Final Technical Report (FTR)

Project Title:	**Distributed Resource Energy Analysis and Management System (DREAMS) Development for Real-time Grid**
Project Period:	11/30/2009 – 6/30/2016
Reporting Period:	11/30/2009 – 6/30/2016
Submission Date:	October 2016
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Award Number:	DE-EE0006331
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Final Technical Report
DOE-EE0006331-FTR1

Distributed Resource Energy Analysis & Management System (DREAMS) Development for Real-time Grid Operations

Submitted by
Hawaiian Electric Company

to

U.S. Department of Energy

DOE Award Number: DE-EE0006331
Project Period: November 2009 – June 2016
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Date of Report: October 2016

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ACKNOWLEDGEMENT

The Hawaiian Electric Companies would like to thank the U.S. Department of Energy for their sponsorship of the DREAMS project, conducted under U.S. Department of Energy Award No. DE-EE0006331. We would like to extend our appreciation to our project sponsors, various technical managers and support staff.

Our DREAMS team of industry collaborators and vendor partners were instrumental in helping us achieve the successes under the DREAMS initiatives. Together we all developed better appreciation and collaborative understanding of the needs and requirements to move toward the grid of the future.

The DREAMS team would like to acknowledge our strategic western utility partners: Ms. Elaine Sison-Lebrilla at Sacramento Municipal Utility District (SMUD), Mr. Jack Peterson at Southern California Edison (SCE); Mr. Jim Blatchford at the California ISO and Mr. Randoph Manion at the Western Area Power Administration (WAPA). Their candid feedback and participation, consistent vision and active review of the results improved the robustness of renewable forecasting, DG integration, REDatabase development and modeling activities including circuit load evaluation and load forecasting. Sincere appreciation to the members of the first of its kind Utility Advisory Team (UAT) and willingness to share perspectives to advance the utilities' state of knowledge in application of short term wind forecasting and ramp event forecasting capabilities. Enhancing utility capabilities and partnerships will enable better management and integration of renewables onto the nation's grids.

Finally, the work presented represents culminating efforts of a number of key personnel from across the Hawaiian Electric Companies who are endeavoring to make the system more reliable and cost-effective for our customers. Special thanks to our Project Manager, Ms. Lauren Gouveia; System Operations Manager at Hawaii Electric Light Company (HELCO), Ms. Lisa Dangelmaier and System Operations Manager at Maui Electric Company (MECO), Mr. Chris Reynolds. Appreciation and acknowledgement is extended to our corporate executive sponsors, utility operations staff and to all the utility technicians and field staff supporting this effort across the tri-Companies. Without their dedication and ingenuity, these pioneering efforts would not have been successful.

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EXECUTIVE SUMMARY

With increasing levels of behind the meter distributed photovoltaic (PV) resources, that in aggregate are as large as utility scale generators, the ability to see, forecast and manage distributed variable resources needs to be integrated into the system operations environment. The goal of the Distributed Resource Energy Analysis and Management System (DREAMS) Development for Real-time Grid Operations project was to support development of the next generation energy infrastructure and energy management environment with the capability to account for contributions from a growing fleet of behind-the-meter distributed generation in an aggregated fashion and be able to factor in 15-min short-term probabilistic weather information into the utility energy management system (EMS) algorithms to inform more real-time operational decisions (e.g. unit commitment, load forecasting, reserve monitoring and ramp alerts). The purpose was to provide utility operators with more timely information and enable seamless EMS capability to cost-effectively "see and manage" change impacts arising from high penetrations of renewable resources from transmission down to distribution levels, specifically distributed PV located on the customer side where utilities have limited visibility and controls.

The work undertaken in the DREAMS project with support from US Department of Energy (DOE) was both timely and novel as it helped address two critical gaps in advancing variable renewables and distributed resource adoption levels and integration into mainstream utility operations. The first gap was industry awareness of and prioritization of distributed generation integration needs. Smaller utilities, such as Hawaiian Electric Companies (HECO) and Sacramento Municipal Utility District (SMUD) are feeling the effects of high penetrations on the grids, such as the California [1, 2]. However as smaller utilities, both SMUD and HECO lack the market momentum to drive foundational change in standards and establish software systems. The second gap was in the development of integrated end user tools. Considerable efforts and investments have been spent to develop and improve renewable forecasting tools for transmission level applications, but all stopped short of integrating the distribution information, forecasts and identifying the relevant metrics associated with impacts on utility operations.

The family of Hawaiian utilities and SMUD offered four distinct utilities with solar penetration levels ranging from 15% to over 250% penetration during the daytime on distribution systems and were uniquely posed to inform, develop and evaluate new distributed generation integration capabilities within common utility operational tools. To ensure success and minimize transformational risks, DREAMS approach built on familiar utility environments to grow existing workforce capabilities. Though based on Hawaii and California experiences, the DREAMS collaborative teaming efforts continue to generate more industry awareness for common utility integration challenges as they pertain to integration of distributed generation resources. Tools and solutions developed in DREAMS are being implemented today and will help jumpstart replicable and transformational process change for the future within traditional utility energy management environments used around the world.

The project involved EMS vendors, forecasters, distribution system modelers, utility end-users and active feedback from an Utility Advisory Team (UAT) to help inform how renewable forecasts and distributed resource information can be used to enhance operational functions (e.g. unit commitment, load forecasting, Automatic Generation Control (AGC) reserve monitoring, ramp alerts). Dissemination of capabilities and support was provided by a multi-functional team of world-class industry technology providers.

Viability of the DREAMS approach was successfully implemented on two major EMS platforms. Successes demonstrated in this project include:

- Use of one of the first operational distributed resource forecasting capabilities, Solar and Wind Integrated Forecast Tool (SWIFT), to create situational awareness and successful integration into two operational EMS;
- Recommendation of one of the first applications of CIM schema for renewable forecasting data interface to EMS;
- Novel application of modeling simplification technique to account for aggregated distributed PV resources as "virtual generators" at distribution substations;
- Use of aggregated equivalence approach to reduce computational overhead and help reduce tracking of individual DG resources by orders of magnitude;
- Early utility engagement by solutions providers to jumpstart development of end-use displays, alerts and content that integrate relevant DG and renewable forecasting information;
- Development of a common, integrated decision analysis platform (REDatabase – T-REX) that included both real-time wind and solar forecasting information and timely distributed resource information based on customer location and real-time system data from utility SCADA;
- Unique utility originated visualizations tools (LVM, REWatch, EMS views) to support real-time operation and planning and customer engagement needs;
- Timely dissemination of project learnings through various industry sponsored workshops and conferences. Received award recognition on materials disseminated;
- Active Utility Advisory Team (UAT) engagement broadening applicability of solutions; and
- Continued workforce training and process enhancements via continuous training and coursework development recommendations for utility personnel (UAT and WAPA collaboration).

Major lessons learned include:

- Simplified visuals providing 1 to 3 hour renewable forecast look ahead provides real-time situational awareness;
- Geographic views help orient users and are important for distributed generation management;
- Reduced risks and discomfort by demonstrating replicable capabilities to enhance operational awareness using familiar vendor products and within familiar environments;

- Incorporated new information into existing consoles and alerts for operational awareness without overwhelming operators;
- The importance of timely and frequent end-user feedback and prototype iterations;
- Common nomenclature and framework are critical for automation needs; and
- Renewable forecasting as well as load forecasting both become important when considering high penetrations of variable resources due to impact of weather on renewable resource performance and end use load and user consumption.

1.0 INTRODUCTION

As the world becomes more energy conscience, utilities around the world must take action to modernize fleets and adjust for a changing portfolio of generating resources. Variable renewables such as wind and solar have traditionally been treated as “must-take” resources and thus were not factored into the planning or dispatch processes. With deregulation, more environmentally conscious policies and market driven systems will drive variable renewable resources. As distributed generation continues to emerge, more sophisticated tools for renewable forecasting are needed to track, trend and forecast for these resources for reliable grid operations.

Several notable studies have documented the intermittency impact of wind resources around the world. A 2009 report by IESO on “Centralized Renewable Forecasting,” summarized some of the major activities ISO’s around the country were doing to test and better incorporate forecasting into market operations and grid management [3]. Stakeholders and utilities agree that there is a need to improve accuracy of renewable forecasts but along with accurate resource forecasts, the ability to use and factor real-time, probabilistic forecasts and other strategies and tools to manage and support renewable integration also need to be developed. As noted in the 2012 Alstom report by Lawrence Jones, completed under US DOE Award DE-EE0001375 [4], “…integration of large amounts of wind energy into the power grid requires a paradigm shift in how the grid is operated.” The report gathered feedback on strategies, lessons and best practices from an international set of utilities as “experience from actual operators provides some of the most valuable feedback on how operations are changing, what tools are needed, and which actions are providing the most benefit.”

As such, the DREAMS effort drew from the expertise of a broad team of utility and industry stakeholders to proactively develop cost-effective tools based on actual experience and need. The solutions required interaction and “shared perspective and understanding” for needs by utilities, renewable forecasters, EMS providers, IT expertise and modeling experts to develop responsive strategies and new tools. Along with re-tooling, workforce and processes needed to be aligned in order to use, watch for, understand and manage emerging new resources, especially distributed generation resources, onto the modern grid. Via the DREAMS effort, it was found that operators today are inundated with data. With increasing levels of behind the meter distributed PV resources, that when aggregated, are as large as utility scale generators, the ability to see, forecast and manage distributed variable resources needed to be seamlessly integrated into the system operations environment.

This report documents the progress made from November 2013 through June 2016 as part of the DREAMS effort and captures the value of the teaming environment to jumpstart integration efforts. Section 2 describes the overall DREAMS methodology and practicalities. Sections 3 to 5 provide results and additional context on the data development, operating tools integration and user engagement to gain insight on needs along with feedback on practical and useful enhancements for development demos. Sections 6 and 7 summarize lessons learned and provide recommendations on continuing efforts. Additional project information is provided in the Appendices.

2.0 PROJECT METHODOLOGY

Utilities around the world, including military facility planners and grid balancing authorities, are finding it increasing more difficult to track, plan and manage change as more weather dependent, distributed and variable energy resources emerge on the transmission and distribution systems. The existing lack of visibility and dearth of data down to the distribution level are also hindering the ability to develop reliable solutions for control and management of variable distributed energy resources (VDER). Current utility "rules-of-thumb" are no longer adequate for engineering the future electric power system, and new data and industry collaborative partnerships are needed to define, design and develop our future solutions.

2.1 Project Goal and Objectives

The goal of the Distributed Resource Energy Analysis and Management System (DREAMS) Development for Real-time Grid Operations project is to support development of the next generation energy infrastructure and EMS environment with the ability to account for behind-the-meter distributed generation in an aggregated fashion reducing individual renewable forecasting by 2 orders of magnitude and be able to factor in 15-min probabilistic weather information into EMS algorithms to inform operational decisions. The purpose is to provide utility operators an awareness of distributed generation (DG) resources with more timely information and seamless capability to "see" and "get a heads up" to manage change impacts arising from high penetrations of renewable resources from transmission down to distribution levels. Specifically the DREAMS approach provides operational awareness to account and forecast for distributed PV located on the customer side where utilities traditionally have had zero or limited visibility and controls.

Consistent with DOE SunShot objectives to facilitate incorporation of renewables onto the grid, federal funding on this project has helped utilities and supporting industries reduce the risks of transforming and modernizing the electric power system by encouraging more utility-vendor development and technology enhancement efforts. The DREAMS concept brought together various groups across the industry developing renewable resource forecasting tools, DG tracking visualization capabilities and EMS controller enhancements to address real-time operational needs (Figure 2.1). The DREAMS team includes four distinct utilities with immediate high penetration VDER needs (SMUD, HECO and sister utilities MECO and HELCO), two leading EMS providers (Siemens and Alstom/GE), a leading wind and solar forecasting provider (AWS Truepower), world-class strategic modeling expertise (DNV GL) and an innovation provider of secure IT and data analytics capabilities (Referentia Systems Incorporated/In2lytics). While distinct in their organizational size, geographic location and electrical connectivity, both SMUD and the HECO Companies share common planning and system operation tools. Solutions developed should address common issues and concerns including.

- How accurate does the forecasts need to be to be useful?
- Can the EMS handle the DG and real-time forecasts without adding more complexity?
- What will the EMS do with forecasting and DG information?
- Are these solutions applicable and scalable to utilities beyond Hawaii?

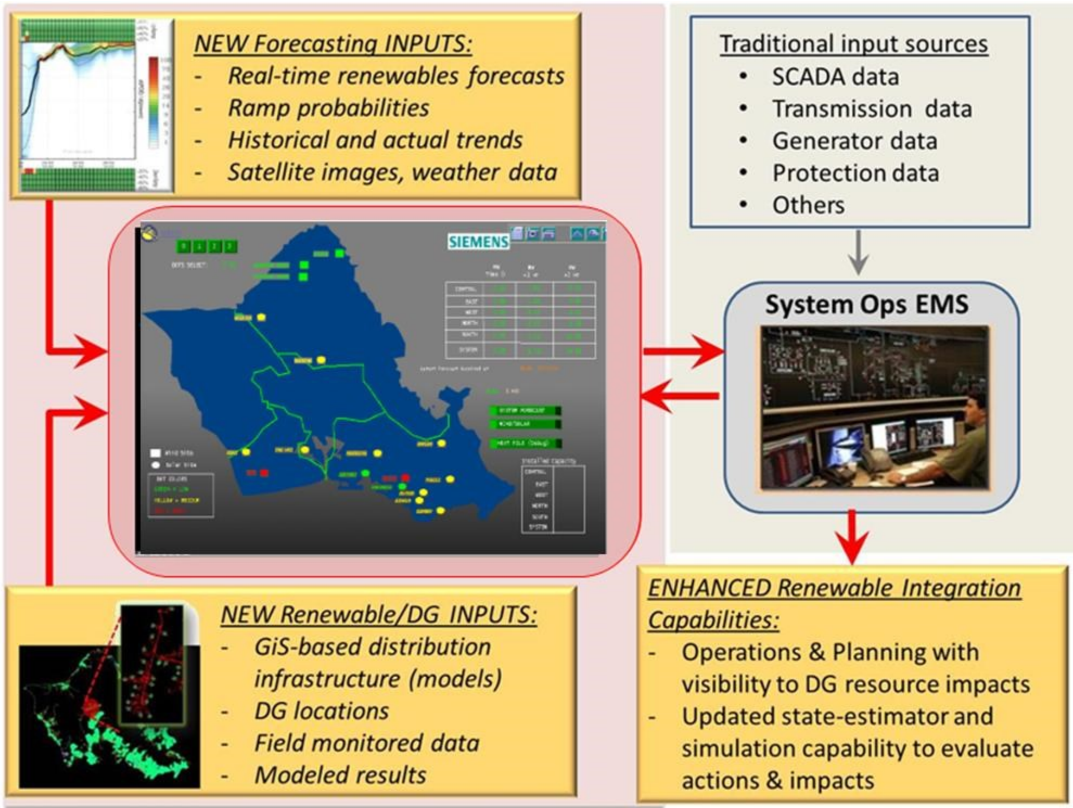


Figure 2.1. DREAMS concept integrating distributed generation and real-time renewable forecast information into real-time operations.

Project objectives included:

- Engage utility operators to provide user input on displays and expected performance;
- Prototype DG aggregation approach to seamlessly account for DG impacts in 4 distinct utilities, each running different EMS systems (Alstom e-terra and Siemens Power TG) in different operational environments;
- Implement a common decision analysis platform for SCADA and non-SCADA data;
- Seamless integration of new information into operations without increasing workload and complexities
- Support efficient decision-based analytics to inform new operating practices and procedures;
- Disseminate project lessons learned through industry sponsored workshops and conferences; and
- Priorities and jumpstart industry capabilities to support DG integration needs.

2.2 Project Approach

This project employed an end user-focused technical approach to inform development of the next generation energy information and EMS environment. This required concurrent development of advance real-time forecasting, data handling, model aggregation and analysis, and active user feedback. Project approach focused on developing insights through rapid prototyping and iterations. Development and piloting occurred within a development platform that mirrored actual EMS environments. In this way, actual insight on the value and challenges of incorporating distributed resource information and real-time forecasting into existing tools for decision analysis (e.g. load forecasting, Automatic Generation Control (AGC) reserve monitoring, ramp alerts) was gained on two major EMS platforms. Situational Awareness improvements and new analytics were demonstrated and shared with end-users through new visualization displays built within the existing control environments. While variable distributed energy resources (VDER) visualization capability and weather-based, probabilistic renewable energy generation forecasting capability (SWIFT) developed under the US DOE ARRA funded WindHUI (DE-EE0001379) [5] and various California CSI grants was leveraged, both the SWIFT capability and the REDatabase were enhanced to offer tri-Company coverage and provided new 24/7 reliability and operating efficiencies. A modeling aggregation technique was also applied to cost-effectively account for and simplify tracking of thousands of behind-the-meter PV at the distribution level (e.g. 12kV) for EMS integration. Efforts leveraged the Proactive Modeling efforts that developed geo-rectified SynerGi distribution models and enabled tracking of distributed PV as distinct generators on the circuit rather than hidden as part of negative load.

Work efforts included investigating the new PV aggregation by circuit techniques, enhancing EMS logic with forecasting and DG data, application and testing of new logic, development of new user visualization and interface screens and EMS functionality, and user development/training, quantification of benefits/metrics, and documentation to capture lessons learned. The project followed the technical tasks proposed and the execution details are captured in Sections 3 to 5 of this report.

To connect the various tasks conducted in this project, the results are organized for reporting purposes in the following 3 major areas: Data, Integration of Tools and User Outreach.

- **Data:** focused on review and engagement with end users on what information content was missing and how best to acquire; data format and resolution for transfer; and supporting architectures needed to support real-time access to behind-the-meter DG resources. Sources and tools for new data content (i.e. LVM, Aggregation Models); data format for integration and common data analysis framework were integrated to provide new information. (Section 3)
- **Integration of Tools:** focused on identifying existing analysis and control platforms, data exchange/communication and working with the technology providers to implement enhancements, simplification techniques and leveraged cross-industry learnings. (Section 4)
- **User Outreach:** focused on engaging end-users to provide feedback on what worked and what didn't and how they would like to see things. As a key utility partner with similar issues and conditions, SMUD, SCE, APS and WAPA staff supported HECO's efforts by providing timely feedback on development needs, diversified utility operating

perspectives (with market and without market) on integration challenges as part of a Utility Advisory Team. (Section 5)

2.3 Project Milestones and Success Metrics Discussion

Project milestones and associated task are provided in Table 2.1. Milestones provided a gauge on progress of the project. At the end of the first year, unexpected cyber upgrades and EMS enhancements at each of the utilities delayed progress on the EMS logic enhancements. As a result, a one year extension was requested and authorized to accommodate the unforeseen delay. While slips in project schedule were encountered due to timing and resource constraints, the project was managed to maximize progress despite delays.

EMS enhancement tasks were delayed due to required cyber security upgrades and EMS upgrades. During that time, sufficient accommodations were made to work around delays to ensure that development of algorithms and functionality stayed on track. For example, due to delays in deployment of the consolidated database for Hawaii Electric Light Company (HELCO), data was replicated on sister company Hawaiian Electric's REDatabase using the T-REX server, so logic development for wind and solar forecast integration could continue. Also, since Maui Electric Company (MECO) and HELCO share similar Alstom EMS and GIS platforms, development continued based on Maui's architecture. Additionally, some tasks were accelerated to avoid delays downstream. The first UAT was accelerated and scheduled to coincide with the US DOE Sunshot Summit in 2014. Southern California Edision (SCE) hosted the meeting.

The additional year allowed the team to align with EMS/cyber upgrade needs and continued to improve and enhance performance and reliability of the integrated forecasting tool (SWIFT) for renewable resources, to develop and implement the common analysis database platform (REDatabase) across the Hawaiian Electric family of utilities, and to automate the distribution model extractor (SynerGEE extractor) and new DG resource visualization display capabilities (LVM and REWatch) for all islands. Specifics included:

- The SWIFT tool was significantly improved by AWS to incorporate feedback received by utility operations staff every quarter over the project term. This also required significant architectural improvements on the AWS side to support the 24/7 real-time requirements and provide a more stable and reliable renewable forecast data stream for future integration needs.
- Enhancements to field sensor health reporting and tracking for routine maintenance and servicing were made to reduce outage times in support of real-time renewable forecasting needs.
- REDatabase development leveraged similar architectures on sister utility companies to minimize impact of delays. All 3 Companies now have active T-REX servers providing real-time upload and interface of renewable forecasting, DG and SCADA data.

- Enhancements were also made to the Locational Value Map (LVM) to consistently automate views for all 5 islands operated by Hawaiian Electric Companies. This visualization tool required the common REDatabase to be in place.
- Development and roll-out of REWatch real-time visualization tool to all 5 islands. REWatch provides near-real time system generation and how much renewables (DG solar and wind) is contributing to each island system. REWatch also made visible the net load compared to the total load served by each system.
- Modeling tools were further enhanced to include evaluation of mitigation capabilities and automation of distribution model extractions to account for the over 50,000 new distributed PV systems.

Over the span of three years, the UAT held three in-person meetings to gather feedback on project tools and products. Overall the project tracked with proposed milestones despite unforeseen delays. The project executed on the 6 major tasks as defined in the Statement of Project Objectives (SOPO) over the project period. A summary of tasks is included in the Appendix 9.1.

These techniques piloted and investigated are immediately transferrable to other utilities to inform resource monitoring and distribution model development; are scalable to address management of the high volumes of distributed generators; and are jumpstarting integration of new DG information into familiar utility planning and operational tools and environments supported by established industry providers. Success metrics include:

- Visibility to distributed resource and renewable forecasting information that was previously invisible;
- Time savings and insights gained through common data handling and analysis platform;
- Efficiencies gained in reducing the complexity of large volumes of distributed resources using the bottoms-up aggregation approach;
- Orders of magnitude reduction achieved through aggregation of DG technique while still preserving circuit level and regional diversity granularity needed to capture local micro-climates and conditions; and
- Active participation and feedback of UAT membership (WAPA, CaISO, SCE, SMUD, TEP, APS, Kauai Island Utility Coop, Hawaiian Electric Companies) to broaden lessons learned and application of solutions to utilities, nationally and internationally.

Table 2.1. Table aligning milestones and dates.

	Milestones				
Milestone	**Task Title and Milestone Description**	**Task Start Date**	**Milestone Completion Date**		
			Original	**Actual**	**% Complete**
	1.1 Project Management & Team Coordination				
M1	*UAT Identification & Membership*	*11/1/13*	*1/31/14*	*12/20/13*	*100%*
M2	*Go-No-Go Documentation*	*7/31/14*	*9/30/14*	*9/30/14*	*100%*
	1.2 User Engagement & Data Development				
M7	*Aggregation Methodology for Solar*	*10/1/13*	*6/30/14*	*5/31/14*	*100%*
M5	*Baseline Penetration Levels*	*11/1/13*	*12/31/13*	*11/30/13*	*100%*
M6	*Data Access & Transfer Process*	*11/1/13*	*6/30/14*	*9/30/15*	*100%*
	2.0 Integration & EMS Interface Enhancements				
M8	*Siemens forecast screens and enhanced EMS logic*	*10/1/13*	*thru project*	*6/30/16*	*100%*
M9	*Alstom forecast screens and enhanced EMS logic*	*10/1/13*	*thru project*	*5/30/16*	*100%*
	3.0 User Testing, Training & Pilot Implementation				
	4.0 Industry Technical Outreach & Reporting				
M11	*Industry venue abstracts*	*11/1/13*	*6/30/14*	*5/31/14*	*100%*
M12	*Conduct UAT meetings*	*11/1/13*	*11/1/14*	*5/31/14*	*100%*
M13	*Final Report*	*3/1/16*	*9/30/15*	*9/30/16*	*100%*
	5.0 Go-No-Go				
M3	*Sept 3, 2014 In-person Project Review Meeting (DC)*	*7/31/14*	*9/3/14*	*9/3/14*	*100%*
Milestone	**Task Title and Milestone Description**	**Task Start Date**	**Milestone Completion Date**		
			Original	**Actual**	**% Complete**
	6.1 Project Management & Team Coordination				
M4	*Project Meetings & Calls*	*8/1/15*	thru project	*6/30/16*	*100%*
	6.2 User Engagement & Data Development				
M10	**7.0 Integration & EMS Interface Enhancements**				
		1/31/14	*5/1/14*	*6/30/16*	*100%*
	8.0 User Testing, Training & Pilot Implementation				
M14	*Document Testing & Recommendations*	*9/1/14*	*thru project*	*6/1/16*	*100%*
M15	*~~User Experience Survey~~ (REPLACED by USER feedback and Operation visits due to time constraints)*	*10/1/14*	*thru project*	*6/30/16*	*100%*
M16	*Presentation Development*	*6/1/15*	*2/1/15*	*6/30/16*	*100%*

3.0 DATA NEEDS

This section highlights the various sources of data (new and existing), including new content, new visualization tools and data derivation to support real-time integration needs. The design philosophy was to acquire basic resource data from field sensors, to use common data streams for multiple purposes and to organize data content using a bottoms-up content approach to preserve high resolution, locational details and provide data content for high level summaries and alerts. The approach, data content, access and supporting software and hardware architecture are discussed in the following sections along with results and recommendations.

3.1 Data Sources and New Content

Distributed resource data is as diverse as it is plentiful. However in the current state, the diversity and volume are not conducive to grid operations. Figure 3.1 illustrates the various sources of data, different resolutions (volume of data and sampling rates, historical vs real-time) and different fidelity and connectivity. With increasing levels of distributed generation and renewable resources, utilities are finding that additional field measured renewable data and distribution level data are needed to inform future grid operations.

Collecting, managing and evaluating such large volumes of data from diverse monitoring systems including field devices, SCADA systems, AMI and other behind-the-meter resources (Figure 3.1) required advanced analytical tools that were not readily available in current utility environments. With network firewalls, real-time data handling and analytical limitations, utilities were hindered from evaluating such data in a common framework environment. Yet the data was vital to understanding the new operational impacts and informing integration of variable, renewable energy into the grid. Over the project duration, Hawaiian Electric Company operationalized the Renewable Database and Decision Analysis Framework (REDatabase) across the tri-Companies. The REDatabase was comprised of an advanced, time-series data management and common data analysis platform to support high-resolution, large volume data exchange and integration of diverse datasets across a secure network. This REDatabase provided the backbone architecture to support real-time data exchange and automation supporting visualization tools, distribution models and robust information sharing via online web-tools.

Dealing with distributed system management, the speed to access a diverse data pool was paramount to information real-time decision making. Hawaiian Electric Companies partnered with Referentia/In2lytics, a local Hawaii-based information technology company to develop a high performance database and user interface for high resolution, time series data analytics. Such analytical capabilities did not previously exist. Staff now have access to quickly retrieve and merge non-SCADA and full resolution SCADA information at data access speeds that are 200 times faster than previously available and can build customized tools to access high resolution, high volume data from field devices like synchrophasors and AMI meters and interface with other customer information to troubleshoot or plan. Utility operators and planners are now able to easily access and evaluate data from different data platforms (public, corporate-level secure SCADA networks) while preserving confidentiality and network security requirements.

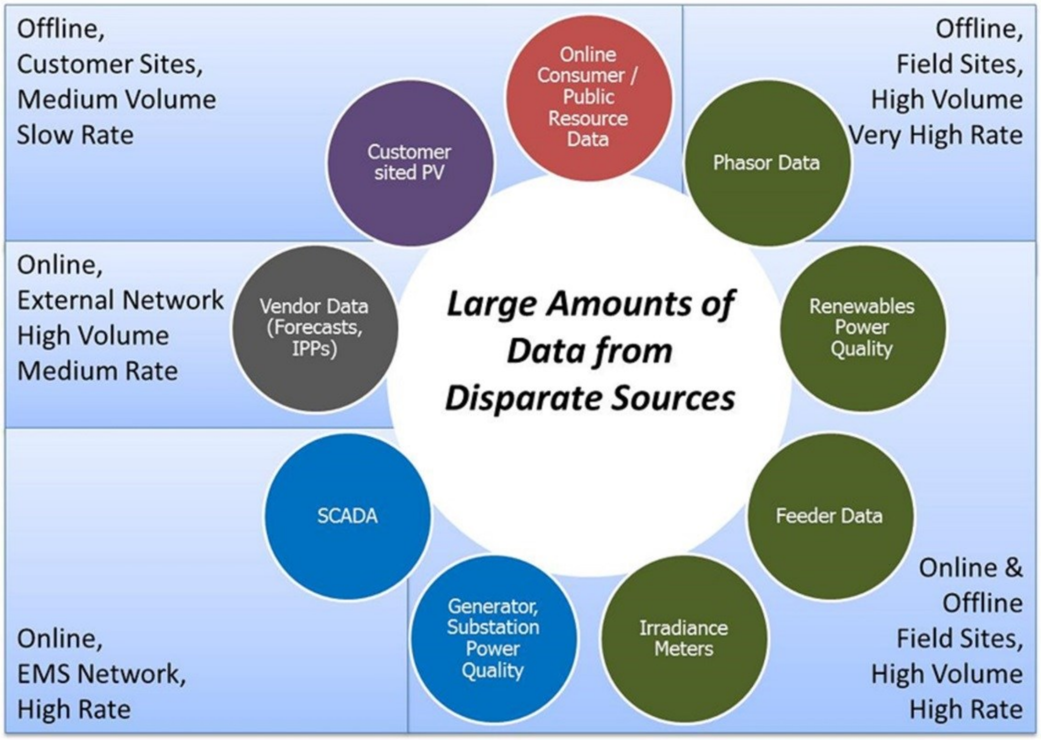


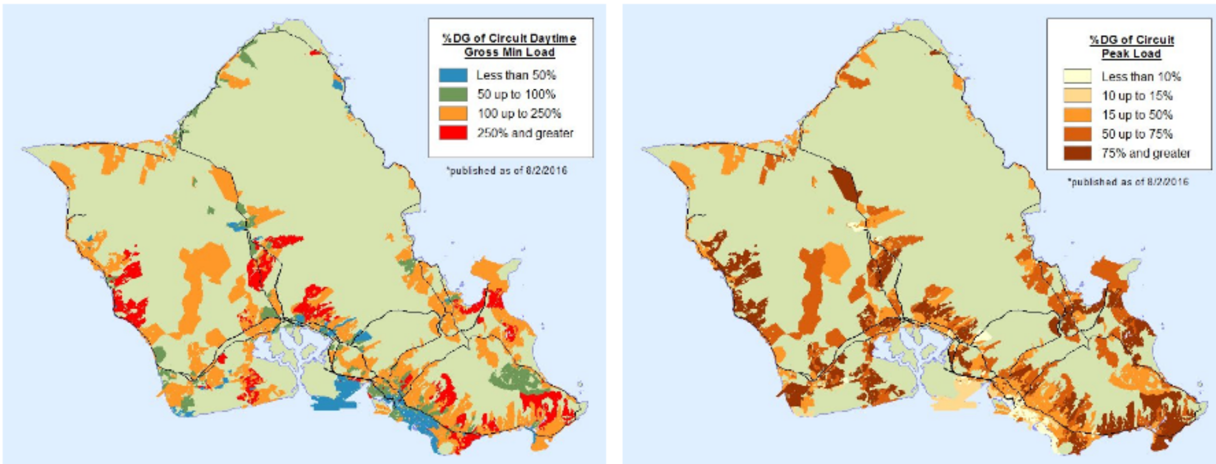
Figure 3.1. Diversity of distributed data sources and formats.

3.1.1. Customer PV System Data Organization Using Locational Value Tools

This initiative focused on two major objectives including 1) established baseline circuit-level penetrations values (%) by island to contend with high penetration PV in Hawaii and 2) routine access and evaluation of time-series data between SCADA and non-SCADA platforms.

Figure 3.2 depicts the current LVM for Oahu. The LVM were developed and successfully implemented on the utility websites providing awareness on high penetration PV locations to better inform customers and developers. The LVM depicted is a percentage of the installed megawatt (MW) of PV to the load of the circuit serving the area. Two views provided include 1) circuit load conditions based on day time minimum load (Figure 3.2a) and 2) circuit load conditions based on maximum circuit peak load (Figure 3.2b). The Locational Value Maps (LVM) [6] were developed and operationalized across the islands to routinely assess the impact of distributed PV and provided a useful visual tool to track and communicate high penetration levels by location.

LVM based on DML uses red-yellow/orange-green-blue colors to quickly highlight hotspots. Red and yellow/orange colors indicate locations that are likely to have backfeed and potential voltage conditions due to high penetration. Backfeed conditions were observed as daily occurrences where ever the local distributed PV generation exceeded the local circuit load requirements. Such areas were likely to experience longer interconnection times or required upgrades for interconnections due to high penetrations of existing installed PV levels. Blue and green colors indicated little or no issues presently and not likely to experience interconnection issues.



This map shows circuits with installed PV up to and greater than 250% of daytime minimum load (DML)*. For systems up to 10 kW, an interconnection study will not be needed if total PV on the circuit is equal to or less than 120% of DML. However, upgrades may be necessary.

This map shows distributed generation (mostly solar photovoltaic or PV) on each circuit compared to 15% of peak electricity demand, or "load" on each circuit. It also shows levels beyond 15%.

(a) (b)

Figure 3.2. Locational Value Map of Oahu calculated based on a) daytime minimum load (DML) and b) maximum circuit load.

3.1.2. Renewable Resource, Forecasting and Field Sensors Data

With increasing levels of distributed roof-top PV systems, utilities around the world are becoming more aware of variability impacts and desire capability to account for both wind and distributed solar generation within planning and operational models. To date, considerable efforts and investments have been spent to refine and improve renewable forecasting tools at the transmission level, but all stopped short of integrating the distribution information into the EMS. This left a gap in utilities' ability to see and manage the grid, especially at high penetration levels. While the focus of DREAMS was not to re-develop wind or solar forecasting tools, the project required that a robust, valid and reliable (24 hrs /7 days a week) forecasting capability be available to provide probabilistic forecasts for both wind and PV at distributed levels. Deterministic EMS systems relied on telemetered points and historical data to optimize dispatchable generation.

The SWIFT capability provided real-time 15-minute up to 6 hour look ahead of prevailing conditions in wind and solar for the Hawaiian Electric Companies service area. In collaboration with AWS Truepower, an established leader in renewable forecasting and consulting, the SWIFT tool used state-of-the-art numerical weather prediction and meso-scale models along with one of the first utility operated remote sensor networks comprised of SODARs, LIDAR, irradiance sensors and radiometer (Figure 3.3) to provide renewable wind and solar forecasts and a bird's eye view of the wind contours and solar cloud conditions for the islands (Figure 3.4).

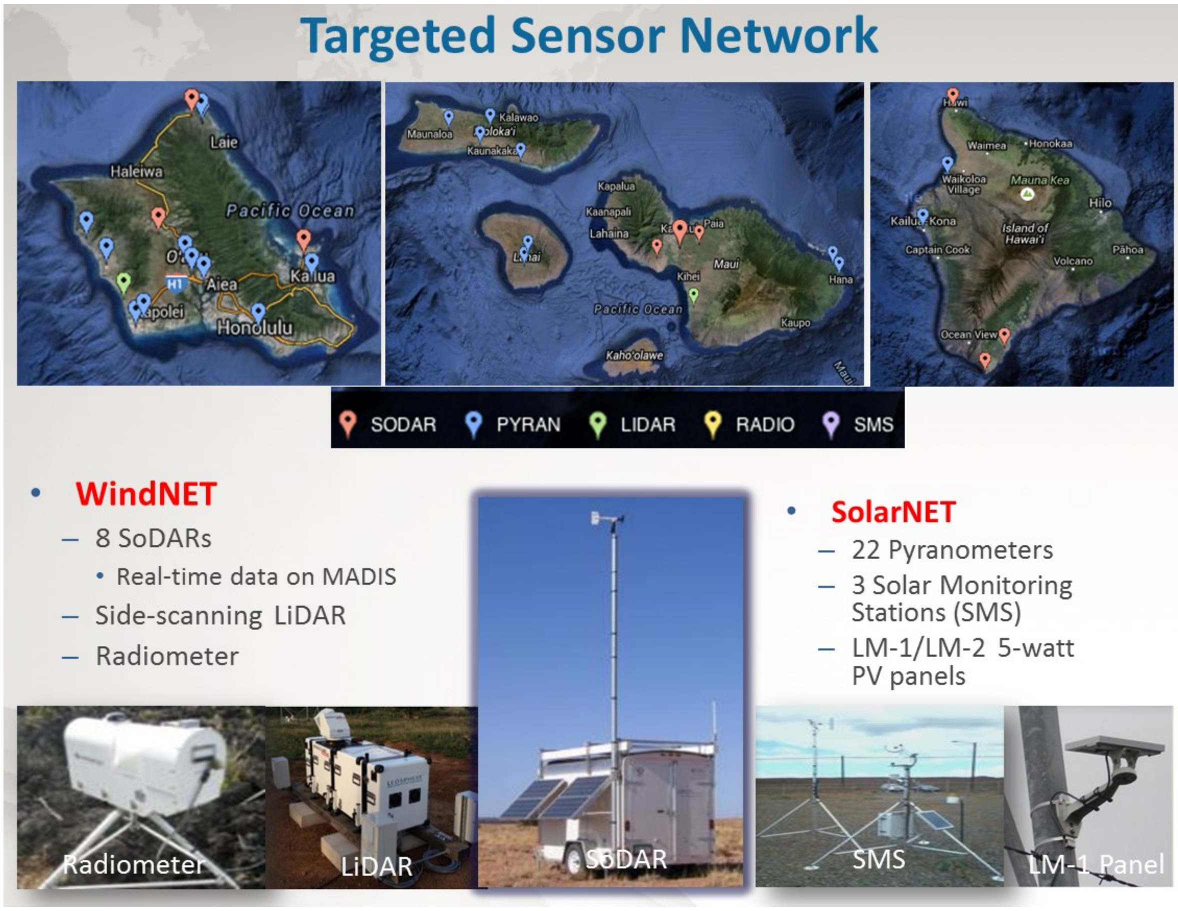
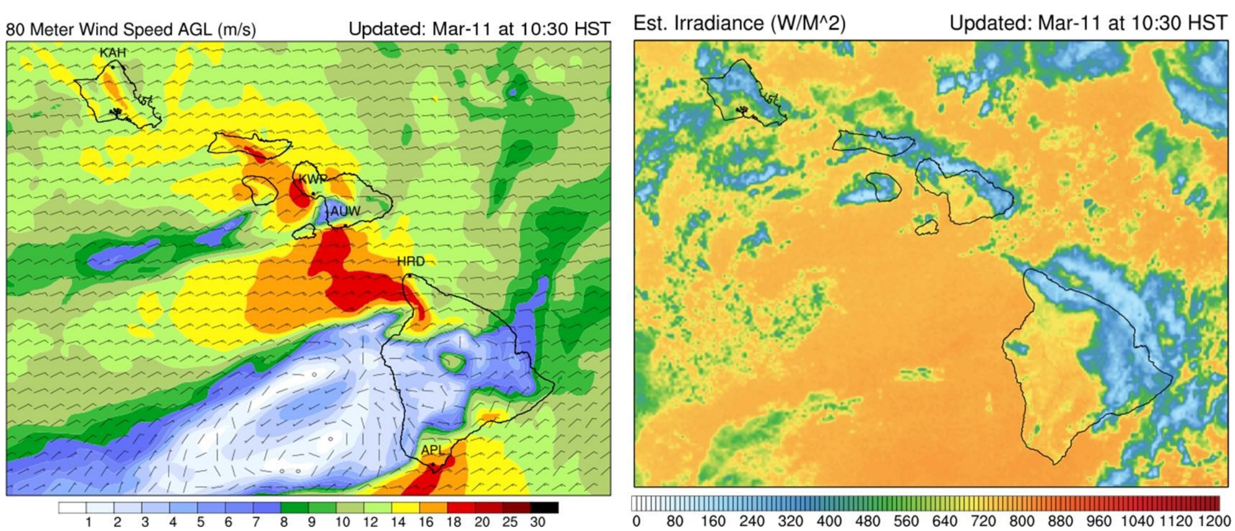
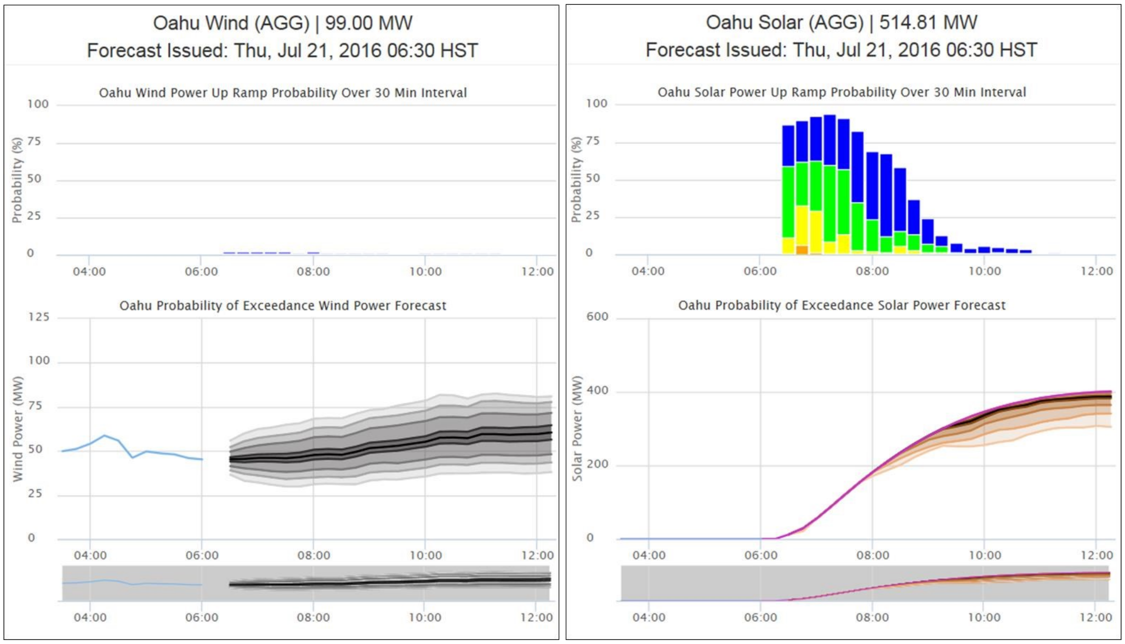


Figure 3.3: Fleet of remote sensor network for wind (WindNET) and solar (SolarNET) used in supporting resource monitoring and renewable forecasting needs.



(a)



(b)

Figure 3.4: SWIFT forecasting views – a) Bird's-eye of islands wind and solar resource and b) wind and solar probability and ramp forecasts.

Unique to Hawaiian Electric's SWIFT tool was the distributed solar forecasting feature. It provided discrete forecasts for distribution level solar resources providing both the localized substation and system views. Although developed for Hawaii, this capability is transferrable to other utilities implementing distributed forecasting tools.

Additionally, the bird-eye views were important for informing and balancing localized solar impacts on system-wide operations. These tools were shared at various industry conferences and user groups to create awareness on the importance of tracking routine events like cloud cover, cloud variability and clear sky conditions. Views like Figure 3.5 were useful to explain cloudy vs clear day PV impacts to customers and to describe variability conditions throughout the day, especially on cloudy days.

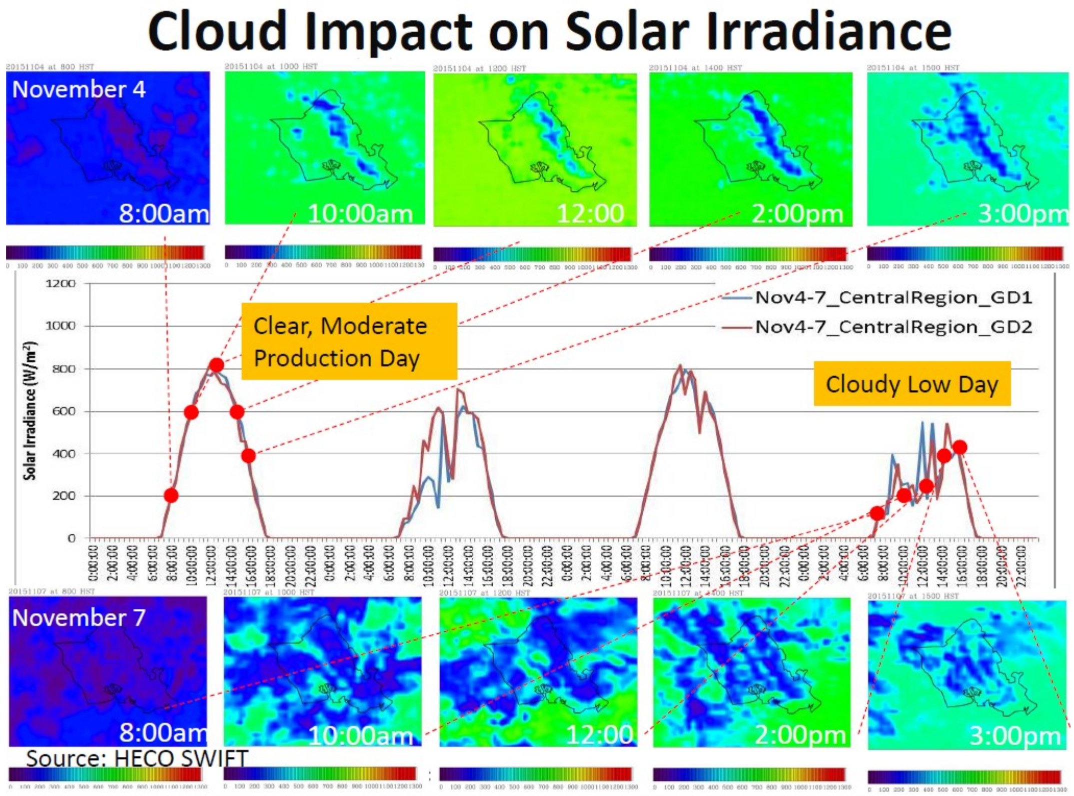


Figure 3.5: SWIFT forecasting views created awareness by visually showing how clear day and cloudy conditions affect PV production. Visual tools helped develop customer awareness and set expectations and understanding on PV integration needs.

Renewable forecasting is not a "silver-bullet", however, by integrating the information into existing tools and familiar utility environments, such as the EMS, DREAMS efforts developed operational confidence and trust to use forecasts to proactively inform and cost-effectively manage impacts of variable renewables. Emerging from this effort, load forecasting is also becoming an important consideration due to variability impact of weather on end use load and user consumption.

3.1.3. Distributed PV Data Aggregation Methodology

Though utilities have information on the design, size and customer site information for the over 50,000 rooftop PV systems, actual PV system production is not currently monitored or controlled by the utility. Monitoring each individual PV system was neither economically practical nor technically prudent. To overcome this challenge, Renewable Energy Planning staff at Hawaiian Electric developed a PV power production estimation technique to account for the behind-the-meter generation.

To track and account for distributed PV resource generation, Hawaiian Electric leveraged the fleet of solar monitoring sensors to provide solar irradiance data close to circuits and implemented a bottoms up aggregation approach to estimate distributed PV impacts to local

12kV distribution substations. PV generation performance curves were developed using actual system performance data provided either by the solar installer, customer or other direct monitoring. Performance curves were developed and validated per circuit and accounted for the production efficiencies of PV systems installed under a different program ranging from typical customer roof-top PV systems (average size from 1kW to 20kW) under net-energy metering (NEM), standard interconnection (SIA) typical for larger systems designed to offset commercial or industrial loads, and feed-in-tariff (FIT) or PPA installations connected on the distribution system designed to sell power back to the grid. Depending on the design, performance curves varied with NEM installations with the highest variability and inefficiencies due to rooftop limitations and customer locations. By aggregating individual PV systems by program type per circuit and weighting by the installed MW capacity of each program type per circuit, characteristic DG output profiles were developed representative of the aggregated set of PV systems on that circuit and their production characteristics. The link to aggregated PV by circuit and irradiance resource allowed for aggregated estimation of PV production from behind the meter resources and application of this data within REWatch visualization screens (Figure 3.6). As part of DREAMS, the REWatch was enhanced to support real-time updates across the 5 islands including Molokai and Lanai.

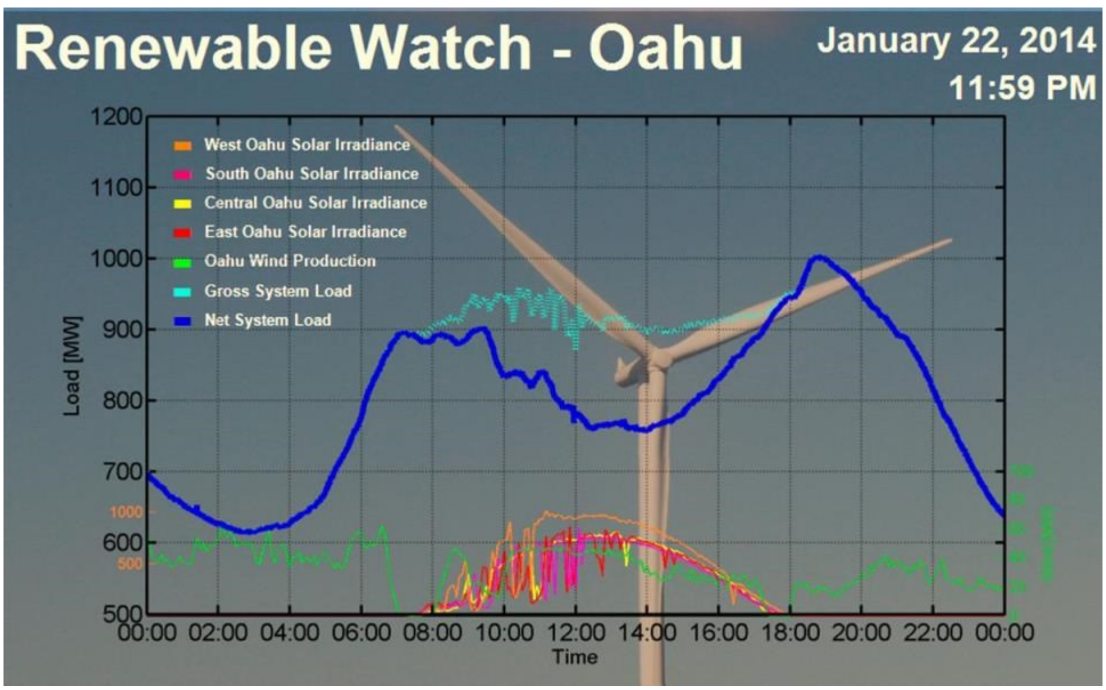


Figure 3.6. REWatch displayed existing levels of renewables (wind and solar) contributing to meet the system load. Solar production (light blue) is overlaid on the net system load (blue) resulting in the total load that is serving customers [7].

Figure 3.7 illustrates the process flow for this estimation capability. Estimates aided system operations to plan generation dispatch, account for solar variability by regions on the grid and awareness to weather induced conditions using the SWIFT solar data and field monitoring sensors.

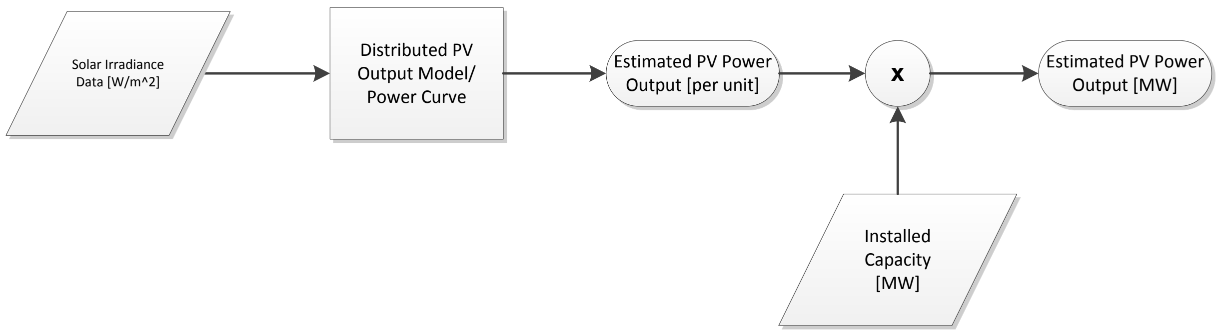


Figure 3.7. Process flow for estimating the power output of distributed PV using solar irradiance measurements.

3.1.4. Circuit to Grid Data Organization by Electrical Infrastructure

Utility staff worked with DNV GL to develop new enhanced distribution models that proactively accounted for the distributed PV systems. This included disaggregating the behind the meter PV generation from the load and accounting for the PV system's power production using a nodal estimation approach discussed in Section 3.1.3. PV production data was then organized by circuit, region and finally by system. This technique provided visibility to the behind the meter PV systems that previously was not available. Figure 3.8 illustrates how the PV was represented as discrete aggregated distributed generators independent of load and the grouping of the data by local feeder, substation, region and finally as a total system. Gaps in obtaining distributed resources data was resolved by leveraging modeling techniques and equivalence aggregation techniques to preserve details and system reporting needs.

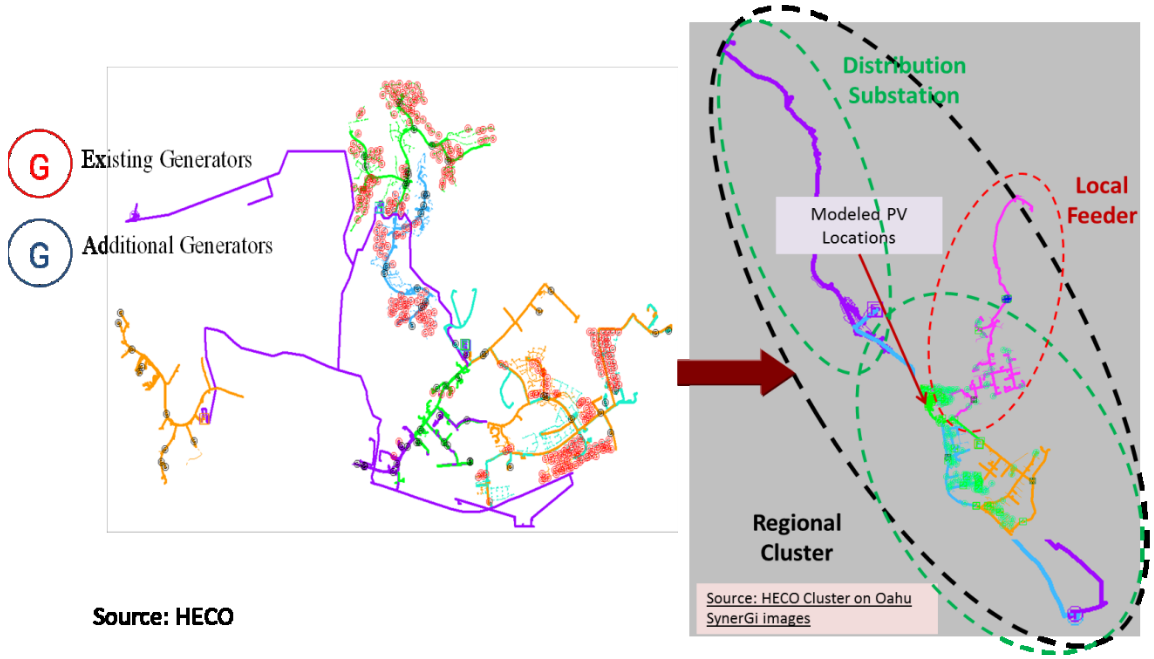


Figure 3.8. Distributed PV generation schematic representation and equivalence aggregation representation by feeder, substation grouping and regional cluster grouping.

Leveraging these models, the aggregation technique to "roll-up" an equivalence representation of distribute PV was used in DREAMS to try to account for the impact of distributed energy resources (DER) that were previously unaccounted and unplanned for at the system level.

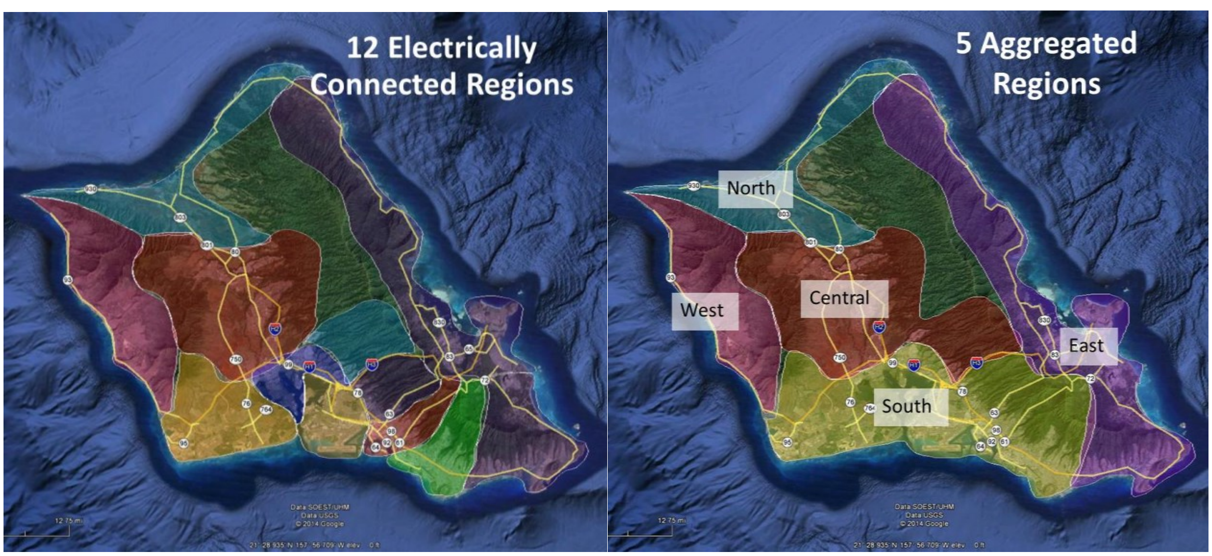


Figure 3.9. Illustrating "roll-up" from individual feeders to regions (north, south, east, west and central) and to a total system view (EMS).

Figure 3.9 shows how Oahu is divided into 12 regions to track distinct local impacts for planning purposes and then grouped into 5 geographic regions (north, south, east, west, and central) and finally summed to provide a system total. The aggregation of distinct feeder to 5 geographic regions was based on discussions with system operators as this was found to be more intuitive and supported faster user orientation. This same aggregation scheme for substation up to system was utilized by AWS Truepower to provide consistent distributed forecasts for distributed PV at the substation level and at the system level for use by EMS.

3.2 Data Format for Integration

In relation to existing standards, the project sought to leverage the Common Information Model (IEC 61970-301/61968-11) and the associated Common Distribution Power System Model (CDPSM IEC 61968-13) to integrate the transmission model from a Siemens PTI PSS/E model with a SynerGEE distribution model to create a CIM network model compatible with the Siemens DMS and Alstom eterra platforms. Figure 3.10 provides a flow chart using CIM format at various levels to convert information from distribution level to transmission models.

A number of projects were underway around the world that utilized CIM including:

- ENTSO-E [8] for exchange transmission models between transmission system operators in Europe. This work is to support the exchange of data between operators to allow them to support the integration of renewable energy resources onto the grid. The initial work has been to support the exchange of bus-branch models for Day Ahead Congestion Forecasting (DACF) but is being developed to support operational model exchanges.
- The CEN/CENELEC/ETSI Joint Working Group on standards for Smart Grids has identified CIM as being a core standard that will enable common standards for the smart grid, and it is part of their technical reference architecture [9] and Smart Grid Architecture Model. This work is driven at a European level to increase sustainability, security of supply and competitiveness (including energy markets) with a focus on integrating renewable sources.
- The Generic Strategy for Standards-based Systems Integration for Electric Distribution Utilities [10] is an international project between grid operators and research organizations that builds on the M490 mandate and develops a generic strategy to use CIM and build an integration platform for MV and LV networks. This work also includes a proposed update to CIM IEC 61968-13 to upgrade it to the latest version of CIM that will support more renewable modelling and harmonization with the updated transmission model used at ENTSO-E.

The work being undertaken at HECO was similar to this work but with the added complexity of:

- Data transformation from existing non-CIM sources at transmission and distribution levels coming from different vendors;
- European models are generally modelled as being balanced while North American models are modelled to the unbalanced single phase level; and
- The models were not previously integrated in their native formats.

The work being conducted as part of the DREAMS initiative built on existing platforms and standards with the desire to support existing IEC standards and ensure the outputs conformed to the CIM data model and CIM exchange profiles (i.e. CDPSM). Efforts also leverage industry developments in time-series data management and large data handling capabilities.

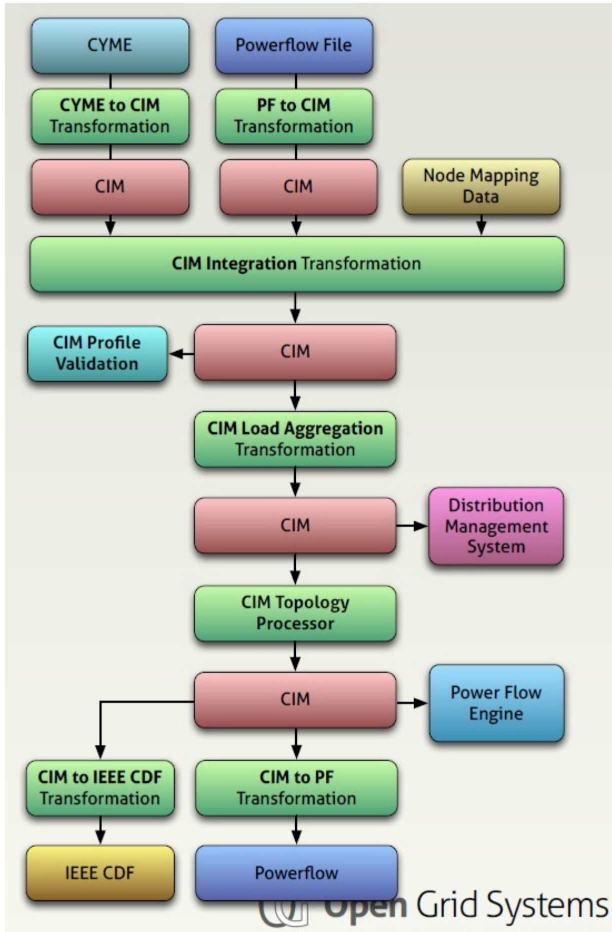


Figure 3.10. Flow chart of CIM conversion between distribution and transmission models.

To facilitate data exchange, Referentia System's time-series, rapid export (T-REX) tool provided a way to support secure transfers and monitoring of the data exchange process. DREAMS efforts equipped the tri-Companies of Hawaiian Electric Company (HECO), responsible for operating Oahu's grid, and Maui Electric Company (MECO), operating Maui, Molokai and Lanai grids, and Hawaiian Electric Light Company (HELCO), responsible for operating Hawaii island's grid, with a common data analysis platform and T-REX server enabling timely access to multi-source data. Efforts underway will continue to link T-REX for purposes of data exchange to AWS forecaster and operations.

Despite this delay in deployment at HELCO, Referentia continued with initial design for the EMS and T-REX bridge using the existing Alstom e-terra environment at MECO. Both MECO and HELCO use the Alstom EMS and HECO used the Siemens platform. HELCO data was also replicated on HECO's T-REX so as to continue support of data exchange and access development by AWS Truepower and Alstom to forecasting data. These workarounds enabled work on all three utility systems to continue development through BP1. Figure 3.11 provides a flow chart view of the EMS-T-REX bridge designed to improve data transfer and provide visibility to the data exchange process.

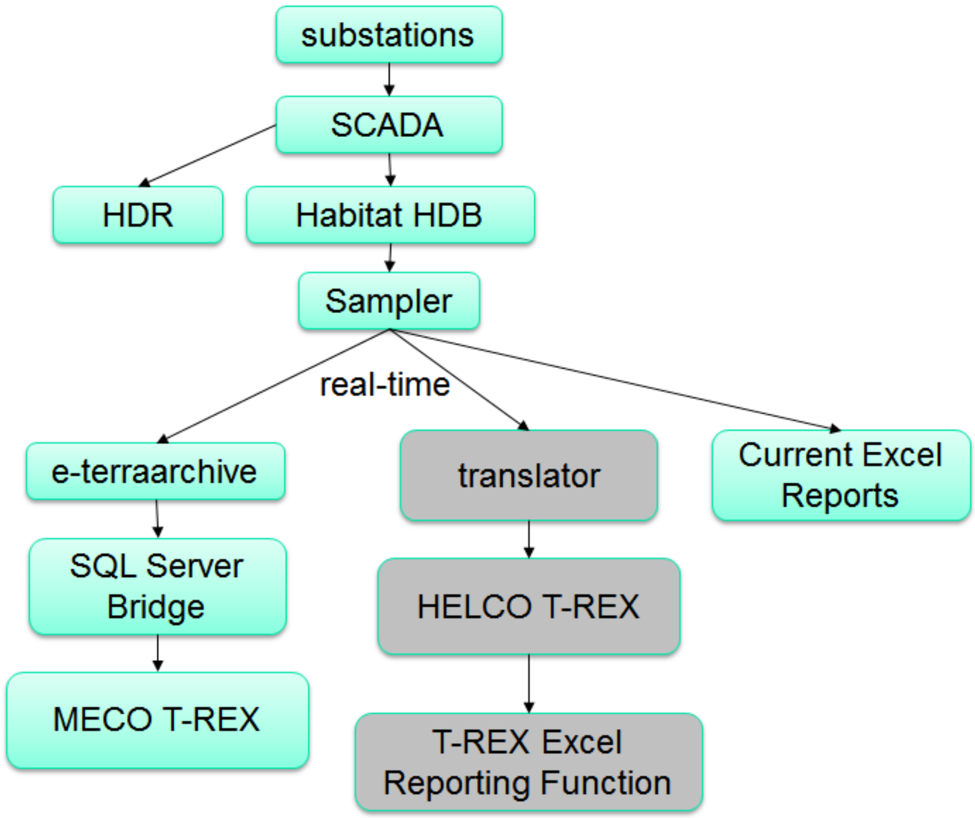


Figure 3.11. Initial design of EMS-T-REX bridge within Alstom e-terra environment.

Benefits of this design included:

- Improvement on data flow for both Maui and Hawaii T-REX:
  - Removed eterraarchive and SQL server bridge, simplifying the architecture and moving the connection closer to the data source;
  - Communicated directly with Sampler using eterrapclink C API; and
  - Resulted in better performance.
- Improvement on data exchange through reporting capabilities:
  - Updated existing reporting to work with modern operating systems; and
  - Replaced legacy code which is inflexible and unmaintainable.

3.3. Common Platform Architecture for Real-time Access

During the DREAMS project, Hawaiian Electric Company's (HECO) Renewables Database (REDatabase), which is an instance of Referentia's T-REX Database, was used for integration, management, and analysis of time series data collected from HECO, HELCO, and MECO. The desired achievements and critical milestones for the Referentia tasks included the following:

- Established a common platform (T-REX) to support decision-based analysis and EMS integration;
- Completed tri-Company (HECO, MECO, HELCO) T-REX deployment and completed links across companies;
- Supported an integrated REDatabase for ease of access to SCADA and non-SCADA data available for analytics; and
- Enabled data automation and time saving goals through the DREAMS project, by modernizing the EMS system reporting processes to provide a more flexible and extensible reporting process, and enabled users to generate their own reports demonstrated on the HELCO system.

3.3.1. REDatabase Architecture

With 3 distinct island grids and software/hardware networks that have developed over time, implementing a common database architecture presented a number of challenges. Cyber security considerations on the Operations Technology (OT) side drove the initial integration of the REDatabase.

For the MECO design, the T-REX database replaced the operating historian and was placed on the OT side with controlled access to SCADA data and easier access to data for reporting needs (Figure 3.12). MECO needed a system that would allow them to easily archive and access their SCADA data for review and reporting. Reports were taking them up to 4 days to produce, and if a variable needed to be changed, it took them 4 more days to re-do the report. Additionally, the corporate users needed access to the information, but since the data was only available in the closed EMS network, someone with access to the EMS side had to manually copy data and transfer out to the Corporate network. As such the T-REX database was first implemented at MECO and is now capturing all of the SCADA 2-second data at full resolution, and currently has multiple years of online data for easy access. The data is mirrored from a copy of T-REX running in the Operations network, to a copy of T-REX running in the Corporate network through a secure one-way diode, specially developed for a one-way push of data. This one-way diode only allows network messages to go from the EMS network out to the corporate network, thus ensuring the security of the EMS network. With T-REX, MECO's SCADA data is available and easily accessible. The reports that used to take 4 days to produce can be done in seconds. Corporate users who need access to the data can now get the information themselves.

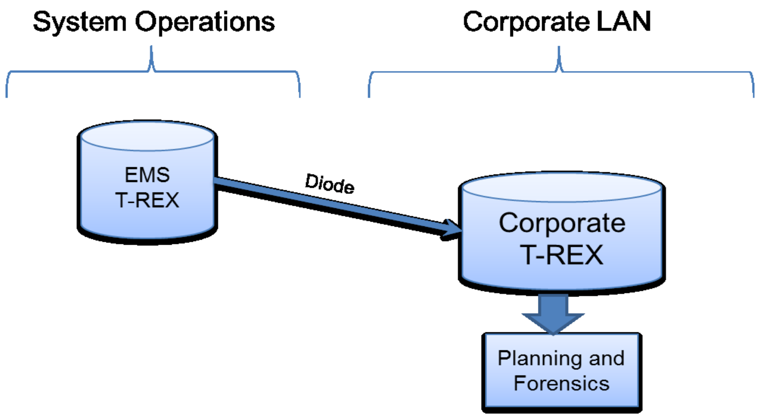


Figure 3.12. Maui (MECO) T-REX integration architecture with secure diode for one way data flow.

HECO's design situated the T-REX tool on the corporate side of the network (Figure 3.13). HECO had several disparate time-series data sets situated in separate, siloed databases across the organization. To do integrated analysis, it was difficult to gain special access and was time consuming to pull data from the different databases together, and adjust for different time resolutions in order to correlate the data. HECO recognized the value of integrating the data together, and T-REX was used to create the integrated data set which incorporates SCADA, PV, wind, irradiance, and AMI data, allowing HECO to quickly look at the data, perform analytics and develop applications such as Renewable Watch which displays a graph of the current load, and the energy produced by different renewables.

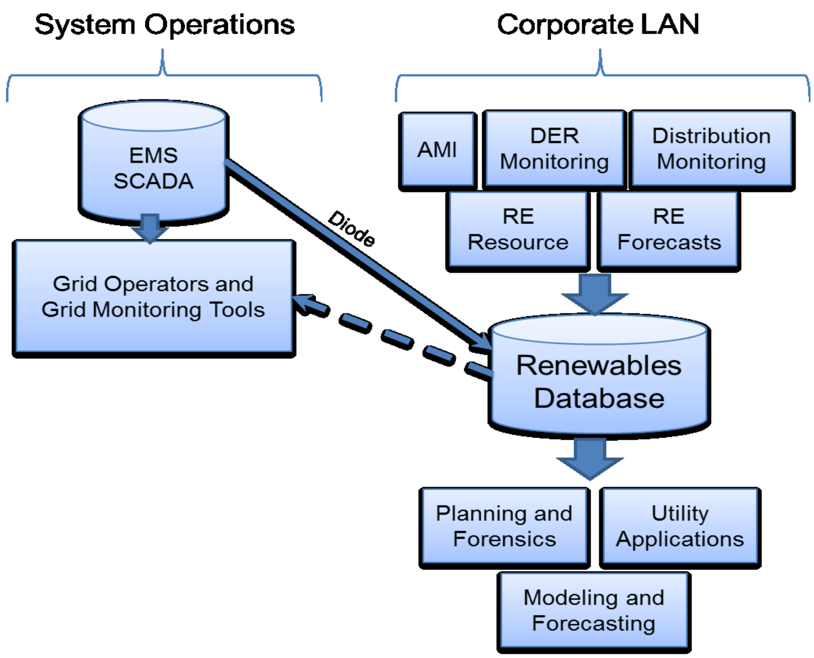


Figure 3.13. Oahu (HECO) T-REX integration architecture.

For HELCO, a two server approach was initially recommended as the most preferred deployment providing for both secure interface and robust access to diverse data sets and would require support from both OT and IT. Given timing constraints impacted by EMS upgrades, the T-REX was implemented at HELCO, pulling in the SCADA data in an EMS environment similar to MECO (Figure 3.14).

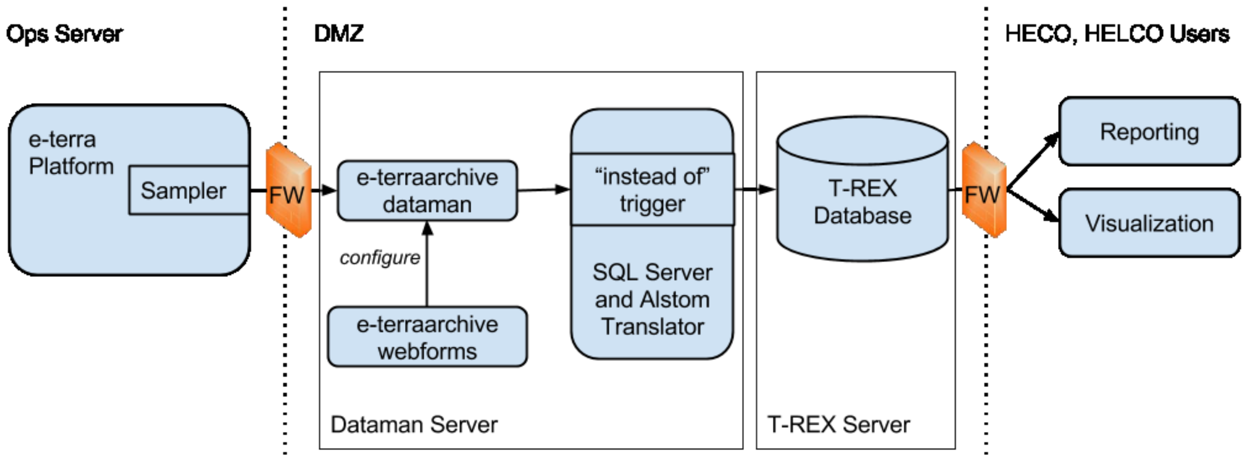


Figure 3.14. Hawaii (HELCO) T-REX architecture across cyber-secure domains and enhanced firewalls.

With T-REX in place at HELCO, a major milestone was obtained under the DREAMS project as it was the first time that all three utilities' information could be shared and viewed using a common analysis platform. The REDatabase readily supports real-time data sharing and enabled common visualization and analysis tools supporting internal and external needs. Prior to this, the tri-Companies could not support real-time data sharing or creation of visuals like the LVM and REWatch or other tools that offer more transparency to how much renewables are contributing to the system. Additionally, with the REDatabase in place, HELCO's existing Excel-based reporting scripts were upgraded to run on a more current operating system compatible with the new DMZ and cyber requirements. The capability provides a more flexible and extensible reporting process. This will eliminate hardcoded values such as sheet names and machine names from the reporting process. A reporting process based on the Renewables Database provides the following benefits:

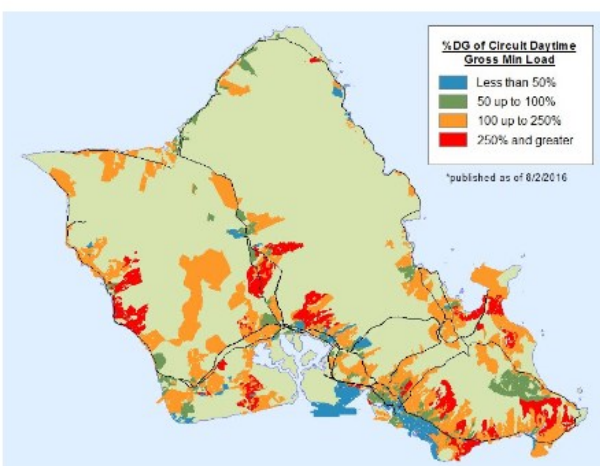
- Allow users to design and create their own reports; and
- Enable reports to be generated that span multiple days.

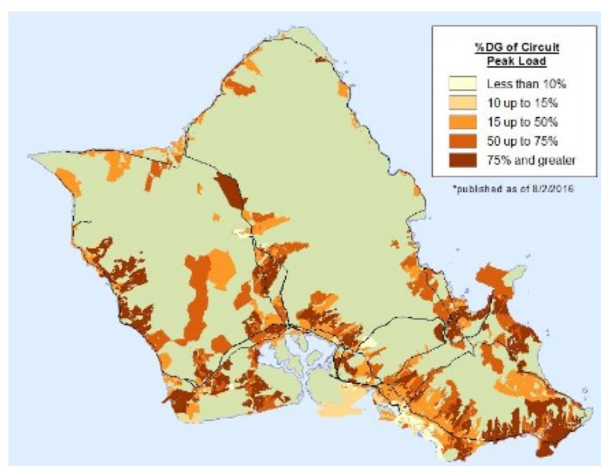
Because the T-REX platform is specially designed to handle time-series, rapid export (T-REX) of high resolution, high volume datasets, other data intensive initiatives such as the US DOE funded Synchrophasor Visual Integration and Event Evaluation for Utilities (SynchroVIEEU) project was also able to utilize the REDatabase and analysis platform for incorporating synchrophasor data, facilitating access and review of existing synchrophasor data in combination with other grid data for forensics, model validation and informing scenario planning needs to increase operational awareness of the impact of high penetration of renewables.

The role of the REDatabase will continue to grow as HECO kicks-off SEAMS for SHINES, a project under DOE's Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES) funding opportunity. New sources of data from edge of network devices will be integrated into the database, including data from a battery management system and smart inverters. T-REX will become an integral part of the Decision Interface and Integration (DII) platform in the SEAMS project, making the data available through a standards-based interface. T-REX will continue to support the next generation energy infrastructure at the Hawaiian Electric family of utilities, providing grid visibility to enable integration of increasing amounts of renewables towards the Hawaii goal of 100% renewables by 2045.

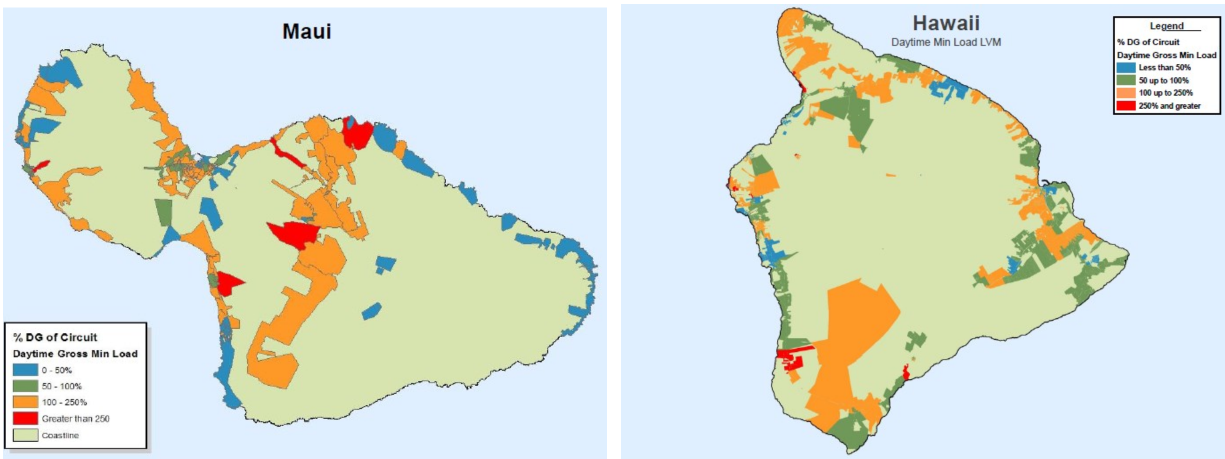
3.3.2. Locational Value Map (LVM) Visualization and Data Map Architecture

As described in Section 3.1.1, the LVM visualization map (Figure 3.15) and internal tool supports tracking of high penetration PV by location and circuits. Figure 3.15a shows circuit coverage areas that have installed PV from zero penetration to greater than 250% of daytime minimum load (DML), where the DML is the daytime total load on the circuit. Figure 3.15b shows areas by peak circuit load which for many residential circuits in Hawaii occur at night, between 7pm and 8pm when there is no solar. Figure 3.16 provides the data flow of files and databases needed for creating the displays. Linking the DG databases and automating the data transfer was a critical requirement to supporting timely (daily vs annual) updates. Unlike system and transmission resources, DG resources can readily change from one day to the next and requires timely updates to the amount of distributed PV resources installed on distribution feeder to support planning models and for EMS integration.





(a) (b)



(c) (d)

Figure 3.15. LVM for a) Oahu based on DML and b) peak circuit, c) Maui LVM based on DML and c) HELCO LVM.

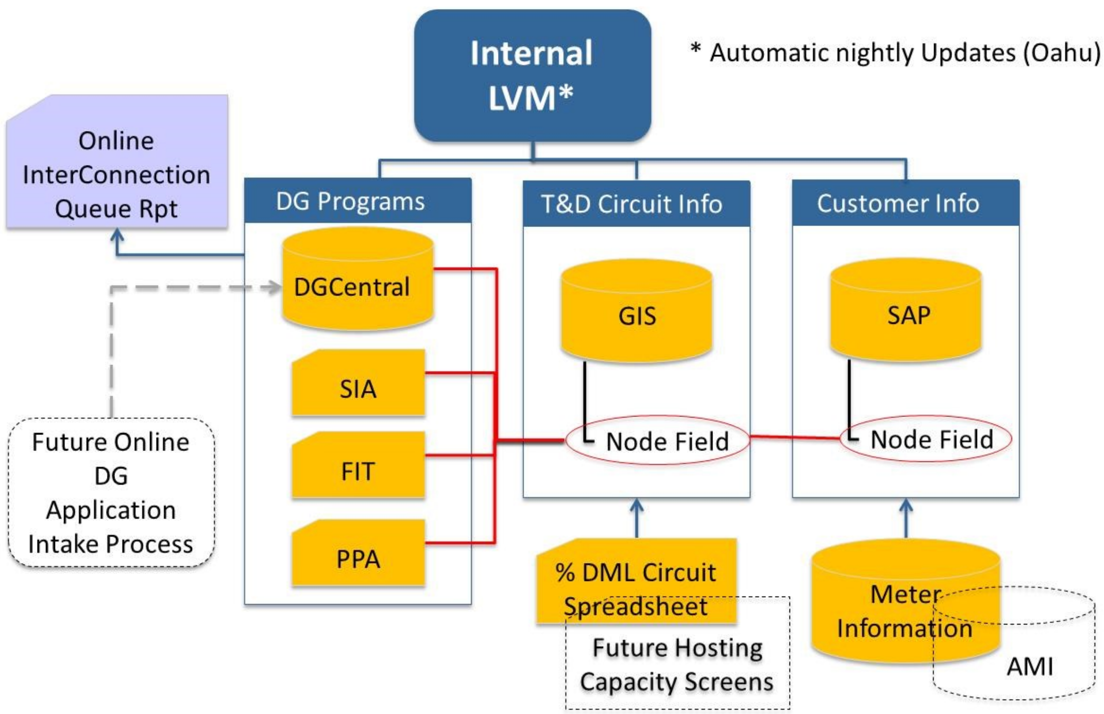


Figure 3.16. LVM data flow and access map. Dotted boxes are new applications being developed that can leverage this architecture for organizing DG resources.

3.3.3. Secure Data Transfer Mechanisms

For IT and OT needs, critical data content identified that is outside of SCADA was reviewed for data backhaul and storage. SCADA and remote access via microwave and dedicated fiber optics are typical utility communication capabilities. With increasing levels of DG, it quickly became economically unfeasible to run point to point communication to all rooftop PV systems. Questions were raised as to how the data was to be used and if there were any customer confidentiality concerns. Standard utility data use and corporate compliance on permissions to use the data for the project was followed. Grid side data access required authenticated login to access mirrored EMS data within the T-REX database. There the data was combined with non-SCADA data recorded via customer-sited sensors and substation field devices and transferred either via real-time cellular communication, historical flat files (hours to days delayed) and API data pulls. Non-SCADA data backhaul included periodic to daily ftp or sftp file transfers, scripted processes to login to web-based portals to pull data and custom API transfer scripts.

Incorporating the real-time SWIFT forecast into EMS used a CIM formatted schema. AWS Truepower hosted the ftp site to transfer forecast input data and provided the 15-min forecast updates and associated probability of exceedance (POE) in consecutive files. Input data included the updated aggregated PV by substation.

Incorporating distributed PV resource data posed some challenges to the stand-alone demos. Both EMS vendors eventually incorporated a separate module outside of EMS to capture the distributed information. Additional EMS integration logic had to be developed to incorporate into load forecasting and dispatch needs. Both EMS providers implemented their solutions in the stand alone EMS development environment so as not to jeopardize normal grid operations. While additional time to test out the stand alone features of the integrated tools is needed, primary results show that gaining visibility to the status, availability and control (discrete or aggregated) can have value in improving dispatch of traditional units thereby avoiding the costs of firing up units when renewable resources are available. Results of the development screens incorporating renewable forecasts and DG resources are provided in Section 4.

4.0 EMS INTEGRATION AND INTERFACE

A unique, dual EMS platform approach was initiated as part of this project and involved two leading industry EMS providers. Siemens and Alstom/GE are working with the Hawaiian Electric Companies to enhance the EMS platforms to accommodate changing utility requirements to better see and manage distributed resources and account for variable energy resources (VER). As part of the effort, each provider reviewed the existing EMS design for ability to accommodate new DG data and logic. To support new data requirements from DG resources, both providers had to evolve their platforms.

In BP1, both Siemens and Alstom successfully integrated visualization capability to see the new data. In BP2, EMS enhancements and new visualizations became the focus. Though both EMS vendors started with very different architectural platforms and approaches, both eventually took similar approaches to manage DG outside of the EMS and interface needed information and logic into the EMS. Siemens took the more traditional file transfer approach with an ASCII file transfer format whereas Alstom/GE utilized .xml web-services via online tools.

Major accomplishments include:

- Finalized plans with both Siemens and Alstom to use their existing platforms. Siemens DMAS and Alstom's e-Terra platforms were utilized for purposes of this project.
- Delivery of Siemen's DMAS platform to Oahu for side-by-side comparisons.
- EMS mirroring using Alstom e-terra platform. Virtual platform will remain at Alstom's Redmond facilities for continued development per utility request.
- Both EMS platforms successfully integrated the DG data and renewable forecasting data streams.
- Logic enhancements to interface with EMS state estimator and dispatch functions and provide new visuals using live production data.
- SWIFT forecasts data successfully translated into T-REX environment, a common platform for secure data exchange between EMS environment and non-SCADA environments. Work conducted by Referentia and utility staff.
- Development accomplished in both EMS environments leveraging stable core products as a baseline to ensure stable and tested products on which to build new solutions.

4.1. Siemens DMAS Platform

Siemens proposed to use a modified version of the Spectrum Power TG DTS (Dispatcher Training Simulator) to produce relevant operational data useful for managing the system. This modified platform is being referred to as the Distribution Management Application Server (DMAS). The DMAS application is interfaced with all the relevant subsystems of the EMS, including:

1) Data Management System (DMS): data handling system for EMS functions

2) Operator Interface System (OIS): for design and layout of EMS displays
3) Real-time State Estimator (RTSE): decision tool for evaluating different line conditions during normal and non-normal operations
4) Outage Scheduler (OS): outage management and crew scheduling system
5) Study Contingency Analysis (CA): evaluation and decision tool to conduct scenario analysis and non-normal operations studies
6) Similar Day and Adaptive Load Forecast (SDLF and ALF) Applications: load forecasting analysis tool for dispatchers
7) Alarms and Events: scheduling and display tool showing outage and operational alerts

4.1.1. Design Approach

For Siemens, the Spectrum Power TG system is in use at HECO as the EMS. Traditional EMS systems require direct SCADA telemetry from devices in the field. While large renewable power purchase facilities (PPA) had SCADA, it was not practical or possible to implement direct SCADA telemetry to every rooftop PV generation source to capture DG attributes. Siemens original goal was to modify existing displays and use current software products to create new screens that will allow users to view a combination of forecast generation data, provided by a third party (AWS), against the utilities planned generation for a 24 hour period. Figure 4.1 provides an overview of how the Siemens DMAS components interface with the various data from AWS and DNV.

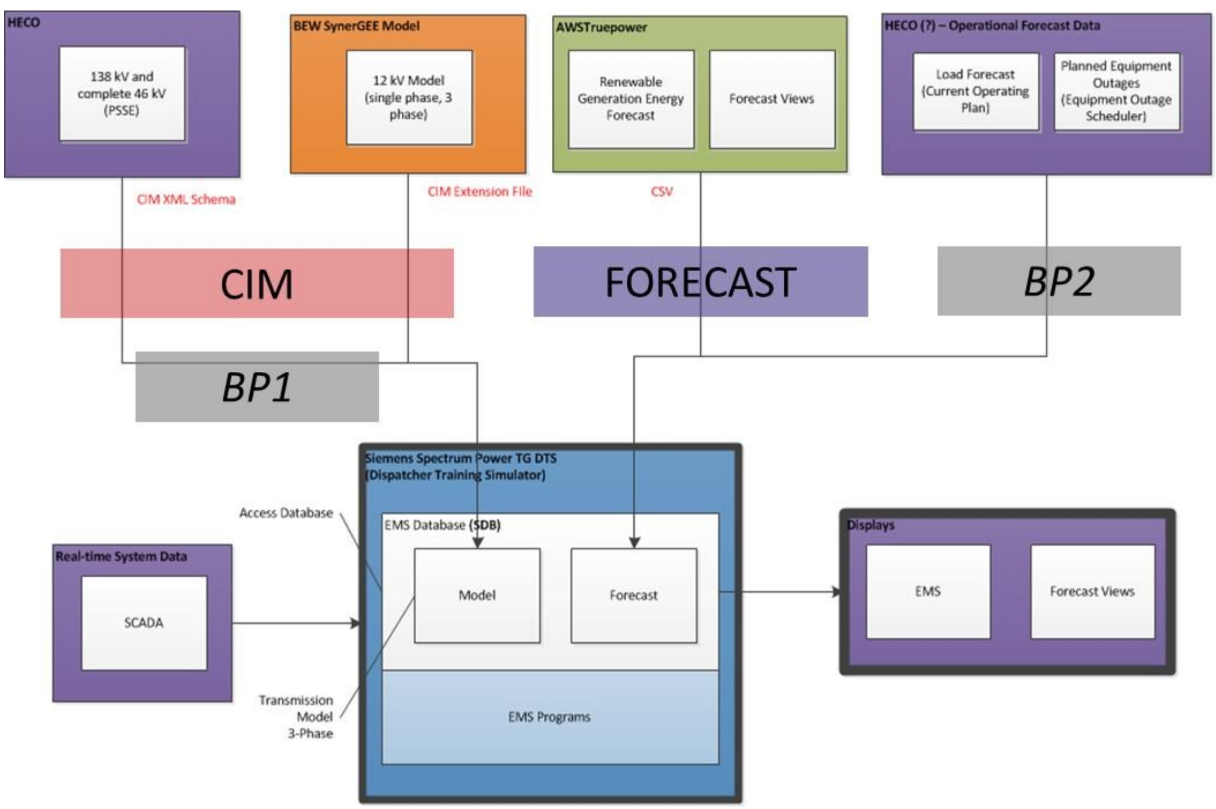


Figure 4.1. Overview of Siemens DMAS interfaces and project phases (BP1 and BP2).

This work had already been started, when another group within Siemens developed a product called WebSDK that was an independent software package outside of the EMS that could receive data from the EMS and display the values of both forecast and real-time EMS generation together. This new product had better graphing capabilities and offered a degree of flexibility the legacy Spectrum Power TG could not match, and was a component of the next generation Spectrum Power 7 platform. It was decided late in 2015 to take a risk and change the design approach. This was a risky decision as the project completion milestones were quickly approaching, yet the benefits of this newer technology for system operators outweighed the risks.

4.1.2. Results and Displays

Highlights include:

- Use of CIM schema to import distributed PV information to proper points within the EMS. Considerable experience was gained importing CIM compliant data including the aggregated DG network models developed by DNV and trimming the model to levels of use for the EMS as not all distribution devices are telemetered or represented within the EMS. As the PV devices are aggregated up to the subtransmission device level, new device objects had to be expanded using the Source Database Builder (SDB) CIM import tool to include the distribution format so the subtransmission layer and associated transformer (with or without SCADA) could be represented. Naming conventions and associations had to be created within the SDB to resolve these issues. Lesson learned for future reference is that standardized nomenclature will greatly improve interface capabilities as modeled data, GIS data and EMS data currently do not follow similar naming conventions or any CIM format. Figure 4.2 shows how additional translations had to be made to interface the various components of data.

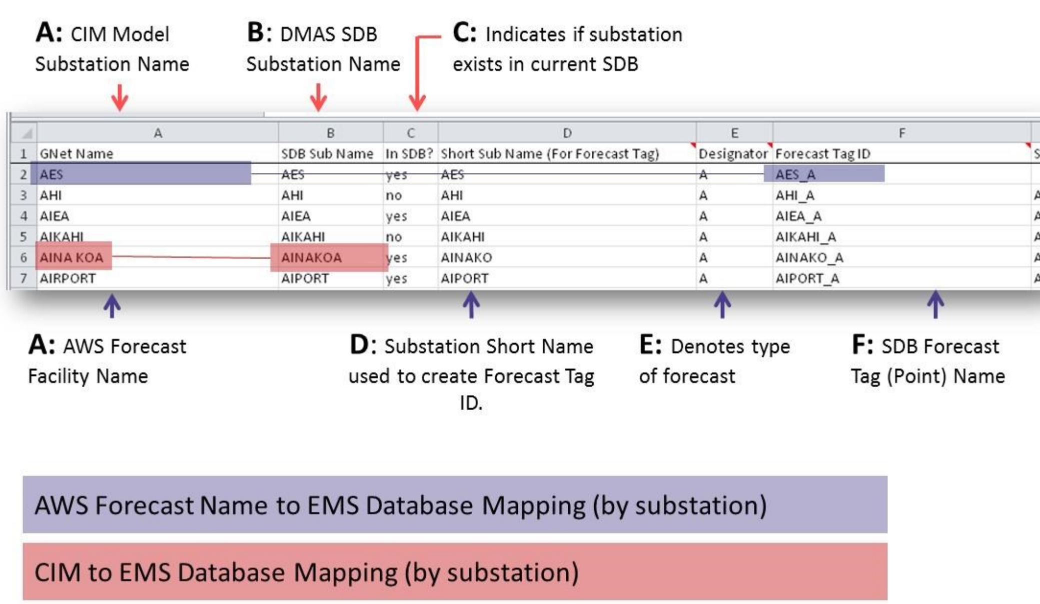


Figure 4.2. Mapping data from EMS (DMAS) to substation and CIM formatted forecasts.

- Integration of AWS Truepower Solar and Wind Integrated Forecasting Technology (SWIFT) forecasts is managed across a secured FTP server at this time. Siemens utilizes a PCLink tool to access the file through a secure port and make it available for the DMAS Server through a read script. This process is a bridging technique and will be enhanced as the DMAS tool is implemented.
- Visualization displays were created to convey the forecast information in a way that utility operators would find useful and not overwhelming. Various prototypes were created and a working view is shown in Figure 4.3. Important feedback included preference for geographic representation to provide quick orientation and situational awareness; clean and uncluttered; use of intuitive color schemes (may be limited depending on viewer display); summary view with drill down capability in pop-out screens; and system and regional views. The visual display for the system and regional views are consistent to the aggregation and roll-up scheme described in Task 2. Features include:
    1. A current time ("Time 0") to 2-hour ("+2 hour) forecast look ahead in MW generation is displayed on screen based on the AWS forecasts for the regions (north, south, east, west, central) and total system in the tabular box on the upper right corner.
    2. User selected view to display the current hour or view up to the next 3 hours by clicking the number indicated in the green box.
    3. Circular and square dots indicate either a wind or solar (aggregated DG or utility scale PV) facility. The color of dots indicates probability of ramp events from low (green) to high (red).
    4. User drill down option to access additional screens of the forecast probability and total forecasted wind and solar for system view (Figure 4.4).

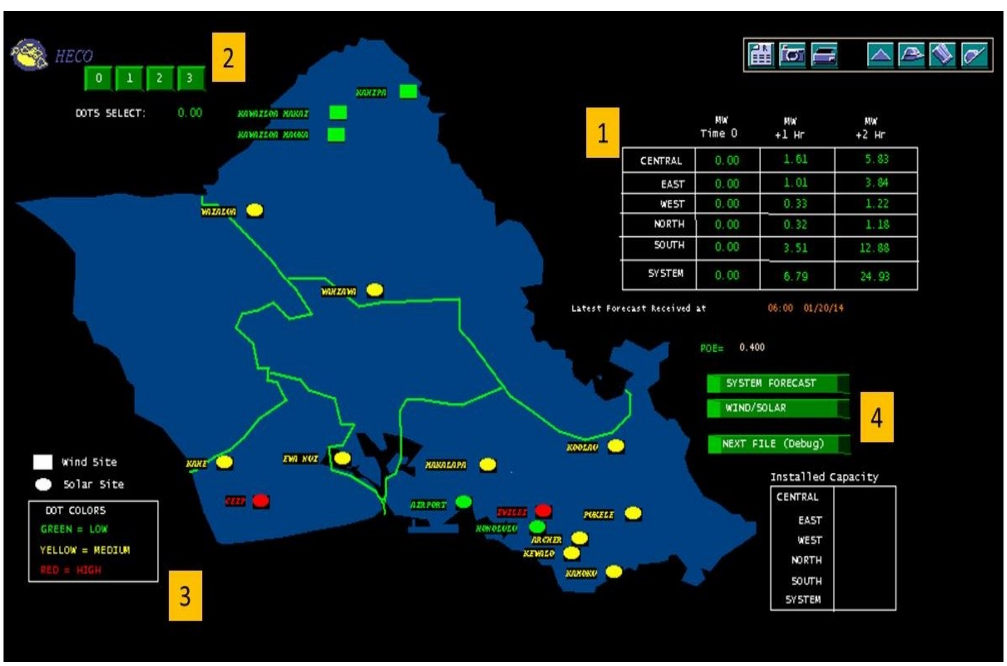
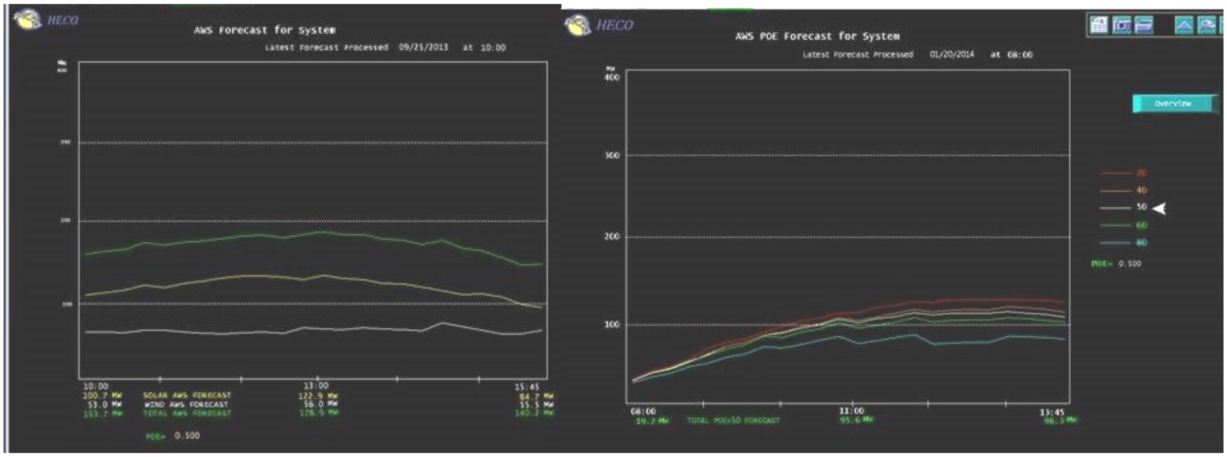


Figure 4.3. Visual display of forecast information for next 3 hours in Siemens DMAS.



(a) (b)

Figure 4.4. Drill down screens showing details for a) total forecasted system wind and solar and b) probability forecasts for next 6 hours based on AWS SWIFT forecasts.

Work began in earnest to devise how this new WebSDK product would receive data from the live EMS system, plus display the weather forecast projections for up to 6 hours ahead. Additionally, as the forecasted values approached current time, their accuracy would improve and hence the confidence to operations that the expectations for weather related changes could be monitored and adjustments made in real-time.

<u>Issues Encountered</u>

This latest WebSDK product from Siemens was designed to support Micro Grid management systems in a standalone configuration. The database resides on a server in Oracle. For Siemens the challenges were to connect this product to the Spectrum Power TG EMS that is used to control the transmission system for the entire island of Oahu. When the Spectrum Power TG was developed, the graphical tools had just moved from DOS based/character graphics to vector graphics. Even with this advance, the drawing tools seem limited when compared to current expectations for data representation. Additionally, the EMS system uses a PI based archive system for data storage. Siemens needed to define a way to have data also route to the WebSDK's Oracle database, so it can render the displays for operations.

Finally, with the advent of new renewable energy products and advanced power storage solutions, the EMS system was not originally designed to support these technologies, nor to render data collected from them, let alone to forecast future unplanned (not utility controlled) changes in power output due to natural changes in solar output from cloud interference.

<u>Resolution</u>

So with the advent of this new WebSDK product, Siemens was able to provide a working solution that allows for a complete overview of the systems condition and the potential impacts for changes to the variable behind the meter generation. For HECO, this amount of generation can lead to zero system load, as the solar is contributing all the power required for the entire island (Figure 4.5).

With this new design and the power forecast data being provided by another outside supplier to HECO, Siemens was able to construct a display that provides a 6 hour look ahead (right quarter of the center graphics in the below display).

With this visibility, operations can plan spinning reserve generation balanced against load and the contribution from renewables. The flexibility of this new tool also allows Siemens to evolve the display to include future products such as battery storage for peak load shedding, additional wind and solar farms. Charging of the battery systems will appear as negative generation and be below the "zero" line.

As this product matures and HECO's system needs to change over time, Siemens can add additional links to provide weather details (top left of display) or even emissions and fuel expenditures (lower right graph). Plus, this flexibility allows Siemens to market this solution to other customer's facing similar challenges to their operations.

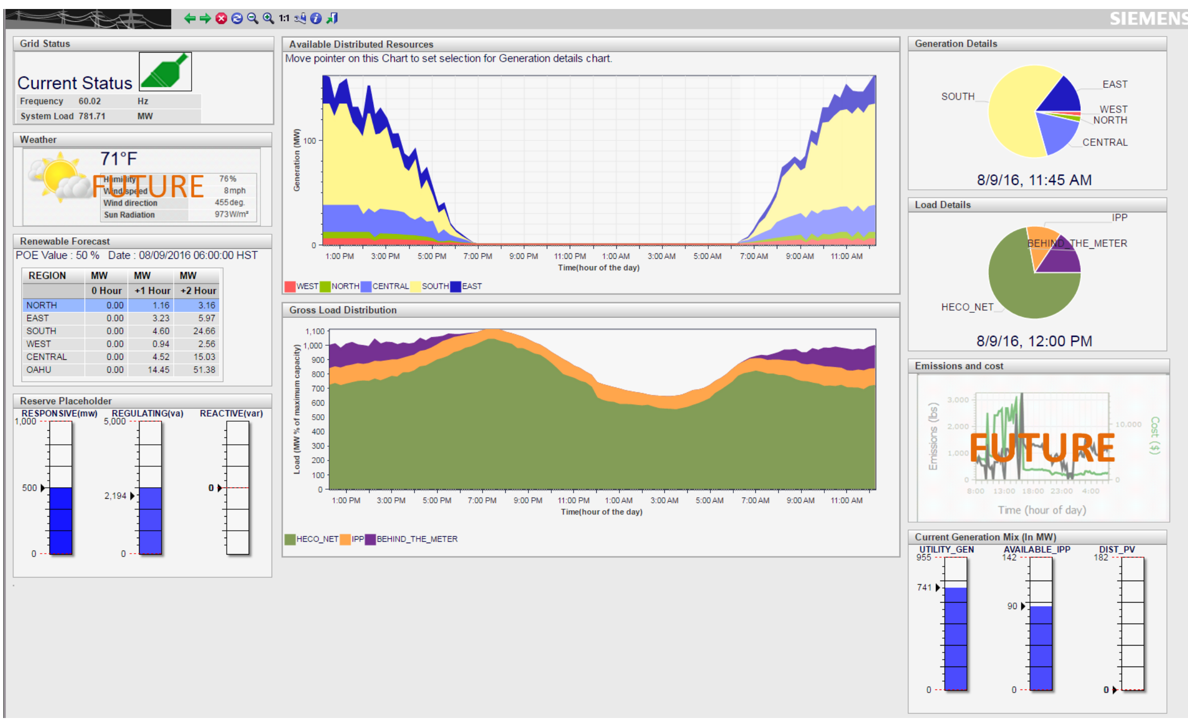


Figure 4.5. New WebSDK demo screen showing consolidated "stack" view of DG resources, probabilistic forecasts, conventional generation and reserves. Pie charts provide real-time operational awareness to the level of each type of resources and variability.

4.2. Alstom eterra Platform

Alstom Grid's effort is based on its **e-terra***renewableplan* product installed as standalone virtual machines at MECO and HELCO and mirroring SCADA data from the existing **e-terra***platform* Energy Management Systems *(*EMS) existing at both sites. The **e-terra***renewableplan* and **e-terra***platform* EMS products are addressed in separate agreements between the parties. The solution is aimed at providing operations and planning personnel with the infrastructure and tools they need to address renewable integration at both the distribution and transmission level. The project focuses on accounting for impacts of Distributed Generation (DG), specifically wind and solar, on the power system.

Enhanced capabilities desired include:

- Provide operators with information and means to assess and simulate impacts of aggregated DG.
- Ability to incorporate third-party vendor forecasts and statistics for wind and solar technologies.
- Provide simulation-based decision support to inform operators on impacts of DG on real-time operations.

The DREAMS project served as an extension to the RDG-VIS project. Accomplishments include:

- Staging of two virtual EMS systems mirroring the existing HELCO and MECO actual EMS systems. The virtual EMS mirrors are referred to as demo platforms.
- Extending the demo platform infrastructure to receive, store, analyze and visualize renewable generation forecasts.
- Interfacing the demo platform with the respective HELCO and MECO forecast web services provided by AWS Truepower.
- Adding the capability to aggregate forecast data by regions, island, and system.
- Making selected AWS forecast data available to the SCADA application.
- Developing maps, charts and SCADA displays to present the renewable generation forecast to EMS operators in real-time.
- Enhancing Load Forecasting and Reserve Monitoring capabilities with forecasts and DG insight.

The last two enhancements – load forecasting and reserve monitoring – are discussed in detail in the next sections as they best illustrate how incorporating new DG information requires augmentation to EMS logic and functionality.

4.2.1. Design Approach

Alstom is actively engaged with utilities in the US and Europe to integrate better controls and visualization capabilities within the EMS. As such, the DREAMS project leveraged prior development work on the eterra environment but also introduces some novel new capabilities to enable access to real-time renewable forecasts and DG information for grid management. Project development included creating three new interfaces for e-terrarenewableplan. One additional real-time interface was created, allowing for retrieval of forecast data from AWS into e-terrarenewableplan. Two modeling interfaces were created for this project for retrieving GIS data and aggregated PV data. Alstom's e-terrarenewableplan product uses Alstom's standard Intersite Data (ISD) protocol for real-time communications with the Alstom EMS e-terrascada application.

Similar to Siemens, it was not prudent to conduct live changes directly within the existing eterraplatform or EMS. As such, a virtual development EMS mirroring what MECO and HELCO were using was developed for purposes of development and demonstration. The Alstom platform also provided perspective on a different EMS architecture, one with a more modular build onto which the same third party renewable forecasting CIM-based data and DG information had to apply. Alstom's approach is uniquely different than Siemens and serves as a reminder that while approaches can be different, the data stream must be consistent.

The demo environment included one Virtual Machine at HELCO and MECO. The Programmer Development System (PDS) VMs at MECO and HELCO were duplicated to be used as PDS platforms for this project. Each project environment will consist of two virtual machines and integrated to work together as a system:

- One VM containing a copy of the current PDS server.
- VM's for **e-terra***renewablesplan* on the RDG-VIS project were reused; however, new VM's were created emulating existing MECO and HELCO PDS systems since previous EMS VM's were based on the EMP 2.3 system which is incompatible with the Reserve Monitoring enhancements required in this project (requires VM's to be based on EMP 2.6 for reserve monitoring calculation compatibility on AGC).
- One VM containing the e-terrarenewableplan software.

Development highlights include:

- Integration of AWS Truepower SWIFT forecasts using a web services interface. The adapter fetches information from the AWS web service site and sends the data to the ETRP web service as shown in Figure 4.6.

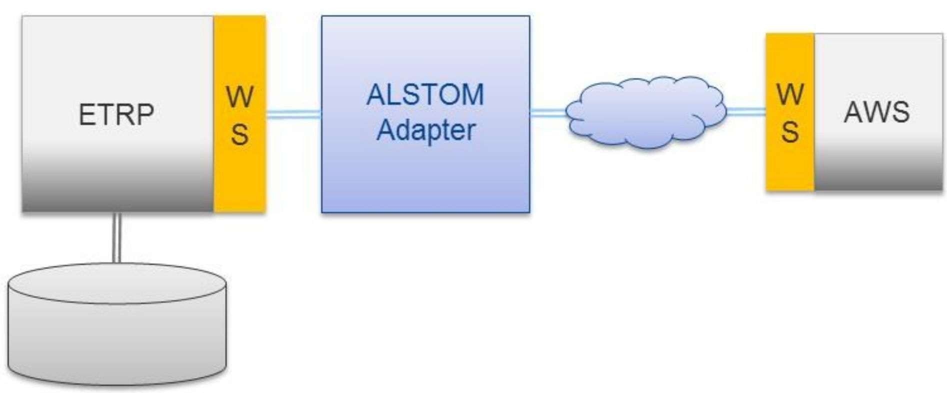


Figure 4.6 Web services interface approach used by Alstom to transfer data.

- CIM schema used for transferring renewable forecast data within EMS tools. Over the course of the project, there seems to be more awareness within the IEEE communities to build CIM standardization and leverage DREAMS efforts with OpenGrid. In discussions with UAT members, all agreed that standard CIM interface and schema for renewable forecasts would help industry and utility begin to better utilize the information and make integration efforts less challenging.

- Figure 4.7 depicts a DREAMS schema implementation for forecasting data interface to the EMS.

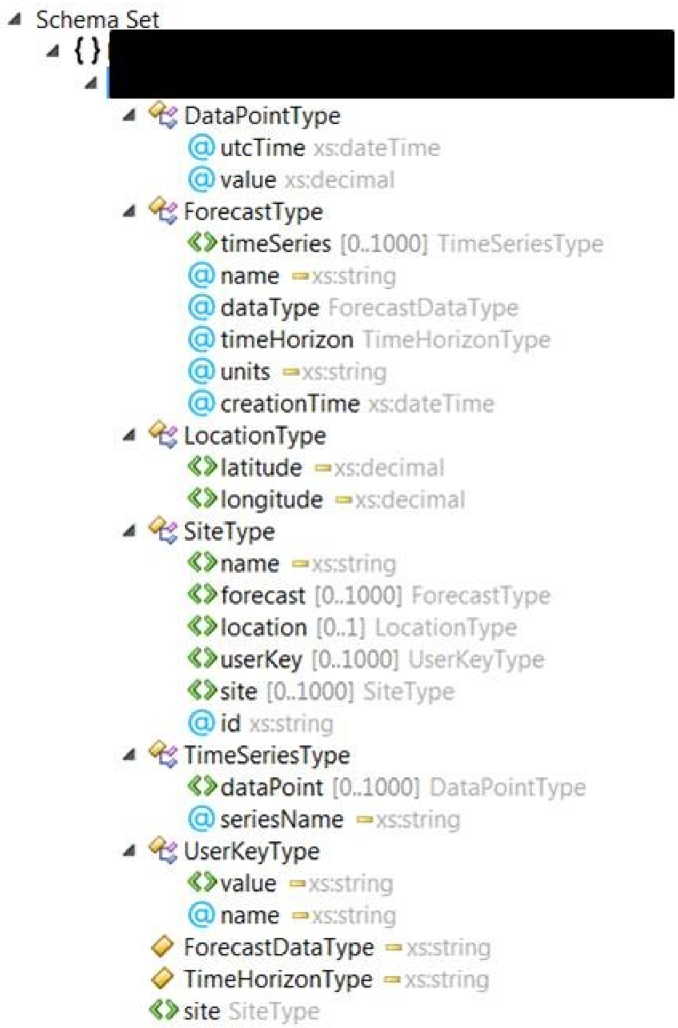
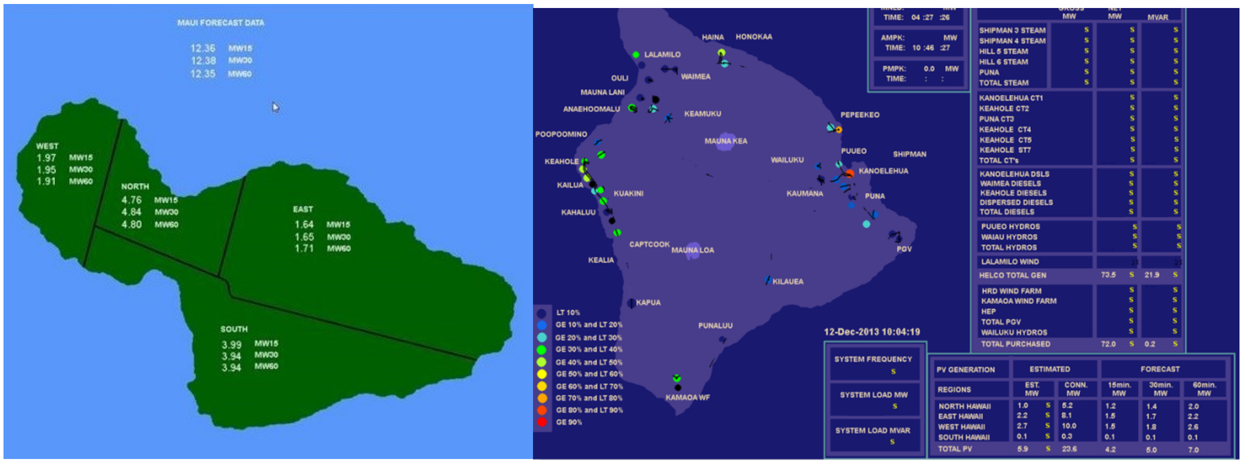


Figure 4.7. A DREAMS recommended CIM schema and data parameters for integrating renewable forecasts to EMS.

- Visualization displays were created to convey the forecast information in a way that utility operators would find useful and not overwhelming. Various prototypes were created. Figure 4.8 captures the working version of the visual displays. Alstom enabled a demonstration of this prototype screen that integrates real-time acquisition of 15 minute interval forecast over the next 6 hours for both wind and solar for Maui and Hawaii islands. The island of Hawaii display replicates the current geographic based view of the EMS system and added the forecasted values by region at the bottom tabular section. Displays are accessible on SCADA displays. Figure 4.9 shows the additional screens available if further analysis is desired by the operators.



(a) (b)

Figure 4.8. Visual display of a) forecast information for next three 15 minute intervals in Alstom's eterra for Maui and b) Hawaii Electric Light's EMS display for Hawaii island.

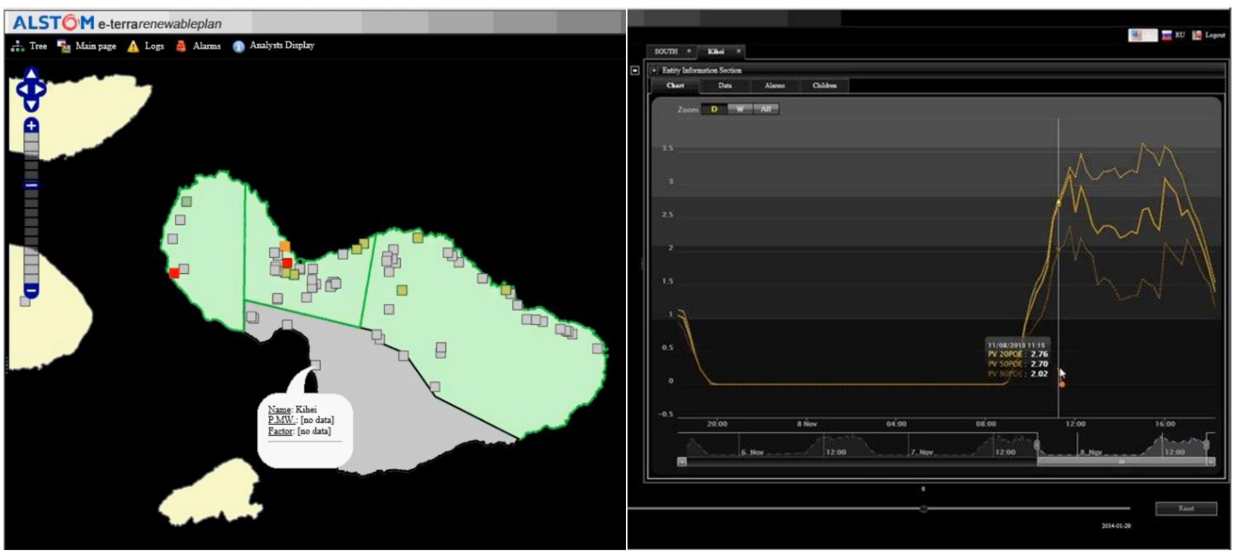


Figure 4.9. Detailed screens on DG aggregated locations, sensor results and probabilistic forecast from AWS SWIFT forecast.

4.2.2. Results and Displays

Primary areas enhanced as part of the DREAMS project were in the load forecasting and reserve monitoring logic as summarized below. Highlights include:

Load Forecasting

e-terra*loadforecast* 2.6 was used for this project. The Load Forecast (LF) models were configured using sample historical data based on common weather patterns. Both MTLF (weekly forecast in hour intervals) and STLF (1-6 hour forecasts in 5-minute intervals) were configured.

Load forecasting was added to both HECO and MECO demonstration platforms. The load forecast application was enhanced to account for unmeasured load served by Distributed Generation (primarily residential PV). For grids with high penetrations of behind-the-meter distributed generation, this new ability adds capability and situational awareness to see and plan for the “hidden” component of the load (shown in blue, Figure 4.10)previously not available to system operators.

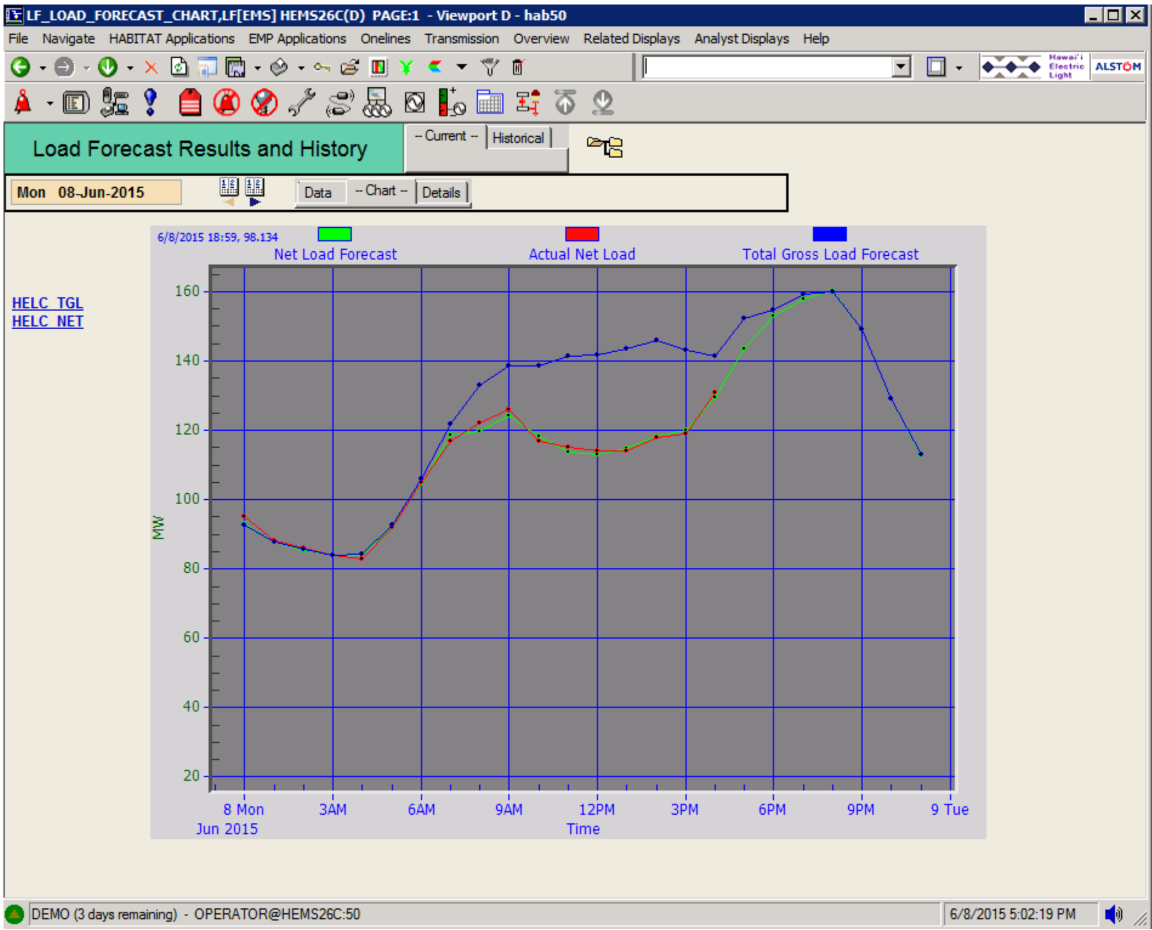


Figure 4.10. Load Forecast display accounting for unmeasured DG resources information.

<u>Reserve Monitoring</u>

The e-terragenertion running on the e terraplatform 2.6 was customized after e terraplatform 2.3 was upgraded to version 2.6 to provide the required code, display, and modeling changes. The Alstom AGC process was modified to retrieve system-level values from SCADA for the current estimated Renewable Generation (RG) MW value, as well as the most likely (50% POE), maximum (e.g. 40% POE), and minimum (e.g.60% POE) estimated RG MW values for 4 evenly spaced time points (e.g. 0 min, 15 min, 30 min, and 45 min in the future). For purposes of the demo, these time points were fixed at 15 minute intervals from the top of the hour, so for a fifteen minute period the values will not change. The interval used was based on a parameter that was defined both in e-terrarenewableplan and e-terraplatform to simplify the forecasting data which has additional probabilistic information. It is expected that if the e-terrarenewableplan falls behind in updating the SCADA values, the processing may not have the full set of 3 future time points and if the update of telemetered data is delayed such that there is only one future breakpoint available, an alarm will be issued by AGC to indicate the data is getting old.

AGC also obtained deterministic (most likely only) load forecast values for the current time and for the 3 future times as a simplification to evaluate logic for the demo. AGC was modified to use the RG MW and Load Forecast data to determine the worst case and most likely scenarios for the required generation change in each direction for each of the 3 future time points. These calculations were run at the same rate as the Reserve Monitor calculations which can typically be anywhere from 30 sec to 300 sec. Whether this is the final interpretation or implementation it will require additional interaction and feedback with HELCO and MECO as they begin to utilize more of the functionalities for DG resource management.

Displays below provide an overview of where the new DG and probability forecast information are incorporated as part of the demonstration.

- Summary Display: A custom generation display was built to show all of the inputs and outputs of the DG reserve calculations with probability in terms of probability of exceedance values accounted for (Figure 4.11).

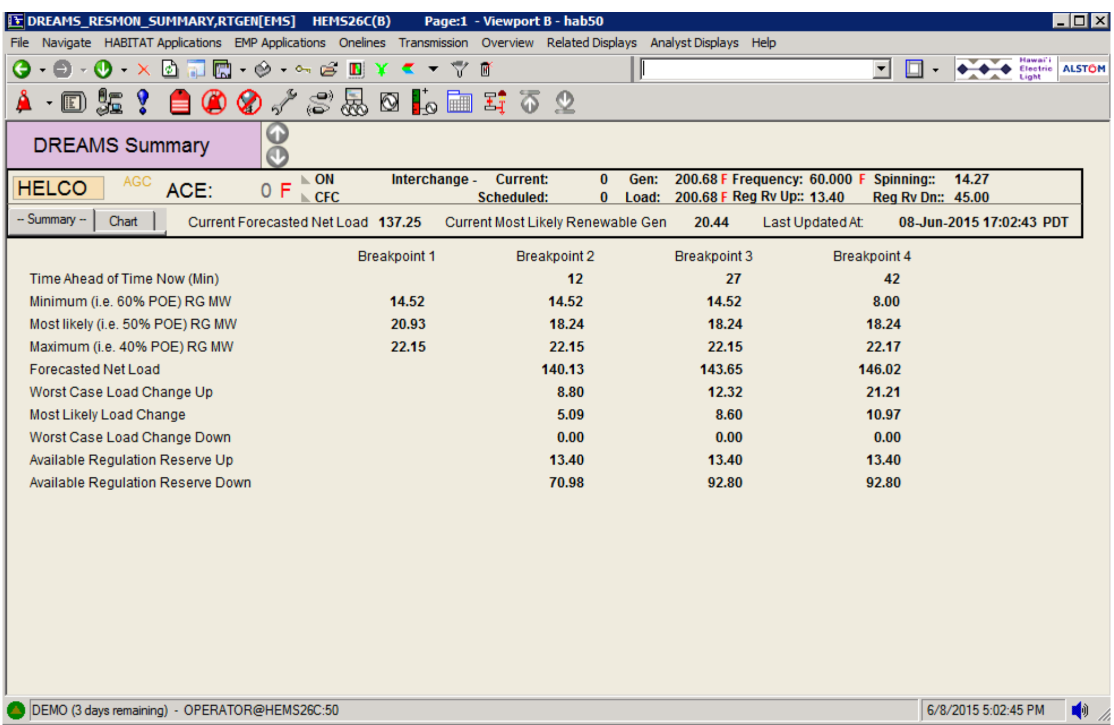


Figure 4.11. Input and output data summary used in DG reserve calculations.

- Graphical Reserve Summary Display: Figure 4.12 illustrates in a chart where the worst case load change and most likely load change values are combined with information on the reachable MW deltas for conventional generators to provide reg up and reg down for each of the 3 future forecasted time points.

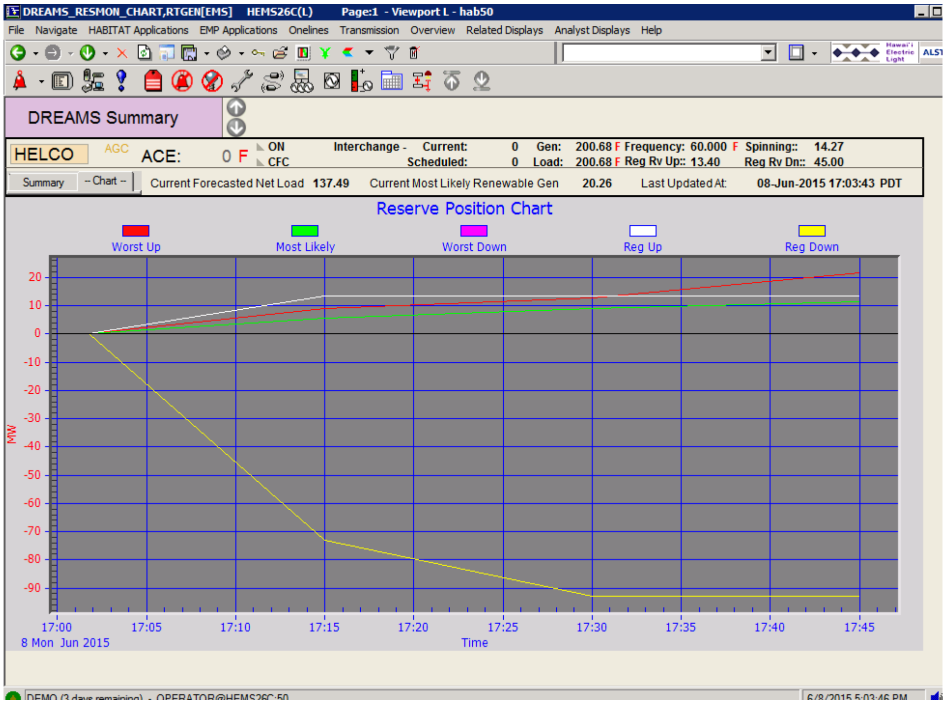


Figure 4.12. Graphical display capturing heads-up on forecasted time points where projected load, accounting for DG forecasts, exceeds planned reg up and reg down reserves.

- Generation Area Status Details Display: Figure 4.13 shows where the reg up exceedances show in summary displays to provide operators an alert. Whether or not action is needed, depends on the conditions on the grid.

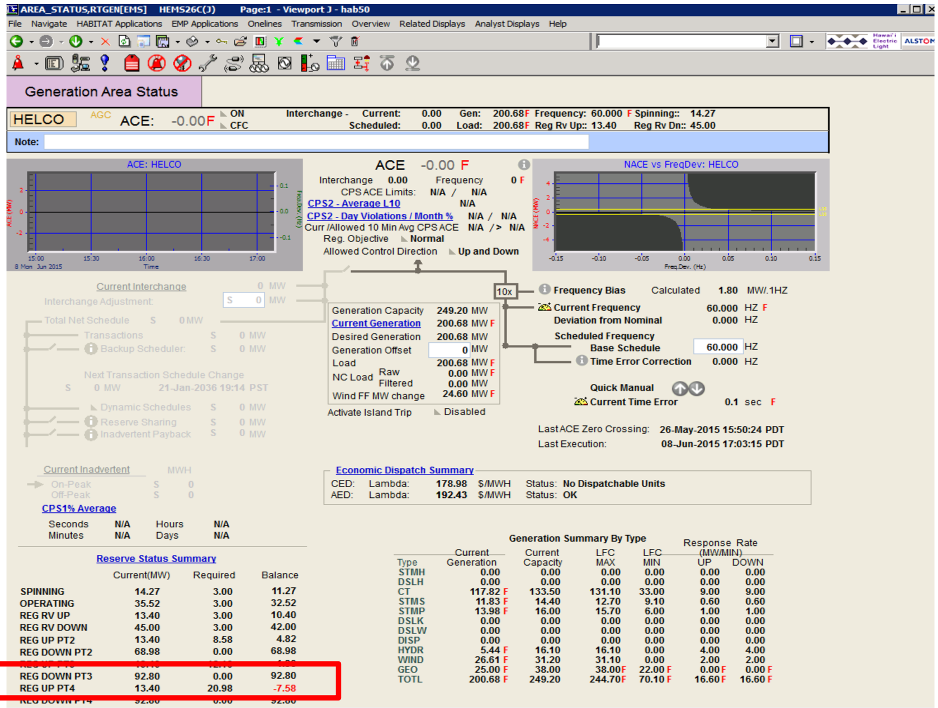


Figure 4.13. Graphical display showing where any exceedance information is captured as part of Generation Area Status.

- Alarm Summary: As part of the demo, the Generalized Reserve Monitor (GENMOM) alarming functionality was used to issue alarms when the worst case scenario load change for a given direction exceeds the available regulation reserves from the conventional units. The reserve calculation and alarming was performed for all three time points in the futures forecast. The calculated regulation reserves for each time point was exported back to GENMOM for use in the visualization charts such as Figure 4.14.

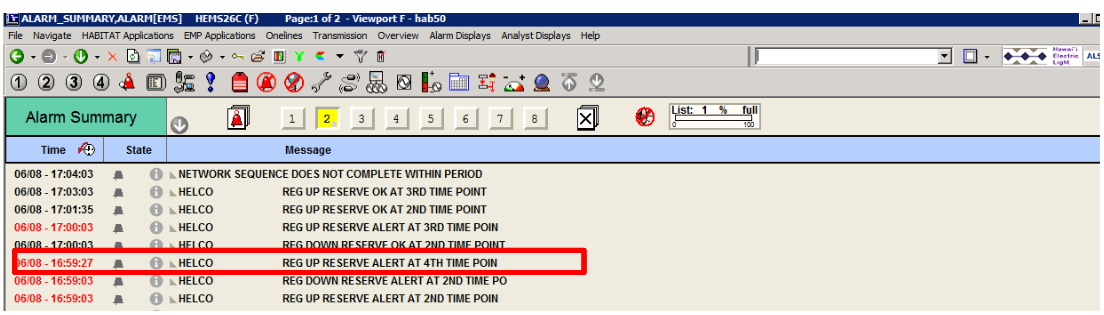


Figure 4.14. Alarm summary incorporating reserve exceedance information from the forecast.

Through logic enhancements and demonstration displays, project objectives for incorporating DG and renewable forecasting data into the enhanced e terrageneration (AGC) function on the HELCO and MECO demonstration systems was successfully implemented. Logic enhancements successfully accounted for renewable and DG generation variability, using renewable forecasts, as well as forecast uncertainty based on confidence intervals. Operator requests to provide generating ‘early’ alerts whenever forecasted renewable variability exceeds the amount of regulation available from the system was achieved through the summary alerts (on the Generation Area Status Details screen) and alarms messages (on the Alarm Viewer screen). Whether or not actual operator action is required depends on system conditions and additional effort to classify as alarm or information alerts.

Although simplifications were made to implement in initial prototype screens, the EMS enhancements provided the project team insight to the customizations and details needed to account for distributed resource information.

5.0 USER ENGAGEMENTS

5.1. Visualization Tool Adoption & Operational Feedback

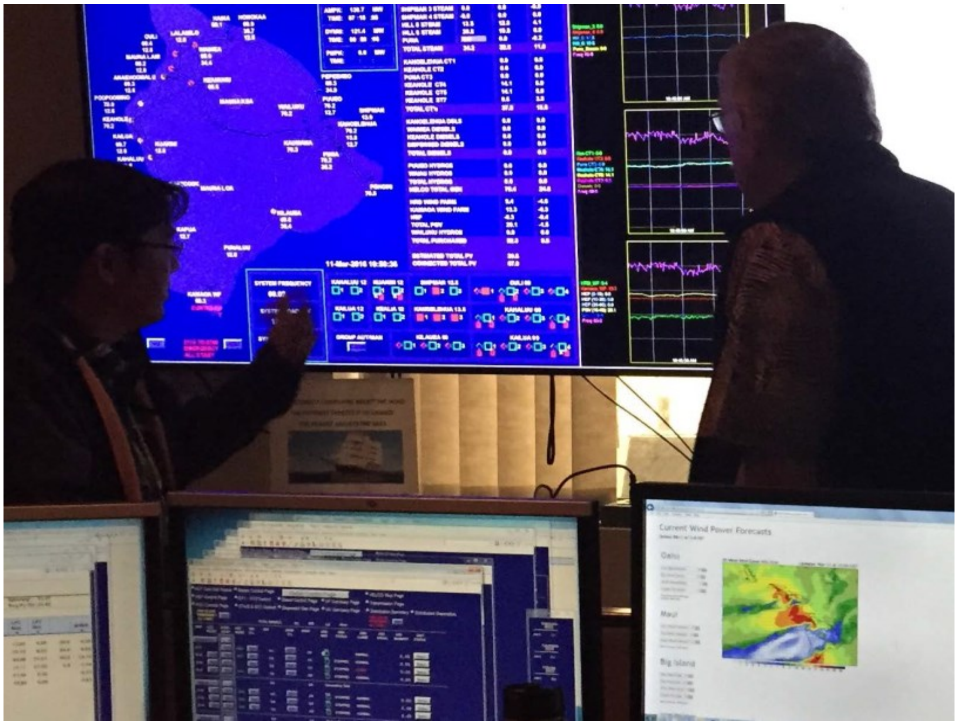


Figure 5.1. HELCO Operations Control Center, SWIFT tool in foreground and HELCO's Alstom/GE geographic view of system incorporating solar irradiance monitoring at substations.

Tri-company operations staff and UAT provided active feedback at user meetings conducted throughout the project. As operators were typically on duty, control room visitations were limited but they provided the most insightful feedback direct from the users. Figure 5.1 shows how the Alstom geographic displays and the SWIFT forecasting tool are actively used in the control room providing Operators both situational awareness and continuous feedback on renewable conditions that may affect their planned settings. Feedback provided by utility operators and staff focused on making the tools more useful, simplification of the solar and wind forecasting data streams and displays, less EMS system alarms and more information consolidated into existing screens and summaries. Key points are summarized below.

Improving Situational Awareness:

- Most operators like a "heads-up," and the sweet spot for this heads up is around 30 to 60 minutes under normal conditions when resources are steady and predictable. This provides time for operators to respond and make decisions on what to do including adjust dispatch decisions and looking at ways to optimize the commitment of units. Opinions differ as to the best way to alert operators as well as what content. Alerts also need to be further classified as alarms or information alerts that can be cleared by the operator. All agree that nuisance alarms will be ignored.

- During highly variable conditions, while forecast accuracy and persistence of the forecast is important, getting a “sense” of the magnitude of change provides utility staff a gauge on how to respond. During variable conditions, a specific number for generation is not necessarily the most important as operators will not want to chase the wind or solar resource, but rather set an acceptable threshold for accommodating the variability. A 60-120 minute forecast may be more useful as threshold will need to be determined per system. As operations gain experience using the new forecasting information, new setting and procedures can be introduced.

Informing Operational Settings and Changes

- For islanded systems, the ramp rate limit based on online dispatchable generators provides an initial quantifiable value to plan MW thresholds for accommodating variability. For example, if three base generators are on line and each carries 20 MW of ramp up or down capability, then the initial variability threshold is +/- 60 MW. Alarm limits can be set around the criteria to alert operators when variability conditions exceed the ability of online units to respond to ramp events.
- Integration of the forecasts and DG MW information can significantly help automate what is currently a manual process and highly dependent on the proficiency of the operator and the conditions on the grid. Building comfort in using the automated and integrated tools will come with time. Efforts will continue to engage and revisit performance of tools through post-event reviews and side-by-side result evaluations.

5.2. UAT Guidance and Feedback

Three Utility Advisory Team meetings were held during the course of this project to broaden the list of potential high penetration DG issues/concerns encountered outside of Hawaii and to provide real-world feedback to the DREAMS team on tool development. Goals of the UAT included:

- Project review, feedback and knowledge sharing;
- Building utility-to-utility partnerships and utility-to-vendor understanding on needs; and
- Dissemination of best practices and lessons learned.

Composition of UAT members for this project focused on western utilities currently using similar EMS control systems for economic dispatch that have high penetration solar issues or expect to be contending with them and currently have wind and/or solar forecasting capabilities and needs. Western utility partners including SMUD, TEP, CaISO, SCE, WAPA and the Hawaiian Electric family of utilities (HECO, MECO, HELCO) participated in the first UAT. The forum provided a venue to have detailed discussions on utility challenges, integration needs and candid feedback to vendor teams on their tools and areas of improvement. Over the course of the project, AEP, KIUC and US DOE technical lead joined and participated in various discussions. The third UAT attracted interest from BPA, Duke, Guam Power Authority, MidAmerican Energy Company, MISO, NYISO and Sharyland Utility. This group forms a reasonable base of utilities actively engaged in high PV issues.

During the course of the project two UAT sessions were held as planned, however due to the project extension a third and final UAT was held to wrap up the project and provide recommendations for the kick-off of the SEAMS for SHINES [11, 12] project and the formation of the Utility and Balancing Authority Advisory Team (UBAT). The three UAT sessions were all held on the mainland and hosted by partnering utilities.

- UAT 1, May 23, 2014, hosted by Southern California Edison, Westminster, CA
- UAT 2, February 17, 2015, hosted by WAPA EPTC, Golden, CO
- UAT 3, April 11, 2016, hosted by WAPA EPTC, Golden, CO

The first UAT was held following the US DOE Sunshot Summit in Anaheim, CA. At this first UAT, the teams met for the first time with the advisory utilities and presented preliminary DG display ideas and prototype screens. Early in the project, this direct involvement and utility user feedback and perspective sharing was valuable to the development team. UAT members provided input on the use of the screens, commented on value added of this project and SMUD (municipal utility) and SCE (IOU) provided insight on how renewables were becoming a concern on their systems in California. Pockets of high penetration on rural circuits and anticipated "duck curve" on the California grids, were indicative of similar pockets of high penetration on the island grids. Other utility advisors were not necessarily aware of the severity of the high penetration issues on the Hawaii islands or familiar with the progress on some of the advanced forecasting capabilities.

Over the course of the extended 3 year project and in consecutive meetings, there was a noticeable increase in the level of awareness of impacts of DG by all UAT participants. The US DOE technical manager attended the 2nd UAT. The most surprising feedback was provided by WAPA and CaISO at the 2nd UAT. Because of the lack of awareness and insight to high penetrations of DG, the increased variability in load compounded by high penetrations of utility-scale wind and solar, the balancing authorities were having a difficult time "balancing" for resource changes even with spot market and hour ahead market capabilities. They were requesting more visibility from the utilities. Discussions also highlighted the importance of DG monitoring and improved technology to track DG resources performance in light of aggressive market and regulatory policy encouraging accelerated development of DG and DER resources. The 3rd UAT meeting was held to provide closure and opportunity for UAT members to see the results of the demonstrations developed as part of the DREAMS effort. Several utility members stayed a 2nd day to further discuss technical tools and workforce development needs with DREAMS vendor partners and WAPA EPTC. Hawaiian Electric Companies also kicked off the SEAMS for SHINES project and all UAT members agreed to continue as part of the Utility/Balancing Authority Advisory Team (UBAT) to assist with the SEAMS project.

Thus the UAT meeting served the intended purpose to get all the partnering utilities aware of the issues, potential issues and capabilities moving forward to see and manage DG resources. Based on the groups familiarity with interface requirements across different operational platforms including the EMS, CIS, GIS and T&D modeling platforms, all were in agreement and supportive of efforts to develop CIM standards, forecasting resources and visualization tools for integrating variable renewables and distributed energy resources. Follow-ups are anticipated under the UBAT with a broader team of utilities and balancing authority advisors.

5.3. Industry Technical Outreach, Reporting and Recognition

UAT meetings brought utility stakeholders from California, Hawaii and Arizona along with EMS vendors, renewable forecasters, IT integrators and DG integration consultants together to understand issues and discuss collaborative solutions.

A number of outreach activities and opportunities were pursued during the project performance period. DREAMS activities were shared at a number of industry venues including the American Wind Power Association (AWEA), Solar Electric Power Association (SEPA), SEIA/SEPA PV America East, US DOE Sunshot Summit, Distributech, Asia Pacific Clean Energy Conference, Storage Week and SEPA USC.

Major project accomplishments include:

- Abstract submission and acceptance at 3 major renewable industry events including AWEA, SEPA and PV America East in 2014.
- Industry Venue Presentations
  - A. Brightbill, "Building Operational Confidence in Using Probabilistic Forecasts for Managing Variable Renewables," presented at AWEA WINDPOWER. Las Vegas, NV, 2014
  - D. Nakafuji, "The State of Solar Forecasting," presented at Solar Electric Power Association Utility Solar Conference (SEPA USC), Newport Beach, CA. 2014
  - D. Nakafuji, "Grid Integration Planning," presented at PV America, Boston, MA. 2014
  - D. Nakafuji and A. Brightbill, "Utility Operating Experience with Real-Time Solar Forecasting (SWIFT)," presented at PV America, Boston, MA. 2014
  - D. Nakafuji and L. Gouveia, "Distributed Resource Energy Analysis and Management System Developed for Real-time Grid Operations," presented at SunShot Grand Challenge Summit and Peer Review, Anaheim, CA. 2014
  - D. Nakafuji, A. Brightbill, "Perspectives on Learning to Operationalize Renewable Forecasts," Utility Variability Integration Group, Denver, CO, February 2015
  - D. Nakafuji, T. Sokugawa, "Seeing is Believing – Unmasking Load and Resource Variability," Utility Variability Integration Group, Denver, CO, February 2015
  - D. Nakafuji, L. Gouveia, "Integrating Renewables in Modernized Utility Operating Environments," Utility Variability Integration Group, Denver, CO, February 2015
  - D. Nakafuji, "Managing the Grid: Perspectives from Paradise," Utility Solar Conference SEPA, April 2015
  - D. Nakafuji, K. Geisler, G. Salah, T. Glauthier and A. Gonzaga, "The Grid of the Future: Lessons Learned to Address High Penetrations of DG," Asia Pacific Clean Energy Conference, Honolulu, HI, August 2015

  - D. Nakafuji, “Envisioning the Future Grid 3.0,” Distributech 2016 Conference, Orlando, FL, February 2016
  - D. Nakafuji, “Envisioning the Future Grid,” SEPA USC, Golden, CO, April 2016
- Received Best Technical Poster Award sponsored by SEPA and SEIA best poster award at PV America on efforts enabling DREAMS.
- Received Woman of the Year Award by Women of Wind Energy at the American Wind Energy Association meeting 2016, New Orleans, LA.
- UAT 1 DREAMS Kickoff, May 23, 2014, hosted by Southern California Edison, Westminster, CA
- UAT 2 DREAMS Project Update, February 17, 2015, hosted by WAPA EPTC, Golden, CO
- UAT 3 DREAMS Project Wrap-Up, April 11, 2016, hosted by WAPA EPTC, Golden, CO

6.0 SUMMARY AND ACCOMPLISHMENTS

Considerable insight was gained through the visualization and data integration process. Both EMS vendors, utilities and AWS have greater awareness of the importance of standard naming convention and how to manage older inconsistent databases. T-REX system as a common platform supported a number of the data cleanup and access to new forecasting data. Continuing efforts by the utilities in Hawaii build on prior lessons and work and will focus on developing the EMS logic to best utilize the forecasting data and update DG information as two new information streams for dispatch and reserve planning. Preliminary before and after enhancements testing within the Siemens' DMAS and Alstom's eterra demo environments showed the tools were able to capture the PV as a "virtual generator;" however, the connectivity to the EMS requires additional effort. Based on feedback from end users, a side by side experience will help testing efforts and build confidence in the new tools. In general, the project achieved the intended outcomes of integrating real-time renewable forecasts and DG resource information into EMS tools. Vendor partners continue to work closely with utilities to ensure that the development of new interface features and visualizations remain responsive to operational needs.

Results include:

- Use of one of the first operational distributed resource forecasting capabilities to create situational awareness and successful integration into two operational EMS.
- Recommended and applied CIM schema for forecasting data interface.
- Novel application of modeling simplification technique to account for aggregated distributed PV resources as "virtual generators" at distribution substations.
- Reduced computational overhead and orders of magnitude reduction in the number of distributed generators to track by using aggregated equivalence approach.
- Early utility engagement and solutions providers to jumpstart development of end use displays, alerts and content that integrate relevant DG and forecasting information.
- Development of a common, integrated decision analysis platform that included both real-time wind and solar forecasting information and timely distributed resource information based on customer location and real-time system data from utility SCADA.
- Unique utility originated visualizations tools (LVM, REWatch, REDatabase, EMS views) to support real-time operation and planning and customer engagement needs.
- Timely dissemination of project learnings through various industry sponsored workshops and conferences. Received award recognition on materials disseminated.
- Active Utility Advisory Team (UAT) engagement broadening the applicability of solutions and tools.
- Continuous workforce training and process enhancements through project information sessions, including support of Western Area Power Authority, Electric Power Training Center (WAPA's Electric Power Training Center).

6.1. Overcoming Challenges and Lessons Learned

This project was one of the first cross-disciplinary team efforts to tackle challenges ranging from renewable forecasting, big data analytics and database architecture, EMS integration and utility process change (Figure 6.1). Challenges emerged on all fronts. This section captures various issues and resolutions and workarounds implemented in order to capture distributed PV resource and substation forecast data within the EMS.

EMS limitation and challenges:

EMS required consistent and common SCADA-based telemetered data to integrate into the state simulation and load forecasting algorithms. EMS also lacked point-to-point controls to the tens of thousands of distributed PV systems. Discussions with EMS developers identified that it would be technically impractical to have point-to-point controls and economically not feasible to directly monitor these systems. The aggregated PV approach provided a way to systematically account for distributed impacts and reduce the number of point-to-point monitoring by several orders of magnitude.

Data analysis and content challenges:

DG resources lacked the consistency and common SCADA-based telemetry to backhaul data for control or analysis. The volume and customer-site access posed additional challenges. Following the methodology described in Section 2, distributed PV generators and forecasting data by distributed substations was made available. Cyber security concerns were also raised by ITS when automated access was needed to pull or push data across the various database platforms. The common REDatabase platform resolved a number of the data ownership and individual access requirements. While graphical displays are readily available, support staff knowledgeable about the data content, what is available, what the data means and how it is measured is needed. A dedicated group to identify data content, quality check and prep data ideally is required.

Renewable forecast challenges:

Accuracy of probabilistic renewable forecasts has always been an issue and source of debate amongst users. One-hundred percent accuracy was not possible, however creating a better awareness of hits and missed conditions will help build confidence in forecasts and guide practical application of when to rely more or less on a forecast due to uncertain weather conditions. This understanding in the use of the tools has helped system Operators at Hawaii Electric Light implement a dynamic dispatch informed by the latest SWIFT forecast (1-2 hours ahead). By tracking the 1-2 hour projected forecast for wind and distributed solar, HELCO operators have developed and will continue to gain practical experience and insight as to when to make decisions informed by the forecasts. HELCO System Operations currently use the SWIFT forecast to track and plan for the hour ahead operation and each shift prepares the dispatch for the next shift. In this way, operators are building an awareness and sensitivity to conditions that make the SWIFT tool useful. Recent engagements also indicate that 1-2 day and 7-day forecasts are also valuable to dispatch operators.

Utility legacy process challenges

To ensure success and minimize transformational risks, the DREAMS approach built on existing utility baseline environments and processes to grow existing workforce capabilities. However during the course of the project considerable new information was being incorporated into traditional tools and will require new work practices, methodologies and techniques such as forecasting and DG aggregation schemes typically used in modeling applications to be incorporated into real-time EMS environments. Consistency in equipment nomenclature may previously not have been an issue in the past, however as tools become more automated and use more non-SCADA datasets, quality checks and data content will need to be more systematic. Understanding legacy processes (why and how) and new requirements must be continuously reviewed to inform necessary process changes in a timely fashion. Interoperability and reliably relies on proper workforce training and procedures in place.

Feedback gathered with end-user operators gave the DREAMS team perspective on what parameters and conditions are important to capture. Learnings included:

- How best to display a lot of information without overwhelming the users;
- How much information is sufficient; and
- What user options should be retained to drill down on data.

Feedback also focused on developing the visualizations to be used by operators. While input varied, general consensus centered about the following:

- Use a geographic view of the region to help orient users;
- Use a simplified rendering of up to a 3 hour look ahead on main displays for ease of access;
- Enable user selectable views to further drill down into details on confidence levels, specific regions, substation and feeders;
- Automatically update forecasts without having to refresh screens;
- Stick with familiar color schemes to minimize confusion on alerts and alarms; and
- Keep displays clean and simple.

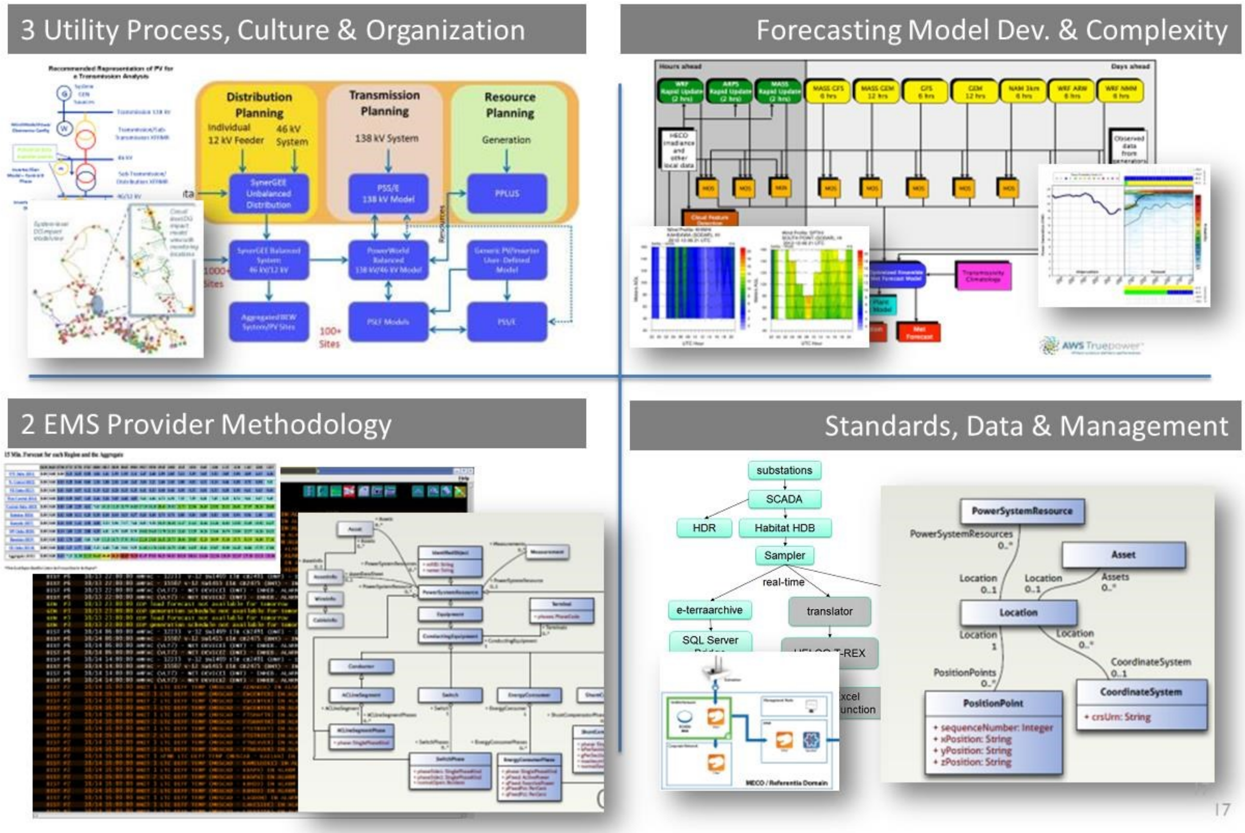


Figure 6.1. Challenging areas for development and deployment.

6.3. Benefits and Significance of Accomplishments

Significant contributions of DREAMS to advance grid integration capabilities included:

- Employing a modeling technique to roll-up and equivalence distributed PV resources and reduce computational overhead from thousands of new generation points to tens of generators.
- Developing one of the first CIM schema for use by renewable energy forecasters to interface into EMS environment.
- Enabling inclusion of updated DG resource information and real-time wind and solar resource forecasting information to increase operational awareness of DER/VER impacts.
- Developing tool enhancements and new capabilities and visualization screens with a host of utility partners and utility advisory team.
- Enabling novel dual vendor approach to see how different techniques are being used to address integration needs.

Accomplishments included:

- Formation of UAT and utility partners who helped provide review and input on the direction for DREAMS. The UAT interactions are beyond expectations and have provides additional incentive to continue collaborations. Issues addressed are not only useful for utilities but provide value added insight to user need that vendors can respond to.

- Successful development and demonstration of visual screens that capture the DG resources and forecasting data are major milestones under this project. Progress thus far indicate that despite differences in EMS platforms, consistent data content provided following standard schemas will enable more rapid adoption and compatibility across different database systems.
- Operator engagement and feedback have been invaluable. The interactive exchange through the prototype development stage resulted in a more refined demonstration display for the islands. The Task2 organization and aggregation techniques enabled consistency of forecasts with grid infrastructure and organized access to information for EMS displays.
- Initial curriculum and training material on renewable forecasting and field monitoring campaigns are being considered as part of WAPA’s core utility training curriculum. Working with utilities and AWS, information can be captured and disseminated to increase awareness and competency for new tools and resource needs.

While the accomplishments were worth nothing, there was an overall consensus that the work being done as part of this project was novel and necessary to inform and jumpstart future modernization of the electric grid and to reliably operate with renewable fleet of generator.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Efforts to date have provided hands-on, practical opportunities for utility staff and industry forecasters and EMS developers to engage and dialog on needs. By “kicking the tires” on forecasting tools, analytical tools and deploying field equipment, forecasters and utilities have shared understanding of the level of details and forecasting accuracies necessary to support real-time operations. Lessons learned through our partnerships resulted in more intuitive visualization tools, data sharing and EMS logic to help other utilities gain more sense integrating renewables. No one technology will be a “silver-bullet”, however, by seamlessly integrating more edge-of-grid devices and merging information into existing tools and familiar environments, such as the EMS, utilities can begin to build operational confidence and trust to proactively inform and cost-effectively manage impacts of variable renewables.

7.1. Next Step Priorities

DREAMS provided access to real-time wind and solar forecasting data and distributed PV resource information that previously was not available to system operators. As such, EMS logic enhancements (both software and hardware) had to be reviewed to accommodate the probabilistic nature of the variable renewable resource data and non-SCADA data streams. Both EMS environments required an interface to organize and help the EMS manage distributed information. Going forward, priorities are to continue working on improving the real-time interface needs and enhancing the logic on how best to determine controls for DG resources. Current “set point” operations are useful but further enhancements can be made to optimize the controllability to DG resources via aggregator technologies. Efforts will continue to exercise the control features via aggregators and capture response times, feedback of response and explore use of distribution level solar forecasts.

Following the 3rd UAT meeting, the SEAMS for SHINES project [9, 10] was kicked off and a new advisory team comprised of utilities contending with high penetration PV and balancing authorities who are managing the imbalance due to increasing penetrations of behind the meter resources. UAT members all agreed to continue on as part of the new Utility and Balancing Authority Advisory Team (UBAT) with new utilities and new balancing authority members also added.

Although SEAMS for SHINES project will be a standalone project from DREAMS, the project involves similar industry teams from DREAMS with addition of new smart inverter and storage technology providers of intelligent behind-the-meter solar and storage (SHINES) technologies. Objectives include sharing utility renewable resource forecasts to inform intelligent SHINES technology controls and developing and demonstrating aggregator grid responsive controls to support utility integration needs. Lessons learned from DREAMS is already helping to organize the EMS providers, forecasters, modeling and analysis teams to engage with SHINES technology providers.

7.2. Continuous Improvements

Fast paced change and emerging technologies with limited track records make documenting best practices a challenge. However as electric utilities, fundamental principles of keeping the lights on safely and reliably provide a solid foundation to continuously improve and transform the grid to a more modern, intelligent and trans-active grid. Based on the DREAMS effort, the collaborative working environment helped achieve several milestones in record time. By working to enhance familiar software and hardware environments, creating real-time visualization tools and engaging end users throughout the development and review process all helped to balance change, risks and user expectations.

Recommendations on areas of continuous improvement include:

- Standardization of modeling tools and nomenclature system for T&D infrastructure that can be replicated across different platforms including GIS mapping tools, customer information and tracking databases and modeling tools. As more automation emerges, following CIM-based data formats and establishing nomenclature system for hardware in the field will help ensure consistence and upkeep of automated processes.
- Establish version control protocol on distribution models, extractions and validation datasets. Simulation based tools require more information to accurately model distribution feeders and diverse control devices. Centralizing and automating extraction processes will help enforce maintainability of real-time tools and timely updates.
- Integrate field sensor resource monitoring program into active asset monitoring initiatives to maximize benefits to all customers.
- Implementation of field sensor tracking logs to ensure proper maintenance and upkeep including recalibration and replacement. Probability forecasts have inherent uncertainty due to natural resource variability and uncertainties. Minimizing instrumentation error and failure rates will improve accuracy and forecasting performance, especially at distribution scales.
- Conduct frequent listening sessions that involve cross-disciplinary teams of IT/OT, planning and operations personnel within and external to the utility to feature changing technologies and new capabilities.
- Continue formal and informal UAT type advisory teams when discussing new initiatives and leverage lessons learned from other controls-based industries like airlines, telecom and rail.
- Establish a workforce familiarization program to create awareness and showcase integration technologies and how they are developed and used to support cost-effective renewables and distributed energy resource integration and customer engagement priorities.

Faced with fast paced change on all fronts and unique operating challenges of an islanded systems that do not have the backup support of major interties to other states, Hawaiian utilities are strategically teaming with innovative industry partners via grants and pilots to bridge the knowledge gap. Efforts are underway to deploy new technologies and tools integrating real-time forecasting tools, advance decision-based analytics and visualization techniques to better "see and manage" high penetrations of distributed and weather dependent renewables. A number of initiatives are also jumpstarting demonstration of new distribution level solutions including grid responsive storage, distribution level controls and intelligent monitoring options for customers. With support from US DOE, Hawaii utilities and utility partners like SMUD are demonstrating how collaborative partnerships with industry can successfully build new practical solutions, inform proactive change and sustainably transform today's grids toward the next generation grid with cleaner and more cost-effective renewable generation portfolios while minimizing reliability risks.

8.0 REFERENCES

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9.0 APPENDICES

List of appendices to include

Appendix 9.1: Summary of Project Tasks
Appendix 9.2: Project Factsheet
Appendix 9.3: Field Device Enhancements and Sensor Specifications
Appendix 9.4: Detailed Reports List

Appendix 9.1: Summary of Project Tasks

Task 1: Project Management & Team Coordination

This task covered the administration and project/team coordination. Organization and project follows the SOPO and PMP. Efforts also included coordinating Utility Advisory Team (UAT) meetings and communication of UAT feedback. The team was organized as shown in Figure A9.1.1. Hawaiian Electric staff acted as primary project managers and leads.

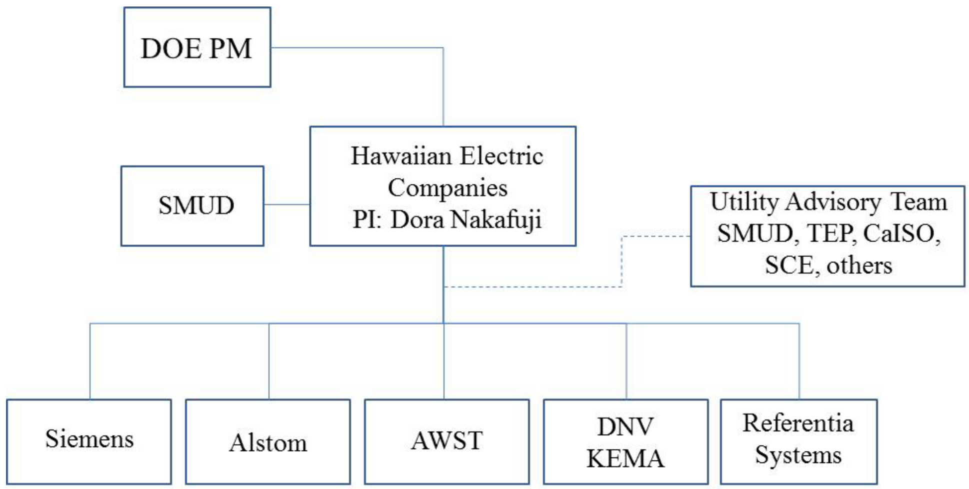


Figure A9.1.1. Project teams and organizational structure.

Task 2: User Engagement & Data Development

This task focused on identification of the data and integration needs to effectively support "seeing" and "managing" VER and DER. Data included information on traditional grid infrastructure, new resource information from renewable resource forecasts and listing of the distributed PV on the systems. Focus was on how to access (transfer), use and incorporate data not within SCADA (i.e. forecast data and distributed PV info) into the EMS.

Task 3: EMS Logic Enhancement

This task was focused on the unique, dual platform approach to integrate the new VER/DER information into the EMS. Siemens and Alstoms were leads in designing the visual interface as well as logic to integrate the new information into the existing state estimator and dispatch logic such as unit commitment and reserve calculations. Design of new screens and alerts to increase situational awareness involved utility operators and UAT providing active input and feedback.

Task 4: User Testing, Training & Pilot Implementation

This task directly addressed the side-by-side demonstration of the new integrated environments developed as part of Task 3. Implementation needs, ITS coordination, user support, training and post-deployment analysis were planned to compare pre-enhancement and post-enhancement capabilities. Due to EMS upgrade conflicts and timing constraints, an abridged testing was conducted with end users and Operations support in the stand-alone demo environments. Alstom and Siemens staff supported the demos via remote locations. At the time of this report, utility EMS systems were still undergoing final conversion evaluations and the decision was reached by utilities to leave enhancements in the mirrored environments and migrate tools to the latest version of the EMS platforms to be consistent for future testing and integration needs. This will support future integration efforts including SEAMS for SHINES.

Task 5: Industry Technical Outreach & Reporting

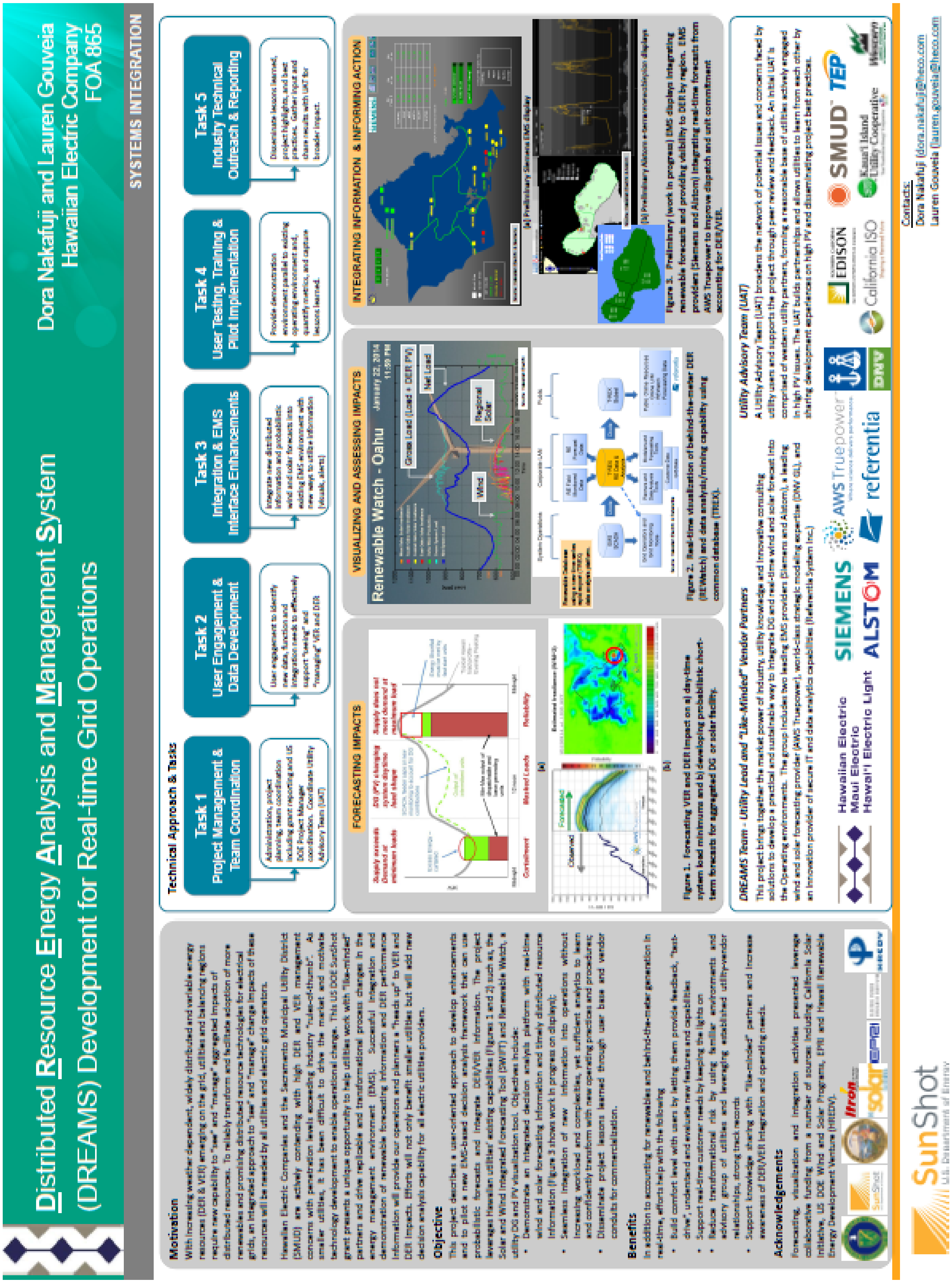
This task supported dissemination of lessons learned and best practices resulting from this project to broader stakeholders. Things that worked and did not work were documented and shared with the industry via workshop review venues and conferences. A number of abstracts were submitted, accepted and presented at industry conferences or user group workshops. Hawaiian Electric staff supported abstract submittal and development of presentation materials.

Task 6: Other - FOA Administration

Other FOA administration tasks include:

- Go/No Go Decision Point at end of the first Budget Period (BP1).
- Scheduling and attendance at required review meetings (Summit and DC).
- Tracking of technical milestones.
- Managing operational risks.

Appendix 9.2: Project Fact Sheet



Appendix 9.3: Field Device Enhancements and Sensor Specifications

Enhancements to Field Operations Related to SWIFT Forecasting for DREAMS
Atmospheric Research & Technology, LLC, Barry Neal

In support of the wind forecasting efforts for DREAMS, Hawaiian Electric procured eight Model VT-1 sonic detecting and ranging (sodar) systems manufactured by Atmospheric Research & Technology, LLC. The Model VT-1 sodar is a remote sensing device that provides wind profile data from a height of 30 m up to 200 m (see Table 1 for Model VT-1 specifications). These systems were installed at locations on Oahu, Maui and Hawaii Island and were operated continuously for the duration of the DREAMS project spanning over 3 years. The systems were all equipped with cellular modems and programmed to send out data every 10 minutes to the wind forecast center in New York. Many of the eight systems deployed were located at relatively remote locations and were provided with solar power systems due to the lack of commercial power (Figure A9.3.1 and Figure A9.3.2).

In an effort to keep the sodar systems operating optimally, a Hawaiian Electric contractor visited and serviced the units approximately every four months. Due to the remote nature of several of the sites, each visit for routine maintenance required an effort of about one man-day. Routine servicing involved testing each of the 48 speakers in the sodar speaker array, measuring transmit voltage levels with a handheld oscilloscope and checking frequency response with a tone generator. At the time of installation, all of the sodar systems were either new or newly refurbished, but because the systems were operated continuously over a period of several years, major maintenance was performed on about a three-year schedule. This was done to keep the systems operating at a high level of performance and to reduce the need to make unscheduled visits for repair. During the course of the project, the sodar systems were also upgraded with self-test options for remote health detection. This automatically tests the system performance once each week, and if a problem is found, the system emails an alert message. This also reduced the need for non-scheduled site visits and increased confidence in system performance and data validity.

In addition to the eight sodar systems, the field work for DREAMS included the procurement, installation and operation of a Radiometrics Model MP-3000A microwave radiometer (Table 2 for Model MP-3000A specifications). The Model MP-3000A radiometer was initially installed at a site on Hawaii Island where it was operated for a period of about one year before it was relocated to a site on Maui (Figure A9.3.3). The Model MP-3000A radiometer is a remote sensing system that provides profile data for temperature and humidity from the surface up to as high as 10 km. Similar to the sodar systems, the MP-3000A was equipped with a cellular modem and data was sent to the New York forecast center every 10 minutes. Routine servicing of the MP-3000A was done on a six-month schedule, and calibration of the system was performed annually using liquid nitrogen.

In general, a high level of data recovery was achieved over the course of the project. No major failures or property losses due to vandalism or theft occurred.

Figure A9.3.1a: Solar powered, battery back-up HRD Sodar on Big Island providing data for both HRD wind facility and Auwahi wind facility on Maui.

Figure A9.3.1b: Local powered, battery back-up Turtle Bay Sodar on Oahu providing data for Kahuku Wind Farm and SWIFT forecasting.

Figure A9.3.2: Self-powered, mobile Kaheawa Sodar on Maui.

Figure A9.3.3: Waena Sodar and Radiometer on Maui.

Table 1: Model VT-1 Specifications

Parameter	Specification
Maximum altitude	300 m (1000 ft)
Minimum altitude	15 m (50 ft)
Effective sampling depth	10 to 40 m (30 to 130 ft)
Transmit frequency	4504 Hz (adjustable)
Pulse duration	10 to 200 milliseconds (adjustable)
Averaging interval	1 to 60 minutes (adjustable)
Horizontal wind speed range	0 to 25 m/s (0 to 55 mph)
Horizontal wind speed accuracy	±0.25 m/s (±0.55 mph)
Horizontal wind direction accuracy	±2 degrees
Vertical wind speed range	±7 m/s (±15 mph)
Vertical wind speed accuracy	±0.04 m/s (±0.09 mph)
Power draw (electrical)	40 to 50 watts (basic unit without options)
Voltage input (nominal)	12 VDC
System weight (without batteries)	135 kg (300 lbs.)
System width	1.5 m (5 ft)
System length	1.8 m (6 ft)
System height	1.5 m (5 ft)

Table 2: Model MP-3000A

Parameter	Specification
Calibrated brightness temperature accuracy	0.2 + 0.0002 * (Temp black body – Temp sky)
Long-term stability	<1.0 K / year typical
Resolution	0.1 to 1 K
Brightness temperature range	0 to 400 K
Antenna system optical resolution and side lobes: 22-30 GHz 51-59 GHz 170-184 GHz	 4.9 – 6.3 deg, -24 dB 2.4 – 2.5 deg, -27 dB 1.0 – 1.1 deg, -40 dB
Frequency agile tuning range: Low water vapor band Oxygen band High water vapor band Minimum frequency step size (K, V and 183)	 22.0 – 30.0 GHz (K band) 51.0 – 59.0 GHz (V band) 170.0 – 183.6 GHz 2.0, 4.0 or 12 MHz
Standard calibrated channels	35
Pre-detection channel bandwidth	300 MHz
Surface sensor accuracy: Temperature (-50 to +50 C) Relative humidity (0 to 100%) Barometric pressure (800 to 1060 mb) Infrared temperature (delta T = ambient – cloud)	 0.5 C @ 25 C 2% 0.3 mb 0.5 + 0.007 * delta T, C
Brightness temperature algorithm	4-point nonlinear model
Retrieval algorithms	Neural networks
Environmental operating range: Temperature Relative humidity Altitude Wind (operational / survival)	 -40 to 35 C 0 to 100% -300 to 3000 m 30 m/s / 60 m/s
Physical properties: Size (H x W x L) Weight	 50 x 28 x 76 cm 27 kg
Power requirement	200 watts typical / 200 watts max
Data interface: Primary computer port Auxiliary port Standard cable length	 RS422 RS422 30 m

Appendix 9.4. Detailed Reports

Appendix 9.4.1. AWS Truepower Detailed Report

Appendix 9.4.2 Referentia Detailed Report