High Penetration PV Initiative

Elaine Sison-Lebrilla, P.E.

Webinar

June 5, 2013

Powering forward. Together.

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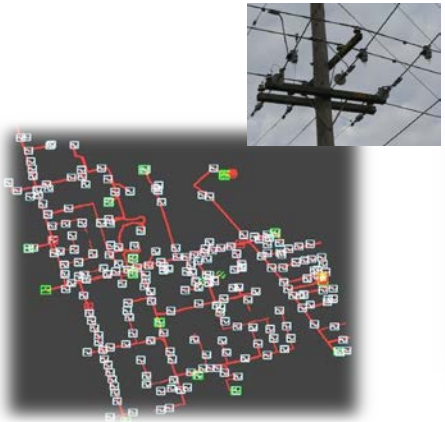

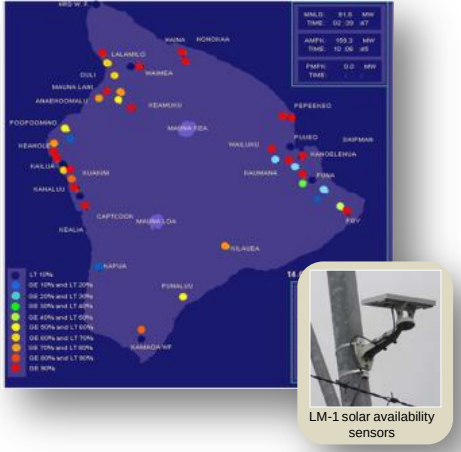

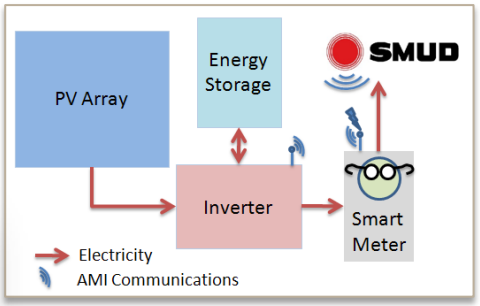

High Penetration PV Initiative

Objective: Development and testing of hardware and software to evaluate the impact of high penetrations of PV systems on our grid.

Team: SMUD, HECO, DNV KEMA (BEW Engineering), EPRI and NEO Virtus Engineering

Project activities: Feeder and system modeling, baselining, field monitoring and analysis are conducted on identified case studies that include sites and feeders within SMUD territory and Hawaii. Visualization tools are being developed. Irradiance monitoring sensors are deployed. Solar resource data is being collected and forecasting activities conducted. Demonstrate inverter monitoring via AMI communication from smart meter to inverter.

Motivation - Timeliness of Partnership

- Exponential growth in levels of distributed generation “behind-the-meter” generation (variable & baseload)
- Levels of penetration exceeding “rules-of-thumb” and standards used in traditional utility practices for planning & operations
- Industry lacks capability (tools/data) to effectively plan and account for PV impacts on the grid (especially at the distribution and DG level)
- Limited commercial solar forecasting capabilities, experience and integration at utilities
- Lack industry guidance (standards/best practices) for monitoring equipment, measurement parameters, modeling and data resolutions for planning & operational timelines

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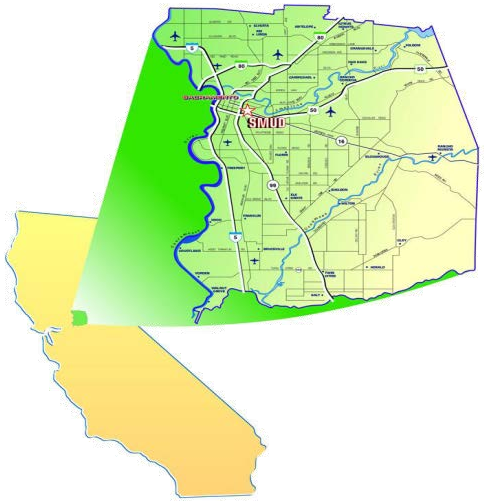
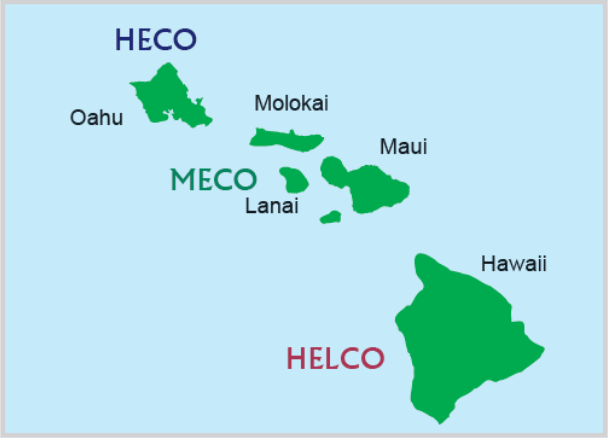


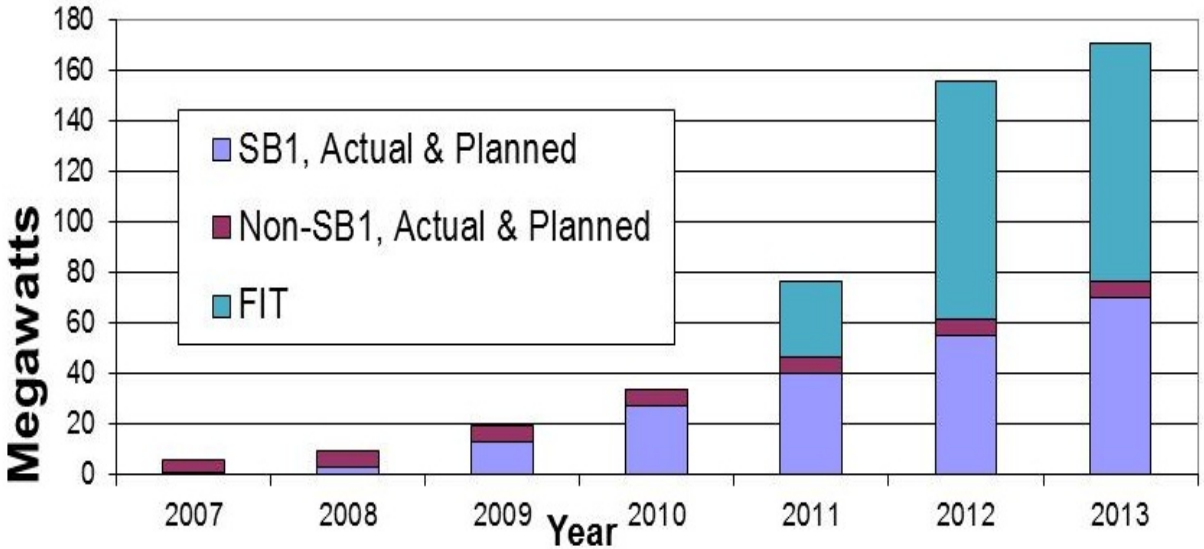
- Publicly Owned (Sixth Largest in U.S.)
- Service area of 900 square miles, serving 1.4 Million (Sacramento County and parts of Placer)
- Nearly 600,000 Residential, Commercial and Industrial customers

HECO

- Regulated utility, providing energy for the islands for over 100 years
- Hawaiian Electric Utilities (HECO/MECO/HELCO) serve 95% of the state's 1.2 million residents on the islands of Oahu, Maui, Lanai, Molokai and the Big Island Hawaii.

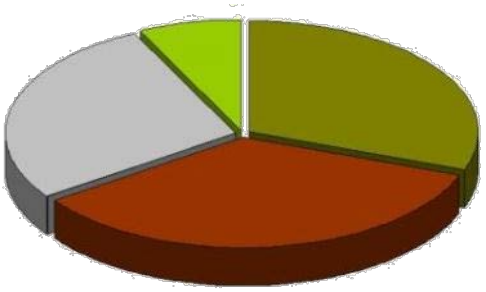


Solar Energy Growth at SMUD

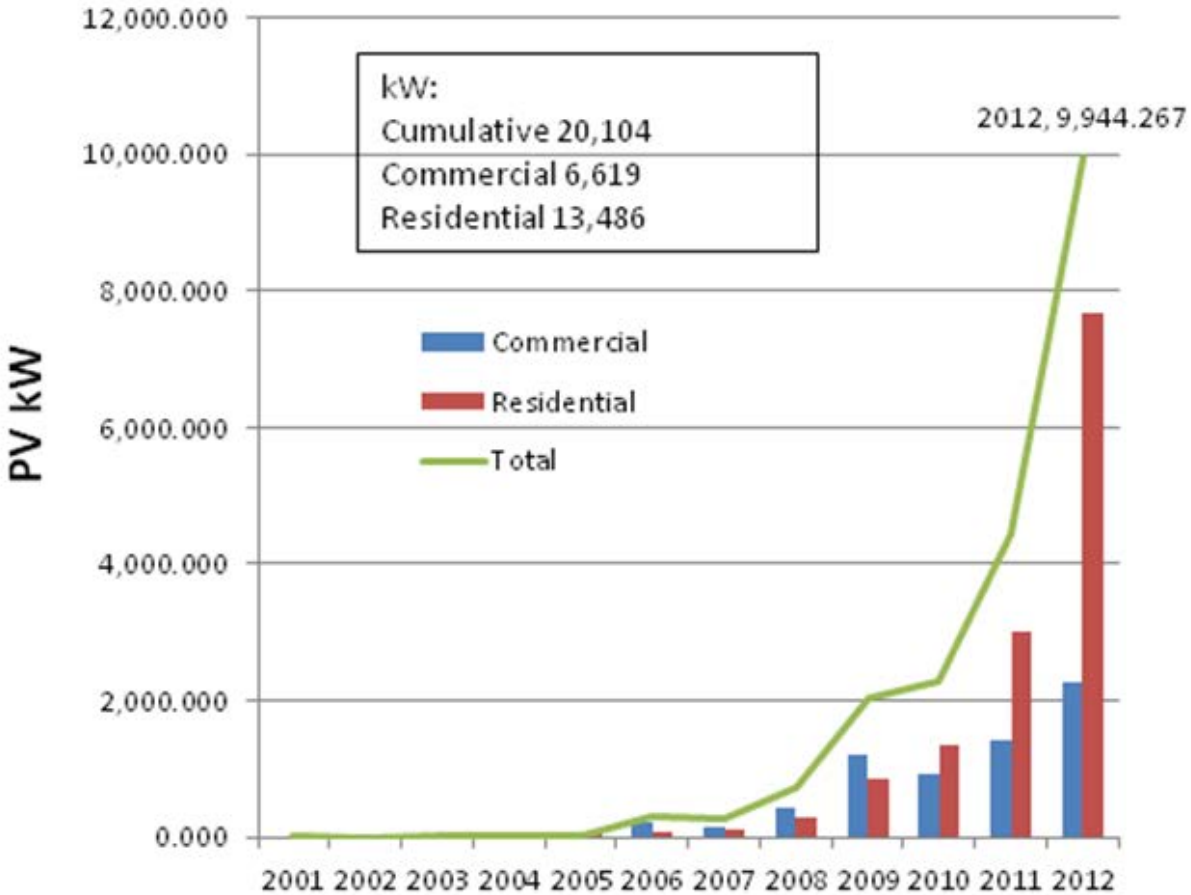


- Rooftop solar projects
- FIT projects
- Aggressive CA RPS – 33% Renewables by 2020

DG Growth in Hawaii



JET FUEL	34%
ELECTRICITY	32%
GASOLINE/ MARINE FUEL	27%
OTHER	7%



Growth of distributed PV at HELCO, 2001-2012.

- RPS – 40% renewables from electricity, 70% total (includes transportation) by 2030
- Energy efficiency standard of 30% by 2030 (3,400 GWh)
- HECO – 17%, HELCO – 42%, MECO – 26%

High Penetration PV Initiative Team

Team	Primary Staff
SMUD	Elaine Sison-Lebrilla, David Brown, Obadiah Bartholomy and TJ Vargas
Hawaiian Electric Company	Tom Aukai, Dora Nakafuji (HECO) Laura Rogers, Hal Kamigaki (HELCO) Chris Reynolds (MECO)
KEMA DNV	Ron Davis, Slavko Vasilic, Billy Quach
NEO Virtus Engineering, Inc.	James Bing, Walter Thomas
EPRI ELECTRIC POWER RESEARCH INSTITUTE	Brian Seal, Gary Aumagher, Ben Dupont

SMUD/HECO High Penetration PV Initiative (HiP-PV)

Goal:

Enable appropriate capability to reliably plan and operate with high penetration of variable renewable resources on the grid especially during high impact conditions (e.g. variable weather, peak loads, minimum loads, contingencies)

Objectives:

- Inform and pilot the development of visual tracking, field measurement and validated analytical (modeling) capability including hardware and software integration needs to evaluate the impact of high penetrations of PV systems on our grids
- Collaborate with other utilities, validate and transfer lessons learned

Workscope

Task 1: Project Management

Task 2: Baseline DG Modeling of SMUD and HECO Systems

Task 3: Field Monitoring and Analysis

Task 3.3: Inverter Communication

Task 4: Visualization Effort

Task 5: Solar Resource Forecasting

EPRI ELECTRIC POWER RESEARCH INSTITUTE

NEO Virtus Engineering, Inc.

Hawaiian Electric Company
Maui Electric Company
Hawaii Electric Light Company

KEMA DNV

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Task 2: Baseline DG Modeling of SMUD and HECO Systems

Ronald Davis, DNV KEMA

SMUD/HECO HiP-PV Initiative Analysis Goals & Tasks

OVERALL STUDY GOALS

- Improve observability and visibility of operations and planning, to impacts of HiP-PV on the distribution feeders
  - Conclude on level of measured data required in the future to improve visibility for operations and planning
- Determine validity of common analysis filters
- Quantify impact on select feeders to demonstrate new modeling and analysis techniques
- Inform how future studies and interconnect processes can be expedited
- Changing perception of how to deal with high renewable penetrations (solutions to address problems)
- Technology transfer/outreach and publication
- Apply results and support strategic studies
  - Example: GE Hawaii Solar Integration work (HSIS)

TASKS

1. Feeder Selection

2. Data Collection and Review

3. Definition of Analysis Points

4. Base Case Definition

5. Model Validation

6. Detailed Analysis

7. Conclude on HiP-PV Impacts feeder of interest

8. Conclude on administrative screens for Feeder Studies

9. Plan roadmap for future Feeder/Regional Analysis Goals based on Results

10. Reporting

CPUC CSI RDD #1 Objectives

- Identify high penetration analysis needs for each circuit
- Identify additional data parameters and placement of high-fidelity monitoring equipment
- Record and collect a minimum of 6 to 12 months of load data and solar data
- Collect electrical equipment nameplate data for the distribution feeder: DG, inverters, circuit data (conductor size, length, loading), switchgear, transformers, fuses, etc.
- Investigate varying incremental levels of PV penetration
- Develop a methodology for extending the findings using simulation tools to inform and expedite interconnection studies at higher penetrations

Develop a methodology for using simulation tools to inform and expedite interconnection studies at higher penetrations

Modeling and Field Verification for Analysis of Results

Monitoring

- Identification of high penetration feeder circuits
- Evaluation of load characteristics over a period of time capturing high and low load conditions

Modeling

- Characterize circuit based on loading profile and generalize for modeling purposes
- Convert GIS database to SynerGEE format
- Identify corrections and where to correct (DNV KEMA/utility)

Validation

- Gather Field data and verify model and analysis output

Integration

- Feed distribution impacts into system level models
- Continue monitoring and model validation as part of planning process
- Develop visualization tool and decision aids for operations & planning

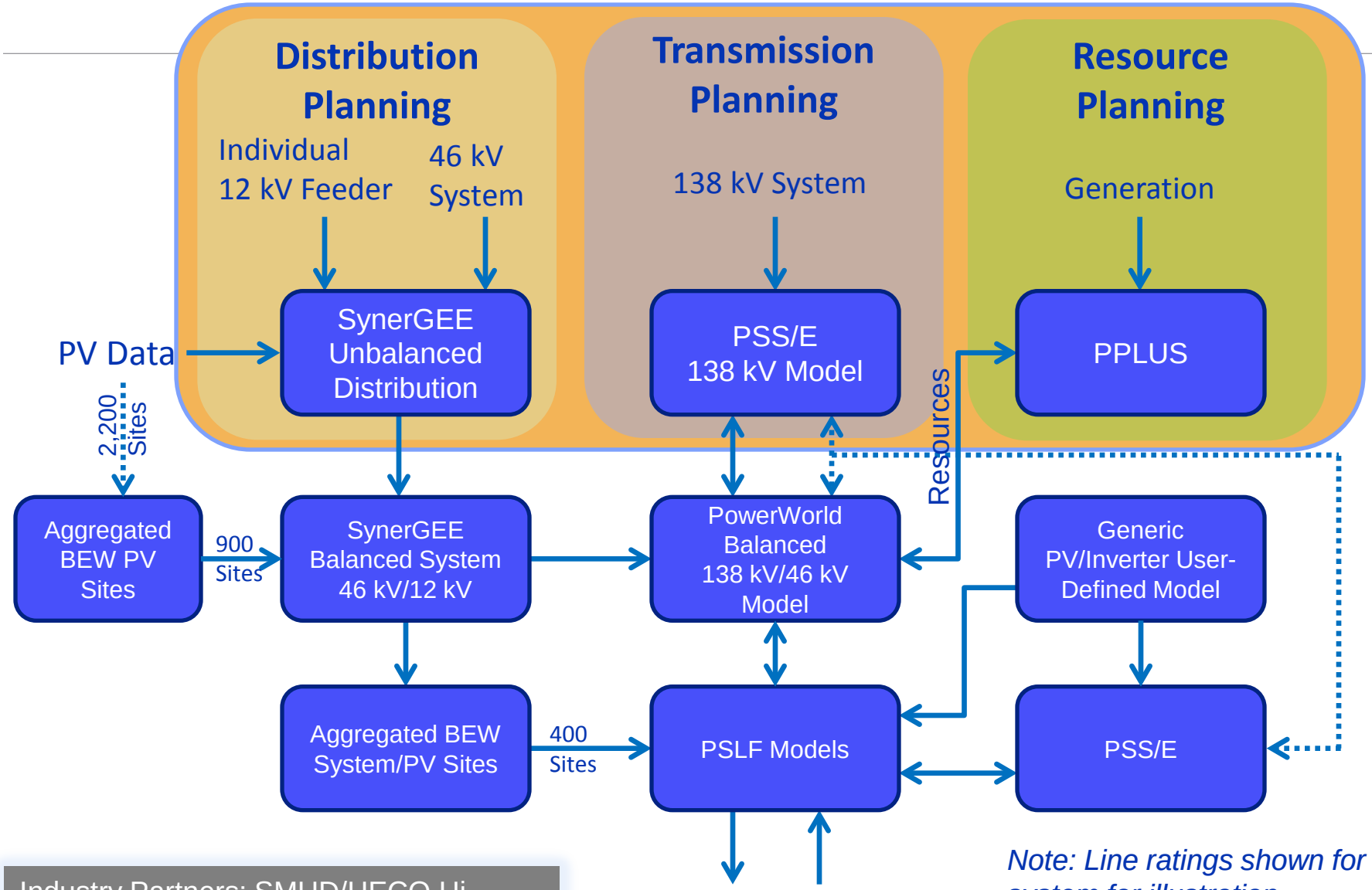
PV Penetration Analysis Steps

- Extract (GIS) or build (when GIS not available) SynerGEE model
- Collect and apply detailed equipment information
  - Transformers, switches, fuses distributed loading, capacitors, inverters, PV panels etc.
- Collect PV data for area of interest if available
- Analyze PV performance
  - Associated weather data
- Collect full system sub-transmission/transmission model, and dynamic data
- Model inverters
  - Future detailed SynerGEE model, or
  - Existing equivalent impedance model, and
- PSLF dynamic inverter model

PV Step Analysis Cont'd

- Perform base case load flow analysis with and without existing PV
  - Single point in time, minimum load day, and maximum load day
  - Perform basic fault current analysis with/without existing PV
- Repeat load flow and fault current analysis for potential and predicted PV cases
- Verify feeder performance with measured data (load flows, voltage levels etc.)
- Repeat analysis after verification of data
- Conversion of data for transient analysis
- Conduct advanced post-validation studies including:
  - Protection coordination
  - Harmonic and Flicker studies
  - Islanding study (voltage and frequency limits)
  - Transient study

Graphical Flow of Handshaking Between Models

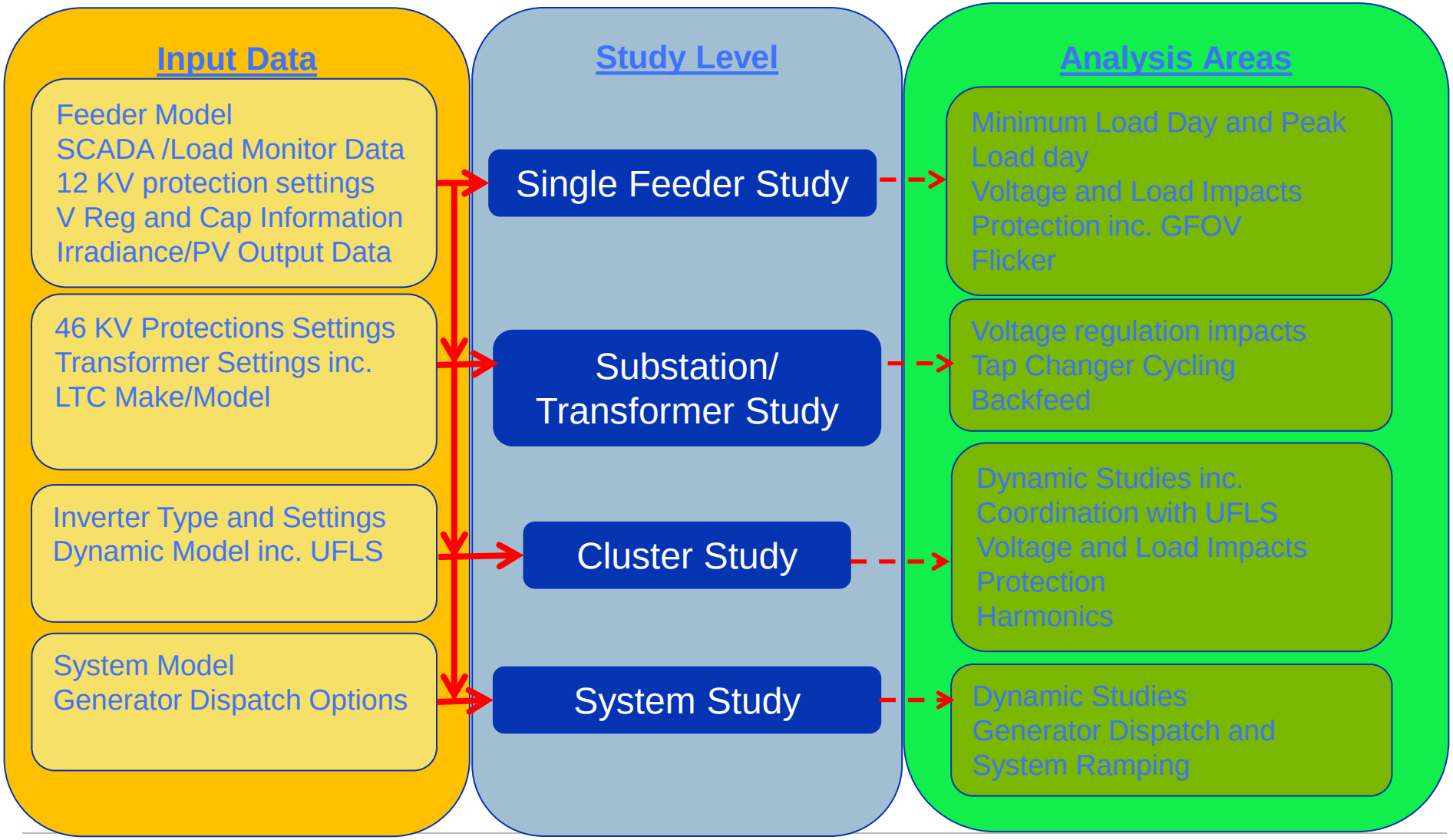


Note: Line ratings shown for Oahu system for illustration

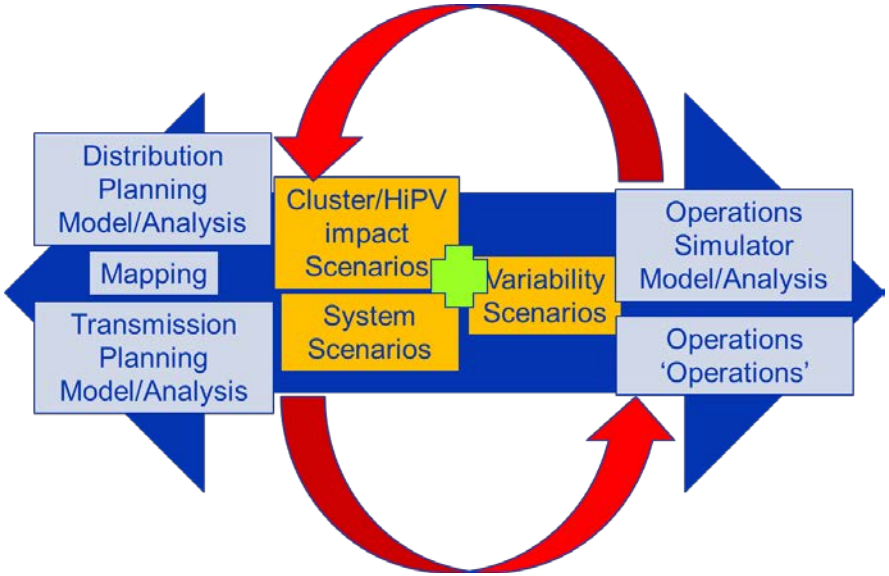
Industry Partners: SMUD/HECO Hi-Penetration Initiative, DNV KEMA, GL Noble Denton, GIS & EMS providers

How impacts are quantified for selected feeders?

Interaction of Analysis Types and Data Input



Flow of Information to other Utility groups



- Interconnection teams will have the technical evidence to start investigating process changed to the existing interconnect
  - Will know what needs to be used for a simple single site interconnect in future versus a cluster or large group of PV level impact
- Distribution Planning and Renewables Integration
- In Future operations and transmission planning can feed the results into their models

Enhancements to Typical Interconnect Process

- Colored boxed show what analysis is important for this feeder/cluster/area
  - Red indicates most important, yellow least
- **<u>Greyed out box indicated has not yet been analyzed for Mikilua cluster, but was for Waiawa</u>**

Analysis Type	Typical Detail Level	Enhancement	
STEADY STATE STUDIES			Importance Color Code
Load Flow - Back-feed potential	Peak Load Conditions Comment on equipment setting (LTC and LDC)	Minimum Daytime Load Investigate equipment settings and impact of changing Irradiance data for capacity vs. generated power	
Tap Changer Cycling	Step Maximum output to Minimum Output at Peak Load, 1% limit in voltage change specified to impact LTC	Time sequential analysis with measured irradiance data over seconds and time delay of LTC Peak and Minimum daytime load conditions	
Protection/Short Circuit Study - Protection Coordination	Evaluation at POI for first screening (Rule 21/Rule 14H), if does not pass screen detailed study include evaluation of the entire feeder	Impact of varied location, impact of changing size of inverter	

Enhancements to Typical Interconnect Process: Steady State Studies

Analysis Type	Typical Detail Level	Enhancement	
STEADY STATE STUDIES			
Load Flow - Thermal Loading	Maximum Peak Demand conditions	Minimum Peak Daytime Demand	
Load Flow - Voltage Profile	Maximum Peak Demand Comment on equipment settings (LTC and LDC)	Minimum Peak Daytime Demand	
Load Flow - Losses	Maximum Peak Demand with and without project	Minimum Peak Daytime Demand With and without a range of projects	
Protection/Short Circuit Study - Interrupt Rating	Evaluation at POI for screening, detailed study include evaluation of the entire feeder	Impact of different locations, increasing PV size and spread	
Harmonics	Only considered if source is present or specifically requested by Utility	Range of inverter types/conditions	

Enhancements to Typical Interconnect Process

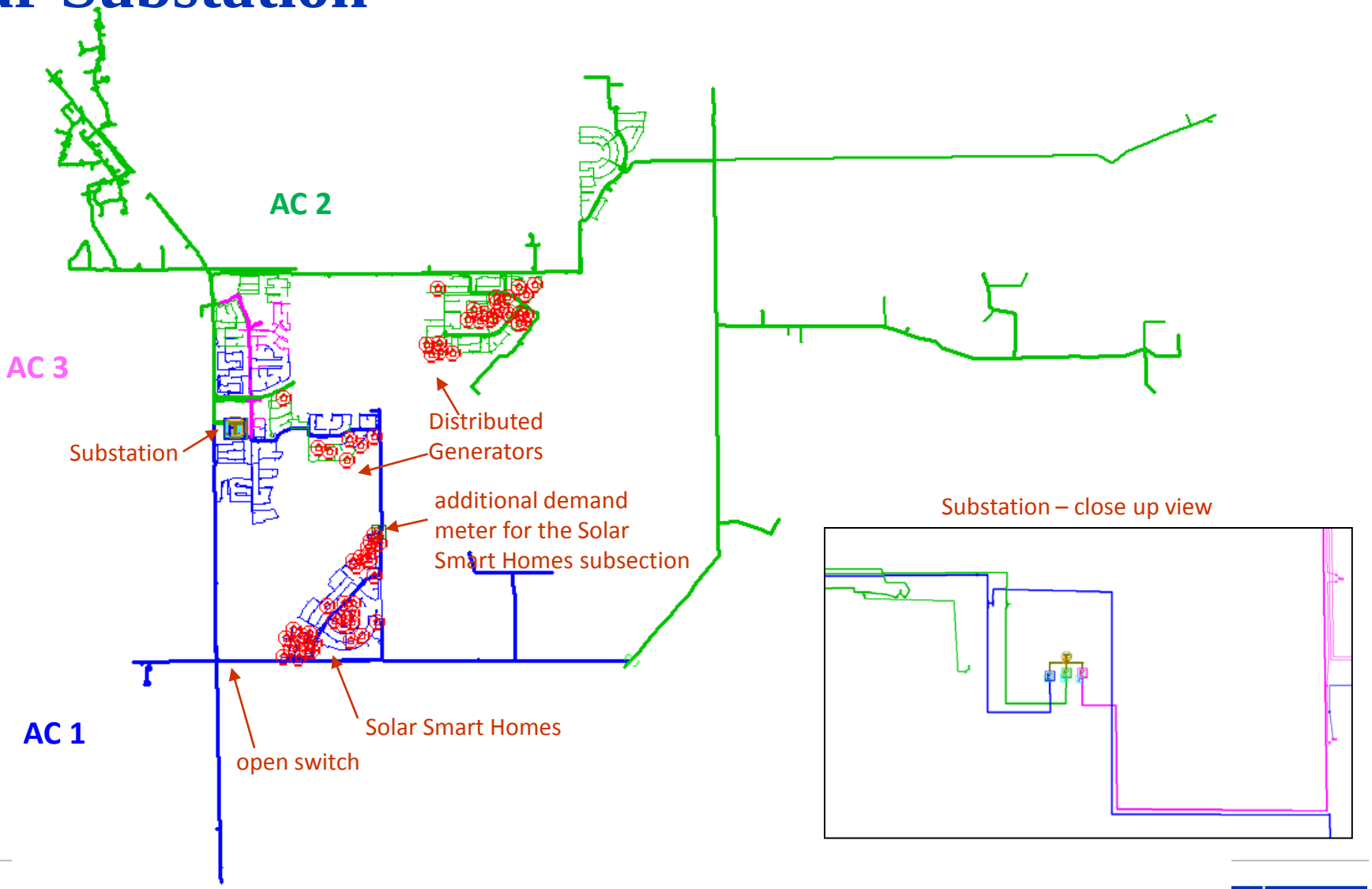
Analysis Type	Typical Detail Level	Enhancement	
DYNAMIC STUDIES			
Dynamic/Stability Studies - All PV trip	Not normally completed	Multiple sites/nodal/cluster studies, PV is dynamic Inverter	
Dynamic/Stability Studies - N-1	Not normally completed	Full dynamic analysis on range of site sizes and configurations	
Dynamic/Stability Studies - Flicker	Instantaneous step change in output compared to IEEE 519 standards	1 second steps time sequential study with high fidelity irradiance data input	

Analysis Type	Typical Detail Level	Enhancement	
ADDITIONAL STUDIES			
UFLS Inverter Coordination (Dynamic)	Reviewed but not simulated	Multiple sites/nodal/cluster studies, PV is dynamic Inverter	
Ground Fault Overvoltage (Protection)	Reviewed but not simulated	Full analysis on range of site sizes and configurations	

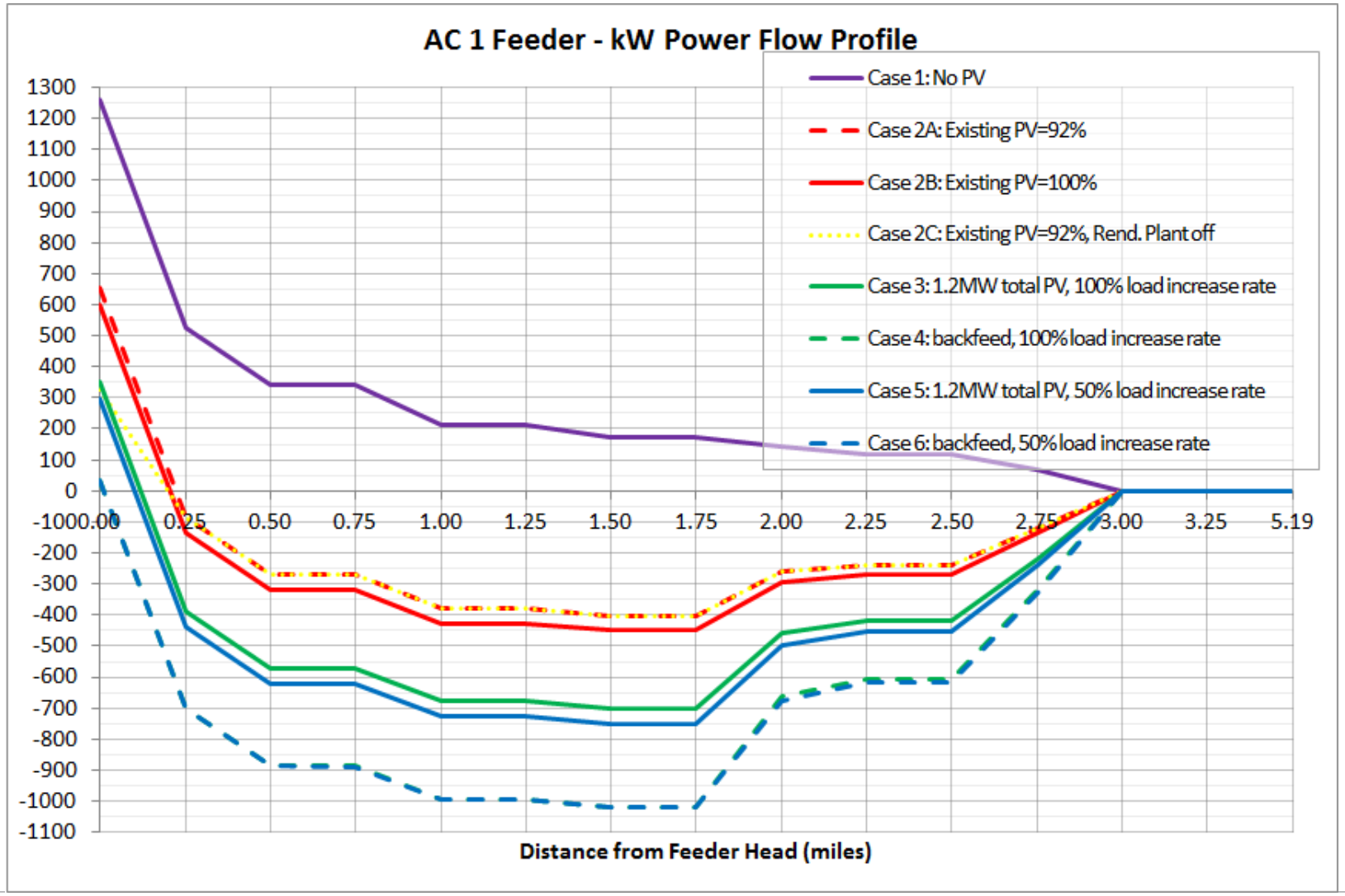
SMUD and HECO Selected Feeders

Feeder	Utility	Voltage (kV)	Feeder Type
AC – 3 Feeders	SMUD	12.47 kV	Residential
RF – 1 Feeder	SMUD	12.47	Commercial and Industrial
EB – 1 Feeder	SMUD	12.47	Rural
CT – 2 Feeders	SMUD	12.47	Residential & Rural
EG – 3 Lines	SMUD	69	Residential, Commercial & Rural
L7 – 1 Feeder	SMUD	69	Industrial
W1 – 4 Feeders	HECO	11.5	Residential & Commercial
ML – 4 Feeders	HELCO	4.16	Commercial
WA – 6 Feeders	MECO	13.09	Residential & Commercial

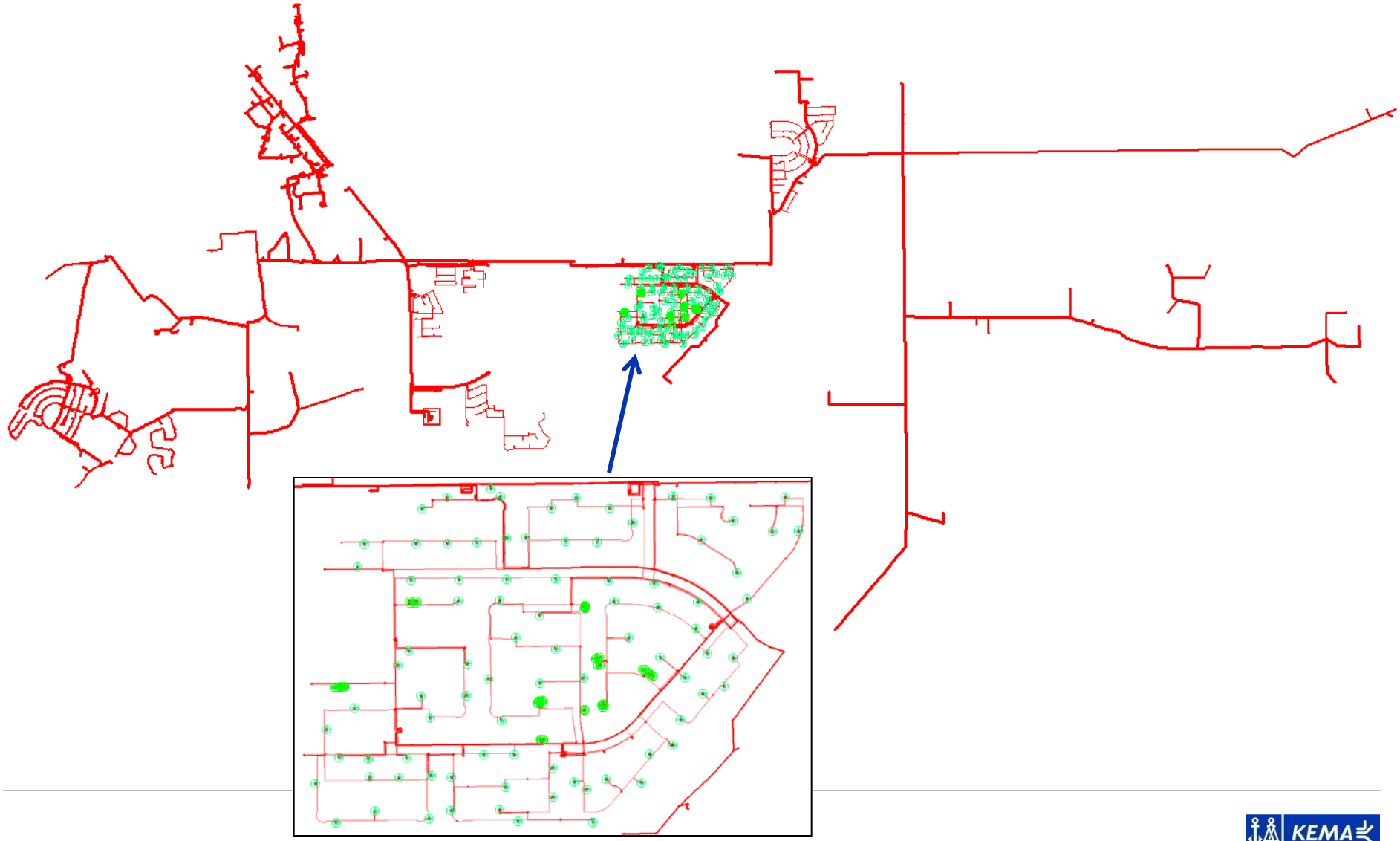
Case of PV impacts at end of Feeder and Load near Substation



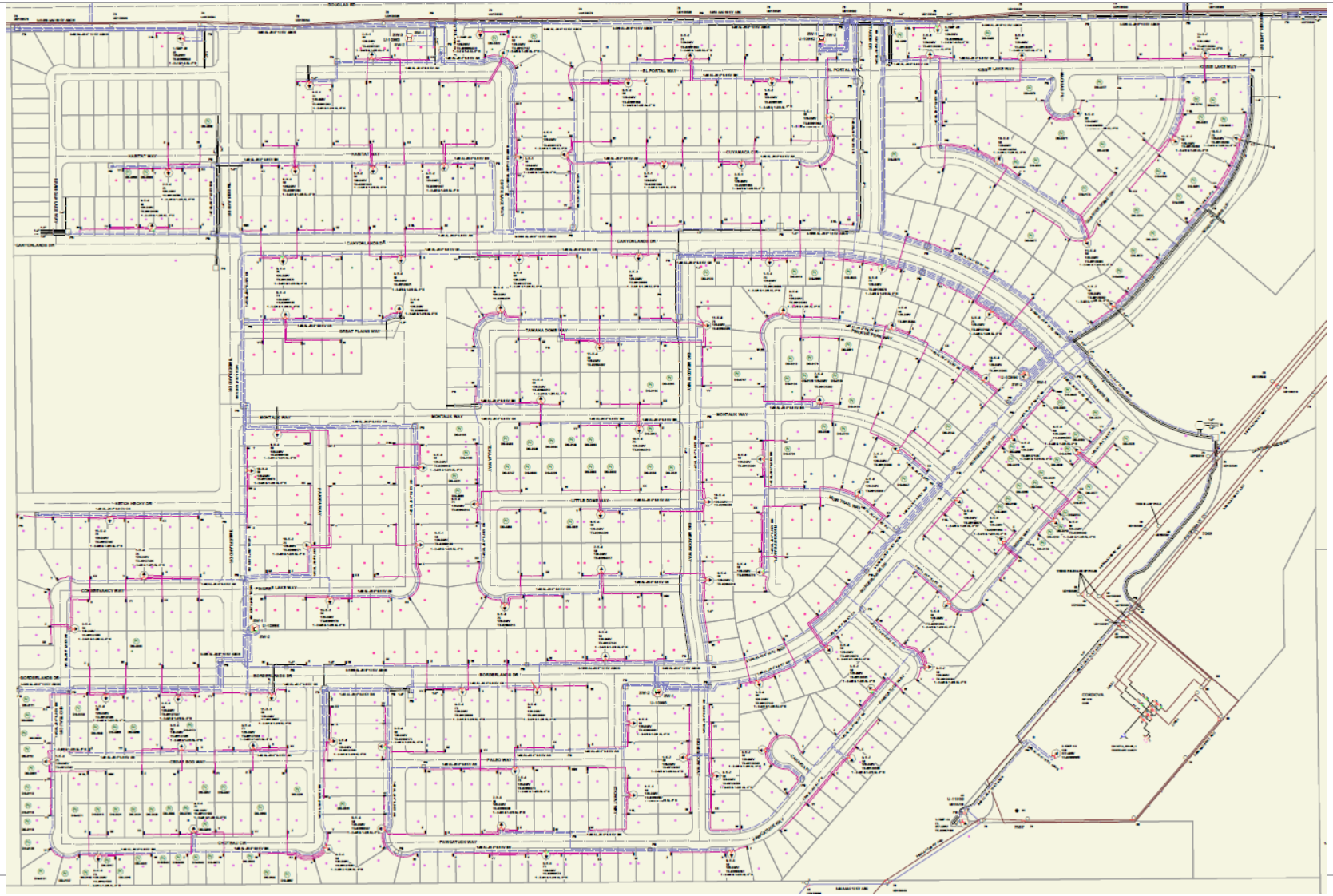
Load Flow Results – kW Profile for all Cases



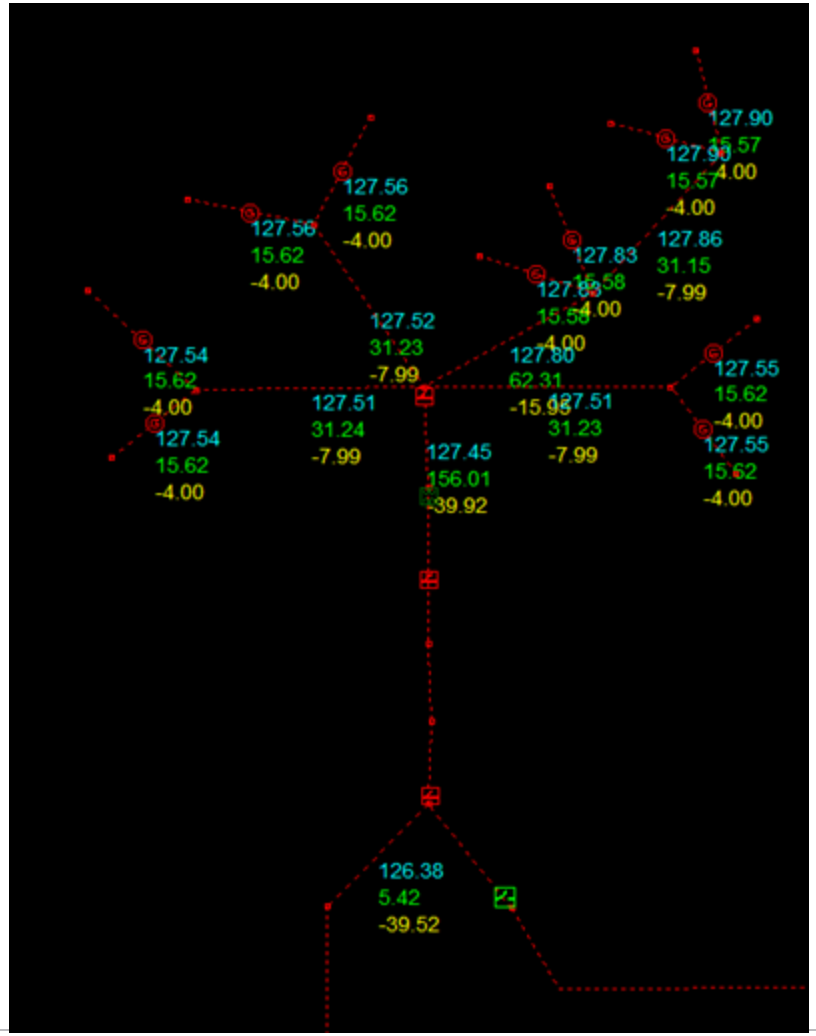
Case of PV Impacts at Residential Secondary Service Connections of 800 Home Substation

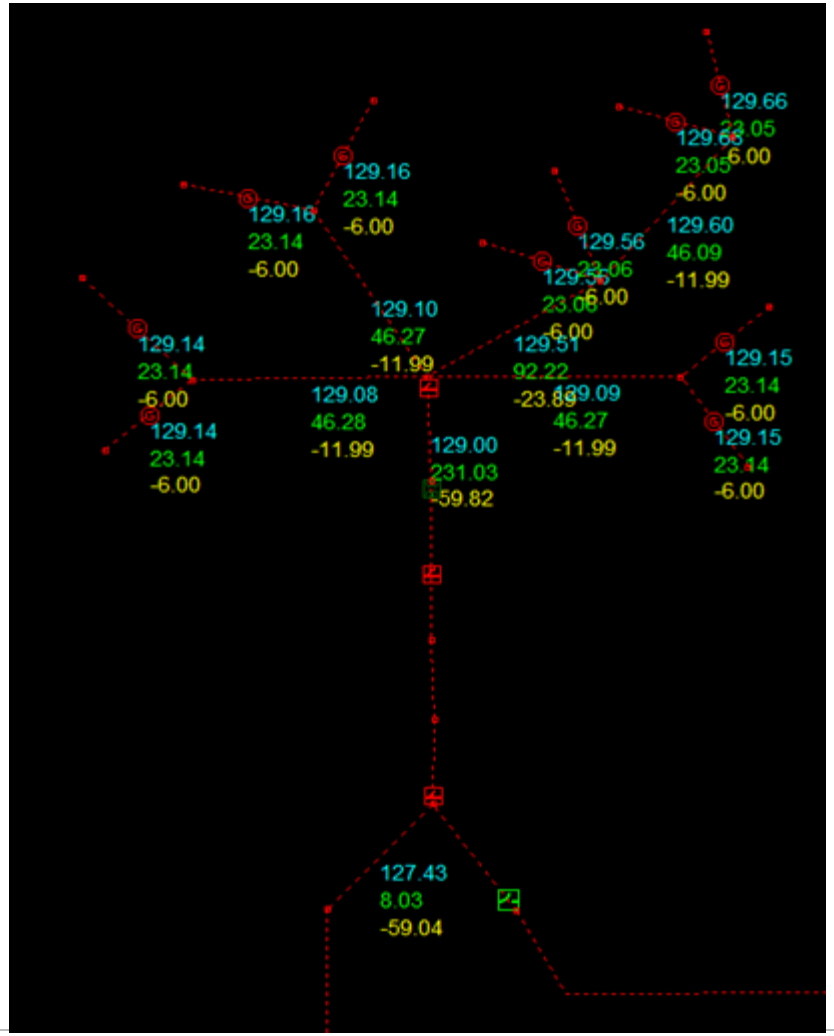


AC-C Area – Design Drawing

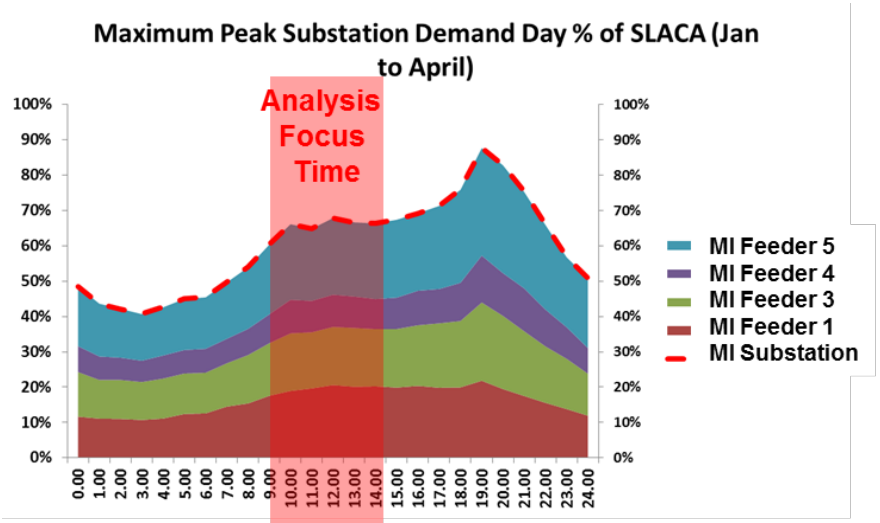


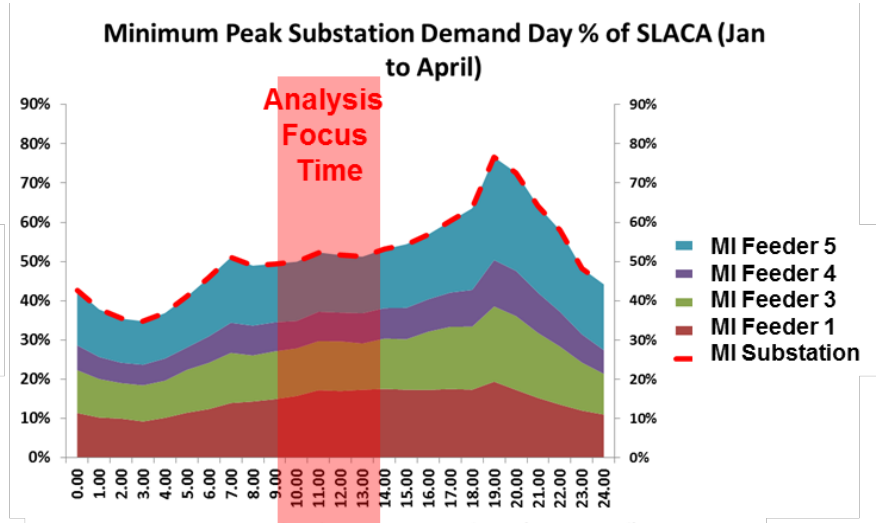
Potential Voltage Impacts of 4 & 6 kW Solar/House for a 800 Residential Community

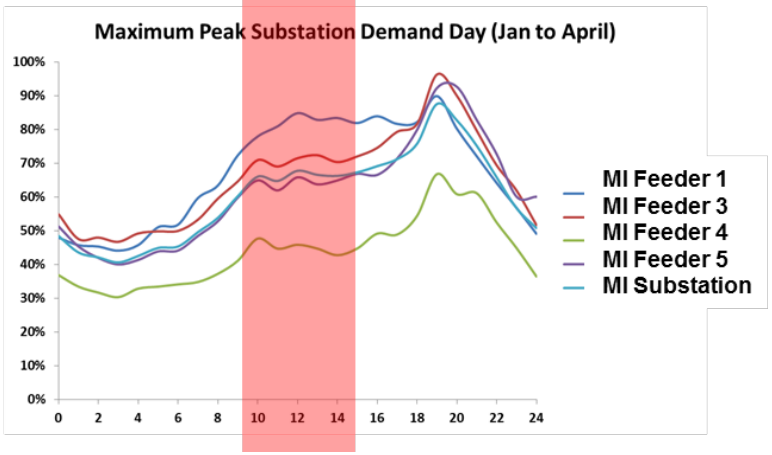


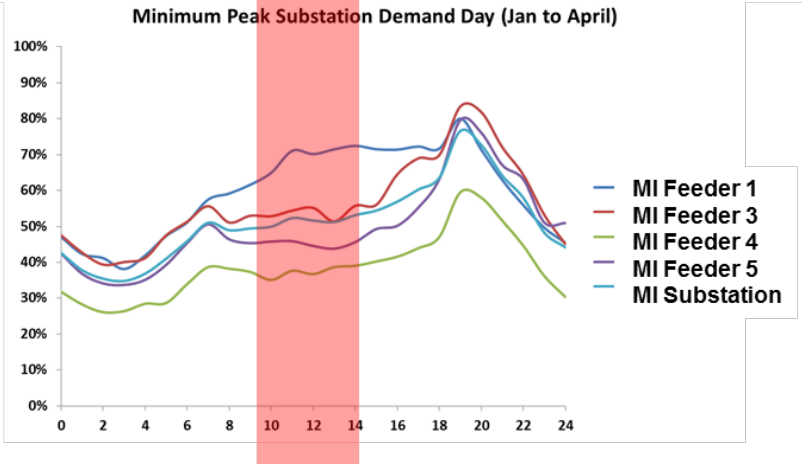


Example of Determining Time Period of Interest for PV

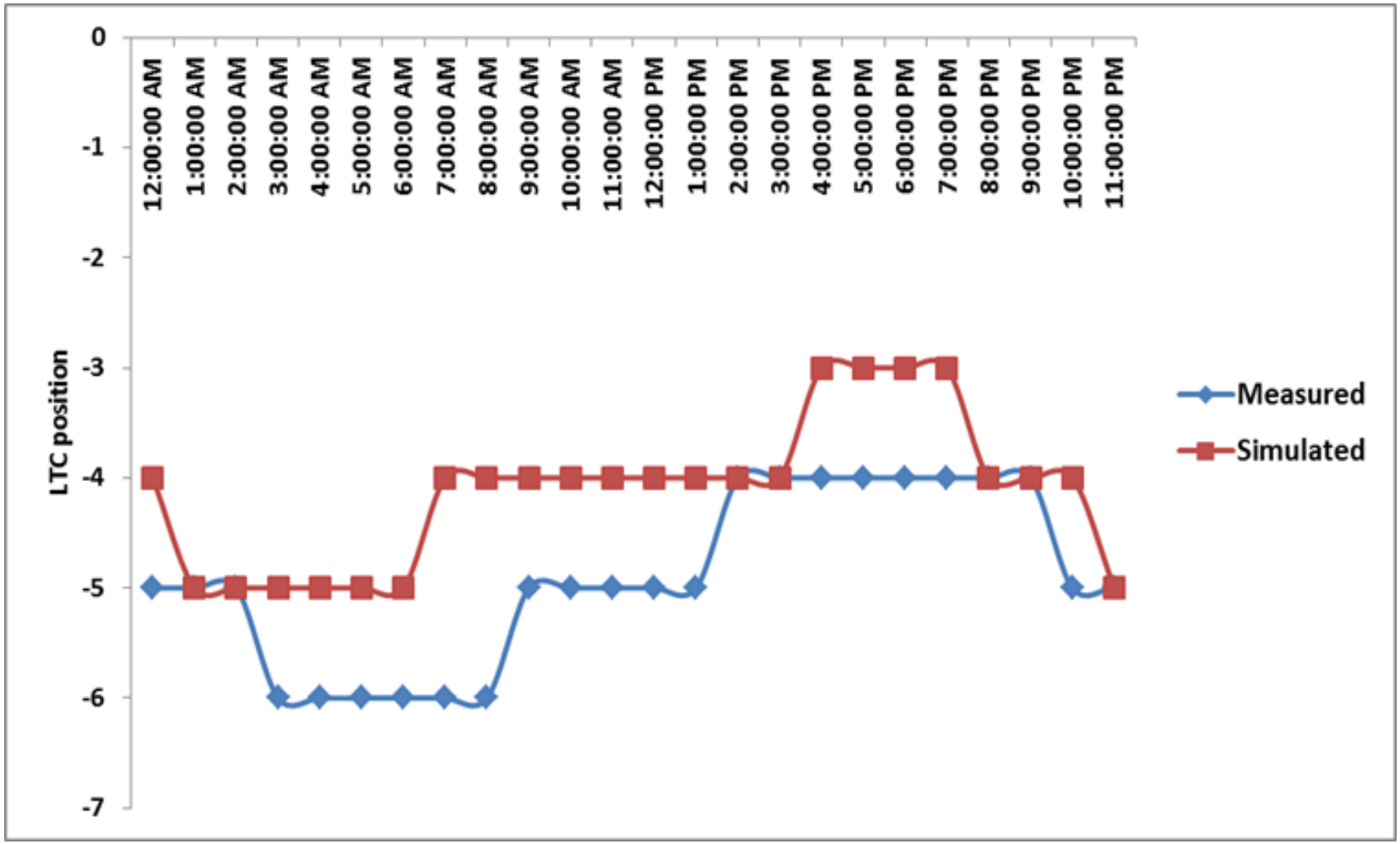




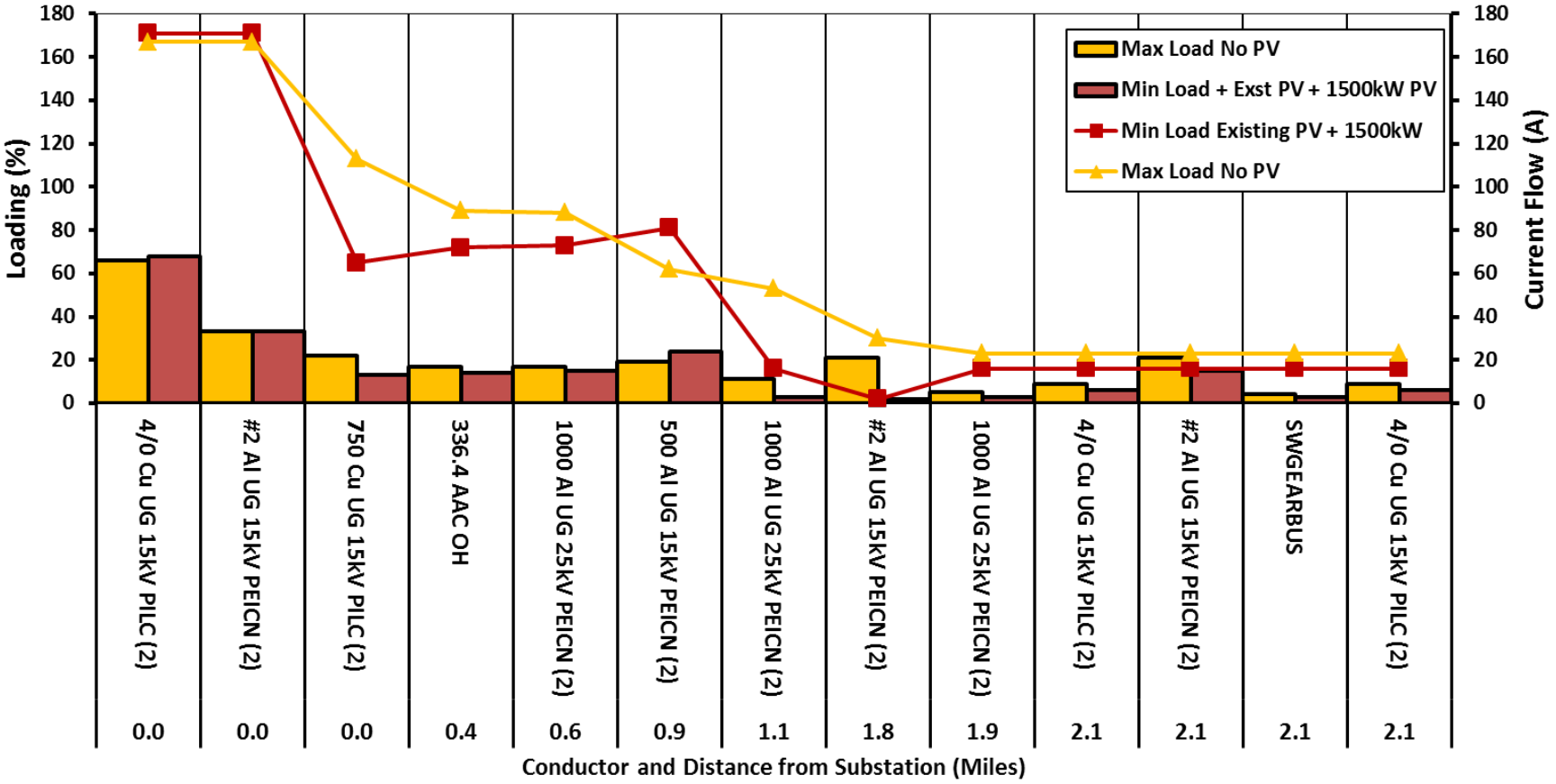




Validating Simulated LTC Operation to Actual



Example of Feeder Power Flow Results



Issues Discovered with Installing Data Recording Equipment

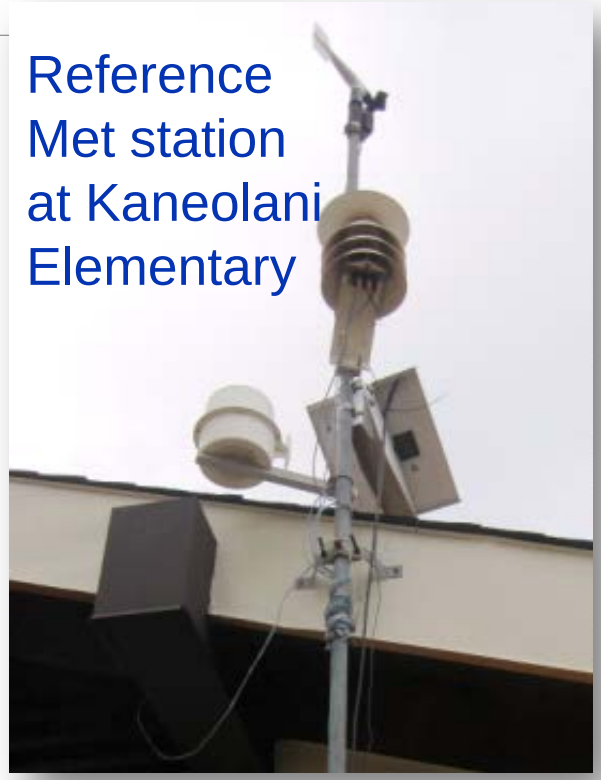
- Safety - Installations would not cause potential risk to injury
- Security – Equipment cannot be stolen easily
- Communication needs – Data transfer by cell phone, SCADA, fiber optics, etc.
- Equipment and budget availability – Type, cost, and utility available budget
- Data storage and management – Data can be one second or higher which creates large data files

Solar & Feeder Monitoring Instrumentation

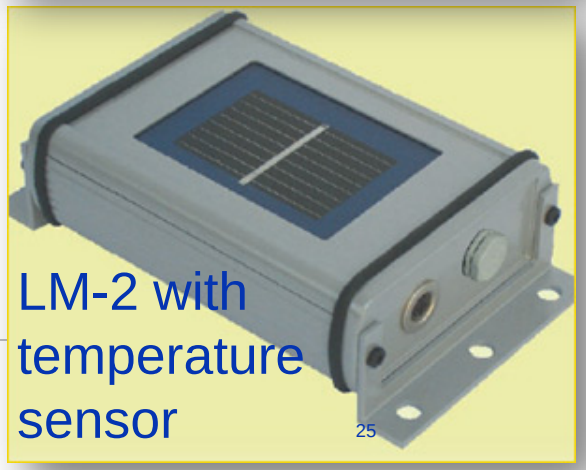
Feeder Monitoring

Reference Solar Irradiance at Waipio Substation

LM-1 at substation



Reference Met station at Kaneolani Elementary



LM-2 with temperature sensor

What was Learned from the Feeder Studies

- 15% of feeder peak was too low of a value for justifying detailed studies
- Unless the LTC was very old, there was not numerous tap changer operations
- High voltage was the most common violations
- Inverters did not significantly impact harmonics or fault current due to current inverter modules and data limitations
- The methodology developed could be easily applied to all feeders with equal ease of use and consistent results

Pre-Study Preparation

- Plan ahead on the number of power quality meters, solar irradiance sensors and customer solar meters
- Solve all safety and security issues ahead of time for installing meters
- Determine proper communication and data storage equipment
- Begin gathering data as soon as possible to reduce study delays and lost data

Preparation Cont'd

- Select distribution feeders of interest ahead of time
- Match load allocation across the distribution transformers so that loads and solar installations match
- Conduct a preliminary feeder simulation to determine voltage profiles and line loadings on the line segments to determine the best locations for meters and sensors
- Hold a series of meetings with planning, operations, renewable acquisition, load forecasting, finance, customer service and other departments to inform all parties to the objectives of the high solar penetration studies
- Hold periodic status meetings with department heads and utility officers on the project
- Review all data requirements and status of distribution models prior to starting

Conclusions

- Even though distribution planning and operations may state that they use the distribution simulation daily or often, the additional data requirements for modelling the injection of variable solar generators with inverters into the system is extensive and often missed
- Delays in installing monitoring and communication equipment impacted study time lines
- This project demonstrated:
  - Problems in creating detailed simulation datasets
  - Need for cross education and support of the project from multiple departments
  - Following the methodology enables the utility to study feeder impacts for high solar penetrations and determine internal mitigation measures
  - Accurate GIS data and mapping function critical for displaying results

HiP-PV Task 3.3 AMI Inverter Communications and Control

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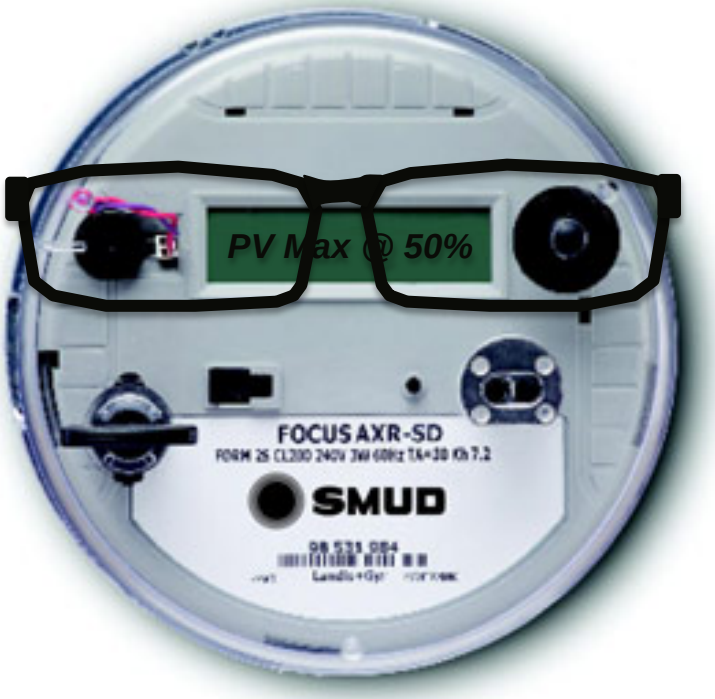
Outline

- Challenge facing California Utilities
- Research Objectives/Approach
- Scope of Work
- Results
- Team



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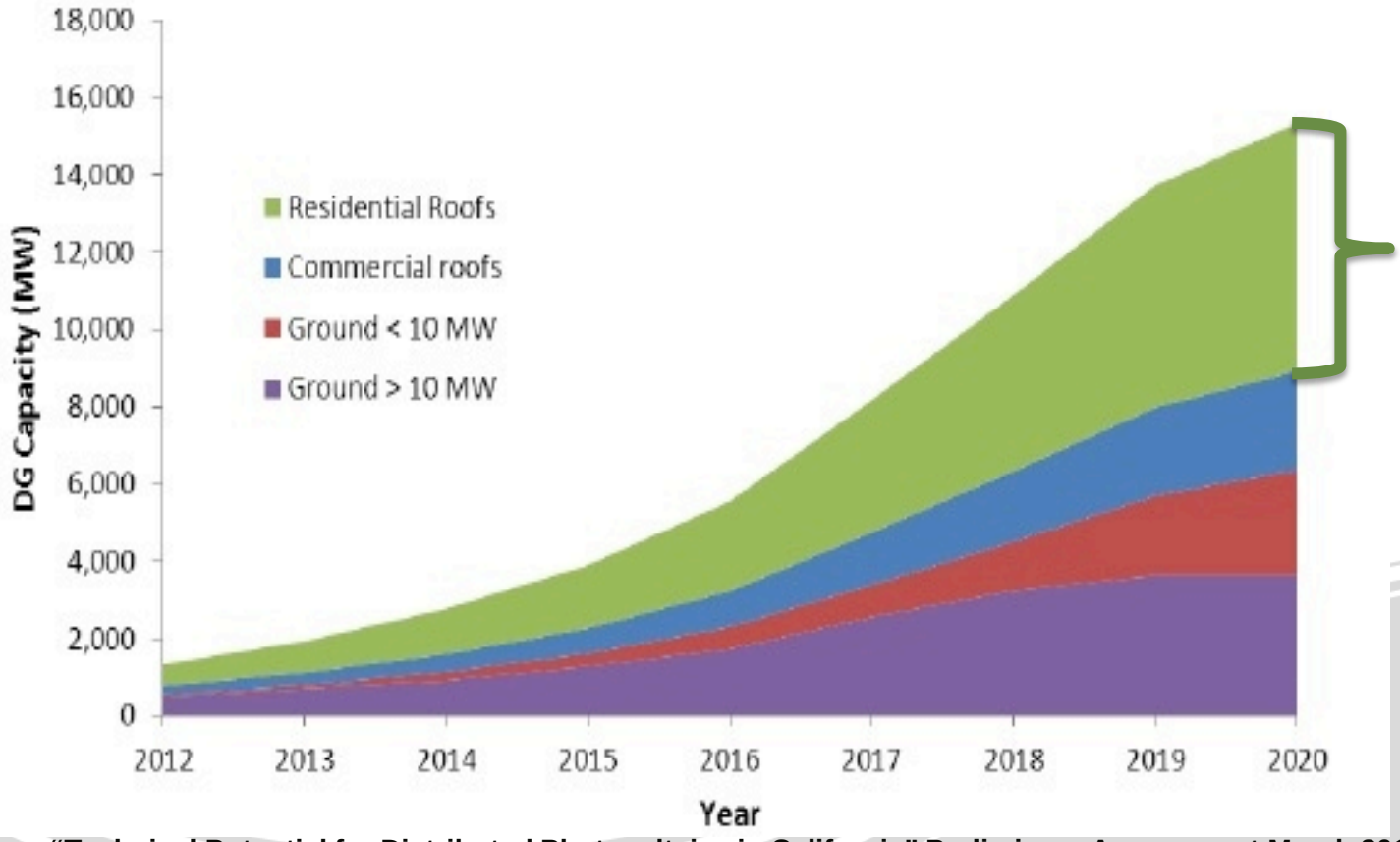
Challenge Facing California Utilities

Figure 1: Installed PV by Type Under the *Least Cost* Scenario, Maximum Without Curtailment



Potentially 6-7 GW of residential PV by 2020 with no current communications or controls strategies, plans, standards, or solutions

From "Technical Potential for Distributed Photovoltaics in California" Preliminary Assessment March 2012, E3

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Challenges Cont'd

- Big Bold Energy Efficiency Strategies:

  "All new residential construction in California will be zero net energy by 2020"

- If between 100K and 200K homes per year, at 4kW per home, this represents additional 400 – 800 MW per year after 2020

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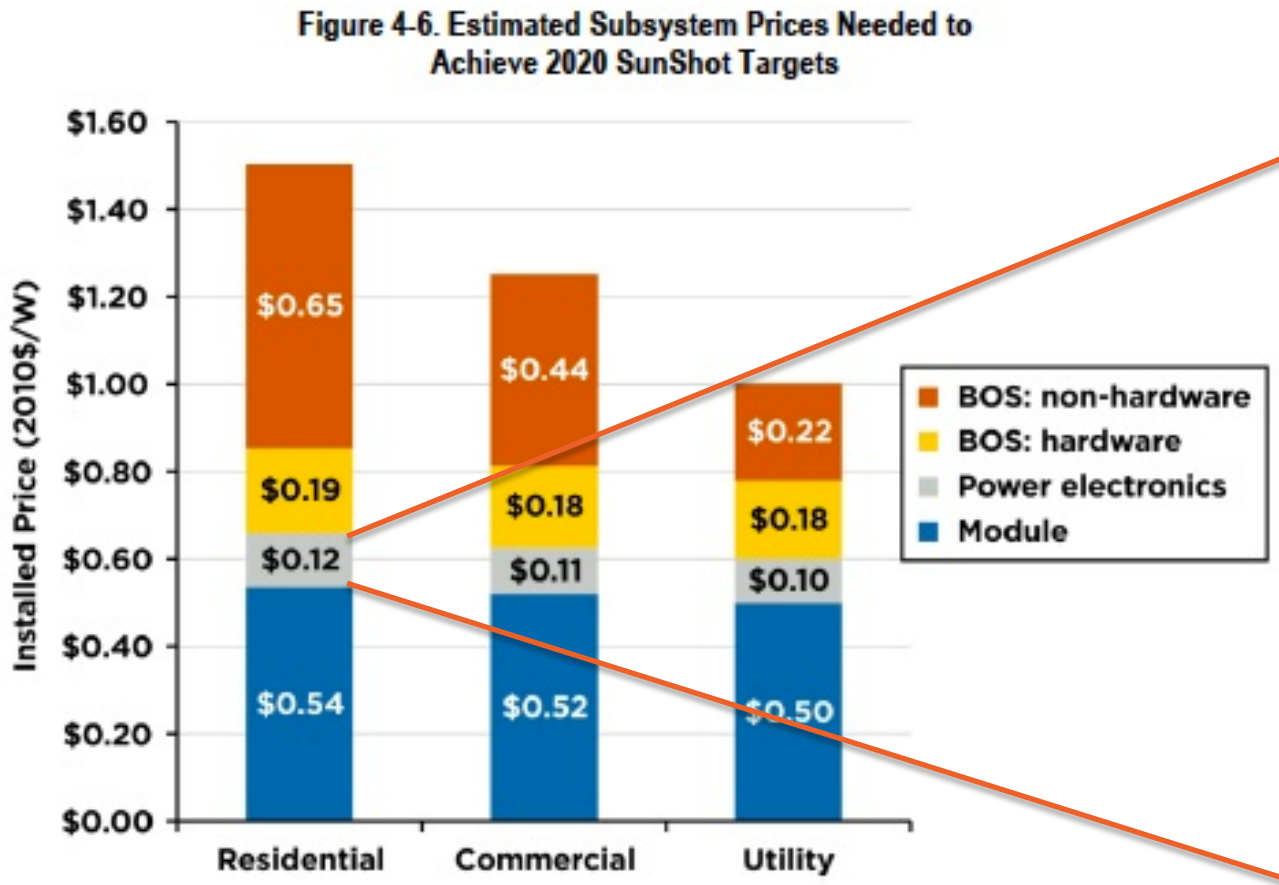
Challenges Cont'd



With targeted residential inverter costs at $0.12 per watt, communications/controls capability must be a fraction of this. At $0.01 per watt, the net cost is $40 per 4 kW system – Solution must be embedded, easily configurable, robust

Sunshot Vision Study, February 2012

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Research Objectives

- Does it make sense to leverage the AMI system for communicating with Residential inverters?
  - Existing/currently being implemented infrastructure
  - Similar capabilities being developed for DR purposes primarily
  - Potential for low-cost communications and control

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Research Approach

- Demonstrate end to end AMI communications/control with PV inverter
- Identify barriers and pitfalls to this approach
- Determine capabilities of AMI system for various desired control functionalities
- Identify alternative approaches that meet objectives
- Recommend next steps for pursuit of AMI-based or alternative communication routes for solution that is:
  - Low cost
  - Robust
  - Flexible
  - Simple

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Scope

- EPRI developed hardware and software to receive and interpret Zigbee SEP 1.1 signal from L&G meter, translate, control Fronius residential inverter
- Using same setup, SMUD demonstrated end to end control functionality at SMUD AMI compatibility lab
  - Test lab mimics SMUD AMI system including actual hardware and provides Production based environment for testing hardware

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Scope Cont'd

- Functionality demonstrated
  - On/Off
  - Max Setpoint Inverter Output
- Additional functionality constrained under SEP 1.1 modules and SSN HAN Communications Manager (HCM) capabilities
  - Monitor functions (output, fault codes, most recent output prior to fault, historical generation) *Demonstrated in EPRI lab with SSN Test Harness*
  - Control functions (Volt/var adjustment, dynamic power adjustment in response to changing system conditions) *Not Demonstrated, waiting for SEP 2.0*

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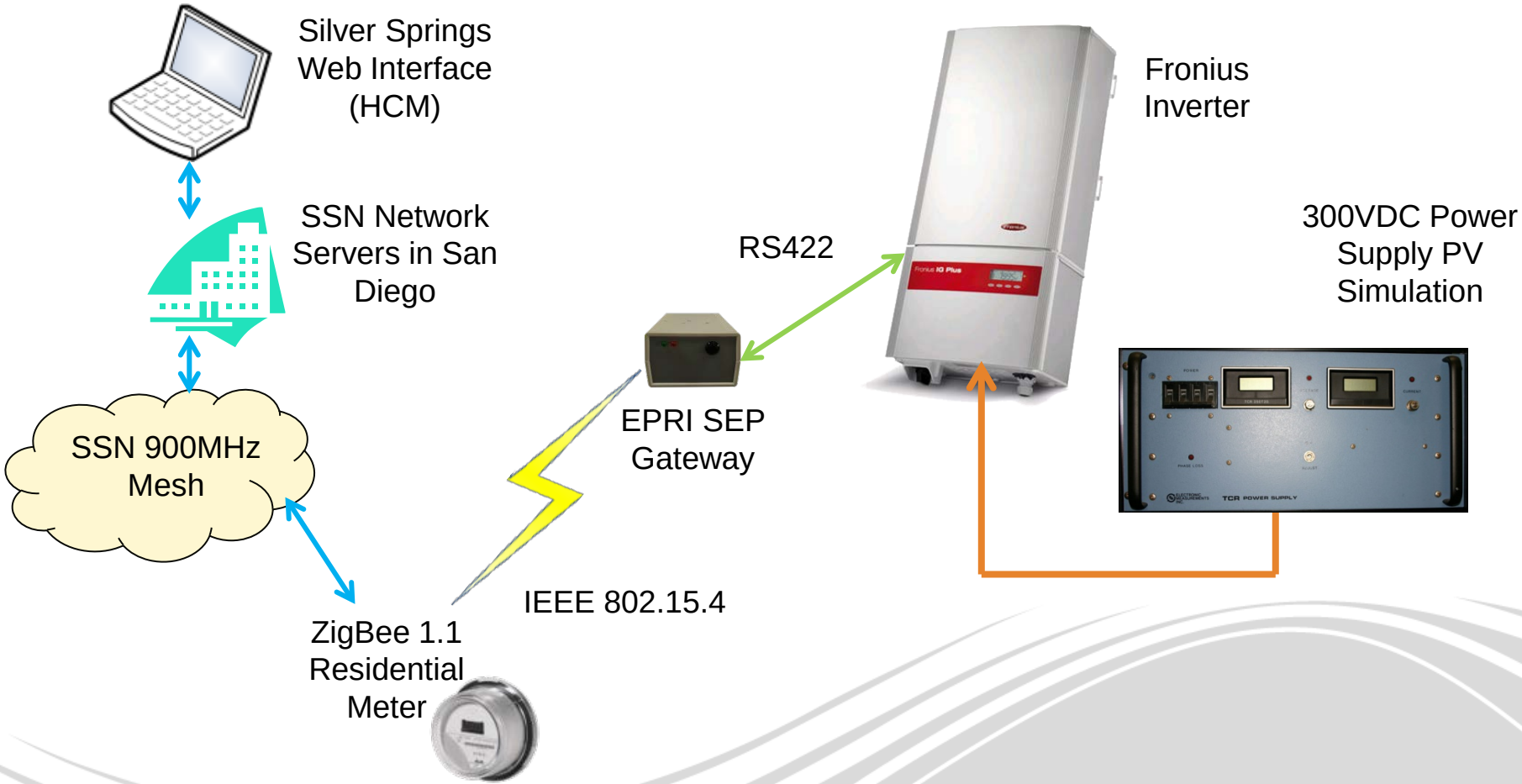
Development Environment

SMUD SmartGrid HAN Test Lab



Testing at SMUD

- Test Inverter Output Level to 25%
  - Creates an event that starts immediately, has a duration of 10 minutes, and limits the inverter to 25% of maximum generation. Fronius inverter will reduce output to approximately 1000 watts.
- Cancel the Output Reduction Event
  - While the inverter is reducing output to 25%, the event is canceled.
- Test Inverter Output Level to 0%
  - Creates an event that starts immediately, has a duration of 10 minutes, and limits the inverter to 0% of maximum generation. Fronius inverter will reduce output to 0 watts.
- Cancel the Output Reduction Event
  - While the inverter is reducing output to 0%, the event is canceled.

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Testing Continued – Supplemental Tests at EPRI

- Read Attributes
  - Inverter status, Output, Fault Codes
- Read Load Profile
  - While each of the tests in the previous slide are in progress, use the SEP Gateway to read the load profile

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Equipment

- Inverter
  - Fronius IG Plus V 3.0-1 UNI rated at 3kW PV with maximum power handling capability of 4kW
- DC Power Supply
  - TRC Model TCR500T20-1 capable of 500VDC at 20 amperes maximum

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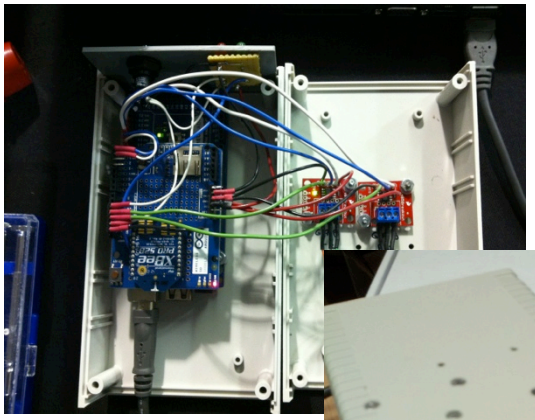
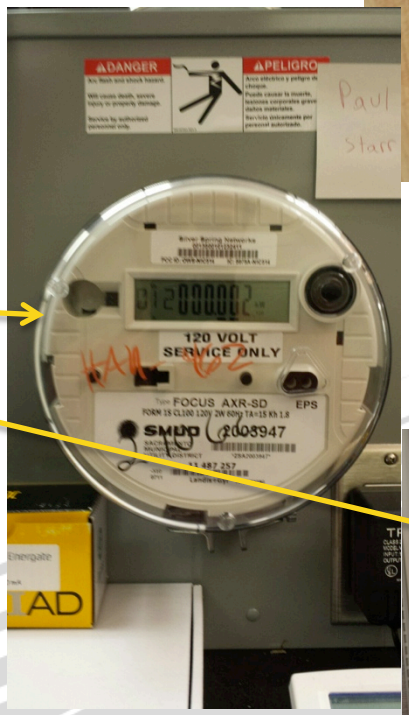
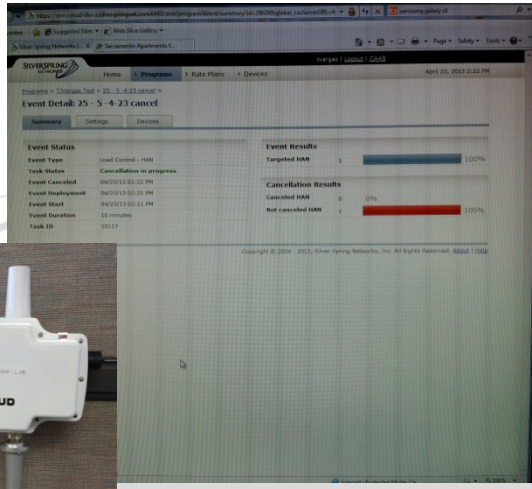
Equipment

- SEP Gateway
  - Device constructed by EPRI to perform protocol translation between ZigBee 1.1 to the Fronius interface protocol
- Electrical Meter
  - Landis & Gyr
- Headend System
  - SMUD Silver Springs Zigbee 1.1 Compliant Netwok







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Test Results and Challenges

- All tests worked as expected excepted for two minor details
- Response time from HCM to inverter through the network was 2-3 seconds
- Cancellation signal successfully received and acted upon by inverter *BUT* the HCM couldn't display response sent back from the inverter until 1-2 hours later
  - SSN has been made aware of bug and is working to remedy
- Using power supply limited the inverter output relative to nameplate rating due to differences between power supply characteristics and a photovoltaic source
  - 1.7 kW max output on a 4kW inverter

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Scope Cont'd

- Evaluate bandwidth needs for end-to-end communication network (Central Data Repository/AMI/HAN/Inverter Comm) and determine scaling parameters needed to achieve appropriately high resolution PV system data and control commands as a function of increasing PV penetration
- Report describing demonstration, necessary next steps for AMI scale-up, barriers to this approach, security concerns/constraints, latency of data signals on AMI system, functionality capabilities and constraints, likely cost of scaled deployment. SMUD authored, with EPRI input

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AMI Network Scale-up Issues

- Current limited functionality with SEP 1.1 will be significantly expanded with adoption of new SEP 2.0 standard
- Bandwidth not a concern for 1X or several per day signals to device (curtail today, or curtail now for next couple of hours)
- Monitoring infrastructure also capable of multiple signals per day
- Uncertainty around high frequency communication (30 secs – 5 mins) with 10's of thousands of devices
  - True of any mesh network
  - Likely some percentage of devices will not receive signal in short timeframe (5 min dispatch) or possibly at all
  - System was not designed with this functionality in mind, so would need to consider impact of partial communications vs. adding access points to network
- Security concerns create a barrier to entry, and ongoing cost
  - Requires both ZigBee and Silverspring Networks compatibility testing, re-testing for any inverter ZigBee SEP firmware updates

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Additional Related Work (DOE)

- Working on broader report that would assess multiple pathways for communications and control functions, compare against multiple criteria to provide context for this demonstration
  - Report would be written by Navigant with input from SMUD, EPRI, Gridpoint

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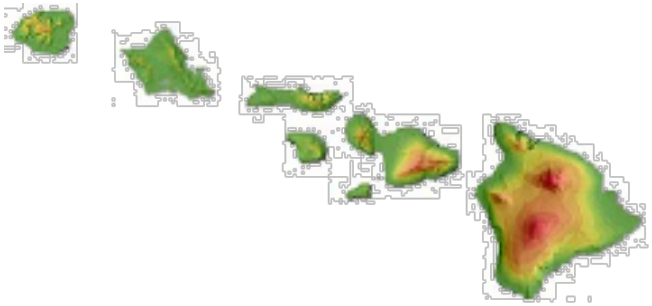
Team

- SMUD
  - Obadiah Bartholomy (ER&D), TJ Vargas (ER&D), Denver Hinds (SmartGrid/IT), Ed Sanchez (ER&D, IT), Don Jacobs (SmartGrid/IT)
- EPRI
  - Brian Seal, Gary Aumagher, Ben DuPont

HIP-PV TASK 4: VISUALIZATION OF HIGH PENETRATION PV



Dora Nakafuji
Hawaiian Electric Company

June 5, 2013
Webinar

SMUD™

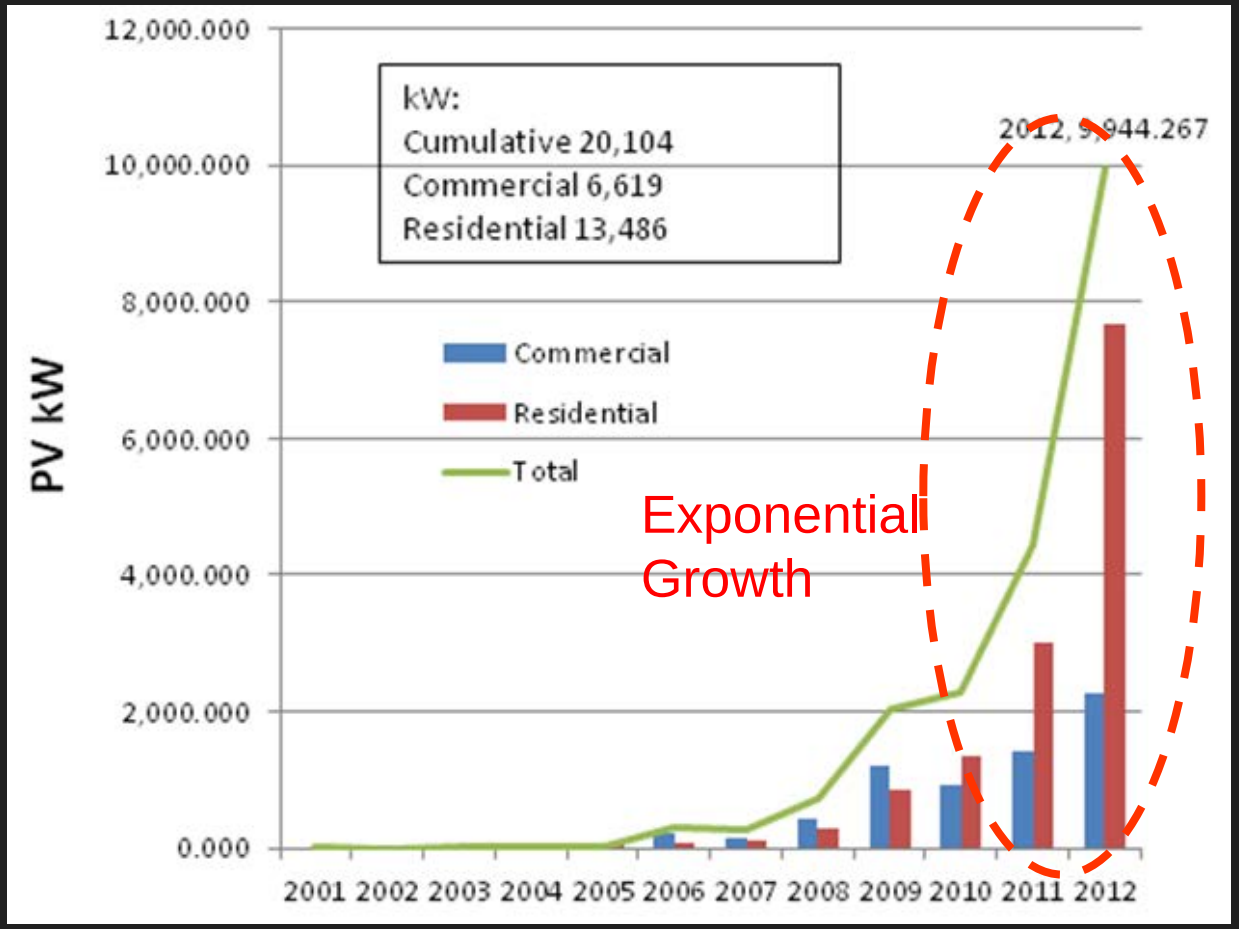
Hawaiian Electric Company
Maui Electric Company
Hawaii Electric Light Company

Overview

- Motivation & Background
- New Visualization Capabilities with Focus on Operations
- Continuing Efforts - Learning to Use & Integrate into Real-time Application (Operations & Planning)
- Timely Collaborations
- Q&A

This was….

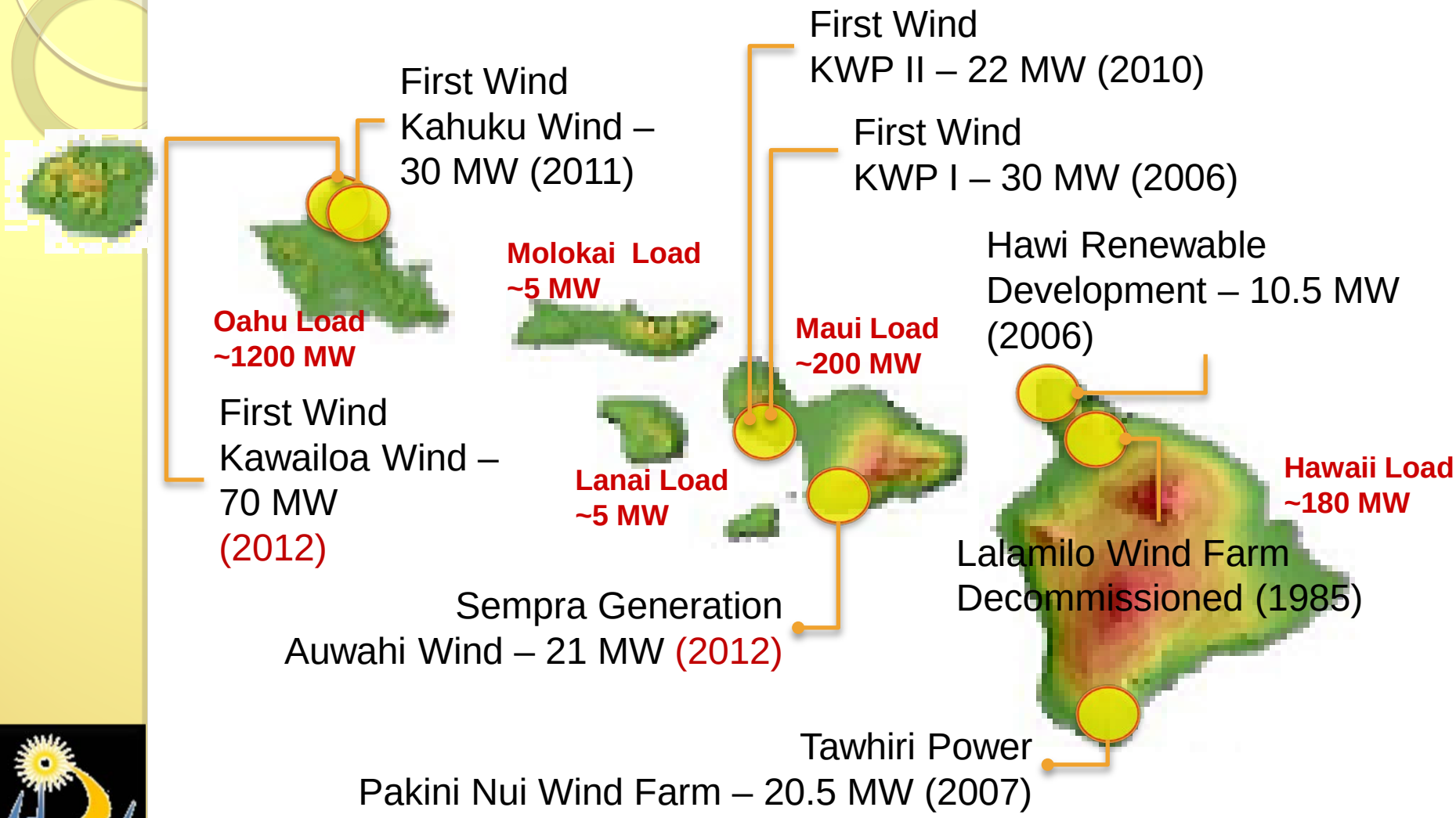
Our Operational View of Wind & Solar….



This was….

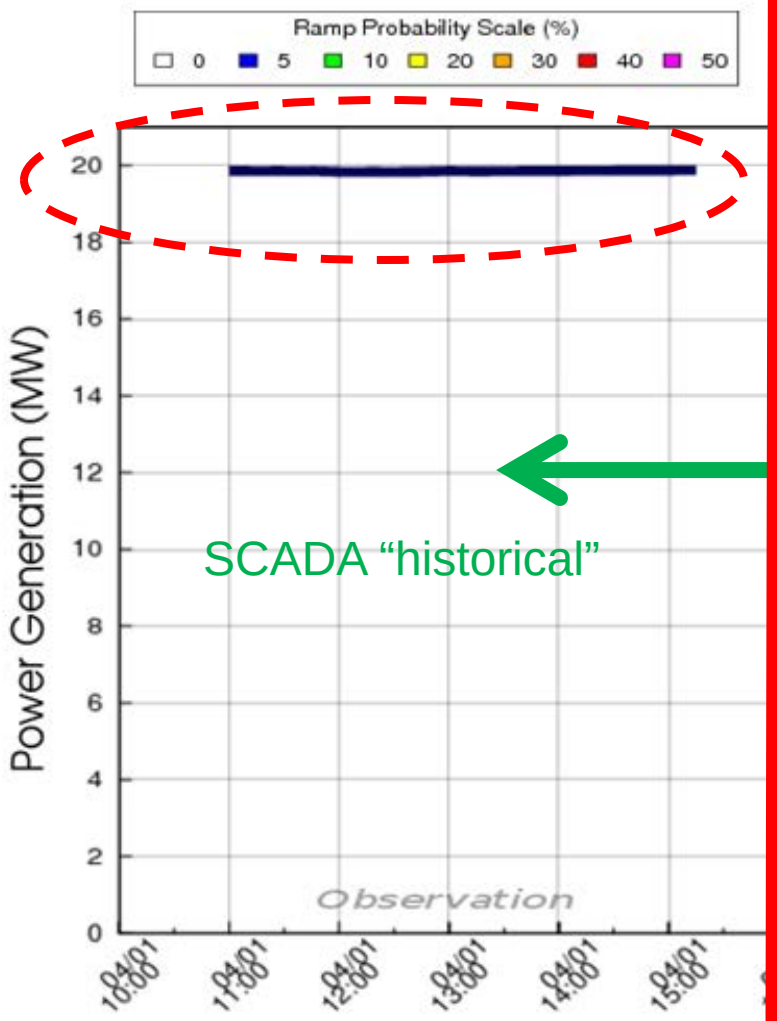
Our Operational View of Distributed Generation (behind-the-meter)….

Island Loads & Wind Sites



Source: HECO 2013

Value of Forecasting: Provide a Hedge



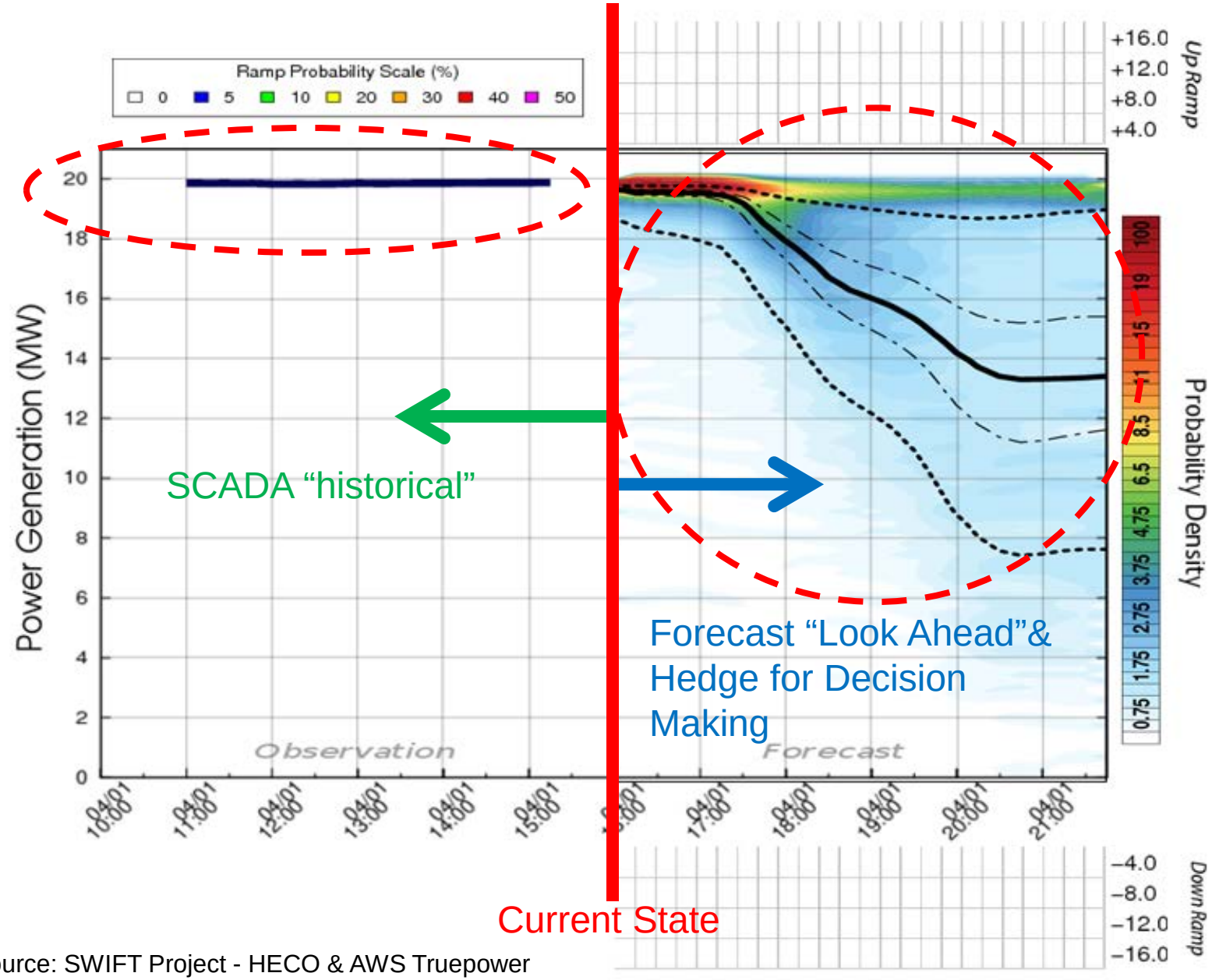
Current State

Can I count on Wind through my evening load rise?

No Idea What's Coming Next

Source: SWIFT Project - HECO & AWS Truepower

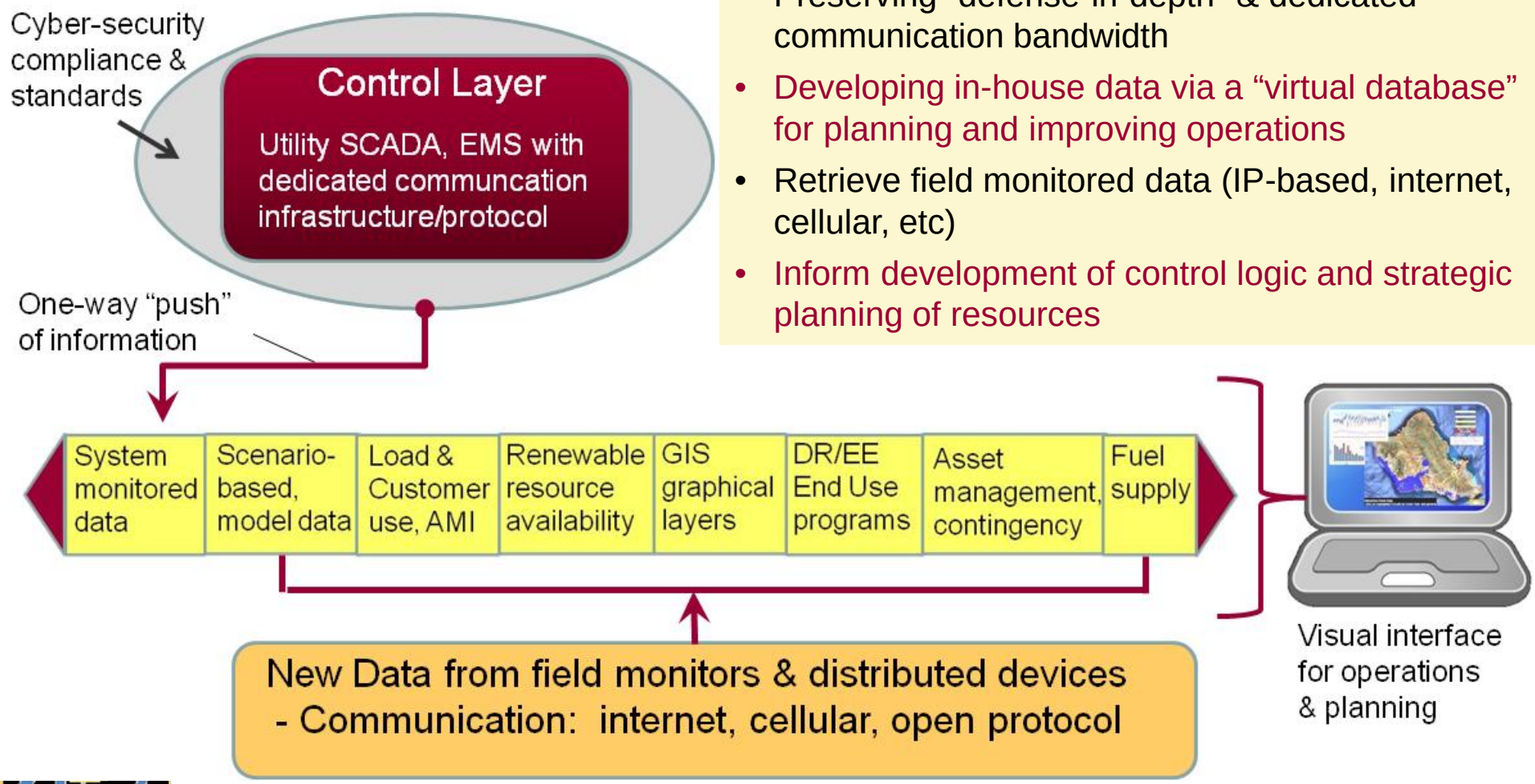
Value of Forecasting: Provide a Hedge



Source: SWIFT Project - HECO & AWS Truepower

What We Have – Access Numerous Databases Across Firewalls

- Preserving "defense-in-depth" & dedicated communication bandwidth
- Developing in-house data via a "virtual database" for planning and improving operations
- Retrieve field monitored data (IP-based, internet, cellular, etc)
- Inform development of control logic and strategic planning of resources

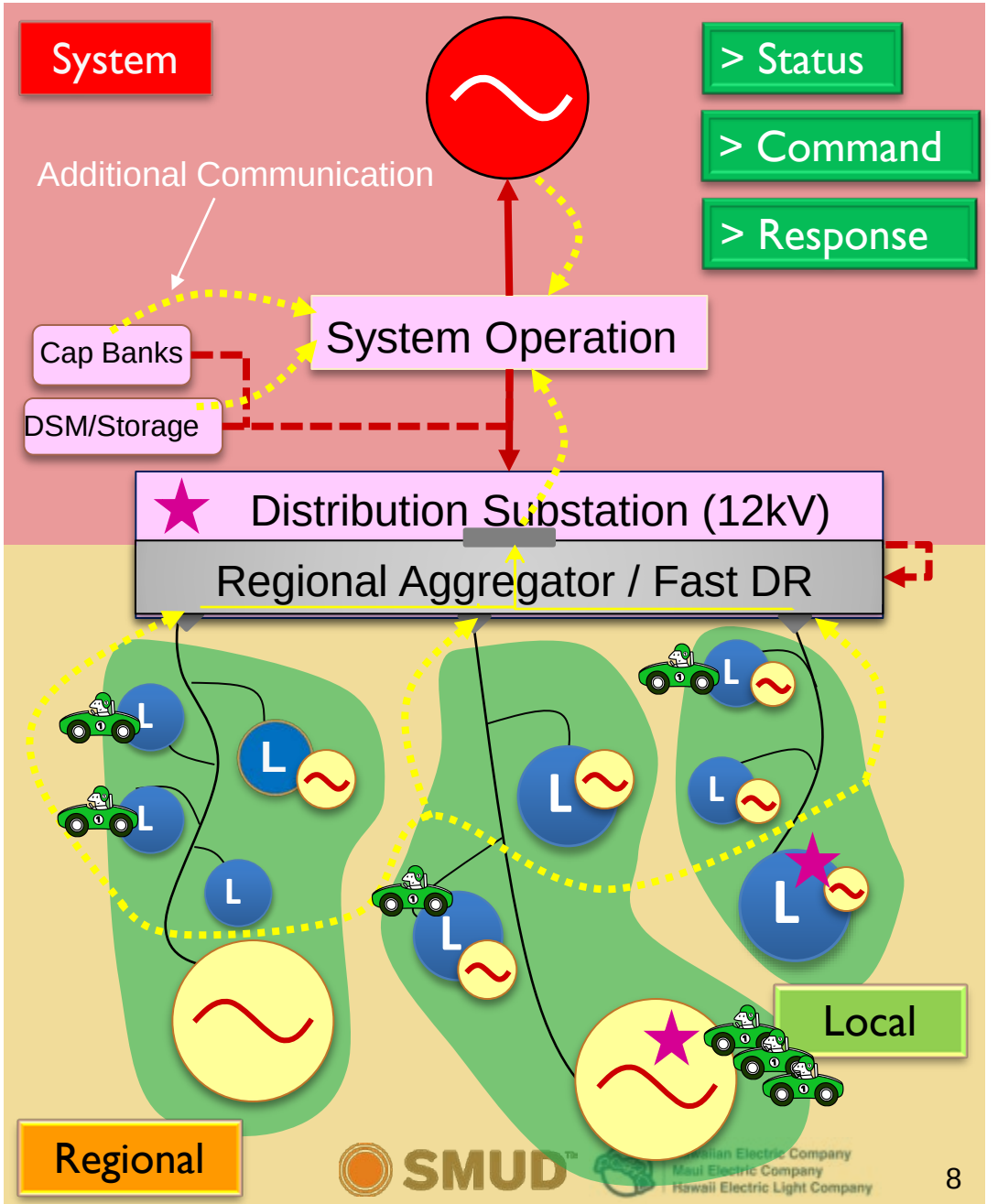


Source: HECO

What We NEED to Inform Future Grid Intelligence

- Identify and capture known distributed resources using LM-1 sensors and DR needs at the LOCAL level
- Employ as available state-of-the-art automation and aggregation at REGIONAL level – substation level
- Determine required data to communication back for SYSTEM level Operational Control (i.e. Status, Command, Response)

Goal: Inform development of simulation and control strategy for strategic placement of "smart" technologies with LOCAL level responsiveness

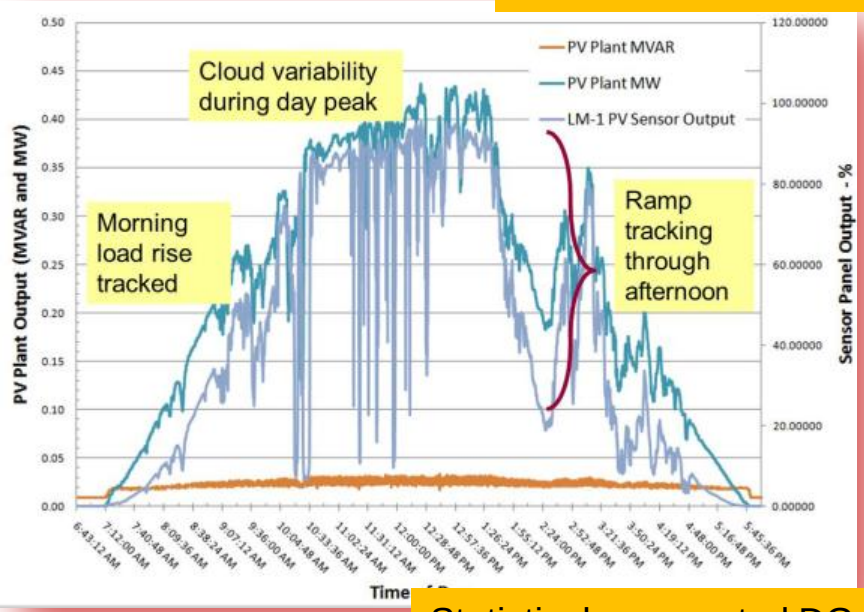


Diverse Data Sources for Renewables

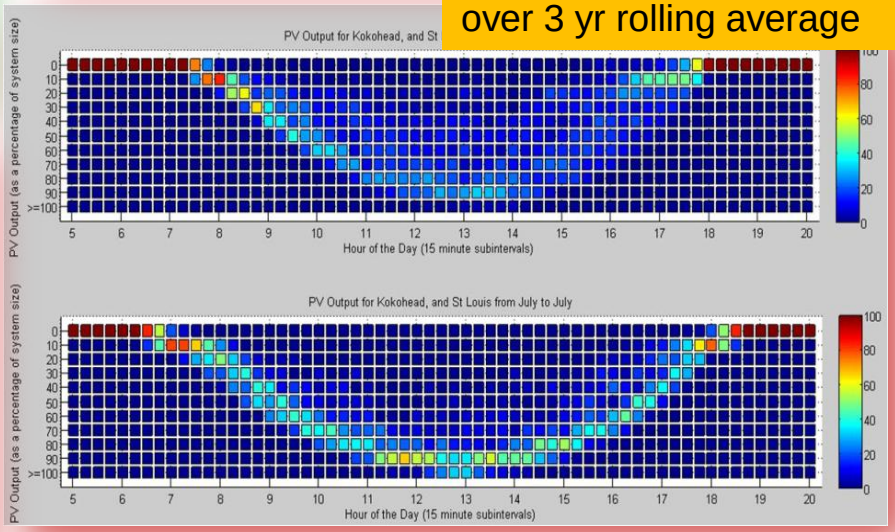
Forecasting data & parameters

Instrument	Measurements	City	Island
SoDAR	U,V,W,TI,TKE	Naalehu	Big Island
SoDAR	U,V,W,TI,TKE	South Point Park	Big Island
SoDAR	U,V,W,TI,TKE	Kahului	Maui
SoDAR	U,V,W,TI,TKE	Kaheawa Wind Park	Maui
SoDAR	U,V,W,TI,TKE	Puunene	Maui
SoDAR	U,V,W,TI,TKE	Kaneohe	Oahu
SoDAR	U,V,W,TI,TKE	Turtle Bay	Oahu
Radiometer	T,RH,Q at multiple levels to 10 km	Kahului	Maui
Side-scanning LiDAR	U,V,W, at multiple levels, radii	Kahuku	Oahu
SMS	GHI,DNI,DIF,T,RH,WS,WD, Pr	Kahului	Maui
SMS	GHI,DNI,DIF,T,RH,WS,WD, Pr	Wailea-Makena	Maui
SMS	GHI,DNI,DIF,T,RH,WS,WD, Pr	Makakilo	Oahu
Pyranometer	GHI	Makaha	Oahu
Pyranometer	GHI	Maili	Oahu
Pyranometer	GHI	Kailua-Kona	Big Island
Pyranometer	GHI	Mauna Lani	Big Island
Pyranometer	GHI	Mokapu	Oahu
Pyranometer	GHI	TBD	Oahu
Pyranometer	GHI	TBD	Lanai
Pyranometer	GHI	TBD	Lanai
Pyranometer	GHI	TBD	Molokai
Pyranometer	GHI	TBD	Molokai

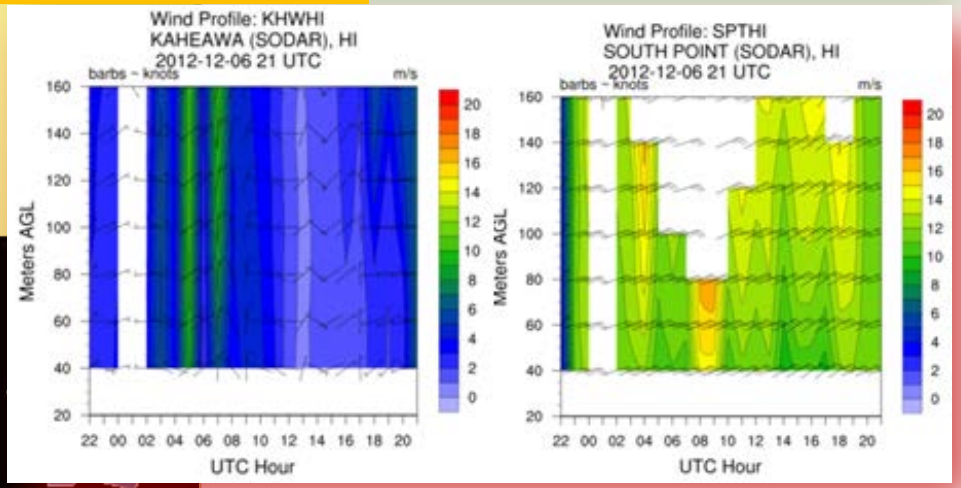
Local DG Production



Statistical aggregated DG over 3 yr rolling average



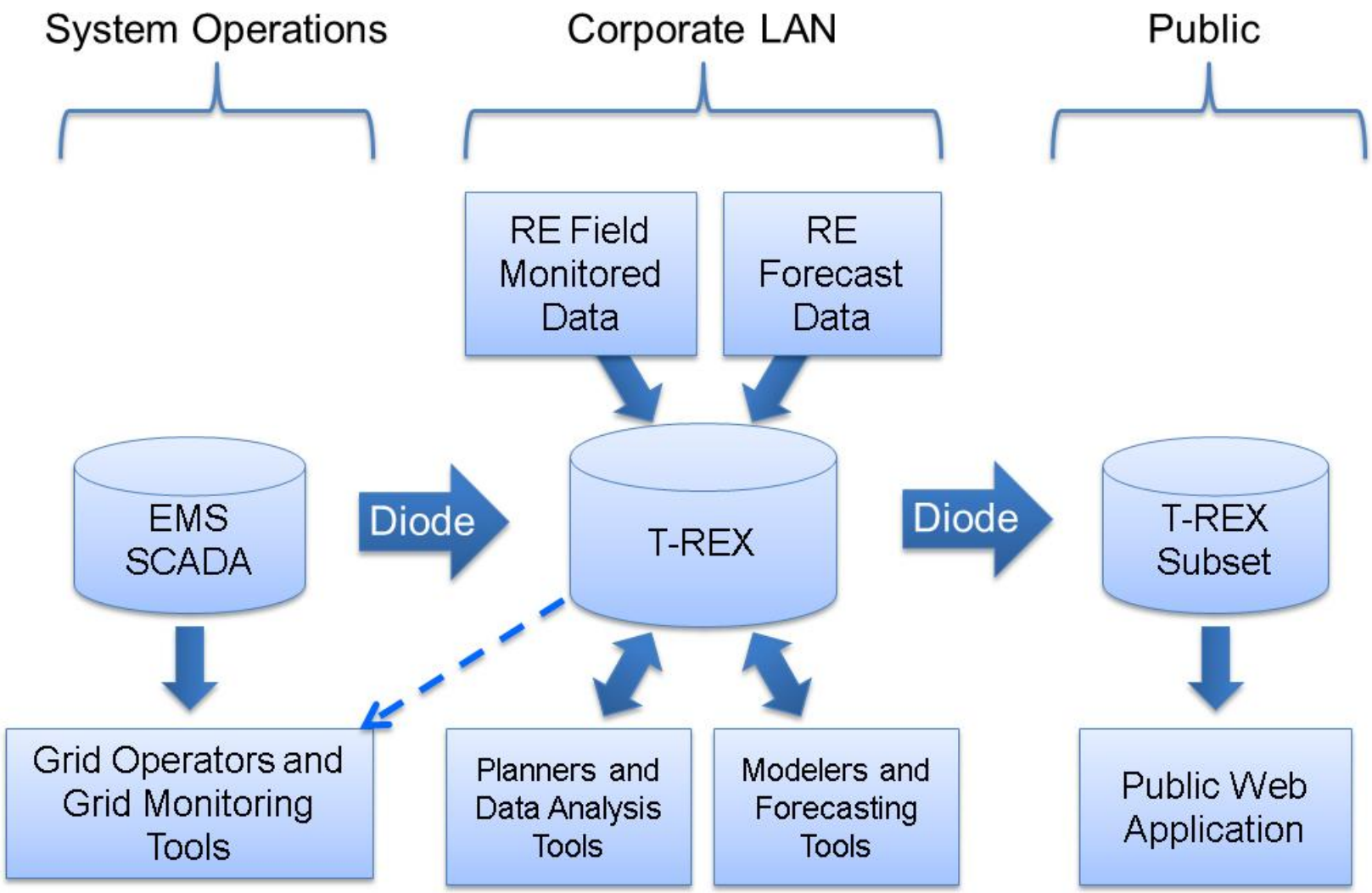
SODAR sensor



Need for New Visualization Tools

- Renewable Database & Analytics
  - TREX developed to gather RE data (SCADA and non-SCADA) into a common format for analysis and planning
  - Applied for outage investigation and informing planning strategies
- Locational Value Maps
  - Provides Visual on Penetrations by Feeders
  - LVM online provides public access to penetration by address
- Renewable Watch
  - Provides a view to the value of renewables by time of day
  - Educating workforce on RE variability and system impacts
- Alstom & Siemens Ops Displays
  - Provide Operators a view to the behind-the-meter DG generation
  - Enable real-time renewable forecasts for system dispatch

TREX: RE Data Architecture to Bridge across Data Networks, Integrate Data, Support Analytics



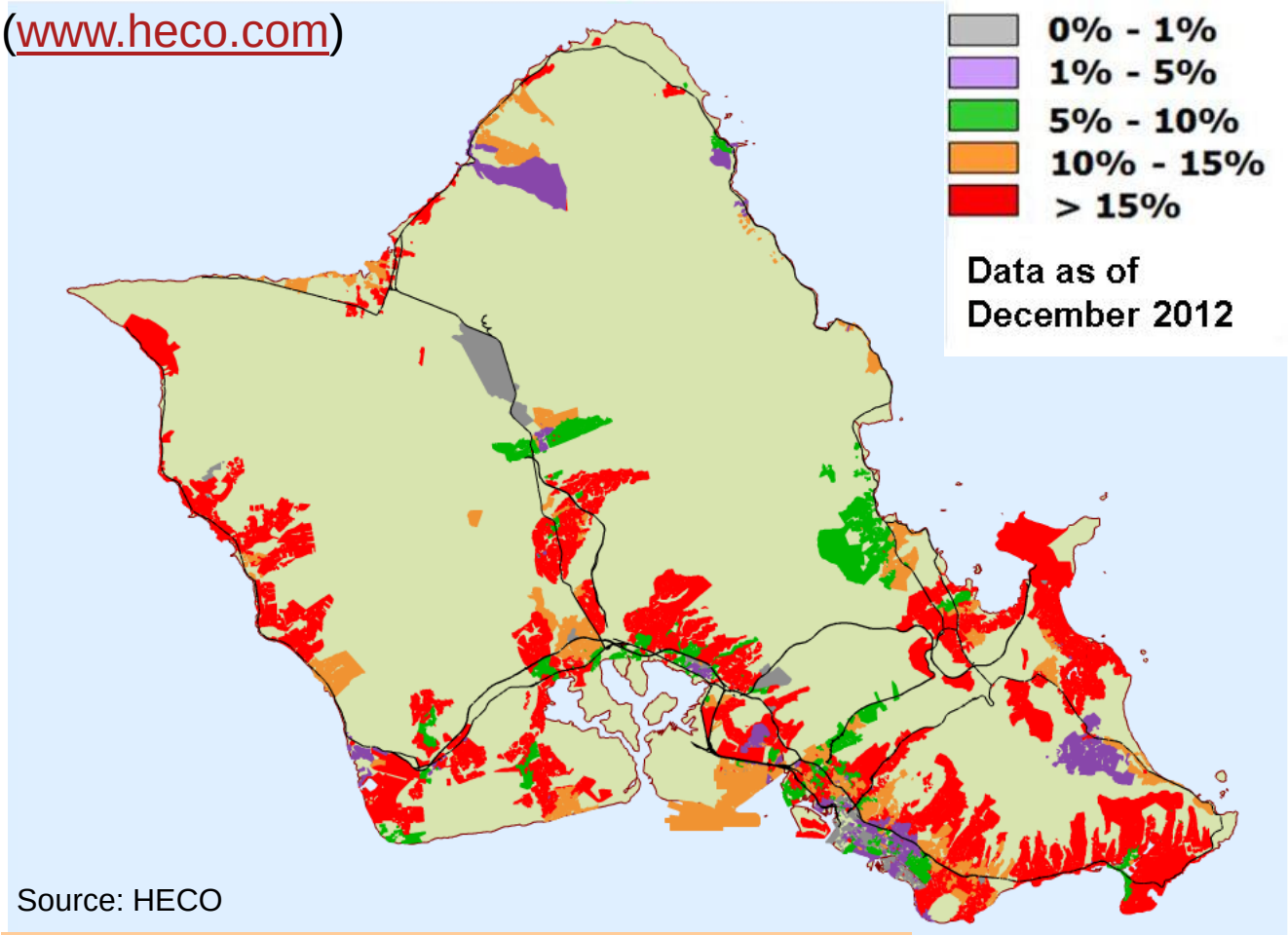
LVM: Visual Tools for Tracking Exponential DG Growth on Hawaii Systems

Value Added:

- Graphical view of PV penetration levels
- More effective data handling, mining and statistical analysis tools
- Transparent tool to see and trend change

HECO Locational Value Maps Trending Penetration Levels

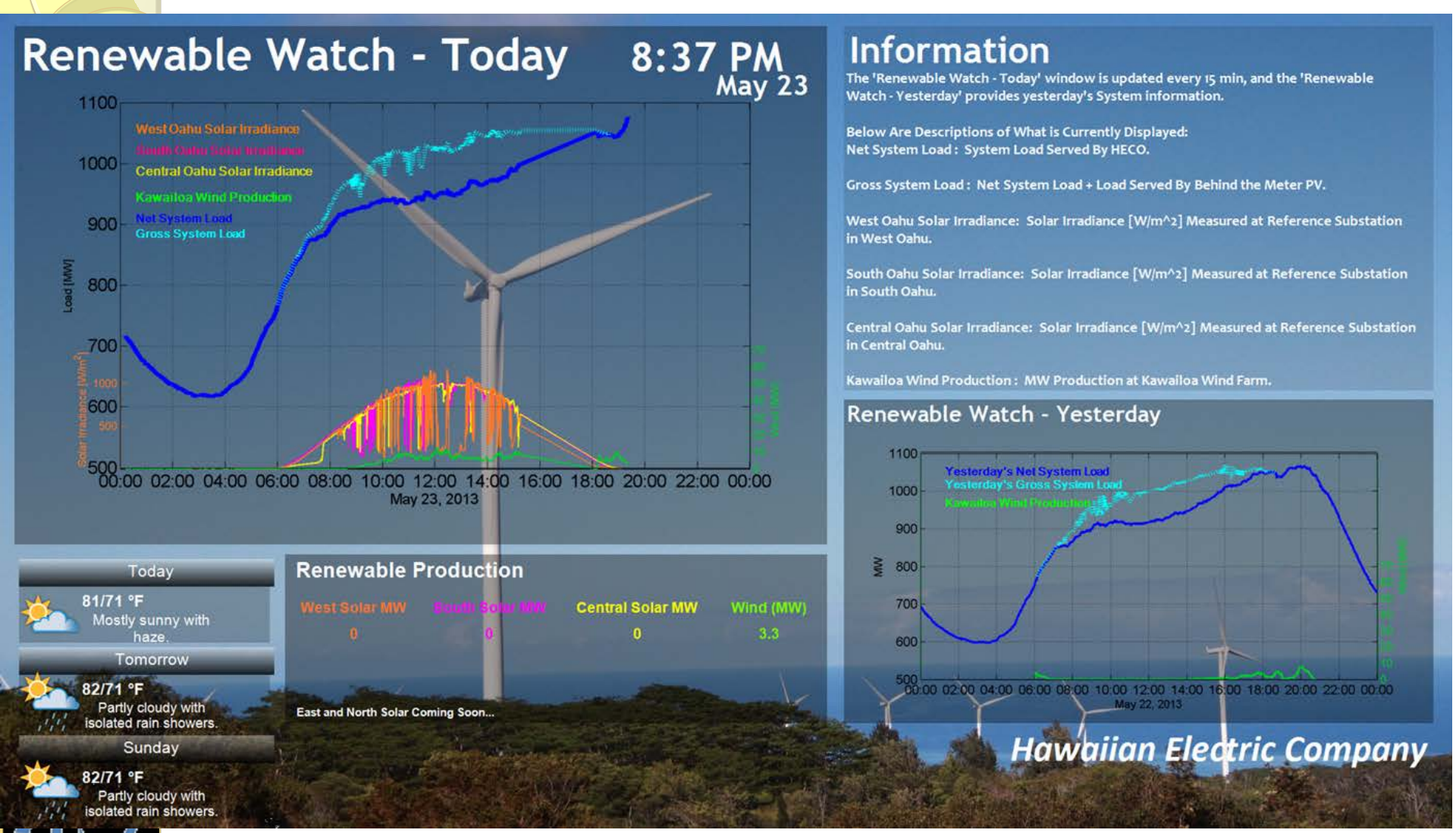
(www.heco.com)



Source: HECO

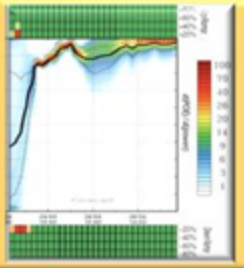
Red areas indicate circuits with > 15% PV penetration

Renewable Watch: Seeing the Value of Renewables in Real-time



Pulling it Together – Application in Real-time

EMS Automation DNV/AWS/Siemens & Alstom

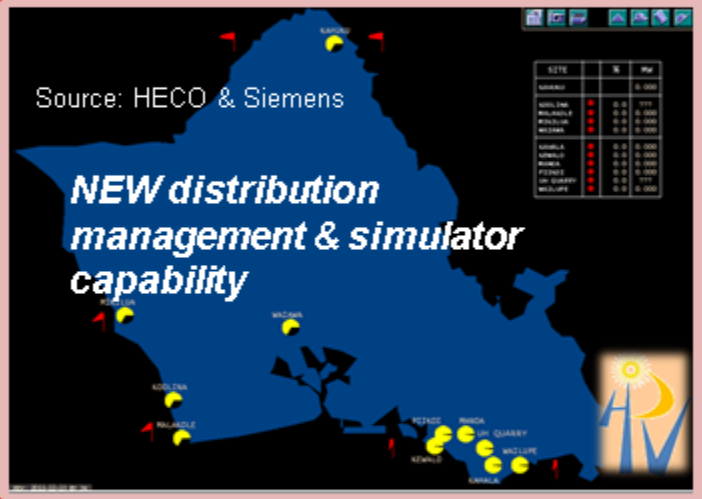


NEW Forecasting INPUTS:

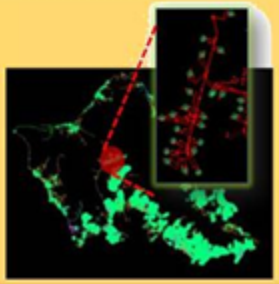
- *Real-time renewables forecasts*
- *Ramp probabilities*
- *Historical and actual trends*
- *Satellite images, weather data*

Traditional input sources

- SCADA data
- Transmission data
- Generator data
- Protection data
- Others



System Ops EMS



NEW Renewable/DG INPUTS:

- *GiS-based distribution infrastructure (models)*
- *DG locations*
- *Field monitored data*
- *Modeled results*

ENHANCED Renewable Integration Capabilities:

- Operations & Planning with visibility to DG resource impacts
- Updated state-estimator and simulation capability to evaluate actions & impacts

Ops Integration Summary

- Purpose: Integrating real-time DG and RE forecast data into Operations
- Challenge: Inertia to Change, Lack of Confidence & Understanding of Needs
- Approach
  - Work directly with EMS vendors to get direct user feedback (What works & What Won't)
  - Develop a sustainable and secure process that updates DG data and state-of-the-art, real-time RE forecast updated
- Benefits
  - Improve management of PV variability and unit commitment with new field information
  - Reduce costs (reserves, heat rate, curtailments)
  - Engage and build workforce & vendor confidence to change

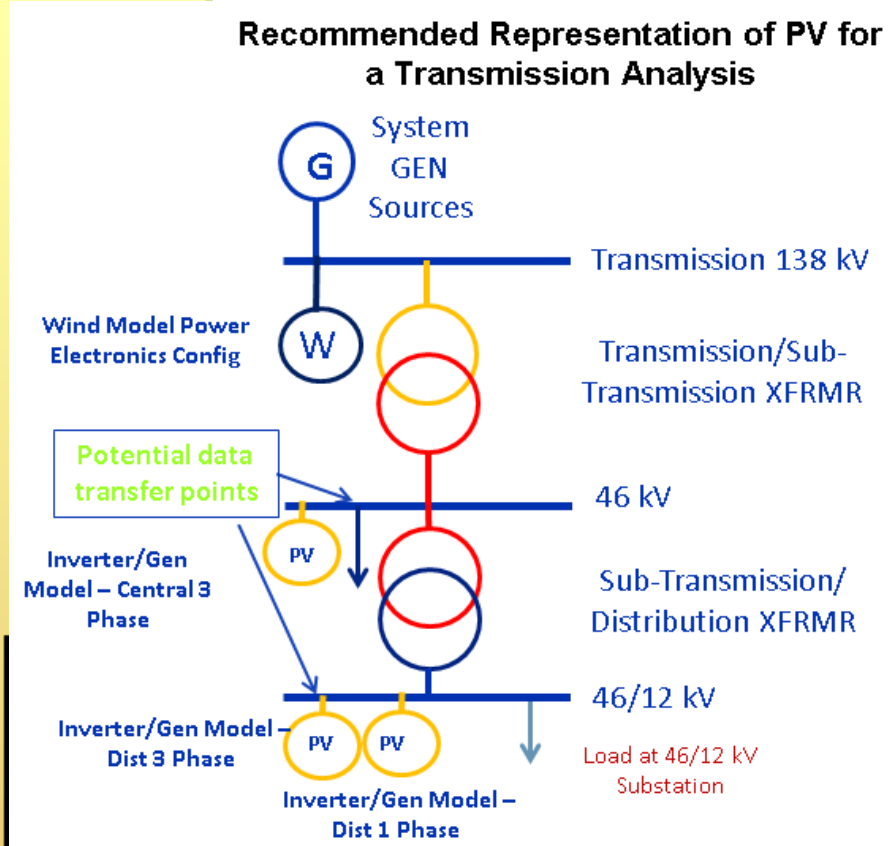
Leverage Models, GIS Tools & Forecasts

- DG Data
  - Use standard CIM transfer protocol to rapidly import the GIS DG information into EMS tools
  - Leveraging GIS and planning models to account for DG

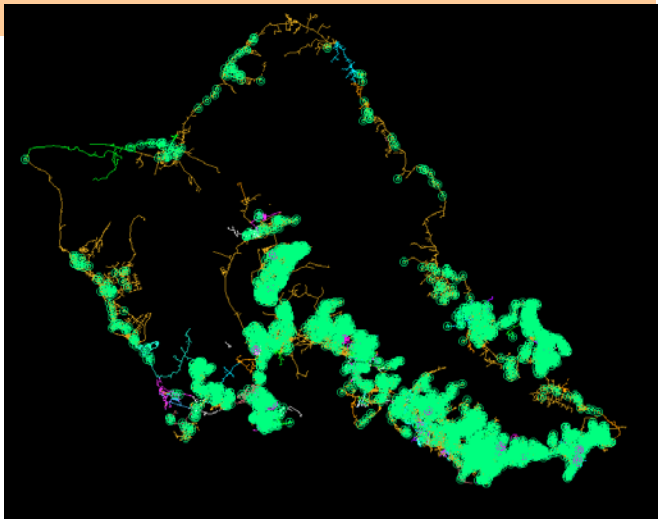
- Real-time Forecast
  - 15 min look ahead
  - Outlook extended to 6hrs and 48hrs
  - Probabilistic forecast
  - Local, regional and system look ahead

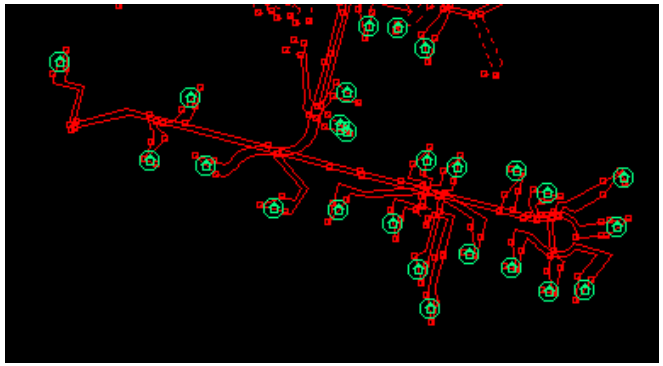
Upgraded Models to Account for PV as Generation NOT as Negative Load

- Enables more accurate modeling of DG resources for planning
- Consistent distribution system model expedites modeling and analysis process
- Allows for "what-if" analysis to stay ahead of system change and minimize risks of stranded assets



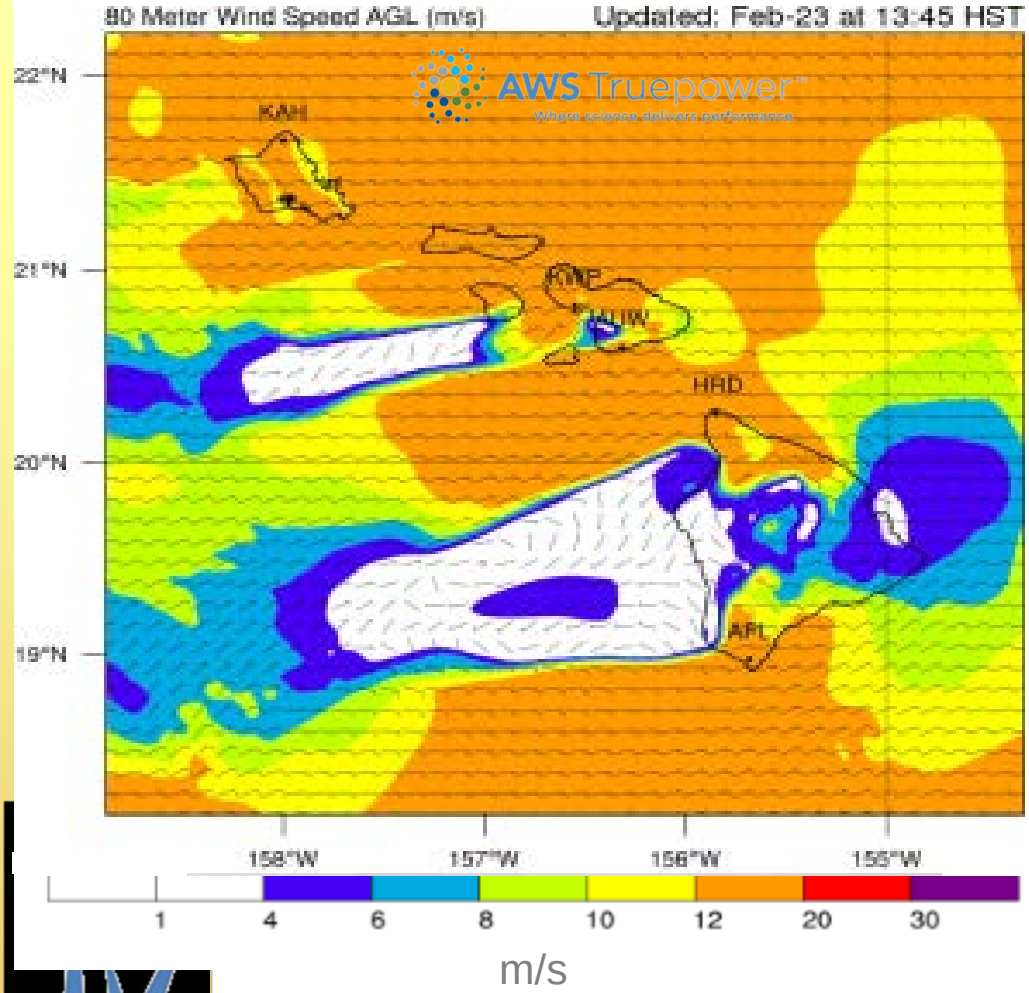
Translate feeder level impacts to system level



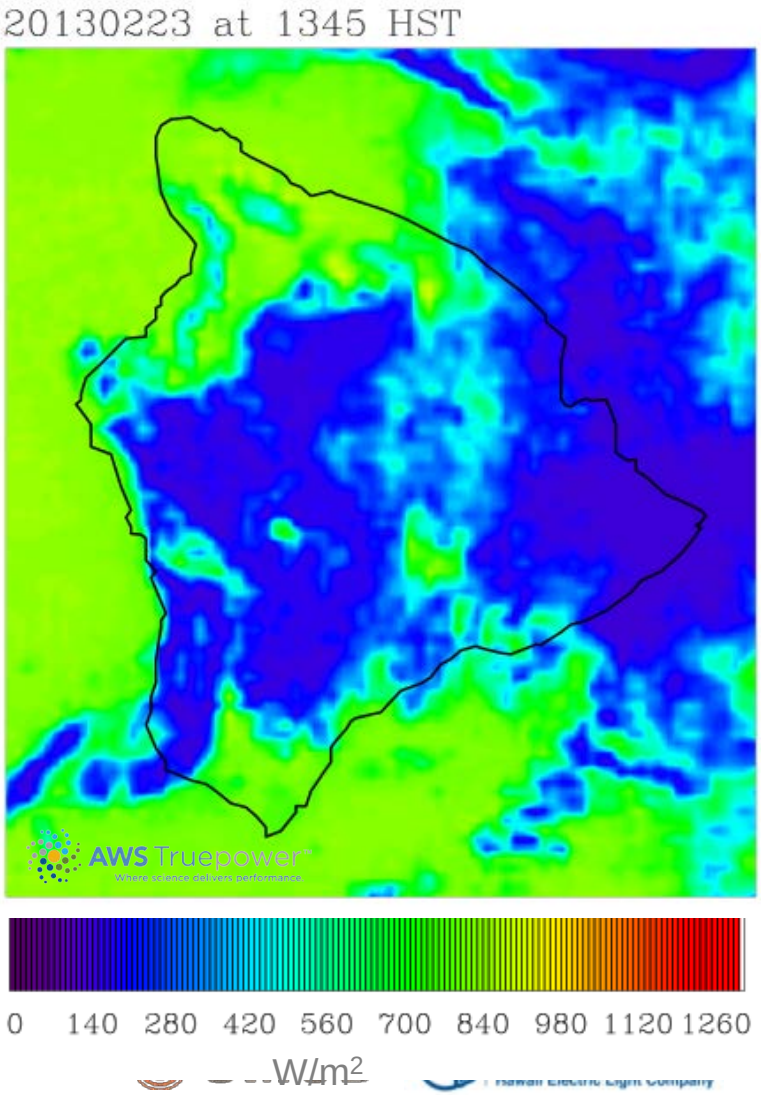


Real-time Solar & Wind Integrated Forecasting Technology (SWIFT)

Forecasted 80m Winds (m/s)



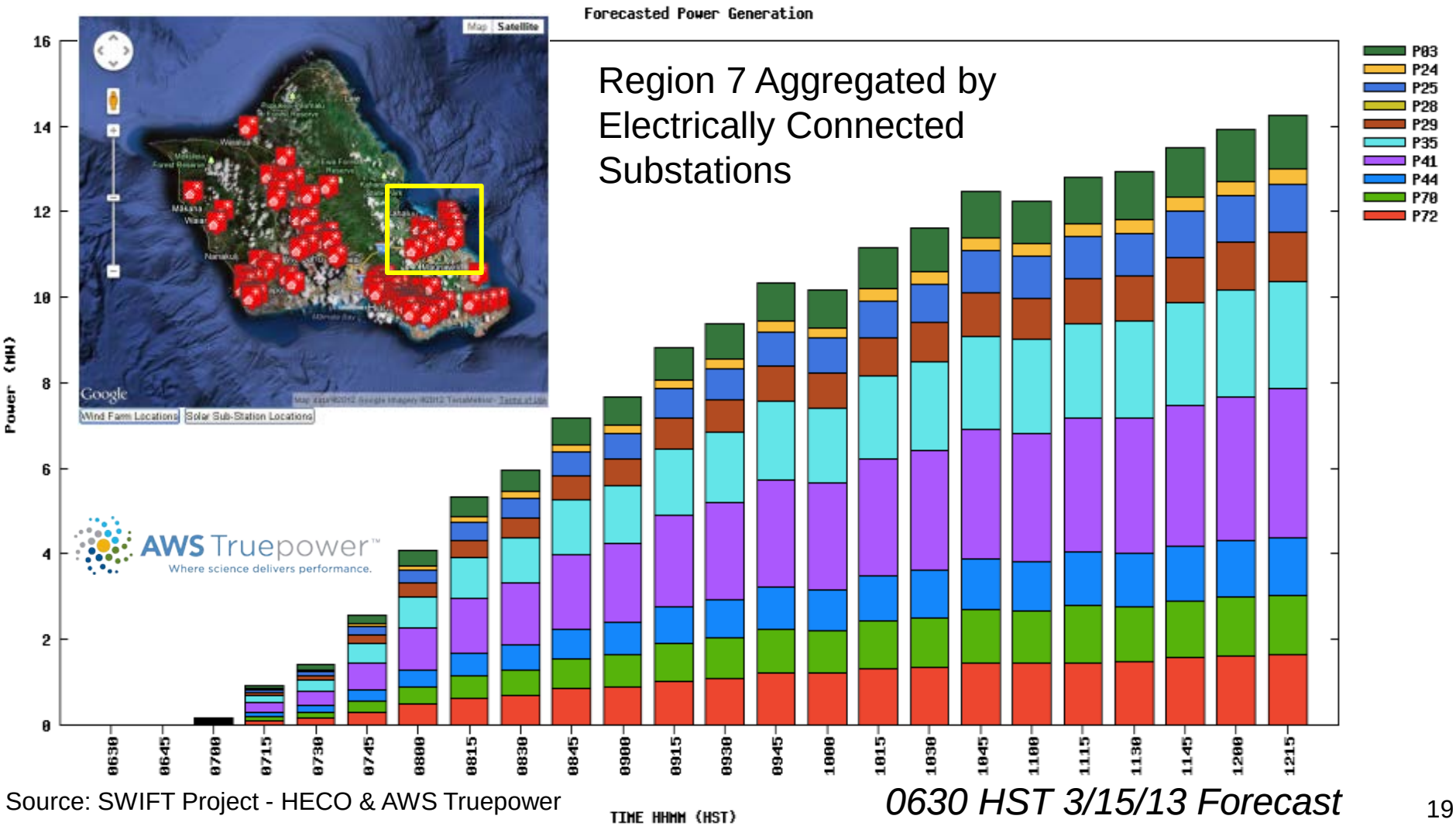
Estimated Irradiance (W/M^2)



Source: SWIFT Project - HECO & AWS Truepower

Learning to Use Solar Forecasts: Region 7 Aggregated Visual

Solar Power Production (MW) Forecast for Oahu in 15-minute Intervals

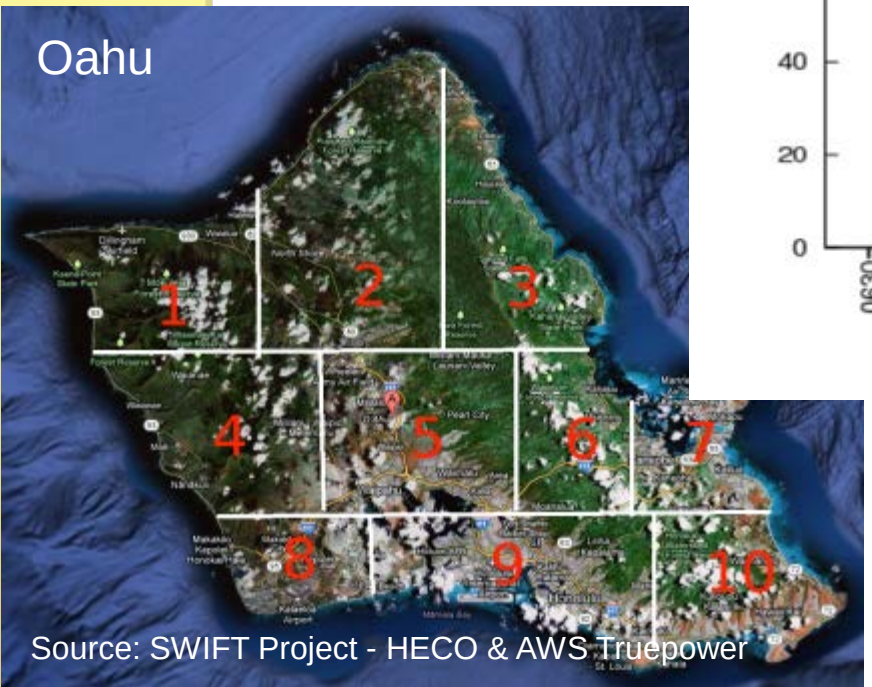


Source: SWIFT Project - HECO & AWS Truepower

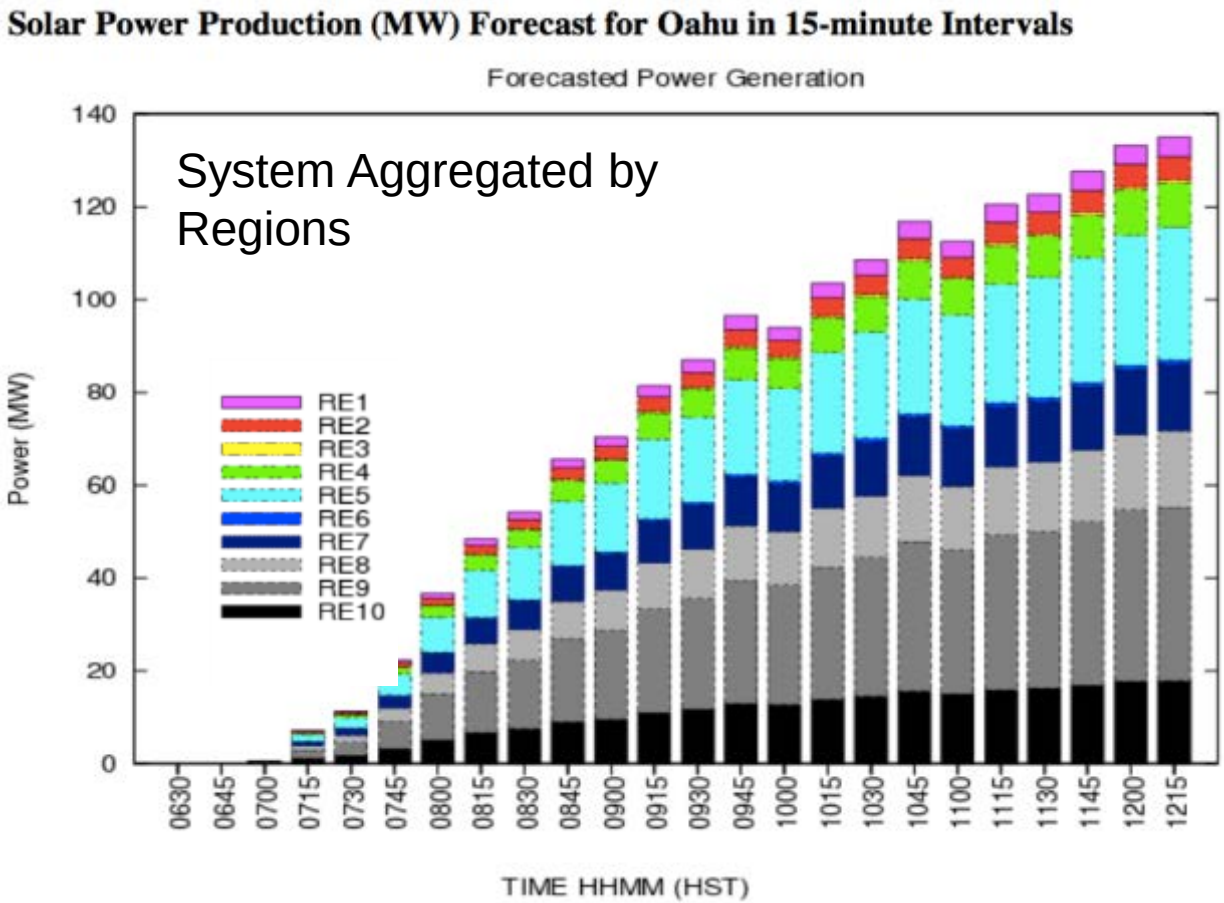
0630 HST 3/15/13 Forecast

Jumpstarting Solar Forecast: System-wide Aggregated by Regions

Aggregate regional forecasts to create System PV (large+DG) forecasts

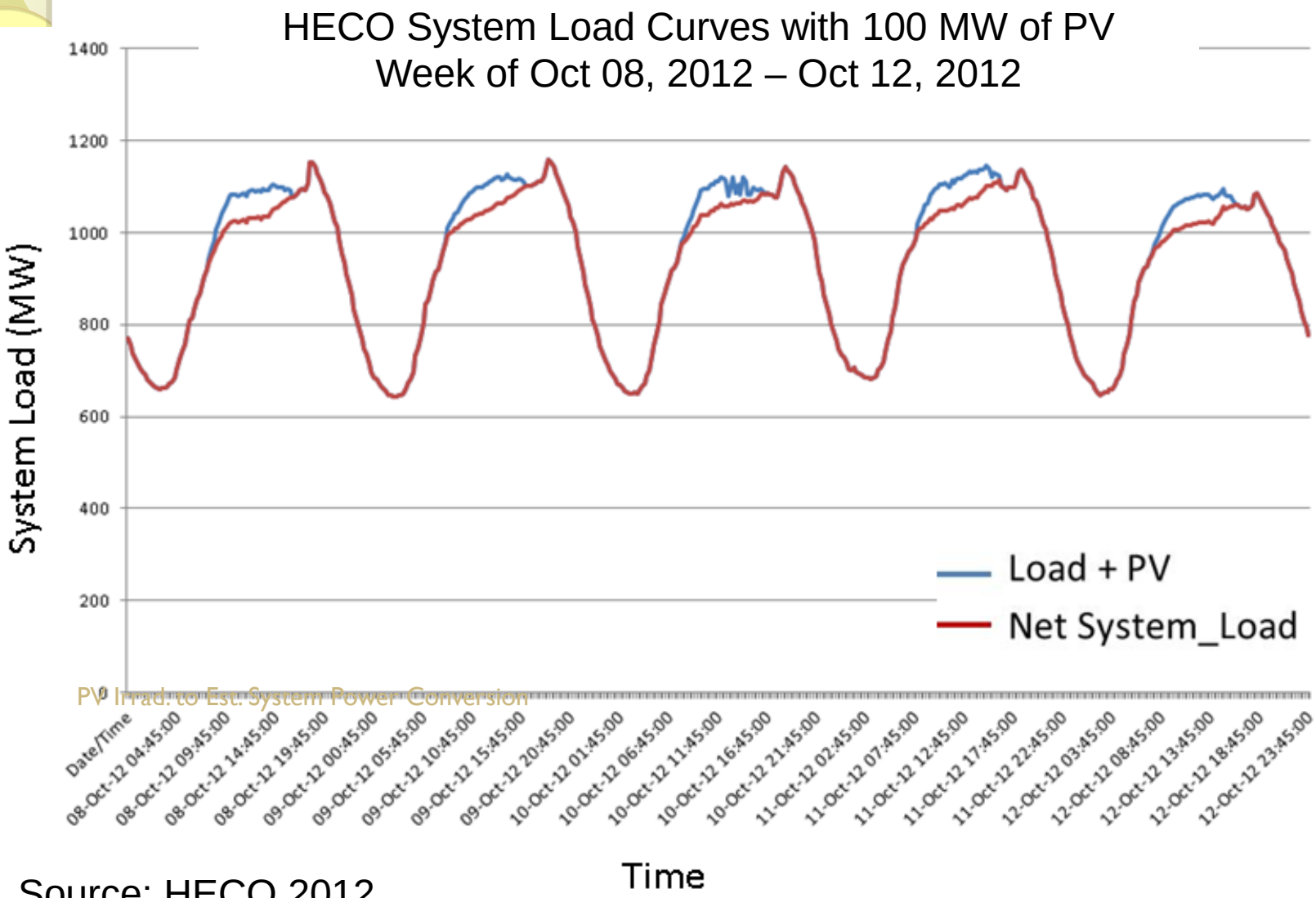


Source: SWIFT Project - HECO & AWS Truepower



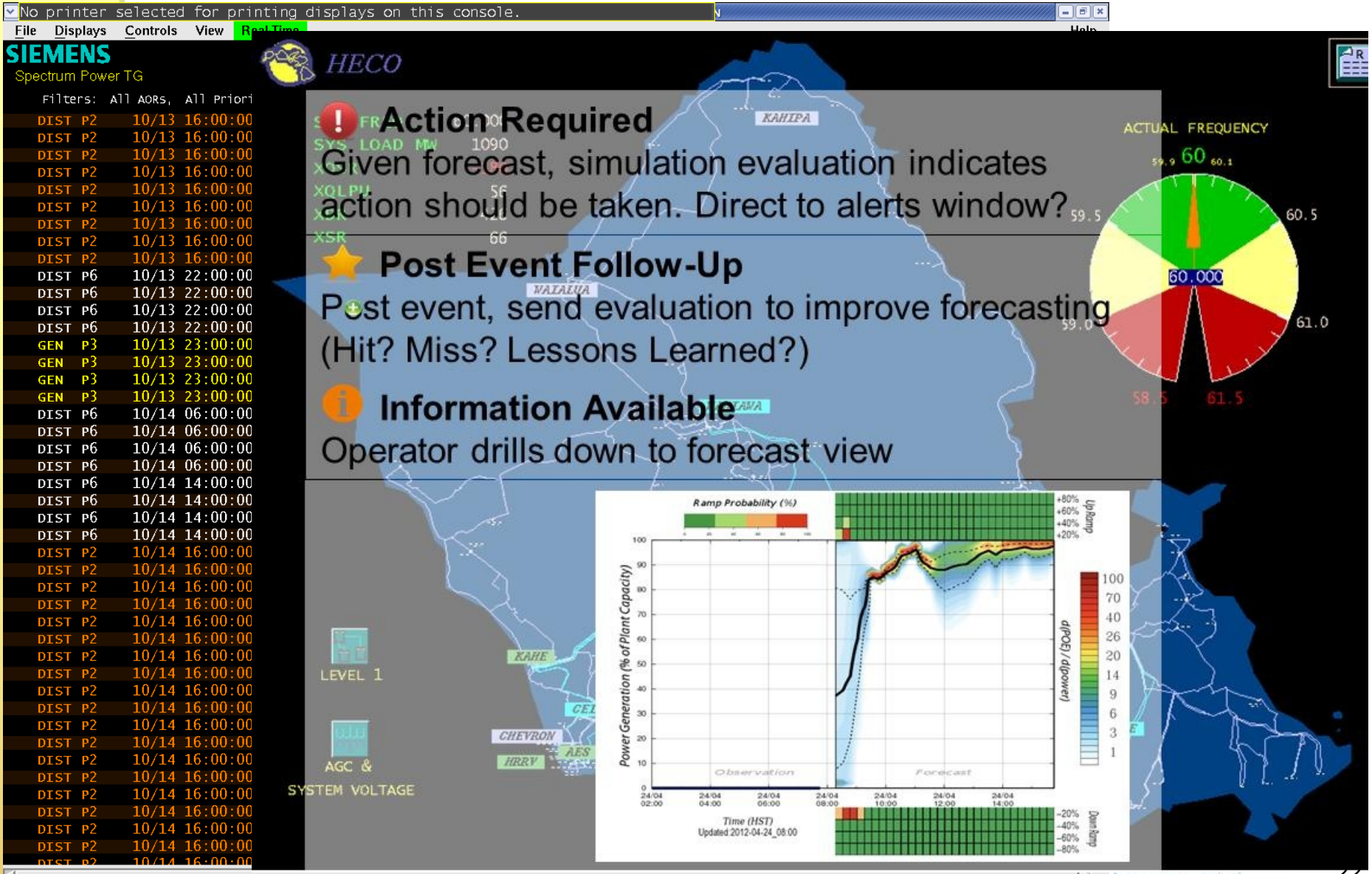
0630 HST 3/15/13 Forecast

"Seeing" DG PV Contributions on the System (Net vs Gross)



Source: HECO 2012

Providing Operational Awareness of DG Production & Forecast



Forecast File Features

- Solar forecast for each substation
- Wind/Solar forecast for each utility-scale facility
- Header will include facility name, substation name, and SDB forecast short name
  - Terminology may vary
  - Format of header file may vary
- Each forecast will include explicit probabilistic forecast values
  - 0, 20, 40, 50, 60, 80, 100% Probability of Exceedance
- Each forecast will include 4 Levels of Up Ramps
- Each forecast will include 4 Levels of Down Ramps

AWS Forecast Format – Mapping GIS to EMS

	A	B	C	D	E	F
1	GNet Name	SDB Sub Name	In SDB?	Short Sub Name (For Forecast Tag)	Designator	Forecast Tag ID
36	FIRST WIND KAHUKU WIND FARM	KAHIPA	yes	KAHIPA	0	KAHIPA_0
37						

##

Site AWSID: KAP HECO NAME: First Wind Kahuku Wind Farm Island: Oahu SUBSTATION NAME: Kahipa FORECAST NAME: KAHIPA_0

Type Power Forecast

Location LAT 21.66610 LON -157.99970

Probability And Ramp

##

Developed common headers between Forecast, GIS and EMS to upload data without manual intervention

AWS Forecast Column to SDB Forecast Point

SDB

- All forecast file data stored in FORECAST station
- FORECAST Tags follow a convention:
  - ANALOG:FORECAST.<substation short name>_<designator>_ <forecast value name>

Forecast Tag ID

Forecast Column	Forecast Value Name
POE 0	P0
POE 20	P2
POE 40	P4
POE 50	P5
POE 60	P6
POE 80	P8
POE 100	P10

Forecast Column	Forecast Value Name
Up Ramp Level 1	UP1
Down Ramp Level 1	DN1
Up Ramp Level 2	UP2
Down Ramp Level 2	DN2
Up Ramp Level 3	UP3
Down Ramp Level 3	DN3
Up Ramp Level 4	UP4
Down Ramp Level 4	DN4

Example of Mapping Substation + Facility Forecast

- Convention: ANALOG:FORECAST.<sub short name>_<designator>_<forecast value name>
- 0, 20, 40, 50, 60, 80, 100 POE values + 4 Ramp Up Levels + 4 Ramp Down Levels
- SDB station will have calculated forecast point

AWS Forecast

Facility Name	Forecast Name
…	
FIRST WIND KAHUKU WIND FARM	KAHIPA_0
…	
KAHIPA	KAHIPA_A
…	

SDB Forecast Points

ANALOG:FORECAST.KAHIPA_0_P0
…
ANALOG:FORECAST.KAHIPA_0_P10
ANALOG:FORECAST.KAHIPA_0_UP1
…
ANALOG:FORECAST.KAHIPA_0_DN4

ANALOG:FORECAST.KAHIPA_A_P00
…
ANALOG:FORECAST.KAHIPA_A_P100
ANALOG:FORECAST.KAHIPA_A_UP1
…
ANALOG:FORECAST.KAHIPA_A_DN4

ANALOG:FORECAST.KAHIPA_Z_P00
…
ANALOG:FORECAST.KAHIPA_Z_P100
ANALOG:FORECAST.KAHIPA_Z_UP1
…
ANALOG:FORECAST.KAHIPA_Z_DN4

_X_ Designator denotes type of forecast:
[0-9] Facility Forecast
[A-Y] Solar DG Forecast

Calculated **_Z_** tags will aggregate substation forecast tags with designators [0-9] and [A-Y]

DG Forecast Example

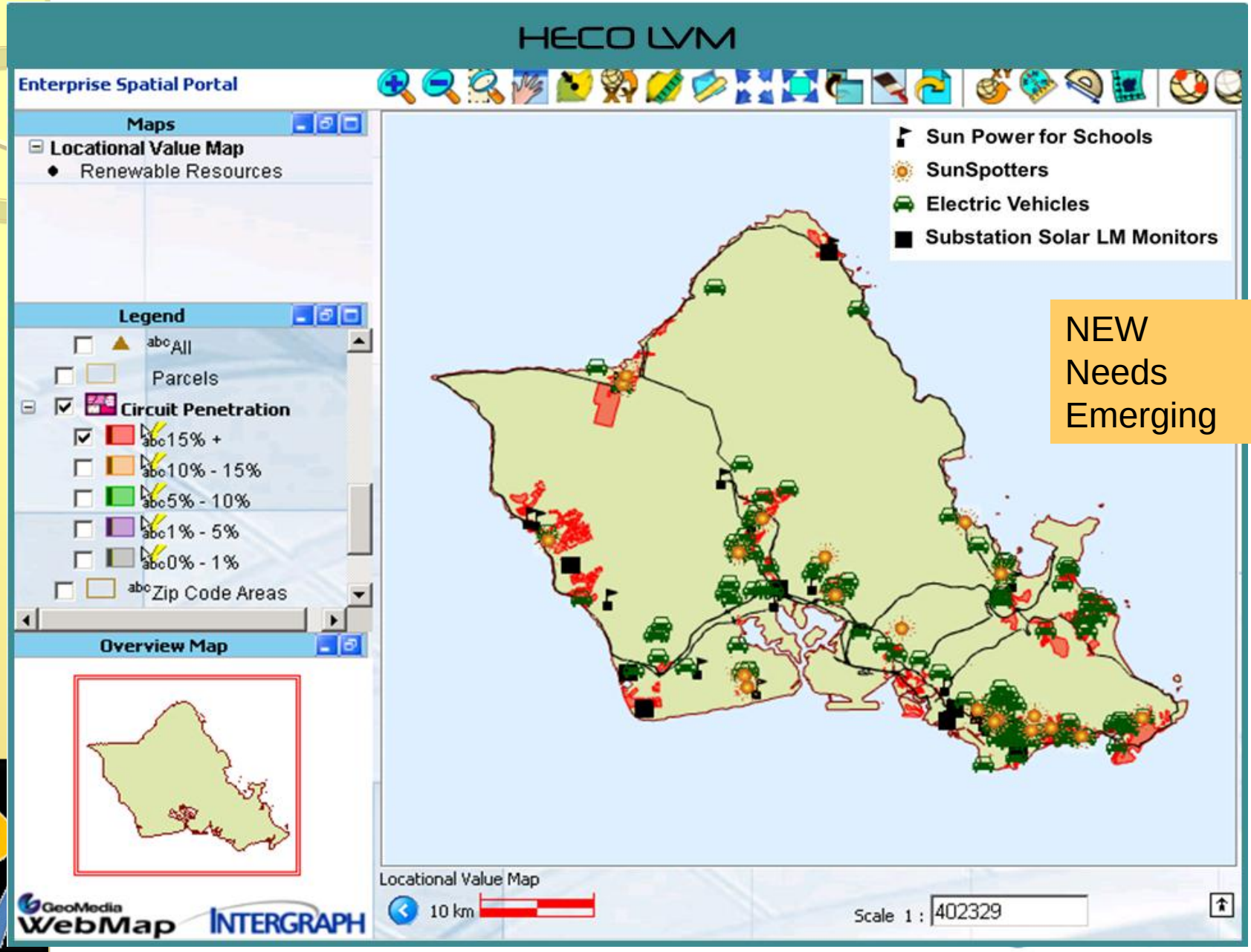
Facility Forecast Example

CIM Model to SDB Mapping

CIM Model	CIM Name	SDB Station Name	SDB Stations
AES	AES	AES	AES
AHI	AHI	AHI	AHI
AIEA	AIEA	AIEA	AIEA
AIKAHI	AIKAHI	AIKAHI	AIKAHI
AINA KOA	AINA KOA	AINAKOA	AINA KOA
AIRPORT	AIRPORT	AIRPORT	AIRPORT
ALIAMANU	ALIAMANU	ALIAMANU	ALIAMANU
ARCHER	ARCHER	ARCHER	ARCHER
BARBERS PT SW STA A	BARBERS PT SW STA A	BARBERS_PT_A	BARBERS_PT_A
...	...		...
WOODLAWN	WOODLAWN	WOODLAWN	WOODLAWN

* Add new SDB Station if not already contained from existing SDB

More Change on the Horizon



Lessons Learned

- Model enhancements
  - Enhanced models & Proactive methodology
  - Data needs for T&D studies
- Monitoring & forecasting capabilities
  - Sensor deployment & statistical analysis
  - Validation to establish utility confidence
- Visualization tools
  - Seeing is Believing
  - Real-time information to help utilities better see impact of renewables and integrate information into planning & Ops
  - Transparency to the public
  - Increase awareness by workforce on value of renewables
  - Sharing of integration experience through industry forums & utility venues
  - Continuing collaboration to seek internal and federal funding

Project Benefits/Continuing Outreach Efforts

- Addressed People, Process & Technology Enhancements
  - CSI funded effort helped small utilities like HECO & SMUD address high penetration needs and was one of the first efforts to focus awareness of distributed RE impacts on system
  - Efforts provided impetus for industry (EMS, forecasting, model providers, standards, regulatory) to partner & focus on integrated solutions
  - Funds jumpstarted lasting initiatives that are being adopted into HECO Companies processes and regulatory recommendations (Interconnection standards, RSWG)
- Effort resulted in numerous technical presentations & papers (IEEE, AWEA, SEPA, Distributech, EPRI, CPUC/DOE joint meetings) throughout project period to inform market product development and industry standards development
- Efforts having long-lasting impact
  - Utility/vendor partnering to further develop and operationalize visualization tools (EMS, forecasting, online tools)
  - Collaborative proposal for industry and federal funding (FOA, laboratory & training center)

SMUD HIGH PENETRATION PV TASK 5: PV PRODUCTION FORECASTING FINAL REPORT

NEO Virtus Engineering, Inc.
June 5, 2013

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Littleton, MA 01460
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Task 5: PV Production Forecasting

- BACKGROUND
- HIGH PENETRATION PV TASK 5: PV PRODUCTION FORECASTING
- CONCLUSIONS
- FUTURE WORK

BACKGROUND

- Solar power forecasting in 2010
- SMUD Validation of forecast claims
- NEO day ahead forecasting patent method

Solar Power Forecasting in 2010

- DOE & CPUC Anticipate Challenges with Grid Integration of High Penetration PV
- Emerging Forecast Technologies:
  - NWP,
  - Satellite imaging,
  - Ground based sensor models
- Emerging Standards & Metrics for Solar Forecasting

SMUD Validation of Forecast Claims

- SMUD 100MW FIT online by 12/2012
- Lack of performance benchmarks for forecast products
- SMUD performance comparison solicitation
- SMUD-NEO Irradiance (SNI) network to provide wide area reference data

NEO Day Ahead Forecasting Patent Method

- Relevant Patents:
  - 2002 NEO starts patent work
  - 2004 solar forecast patent applied for
  - 2008 European Patent Office No. 1660917."Method And System For Predicting Solar Energy Production"
  - 2009 US Patent No. 7,580,817 "Method and System for Predicting Solar Energy Production"
  - 2012 US Patent No. "Method and System for Predicting Solar Energy Production" additional claims (energy trading)

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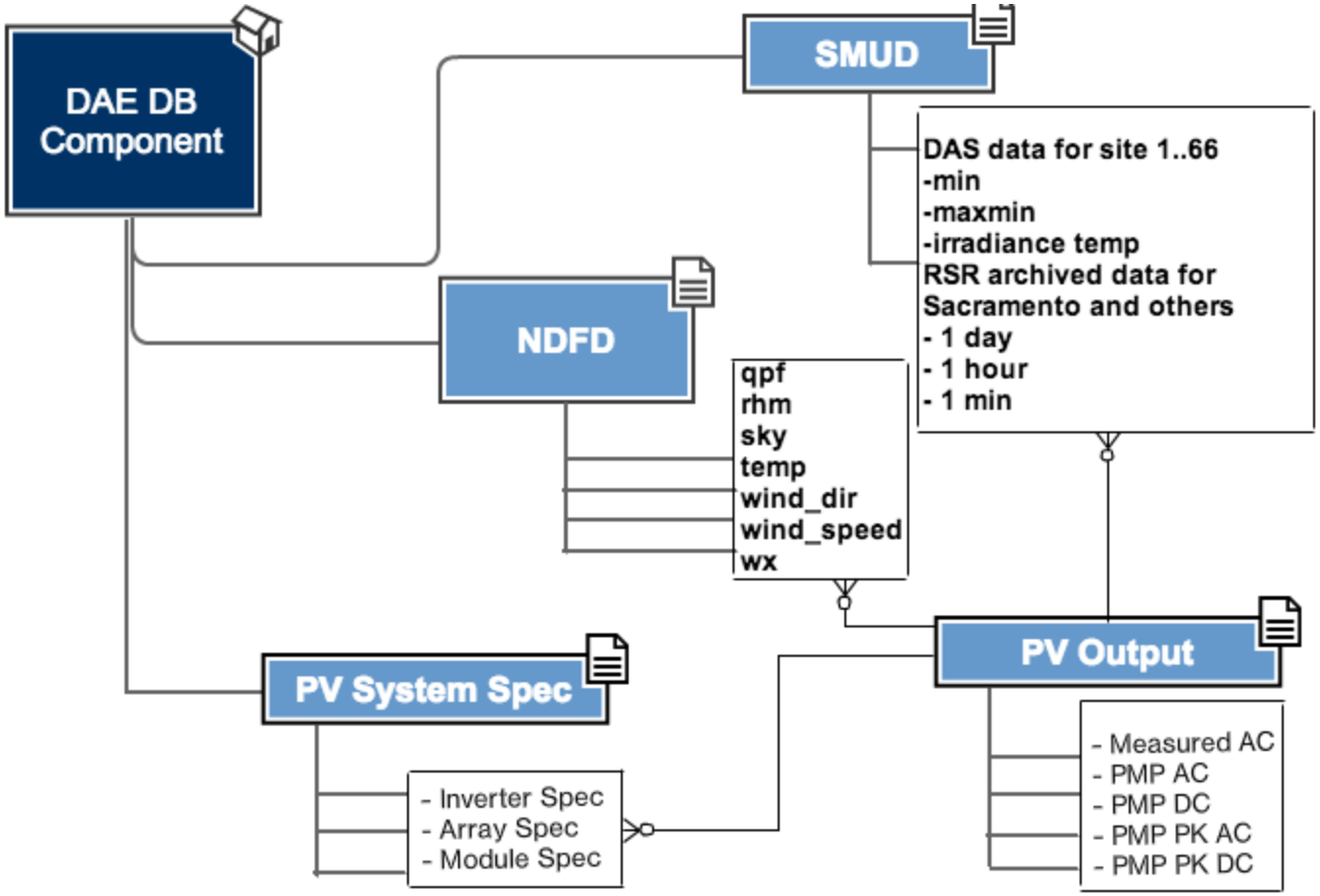
HIGH PENETRATION PV TASK 5: PV PRODUCTION FORECASTING

- 5.1 Irradiance Monitoring Network
- 5.2 20-36 Hour Ahead Forecasting
- 5.3 0-3 Hour Ahead Forecasting
- 5.4 Validation

5.1 Irradiance Monitoring Network

- Design, procure, build, program primary & secondary stations
- Develop relational database (MySQL)
  - NDFD forecast data retrieval
  - Primary & secondary station automated data retrieval
  - Integration of REST2 algorithm
  - Integration of PV system geometry & shading obstruction algorithm
  - Integration of PV system parameters in Sacramento test area

5.1 Irradiance Monitoring Network

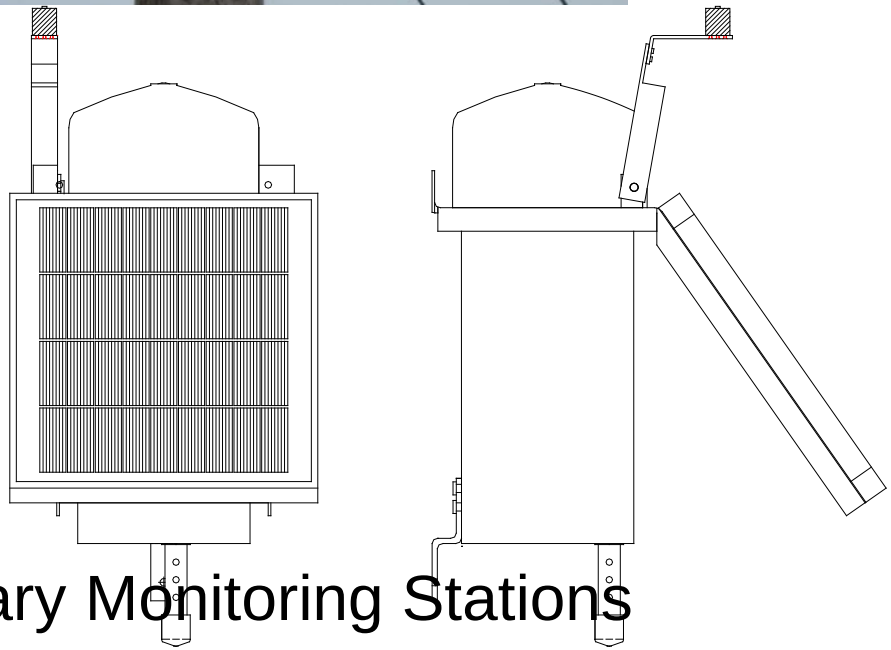


SMUD-NEO Irradiance Network Entity Relationship Diagram

5.1 Irradiance Monitoring Network

- 72-Sensor network deployed in SMUD service territory
  - 5 Primary Rotating Shadowband Radiometers (RSR)
  - 66 Secondary stations
  - 1 existing primary station RSR, owned by NREL
- Unprecedented scale of irradiance data:
  - Covers 2330 square kilometer service territory
  - 2 second sampling rate w/1 minute records

5.1 Irradiance Monitoring Network

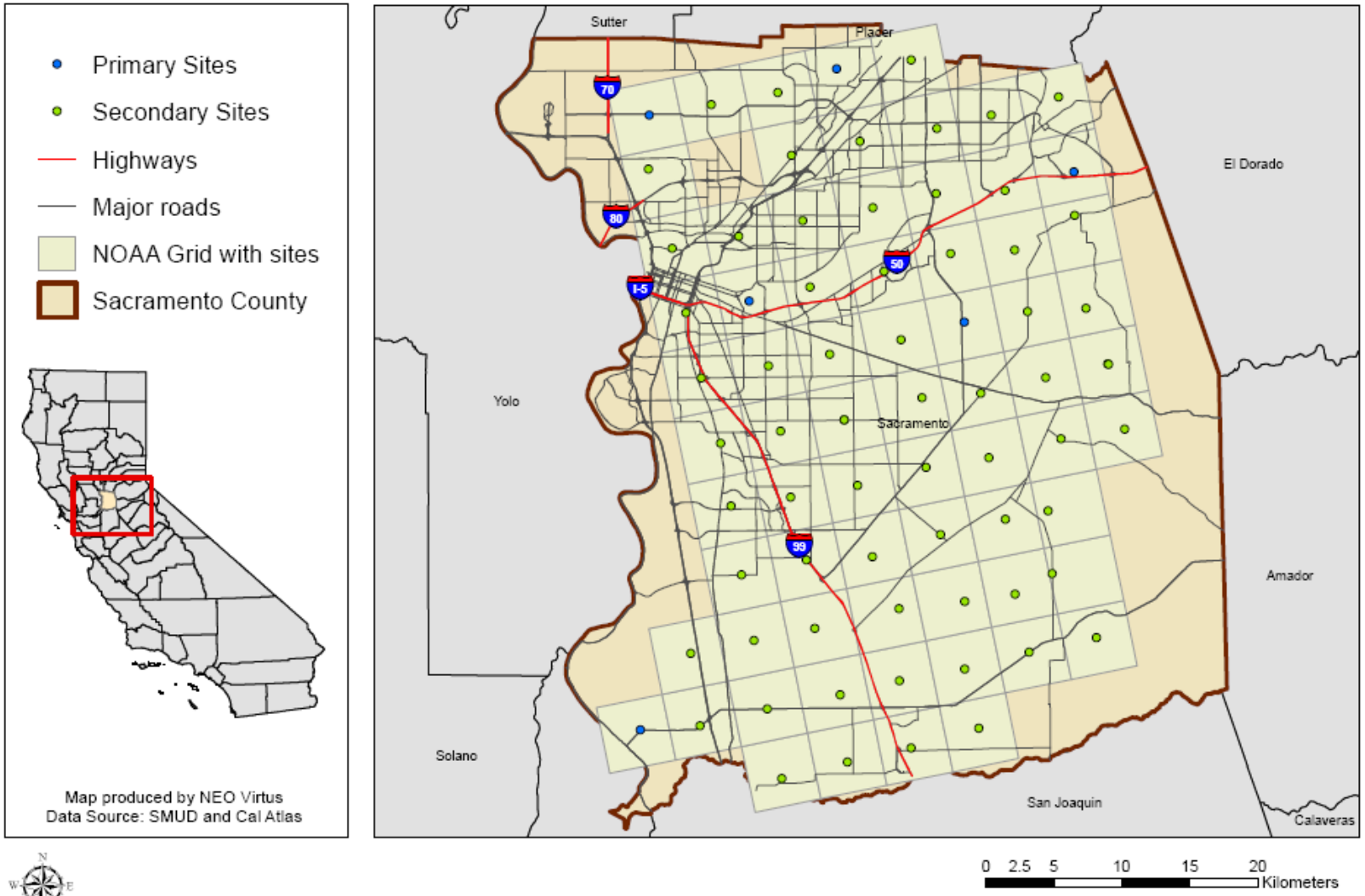


Primary & Secondary Monitoring Stations

5.1 Irradiance Monitoring Network

- Data systems hardware
  - Campbell Scientific data logger based systems
  - Cellular modems
  - Licor silicon pyranometers
  - Autonomous power systems
- Primary stations
  - 1 minute records: DNI, DHI, GHI, ambient temp
  - Ground mount tripod
- Secondary stations
  - 1 minute records: GHI, ambient temp
  - Daily battery max & min
  - Utility pole mount

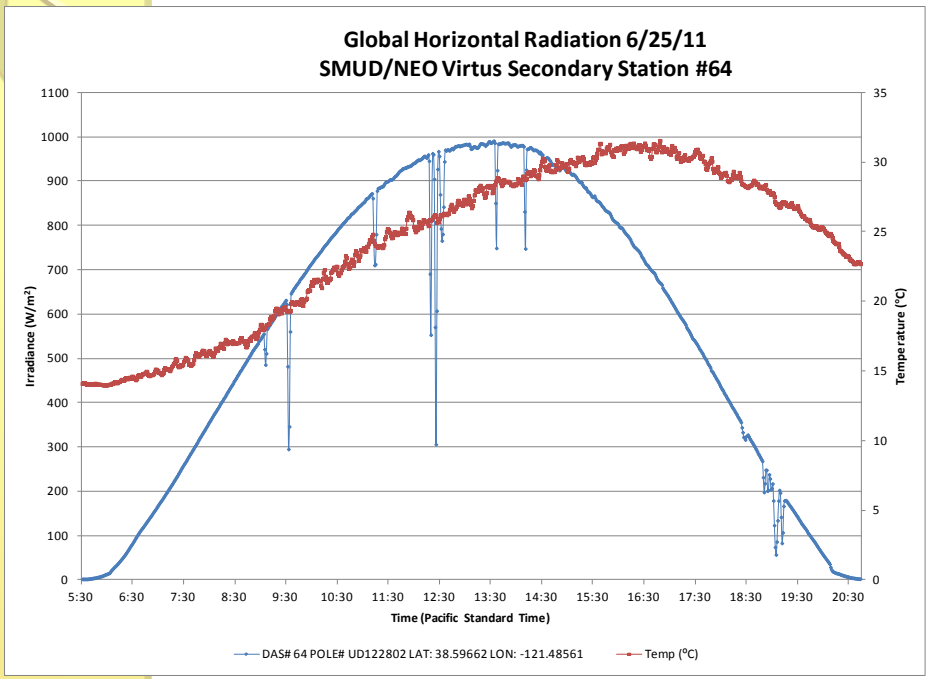
5.1 Irradiance Monitoring Network

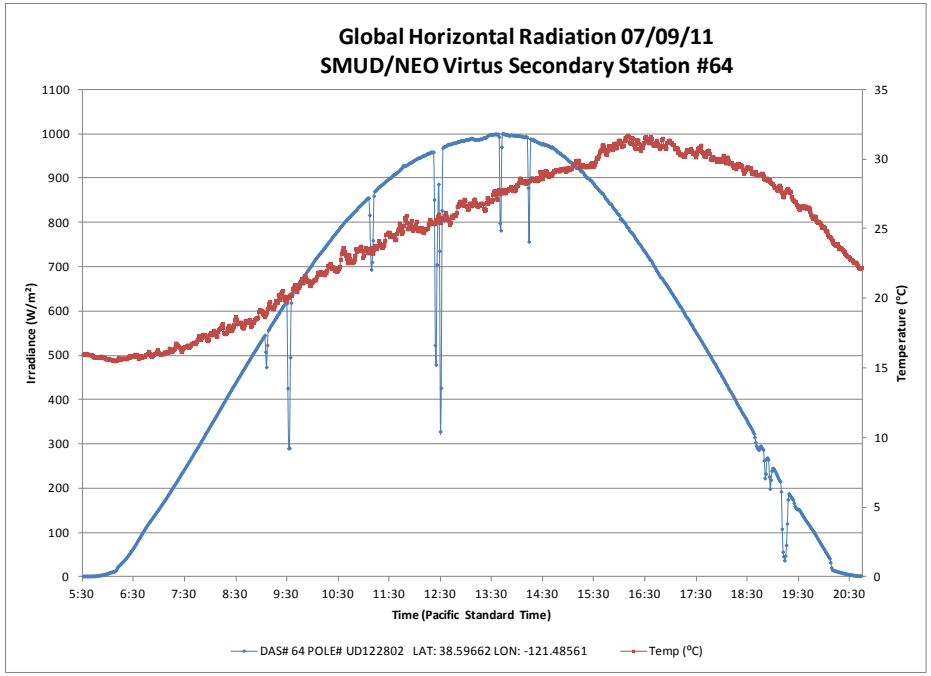


5.1 Irradiance Monitoring Network

- 98.5% of the database is complete
- Failure rates:
  - 6/11-5/12: 8 units
  - 6/12-5/13: 5 units
- MTBF: 3706 days (10.1 years)
- Network service duration
  - Original installation term 14 months
  - 24 months continuous as of 5/31/2013

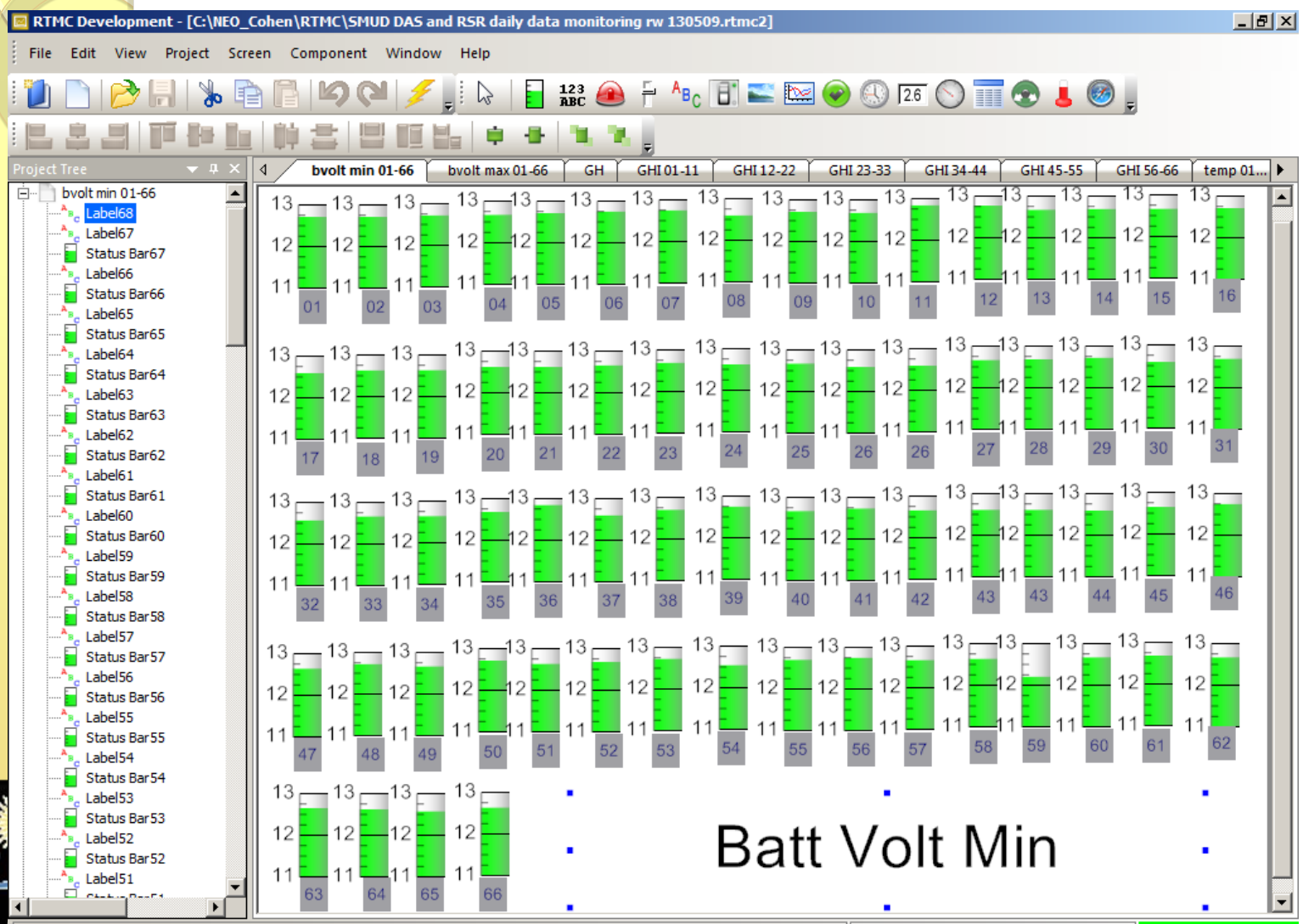
5.1 Irradiance Monitoring Network





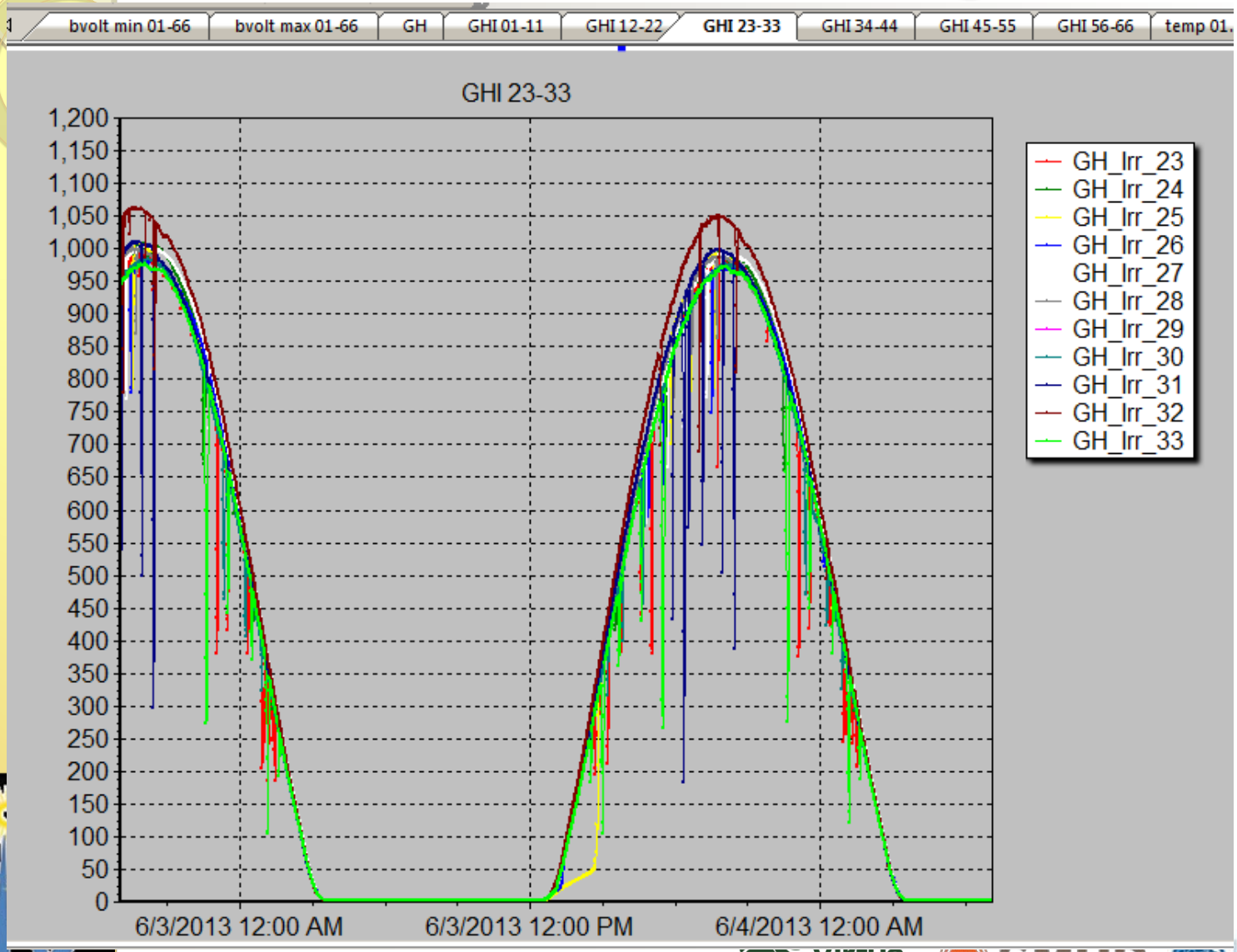
Overhead Wire Shading Anomalies

5.1 Irradiance Monitoring Network



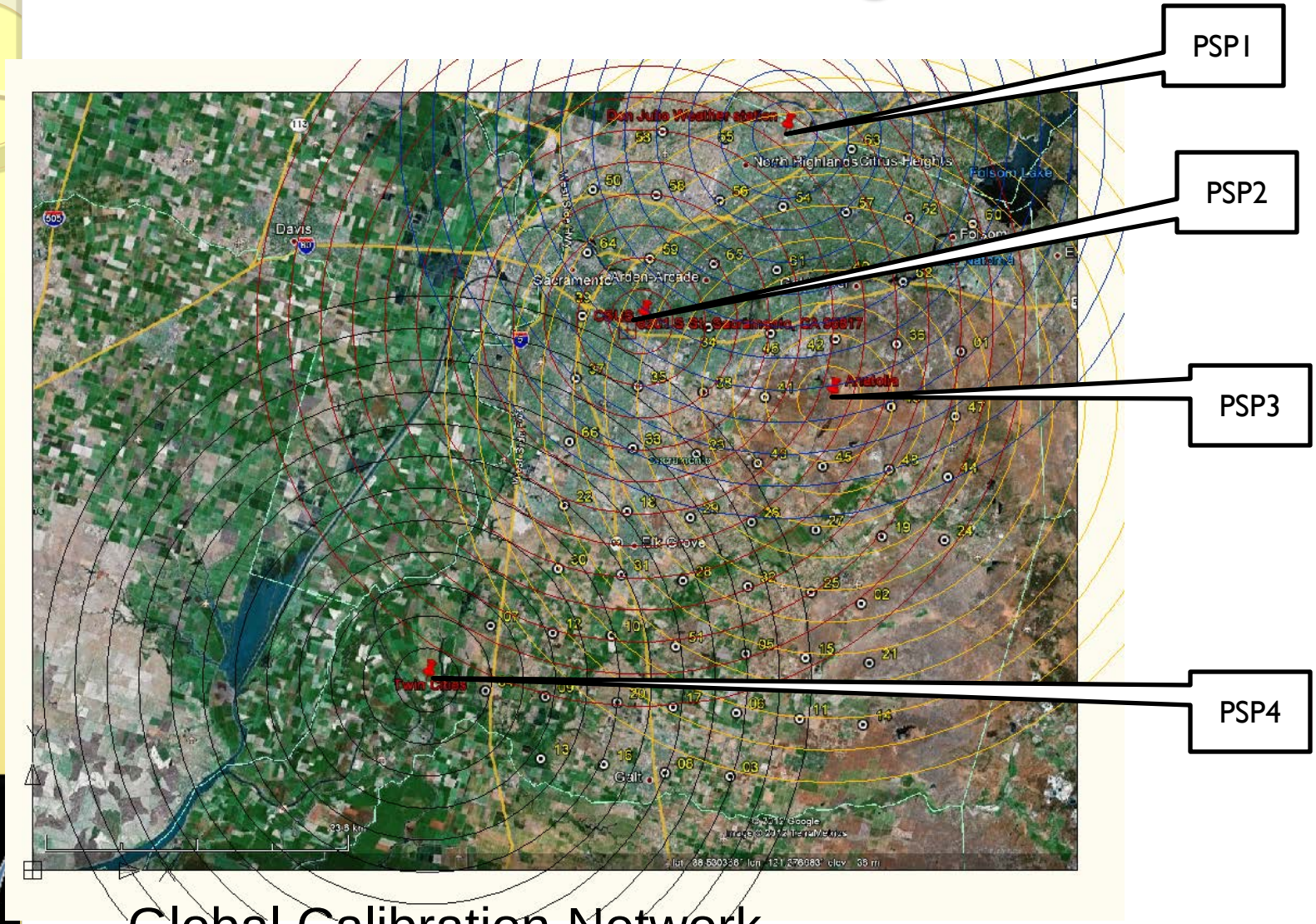
Battery Max/Min Daily Tracking

5.1 Irradiance Monitoring Network



Daily System Quality Assurance

5.1 Irradiance Monitoring Network



Global Calibration Network

5.1 Irradiance Monitoring Network

Station Number	Station Lat	Station Long	GRID Cell Number	Grid Cell Centroid Lat	Grid Cell Centroid Long	SMUD Pole Number	Location description	DAI09 Temp Probe S/N	Pyranometer S/N
99 prototpye	38.55?	-121.43?					SMUD headquarters roof	-	
00 prototype							Shipped to CA with JB	-	PY71690
01 Prototype	38.345556	121.116389					Rancho Seco	-	PY71689
01P	38.616167	-121.146459	88	38.604424	-121.1406	UD073936		DAI09-001	PY67429
01RP	38.616167	-121.146459	88	38.604424	-121.1406	UD073936	NEO Lab	DAI09-067	PY71689
01R2	38.616167	-121.146459	88	38.604424	-121.1406	UD073936		DAI09-038	PY70403
02P	38.420168	-121.171439	46	38.421758	-121.152778	UD052549		DAI09-002	PY69893
02R	38.420168	-121.171439	46	38.421758	-121.152778	UD052549		DAI09-034	PY70399
03	38.276593	-121.231050	11	38.274002	-121.231283	UD026145		DAI09-003	PY69894
04P	38.279507	-121.465403	18	38.283269	-121.464236	UD009060		DAI09-004	PY69895
04R	38.279507	-121.465403	18	38.283269	-121.464236	UD009060		DAI09-010	PY70066

Pyranometer Multiplier	Data logger S/N	Modem S/N	Modem IMEI#	Modem ICCID#	Phone Number	Modem I.P. Address	Pyranometer Multiplier
-11.70	12341					6067b688.eairlink.co	-11.71
-10.25	12342	1042528231			1-978-416-4618	166.130.6.170	-10.26
-11.75						166.130.6.171	-11.75
-11.70	12341	1042528507	353229022857534	89014104232574076625	(978) 496-5193	166.130.6.171	-11.70
-11.75	12916	1052570272	353229023417957	89014103253947600000	(978)727-7589	166.131.24.198	-11.75
-10.27	12542	1103570430	353229023428053	89014104253903269251	(978) 727-7423	166.131.24.170	-10.28
-9.71	12343	1052570624	353229023382722	8901 4104 2538 9540 6374	1-978-727-3294	166.131.24.138	-9.72
-10.28	14838	1102570166	353229023390485	89014104253895662125	(978) 727-7420	166.131.24.173	-10.28
-10.62	12344	1052570886	353229023382706	8901 4104 2538 9540 6358	1-978-496-7328	166.131.24.136	-10.62
-10.36	12345	1052570294	353229023417825	8901 4104 2538 9540 6390	1-978-727-2918	166.131.24.140	-10.36
-10.66	12395	1052570341	353229023417726	8901 4104 2538 9540 6333	1-978-727-2507	166.131.24.134	-10.66

First Date in Data File	Date of Deployment onto Pole	Last Good Data Collection	Last Date of Deploy-ment Or Present	Duration of Deployment (days)	Duration of Data Gaps if any (days)	Duration of Good Data Set (days)	Unit Good Uptime (%)	3/5/12 01	3/5/12 05	3/6/12 10	3/6/12 11	3/7/12 11
5/26/2011	06/22/2011	6/22/11	10/17/11	117	0	0	0%					
11/7/11	10/17/2011	1/2/12	3/21/12	156	0	77	49%	x	x	x	x	x
[redacted]	3/21/12	6/4/13	6/4/13	440	0	440	100%	n/a	n.a	n/a	n/a	n/a
5/1/2011	04/11/2011	1/19/12	3/21/12	345	0	283	82%	-83	-81	-83	-83	-79
3/21/2011	3/21/12	6/4/13	6/4/13	440	0	440	100%	-99	-89	-93	-97	-91
4/[illegible]/11	04/07/2011	6/4/13	6/4/13	789	0	789	100%	-69	-69	-69	-71	-71
5/1/2011	04/06/2011	6/4/13	6/4/13	790	14	776	98%	-79	-77	-77	-79	-77
4/[illegible]	04/07/2011	6/4/13	6/4/13	789	0	789	100%	off	off	-77	-77	off

Secondary System Tracking Spreadsheet

NEO Virtus Engineering, Inc. SMUD™ Hawaiian Electric Company Maui Electric Company Hawaii Electric Light Company

5.2 20-36 Hour Ahead Forecasting

- Gueymard REST2 Model:
  - Calculation of GHI, DNI, DHI
  - Integration of PV FIT system geometry to calculate GTI (GTI = Global Tilt Irradiance; also POA)
  - Integration of self shading & near shading algorithm
- Photovoltaic Generation Model (Sandia Model) Integration
- 20-36 Hour Feed-Forward PV Forecasting Model Integration (22-40 Hours for SMUD Energy Trading)

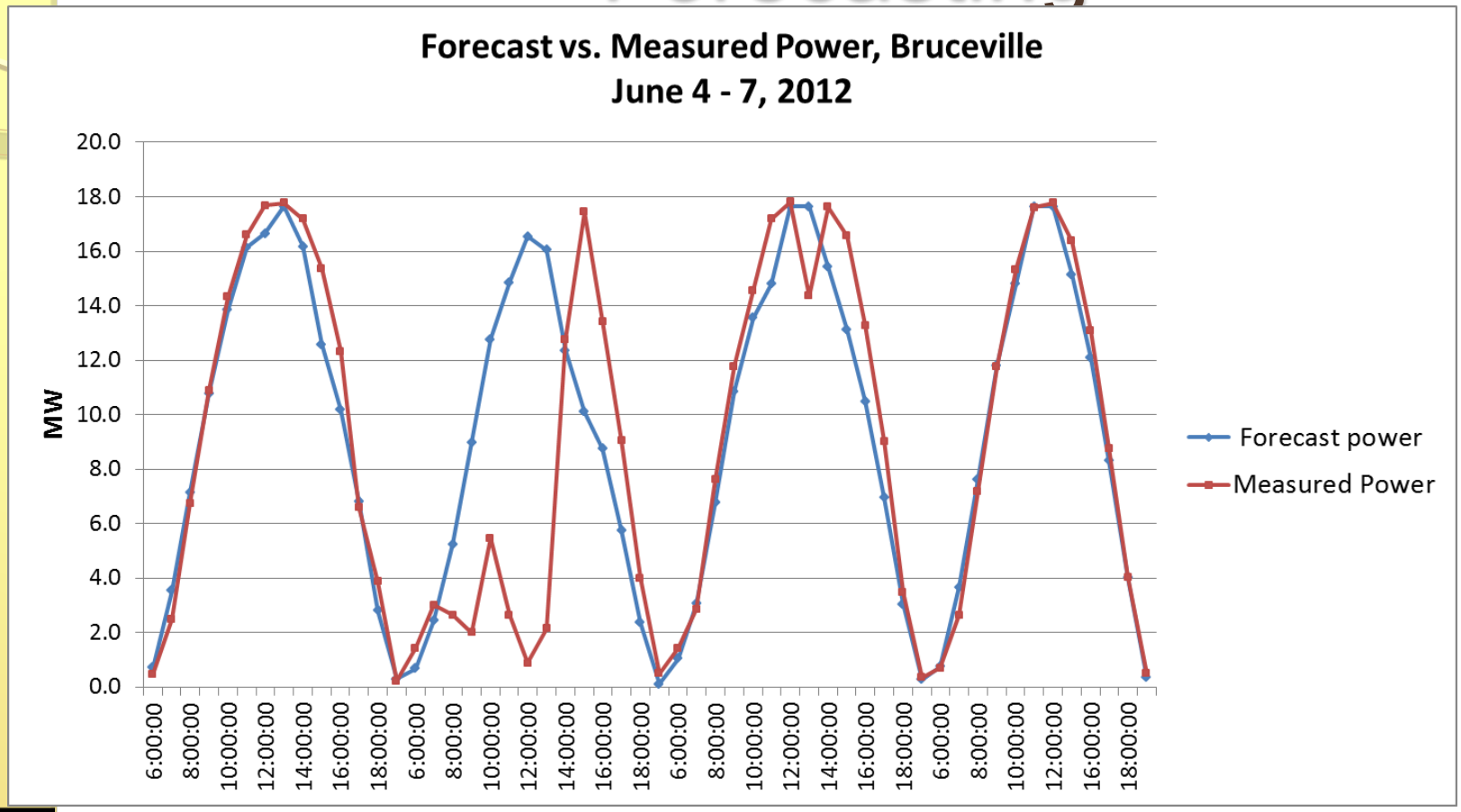
5.2 20-36 Hour Ahead Forecasting

Fetch NDFD Met Data → Collect Site System Data → Run REST2 Irradiance Model → REST2 Calculates DNI, DHI, GHI & GTI → Sandia PV Model Calculates Pdc → NEO System Model Calculates Pac

5.2 20-36 Hour Ahead Forecasting

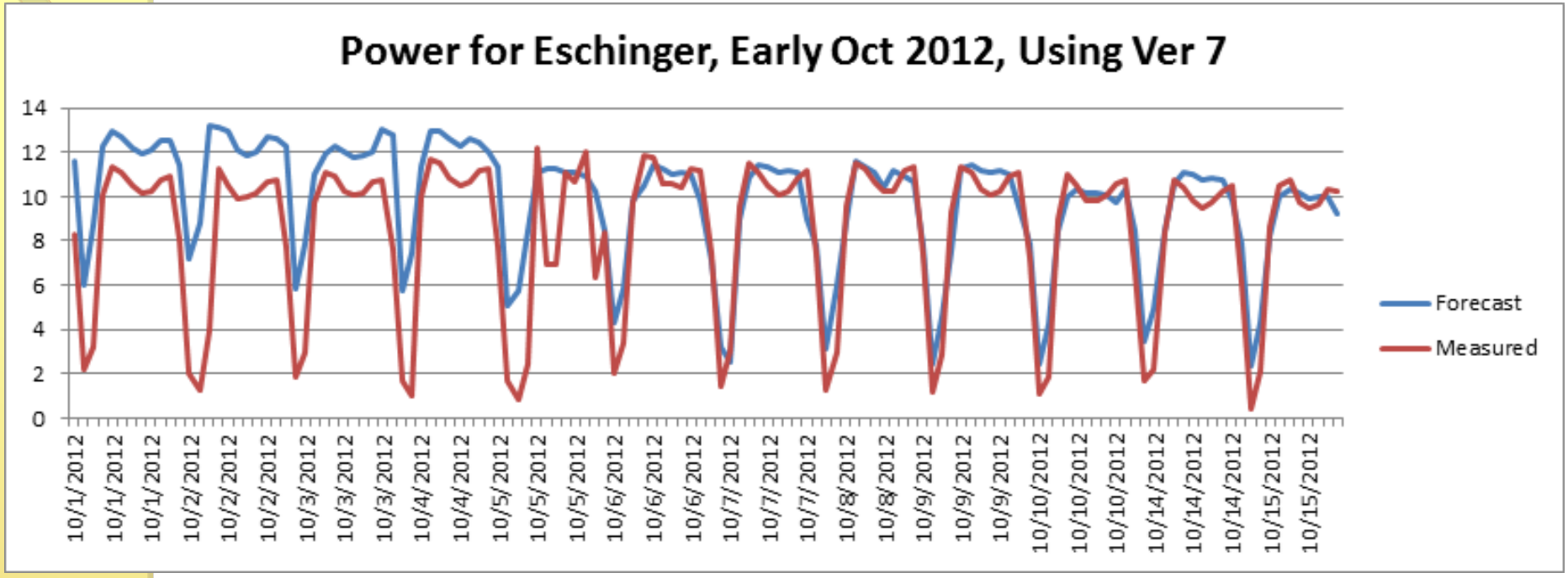
- Network wide (72 sites) GHI forecasting
- FIT system production forecasting 4 sites (30MW)
  - Bruceville, Kost, Boessow, Point Pleasant
  - Daily since June 2012
- FIT system production hind cast 8 sites (94.4MW)
  - Bruceville, Kost, Boessow, Point Pleasant, Dillard, Kammerer, Eschinger, McKenize
  - May 1, 2012 - April 30, 2013

5.2 20-36 Hour Ahead Forecasting



NEO's Day Ahead Forecast vs. Measured PV Production Bruceville 18MW (fixed tilt array)

5.2 20-36 Hour Ahead Forecasting

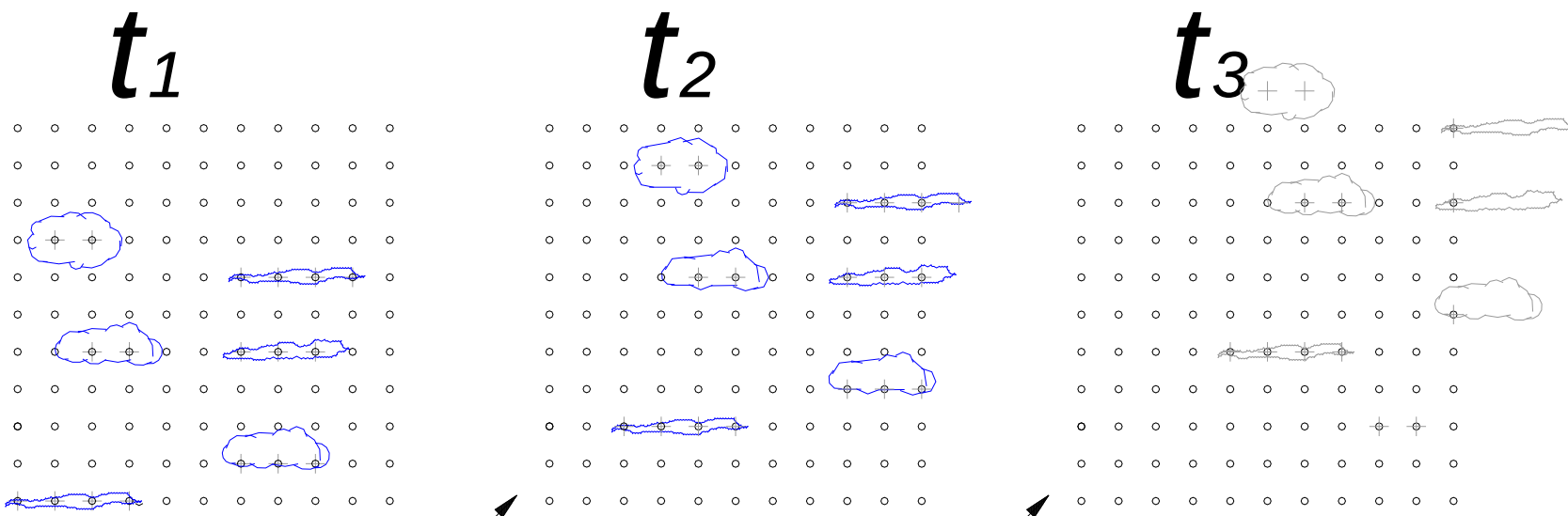


NEO's Day Ahead Forecast vs. Measured PV Production Eschinger 15MW (1-axis tracking array)

5.3 0-3 Hour Ahead Forecasting

- Develop 0-3 Hour Forecasting Algorithm
- Original concept ground level irradiance vector motion
- Only one day (6/22/2013) with cloud front large enough to resolve due to 5km spacing of sensors

5.3 0-3 Hour Ahead Forecasting



IRRADIANCE IMAGE (CROSSES) SYNTHESIZED FROM SENSOR NETWORK (CIRCLES), AT TIME t1, FOR A SCATTERED CLOUD EXAMPLE.

IRRADIANCE IMAGE (CROSSES) SYNTHESIZED FROM SENSOR NETWORK (CIRCLES), AT TIME t2, FOR A SCATTERED CLOUD EXAMPLE. MOTION VECTOR DERIVED FROM IMAGES 1 AND 2.

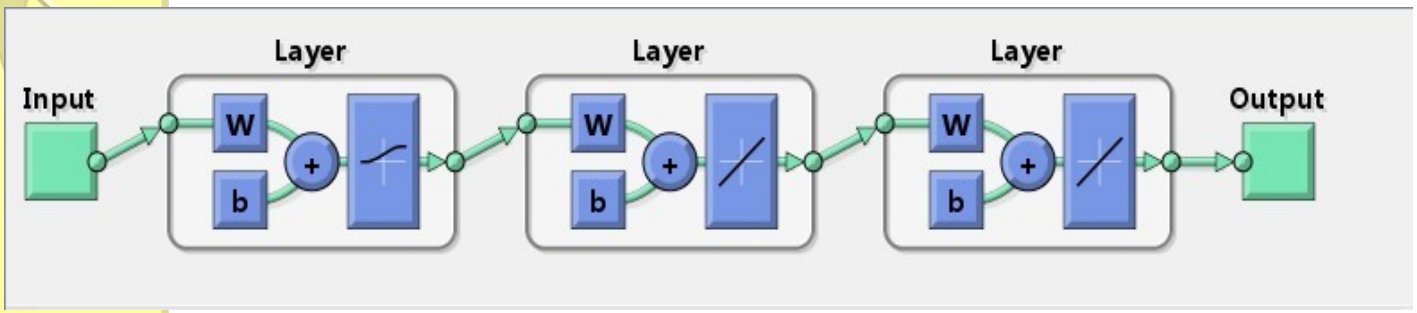
FUTURE IRRADIANCE IMAGE (CROSSES) SYNTHESIZED FROM IRRADIANCE IMAGE AT TIME t2 AND MOTION VECTOR DERIVED FROM IMAGES AT t1 AND t2, FOR A SCATTERED CLOUD EXAMPLE.

Original concept ground level irradiance vector motion was unachievable due to the coarseness of the 5km sensor network.

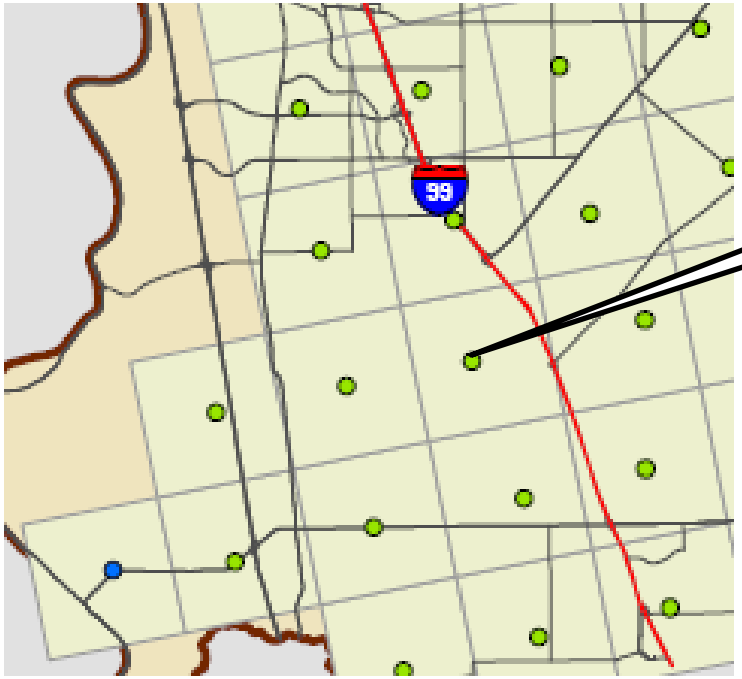
5.3 0-3 Hour Ahead Forecasting

- Switched to neural network forecasting of individual sensors
- Wichita State University model
  - Trains model with three months of data
  - Uses primary sensors and adjacent sensors as inputs
  - Uses three hours preceding to forecast three hours forward

5.3 0-3 Hour Ahead Forecasting

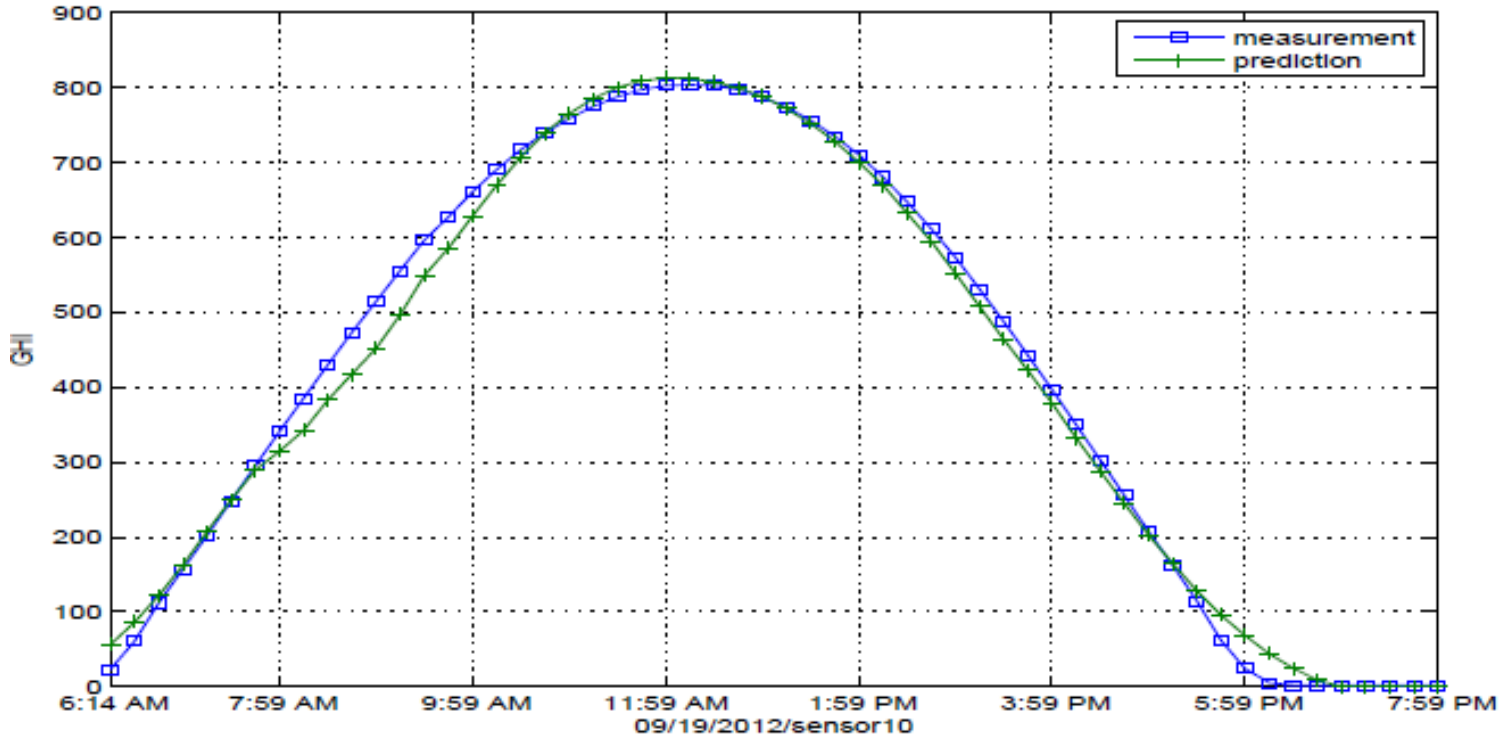


Neural network multi-layer structure



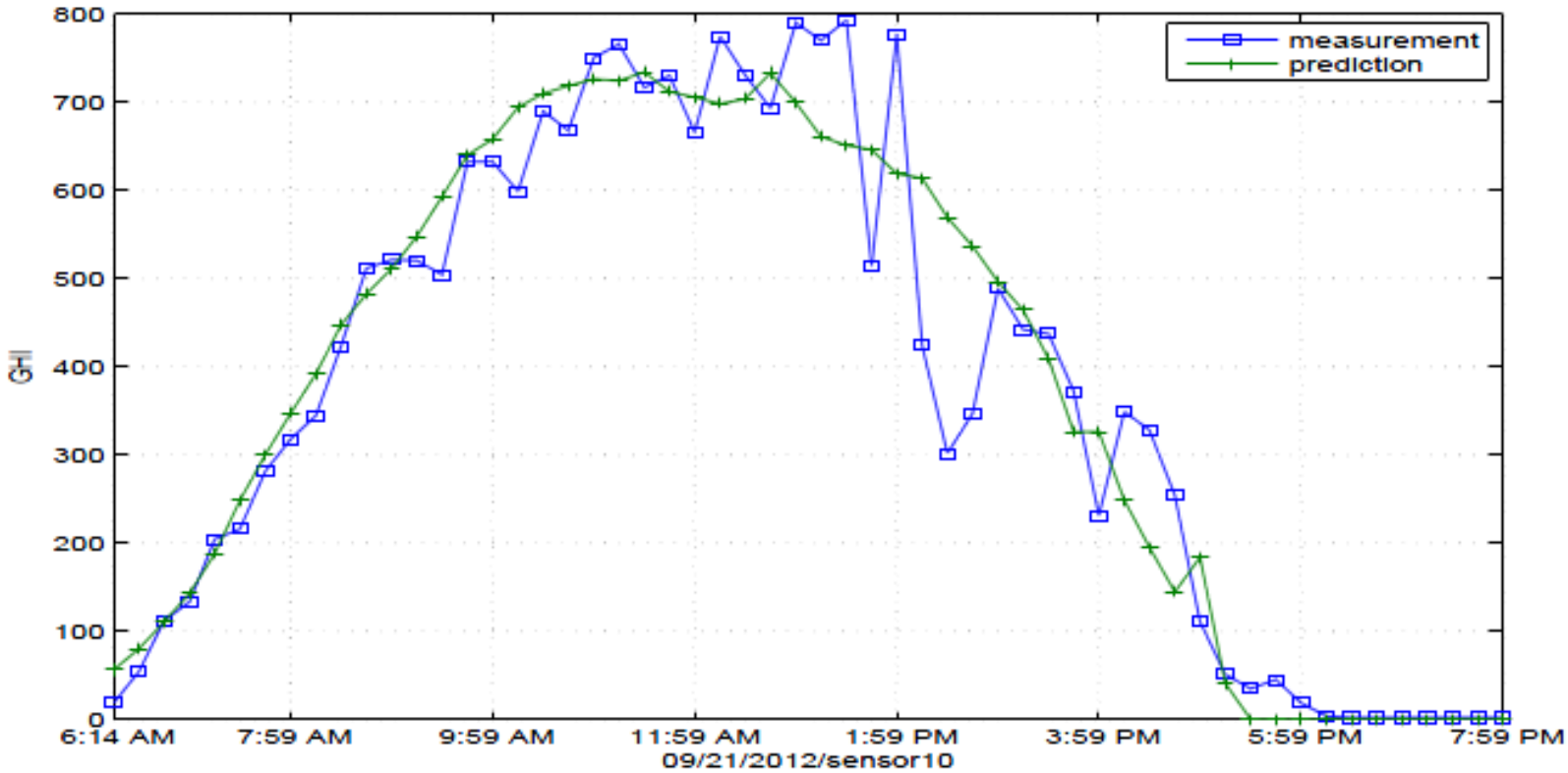
Single sensor forecast from adjacent sensors

5.3 0-3 Hour Ahead Forecasting



Sensor 10, 9/19/2012

5.3 0-3 Hour Ahead Forecasting



Sensor 10, 9/21/2012

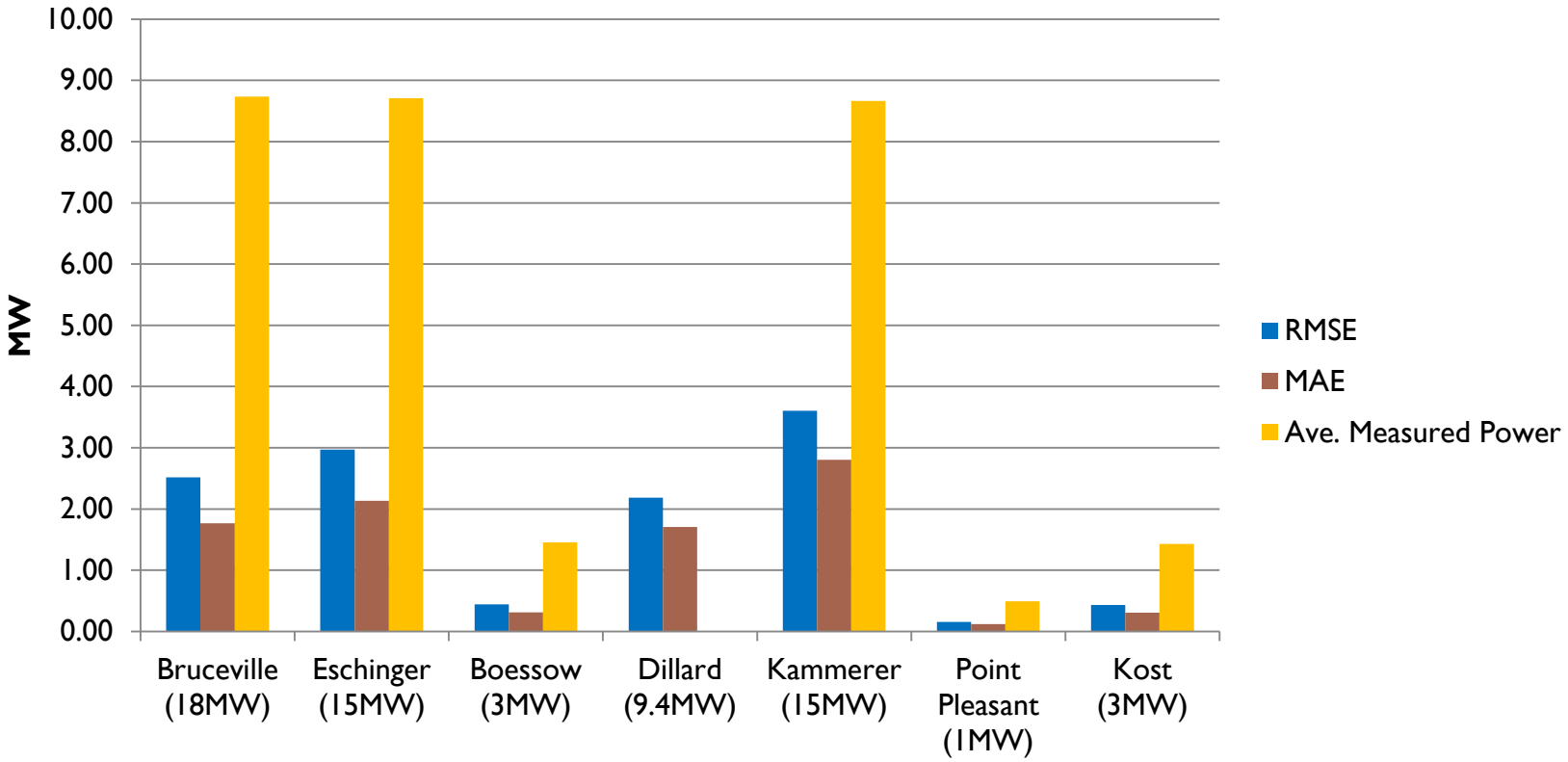
5.4 Validation

- Validation of forecast results
  - Measured irradiance data
  - Measured PV system production data
- Validate Irradiance 22-40 Hour Forecast Model
  - Production data: 5/1/12 to 4/30/13
- Validate Irradiance 0-3 Hour Forecast Model
  - Cleaned/Interpolated GHI data: 5/31/12 to 12/12/12??????

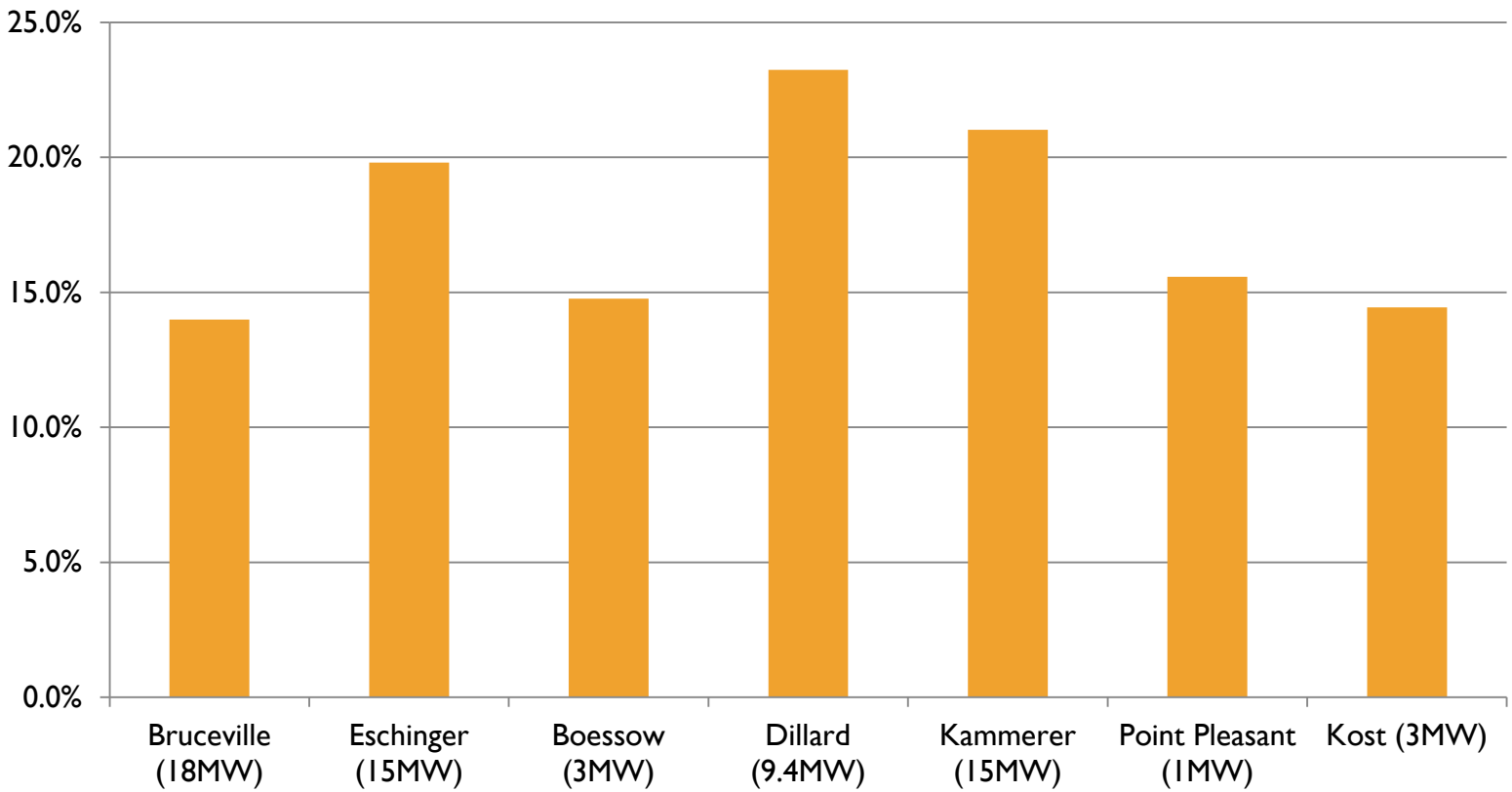
5.4 Validation

- Solar Forecasting Metrics
  - "Reporting Of Irradiance Model Relative Errors"; Hoff, Kleissl, Perez, Stein, Renne
    - RMSE
    - MAE
    - RMSE/Capacity
    - MAE/Average
  - Filter for zenith angle >90 (no night time data)
  - Choice of full year or selected days

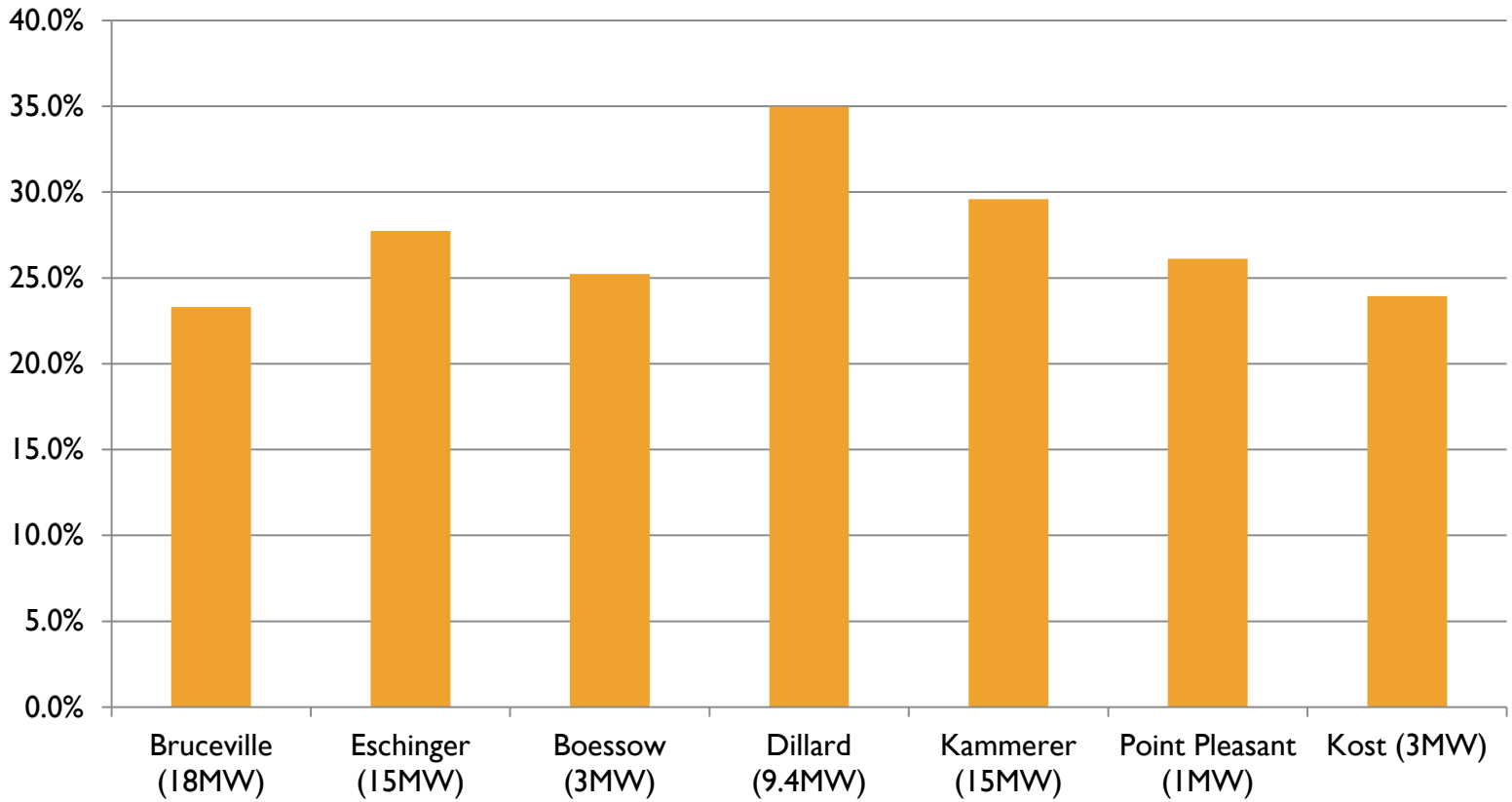
5.4 Validation: Absolute Metrics



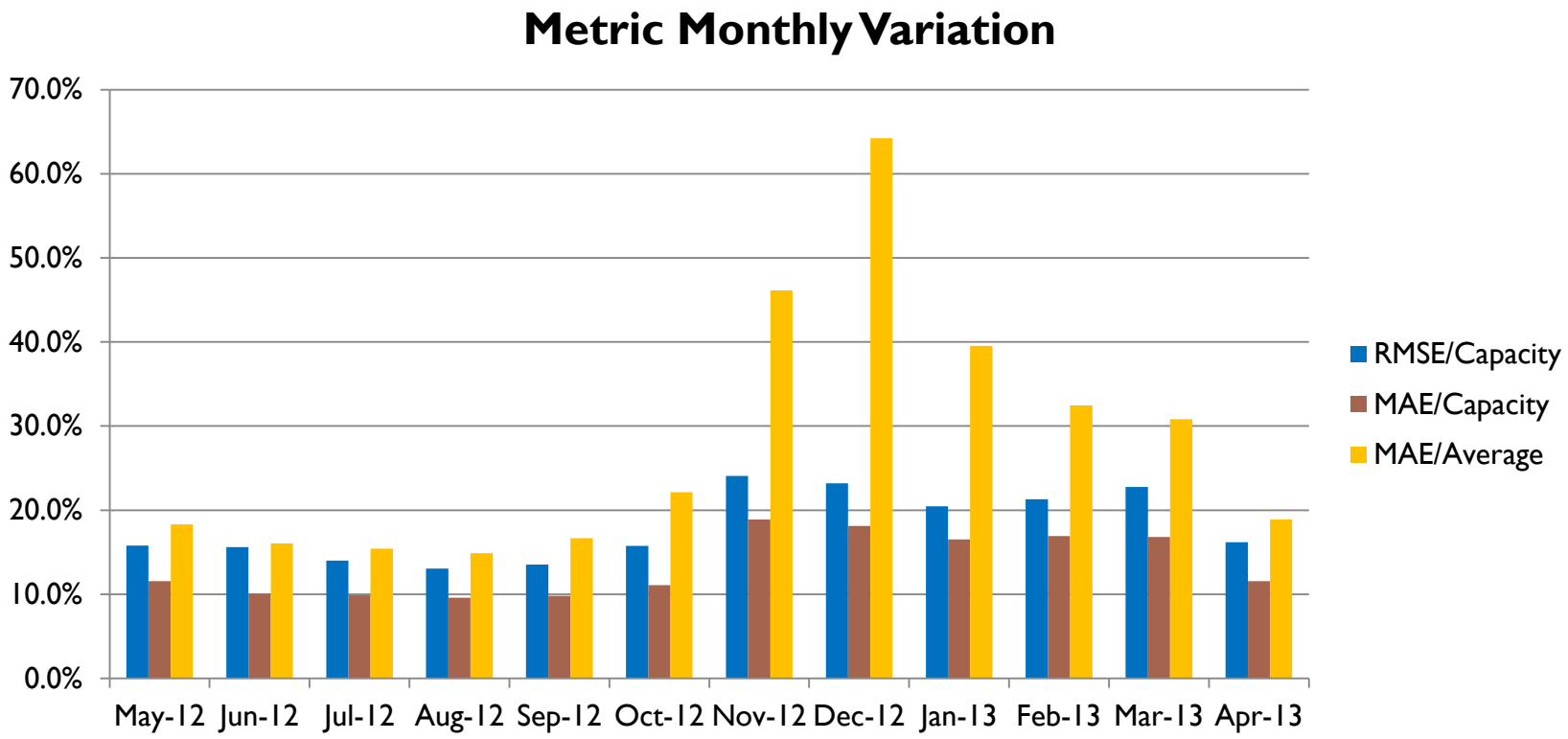
5.4 Validation: RMSE/Capacity



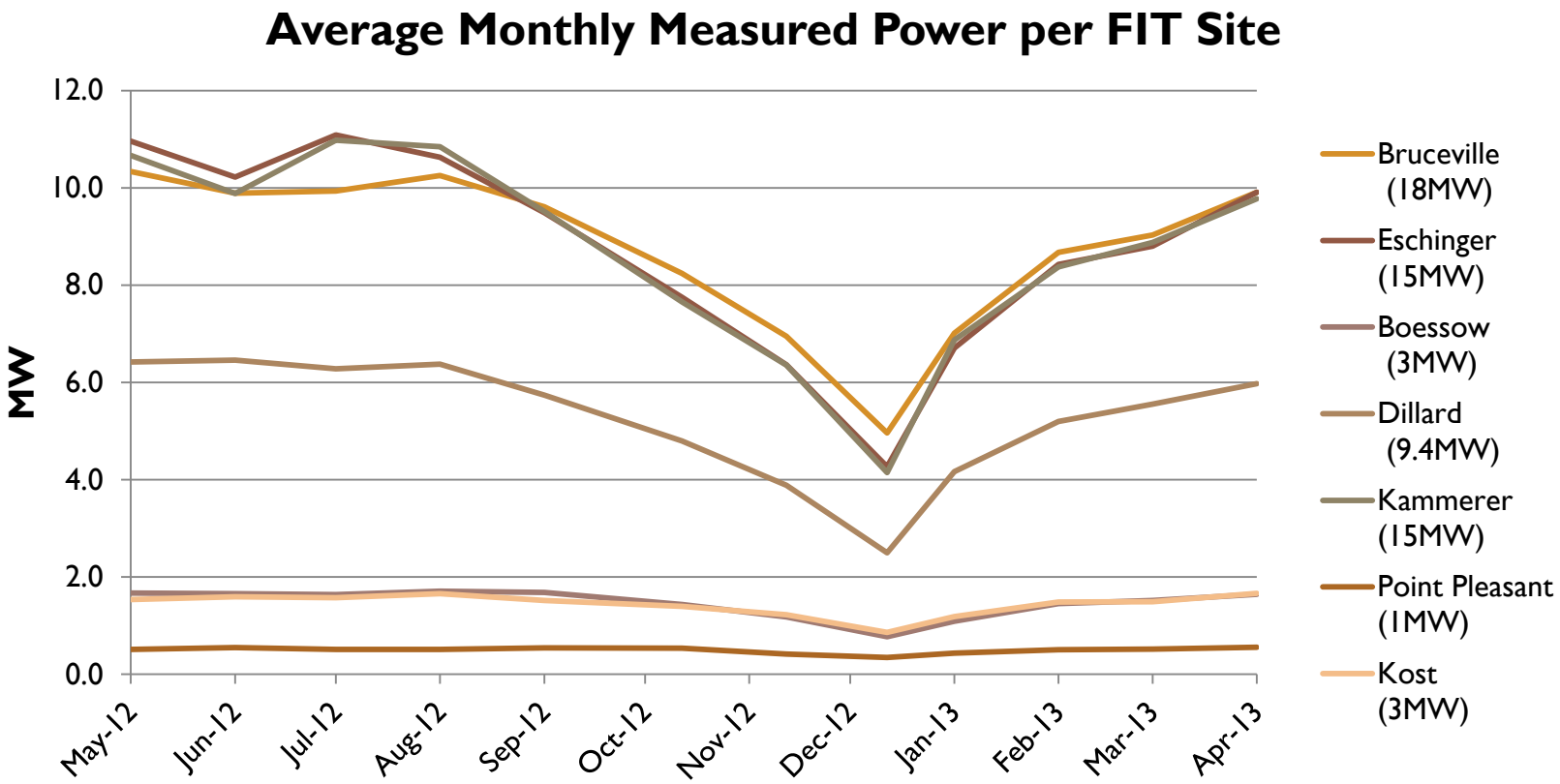
5.4 Validation: MAE/Average Measured Power



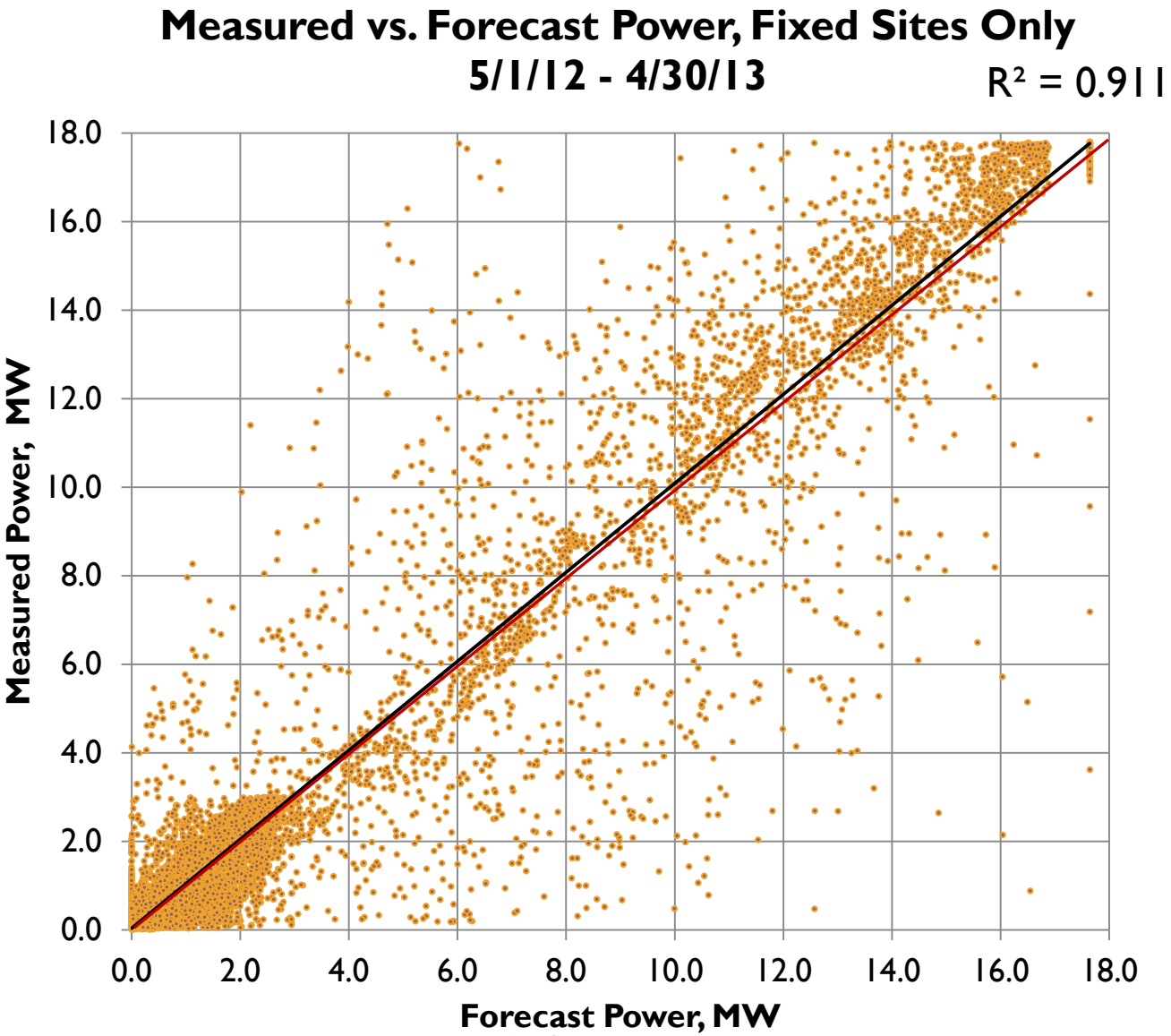
5.4 Validation



5.4 Validation



5.4 Validation



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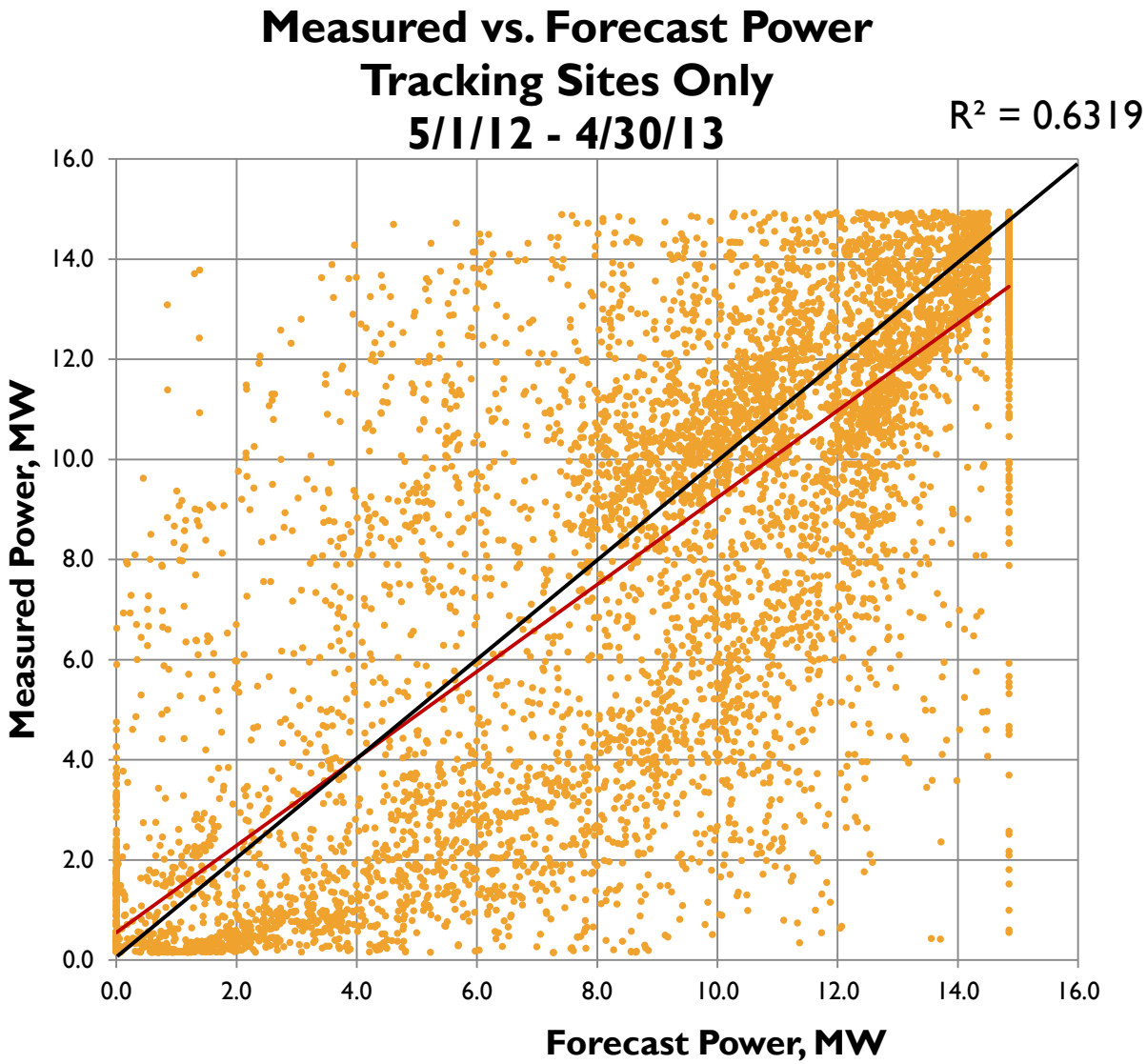
SMUD

Hawaiian Electric Company
Maui Electric Company
Hawaii Electric Light Company

5.4 Validation



CONCLUSIONS

- Lessons Learned
- Papers and Presentations
- Data Access

Lessons Learned

- Limitation NDFD data for day ahead forecasts
- Limitations of 5km grid for 0-3 hour forecasts
- System noise issues (shading artifacts)
- Data logger flash memory issues
- Global calibration methodology
- Clear sky model normalization for 2D analysis
- Need for additional site data (backtracking)

Presentation & Papers

- Scripps Institute DOE/CPUC kickoff meeting
- ASES 2011 paper & presentation
- Lawrence Livermore National Laboratory lunch presentation
- ASES 2012 paper & presentation
- ASES Resource Applications Division newsletter April 2012
- IEEE PES General Meeting 2012
- ASES 2013 paper & presentation:
  - Instructions for Access to SMUD-NEO Irradiance (SNI) Data Set

Data Access

- Data available at ftp://ftp01.smud.org/pub/SNIData/
- The file will be a zip file, and it will be a backup of MS SQL Database table
- There is a "read me" file that includes information about the data
- The data will include raw "shadow events" and interpolated values
- The data will be updated monthly starting in May 2013

FUTURE WORK

- SMUD 2 Year Network Monitoring Extension
- NEO Forecasting Service
- Synthetic Irradiance Imaging (SII) patent app
- Compact Transmitting Pyranometer (CTP)
- Ramp Rate Mitigation DOE proposal
- High Resolution Rapid Refresh (HRRR) Based Forecast Model

Thank You

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