SEEING IMPACTS OF HIGH PENETRATION PV

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October 20, 2011
Honolulu, HI

Hawaiian Electric Company, Inc.

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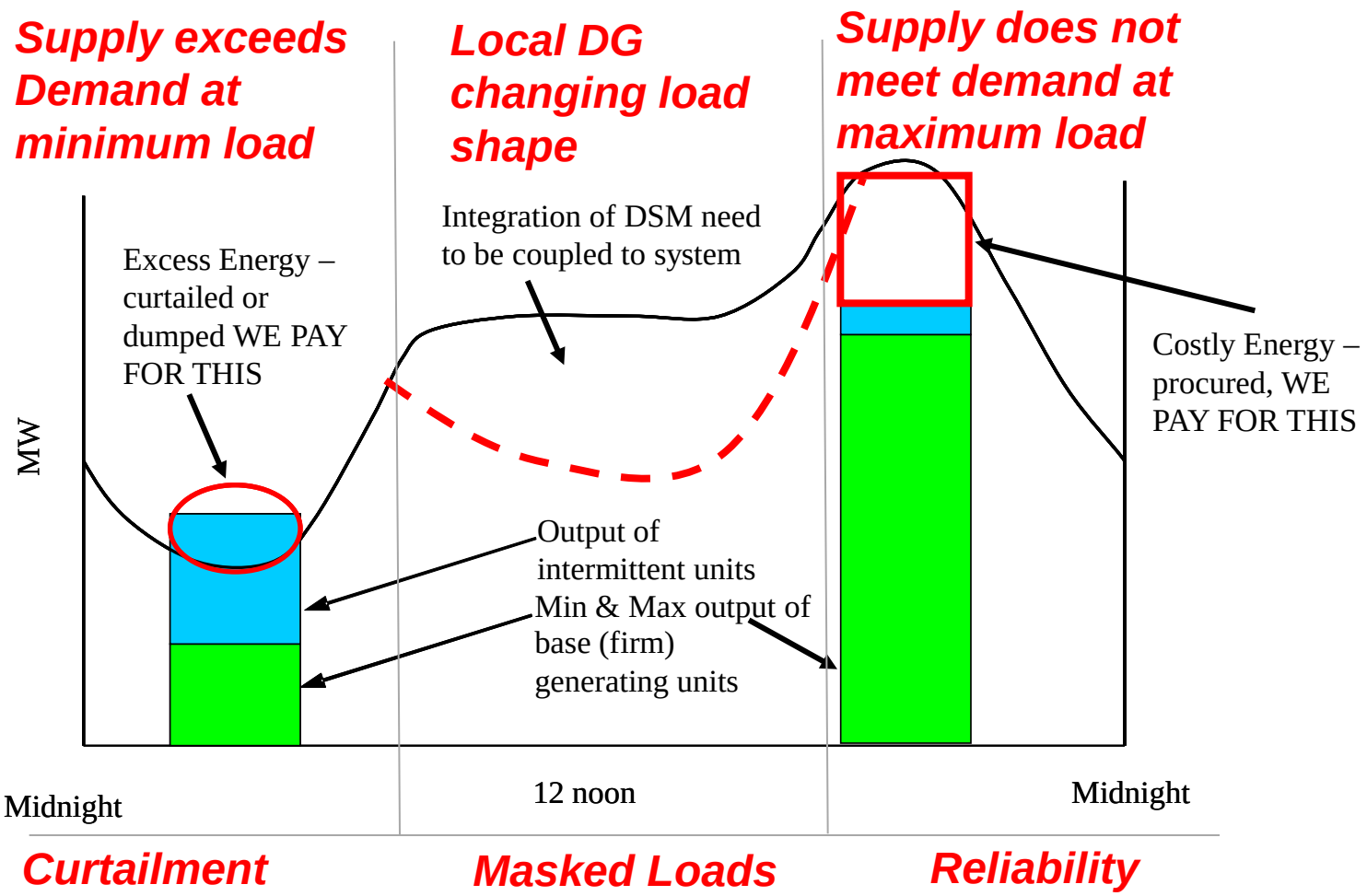
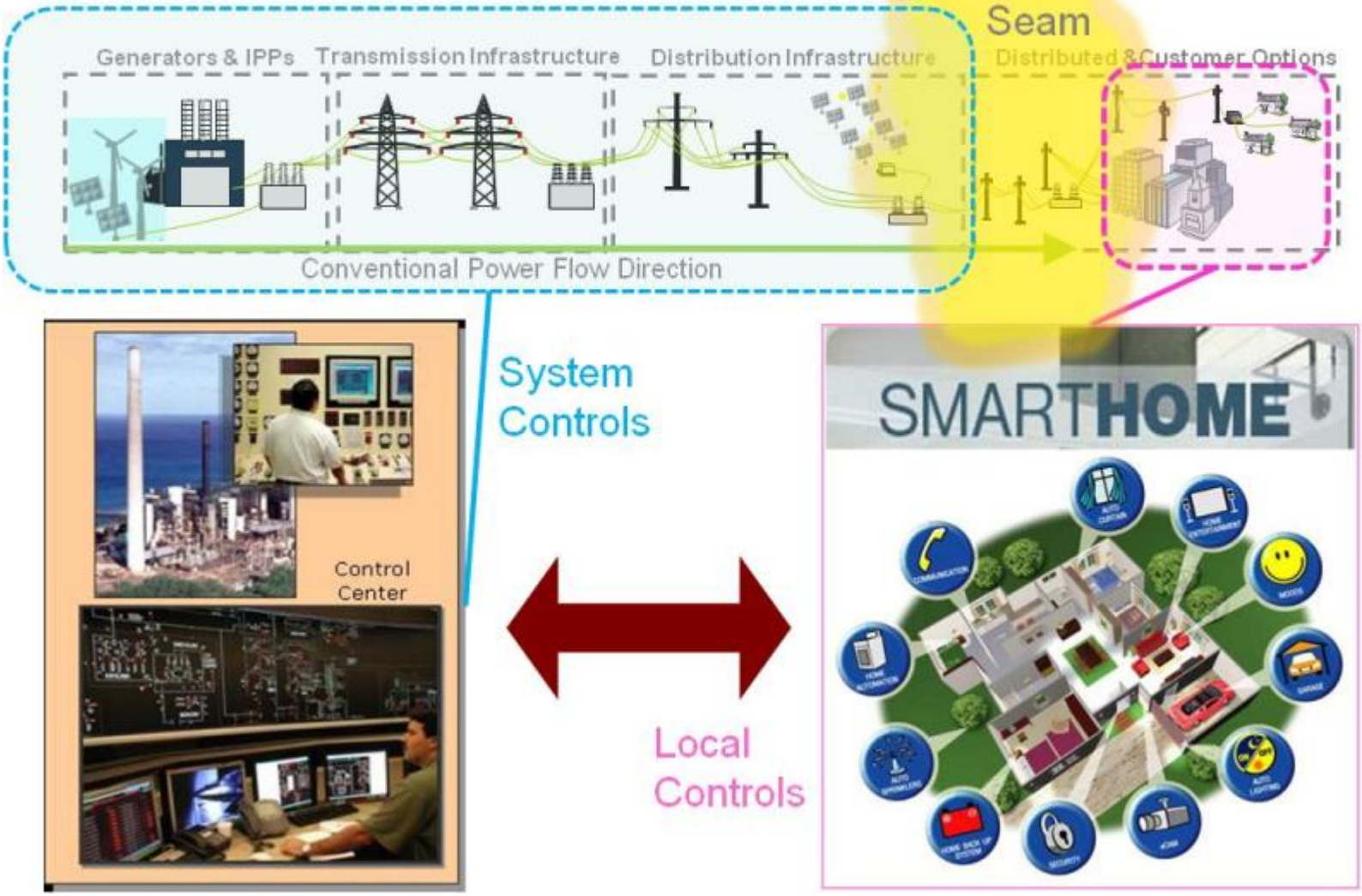
Overview

- Background
  - Drivers/Challenges
  - Major Transformational Areas
- SMUD/HECO High Penetration PV Initiative
- Discussion/Q&A

Issues Being Encountered as Penetration Increases



Electric Sector Paradigm Shift



Work needed to bridge the gaps - “Seams” Infrastructure and Control Interface with Utilities

Integration Questions

- Policy: RPS and climate goals
- Market: Emergence of *Variable renewable* resources and distributed resource incentives
- Interoperability of the Grid: Infrastructure and process changes to accommodate higher levels of variable and distributed resources

Requires Alignment of Policy, Market & Technology

5

Transformational Change

- Unprecedented levels of "behind-the-meter" distributed generation
- Drivers to adopt new technologies with limited performance track record
- Insufficient baseline and knowledge of immediate and longer-term impacts
- Aging workforce
- Significant changes to existing processes and procedures
- Need to establish confidence, buy-in and teamwork of workforce and communities (bi-directional)

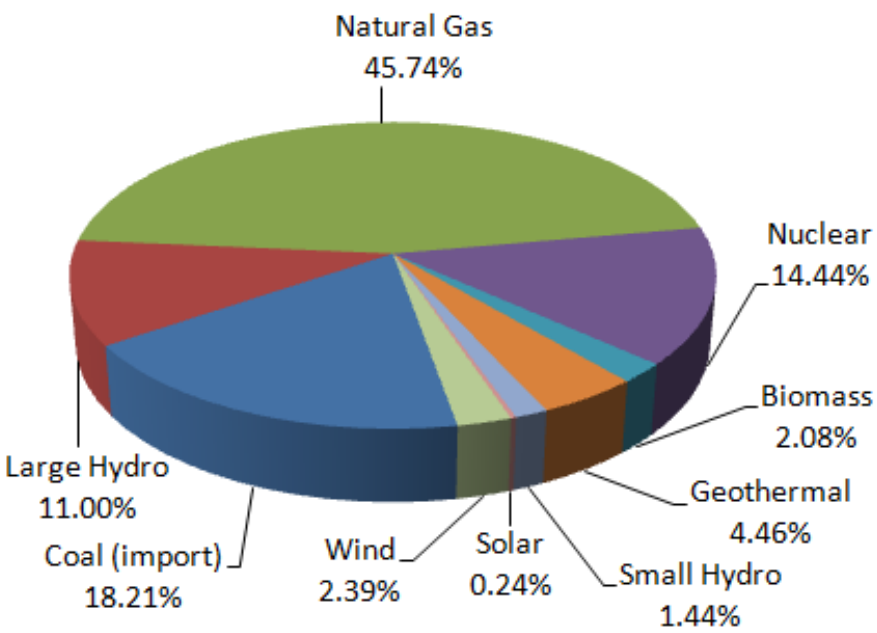
Preserve Utility Guiding Principles

- Reliability of Service
- Maintain cost-effectiveness for Customers
- Ensure safe, robust & secure infrastructure
- Sustainable resources
  - Diverse, flexible and balanced portfolio
  - Knowledgeable workforce
  - Tools to do things "in house"

CA & HI Energy Picture

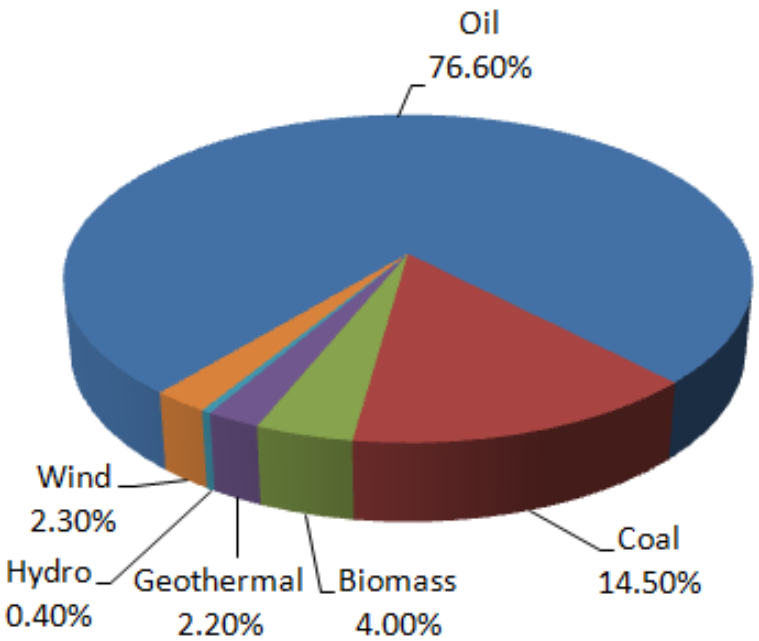
California

- Primary resource is natural gas, 80% imported from other states & Canada
- Top 10 generation plants are gas, nuclear and hydro resources
- Nearly 25% of electricity consumed is imported from neighboring states



Hawaii

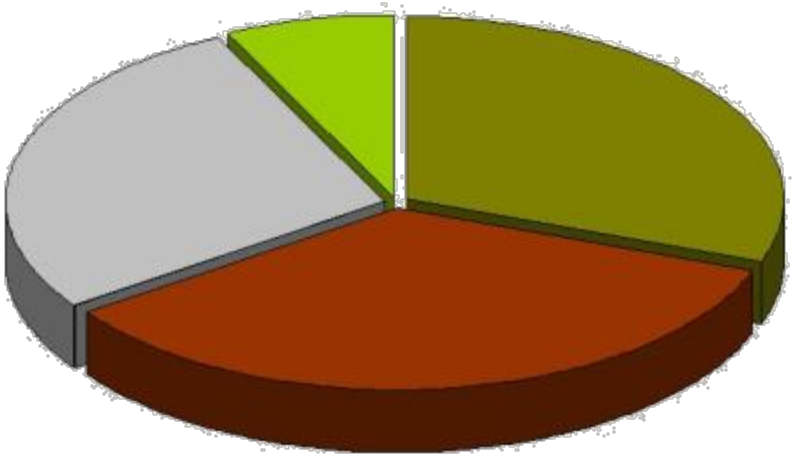
- Primary resource is petroleum, 90% imported (30% for electricity, 60% transportation)
- Top 10 generation plants are petroleum, coal, and waste resources
- Islanded systems



* Source: CEC 2008; HECO 2008

Background – HECO & Hawaii's Energy Use Today

- 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 and Molokai and the Big Island Hawaii.
- Primary energy source (90%) is imported crude oil



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

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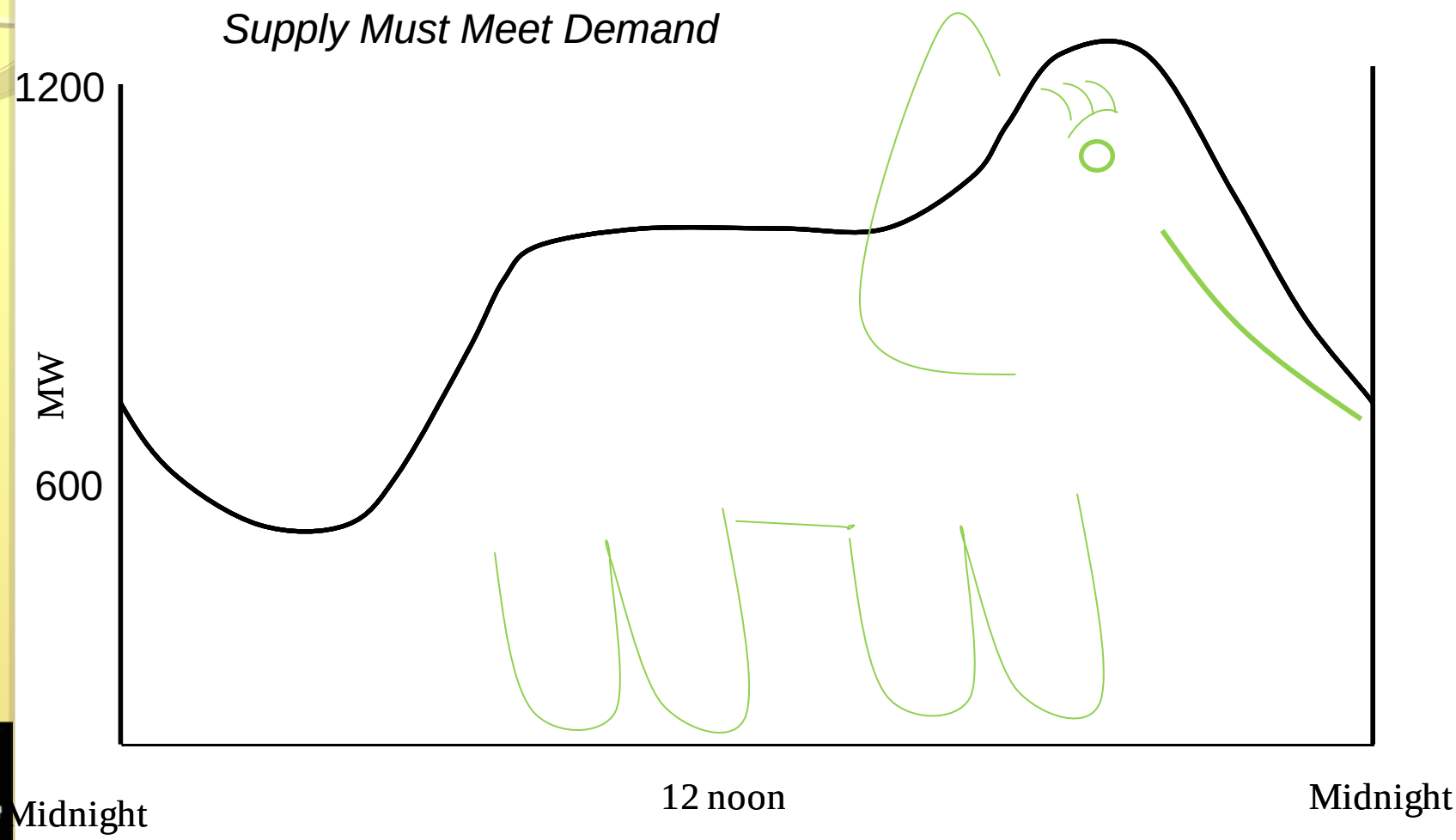
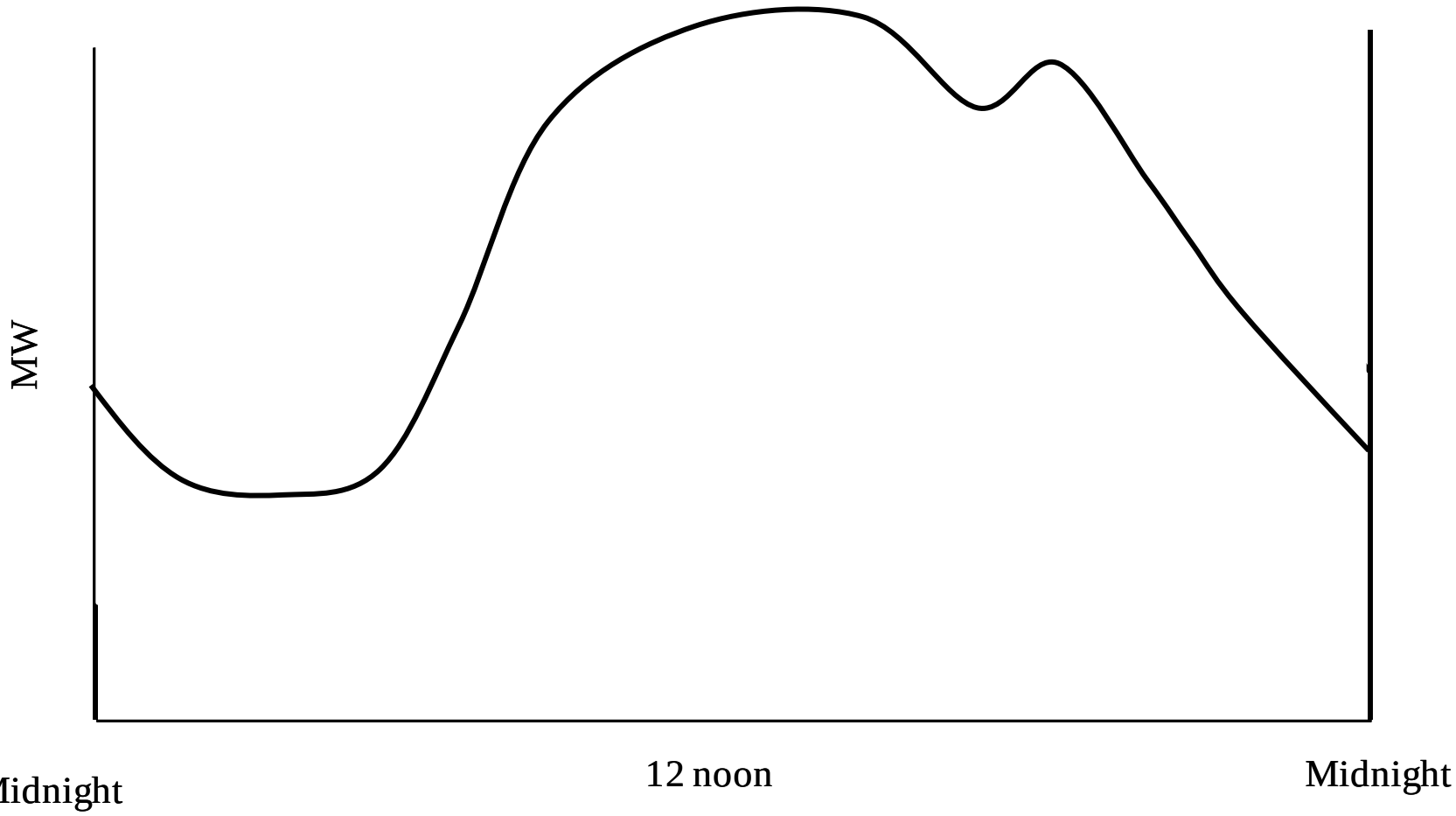
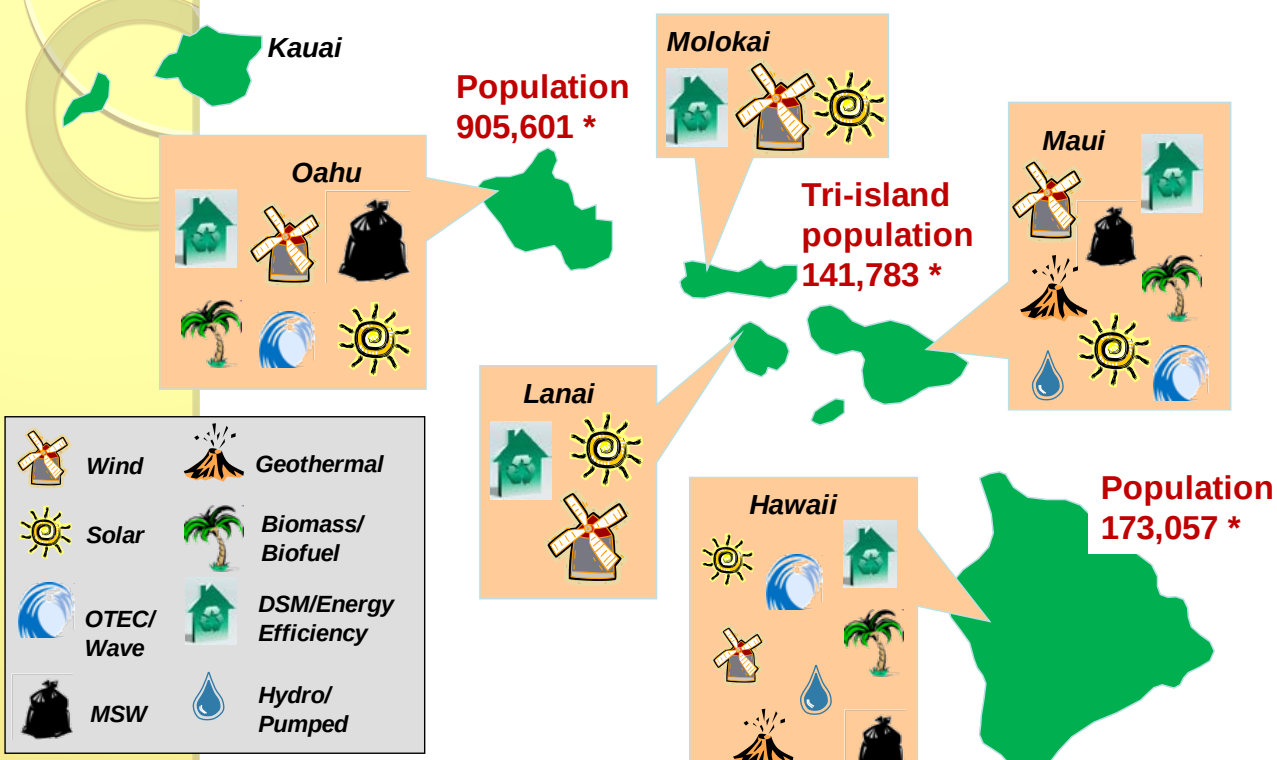
Hawaii Typical Demand Curve



CA Typical Demand Curve

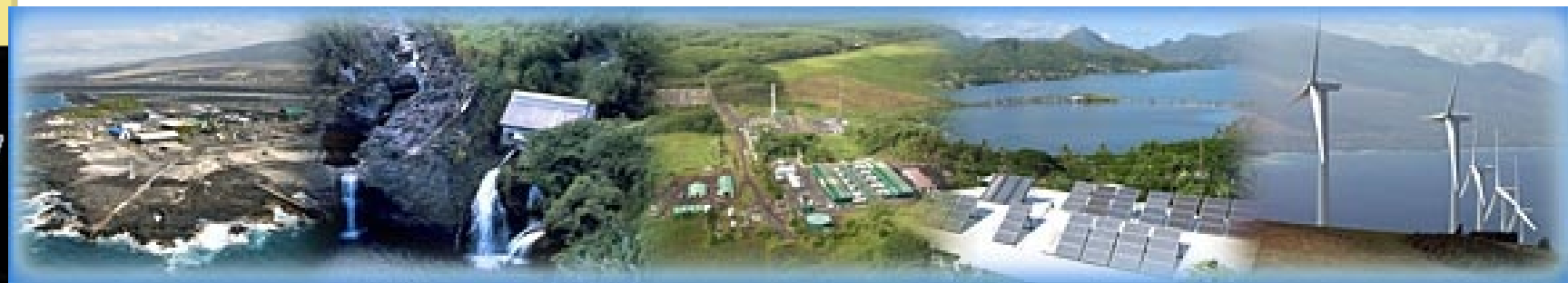


Where are we Today?

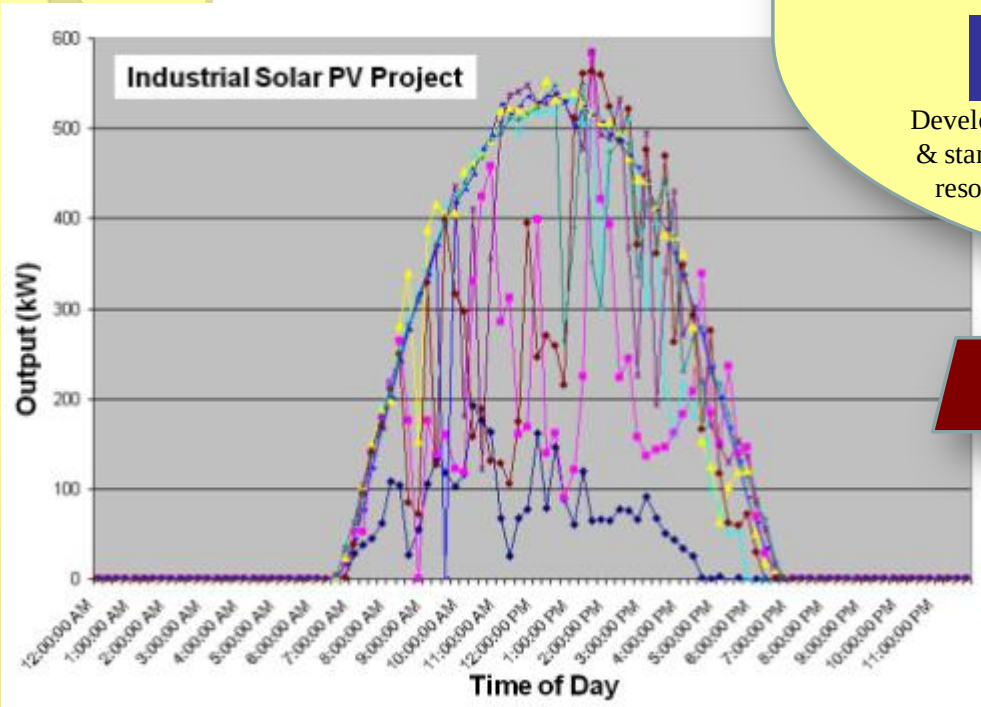


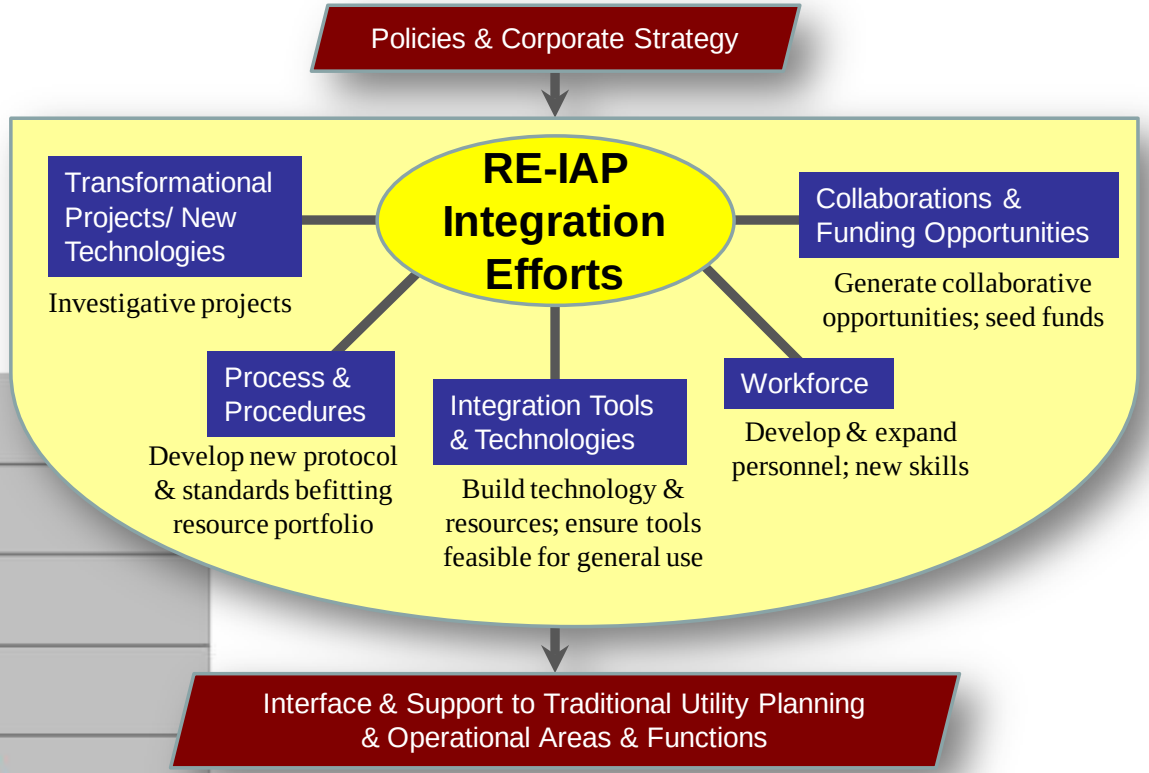
* U.S. Census estimates as of July 2007

- Act 155 established RPS – 40% renewables from electricity, 70% total (includes transportation)
- Energy efficiency standard of 30 by 2030 (3,400 GWh)
- HECO – 17%, HELCO – 42%, MECO – 26%

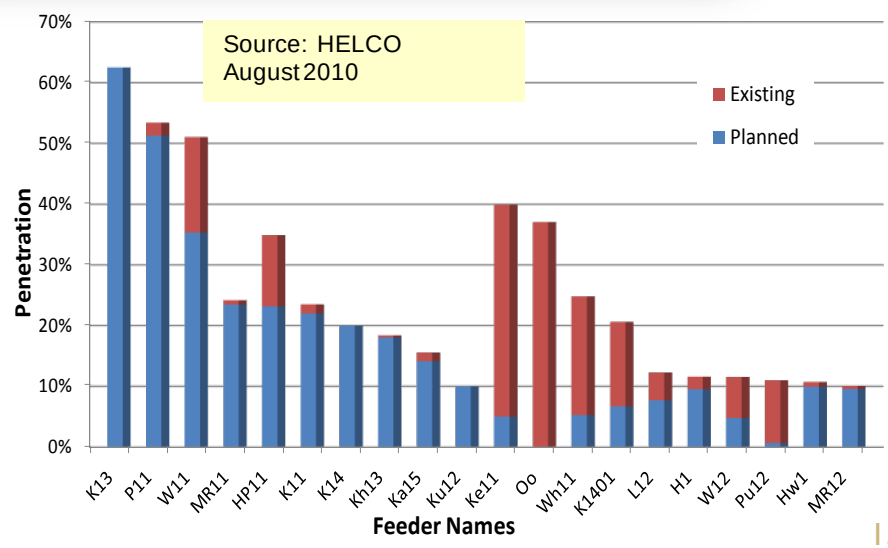


Where are We Today?





$$\text{Circuit Penetration \%} = \frac{\text{Installed PV}}{\text{Max Circuit Load}}$$



Where are We Today - "As-available" DG for Each Island Grid (2009 and 2011 data)

Island Grid	Net System Load at Peak (MW)	Existing DG on System (MW)	Existing DG%		Net System Load at Peak (MW)	Existing DG on System (MW)	Existing DG%
Oahu	1,200	10.1*	0.8%		1,200	42.6	3.55%
Hawaii	194.6	9.1	4.7%		190.6	12.9	6.75%
Maui	199.9	5.8	2.9%		199.4	9.3	4.6%
Lanai	4.7	2.1	43.7%		4.8	2.1	43.4%
Molokai	5.95	0.3	5.0%		5.7	0.6	11.2%

Summary of Interconnected Distribution Level Penetration on Each Island Grid
Ref: 2009 data, FIT Feb 2010 Clarification of Table 1 and 2010 load data; DG status as of July 2011

Background - SMUD

- Publicly Owned (Sixth Largest in U.S.)
- Service area of 900 square miles, serving 1.45 Million (Sacramento County and parts of Placer)
- Nearly 600,000 Residential, Commercial and Industrial customers
- Record peak demand-3,299 MW on July 24, 2006
- Aggressive 23.9% Renewable supply by 2010; 37% by 2020
- GHG Reductions by 2050 (10% of 1990 levels, <350,000 metric tonnes/year)
- CSI Goal of 125 MW, Feed-In Tariff of 100 MW

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Background-Renewable Supply

SMUD Renewable Energy Program	2010 Actual	2010 Goal	2020 Goal
RPS	20.1%	20%	33%
Greenergy	3.9%	3.9%	4%
Totals	24%	23.9%	37%

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Where are we Today?

- Currently, over 30 MW of distributed PV, no visible impacts
- Feed-In Tariff contracts - 100 MW to be installed in 2011-2013 timeframe, in 5 MW increments
- CSI goal is 125 MW of roof-top PV
- Expect to see impacts to grid with higher penetration

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SMUD/HECO High Penetration PV Initiative & Team

Team	Primary Staff
SMUD SACRAMENTO MUNICIPAL UTILITY DISTRICT The Power To Do More.	Elaine Sison-Lebrilla, Obadiah Bartholomy and David Brown
Hawaiian Electric Company	Tom Aukai, Dora Nakafuji (HECO) Laura Rogers, Hal Kamigaki (HELCO) Chris Reynolds (MECO)
B=W ENGINEERING	Ron Davis, Emma Stewart, Billy Quach
NEO Virtus Engineering, Inc	James Bing
SUNPOWER	Matt Galland

High Penetration PV Initiative

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 capability including hardware and software to evaluate the impact of high penetrations of PV systems on our grid
- Transfer of lessons learned to other utilities

Why This Effort is Timely?

Address Common Issues

- Emerging levels of distributed generation "behind-the-meter" generation is increasing
- Levels are exceeding "rules-of-thumb" used in standard utility practices for planning
- Operations lack visibility to control and plan for impact of variable renewables on the distribution grid
- Industry lacks capability (tools/data) to effectively plan for PV impacts on the grid
- No commercially available capability exists to meet solar forecasting needs

Why SMUD/HECO Partnership?

- Aggressive state RPS policies in both California and Hawaii
- SMUD/HECO have very similar system attributes
- SMUD/HECO utilizing similar system and distribution modeling tools
- Facing similar high penetration PV challenges – HECO has high penetration over 30% on a number of circuits
- Cost-effective solutions needed to maintain reliability

Issues & Risks

- Aggressive 2 year project schedule
- Investigative nature of efforts
- Multiple high-penetration sites to consider (HECO/HELCO/MECO)
- Internal resources needed to support rapid deployment of field monitoring devices
- Subject to regulatory agencies (in California and Hawaii) review and benefits reporting
- Involvement of several parties

Task 1: Project Management

- Project Administration & Budgets
- Status Meetings
- Technology Transfer Venues
  - Industry-Utility partnerships
  - Industry conferences to share "lessons learned"
  - Inform new tools, process and procedures

Task 2: Baseline Modeling of SMUD and HECO Systems

- Identify high penetration circuits and characteristics
- Gather circuits data (i.e. voltage, loads, PV production, faults) and baseline models
- Conduct distribution circuit and systems modeling
- Assess and visualize results

Synergee model of Anatolia Subdivision

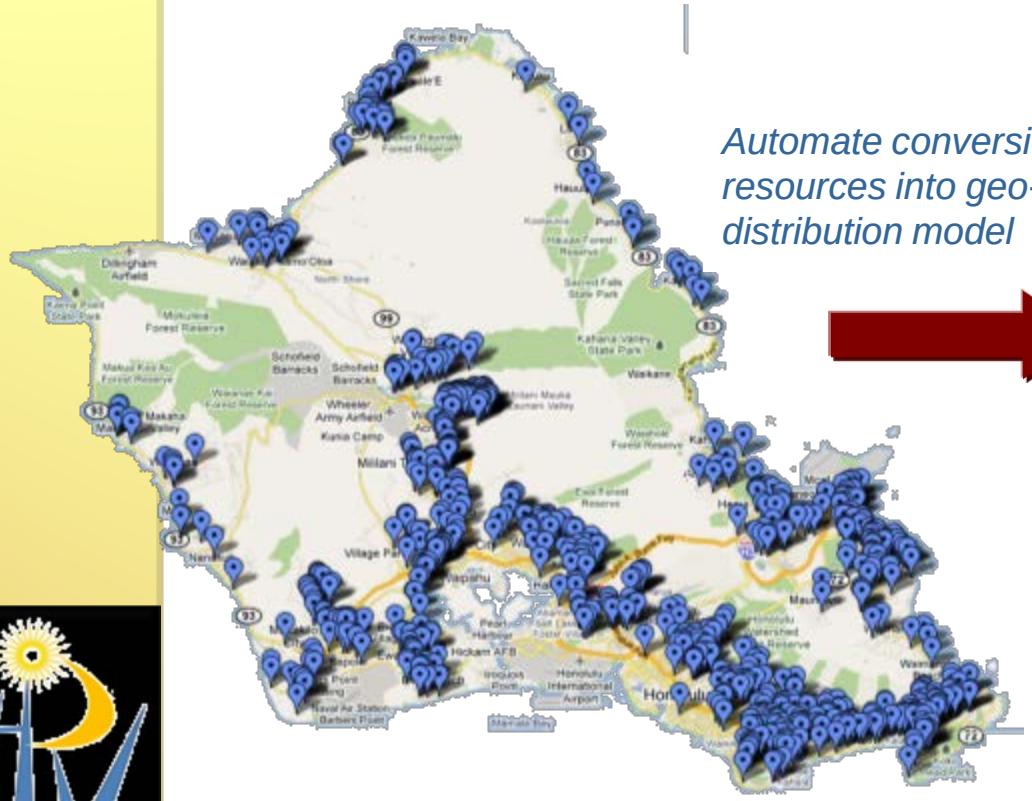
Objectives: Use DG models to simulate and track PV penetration levels for impact and potential value. Link results of distribution model (SynerGEE) to inform transmission modeling

SMUD/HECO Study Feeders

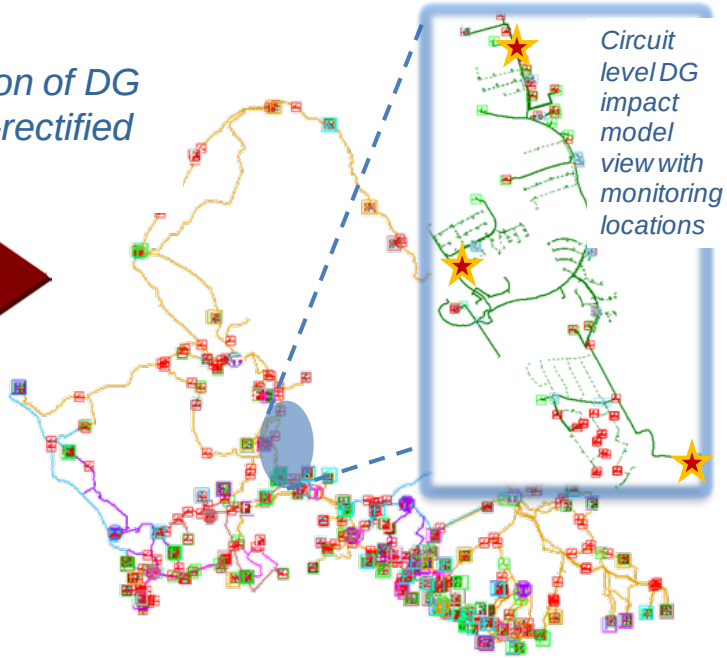
Feeder	Utility	Voltage	Load Type	Existing PV	Existing DG
AN (3 feeders)	SMUD	12.47 kV	Residential	Yes - 0.6 MW	No
EB (1 feeder)	SMUD	12.47 kV	Rural	None	Dairy Digester
CT (2 feeders)	SMUD	12.47 kV	Residential/Rural	Yes – 3000MW	No
EG (3 feeders)	SMUD	69 kV	Residential/ Commercial/Rural	No	No
L7 (1 feeder)	SMUD	69 kV	Industrial	Yes - 2 MW	No
W1 & IN (2 circuits)	HECO	12.47 kV	Residential/ Commercial/ Industrial	Yes – 1MW	No
ML (4 feeders)	HELCO	4.16 kV	Commercial	Yes – 43kW	Yes – possibly out of service
WA (6 feeders) & KI (2 circuits)	MECO	13.09 kV	Residential/ Commercial	Yes	No

Aggregated Scenario Model for DG

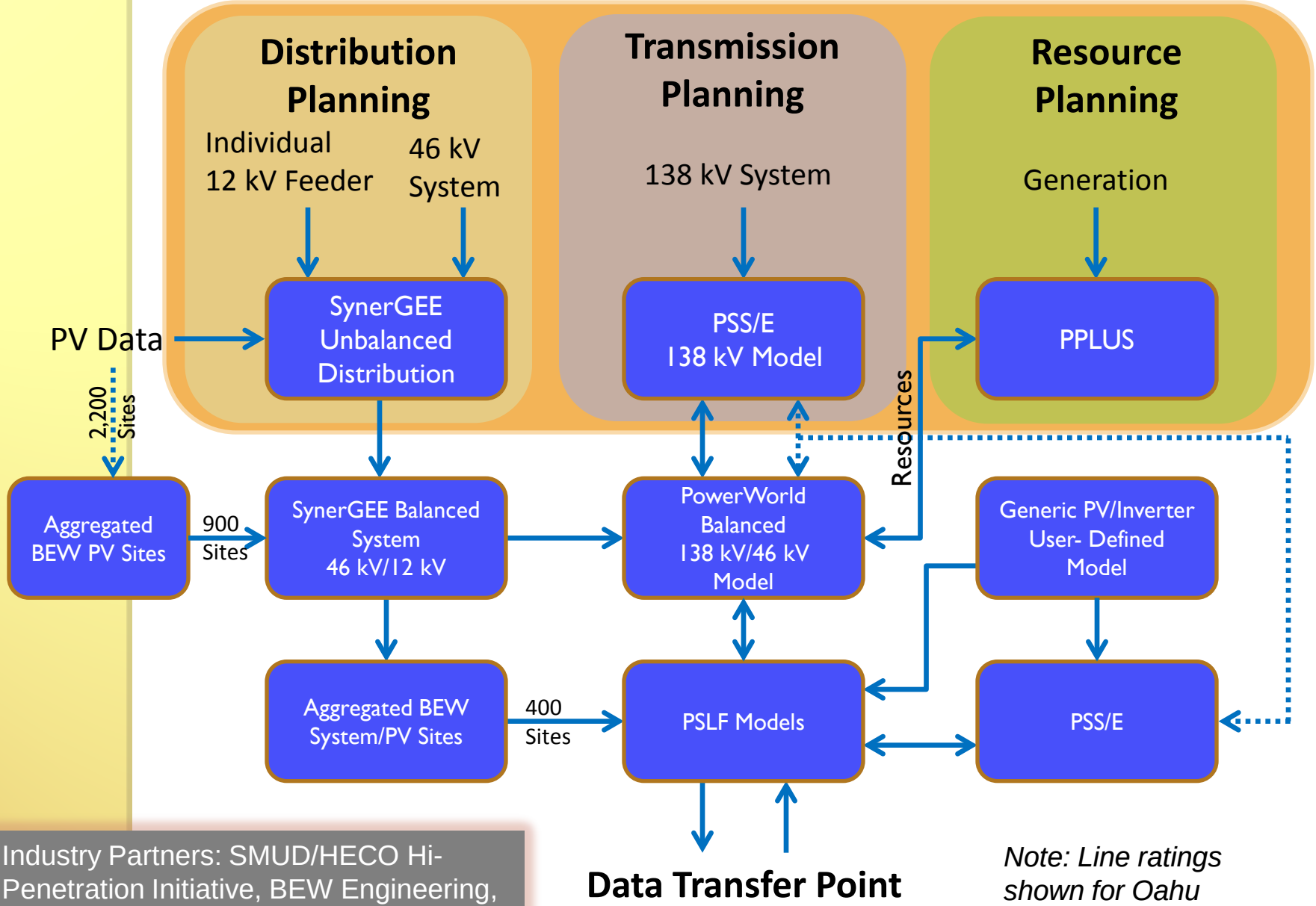
- Enables more accurate modeling of DG resources for planning
- Consistent distribution system model expedites modeling and analysis process
- Allows for "what-if" analysis to stay ahead of system change and minimize risks of stranded assets



Automate conversion of DG resources into geo-rectified distribution model



Graphical Flow of Handshaking Between Models

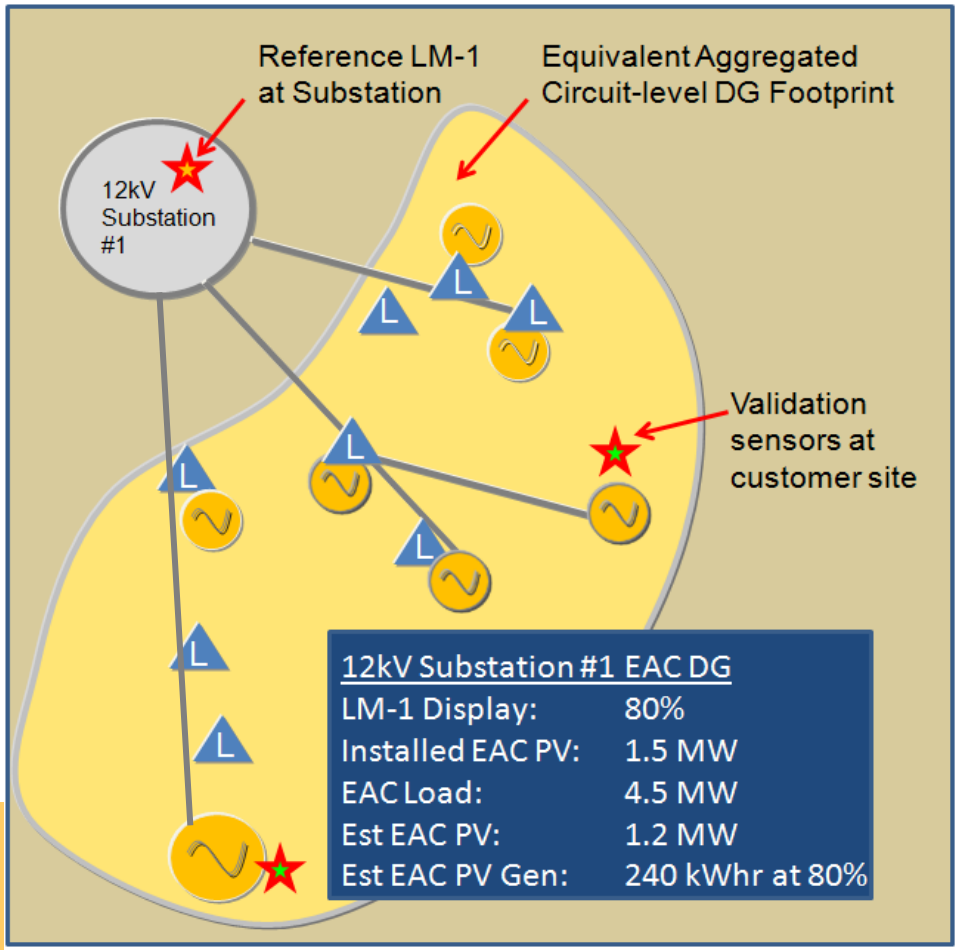


Industry Partners: SMUD/HECO Hi-Penetration Initiative, BEW Engineering, GL Noble Denton, GIS & EMS providers

Note: Line ratings shown for Oahu system for illustration

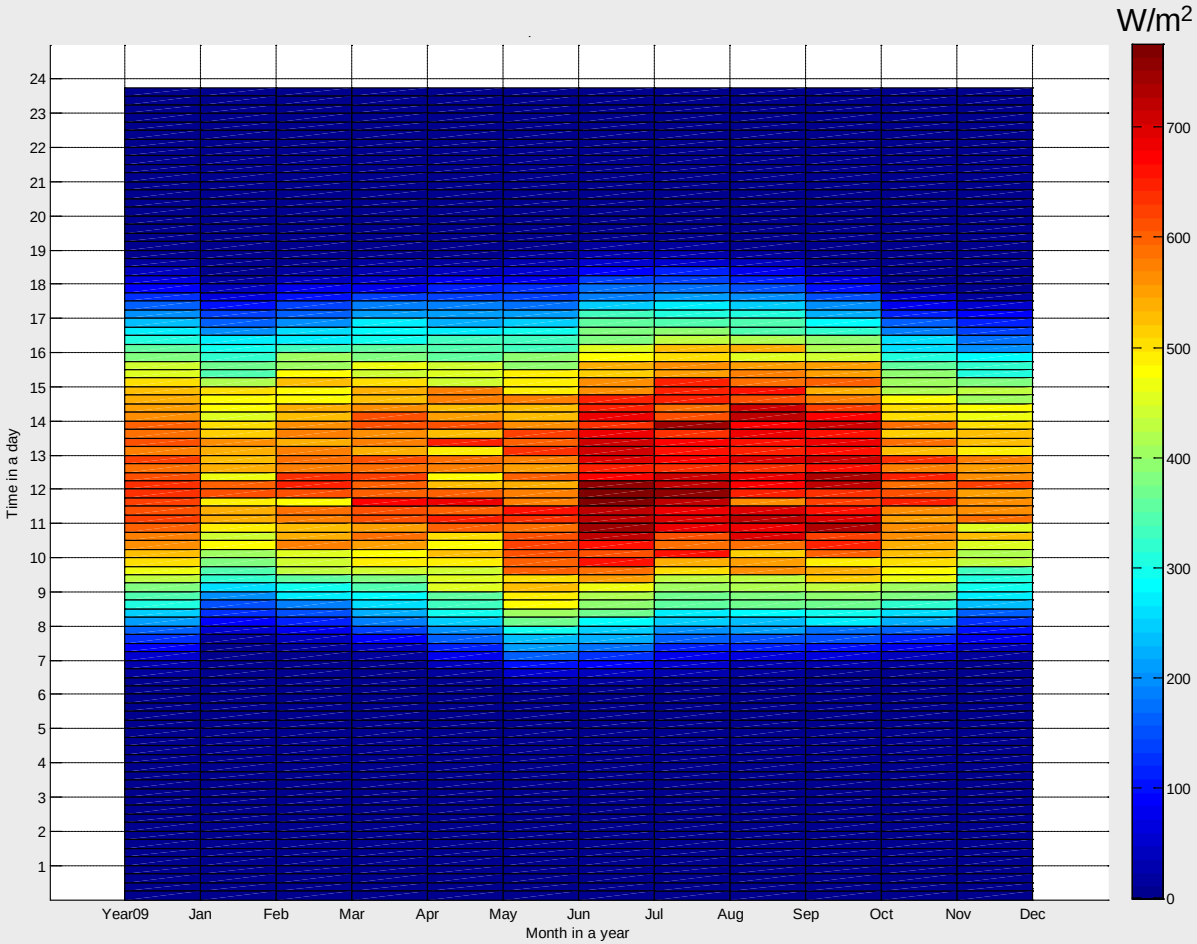
Task 3: Field Monitoring and Analysis

- Install solar monitoring equipment
- Collect high resolution field data (seconds-minutes PV generation and load by circuit)
- Validate nodal aggregation models with field data



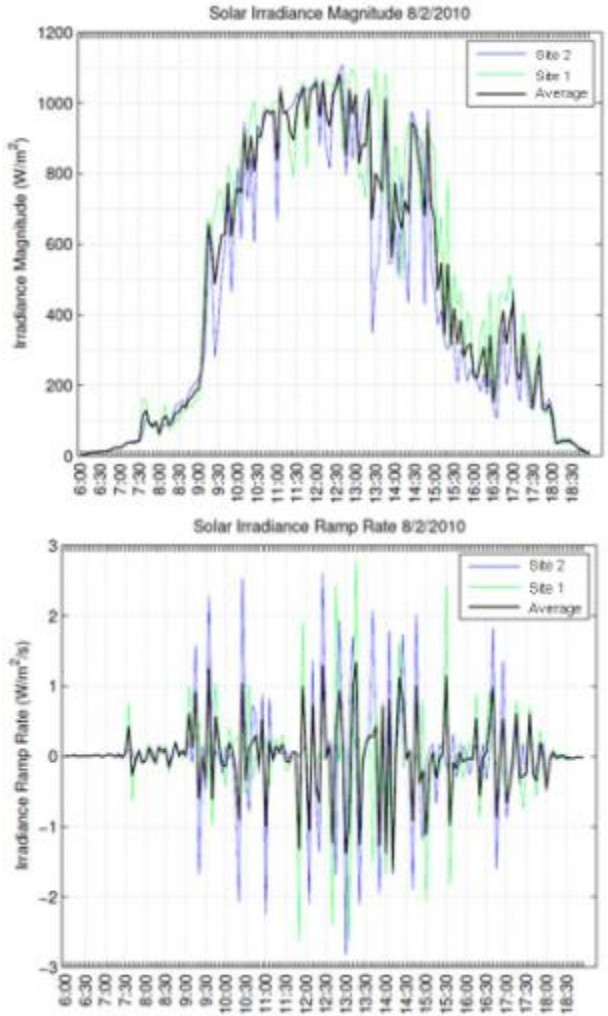
Objectives: Use simulation, testing and validated results to address grid impacts (e.g. protection, voltage regulation, VAR control, fault contribution, reverse power flows, etc.)

Characterizing Long-term & Short-term Solar Variability (Planning)



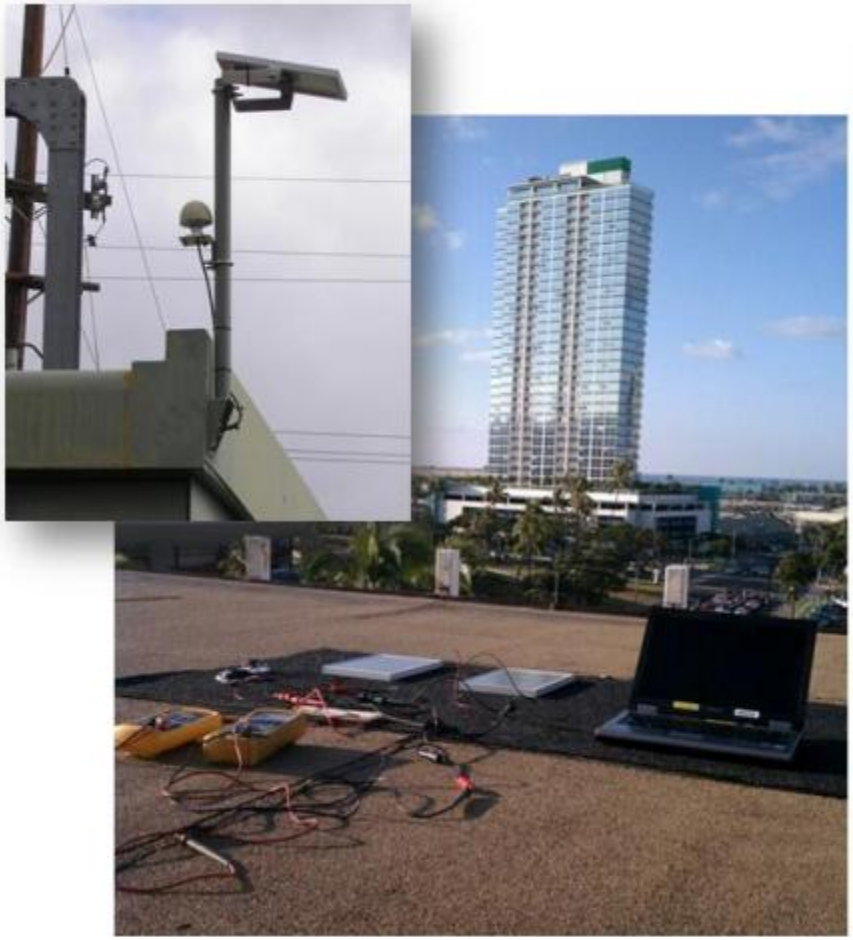
Solar resource (W/m^2) variability over the year

Source: HECO



Sub-hourly solar variability

Field Validation Locations & Devices: Select Feeder/Customer Site Monitoring

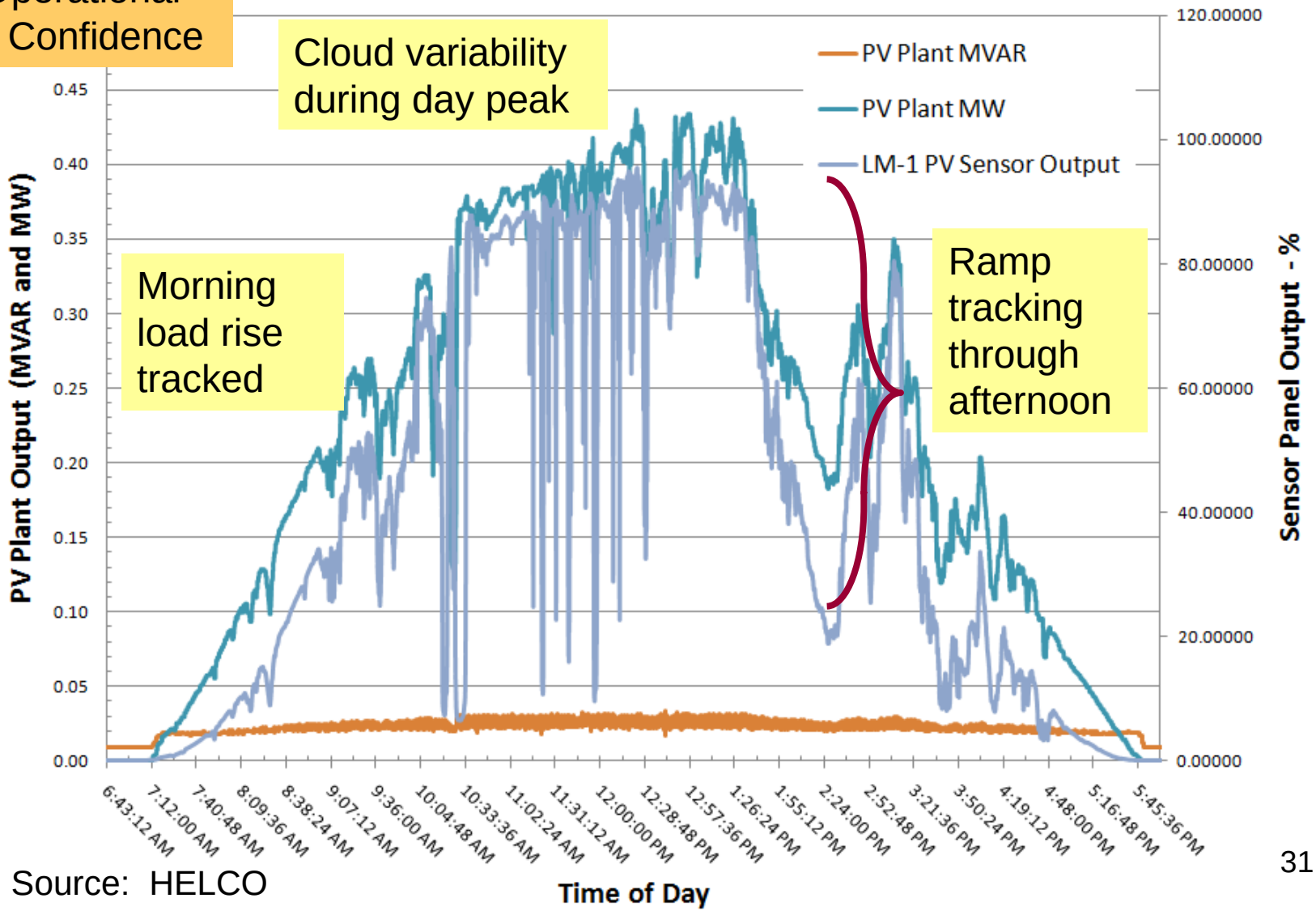


LM-1 monitors & calibration devices

Customer site PV output monitor

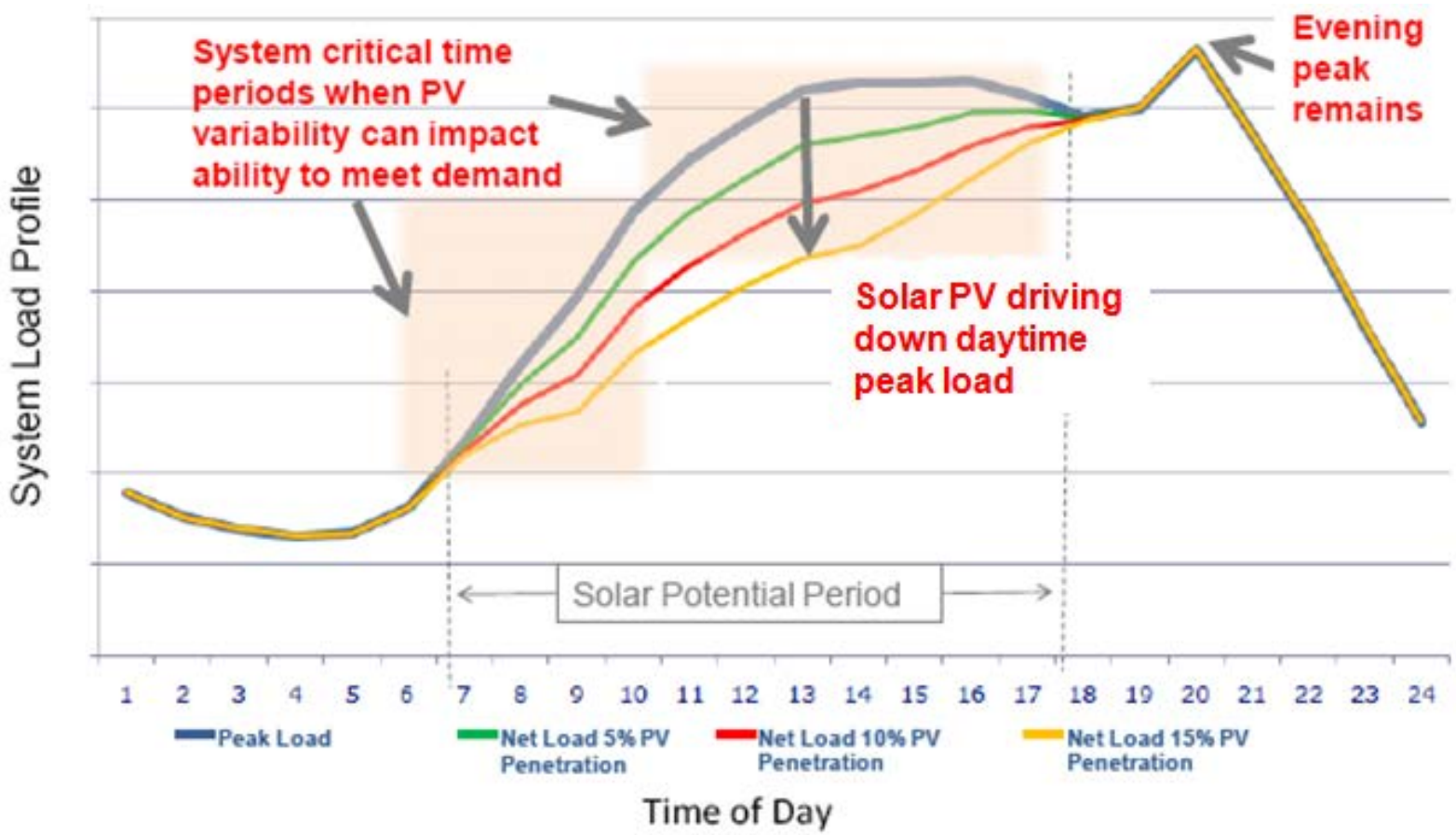
Preliminary Results of LM-1 Sensor & PV Facility Comparisons

Increase Operational Visibility & Confidence



Source: HELCO

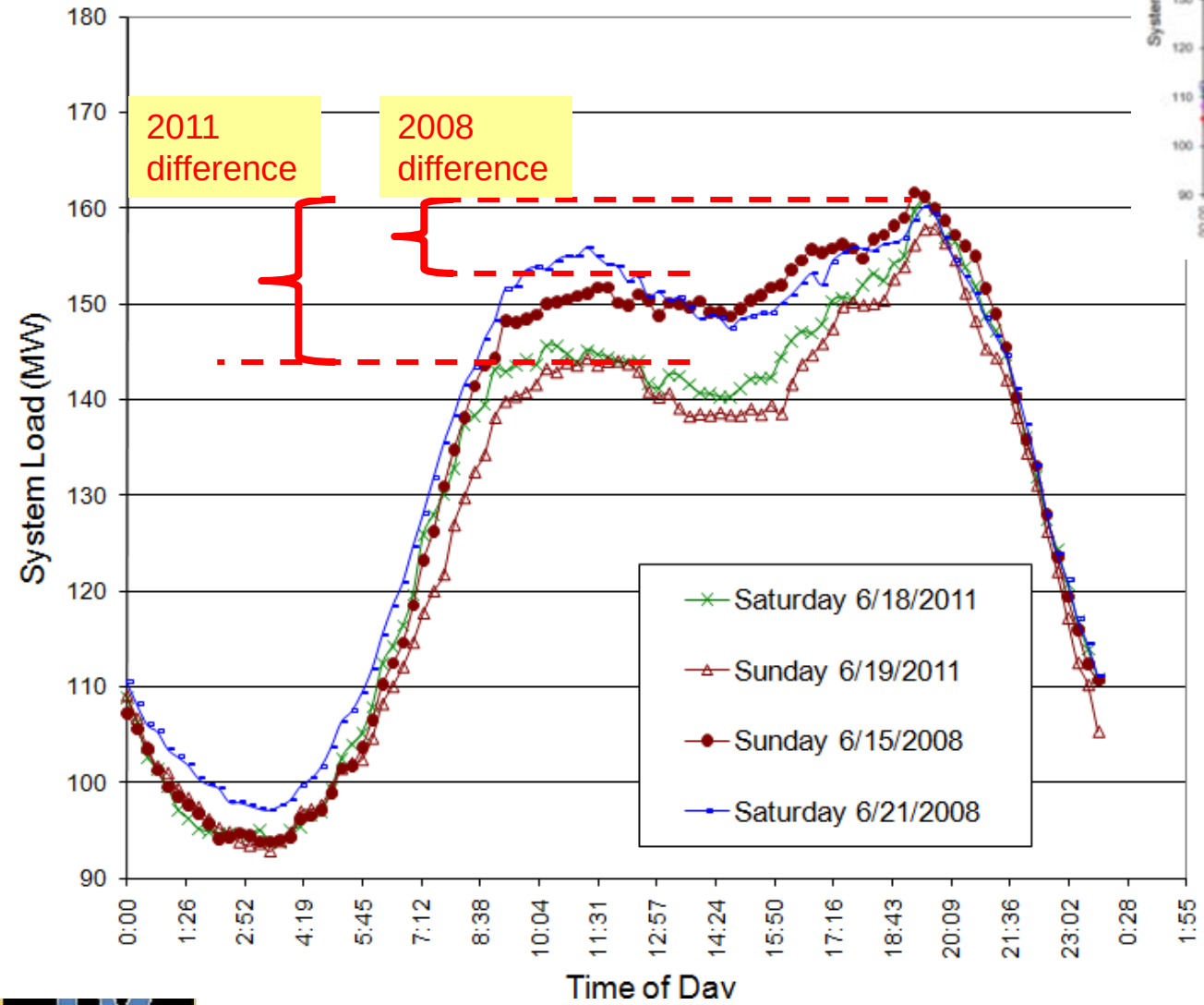
Distributed PV Impacts on System Load

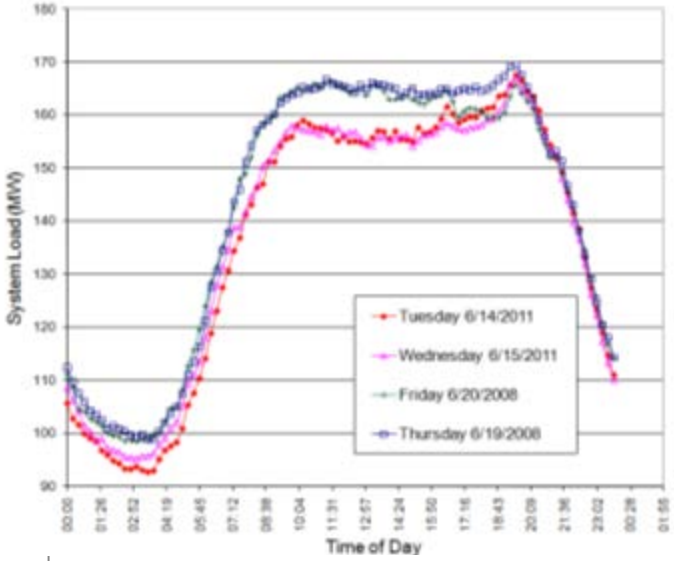


- PV provides energy (kWh) for day time load but misses the evening peak
- Dispatchable resources need to be available to meet evening peak load

Comparison of 2008 and 2011 Weekend (light load)

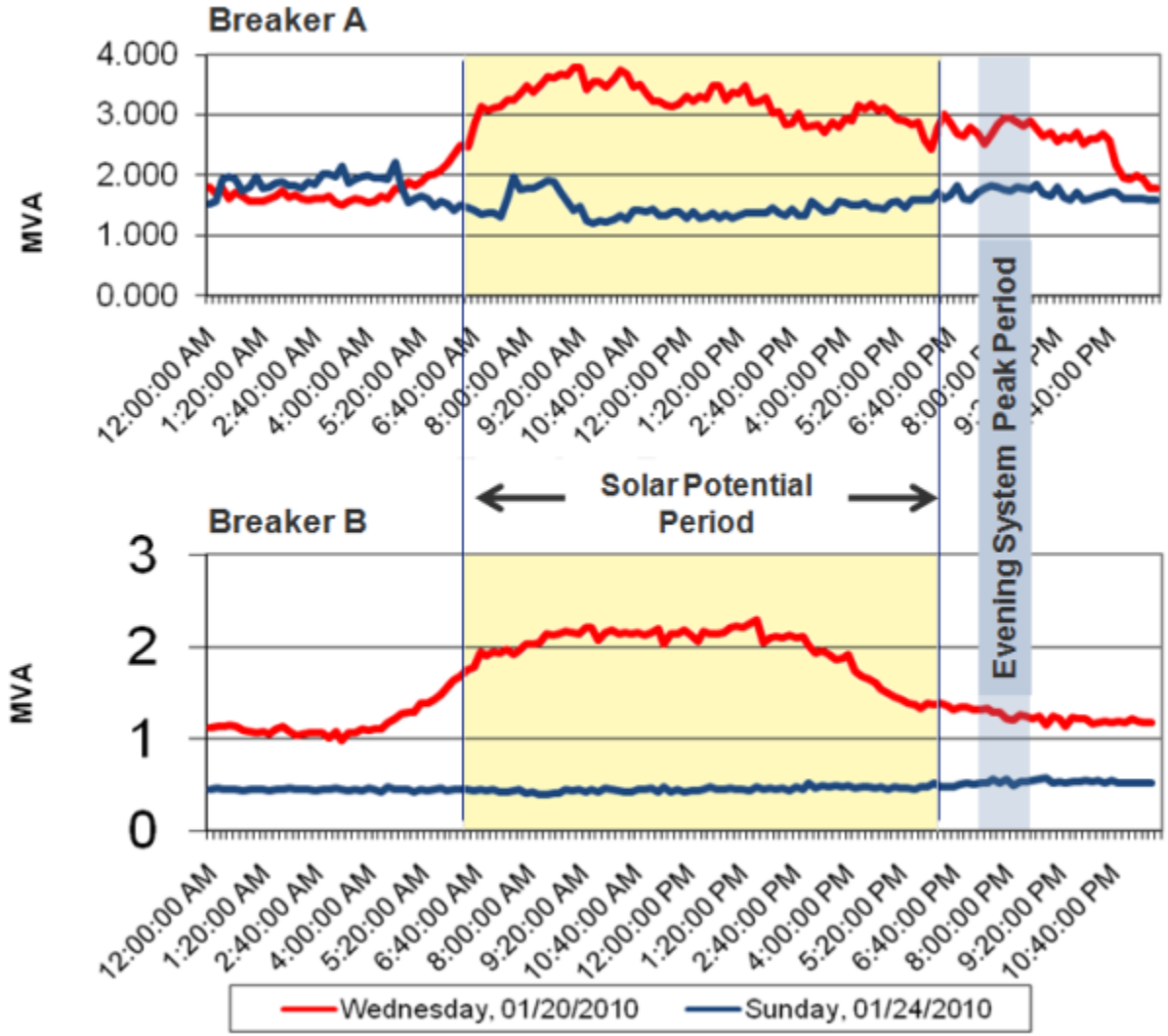
Source: HELCO





- Weekday comparison: evening peak has not significantly changed between 2008 and 2011 but daytime demand has.
- Weekend comparison (light load day): difference between daytime peak and evening peak has increased.

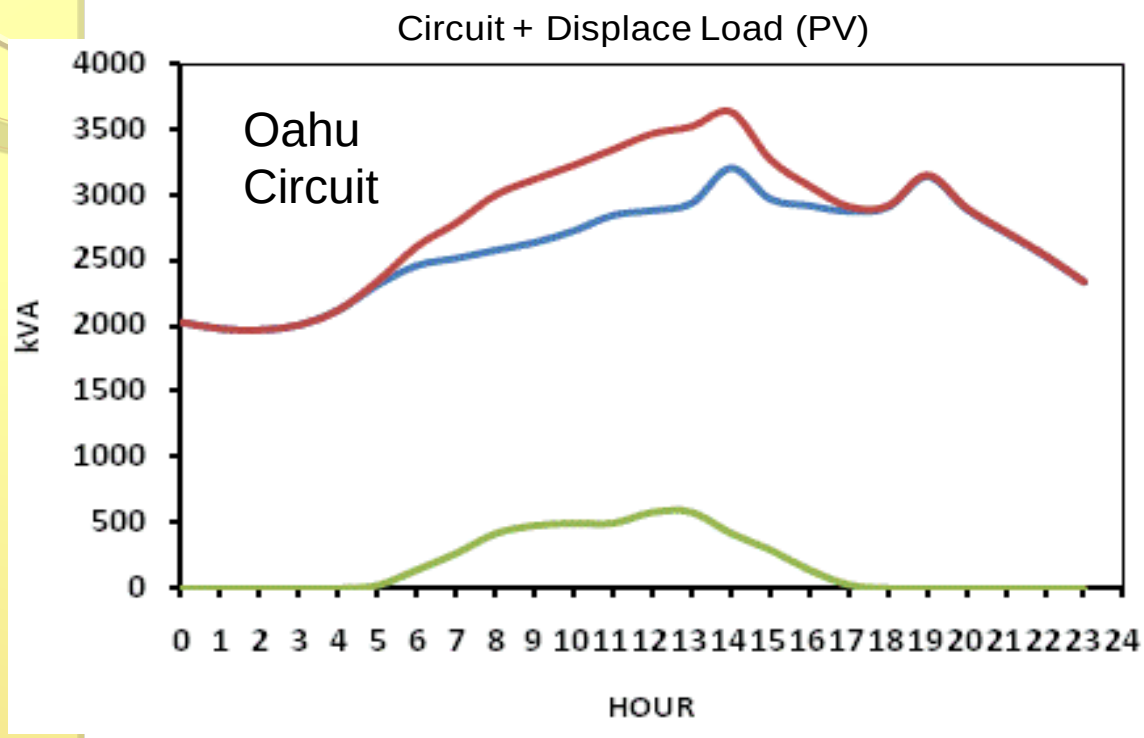
Local Circuit Impact – light load



Concerns:

1. The above graphs illustrate the need to assess the feeder loading not only at peak periods but also on the days where the loads are not as high (light load Sundays) – Rule 14H
2. Circuit peaks often not coincident with System peaks

Hi-Pen PV Impact on the Grid - Substation Circuit Monitoring & Analysis (Operations)

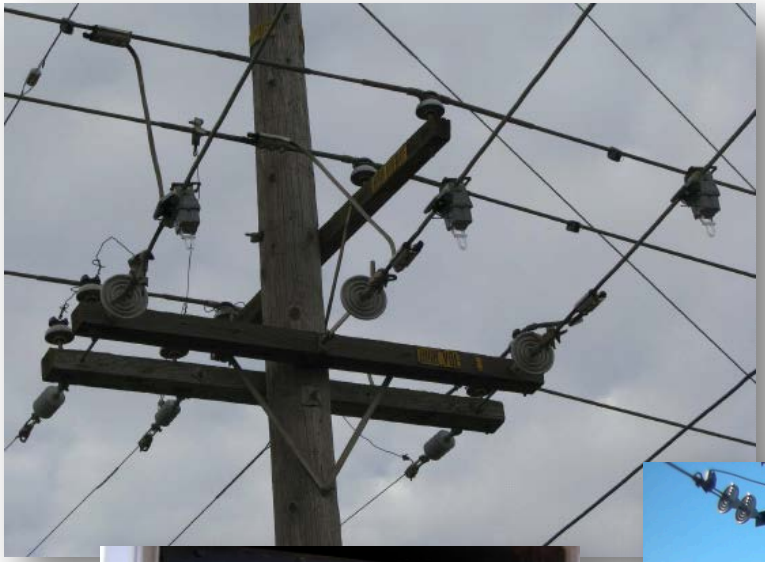


TJD-1 mobile solar irradiance sensors

LM-1 solar availability sensors

- Low-cost capability to account for PV load and actual load for forecasting, operations & planning
- Correlate grid conditions with solar variability to assess impacts (operations, protection, contingencies, reserve plans)

EB - Field Validation Locations & Devices



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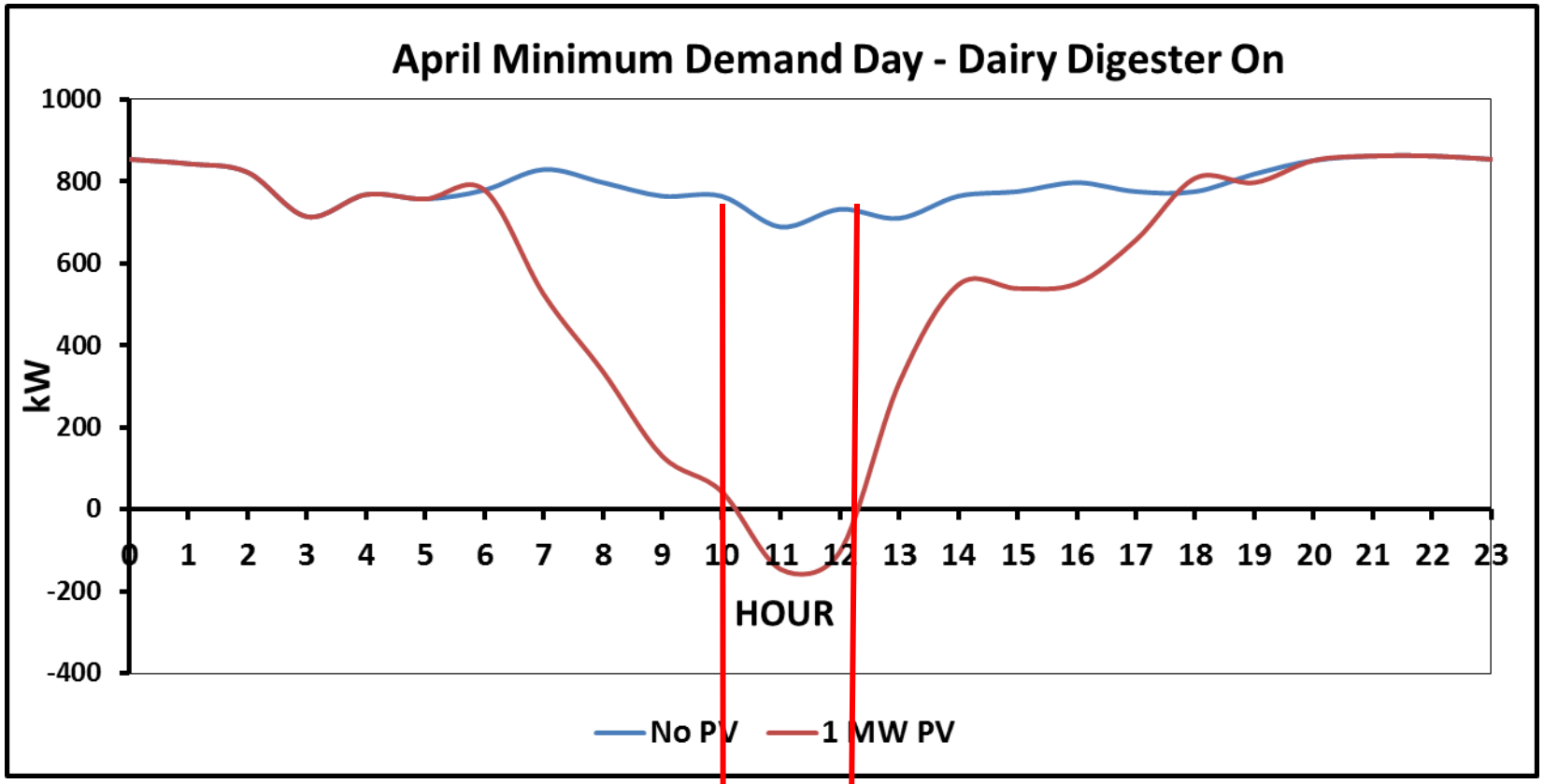
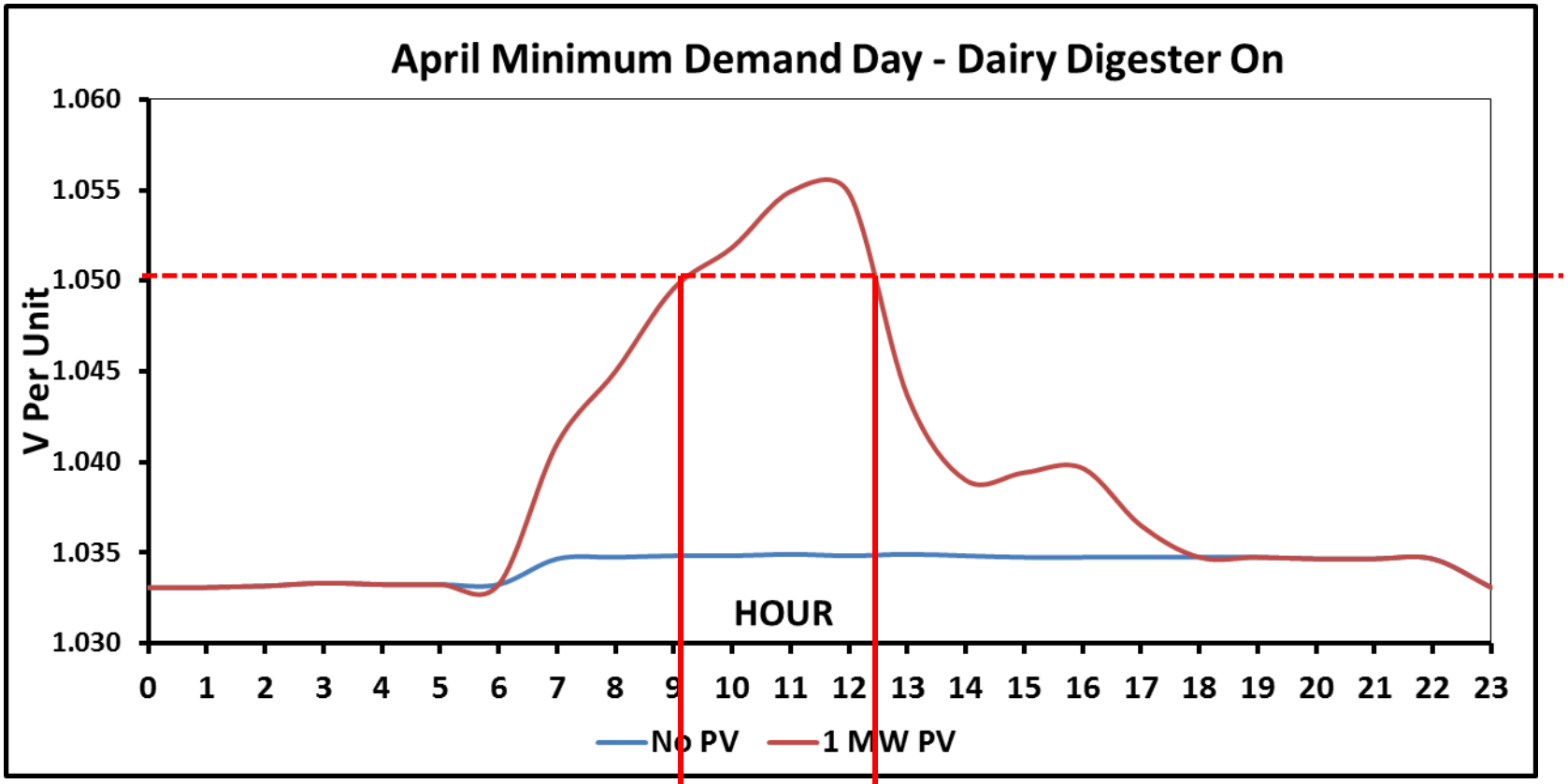
EB - Load Flow Results – 1 MW of PV vs no PV (dairy digester on)



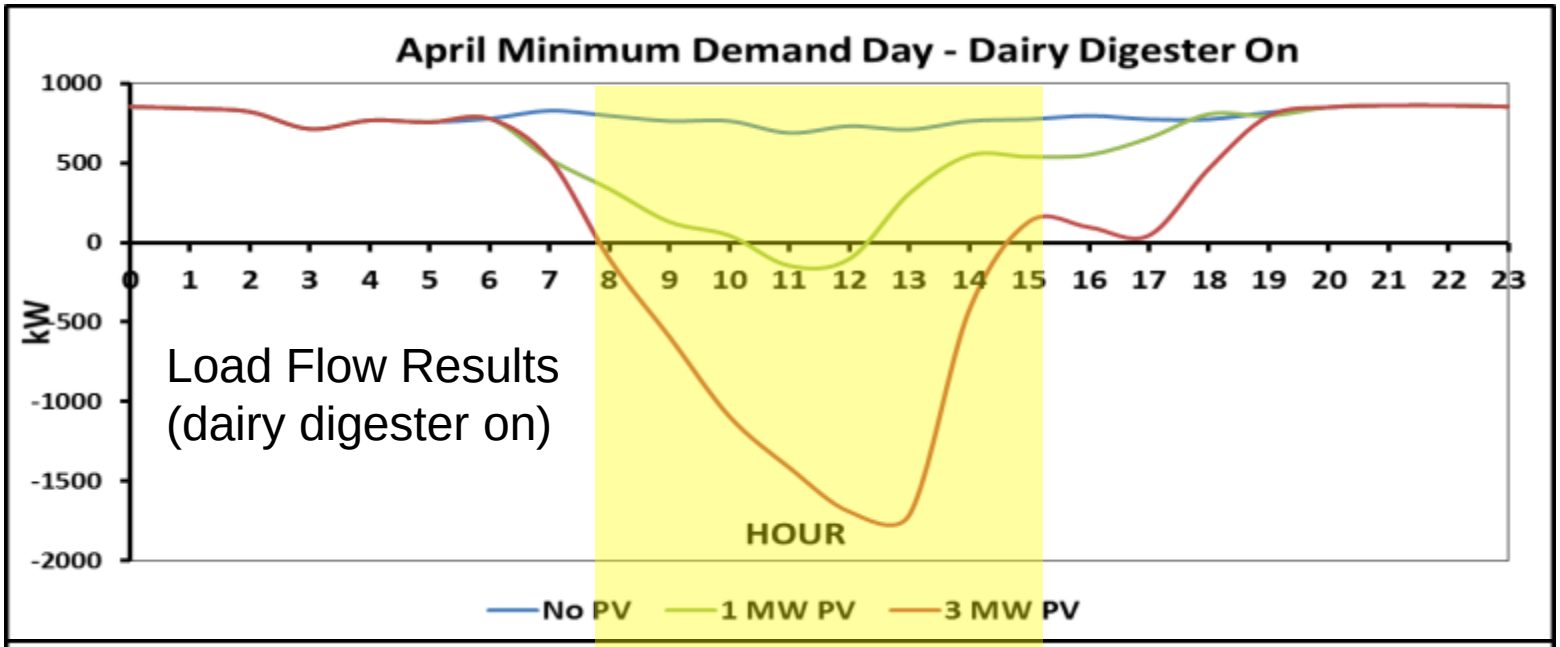
2 hours of back-feed into the substation at peak PV generation hour

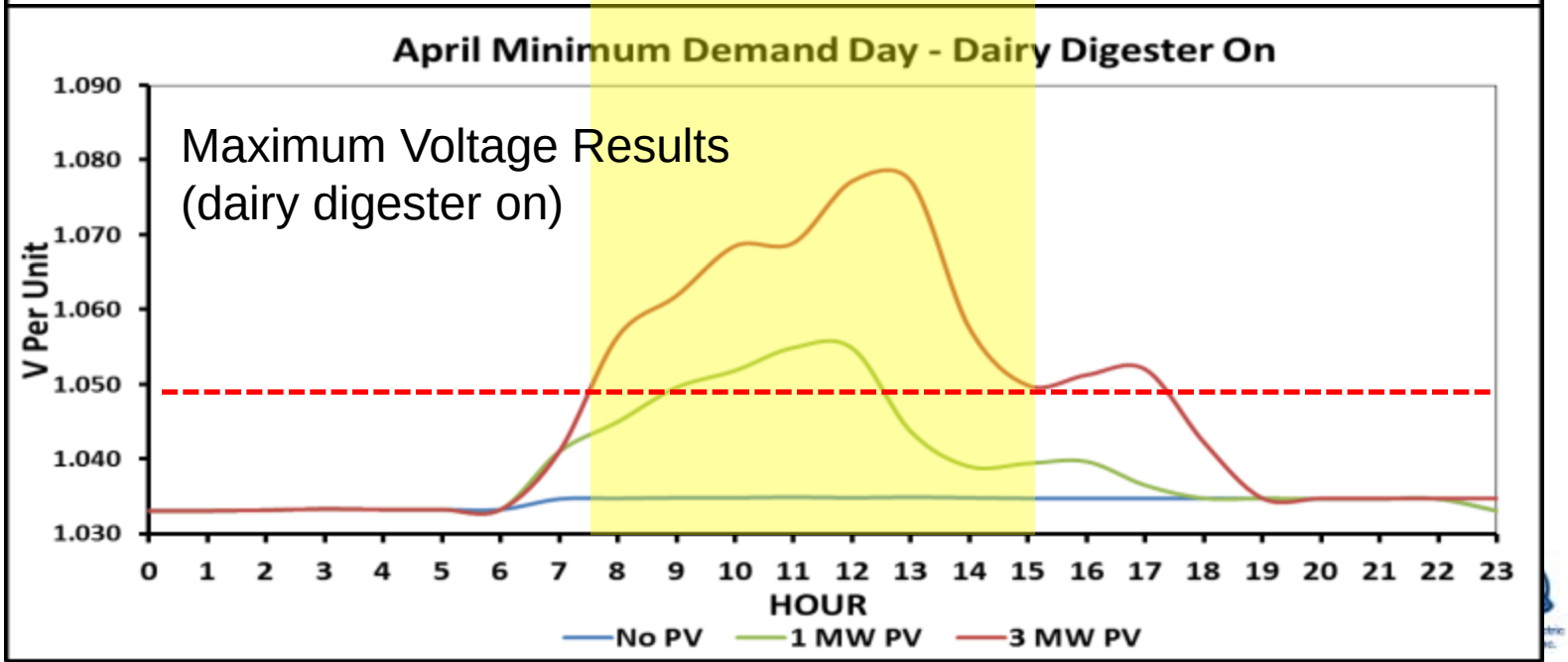
EB - Maximum Voltage Results – 1 MW of PV vs no PV (dairy digester on)



3.5 Hours of high voltage during peak PV generation

EB Circuit at 3 MW



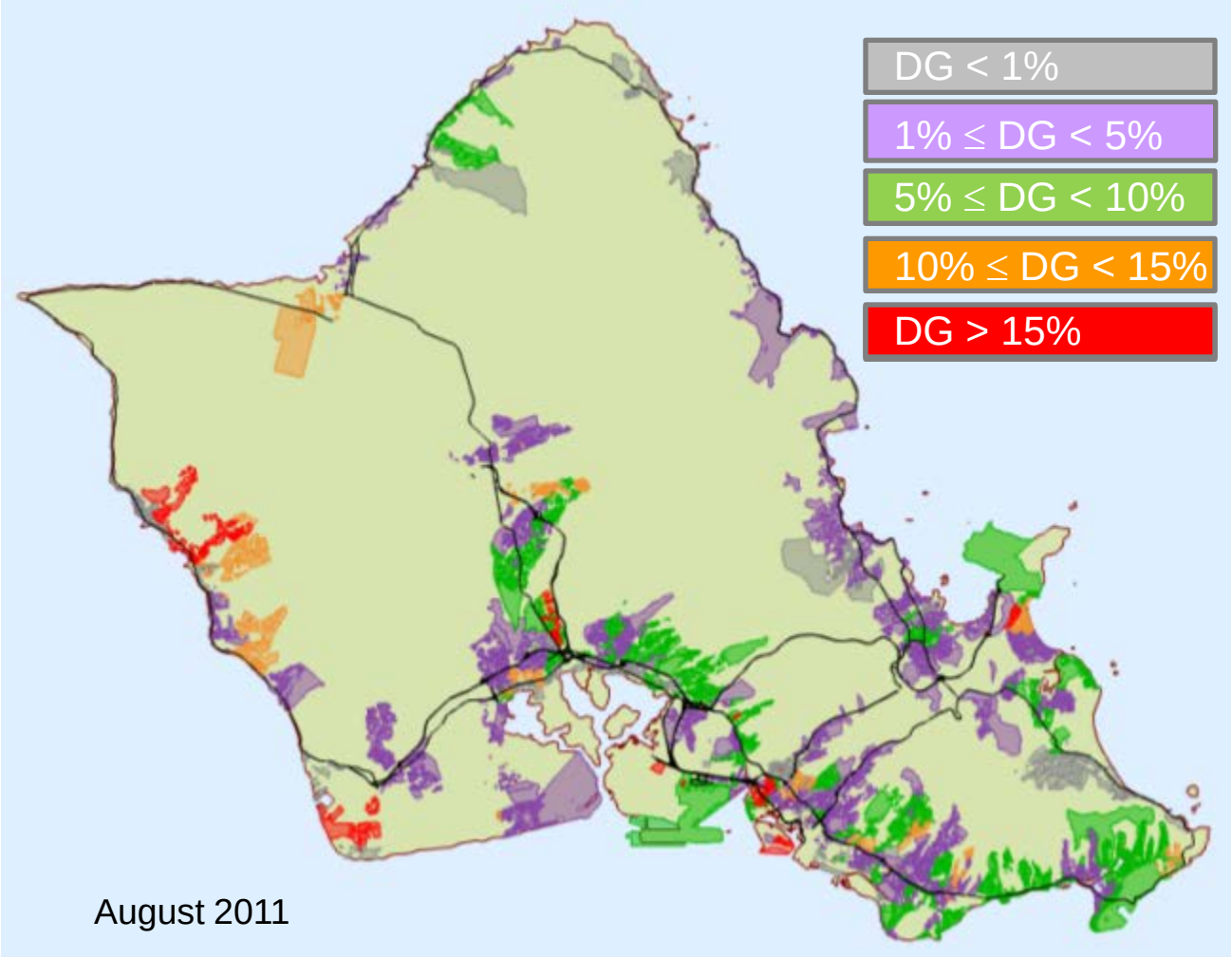


Task 4: High Penetration Solar/Wind Visualization Analysis Pilot

- Graphically displays and visuals to monitor, track and help prioritize renewable resource development areas
- Develop overlay datasets (e.g. geographic information, circuit data, modeling contours)
- Develop and pilot visualization analysis tool for planning and operations

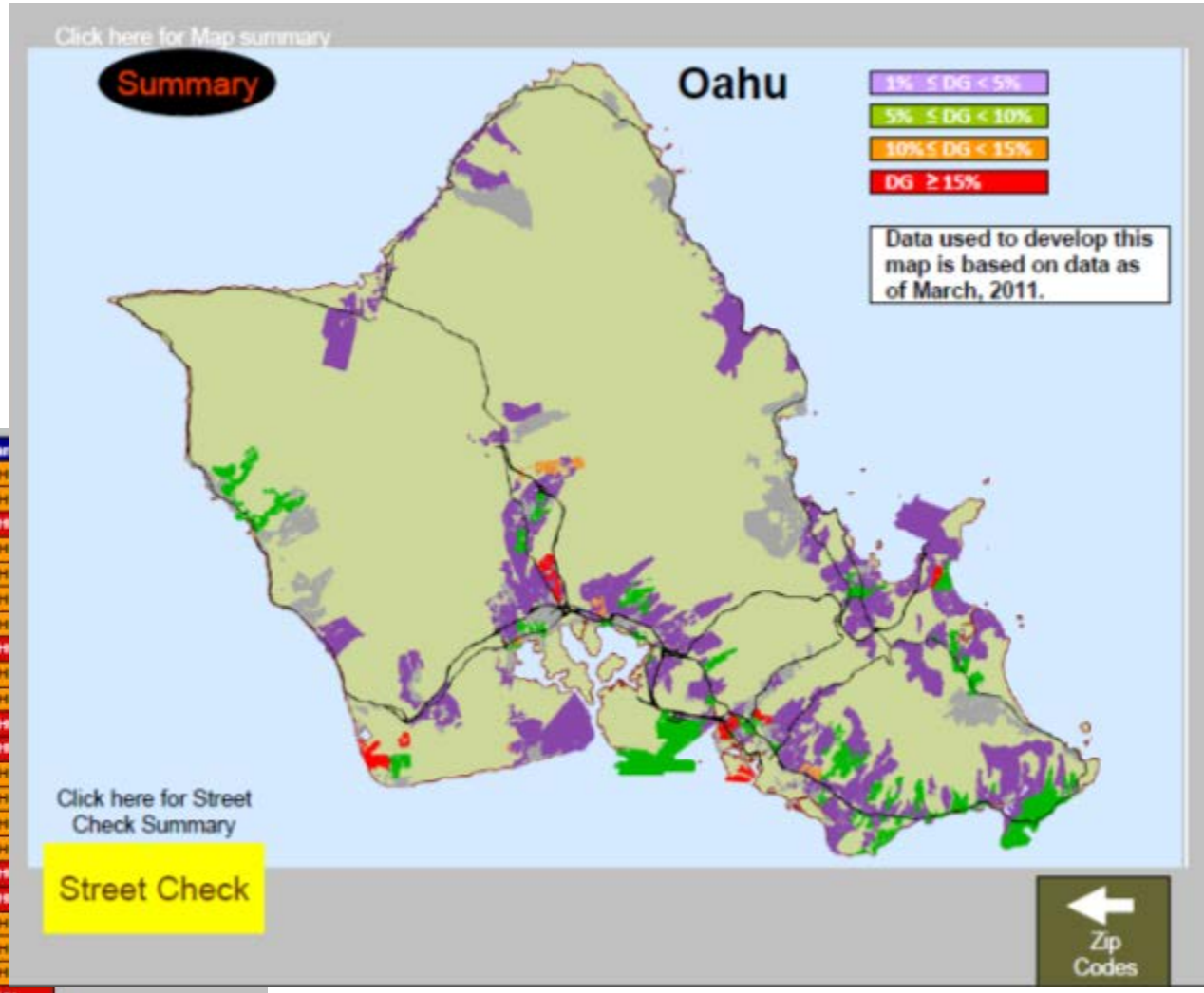
- Solar availability/cloud monitoring for Operations
- LVM for customers & planners
- Nodal approach

Prioritizing Distribution Infrastructure Change



Oahu LVM and Subset of Penetration Levels by Street Names

Subset of Street names with penetration > 15%



10% ≤ DG < 15%
DG ≥ 15%

Street Name	Zip Code	Islan
ANUANU ST	96789	OAH
APAKI ST	96817	OAH
APAKI ST	96817	OAH
APOWALE ST	96797	OAH
AUIKI ST	96819	OAH
AUINA PL	96789	OAH
AUINA ST	96789	OAH
AUIJI ST	96817	OAH
AUMAKA PL	96797	OAH
AUPUNI ST	96817	OAH
AUPUNI ST	96817	OAH
AWAKUMOKU ST	96707	OAH
AWALAU ST	96797	OAH
AWAMOI PL	96797	OAH
AWAMOI ST	96797	OAH
AWANEI ST	96797	OAH
BANNISTER PL	96819	OAH
BANNISTER ST	96819	OAH
CHAMBERLAIN ST	96822	OAH
CLARK ST	96822	OAH
CLEMENT ST	96822	OAH
COLBURN ST	96819	OAHU
DEMOCRAT ST	96819	OAHU
DEMOCRAT ST	96819	OAHU
DILLINGHAM BLVD	96817	OAHU

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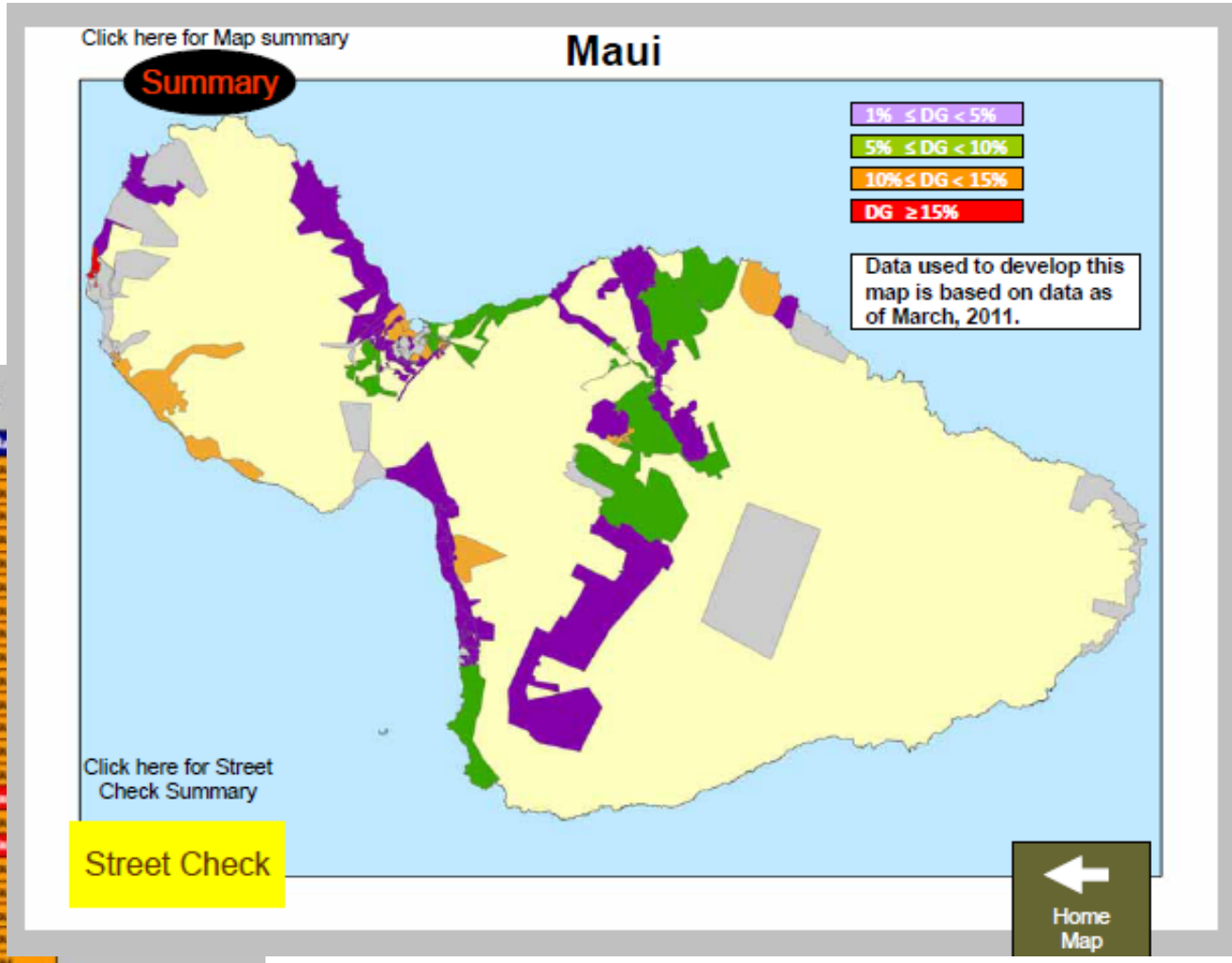
Maui LVM and Subset of Penetration Levels by Street Names

Subset of Street names with penetration > 15%



Street Penetration Check

10% ≤ DG < 15%
DG ≥ 15%

Street Name	Zip Code	Isl
HOOKELE ST	96732	Ma
HOOLAWA RD	96708	Ma
HOTEL ST	96761	Ma
HUAPALA PL	96761	Ma
HUELANI ST	96768	Ma
IAO LP	96793	Ma
IAO PL	96793	Ma
ILIAHI WY	96761	Ma
ILIKAHI ST	96761	Ma
IPU AUMAKUA LN	96761	Ma
IPU KAI LN	96761	Ma
IPU WAI LN	96761	Ma
KAAHUMANU AV	96793	Ma
KAAHUMANU AV	96732	Ma
KAAHAPALI PKWY	96761	Ma
KAEO PL	96761	Ma
KAHEKILI PARK RD	96761	Ma
KAHILI PL	96761	Ma
KAHOOLAWE ST	96732	Ma
KAHULUI BEACH RD	96732	Ma
KAHULUI BEACH RD	96732	Ma
KAHULUI BREAKWATER RD	96732	Maui
KAI ALA DR	96761	Maui
KAI HELE KU PL	96761	Maui
KAI HELE KU ST	96761	Maui

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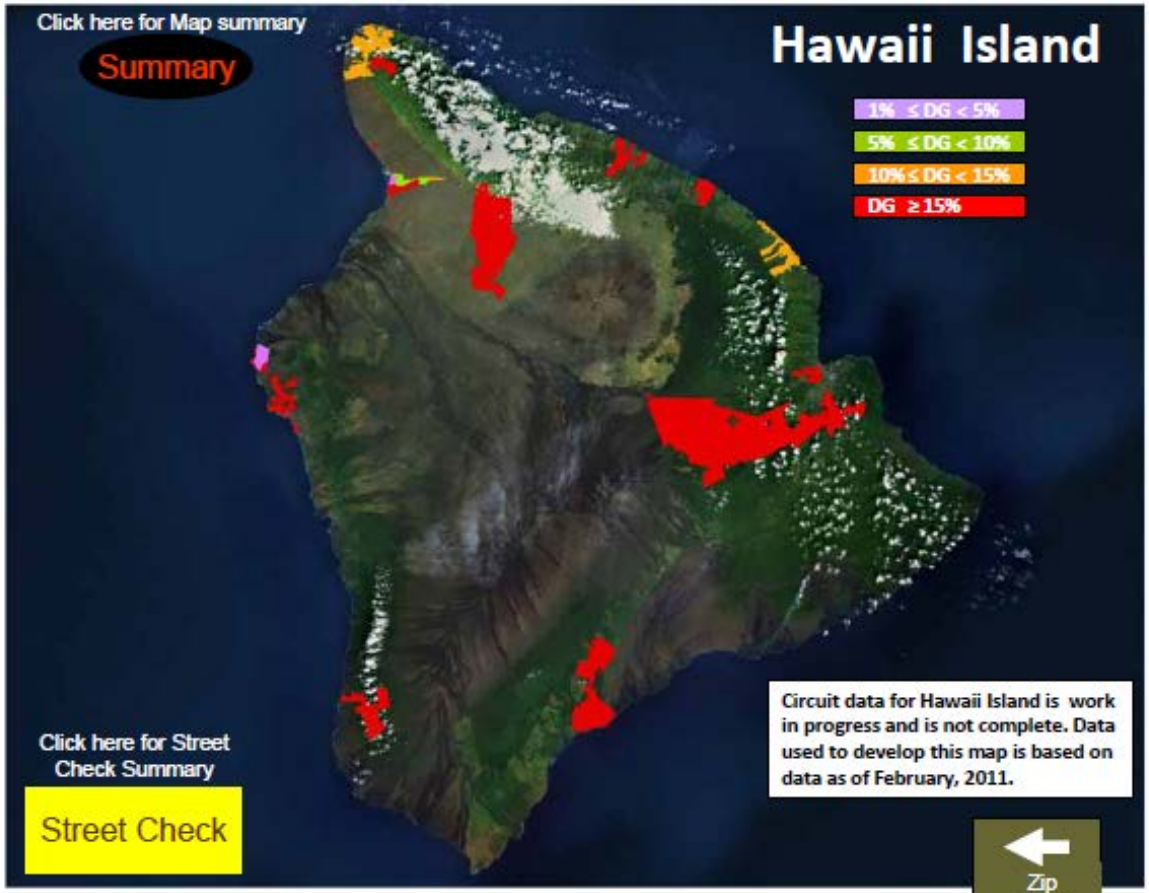
SMUD SACRAMENTO MUNICIPAL UTILITY DISTRICT The Power To Do More.™

Hawaiian Electric Company, Inc.

Hawaii LVM and Subset of Penetration Levels by Street Names

Subset of Street names with penetration > 15%



10% ≤ DG < 15%
DG ≥ 15%

Street Name	Zip Code	Isl
ALA KAHUA PL	96743	HA
ALA WAHI KANAAHO	96740	HA
ALAE ST	96720	HA
ALAPA ST	96740	HA
ALENA PL	96720	HA
ALENAIO LN	96720	HA
ALII DR	96740	HA
ALLIED QUARRY RD	96740	HA
ALOALI PL	96743	HA
ALOALO ST	96720	HA
AMAKIHI ST	96720	HA
AMAUI DR	96743	HA
AMAUI PL	96743	HA
ANE KEOHOKALOLE HWY	96740	HA
ANEKONA PL	96743	HA
ANEKONA ST	96743	HA
ANELA ST	96720	HA
ANINI ST	96740	HA
APOKE ST	96720	HAWAII
AUPAKA PL	96740	HAWAII
AUPAKA PL	96740	HAWAII
AWAPUHI RD	96773	HAWAII
AWIKI PL	96720	HAWAII
BANANA RANCH RD	96719	HAWAII
BEERS RD	96719	HAWAII

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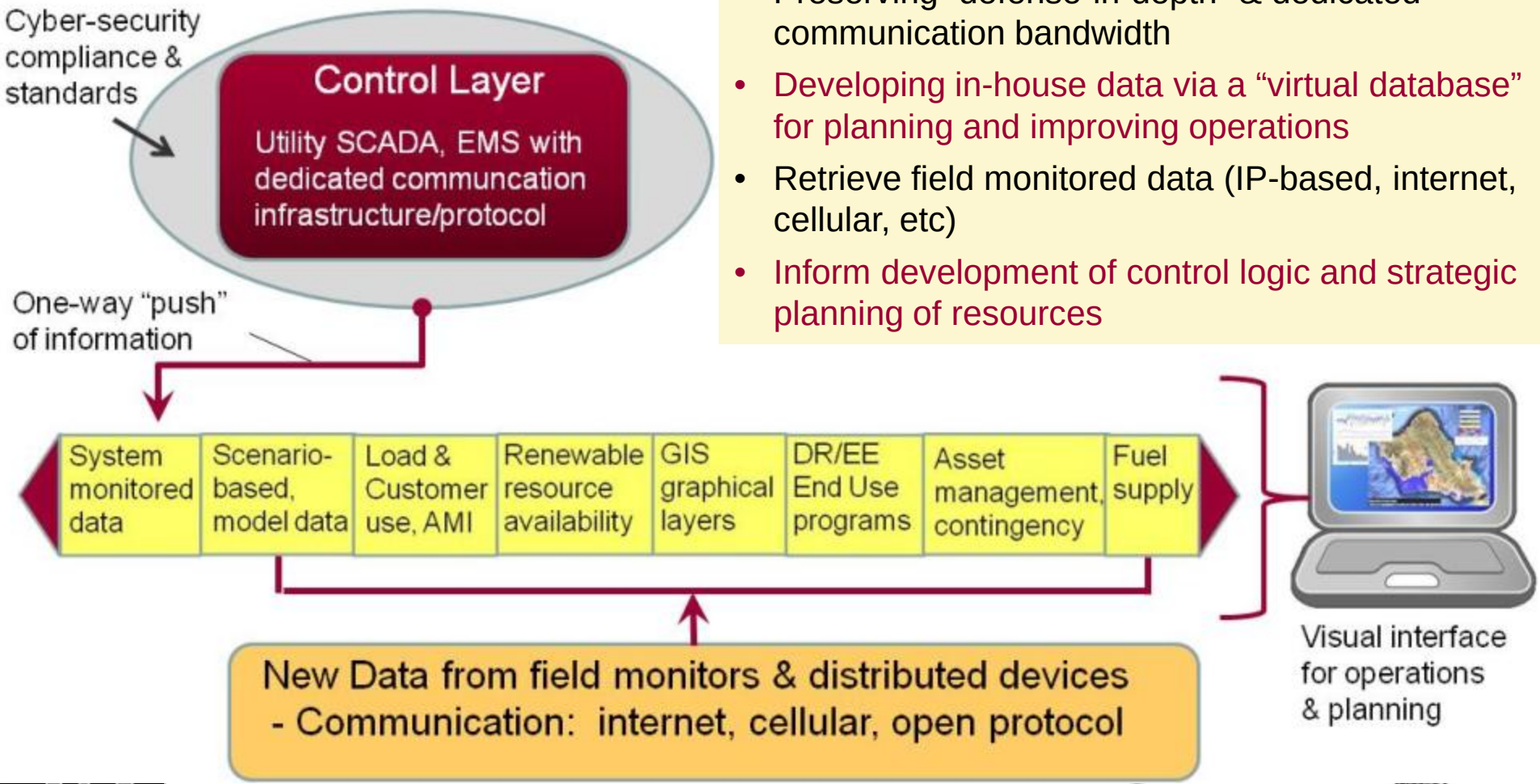
Hawaiian Electric Company, Inc.

Building Visibility by Leveraging Existing Com. Infrastructure & Linking Databases

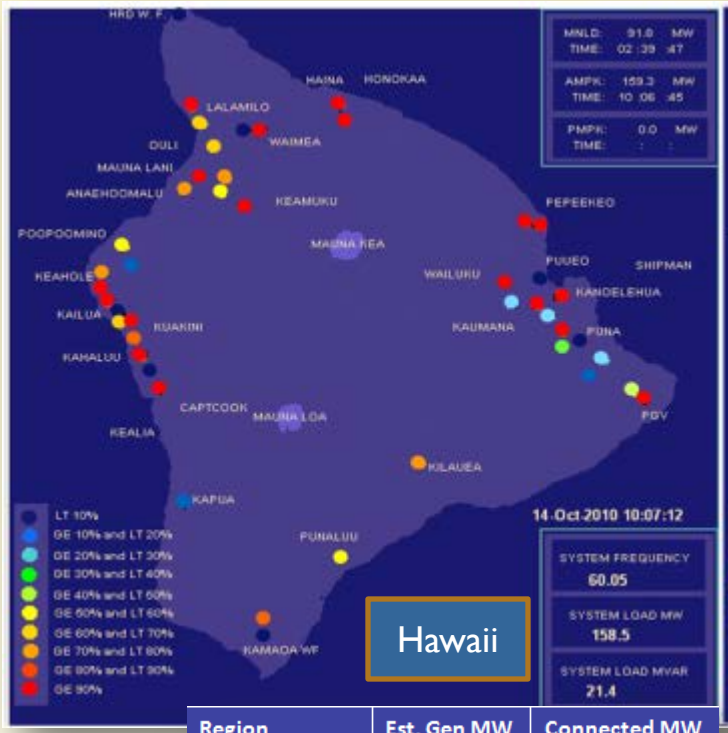
- Preserving "defense-in-depth" & dedicated communication bandwidth
- Developing in-house data via a "virtual database" for planning and improving operations
- Retrieve field monitored data (IP-based, internet, cellular, etc)
- Inform development of control logic and strategic planning of resources



Improving Operational Visibility to PV Availability

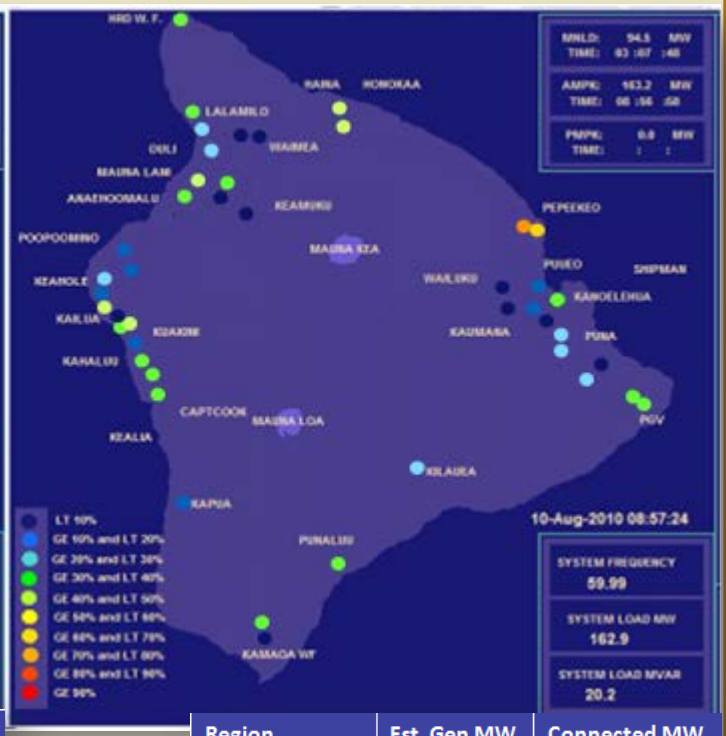
LM-1 solar availability sensors

Ability to visually monitor and plan for "behind the meter" production on the system

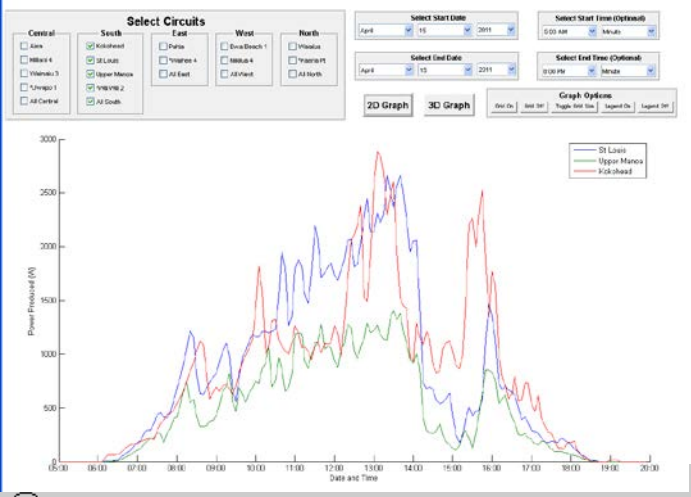


Hawaii

Region	Est. Gen MW	Connected MW
North Hawaii	1.3	1.7
East Hawaii	2.9	4.1
West Hawaii	2.6	3.7
South Hawaii	0.0	0.1
Total PV (MW)	**6.8**	9.6

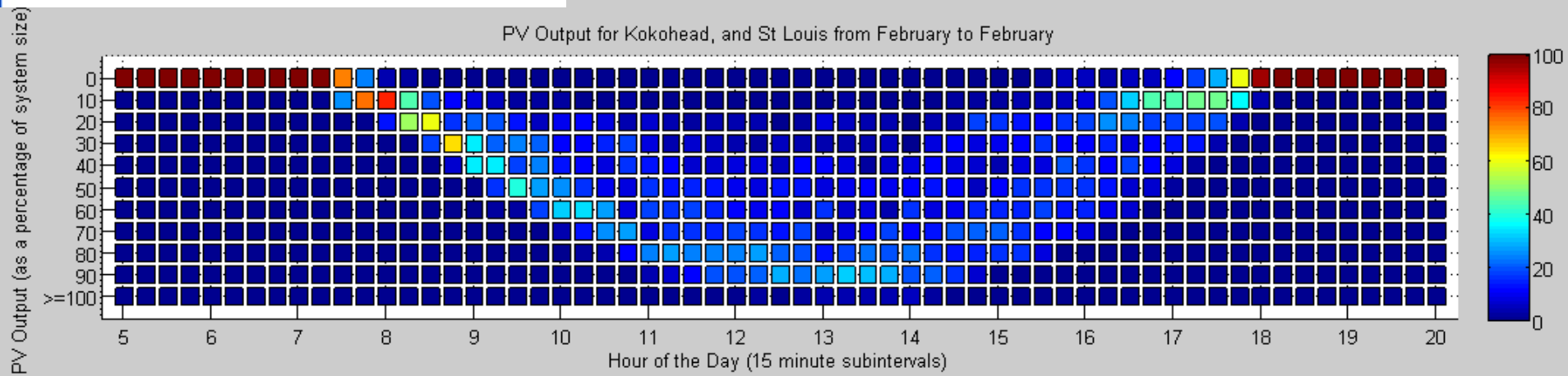


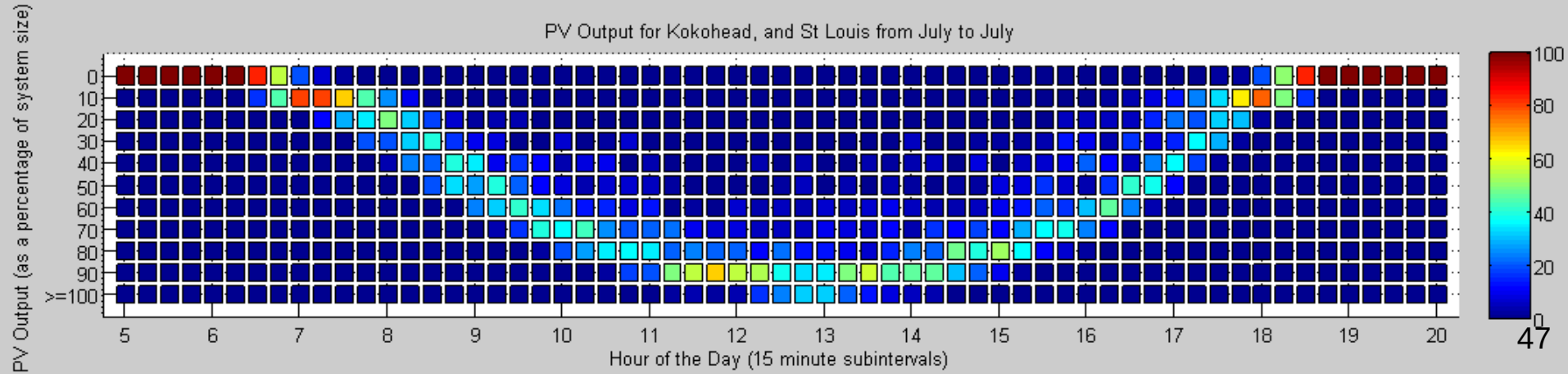
Region	Est. Gen MW	Connected MW
North Hawaii	0.5	1.7
East Hawaii	0.8	4.1
West Hawaii	1.3	3.7
South Hawaii	0.0	0.1
Total PV (MW)	**2.6**	9.6



Statistics & Forecasting to Inform Operations (subhourly intervals)

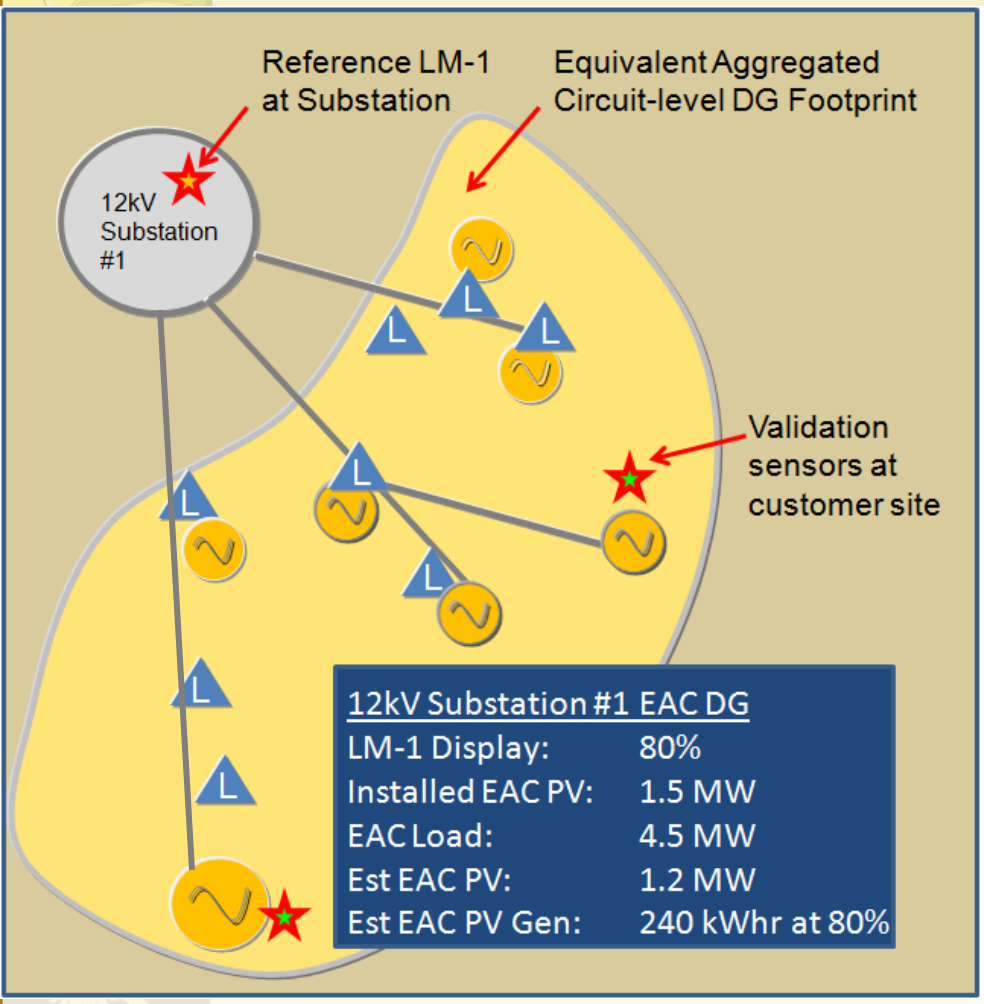
Shows PV production statistics with temporal variation for a region





Nodal Approach for Proactive Planning & Ops

Inverter and Aggregated PV Models



- Characterize discrete and aggregated circuit load profiles at 12 kV substation (residential, industrial, commercial)
- Expedite circuit evaluations and aggregate impacts for planning
- Use reference LM-1 sensors to see & project solar resource potential and circuit loading to account for behind-the-meter generation
- Conduct "what-if" scenario analysis with advance inverter models

Monitoring
- Engage field personnel
- Gain experience

Validation
- Customer sites
- Employee Volunteers

Integration
- Parameterization of ramp rates over various time intervals and locations

Enable Tiered Automation Capability

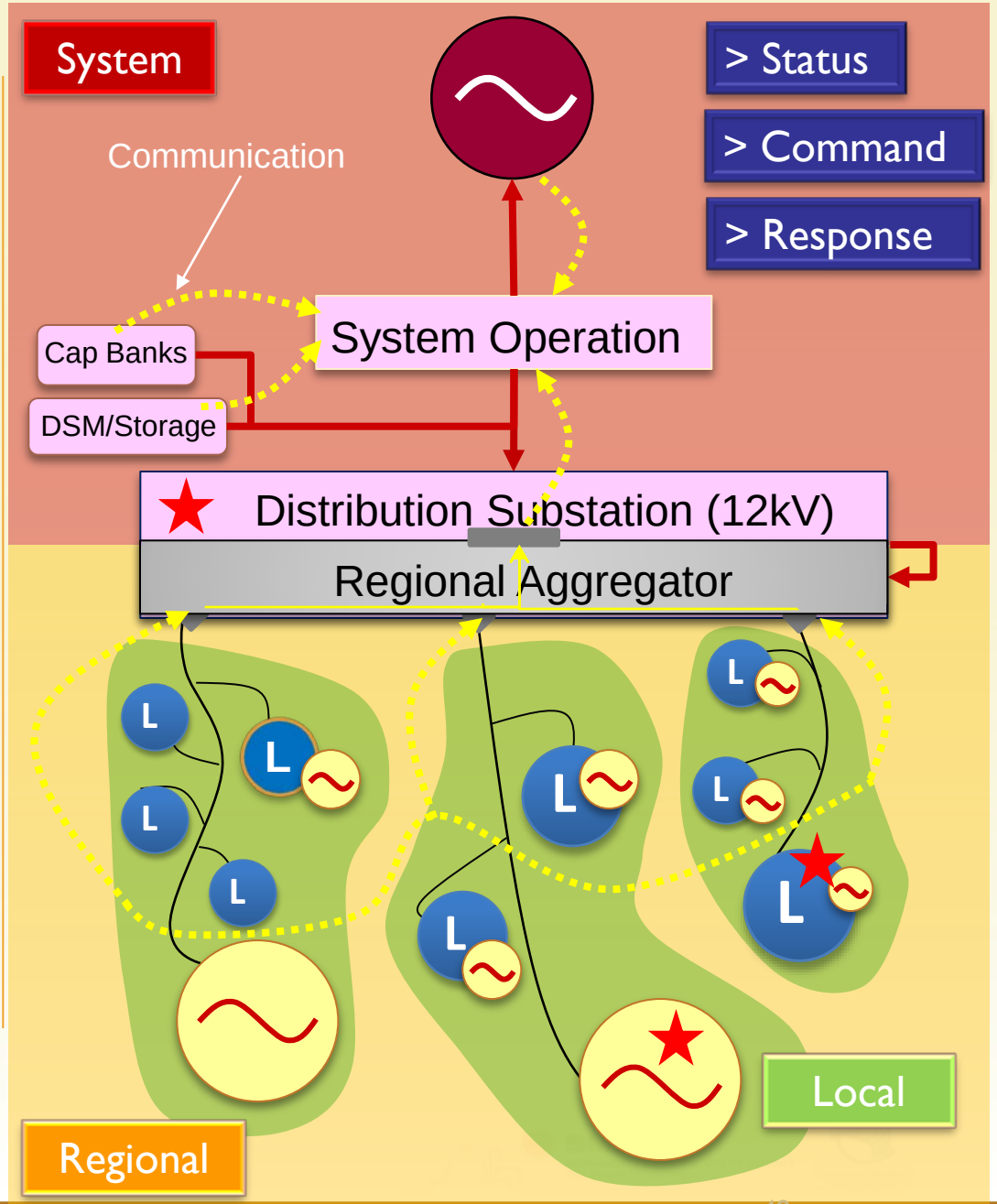
Monitoring
- Engage field personnel
- Gather & gain insight

Modeling
- Simulate response
- ID impact & sensitivities

Validation
- Pilot & iterate
- Communicate results

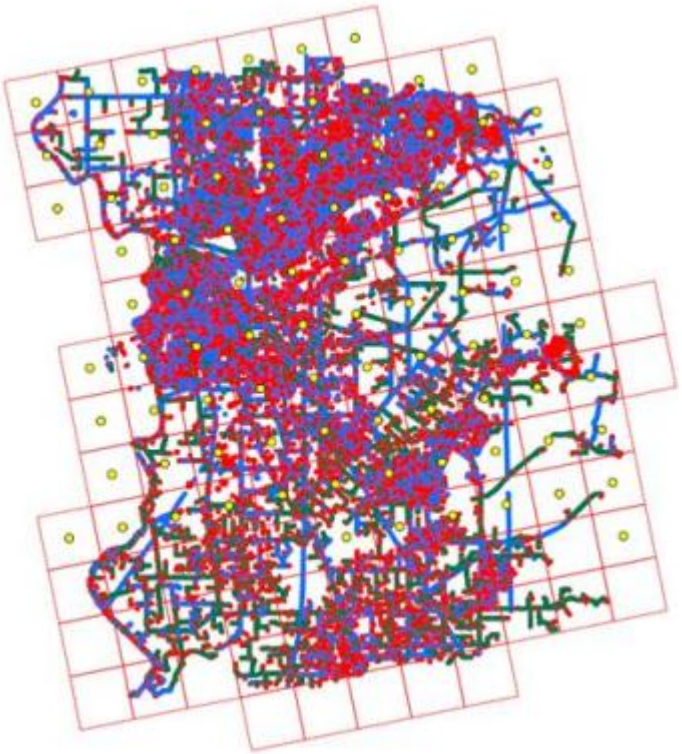
Integration
- Implement & re-evaluate for Ops & Planning

Objective: Strategically deploy "smart" technologies that extend visibility & controls beyond the distribution substations



Task 5: Solar Resource Data Collection & Forecasting (NEO Virtus)

- Deployment of Network of 70 Solar Irradiance monitors, cell modem data collection, 1 minute data
- Modeling/solar forecasting using NOAA weather forecasts, validated using ground network
- Assessment of resource variability across much of the service territory over the year
- Development of a forecasting tool for solar characterization and cloud impacts on system

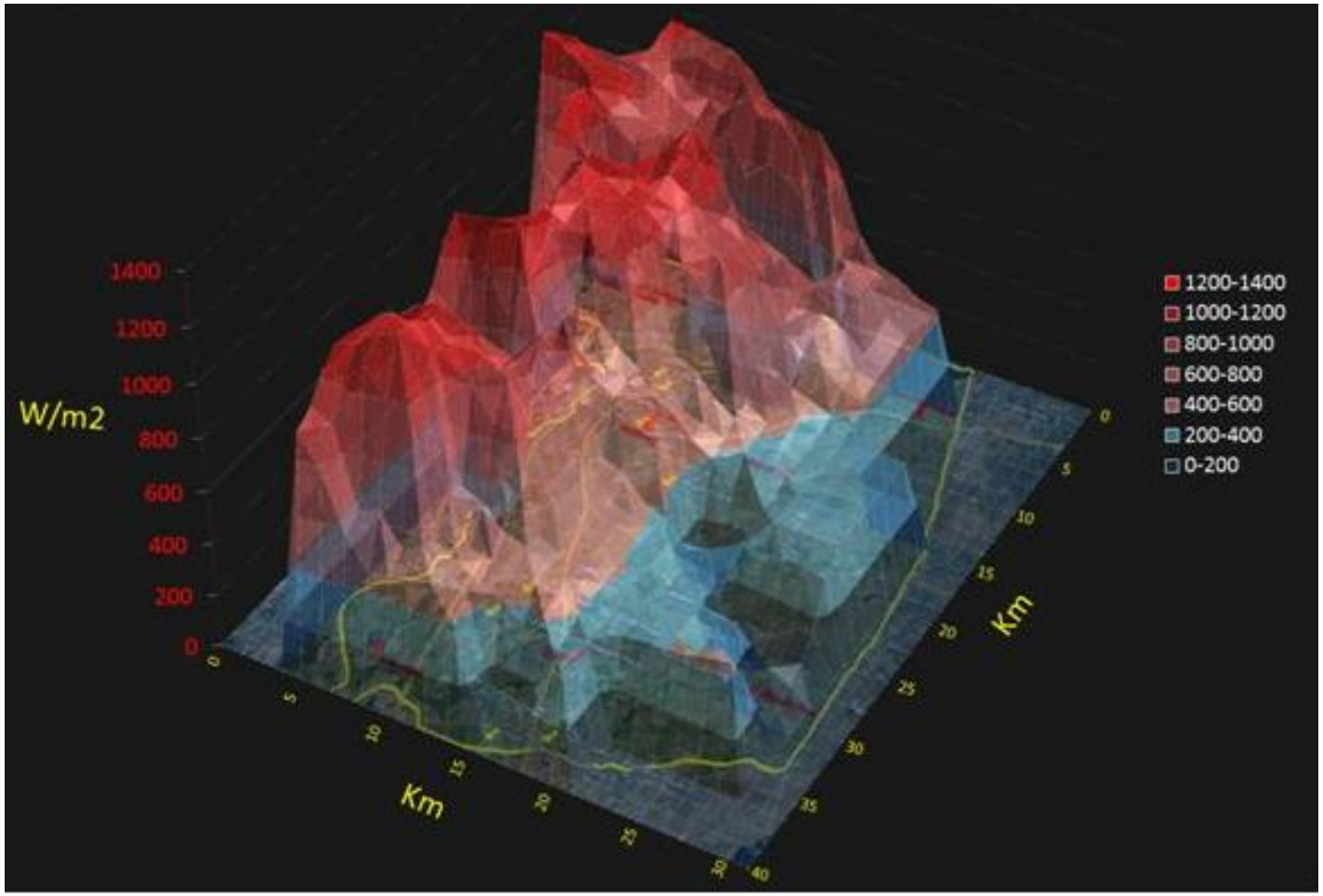


Solar Resource Data Collection

Pre-prototype irradiance monitor

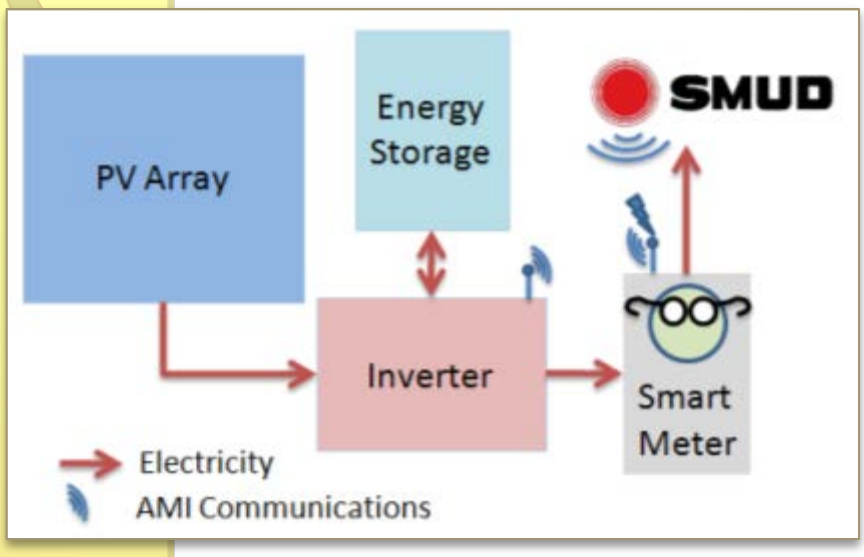
Prototype irradiance monitor

Solar Irradiance SMUD Territory



This is a screenshot of the data from the sensors installed under Task 5 in SMUD Territory at 12:56 PM on 5/14/2011.

Inverter Communications (SunPower) – Task 3.3



- Demonstrate Inverter Monitoring via AMI communication from smart meter to inverter
- Demonstrate receiving data, querying for faults, sending control signals
- Utilized as actively controlled contributors versus passive devices on the grid

HECO has similar effort starting up using Satcon inverters

Summary

- Multiple drivers for increasing Renewable Energy
- Integration challenges with higher levels of variable renewable generation
- Need to gather information through more utility collaborations to look for viable solutions
- Pilot and communicate

Thank You

Questions/Comments??

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