Developing an Operational Eye for Solar

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Abstract

The lack of visibility, accurate modeling and control of distributed generating resources (DG) on the distribution system has created a dearth in knowledge to reliably and affordably advance adoption of significant levels of resources, such as solar roof-top PV systems. Utilities are essentially “blind” to these behind-the-meter resources and need new tools to help capture and understand distribution level impacts. As part of a “back-to-basics” approach, the family of Hawaiian Electric Utilities is partnering with national laboratories, industry experts and other utilities to collaboratively work on gathering data and helping to pioneer a number of monitoring/visualization, modeling and potential forecasting capabilities to better manage growing levels of PV on the electric systems. Contending with over 20%-60% penetration of variable generating resources on distribution circuits, real-time visualization tools for operations using high fidelity solar resource data and improved modeling techniques are envisioned to help proactively plan and reliably integrate additional levels. This paper highlights results from some pioneering data monitoring and visualization efforts currently underway at the Hawaiian Electric Companies. These efforts are part of a broader, more comprehensive renewable integration action plan that also includes proactive investigation of cost-effective integration/mitigation strategies and development of training for a clean energy savvy workforce.

Introduction

A fundamental shift toward more customer-sited, DG is occurring with the emergence of more PV and consumer self-generation programs (i.e. net energy metering - NEM, feed-in-tariff - FIT). The Hawaiian utilities are among an emerging set of utilities around the world leading the nation in contending with high levels of renewable penetration on their distribution systems. Today, the family of Hawaiian Electric utilities, consisting of Hawaii Electric Light Company (HELCO) on the Big Island of Hawaii, Maui Electric Company (MECO) on the islands of Maui, Molokai and Lanai and Hawaiian Electric Company (HECO) on the island of Oahu, are contending with PV penetrations in excess of 20% during maximum load conditions on distribution circuits (Figure 1) and over 60% penetration during light load conditions.

At these penetration levels, there is growing concern that the protection and design of traditional distribution systems are beginning to or are being compromised. While tremendous investments exist on the transmission side for enhanced control, visibility and communication, the distribution system has received considerably less attention, tends to be more disperse, non-standardized across the nation, less automated and as a result, may pose a greater risk to reliability. Given limited communication, control and visibility at distribution sites, utilities are essentially “blind” to the variability impacts of increasing levels of behind-the-meter resources (Figure 2).

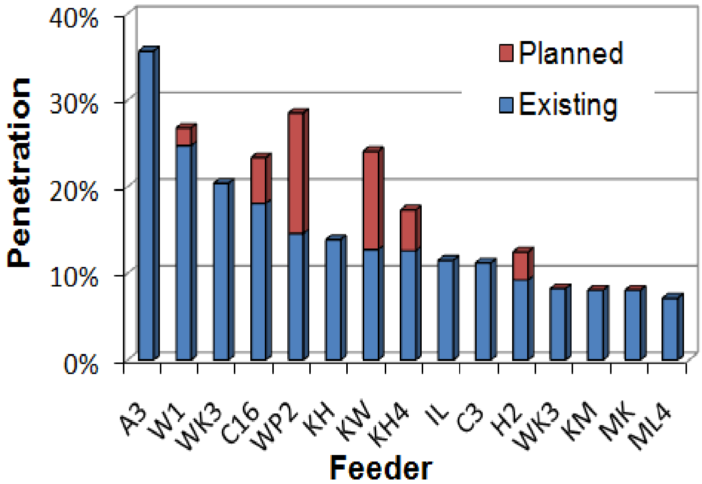


Figure 1. Tracking increasing PV penetration by circuits.

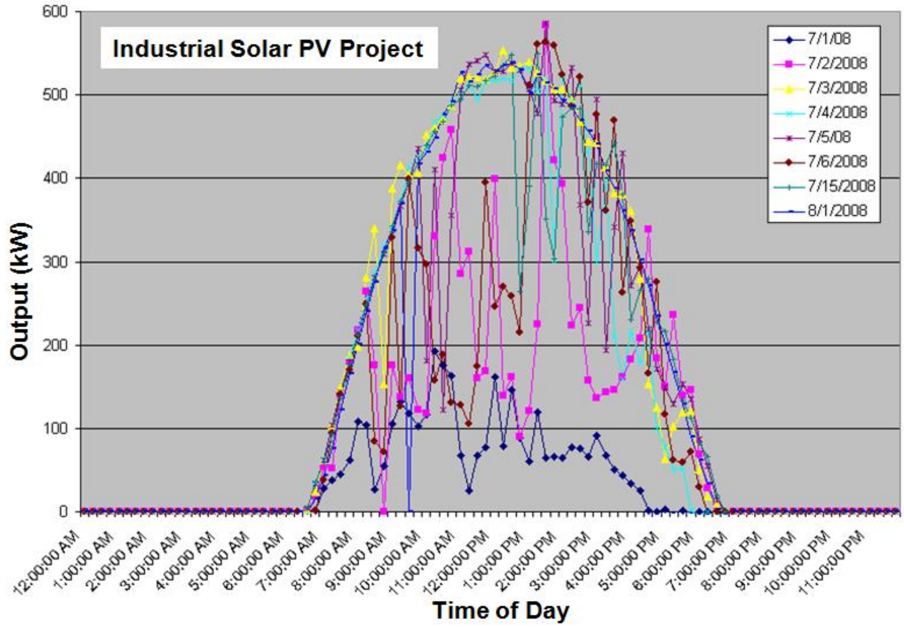


Figure 2. Example of hourly and daily variability in solar PV plant output.

As penetration levels continue to increase with aggressive state RPS targets, challenging questions are being posed by utilities around the world. Questions include,

- How can impacts/benefits of high penetration PV at the distribution level be captured to help inform and guide system planning needs and variability migration strategies?
- What information and modeling/analysis tools are available or needed including data (resolution, location and duration), accuracy and analytical resources to properly address concerns?
- Are the foundational design and operating/protection rules and tools for traditional electric systems still appropriate/sufficient, or at what level will they no longer be appropriate/sufficient (may be system specific)?
- How can information be best shared (graphical displays, validation data) while preserving system security and reliability?

- What are some cost-effective and sustainable approaches that remain mindful of legacy infrastructure and interoperability issues?

To facilitate state energy initiatives and market drivers, Hawaiian Electric utilities are developing an operational eye on solar generating resource via real-time visualization capability and advance locational modeling techniques that are envisioned to enhance our capability to proactively plan, cost-effectively and reliably integrate more demand side generating resources and new technologies. Addressing the questions and finding solutions will require collaborative interaction between utilities, vendors, modelers, developers and regulators to shape future system design, operating knowledge and development of new tools and capabilities.

This paper presents some of the issues/challenges facing the Hawaiian utilities, our strategy, goals and "back-to-basics" approach to addressing these challenges. Current efforts are focused on developing more appropriate utility modeling and analysis tools to support operations and planning. Efforts help develop "insight" for training the workforce in managing variability while considering the benefits/impacts of these resources. Field deployment experiences and preliminary results for some of the pioneering projects will be discussed to show progress toward integration. Future work and benefits will also be discussed.

Approach

Hawaiian Electric Companies are partnering with industry (including grid code developers, forecasters, equipment manufacturers), mainland utilities (including WECC, CaISO, SMUD, PG&E, SCE) and national resources to develop robust and cost-effective visualization, forecasting and modeling capabilities to reliably account for growing levels of PV and prepare for emerging levels of future DG, such as plug-in hybrid electric vehicles (PHEV). A major challenge for PV integration has been the lack of appropriate information needed to develop new models, tools and guiding strategies for managing variability. Thus, we are going "back-to-basics" with an approach that includes,

- *Monitoring* – gather, analyze and characterize high resolution PV resource data along with corresponding system data (time-stamped system performance information and status)
- *Modeling* – develop more accurate circuit level representations and appropriate inverter-based modeling capability and inclusion of DG resources attributes into planning models
- *Validation* – deploy in the field, sensors and visualization tools to observe, assess and verify modeling results with actual system and resource performance data
- *Integration* – develop strategies, processes and procedures adopting new tools and field data into planning and operations
- *Partnerships* – develop strategic partnerships with industry experts, model developers, forecasters, utilities, academia and national resources to improve integration capability, develop workforce, leverage resources and manage risks.

Goals include

- Operationalize low-cost, low-maintenance data analysis and visualization capability to track increasing penetrations of “as-available” DG such as PV
- Integrate timely DG modeling with resource estimation capability (using field data) and forecasting capability for expediting planning and enhancing operational awareness
- Strategically target deployment of new “smarter” automation technology and mitigation measures at regional and local levels to help manage variability and grid resources

Desired benefits

- Increasing public awareness of system critical periods and accounting for aggregated impacts of DG and other variable resources on system reliability and costs
- Improving modeling and assessment tools to incorporate distributed resources and system information for designing new protection and control schemes
- Informing strategic deployment of “smarter” regional/local automation and controls to reliably integrate DG resources

Figure 3 graphically illustrates the strategy to transition data and modeling efforts to field monitoring and demonstration pilots that can then be used to inform the design and development of “smarter” local and regional communication, control and feedback requirements to enhance system operations.

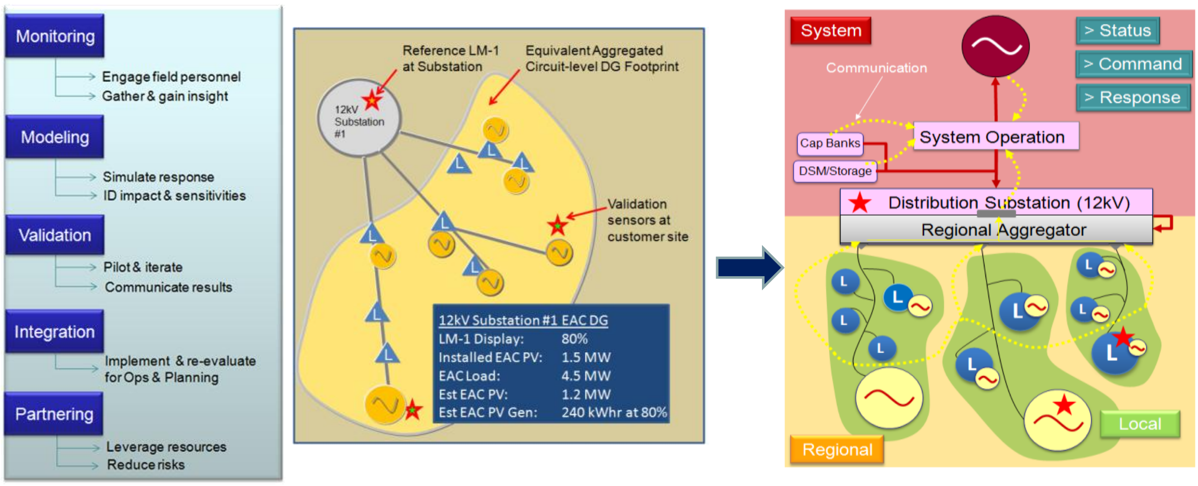


Figure 3. Transition of “back-to-basics” approach to field pilots and development of “smarter” local and regional control infrastructure.

Results

A number of pioneering efforts are currently underway at the Hawaiian Electric Companies to help improve understanding and to develop new capability for managing variable renewable resources such as solar. Specific efforts to help track, trend and monitor significant levels of distributed PV on the island grids are further discussed below.

One of the first efforts initiated is the development of high resolution (2-second) solar datasets to help characterize solar variability and support modeling of potential impacts on the overall system, including generation units and transmission and distribution systems [1].

With sponsorship by the U.S. Department of Energy's Solar Energy Program, Hawaiian Electric has been working with national laboratory technical teams from the National Renewable Energy Laboratory and Sandia National Laboratory to deploy high resolution solar irradiance monitoring equipment throughout the islands (Figure 4a). The basic irradiance monitoring equipment consists of a pyranometer, data acquisition and cellular communication package. A few of these units (TJD-1) have also been modified for deployment at utility distribution substations to support high penetration PV circuit modeling and analysis efforts, shown in Figure 4b. Modifications eliminated the use of a metal tripod which poses potential arcing hazards within the substation and enclosed all equipment within a modular structure. Used in conjunction with public, historical 15-minute data that the Hawaiian Electric Companies have gathered since the 1980s under the Sun Power for Schools Program [2], this high resolution solar irradiance data is being evaluated and used for a number of utility scenario planning analysis, modeling and field validation efforts.

(a) (b)

Figure 4 Irradiance monitoring equipment a) tripod setup and b) TJD-1 substation setup.

In parallel, Hawaiian Electric, Sacramento Municipal Utility District and industry partners including BEW Engineering and GL-Denton have been working on making modifications and tailoring to proprietary distribution models to incorporate field monitored PV resource data and algorithms for modeling inverter-based DG [3]. Modeling improvements and circuit level evaluations are currently underway on all the islands. Preliminary work using GL-Denton's SynerGEE model for circuit level analysis and island-wide PV impact analysis at the distribution level for Oahu is shown in Figure 5.

Results are anticipated to provide initial guidance on high penetration impacts and setting of preliminary DG program targets based on resource availability and system constraints. These enhanced models are also being validated using high resolution field monitored circuit data currently being collected on the systems. The work will provide confidence in using models to conduct scenario-based planning and to help expedite project integration and interconnection studies. Model verification and testing are ongoing for 1) single-phase circuit models for select high penetration circuits on each of the islands and 2) aggregated 3-phase equivalent models that can then interface with the transmission system models for each island.

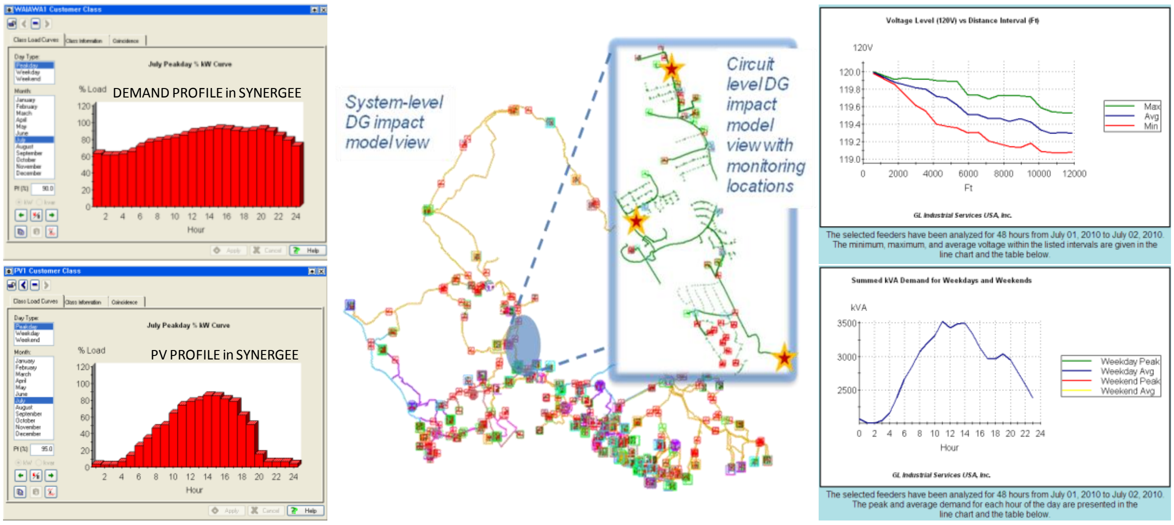
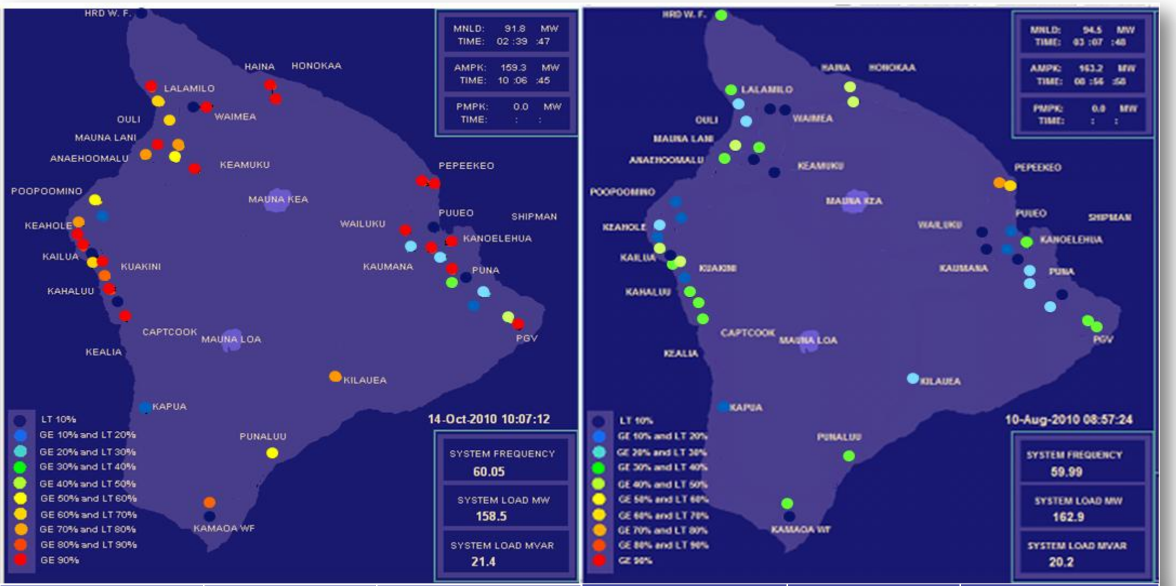


Figure 5. Island-wide enhance distribution model (SynerGEE) and circuit level model preliminary work.

Another project is helping to extend operational visibility to solar generating resources through the use of locational monitors (LM-1), show in Figure 6. This innovative approach uses low-cost, small PV panels deployed at utility substations as sensors to provide a near real-time, island-wide view on solar generation. Deployed throughout the island at utility distribution substations, the LM-1s are providing system time-stamped, voltage output based on the solar irradiance in the local area near the substation.

Figure 6. Various locational monitor (LM-1) installations at substations.

The LM-1 monitors are currently being piloted on the Big Island of Hawaii by HELCO and being deployed on Oahu by HECO. As shown in Figure 7, approximately 50 LM-1 units are deployed on the HELCO system. Readings are transmitted back as a voltage signal to operations where a color-coded visual display and calibration routine convert the reading to an estimate of regional PV generation. By incorporating the LM-1 readings into a visual display, operators now have a real-time view of where PV production is high (red) and where production is low (blue) either due to clouds or other constraints. By tracking and trending these views over time and connecting the system conditions and meteorological conditions, operators and planners will hopefully begin to gain insight for the PV resource and variability patterns throughout the day, season or grid condition and can better track PV growth and anticipate change on the systems.



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

Figure 7. LM-1 graphical interface for HELCO.

Efforts are also underway to investigate use of LM-1 information to improve system-level and circuit-level load and solar forecasts. As penetration of distributed PV increases, historical load shapes and traditional load or demand forecasts based on tracking energy sales and spot readings of circuit load for energy may not longer be appropriate or sufficient. As illustrated in Figure 8, over time, as more customer-sited PV emerges and load changes, net energy sales may decrease thereby masking actual load or demand on the system, especially during cloudy or stormy conditions. For an island grid without the backup of an interconnected grid like on the mainland, keeping an eye on actual load (throughout different seasons, days and time of day, ramp events) as well as the net load will be critical for system reliability, reserve planning, resource adequacy planning and contingency management. By calibrating the LM-1 output to a solar irradiance, the information may be very useful in estimating customer sited PV or other DG serving local load, the net load and the total load by circuit, by substation and for the entire system. Based on this information, operators and planners can begin to track and trend PV performance throughout the system at both the distribution and transmission levels.

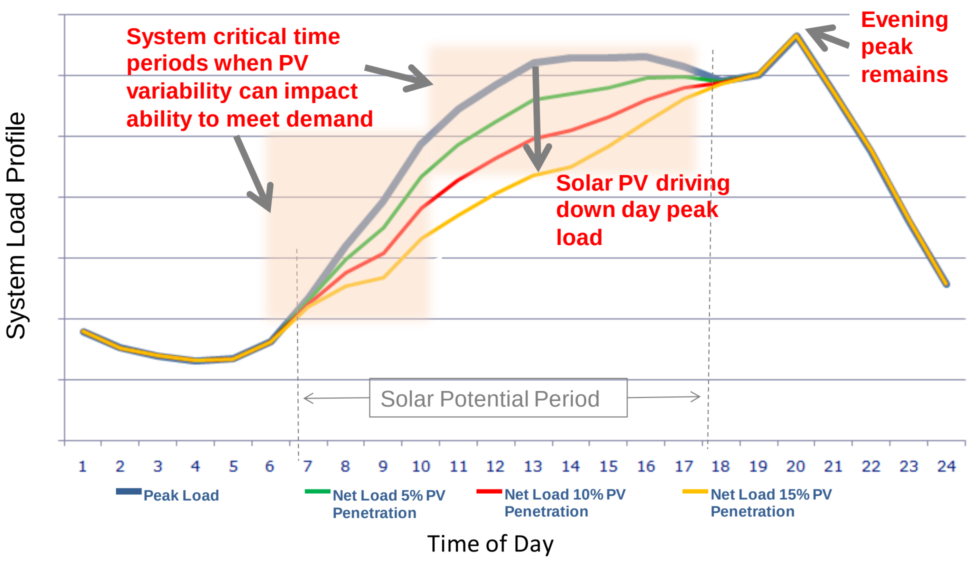


Figure 8. Changing system load profile with increasing levels of PV.

Figure 9 shows the Locational Value Maps (LVMs) developed for the islands and used to graphically track and trend growth of PV penetration by circuit level. This view provides the general public and solar developers a geographic view of the level of PV penetration by percentage on the circuits (identified by street name). The information gives installers and developers an awareness of where new projects may be in existing high penetrations areas and a heads up in planning and scheduling installations.

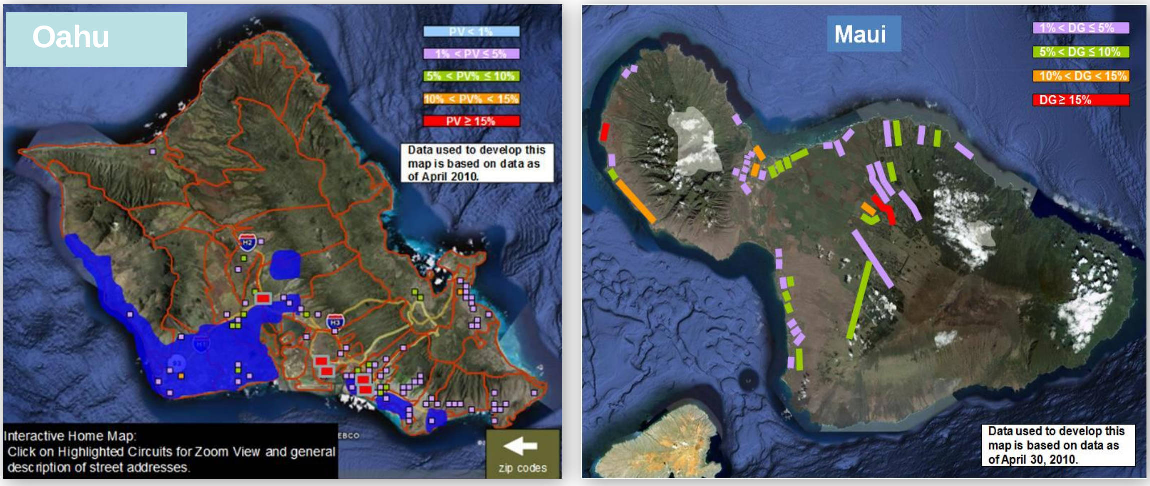


Figure 9. LVM displays used to show high penetration circuits [replace with automated]

For the utilities, LVMs help visually track circuit-level information including

- individual circuit load (minimum, maximum and light load conditions),
- installed and planned PV (capacity),
- penetration level as a percent of maximum or light load conditions and
- growth potential for planning and operations.

This visual tool and information, used in conjunction with LM-1 solar availability monitors and high resolution irradiance pyramometers (TJD-1), is helping utilities better track, plan and communicate with customers interested in net-energy-metering and feed-in-tariff programs.

Through these efforts [4, 5], Hawaiian Electric utility staff is developing a "heads up" on high penetration areas to better plan infrastructure such as communication, substation data monitoring and T&D improvements. Similarly operators now have visibility to the locational value of PV resources to meet demand out to the distribution level. By having visibility to where the distribution generation, load and system constraints are, the potential exists to develop targeted and more responsive load control and management capability. For the island grids, ability to plan ahead and "forecast" needs will be critical in maintaining reliable operations and cost-effective energy services while pursuing clean energy alternatives.

Summary

The Hawaiian Electric utilities are proactively developing analytical capability and new planning and operational tools to support renewable integration efforts. The "back-to-basics" approach requires strategic partnerships with other utilities, modelers, developers, national experts, regulators and consumers. With one of the first efforts in the nation gathering high resolution solar resource information coupled with time correlated distribution circuit and system information, Hawaiian Electric Companies are helping to pilot new modeling capabilities, resource monitoring devices, visualization and renewable integration techniques. By recording and tracking both the solar irradiance and PV production, information can be used by operators and planners to keep an eye on existing solar, to anticipate infrastructure needs of emerging PV system and other grid connected distributed resources such as PHEV and to help shape development of grid responsive variability mitigation strategies (i.e. dynamic load management, storage devices). Insights gained through these efforts will hopefully provide guidance to other utilities around the nation contending with increasing demand side generation. Collaborative development of new capabilities, tools and processes with utility operators will hopefully *inform and pave the pathway* toward "smarter", more cost effective energy management capabilities.

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References

1. NREL Solar Irradiance Website, http://www.nrel.gov/midc/
2. HECO Sun Power for Schools, http://www.heco.com/portal/site/heco/menuitem.8e4610c1e23714340b4c0610c510b1ca/?vgnextoid=529bf2b154da9010VgnVCM10000053011bacRCRD&vgnextfmt=default
3. SMUD/HECO High Penetration PV Website (HiP-PV), http://www.calsolarresearch.ca.gov/Funded-Projects/solicitation1-smud.html
4. D. Nakafuji, "Hawaii Solar Activities, Impact 2030," Utility Wind Integration Group, April 14, 2010, http://www.nrel.gov/eis/pdfs/uwig_solar_wkshp_nakafuji.pdf
5. T. Aukai, R. Choy, and D. Nakafuji, "Keeping and Operational Eye on Wind and Solar," University of Hawaii Manoa Renewable Energy Island Sustainability Seminar Series, Sept. 2, 2010