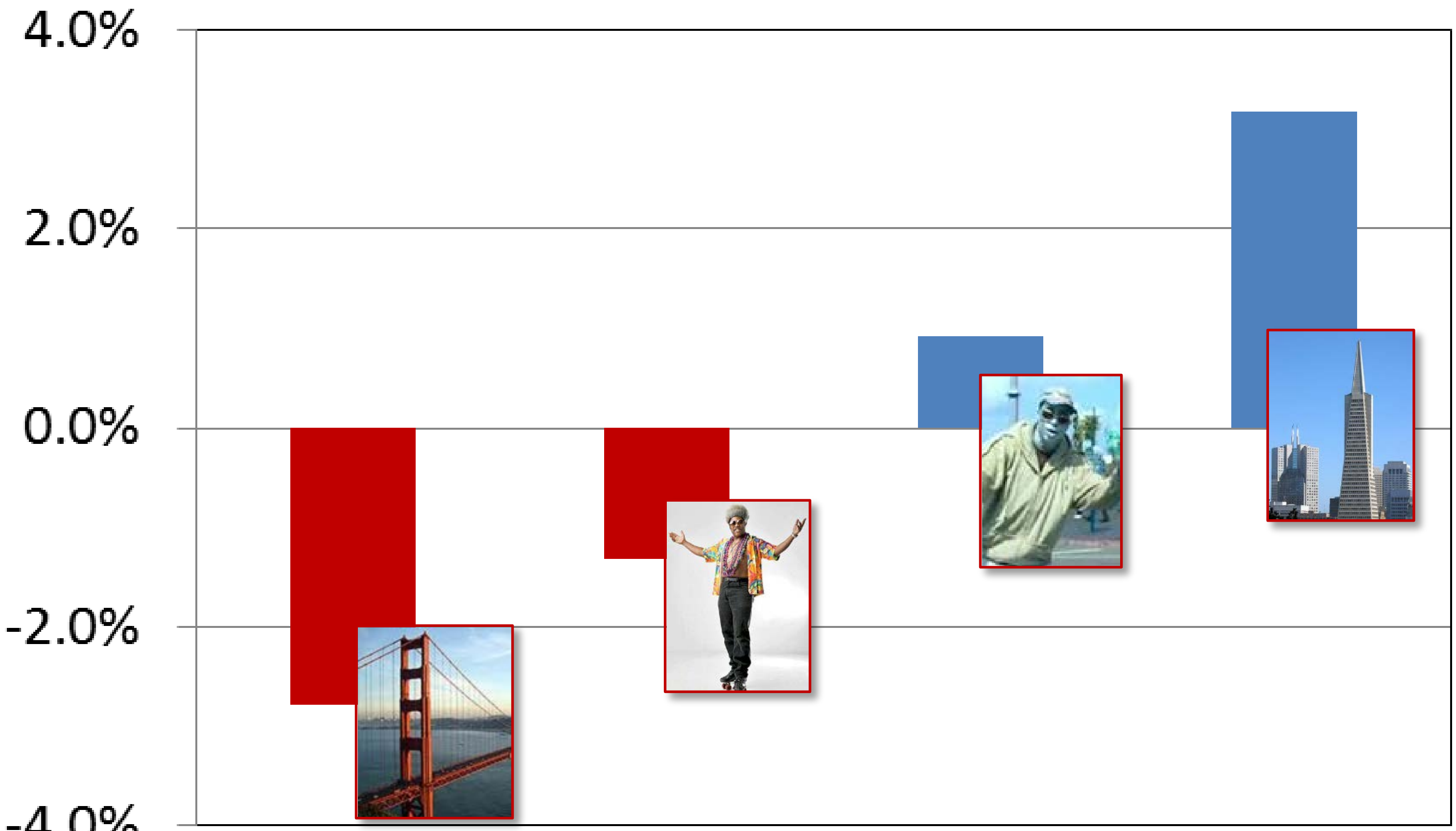
Example: San Francisco, CA



Annual Variation by Location



Result based on 2003-2010 SolarAnywhere Enhanced Resolution data

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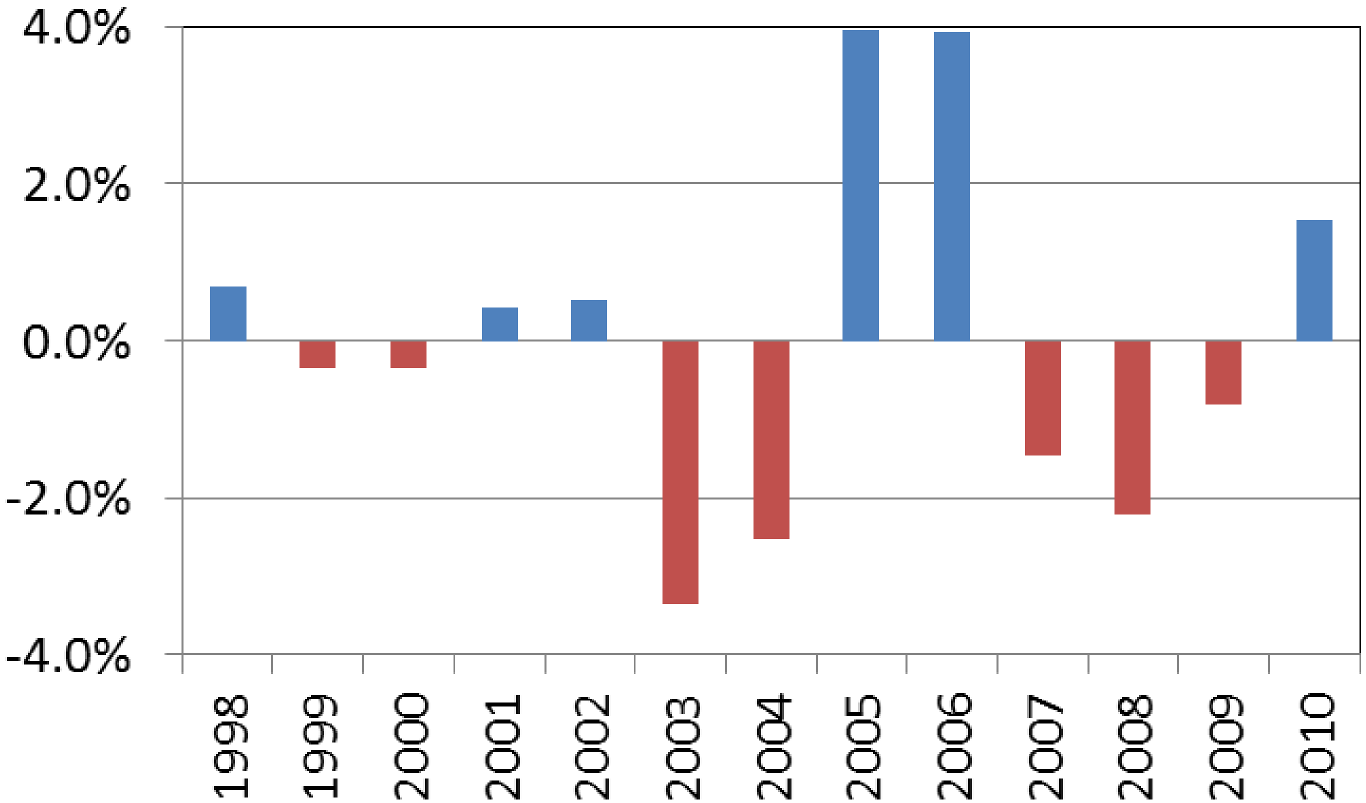
Variability by Year



Result based on 2003-2010 SolarAnywhere Enhanced Resolution and 1998 – 2002 SolarAnywhere Standard Resolution data

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SolarAnywhere Status

- Standard resolution (10 km grid, 1 hour resolution) data from 1998 through 7 day forecast anywhere in U.S.
- Enhanced resolution (1 km grid, ½ hour resolution) data from 2003 through 7 day forecast anywhere in California
- Provide data to perform high penetration renewables studies (e.g., CAISO high penetration study) and multiple validation studies (UCSD)

www.SolarAnywhere.com

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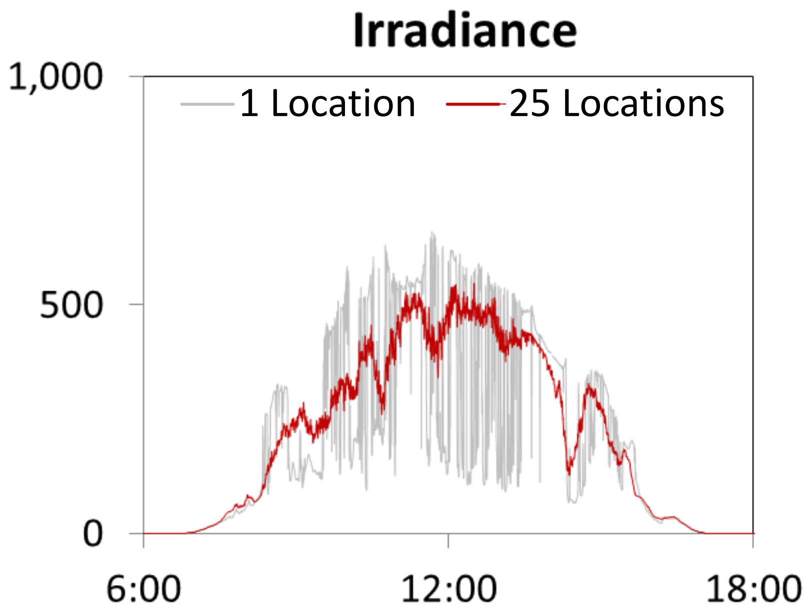
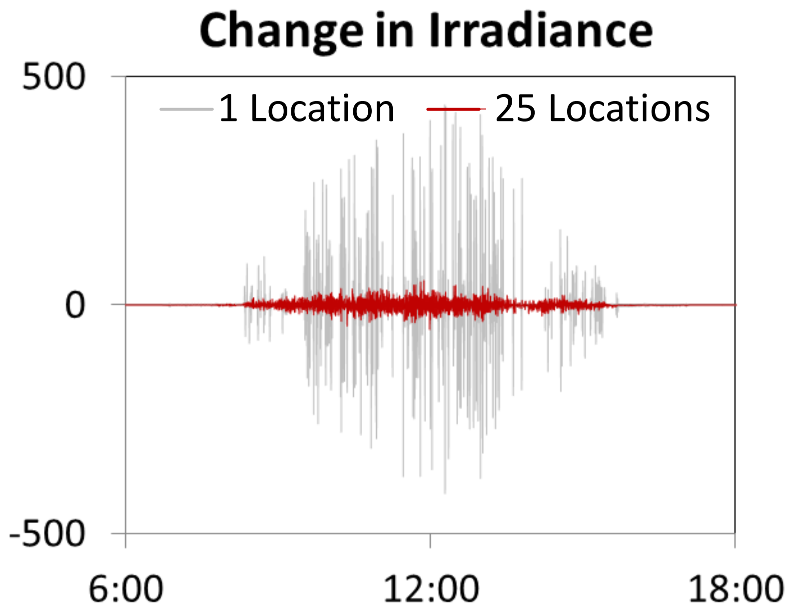
Task 2

Developed, Validated, and Patented Approach to Simulate Both Output Variability and Output

What is Output Variability?





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PV’s Intermittency Challenges

- Who will face the challenges of PV intermittency?
  - Independent system operators
  - Load serving entity schedulers
  - Distribution system planners
  - Distribution system operators
- What do they need to address the challenges?
  - Aggregated fleet power and variability (real-time and forecasted)

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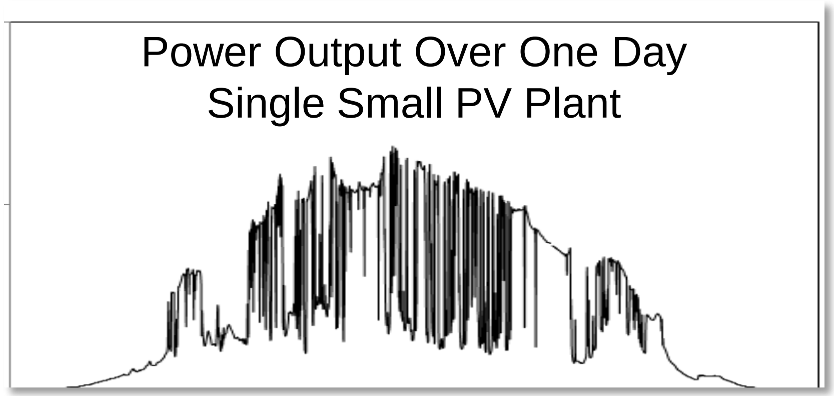
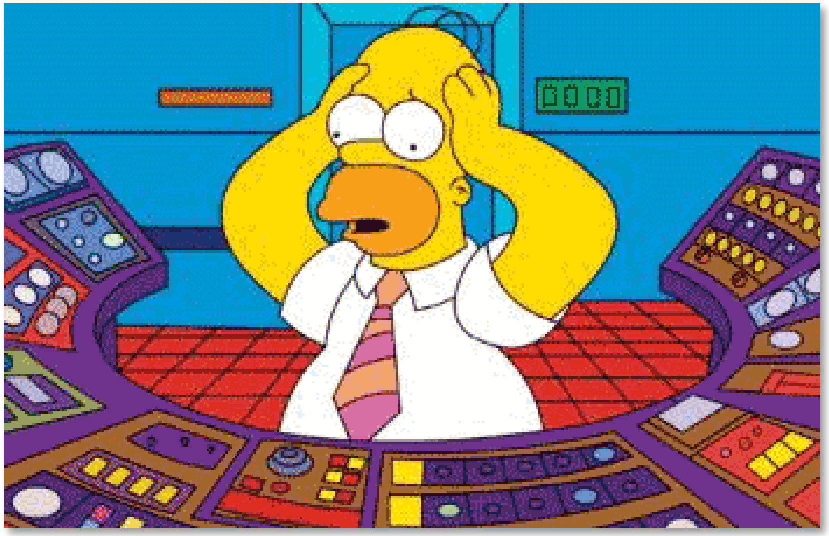
Independent System Operators



If this is 1 PV plant ….

what will I do with 100,000?



- Maintain balancing area reliability
- Plan for resources to accommodate PV
- Procure capacity and ramping resources based on ***PV fleet forecasts***

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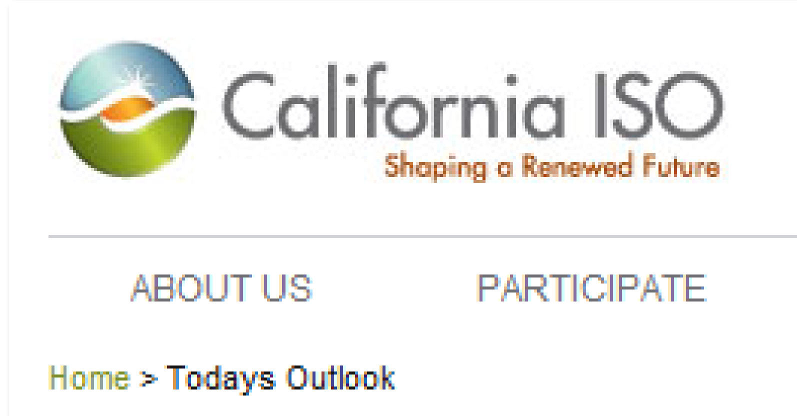
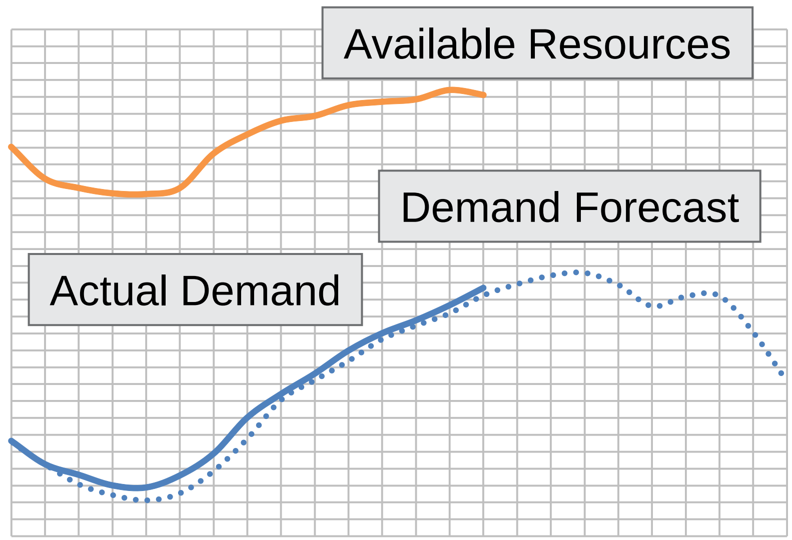
Load Serving Entities

- Submit demand forecasts to system operator
- Distributed PV hampers ability to forecast demand
- Inaccurate forecasts result in financial penalties
- Need to adjust demand forecasts based on distributed ***PV fleet forecasts***





Distribution System Planners

- Ensure customers receive reliable power
- Distributed PV complicates distribution planning
- Customers will complain if power is unreliable
- Planners need to understand ***PV fleet output*** on feeders to keep customers happy

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Distribution System Operators

- Storage will be deployed within smart grids
- Storage needs to be intelligently dispatched to maximize value
- Operators need ***PV fleet forecasts*** within distribution system to intelligently dispatch storage

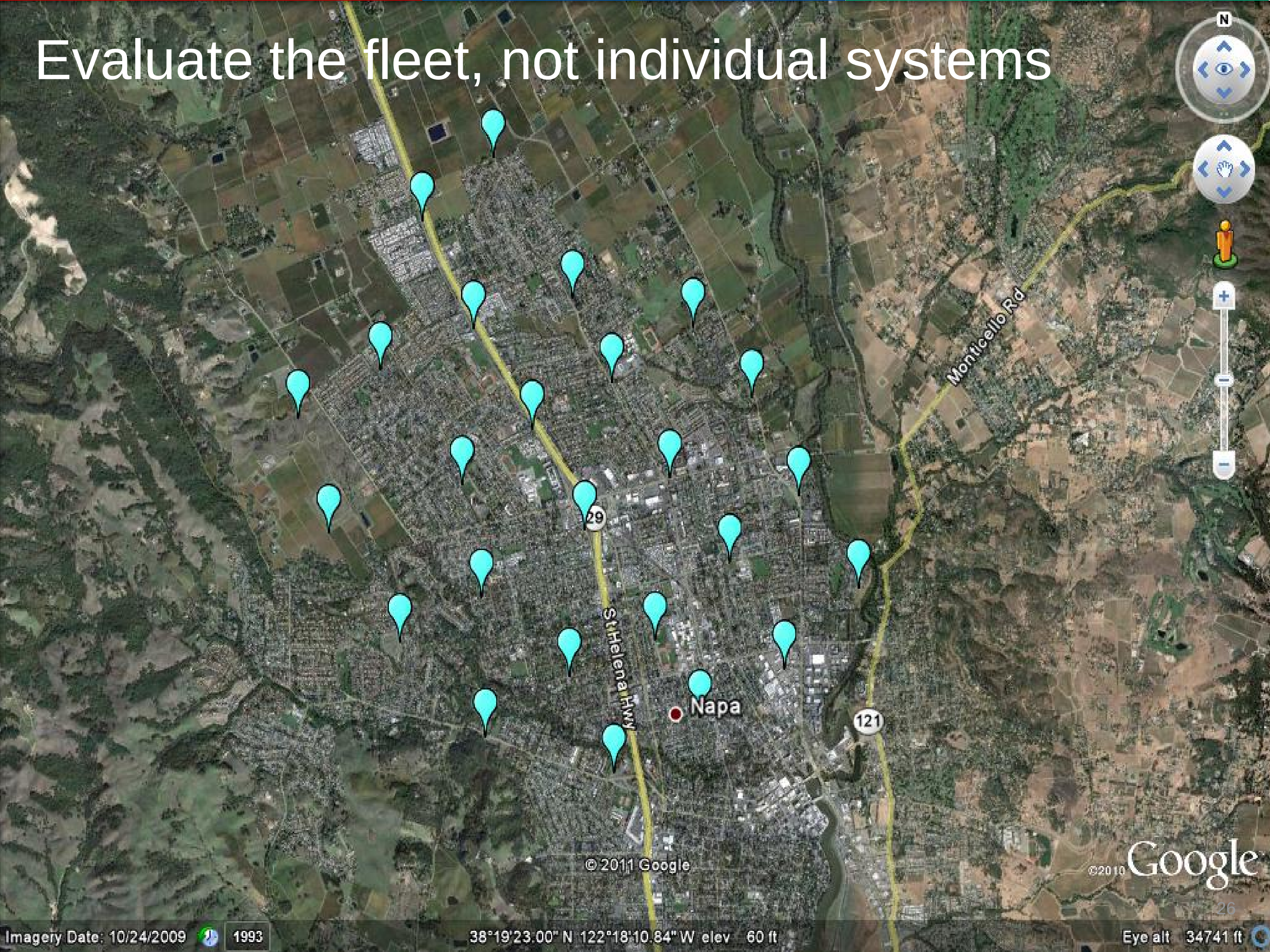
A123 batteries in distribution system

Perception: PV is Highly Variable and Unpredictable

How can high-penetration PV resources be integrated without incurring large backup generation and other equipment costs?

The story begins with assessing variability of an actual PV fleet…

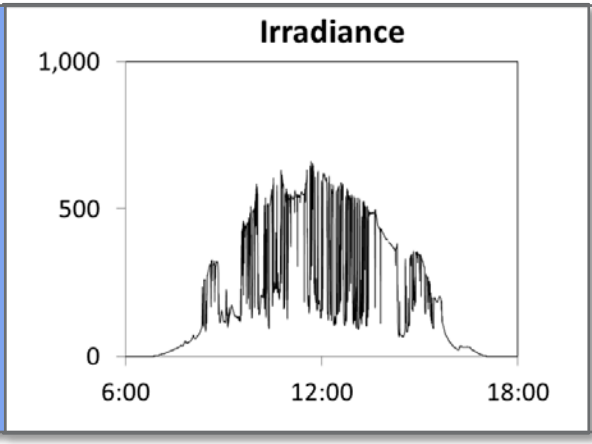
Evaluate the fleet, not individual systems

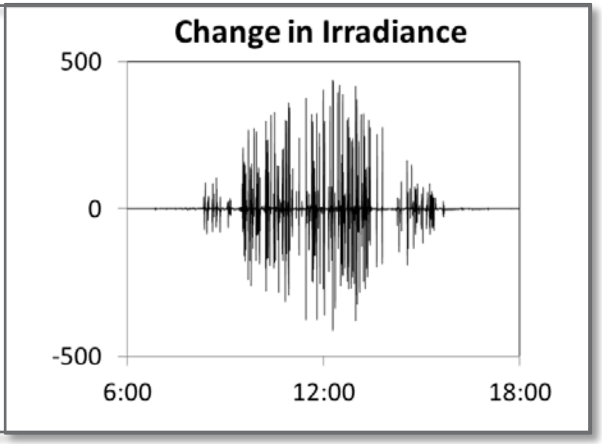


Geographic Diversity Leverages Weather System Inertia

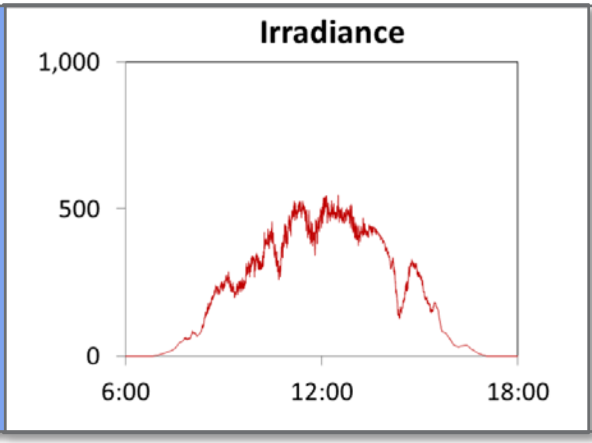
10 second irradiance data from 4 x 4 km grid in Napa on Nov. 21, 2010

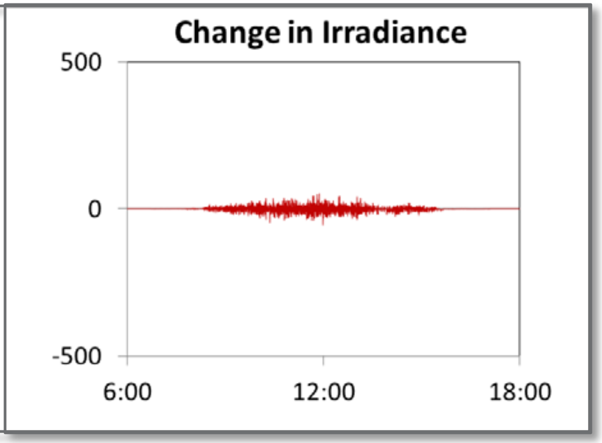
1 Location Measured





25 Locations Measured





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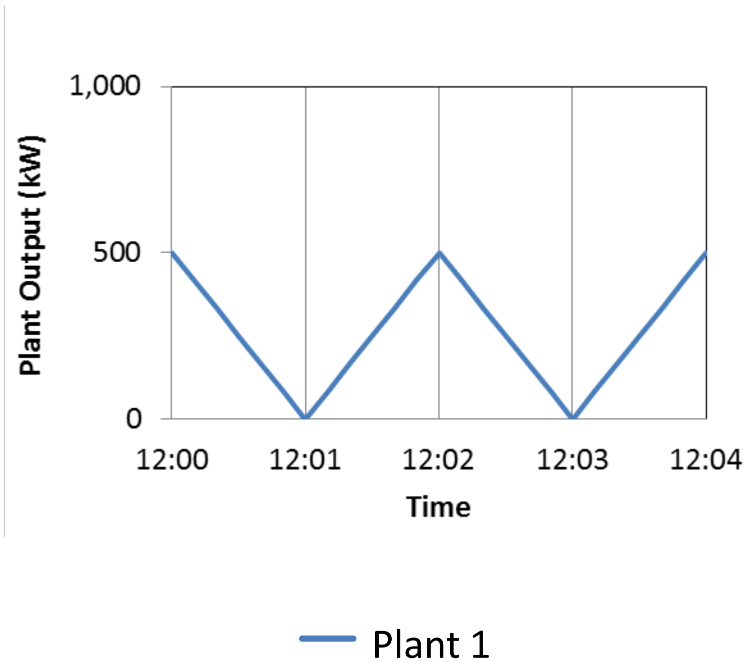
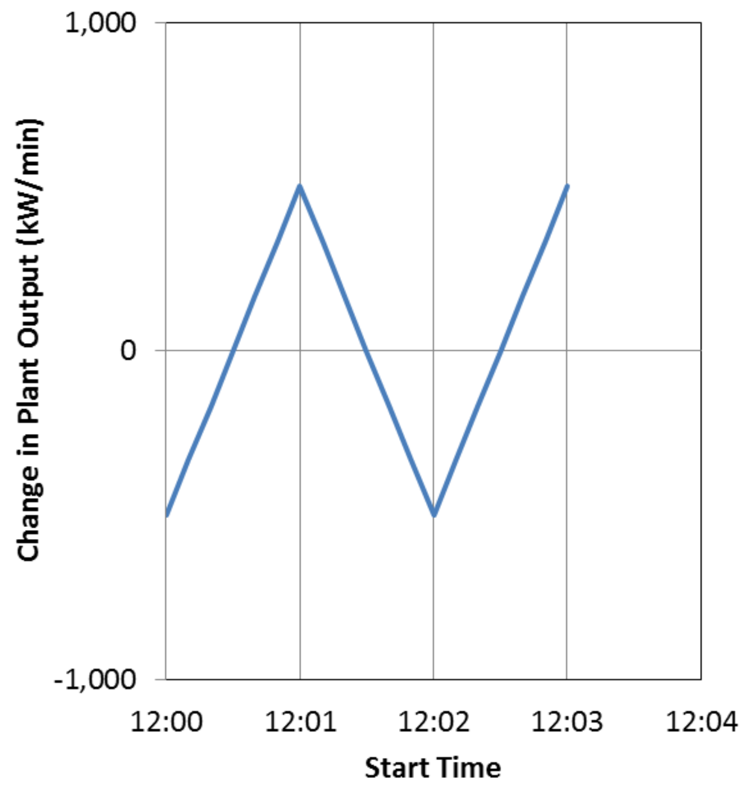
Variability Can Be Quantified Using Correlation Coefficients

Hypothetical Example of Two 500-kW Plants: Perfect Positive Correlation (100%)





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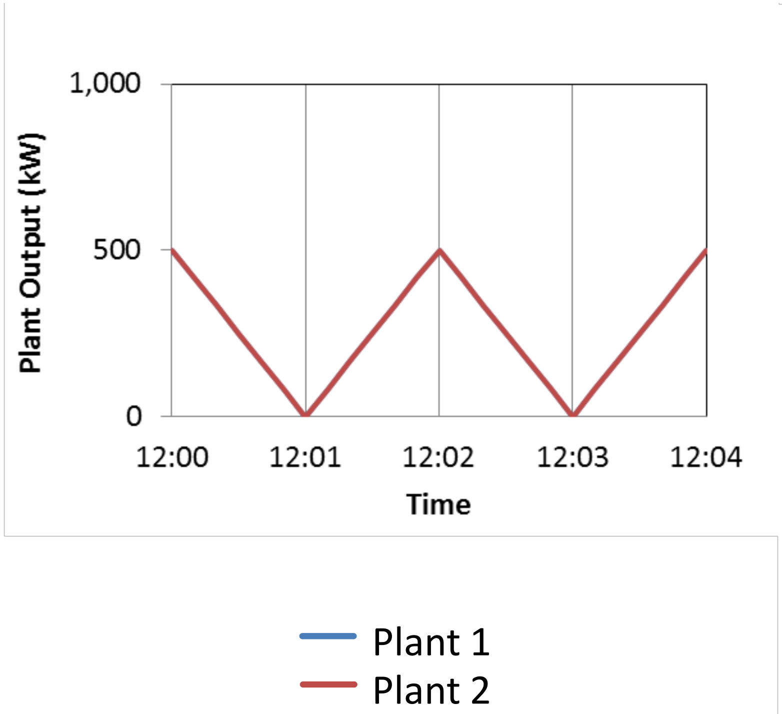

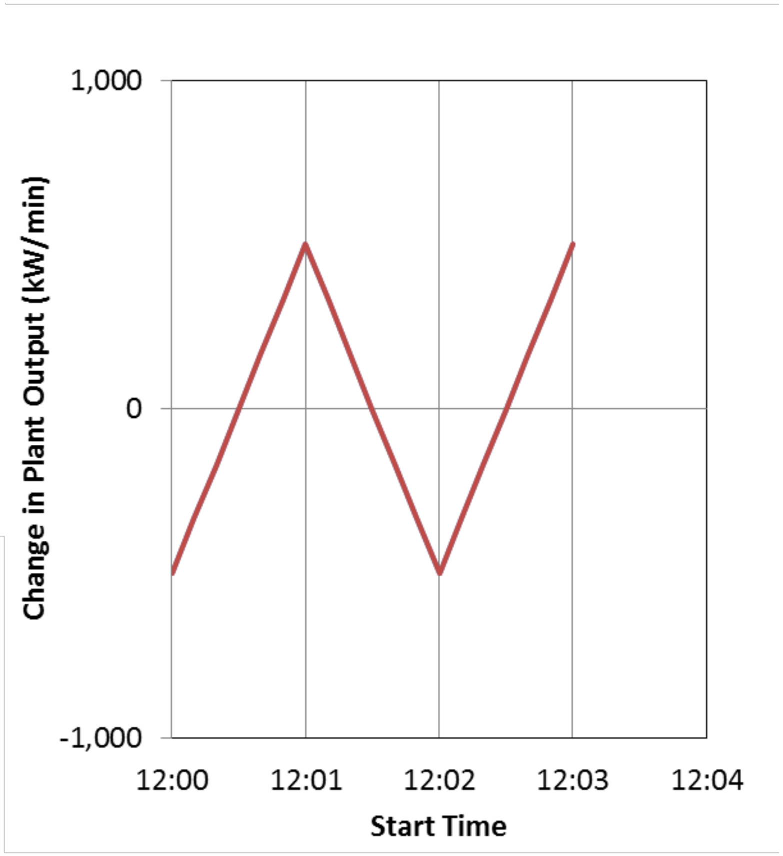

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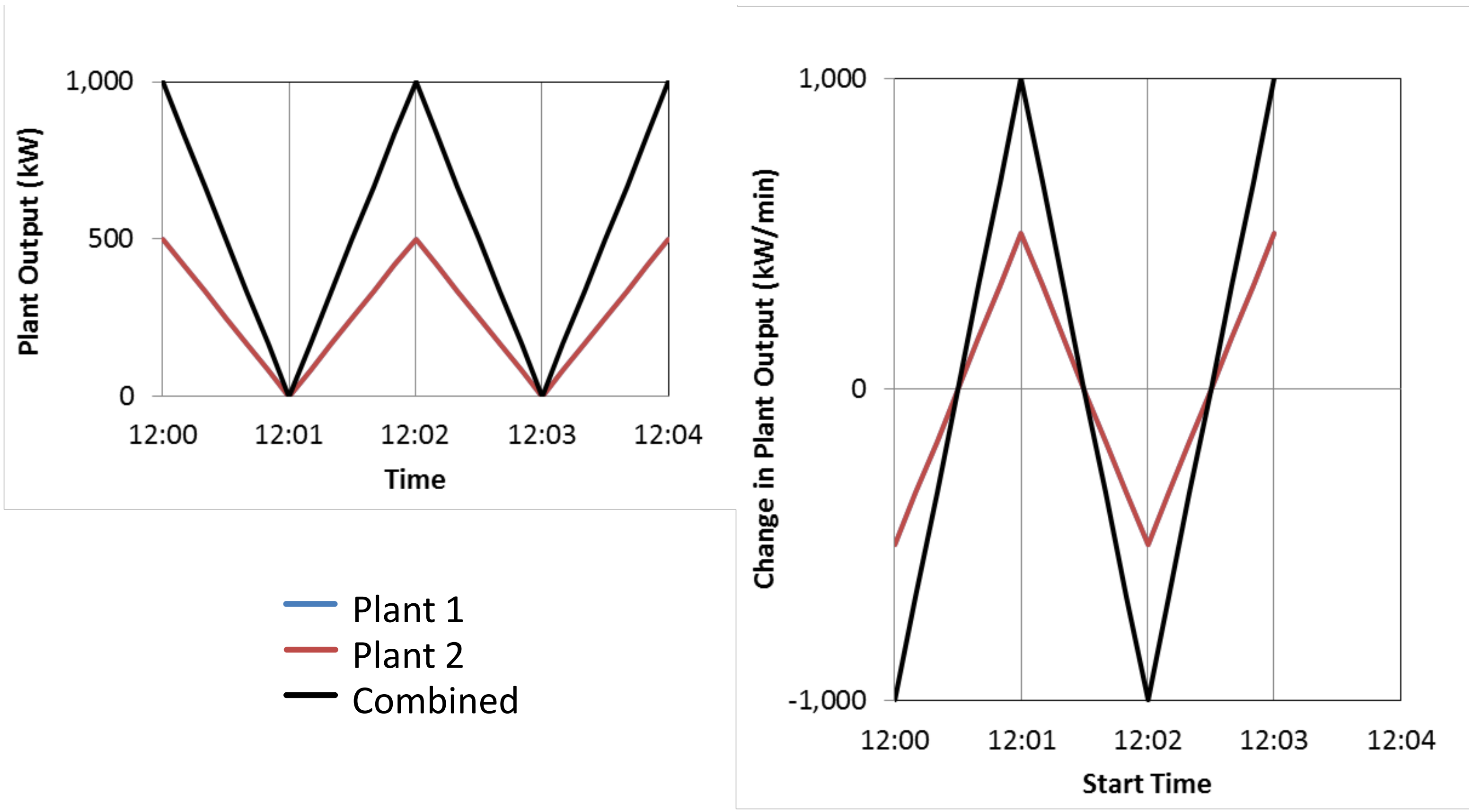

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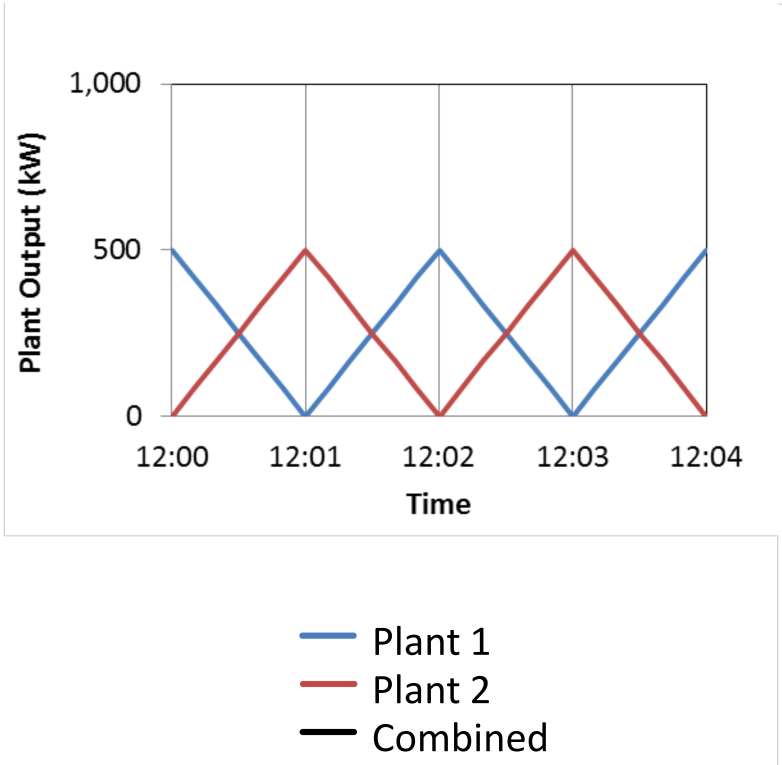
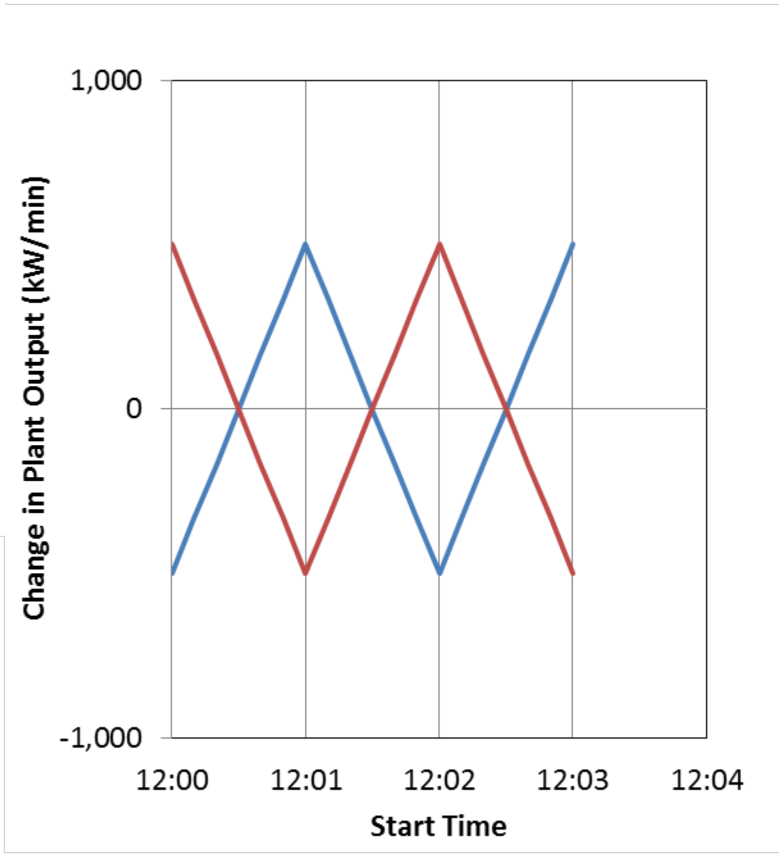
Hypothetical Example of Two 500-kW Plants: Perfect Negative Correlation (-100%)





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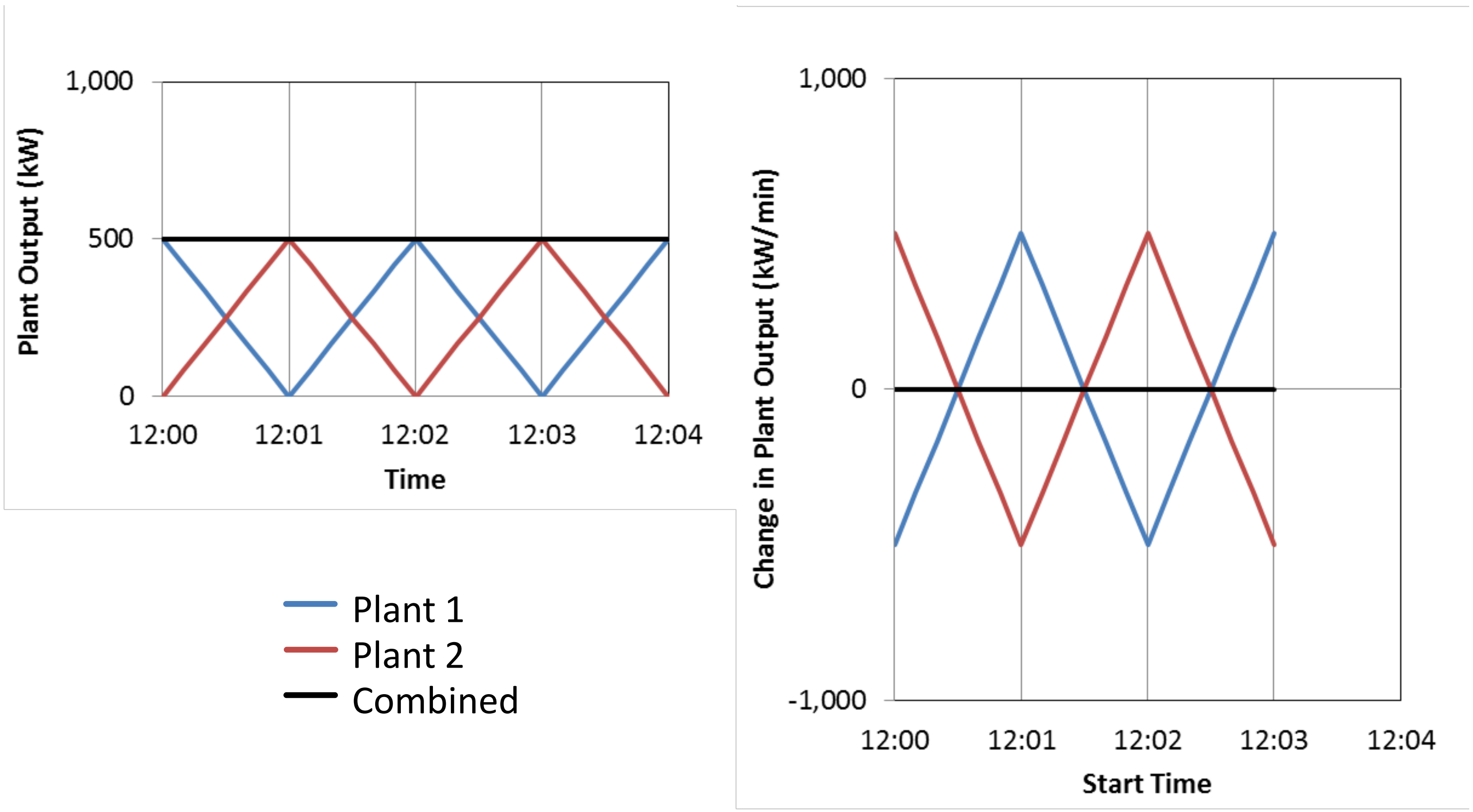

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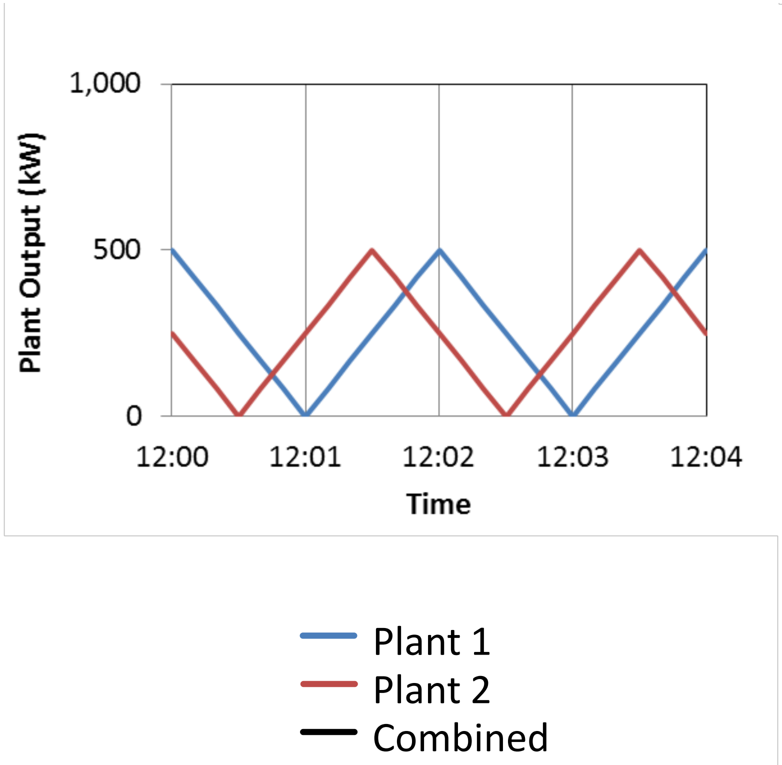
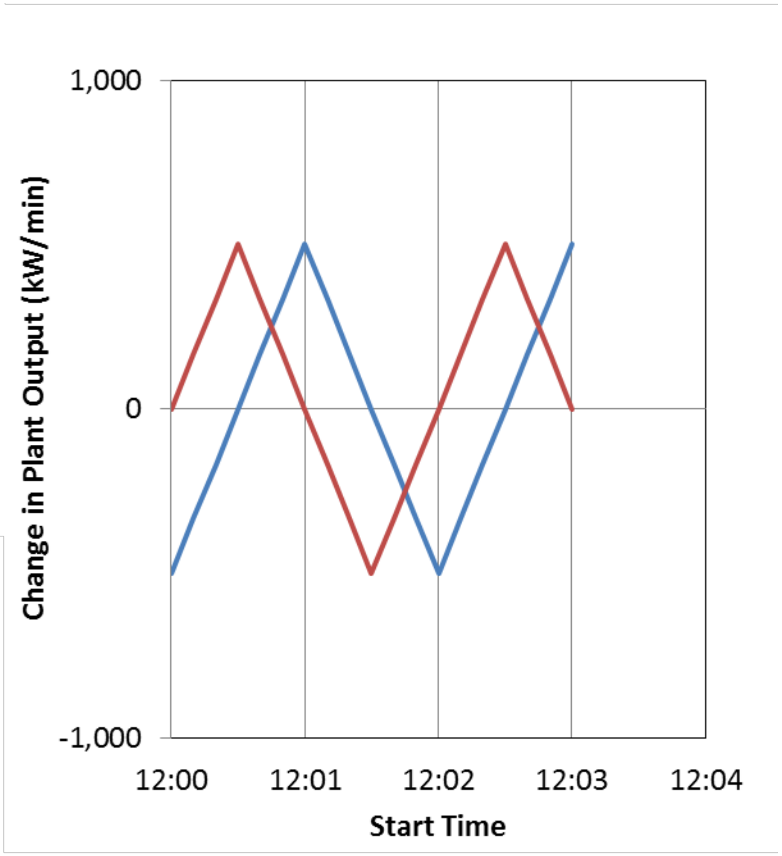
Hypothetical Example of Two 500-kW Plants: Uncorrelated (0%)





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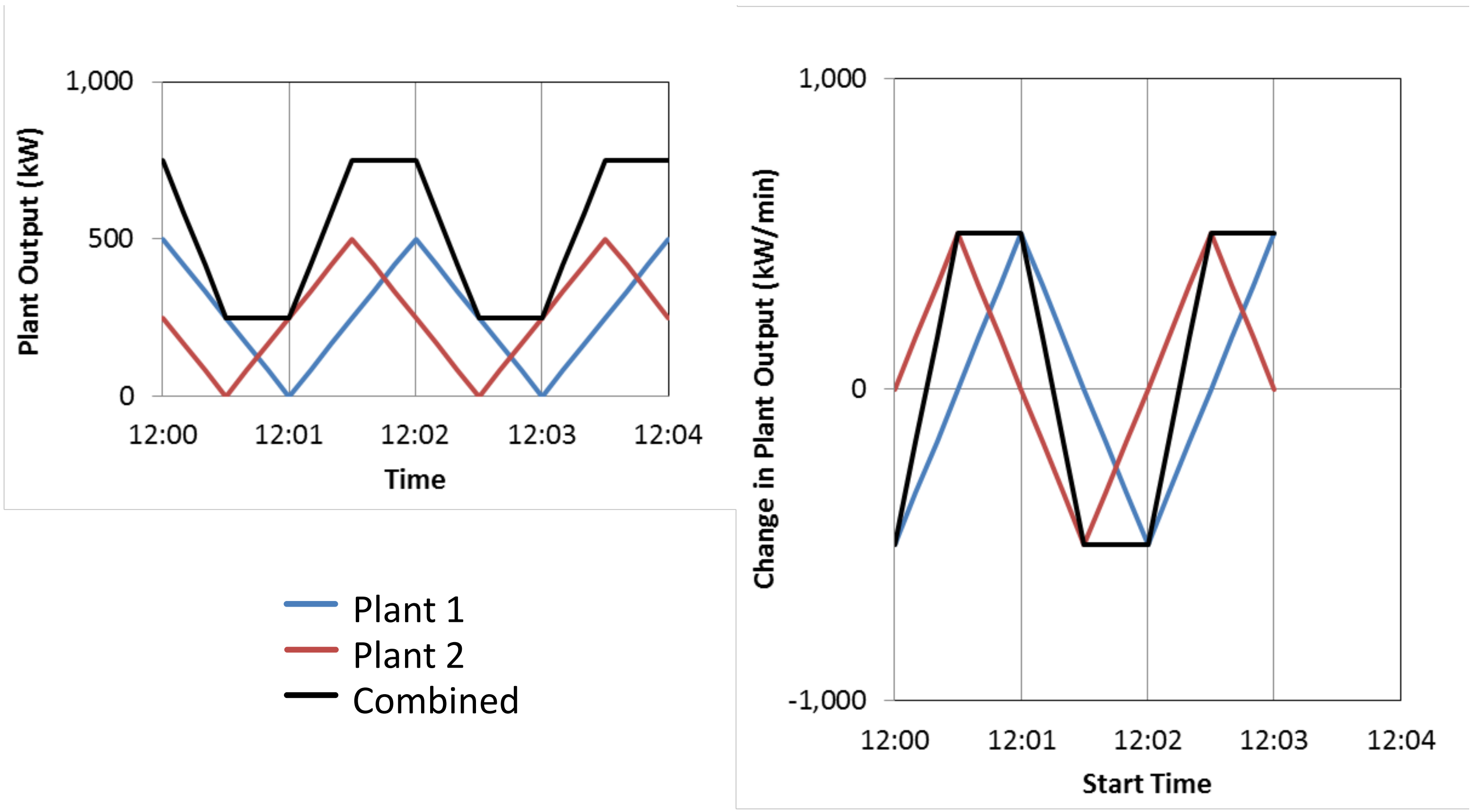
Hypothetical Example of Two 500-kW Plants: Uncorrelated (0%)



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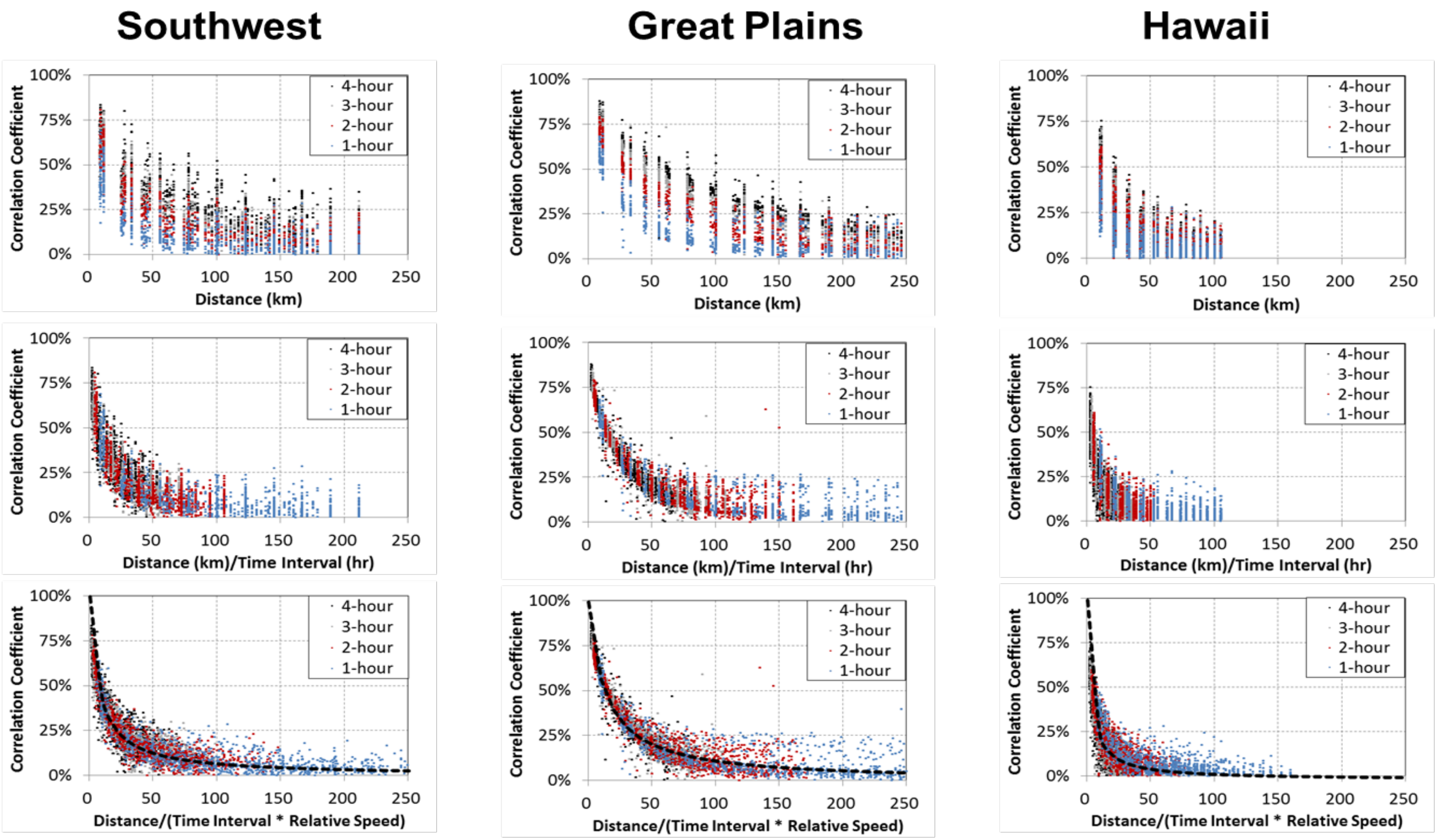
Correlation in Change in Clearness



Note: Distance / (Time Interval * Relative Speed) is related to Dispersion Factor

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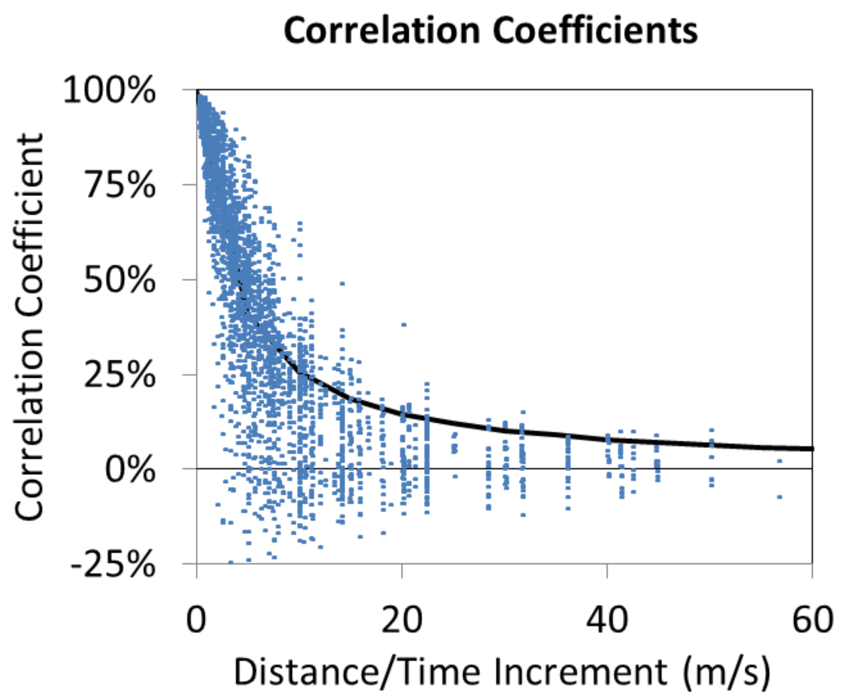
100 km/1 hour = 28 m/sec

Correlation at Cordelia Junction



10 sec. data from 400m x 400m grid at Cordelia Junction, CA (Nov. 7, 2010)

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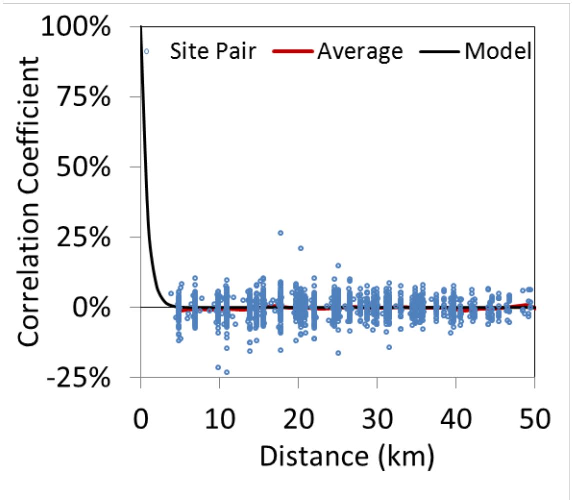
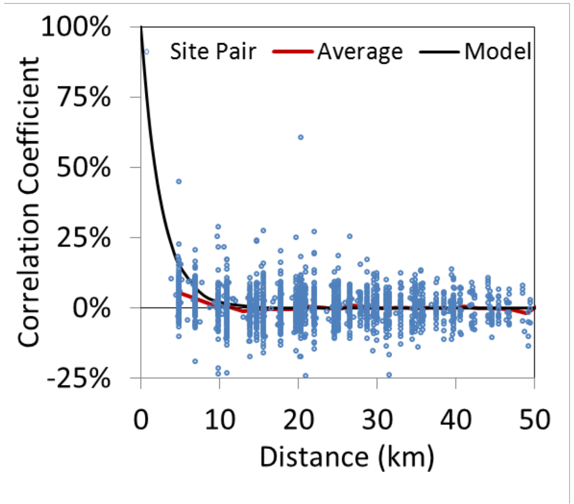
CPR's Model Required to Simulate Variability Confirmed Using SMUD's Network of Irradiance Sensors

Time Interval

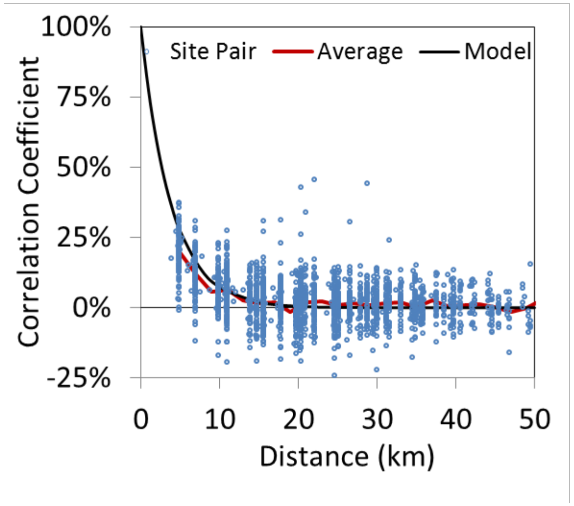
1 Minute



5 Minutes



10 Minutes



Bing, et. al., "Solar Monitoring, Forecasting, and Variability Assessment at SMUD," forthcoming at ASES 2012

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Variability Can Be Minimal for a Large PV Fleet

- PV *fleet* variability is much lower than one would expect based on single *system* performance
- The physical inertia of rotating machines in the current utility system is what minimizes short-term variability
- The weather system inertia that is leveraged by the geographic diversity associated with a large fleet of PV systems is what will minimize short-term variability for PV

…the story continues with determining how to predict PV fleet power generation

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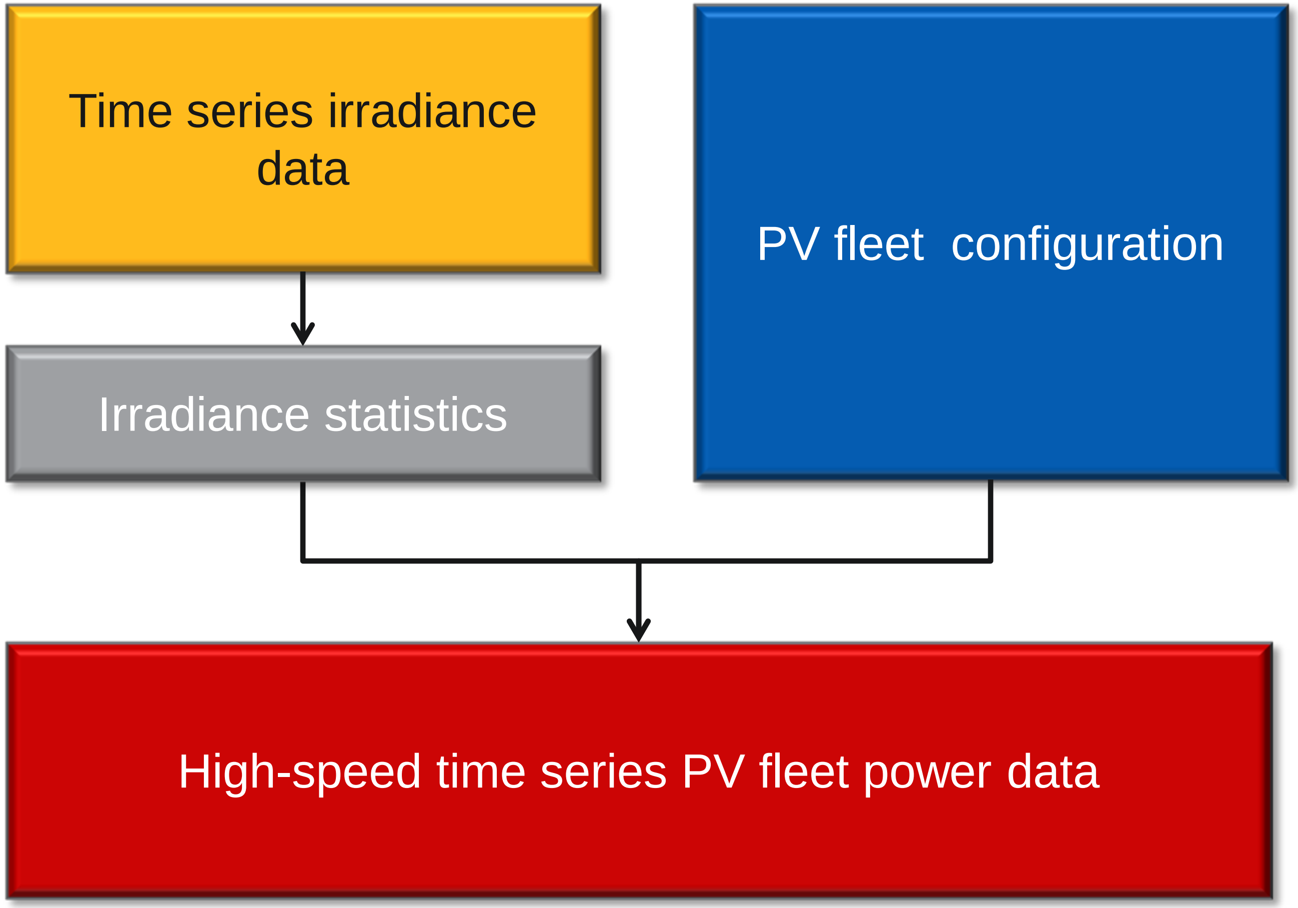
Direct Approach: Measure Everything

- For installed PV systems
  - Install meters on every PV system
  - Retrieve power output at the desired time interval
  - Sum output across all systems in the fleet
- When studying impacts of future systems
  - Collect irradiance data …
    … from dense network of weather monitoring stations
    … covering all anticipated locations of interest
    … at the desired time interval
  - Simulate output for each PV system individually
  - Sum results for all systems

Problems with Direct Approach

- Expensive instrumentation and communications
- Requires measuring equipment
- Data must be recorded at desired time resolution
- Few dense irradiance networks exist
- Not applicable to forecasting

Indirect Approach



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But do tools exist to implement this?

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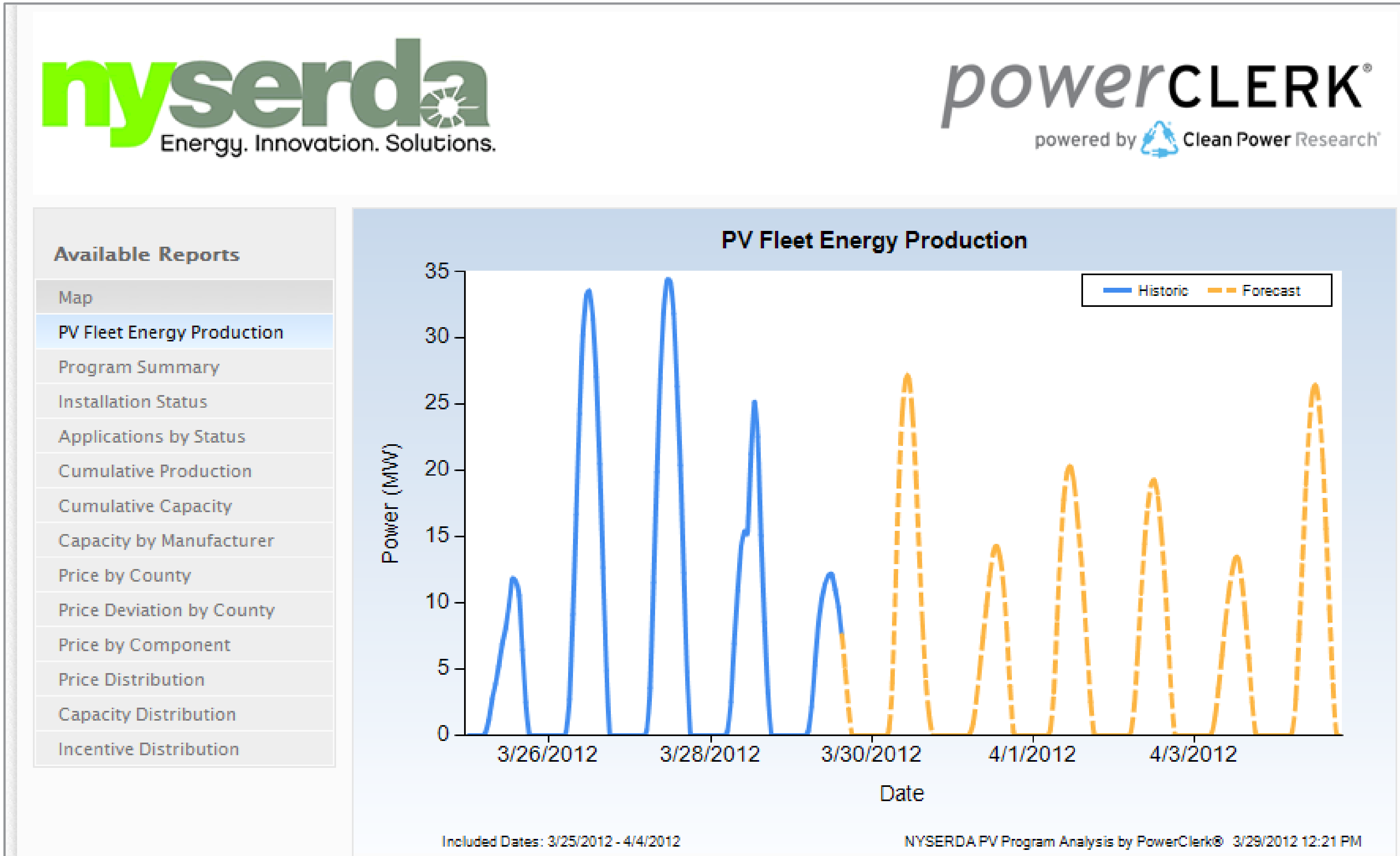
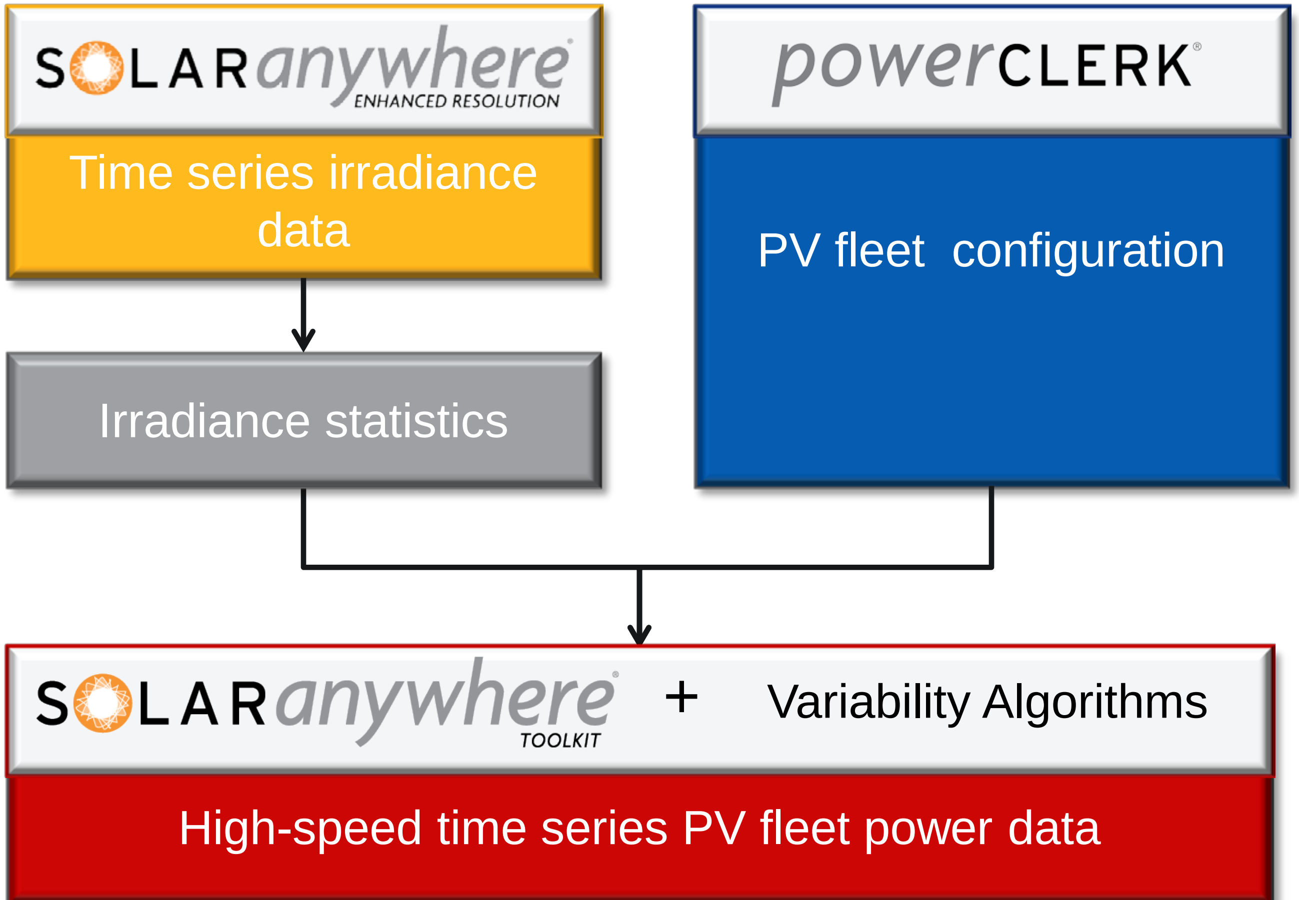
NYSERDA PV Fleet Output: In Use for 1+ Year



Use of Software Services to Implement Approach



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How do the pieces fit together?

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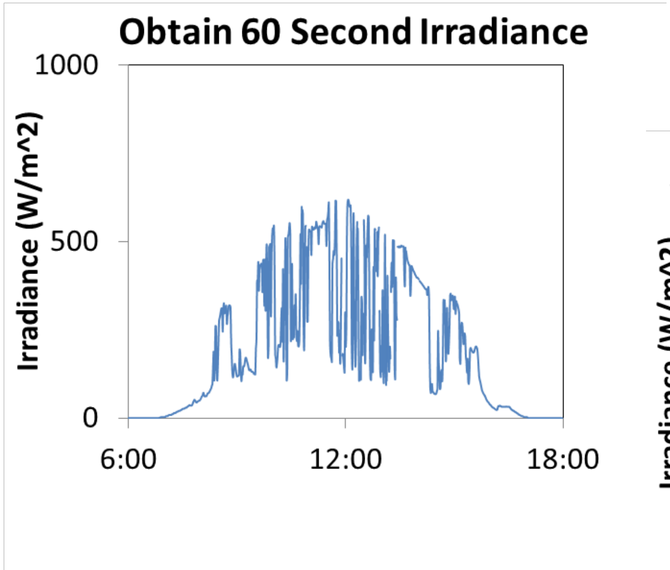
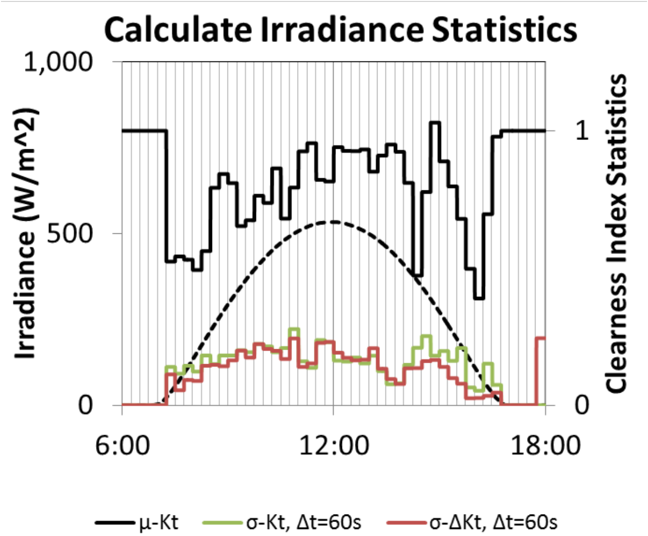
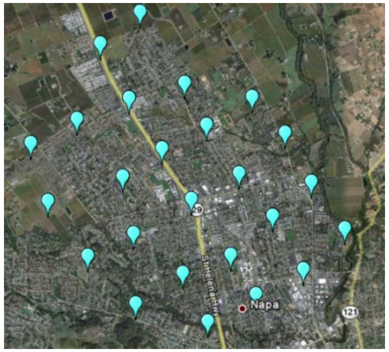
Generate High-Speed Time Series PV Fleet Power Data





Combine with Fleet Configuration



Patent Pending:

1. Computer-Implemented System and Method for Estimating Power Data for a Photovoltaic Power Generation Fleet
2. Computer-Implemented System and Method for Determining Point-to-Point Correlation of Sky Clearness for Photovoltaic Power Generation Fleet Output Estimation
3. Computer-Implemented System and Method for Efficiently Performing Area-to-Point Conversion of Satellite Imagery for Photovoltaic Power Generation Fleet Output Estimation

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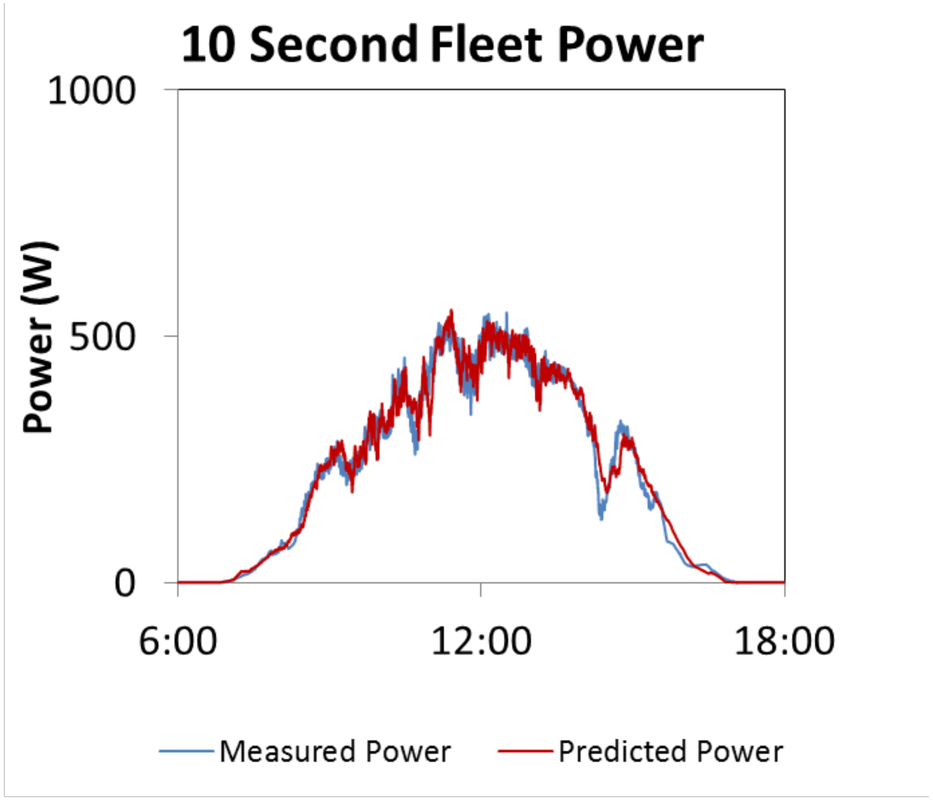
Result: High-Speed Time Series PV Fleet Data

Measured and simulated 10 second data from 25 locations in a 4 km x 4 km grid in Napa on Nov. 21, 2010



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Task 2 Summary

- Utility system planners and operators need tools to predict PV fleet performance
- CPR has been developing such tools
  - ✓ Produced enhanced resolution solar resource data
  - ✓ Obtained PV system specifications
  - ✓ Designed simulation algorithms
- Work underway (CEC & CSI Phase 3 contract)
  - Generate high resolution solar resource data
  - Apply high speed PV fleet simulation algorithms
  - Validate PV fleet simulation using measured PV plant data

Task 3

Developed Web Services to Integrate PV Modeling Capabilities into Distribution System Tools

Grid Services Rationale

Solar Services (belongs at CPR)	Circuit Modeling Software (belongs at developer/utility)

• PV modeling expertise
  • Solar irradiance
  • Cloud effects & shading
  • Sun angles
  • Forecasting
  • Variability
• PV equipment database
• Nationally recognized analytics
	• Circuit analysis expertise
	• Developed and tested
	• Accepted by utilities

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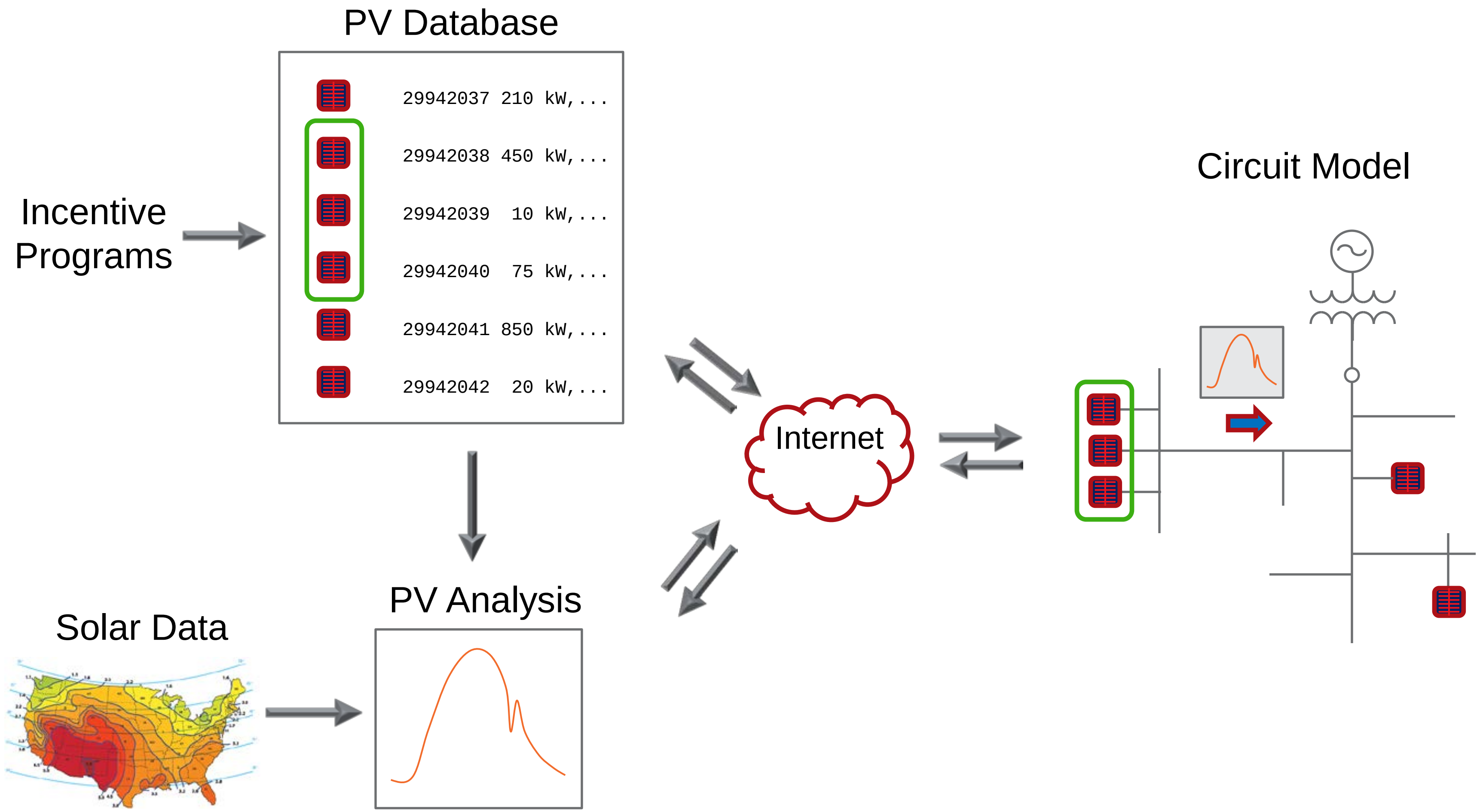
Accessing CPR Grid Services



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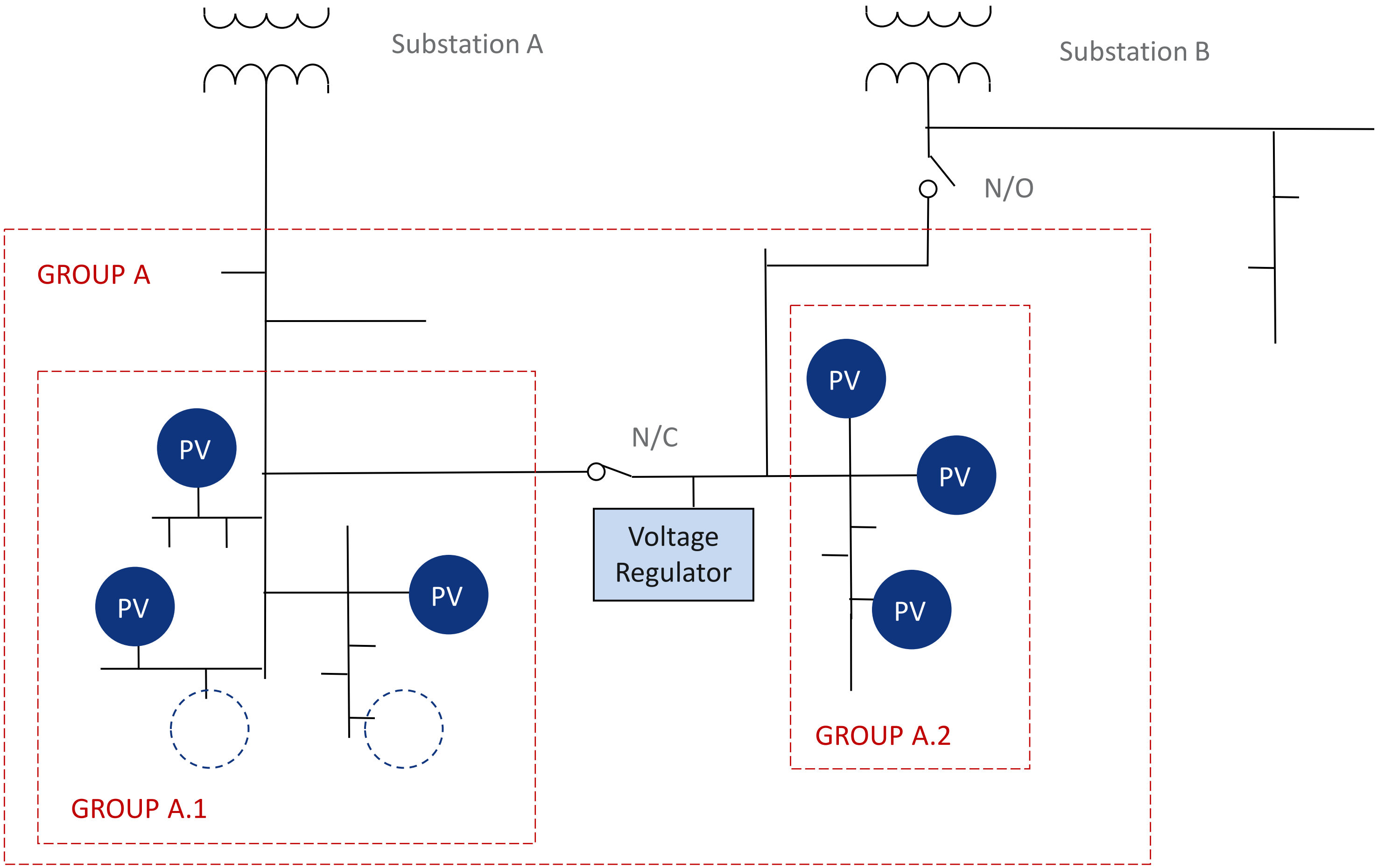
Uses of Software Services

Web service	Result	Uses
PV System Power Statistics (Complete)	PV System: Min, max power by hour (10 year stats)	• Load flow studies (voltages, currents) • CVR
	PV System: Average, standard deviation of power by hour (10 year stats)	• Estimate lifetime of devices (regulators, capacitors) • Monte Carlo simulations?
PV System Power (Complete)	PV System: (real-time & hours-ahead forecast)	• Fault location • Load transfer decisions
PV Fleet Power and Variability (In Development)	PV Fleet: Variability (real time)	• Determine expected voltage swings • Load transfer decisions • Schedule reg. reserves (ISO)
	PV Fleet: Power (forecast)	• Estimate summer peak overloading • Estimate day-ahead "net" loads for scheduling generation • Schedule balancing energy (ISO)

New Concepts: Groups & Grid Status



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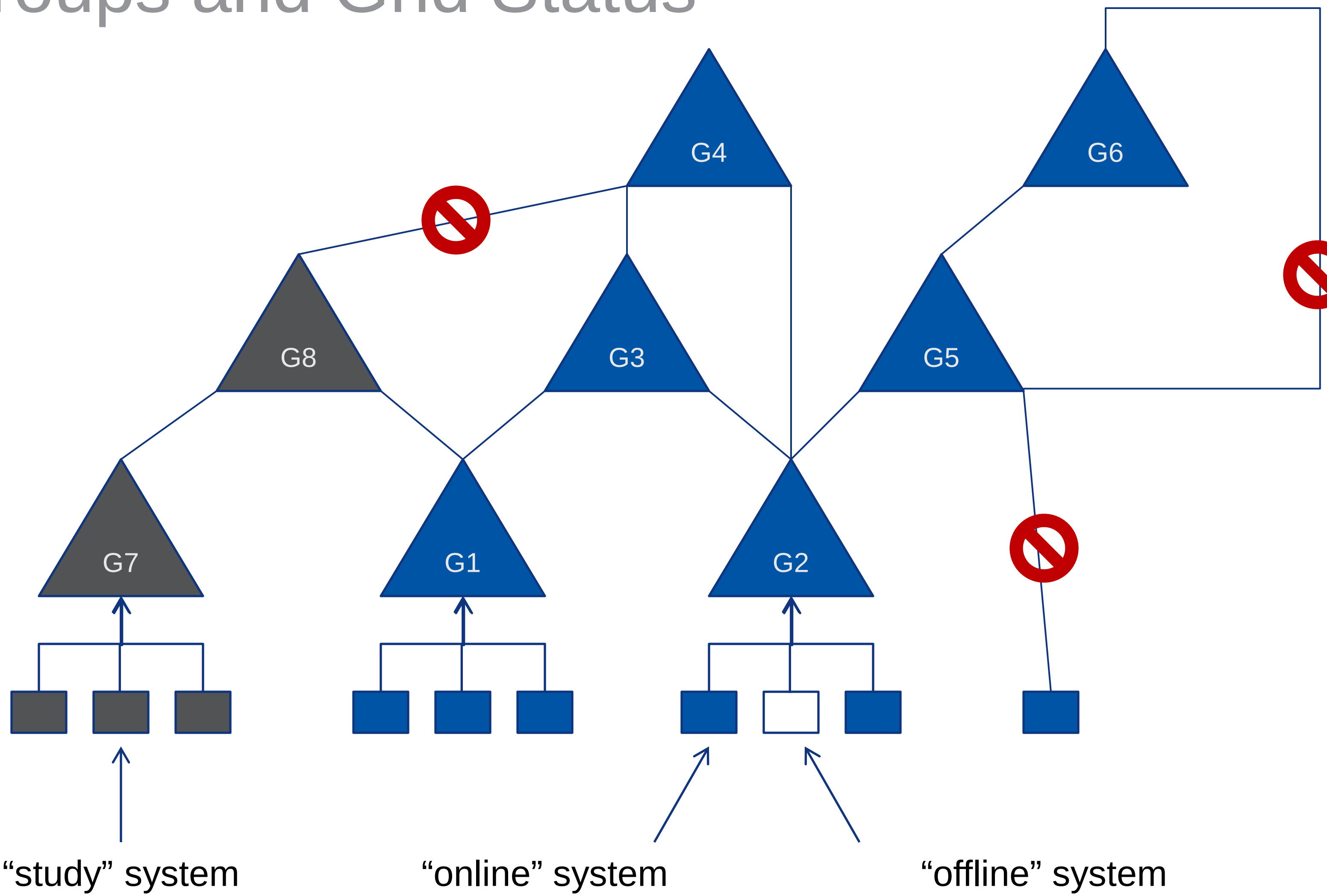
Groups and Grid Status



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Task 4

Created Full Web-based Tool to Calculate Economic Value of a Specific PV Fleet Configuration

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Distributed PV Calculator
Project Objective

- Build a software tool to calculate the location-specific economic value of PV to the utility grid from the utility perspective
- Targeted for use by utility planners and policy analysts

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Sample Study Questions

- How should a value-based Feed-in-Tariff (FIT) be designed?
- Is it worthwhile to target specific distribution areas? Which ones?
- How much PV is needed to delay a distribution upgrade by 1 year?
- How much load reduction is obtained from various PV system configurations?

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Calculator Benefits

Full input control
- PV specifications
- Utility data
- Economic assumptions

State-of-the-art valuation
- Fast
- Repeatable
- Scenario analysis

Uses
- PV incentive design
- RPS planning
- Screening

Saves cost and provides consistency

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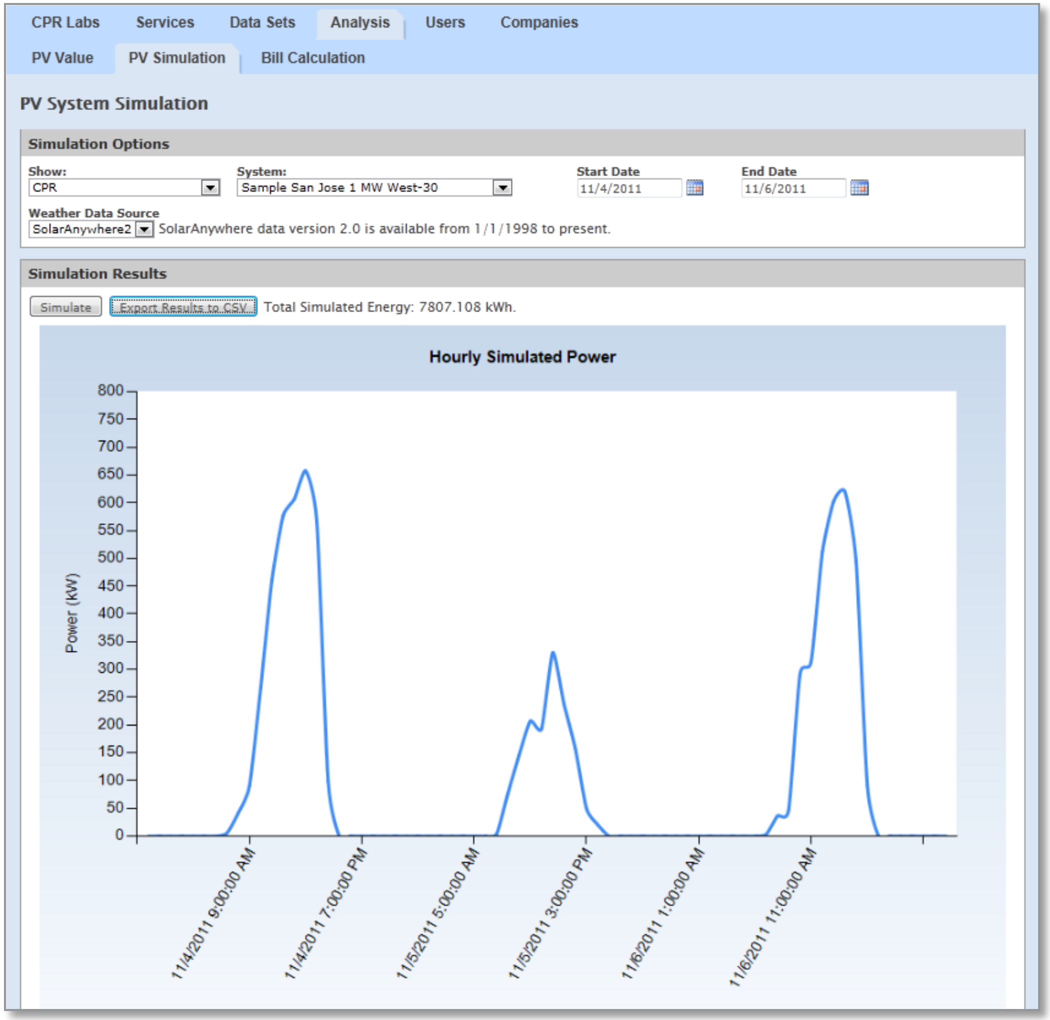
CPR's Distributed PV Value Analysis History

- Grid-Support PV: Evaluation of Criteria and Methods to Assess Local and System Benefits to Electric Utilities (1993)
- Final Results from the PVUSA Project at Kerman (1994, 1995, 1996)
- Photovoltaic Economics and Markets: The Sacramento Municipal Utility District as a Case Study (1996)
- A Preliminary Analysis of Block Island Power Company's Use of Clean Distributed Resources to Provide Power to Its Customers (1998)
- Distributed Resources: A Potentially Economically Attractive Option to Satisfy Increased Demand on Okanogan County Electric Cooperative's Mazama Feeder Line (1998)
- Final Results Report with a Determination of Stacked Benefits of Both Utility-Owned and Customer-Owned PV Systems to SMUD (2002)
- Determination of Photovoltaic Effective Capacity for Nevada Power (2003)
- Determination of Photovoltaic Effective Capacity for New Jersey (2004)
- Moving Towards a More Comprehensive Framework to Evaluate Distributed Photovoltaics (2005)
- The Value of Distributed Photovoltaics to Austin Energy and the City of Austin (2006)
- Shining on the Big Apple: Satisfying New York City's Peak Electrical Needs with PV (2008)
- PV Value Analysis for We Energies (2009)

Clean Power Research®

PV Simulations

- Simulations for any defined systems in company
- Uses SolarAnywhere
- Historical, real time or forecast
- Downloadable results in CSV format



Clean Power Research®

Loss Savings

- Distributed resources reduce system losses by producing power in the same location where it is used
- Loss savings increase the value of other benefits across generation, transmission, and distribution systems
- Correct loss savings depend upon the benefit category
- Loss savings are calculated on the margin

Clean Power Research®

Energy Value

- Definition
  - Benefit from distributed PV generation's offset of wholesale energy purchases
- Methodology
  - Energy value equals PV output plus loss savings times marginal energy cost
  - Marginal energy costs are based on fuel and O&M costs of generator operating on the margin (CCGT)

Clean Power Research®

Generation Capacity Value

- Definition
  - Benefit from added capacity provided to the generation system by distributed PV

- Methodology
  - Generation capacity value equals generation capacity cost times PV's effective load carrying capability (ELCC), taking into account loss savings
  - Generation capacity cost is based on capital cost of CCGT

Clean Power Research®

Fuel Price Hedge Value

- Definition
  - Benefit that distributed PV generation has no fuel price uncertainty
- Methodology
  - Fuel price hedge value is calculated by determining how much it would cost to eliminate the fuel price uncertainty associated with natural gas generation

Clean Power Research®

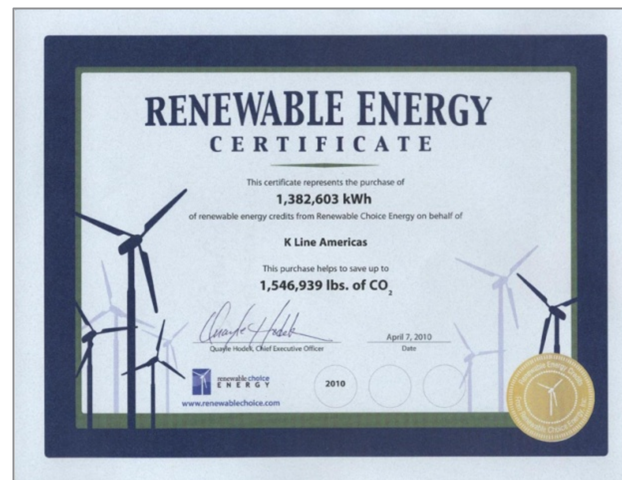
T&D Capacity Value

- Definition
  - Benefit that distributed PV generation provides in reducing the burden on the T&D system and thus delaying the need for capital investments in the T&D system
- Methodology
  - T&D capacity value equals the expected long-term T&D system capacity upgrade cost, divided by load growth, times financial term, times a factor that represents match between PV system output (adjusted for losses) and T&D system load

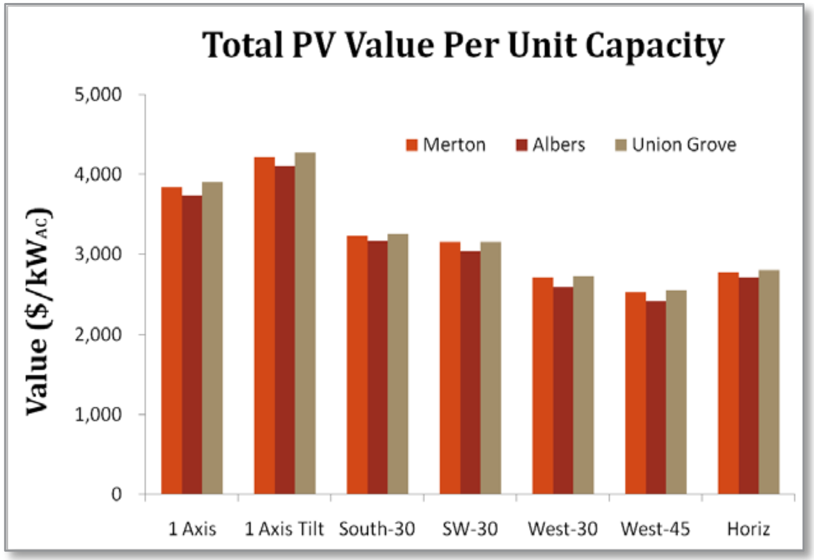
Clean Power Research®

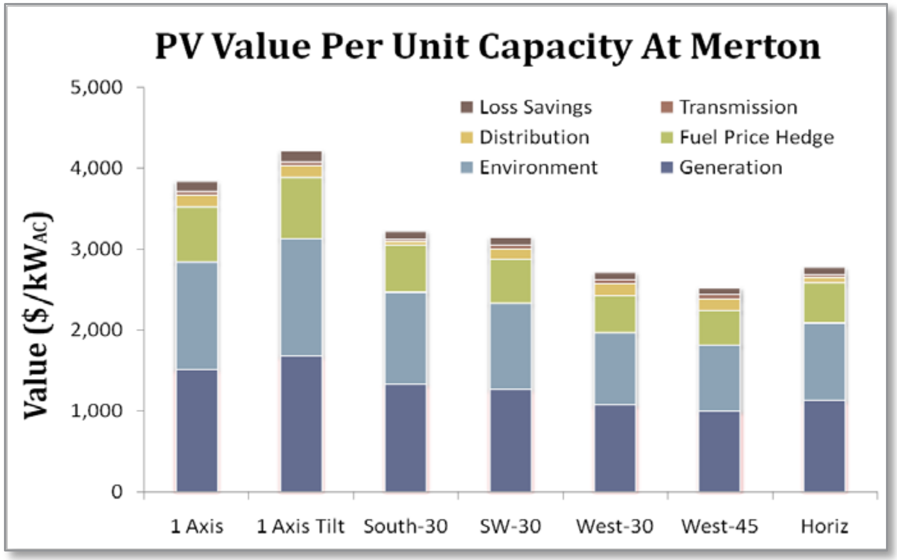
Environmental Value

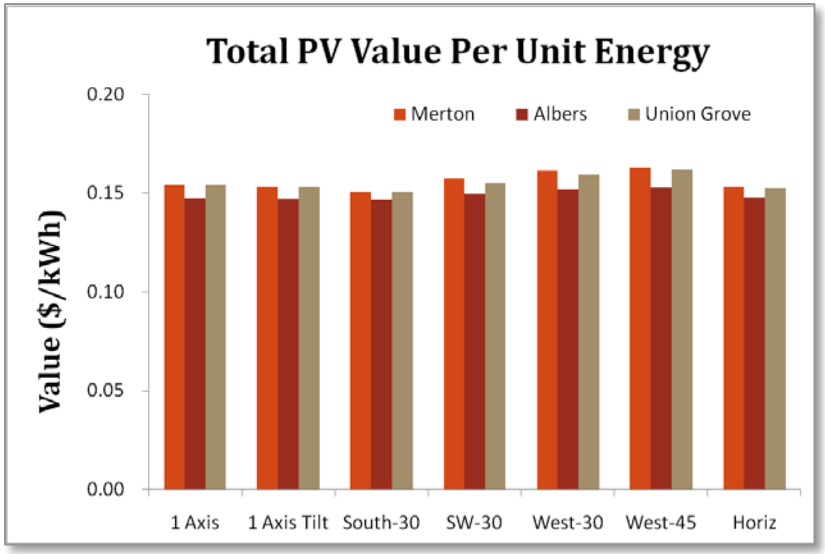
- Definition
    - Benefit that the environmental footprint of PV is considerably smaller than that of fossil-based generation
- Methodology
    - Environmental value equals PV output times REC price



Graphing Results (in Excel)







On-line Tutorial

YouTube

www.youtube.com/watch?v=3lKi0UjD008

Summary of Work Completed

- Enhanced spatial and temporal resolution of SolarAnywhere® for ***the entire state*** of CA
- Developed, validated, and patented approach to simulate ***both output variability and output***
- Developed web services to integrate PV modeling capabilities into distribution system tools
- Created ***full web-based*** tool to calculate economic value of a specific PV fleet configuration

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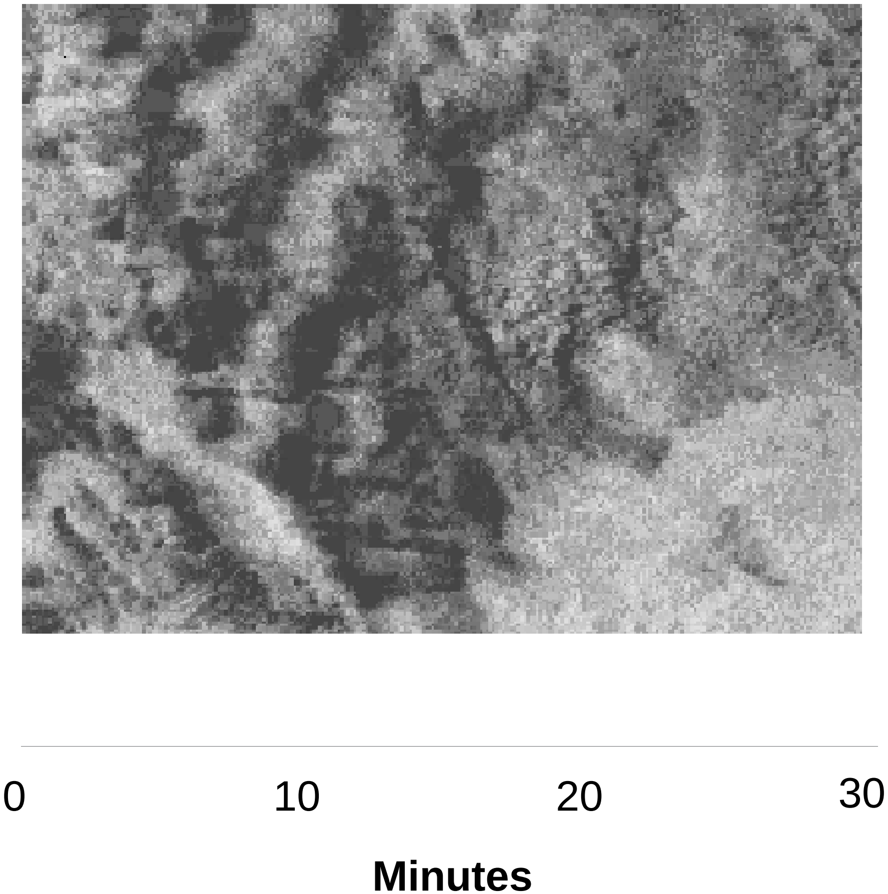
Sneak Previews

Cool Stuff Under Development

Creating 1-Minute Data Sets Using Cloud Motion Vector Approach



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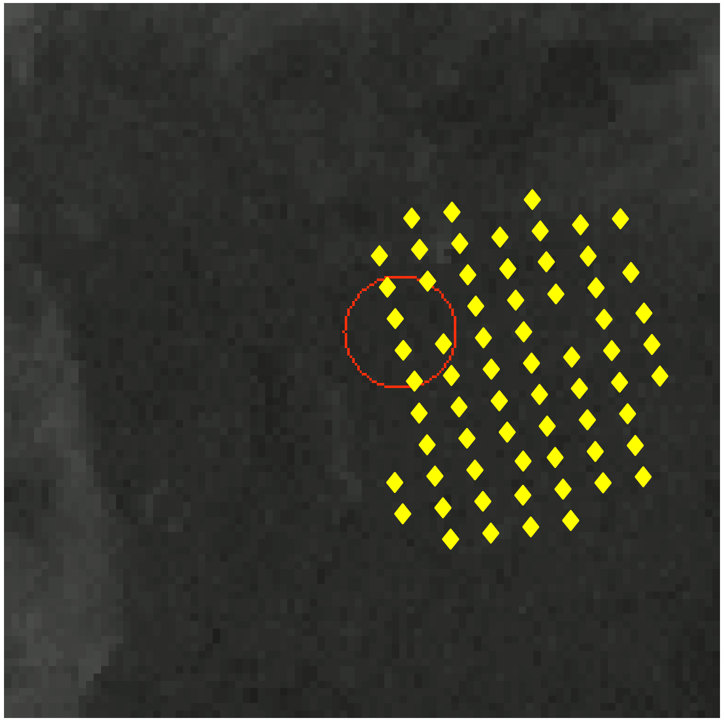
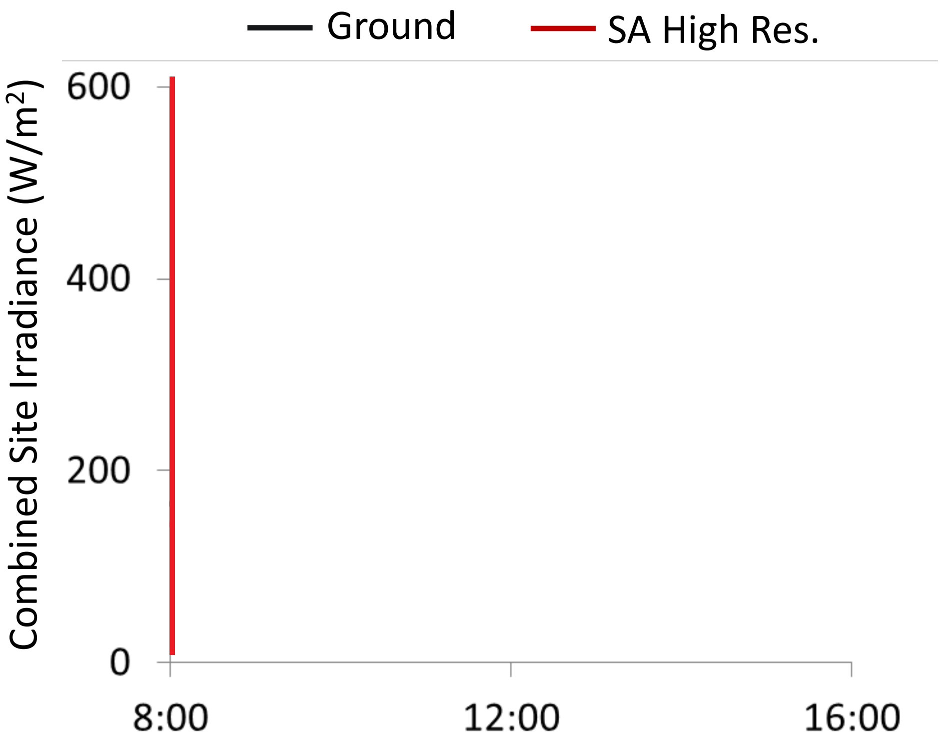
Measured Data From SMUD's 66 Sensor Network vs. Simulated Data on Highly Variable Day

Nov. 18, 2011





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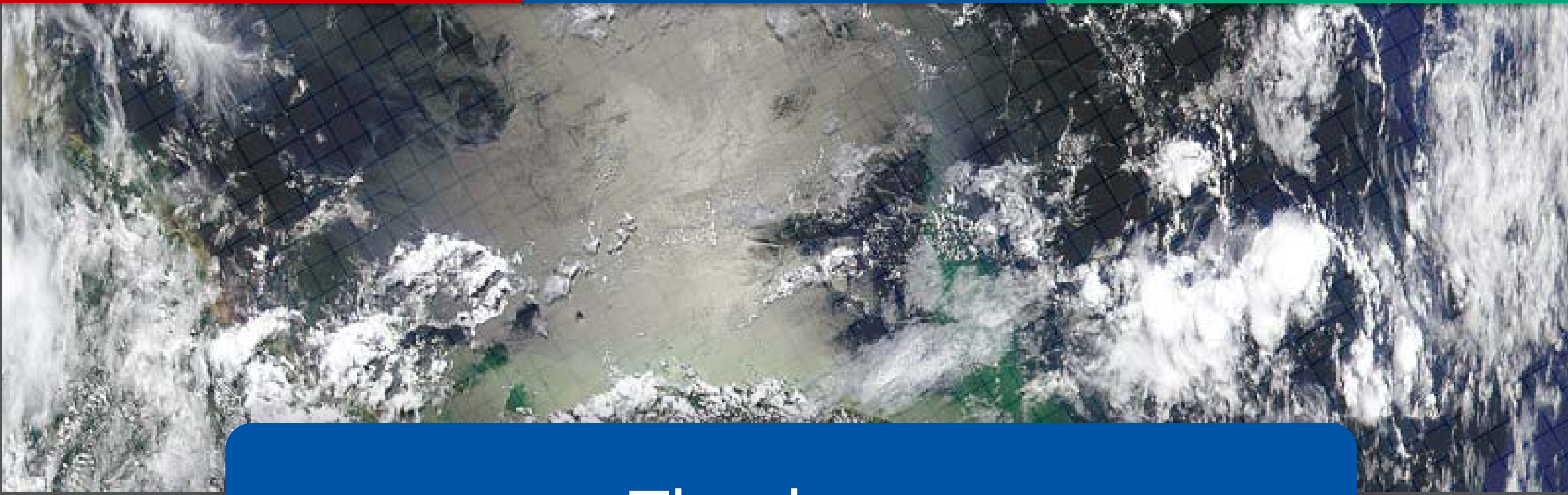

Thank you

Questions?
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