Hawaiian Electric Company

Hawaii Utility Integration Initiatives to Enable Wind (Wind HUI)

Final Technical Report DOE/EE0001379-1

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Finally, the work presented represent culminating efforts of a number of key personnel from across the Hawaiian Electric Companies (HECO/MECO/HELCO) who are endeavoring to make the system more reliable and cost-effective for our customers. Special thanks are extended to 1) our corporate executive sponsors: Mr. Robert Alm, Mr. Jay Ignacio, Mr. Edward Reinhardt (retired), Ms. Lynne Unemori, Ms. Sharon Suzuki and Mr. Colton Ching; 2) utility engineering, planning and operations staff: Mr. Hal Kamigaki, Mr. Chris Reynolds, Mr. Thomas Aukai, Ms. Laura Rogers, Mr. Robert Kaneshiro and especially Ms. Lisa Dangelmaier; and 3) to all the utility technicians and field staff supporting this effort. Without their dedication and ingenuity, these pioneering efforts would not have been successful.

Disclaimer

Any findings, opinions and conclusions or recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of the U.S. Department of Energy.

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Executive Summary

To advance the state and nation toward clean energy, Hawaii is pursuing an aggressive Renewable Portfolio Standard (RPS), 40% renewable generation and 30% energy efficiency and transportation initiatives by 2030. Additionally, with support from federal, state and industry leadership, the Hawaii Clean Energy Initiative (HCEI) is focused on reducing Hawaii's carbon footprint and global warming impacts. To keep pace with the policy momentum and changing industry technologies, the Hawaiian Electric Companies are proactively pursuing a number of potential system upgrade initiatives to better manage variable resources like wind, solar and demand-side and distributed generation alternatives (i.e. DSM, DG). As variable technologies will continue to play a significant role in powering the future grid, practical strategies for utility integration are needed. Hawaiian utilities are already contending with some of the highest penetrations of renewables in the nation in both large-scale and distributed technologies. With island grids supporting a diverse renewable generation portfolio at penetration levels surpassing 40%, the Hawaiian utilities' experiences can offer unique perspective on practical integration strategies.

Efforts pursued in this industry and federal collaborative project tackled challenging issues facing the electric power industry around the world. Based on interactions with a number of western utilities and building on decades of national and international renewable integration experiences, three priority initiatives were targeted by Hawaiian utilities to accelerate integration and management of variable renewables for the islands. The three initiatives included:

1) Initiative 1: Enabling reliable, real-time wind forecasting for operations by improving short-term wind forecasting and ramp event modeling capabilities with local site, field monitoring;
2) Initiative 2: Improving operator's situational awareness to variable resources via real-time grid condition monitoring using PMU devices and enhanced grid analysis tools; and
3) Initiative 3: Identifying grid automation and smart technology architecture retrofit/improvement opportunities following a systematic review approach, inclusive of increasing renewables and variable distributed generation.

Each of the initiative was conducted in partnership with industry technology and equipment providers to facilitate utility deployment experiences inform decision making, assess supporting infrastructure cost considerations, showcase state of the technology, address integration hurdles with viable workarounds.

For each initiative, a multi-phased approach was followed that included 1) investigative planning and review of existing state-of-the-art, 2) hands on deployment experiences and 3) process implementation considerations. Each phase of the approach allowed for mid-course corrections, process review and change to any equipment/devices to be used by the utilities.   To help the island grids transform legacy infrastructure, the Wind HUI provided more systematic approaches and exposure with vendor/manufacturers, hand-on review and experience with the equipment not only from the initial planning stages but through to deployment and assessment of field performance of some of the new, remote sensing and high-resolution grid monitoring technologies. HELCO became one of the first utilities in the nation to install and operate a high resolution (WindNet) network of remote sensing devices such as radiometers and SODARs to enable a short-term ramp event forecasting capability. This utility-industry and federal government partnership produced new information on wind energy forecasting including new data additions to the NOAA MADIS database; addressed remote sensing technology performance and O&M (operations and maintenance) challenges; assessed legacy equipment compatibility issues and technology solutions; evaluated cyber-security concerns; and engaged in community outreach opportunities that will help guide Hawaii and the nation toward more reliable adoption of clean energy resources.

Results from these efforts are helping to inform Hawaiian utilities continue to
- Transform infrastructure,
- Incorporate renewable considerations and priorities into new processes/procedures, and
- Demonstrate the technical effectiveness and feasibility of new technologies to shape our pathways forward.

Lessons learned and experience captured as part of this effort will hopefully provide practical guidance for others embarking on major legacy infrastructure transformations and renewable integration projects.

1.0 Introduction

Hawaiian Electric Companies (Company) which include Hawaiian Electric (HECO) on the island of Oahu, Hawaii Electric Light Company (HELCO) on the Big Island of Hawaii and Maui Electric Company (MECO) on the islands of Maui, Molokai and Lanai, provide electric power services for 95% of the state's 1.2 million residences on the respective islands. Since King Kalakaua served as first lit the streets of Honolulu in 1888, electric services and infrastructure have served as one of the major foundations for innovation, economic growth and modernization for Hawaii. The Hawaiian Electric Companies' mission is to provide secure, clean energy for Hawaii, and as such, our infrastructure must continuously evolve to meet the needs of our changing environment and customer needs.

Collectively, Hawaiian utilities are currently contending with some of the highest penetrations of renewables in the nation. With limited load, islanded grids, and abundant wind and solar resources on our grids, our utilities are routinely challenged with high renewable penetration levels (in excess of 20%) and increasing variability management issues. For example, renewable generation accounts for nearly 40% average generation on the Big Island of Hawaii, on HELCO's system. The generation portfolio on the Big Island includes wind, solar (PV and CSP), geothermal, biomass and run of river hydro resources. Though each island is unique (i.e. in resources, load and operations) common utility challenges include:

- Inability to plan or forecast wind and solar resource production in the operational and planning time frames, for purposes of real-time dispatch and system reliability;
- Tracking, trending and monitoring of system conditions for the purpose of identifying and establishing responsive and economically efficient protocols for managing high penetrations of variable generation from wind and other variable resources;
- Legacy infrastructure require new safeguards with "Smarter Grid" enhancements to confidently incorporate new and secure Smart Grid strategies, to enable management of intermittent resources (i.e. wind, solar and variable distributed generation) and to improve dispatcher visibility of system conditions during faults/events.

With funding from the ARRA, the Hawaii Utility Integration Initiatives to Enable Wind (Wind H.U.I.) kicked off in November of 2009. Three priority initiatives identified to address the common utility challenges listed above include

- Developing ramp event forecasting capabilities to provide "heads-up" for utility operators to manage intra-hour variability,

- Increasing operator situational awareness of grid conditions through use of advance grid monitoring devices and

- Identifying emergent technologies and critical pathways toward building the future grid.
- Identifying necessary system retrofits to keep up with technology changes and maintain system reliability

To remain proactive, we are prudently investigating new energy management technologies and pursuing practical and cost effective solutions to keep pace with policy, technology and providing customer options while managing costs and reliability. Though focused on efforts for Hawaiian Electric Companies, the results and lessons learned apply to utilities nationally and internationally. The goal of these initiatives is to align resources today to ensure adequate planning for future electrical infrastructure and to maintain resource flexibility for transforming toward a sustainable and reliable future grid.

2.0 Background

With support from federal stimulus efforts [1], three priority initiatives were identified and pursued as part of the Hawaii Utility Integration Initiatives to Enable Wind (Wind HUI).

2.1 Hawaii Energy Landscape

Advancing the state and nation toward clean energy, Hawaii is pursuing an aggressive Renewable Portfolio Standard (RPS) targeting 70% renewable energy generation by 2030. As the State of Hawaii's RPS addresses both electricity generation (40%) and transportation (30%) and energy efficiency sector improvements toward adoption of green technologies, it uniquely promotes a sustainable, island-focused approach for tackling the state's energy needs. Though Hawaii is blessed with a diversity of indigenous, renewable generation resources that are being harnessed for electric power generation including wind, solar, geothermal, biomass, biofuels, hydro-electric and waste-to-energy, nearly 90% of Hawaii's energy (Figure 2.1) is still reliant on fossil-based fuels.

Statistics tracked by the State's Department of Business and Economic Development and Transportation (DBEDT) [2], show that approximately 30% of the fossil-based energy is attributed to electricity generation and nearly 60% goes to meet transportation, including marine, air and ground vehicles (**Figure 2.2**).

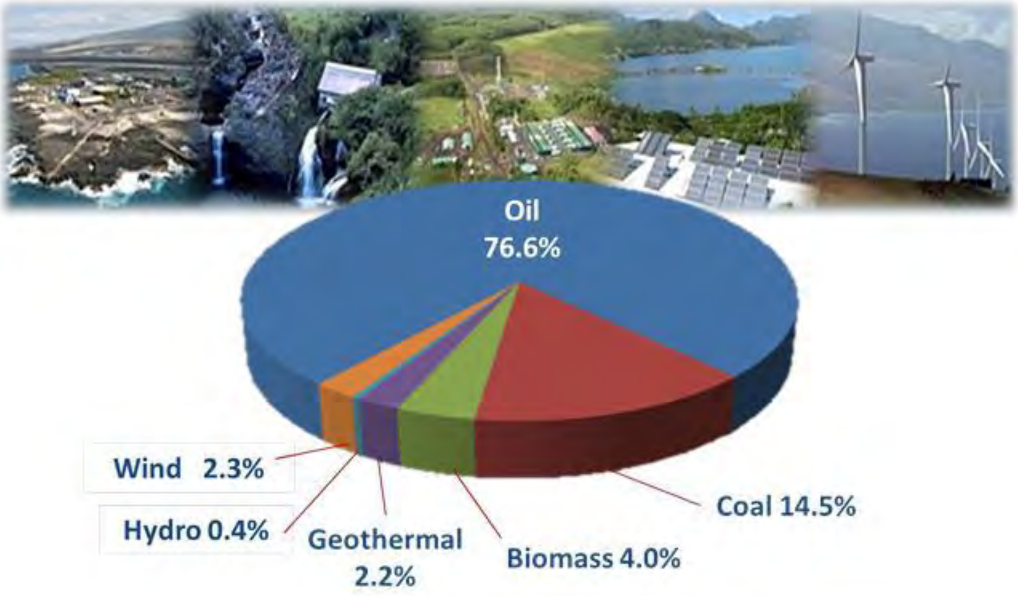


Figure 2.1 Hawaii energy resources (HECO 2007)

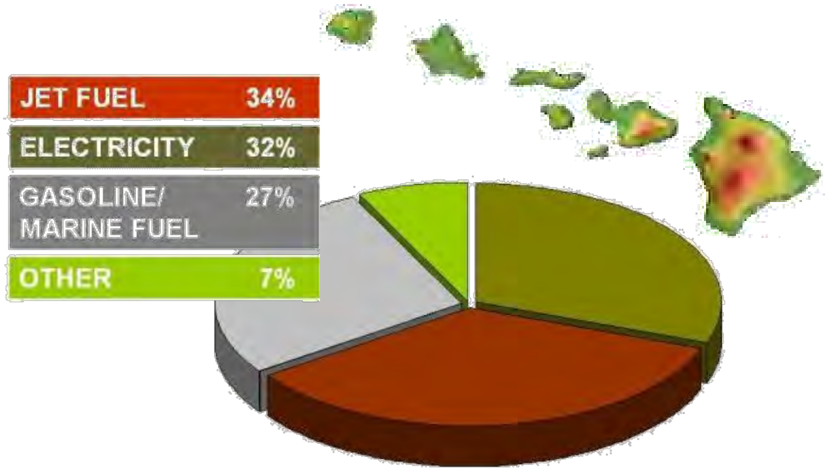


Figure 2.2 Hawaii energy use. (Source: DBEDT 2008)

As such, Hawaii citizens are highly susceptible to global oil price fluctuations. Figure **2.3** captures the fuel price volatility in Hawaii compared to the national average during the summer of 2008 when the price per barrel of oil skyrocketed above $140/barrel, reportedly from a weak US dollar and Middle East tensions [3]. Reducing the dependency on fossil-based fuels, fostering Hawaii's indigenous energy industries and job market, developing more energy efficient and energy conscious communities and reliably transforming legacy infrastructure to more advance technologies remain strong motivators for Hawaii to "go green". However, this drive to "go green" must be supported by knowledgeable workforce with experience and advance tools to manage the emergent resources.

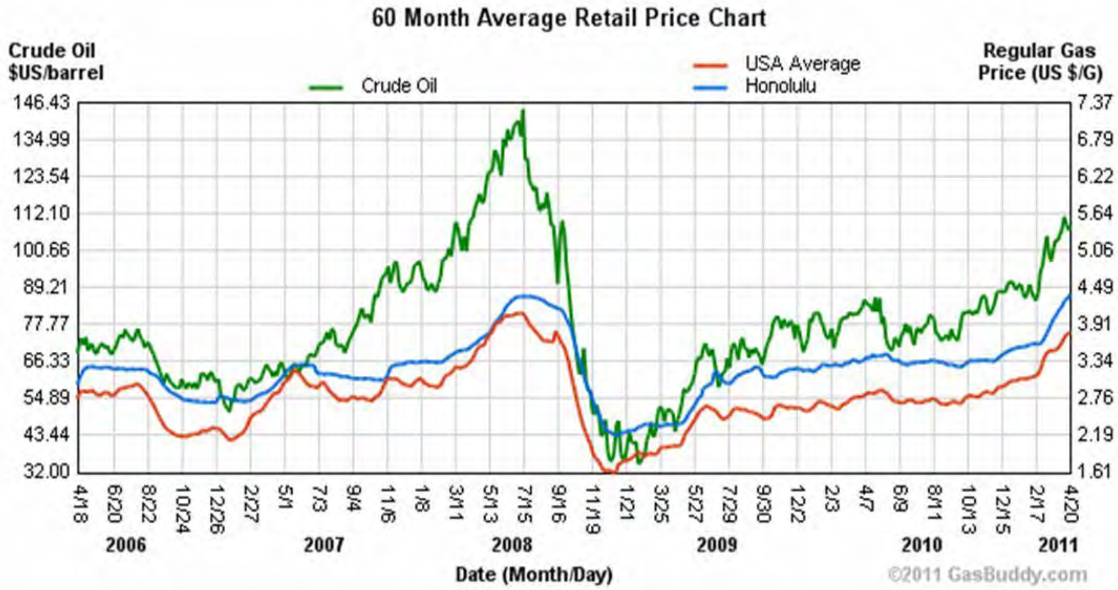


Figure 2.3 Comparison of fuel price volatility on Hawaii and average U.S. Mainland when crude oil soared over $144 per barrel in the summer of 2008. (Source: UHERO)

Unlike mainland states, Hawaii has additional challenges of being an islanded state with no electrical interconnections to other states for backup power. While Hawaii's islanded systems offer ideal testing and demonstration platforms for new renewable strategies, for the people who live on the islands of Hawaii, it is imperative that the integrity and reliability of the electrical system be preserved and economically improved whilst incorporating the benefits of advance, renewable technologies.

2.2 Project Initiatives: Goals & Benefits

The Hawaii system has been described as an ideal "living laboratory" to test and conduct experiments on new energy technologies and control algorithms on an isolated grid. Recently, the number of pilot study and technology prototyping efforts has ballooned across the islands using new technologies with limited track records or uncertain economics. Many of these experiments focus on studying economics of new technology, controls and functional development of emerging technologies; however a number of critical questions remain to be addressed including

- What are the repercussions/risks to the state and residences if these new technologies and experiments fail?
- Are the technologies economically sustainable?
- Are there sufficient safeguards, processes and local resources to reliably maintain and operate?
- What's the long-term plan?

Through reviews and discussions with external utility staff and internal staff on current state-of-the-art and technology shortcomings [4b, 15], common themes and ideas to help better manage diverse variable resources emerged. Ability to "see" and get a "heads-up" on grid issues, get hands-on experience with new technology and establish confidence on the selection and use new capabilities were identified as priorities. For the Wind HUI project, three priority focus initiatives to enable more variable resources such as wind resulted from the reviews and discussions and were proposed as part of the response to the DOE Wind FOA [1]. The initiatives are listed in Table 2.1.

Table 2.1 Wind HUI priority initiatives.

	Description
Initiative 1	Investigating logistics of deployment of a WindNET, an advance wind sensor network (i.e. towers, remote sensors – Doppler, LIDAR, SODAR) to capture prevailing wind information (on-shore or off-shore locations) necessary for real-time system dispatch and to enhance utility

	responsive wind forecasting capability for dispatch and operations
Initiative 2	Conducting “Smart-Grid Prep” enhancements pilots to improve operations of the legacy infrastructure and demonstrate new data visibility of system conditions and management of intermittent resources (i.e. wind, solar and distributed generation)
Initiative 3	Assessing current infrastructure needs and develop a Reliable Adoption Framework for Enabling the Future Green Smart Grid (GSG)

A holistic approach leveraging diverse resources, building expertise through partnerships will maximize our ability to achieve clean energy targets and also support ongoing national and international efforts. The proposed initiatives also layout a proactive technical planning, coordination and communication plan to share results and lessons that are of critical importance for many utilities on the mainland challenged with managing and harnessing significant levels of intermittent resources like wind and solar. As such, Wind HUI efforts in Hawaii continue to involve our western utility collaborators through progress reviews and technical outreach venues (i.e. conferences, industry meetings, technical papers) Successful implementation of these strategies is essential for considering and deploying viable clean energy options for Hawaii and directly contributing to the Department of Energy’s mission of diversifying our national energy resources, developing an energy “saavy” workforce and improving economic security.

2.3 Project Objectives & Approach

For Hawaii’s residences, electricity is a basic necessity. The integrity and reliability of the electrical system must be preserved and economically improved whilst capturing any “green” benefits of new advance technologies. Thus, our approach for the Wind HUI Initiatives involves a multi-phased *Planning-to-Pilot-to-Implementation* strategic approach to learn and inform future transformative direction that maximizes the learning experiences and helps minimize risks. In general, the approach follows three phases:

> Phase 1 Planning - focuses on assessment of the state-of-the-art (via literature review, surveys, interviews) of advance technologies applicable to our system and what factors they introduce (benefits, complexities, impacts, costs) to the existing environment. Staff relationships have been established with other utilities and vendors working on these initiatives and they provide a support network for Hawaii efforts.
>
> Phase 2 Deployment - focuses on building hands on experience and understanding of value in use of new technology/capability through deployment, handling logistics

and "trial" operations. Experiences will hopefully capture real-world issues encountered that add to the knowledgebase.

Phase 3 Implementation - initiates the process of migrating from "trial" use to something more established. Deployments can still be at a scaled level or limited deployment to continue gathering operational history and experience but steps to enable change in existing processes/procedures and integration of new capabilities has begun.

Our phased approach and lessons learned provide prudent pathways to address national priorities that

- Facilitate wind energy integration activities including modeling, analysis and integration
- Validate advance technologies and algorithms via pilots and tests
- Develop strategies and logistics/procedures to enable larger penetration of variable resources,
- Transfer "successes" and enable implementation and adoption of new practices/procedures.

The objectives of the collective Wind HUI efforts include:

- Initiate three specific utility-focused initiatives for increasing wind penetration and mitigate operational impacts of existing wind penetration,
- Lead, scoping and promoting efforts that maximize benefits to all the islands and enhance communication by leveraging resources and lessons learned (achieving economics of scale, standardization where economically prudent, leveraging expertise and experience)
- Coordinate the research, analysis with demonstration pilots that will provide initial operational insight and confidence to enable successful system implementation by utilities
- Continue to facilitate stakeholder involvement and feedback to other synergistic but broader industry integration efforts
- Preserve and economically improve system operational integrity and reliability with a diverse energy resource mix

The remainder of this report is organized to as follows: Section 3.0 provides detail descriptions for each of the initiatives including approach, equipment and guiding hypothesis. Sections 4.0 to 6.0 lay out technical tasks associated with each of the utility identified priority initiatives. Section 4.0 summarizes the experiences and results of the WindNET Initiative. Section 5.0 covers Initiative 2 and PMU deployment activities to date.

Section 6.0 summaries the work on reviewing HECO/MECO/HELCO GSG readiness and consultant recommendations. Section 7.0 covers recommendations and efforts jumpstarted as a result of this project. Section 8.0 highlights the conclusions and experiences gained. Section 9.0 provides a listing of references and Section 10.0 is a listing of presentations made at conferences, review meetings and consultant reports related to the project.

3.0 Initiatives Descriptions

The Wind HUI targets three priority *initiatives* aimed at informing transformative efforts that enable wind and other variable resources to be reliably integrated onto Hawaii grids. With high penetration of renewables (both large-scale and distributed generation) in excess of 20% penetration, Hawaii utility experiences can provide lessons learned for utilities across the nation. Additionally, the HECO/HELCO/MECO systems provide implementation opportunities to showcase potential technology implementation strategies and practical solutions to control and manage high penetration levels of variable and distributed generation presently not seen elsewhere except on the Hawaii systems.

3.1 Initiative 1: WindNET Model Enhancements & Field Campaign

Many of the mainland wind forecasting efforts were interested in investigating the concept of using wind sensor networks (WindNET) comprised of meteorological towers and state-of-the-art remote monitoring devices (e.g. SODAR, LIDAR, doppler) that can be strategically placed in their service territory and near current and/or proposed wind projects sites. The information provided from these monitoring locations could provide predictive indicators for improving forecasts for near-term wind power changes and ramp events (hour ahead and sub-hourly periods) and developing responsive strategies for managing real-time wind-related system events (i.e. ramps) worldwide. This intra-hour and near “real-time” need is currently not being met by presently available forecasting services and required additional model enhancements with real-time monitored data.

The purpose of Initiative 1 is to investigate how in-field measurements can improve the accuracy of state-of-the-art wind forecasts and provide an early warning (15 to 30min) heads up on significant ramp conditions that affect operations of the grid. The assumption is that using advance sensor networks to capture prevailing winds and vertical profiles, the forecasting models as well as utility responsive capabilities can be improved for real-time dispatch needs.

For Wind HUI efforts, Hawaiian Electric Companies partnered with AWS TruePower (AWST), a leading U.S.-wind energy forecasting provider based out of Albany, New York, to conduct the WindNET model research and forecasting pilot campaign. Atmospheric Research and Technology (ART), a Hawaii-based company, provided sensor expertise and field support.

Objectives of Initiative 1 focused on

- Improving accuracy of numerical forecasting models,
- Deploying advance remote monitoring devices (SODARs, radiometer) to address in-the-field logistics of operating, tuning, integrating,
- Informing maintenance and operation logistics of a more permanent wind monitoring network or WindNET
- Creating alert-based visual displays for real-time operations

- Support utilities to operationalize wind forecasting capability by 2014

Initiative 1 leveraged nearly a decade of related research conducted by the western utilities to improve and implement wind forecasts [4, 5]. Considerable national, international, state and industry resources have been devoted to develop, use and improve wind forecasting capability (e.g. California Energy Commission/EPRI/AWS Truewind Wind Forecasting Research and Development [6, 7], Alberta Wind Forecasting Comparative Studies [8], BPA/CaISO International Wind Forecasting Techniques & Methodologies Workshop [9]). Though day-ahead (24-48hr forecasts) and hour ahead (3-6hr) forecasts have been in use for quite some time to inform utilities and control areas dispatch resources (Figure 3.1).

According to the AESO website, Figure 3.1 represents,

> "The aggregate wind power forecast uses near real-time meteorological data at wind power sites to indicate the amount of wind power that will be available to the Alberta grid in the near-term. The report displays data on a twelve hour ahead basis in hourly intervals and is updated every 10 minutes. It is based on current installed wind capacity from wind power assets listed on the AESO's current supply and demand page."

Hawaii utilities (HELCO/HECO/MECO) have found that these existing commercial wind forecasting products do not provide the "resolution" to address the short-term "heads-up" operations/dispatch needs (i.e. 0-30 min, intra-hour) for utilities operating with very little reserve resources/margins.

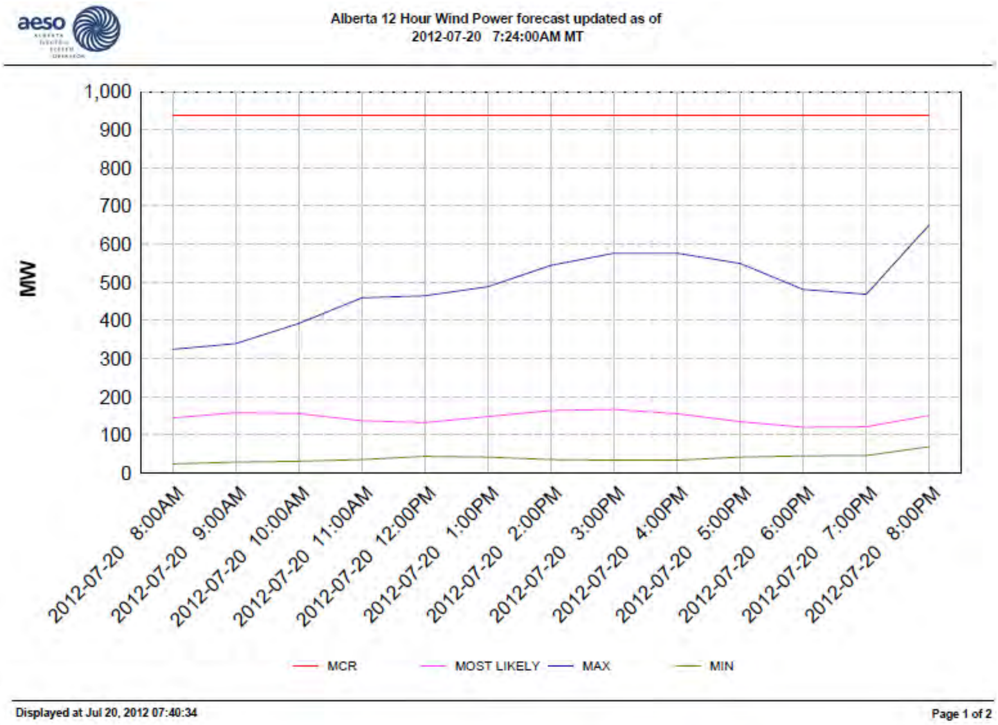


Figure 3.1 Example of current short-term wind forecasting information used by the Alberta Electric System Operator (AESO).

Recent events and industry experience in California, Texas, New York [10], Alberta and the Pacific Northwest - all regions with increasing wind penetration, are driving the industry to further improve the accuracy, timeliness of predictive models and visibility to real-time resource availability. Based on operator interviews, forecasts need to correlate wind-driven events to system conditions and better integrate forecast information into real-time operations, intra-hour market re-dispatch and balancing needs [11, 12, 13].

For Hawaii utilities, wind forecasting efforts are relatively new and as with any field deployment campaign, uncertainties and questions abounded. The phased approach described in Section 2.0 was applied so the modeling enhancements preceded the field monitoring and validation. Modeling results guided the field campaigns and the results were reviewed with utility support team from HECO/MECO/HELCO. By involving the utility support team in reviews, all contributing departments from operations, substation, engineering and planning that supported the deployment efforts, were able to see the value of their efforts and make suggestions for improvements toward utility implementation.

Table 3.1 summarizes the phased approach followed for Initiative 1, objectives and desired outcomes compared to actual accomplishments made at each phase.

The WindNET project leveraged results from previous US DOE WINDSENSE research supported by both Lawrence Livermore National Laboratory (LLNL) [14, 15] and the National Renewable Energy Laboratory (NREL). Research conducted provided the application and validation of industry Observational Targeting techniques [16, 17, 18] that helps to 1) identify what key parameters to measure as indicators for winds at a site and 2) identify strategic locations to place remote monitoring sensors. Combining both an objective numerical ensemble sensitivity analysis (ESA) and subjective diagnostic analysis of observed local site ramp events, Observational Targeting guidance was provided on what variables to measure and at what location to deploy sensors in Hawaii to get the most improvement in forecast performance for targeted wind sites.

Successful testing of these methods would significantly reduce costs and uncertainties for utilities when deploying remote sensors in support of forecasting capabilities, especially in larger, complex terrain territories. With initial guidance based on modeling results, the number of sensors, sites to assess and parameters to monitor can be predetermined and factored into costs for operationalizing forecasting capabilities. Without such guidance, a lot of time and money can be spent using a trial-and-error placement approach that is currently done today.

Table 3.1 Initiative 1 development approach.

Initiative 1		%Accomplished
Phase I **Planning**	**Continue forecasting model improvement and characterization of performance statistics/metrics development** a. Examine actual events and link atmospheric conditions with grid condition b. Characterize trends (tradewinds vs Kona winds) c. Identify of sensitivities/dependencies & prime ramp event indicators/conditions d. Determine strategic monitoring locations to enhance models (Observational Targeting assessment)	**100%**
Phase II **Deployment**	**Field validation and reliable measurement data** a. Deploy remote sensing equipment to gather local site data (ground to 1km) b. Monitor prevailing conditions near wind site to provide 30 min “heads-up” for operators c. Improve horizontal and vertical resolution of measured data d. Provide operators a “sense” of awareness of how local variability and weather conditions affect the grid e. Conduct technology transfer activities to inform industry on progress to date	**100%**
Phase III **Implementation**	**Facilitate control room integration and utilization** a. Provide alert-based, rapid heads-up on changing conditions b. Display information that improve understanding of conditions and establish operator confidence c. Simplify forecasting information; present action-oriented info d. Develop measures for tracking forecast performance (“hits”, “misses”) and capture what works e. Define and finalize data transfer plan with ITS, Operations and forecasting service f. Provide forecasts in real-time to operations and planning needs	**75%**

Observational Targeting analysis was completed for the Big Island of Hawaii for both the existing Tawhiri Wind Facility on the South Shore and HRD facility on the northern tip of the island and for the island of Maui for the Kaheawa Wind Facility area. Figure 3.2 shows all the WindNET candidate deployment locations from the Observational Targeting on the Big Island. Figure 3.3 shows the sites for WindNET candidate sites on Maui. Due to budgetary and time constraints, the field monitoring campaign efforts were limited only to the Big Island as part of the Wind HUI efforts.

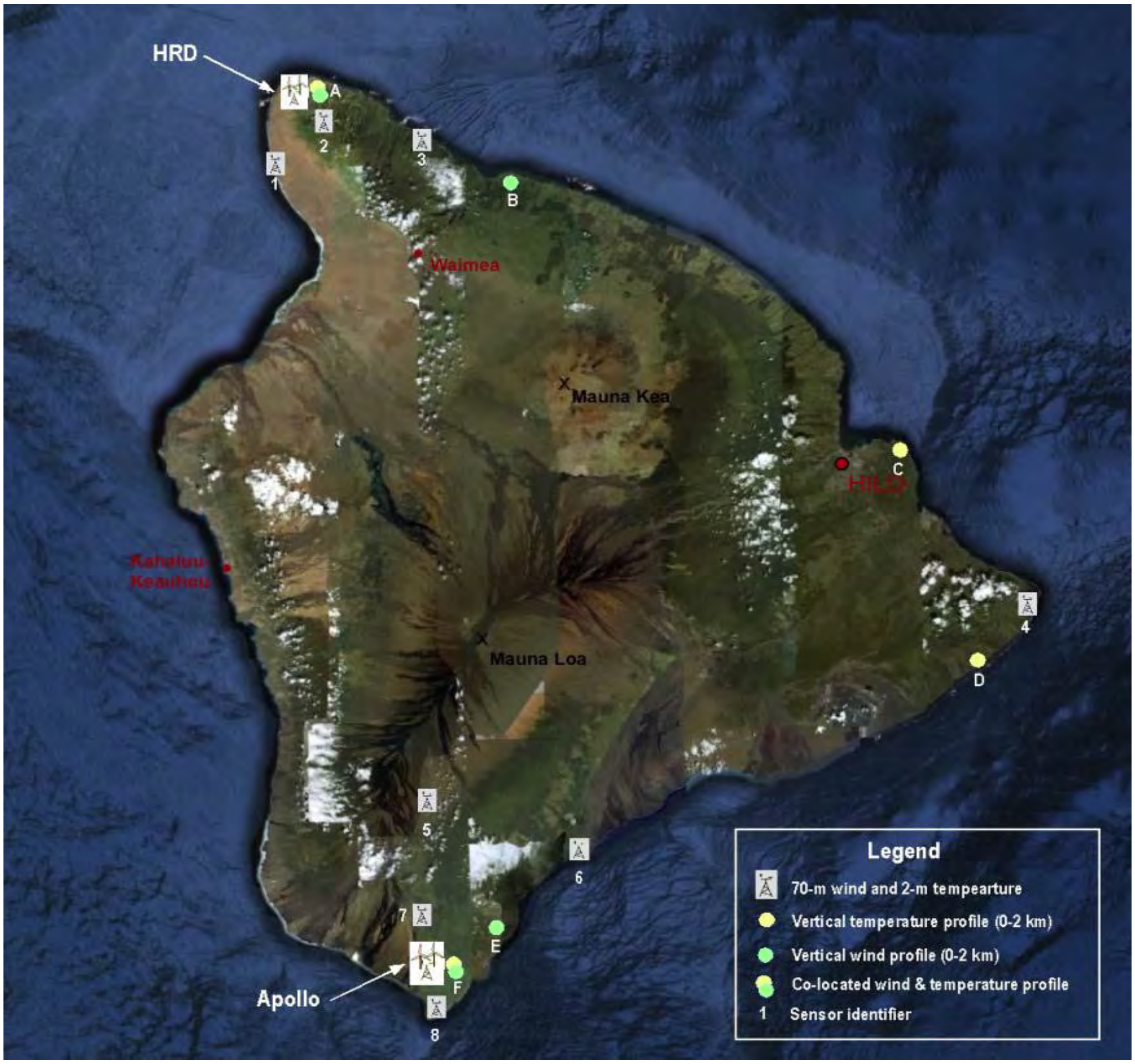


Figure 3.2 Observational Targeting analysis candidate locations and measurement parameters for the Big Island of Hawaii.

Figure 3.3 Observational Targeting analysis candidate locations and measurement parameters for Maui.

Since the Wind HUI project started, additional wind facilities have been completed and proposed for the Hawaiian Islands including the 2 projects on Oahu. Figure 3.4 summarizes current wind deployment locations (existing and in construction) in the state along with the island maximum loads for the Hawaiian Electric Companies' service territories. Growing levels of wind and solar generation and limited island loads are driving the need to operationalize reliable wind and solar forecasting capabilities.

Section 4.0 captures the applied model enhancements, monitoring technology selection and field campaign efforts and results for the Big Island of Hawaii. Efforts captured logistical insight on remote sensor technologies, operational costs and concerns and guidance on measurement parameters to improve forecasting performance. Ongoing efforts also highlight how Wind HUI efforts have been expanded by the Company and operationalize regional wind forecasting capabilities by 2014.

The Wind HUI effort is one of the first comprehensive field-deployment and validation efforts using advance SODAR monitoring to improve forecasting. In-the-field experience deploying remote sensors is also directly tie and support the Western Forecasting Improvement Program (WFIP) efforts currently underway on the mainland and planned for western utilities under the U.S. DOE Wind Program [19]. As such, WindNET efforts and experiences will have broad geographic applicability beyond just Hawaii.

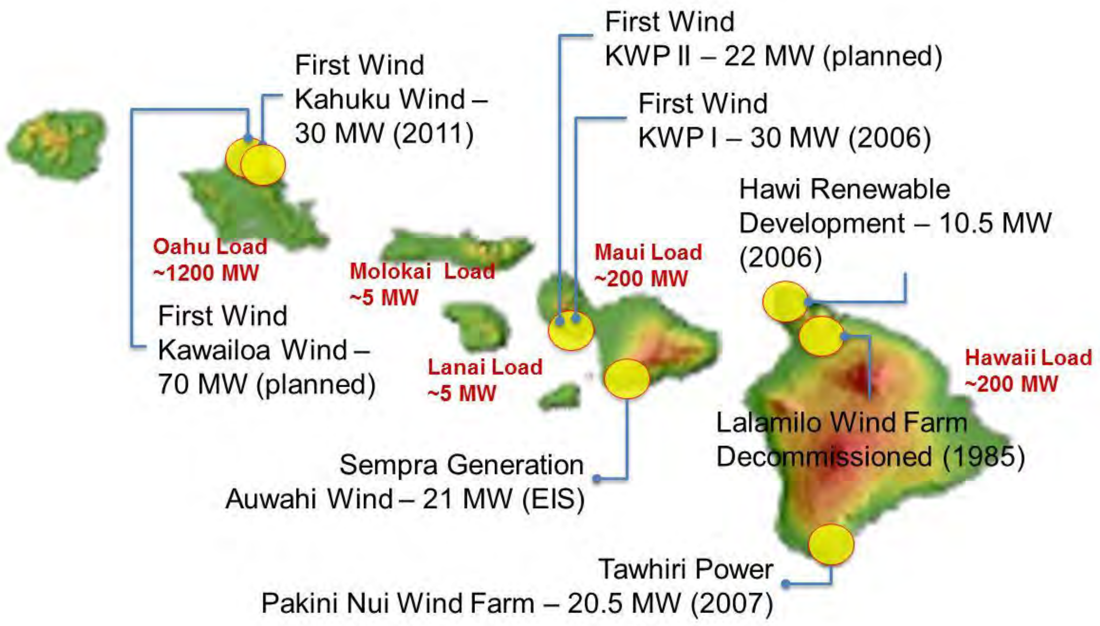


Figure 3.4 Existing and in construction wind facilities in Hawaii.

3.2 Initiative 2: Smart-Grid Preparations

The purpose of Initiative 2 is to begin deploying advance monitoring techniques using phasor measurement units ([PMU) or synchrophasors that capture real-time, high resolution waveform data from multiple points on the grid at the same time. The assumption is that this new information would provide the visibility for operations and planning to “see” where system stability issues are occurring and the resulting system dynamics due to grid variability conditions. This initiative supports preparatory steps toward retrofitting and “smarting” the existing infrastructure by introducing PMU information and control potential to the HELCO grid.

Objectives of Initiative 2 focused on

- Assessing compatible vendor options,
- Identifying key locations on the Big Island of Hawaii for deployment of devices,
- Gaining insight on system upgrades and resource/process preparation needs to adopt and support new technologies,
- Working with vendor provider on setup, training and troubleshooting during deployment and

- Continuing to gain experience with using PMU information and support software to improve situational awareness and strategically inform utility transformative upgrades and process improvements.

The initiative launched a pilot deployment effort on the HELCO system installing SEL 451 series relays and data concentrators to test how phasor and PMU information can improve operation and planning needs [20]. The HELCO system was selected due to the high penetration of wind and diversity of renewable resources ranging from run of river hydro-power, geothermal, biomass and solar. Since the HELCO system often operates close to stability boundaries, by configuring and interrogating field instruments (PMUs, other relays, switch) for additional real-time system performance data such as phase angle measurements, an operator's awareness of the system stability in real-time may be significantly improved. Armed with the new data, system operators can take anticipatory action by adding a stabilizing resource or altering system dispatch. Efforts can inform similar system retrofit/upgrade efforts to economically enhance data monitoring on both the transmission and distribution systems on the other islands and on the mainland to effectively operate/manage more variable and alternative resources. Additional controls via phase shifting technologies may also help HELCO minimize the impact of variable resources (i.e. reverse power flow) on the system during normal, fault recovery and emergency operations. For the islands, these technologies may improve system restoration capability without resorting to major curtailments of variable renewables like wind. Curtailments currently must be done to minimize phase angle differentials and enable fault-clearing and proper reclosing of lines for system restoration. These pilot efforts will help shape and inform transformational efforts for operating with greater diversity on the grid.

Table 3.2 summarizes the phased approach adopted for Initiative 2, objectives and desired outcomes as compared to actual accomplished at each phase. Section 5.0 summarizes the deploy experience, lessons-learned and ongoing effort to enhance operator situation awareness to system conditions and variability.

Table 3.2 Initiative 2 development approach.

Initiative 2 - Phased Approach		%Accomplished
Phase I Planning	**Assess and inventory sites for PMU application** a. Assess sites of interest to gather PMU; type of location; space in existing switchgears and cabinets b. Inventory compatible equipment and assess risks	**100%**

Phase II Piloting	**Procurement and field deployment** a. Select number of equipment and procure b. Identify support infrastructure (communication, fabrication, engineering) c. Coordinate installations with existing crew work schedules d. Conduct infield acceptance testing and functional testing e. Conduct and comply with any physical-cyber acceptance testing	**100%**
Phase III Implementation	**Evaluate Information and facilitate integration needs** a. Collect data b. Assess data for unusual events c. Coordinate with operations to pull data related to grid events d. Assess value/benefit of data in addressing evaluation of grid events, especially those related to wind and renewable resource variability	**30%**

3.3 Initiative 3: GSG Framework Development

The purpose of Initiative 3 is to begin informing retrofit opportunities and developing a reliable adoption framework for enabling the Future Green Smart Grid (GSG). As we rebuild and replace the system with alternative resources and "smart" features, are we keeping an eye on change impacts on the legacy and baseline infrastructure or are we making it less reliable? Worse yet, are we introducing *new* vulnerabilities as transmission, generation and distributed resources become operationally integrated and interconnected via more sophisticated communication and control systems (i.e. SCADA, smart interfaces to optimize renewables and DG resources) [21].

As Hawaii embarks on national and state clean energy initiatives (i.e. RPS, HCEI), utilities must pro-actively consider grid modernization needs, balance risks and make new investments for new infrastructure including appropriate communication and control options to manage the future generation mix, consider interoperability and compatibility of new emerging technologies and new reliability measures and procedures within the context of a transforming infrastructure and grid architecture. In addition, practical and economic operational protocol/standards and security practices for this new GSG must also be considered ahead of, or at least in parallel, to be worked into everyday reliability practices and procedures for operations, and not as a backup or afterthought [21].

Objectives of Initiative 3 focused on,

- Identifying and considering common needs/gaps (i.e. advance communication and controls, data requirements, hardware, procedures) and leverage experiences,
- Identifying viable opportunities to maximize automated control schemes through advance communication/control technology and other enhanced technologies for resolving problems and,
- Developing and recommending critical assets priorities and risk management strategies (i.e. costs, physical, cyber) appropriate for the new grid architecture/infrastructure and cost-effective operations

Hawaiian Electric Company selected Accenture Consulting services through a competitive bidding process to develop a framework for GSG and recommended actions. Their scope included a baseline assessment of the HECO/MECO/HELCO "as-is" system and infrastructure. To gather the information, Accenture staff interviewed utility staff in various areas from communication, substation, planning, operations and field-services. Interviews, surveys of existing infrastructure and site visits were conducted for each of the main operational centers located on Oahu, Maui and Big Island of Hawaii to understand current system challenges and identify potential grid automation and enhancement opportunities. Findings were summarized and presented in a series of review meetings along with follow-on discussions to address questions and concerns. Enhancement options addressed potential system and workforce resource realignment.

Developing this collaborative Framework for Hawaii supports larger national needs as identified in the original funding opportunity announcement (FOA) [1] by forging closer cooperation among regional utilities in Hawaii and facilitating an understanding of system-driven reliability factors/needs during the transformation toward a smarter, greener electrical grid. Options and strategies befitting unique island operations will inform future wind development and investments and improve overall integration efforts.

Deliverables included final presentations on the GSG readiness and value proposition along with recommendations on priority areas of need focus/investment. As the information contains business sensitive and proprietary grid information, limited excerpts are provided to illustrate the process and high level findings. Table 3.3 summarizes the phased approach adopted for Initiative 3, objectives and desired outcomes as compared to actual accomplished at each phase. Section 6.0 highlights results and recommendations along with pathways being pursued by the utilities.

Table 3.3 Initiative 3 development approach.

Initiative 3 - Phased Approach		%Accomplished
Phase I Planning	**Review and assess existing infrastructures that support data gathering and grid automation** c. Secure outside vendor services to conduct assessment and develop business case for GSG d. Information gathering and review of existing infrastructure, focusing on communication, existing grid automation and data management architectures e. Conduct utility interviews targeting functional areas supporting the build and maintenance of GSG architecture (e.g. operations, engineering, planning, customer service, construction & maintenance) f. Inventory compatible equipment and assess risks	**100%**
Phase II Deployment	**Procurement and field deployment** f. Review feedback gained from reviews and interviews g. Identify gaps and enhancement options h. Develop grid readiness levels to adopt technologies across infrastructure and organizational areas i. Help prioritize areas of maximum benefit and costs to achieve j. Support business case development and rational	**100%**
Phase III Implementation	**Evaluate information and recommend next steps** e. Present business case based and prioritized next steps based on evaluation, inclusive of business case and rational f. Support staff in finalizing framework and documenting feedback and guidance gained g. Recommend preliminary approach for prioritized areas and cost estimates	**100%**

4.0 Initiative 1: WindNET Deployment Experiences & Findings

In Phase II, Hawaiian Electric Companies teamed with AWS Truepower (AWST) and Atmospheric Research and Technology (ART) to deploy one of the first fleet of utility remote monitoring sensors for purposes of improving the accuracy of state-of-the-art short-term (0-6hr) wind forecasts with emphasis in the intra-hour (0-1hr) period. Efforts also provided validation of AWS's Observational Targeting methodology for strategic placement of field sensors to provide operator's situational awareness of prevailing conditions and improve real-time forecasting model accuracies [22]. Final deployment sites shown in Figure 4.1 and Table 4.1 were based on a number of factors including, actual site terrain suitability, access availability, security, timing for access and project timing and funds.

Figure 4.1 Deployment locations for WindNET sensors on the Big Island of Hawaii.

Table 4.1 WindNET field monitoring location coordinates on Hawaii.

Location	Latitude	Longitude	Elevation
Naalehu	19° 2' 14.75" N	155° 35' 6.73" W	190 m
Punaluu	19° 8' 55.46" N	155° 30' 42.02" W	120 m
South Point	18° 54' 53.00" N	155° 40' 55.96" W	10 m
Bruns' Residence	19° 28' 6.37" N	154° 49' 58.34" W	61 m

Table 4.2 summarizes the remote sensing equipment deployed on the Big Island as discussed in Section 3.0.

Table 4.2 Summary of field monitoring devices deployed on Hawaii for WindNET.

Site	Instrumentation	Deployment Date	Decommission Date
Naalehu	ART VT-1 SODAR	9/20/2010	-
Punaluu	ART VT-1 SODAR	7/25/2010	8/5/2011
South Point	ART VT-1 SODAR	11/10/2010	-
Bruns' Residence	Radiometrics MP3000-A Radiometer	8/4/2010	9/16/2011*

*Radiometer was unavailable from 10/1/2010 through 10/21/2010 due to hardware failure.

Sections below highlight information on the field devices, field campaign experiences, model enhancements and outreach activities. Additional details and contractor full projects are provided in Section 10 – Initiative 1 Appendices.

4.1 Remote Monitoring Devices

Both SODARs [23] and radiometers [24, 25] have been in use by the weather monitoring and prediction communities for several decades. They provide vertical profile data from the ground up to several hundreds of meters to a few kilometers above the ground. ART SODARs and Radiometrics radiometers were selected to provide vertical wind and temperature profile data from 0 to 2 km above the ground for wind forecasting purposes. Selection of devices was based on recommendations by AWST given prior deployment experiences, utility SODAR experience and availability of vendor support services (e.g. onsite services, amenable to field validation support) in Hawaii's tropical climate. ART has a Hawaii base of operations and local technical support services that complemented AWS field personnel. Radiometrics pioneered commercial ground-based microwave radiometry and their radiometers are known in the industry for their rugged, all-weather performance. Along with ART, they were amenable to support short-term utility forecasting and research application needs for this project.

SODAR (Sonic Detection and Ranging) devices operate based on Doppler phase shifting principals. Small speakers in the SODAR periodically emit focused acoustic pulses that sound like bird chirps into the air. By recording the scatter or shift in the return signal due to the air and particulates in the air, the wind speed and direction can be derived. Rainy and excessively dry atmospheric conditions interfere with the performance of the device by either limiting the return signal or reducing the maximum achievable altitude for measurement. Repeated ambient noise like road or machinery can also interfere with the SODAR performance and must factor into siting considerations.

Radiometers use a microwave beam to measure the atmospheric temperature profile. The Radiometrics MP3000-A is a microwave radiometer designed to retrieve temperature, humidity and cloud profiles in the lower troposphere [25].

4.2 Siting Considerations & Field Monitoring Campaign

Given project budgetary and time constraints, efforts focused on monitoring the priority areas for forecasting the Tawhiri (also known as Apollo) wind facility near South Point. Because of the remote locations and permitting challenges in the area, remote SODAR and modular devices were preferred over traditional meteorological tall towers.

Based on the Observational Targeting results, vertical wind and temperature profile data was needed to measure the predictive indicators for improving wind forecasts. Figure 4.2 through Figure 4.5 show the deployed equipment in the field and the surrounding environment. The field deployment campaign began July 2010 and gathered nearly 10 months of record with all four sensors concurrently in operation.

Though sites were carefully screened for appropriateness for forecasting, each of the sites also encountered site deployment challenges that had to be resolved. For the radiometer site, due to the remote location, additional enhancements had to be made to boost the communication signal so transmission would not be interrupted. This required a reliable power extension to the site that was worked out with the Bruns' residence. For the Punaluu site, the SODAR was situated inside the utility substation. Power, site access and site security were not issues. However ambient noise from the road and also an external generator at the site posed some initial concerns. Noise level readings were initially conducted to ensure the interference was not significant. Both the Naalehuu and South Point sites required land lease agreements. Naalehuu required an easement extension with a private land owner to include the SODAR in addition to communication towers at the same location. The SODAR placement also required additional care so there would not be any interference or blockage due to the existing communication towers. The South Point land belonged to the Department of Hawaii Homeland and required a special use permit. As these sites also were used by cattle ranchers, staff worked with the community to procure additional cattle fencing to protect the SODAR units from the cattle. Appendix I1-2 provides additional field campaign details.

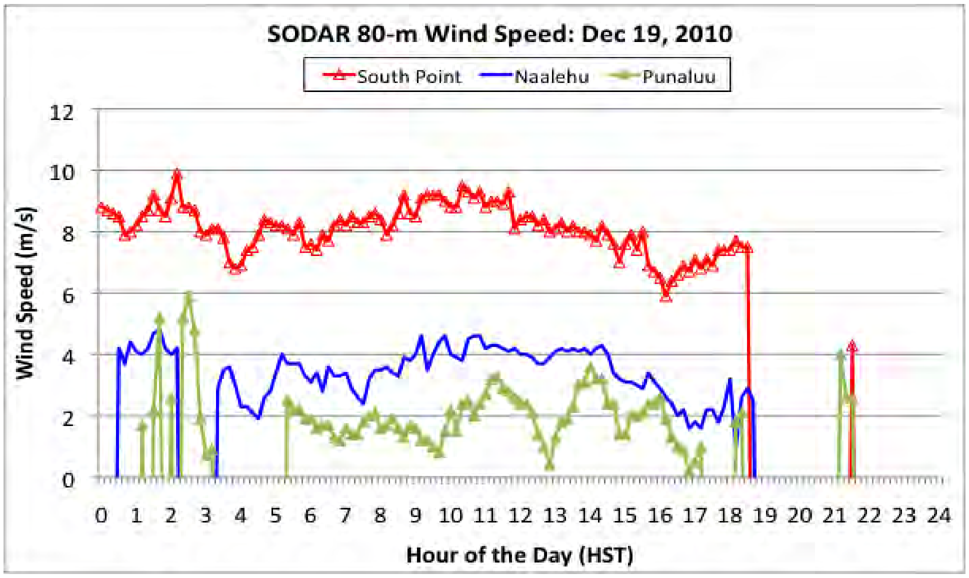
Figure 4.2 Utility powered SODAR at Punaluu.

Figure 4.3 Solar powered, mobile SODAR with met-mast at Naalehuu.

Figure 4.4 Solar powered, mobile SODAR with met-mast at South Point.

Figure 4.5 Radiometer and enhanced communication at Bruns' Residence.

Figure 4.6 shows the 80 m wind speed data collected using the SODAR. Based on the measurement data, the Naalehu site has a stronger correlation to forecasting South Point. SODAR sensors were also sensitive to rain. Data drop outs was at first a nuisance however with better understanding of the driving weather phenomena, data drop outs because a "heads-up" to rainfall.



Missing data at time of the ramp is probably because of precipitation

Figure 4.6 80m level SODAR wind data.

4.3 Wind Forecasting Models and Enhancement Techniques

Efforts leveraged climatology, persistence and multiple state-of-the-art numerical weather prediction (NWP) models and techniques to provide linkage between the weather/terrain induced phenomena and grid impacts, especially ramp events. Figure 4.7 shows how the different NWP models and integration techniques are used to produce a forecast and where WindNET information was integrated to improve forecasting accuracies as part of this effort.

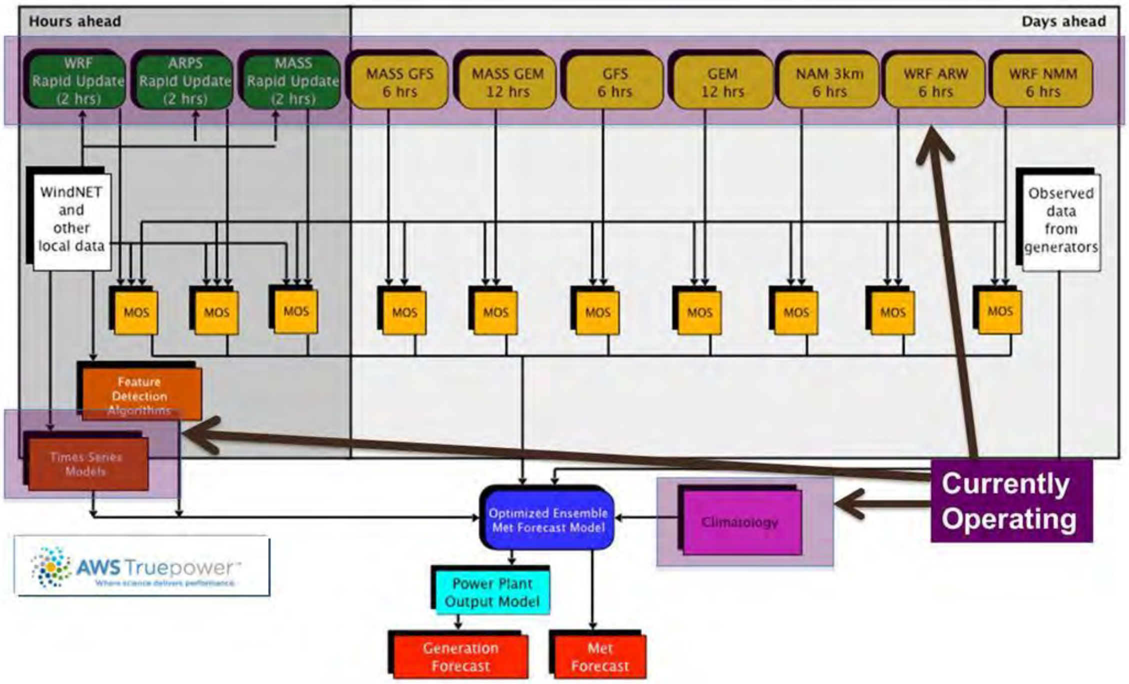
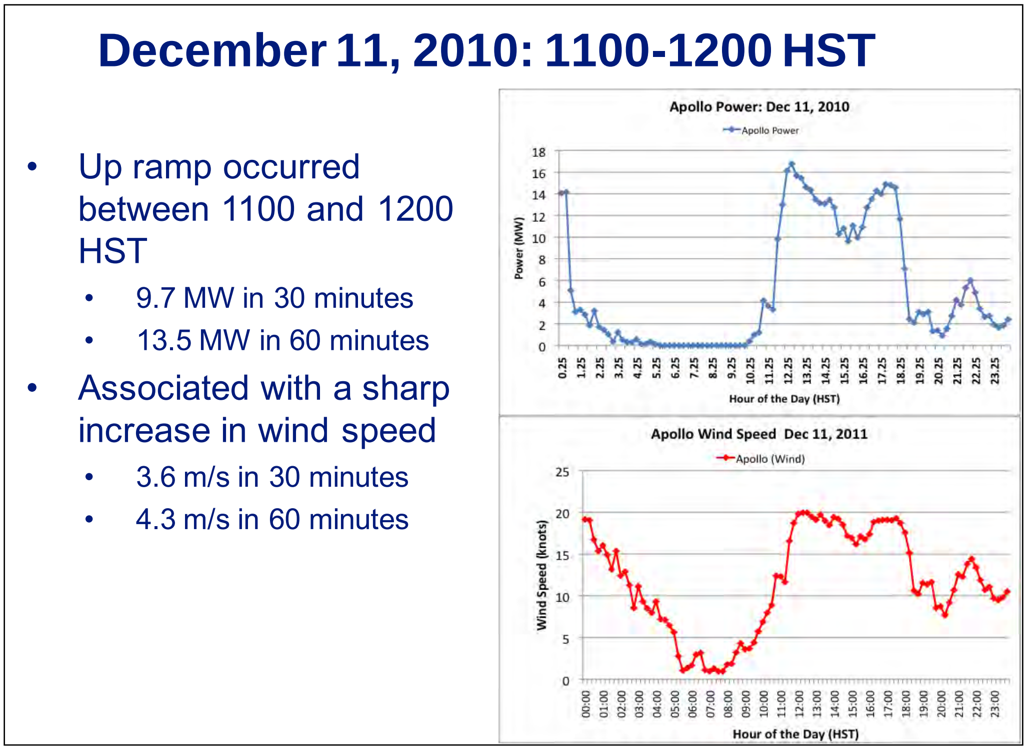


Figure 4.7 AWST Integrated WindNET Forecasting System developed for Hawaii.

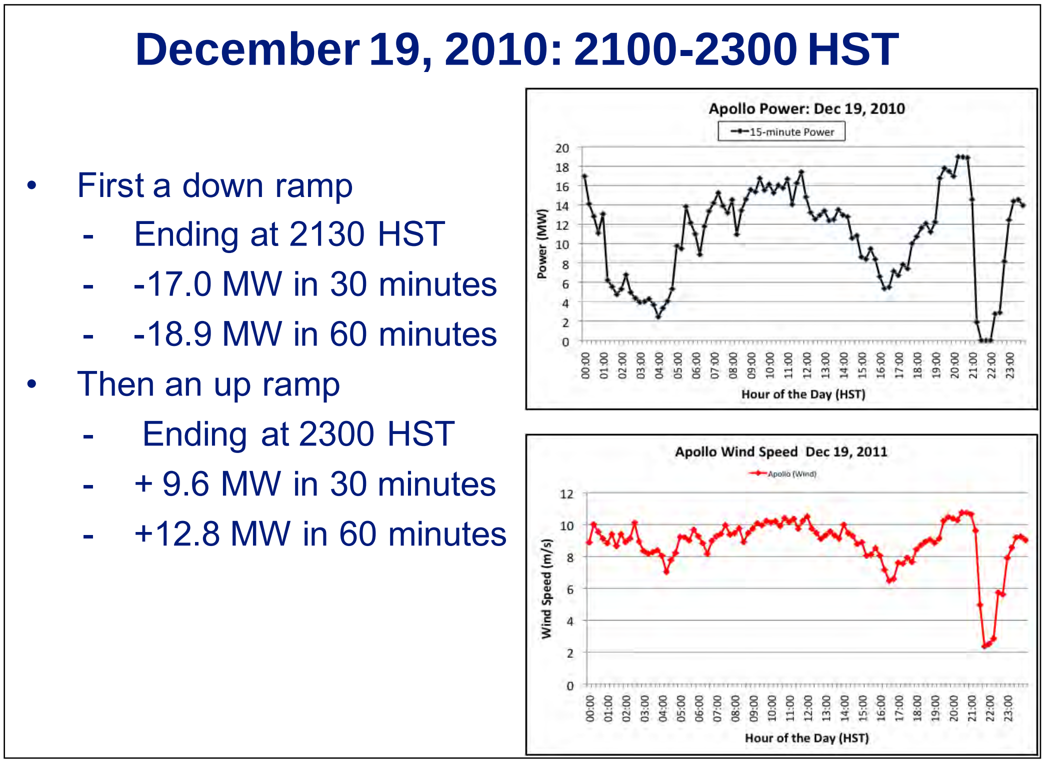
Model validation results also showed that the usefulness of the field measurements is highly dependent on the meteorological phenomenon driving the events as shown by the December 11th and 19th results. Figure 4.8 (December 11th) and Figure 4.9 (December 19th) summarize the ramp event conditions and time periods evaluated. Figure 4.10 and Figure 4.11 compare the NWP forecast with and without WindNET information. Ramps on both days were better captured by having the WindNET data. On December 19th, the ramp event was captured both spatially and temporally. When presented to operational staff, they were very eager to see how this information could be integrated to inform intra-hour dispatch of units. A comparison of the ramp events forecasted using NWP enhanced with field measurement using SODARs showed a 10-15% mean absolute error (MAE) improvement over standard NWP. Figure 4.12 shows the MAE improvements by “look ahead time” with WindNET for different temporal periods.



December 11, 2010: 1100-1200 HST

- Up ramp occurred between 1100 and 1200 HST
  - 9.7 MW in 30 minutes
  - 13.5 MW in 60 minutes
- Associated with a sharp increase in wind speed
  - 3.6 m/s in 30 minutes
  - 4.3 m/s in 60 minutes

Figure 4.8 December 11, 2010 ramp event conditions.



December 19, 2010: 2100-2300 HST

- First a down ramp
  - Ending at 2130 HST
  - -17.0 MW in 30 minutes
  - -18.9 MW in 60 minutes
- Then an up ramp
  - Ending at 2300 HST
  - + 9.6 MW in 30 minutes
  - +12.8 MW in 60 minutes

Figure 4.9 December 19, 2010 ramp event conditions.

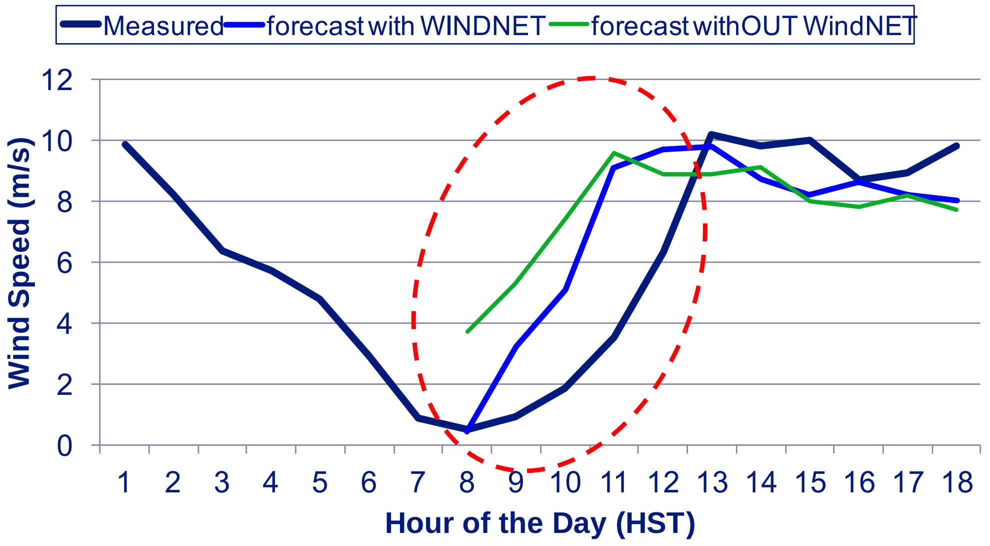


Figure 4.10 Comparison of December 11th measured ramp and rapid update NWP forecasts with and without WindNET data for South Point.

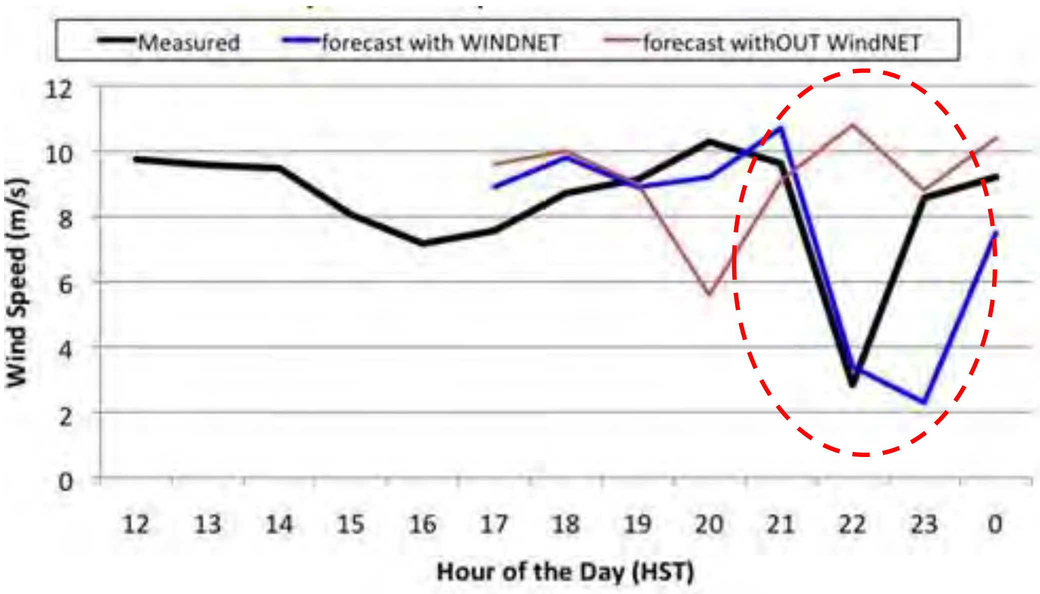


Figure 4.11 Comparison of December 19th measured ramp and rapid update NWP forecasts with and without WindNET data for South Point.

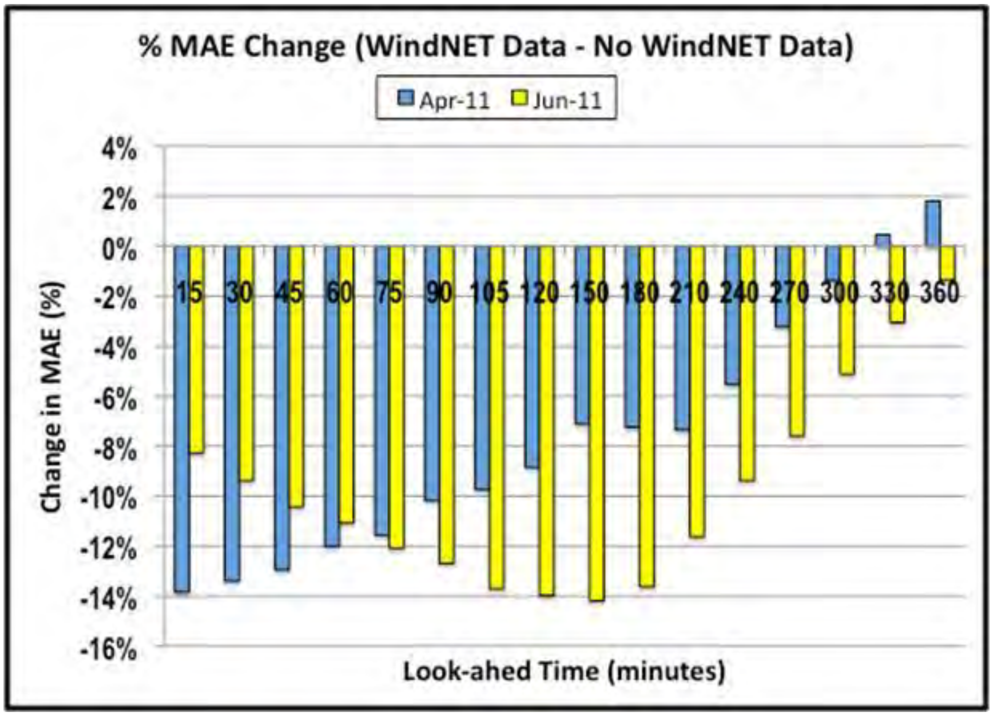


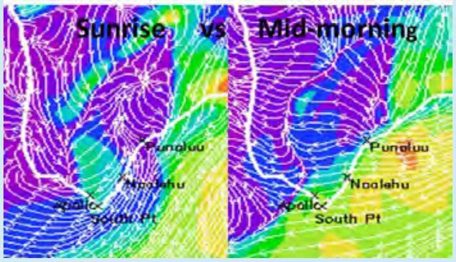
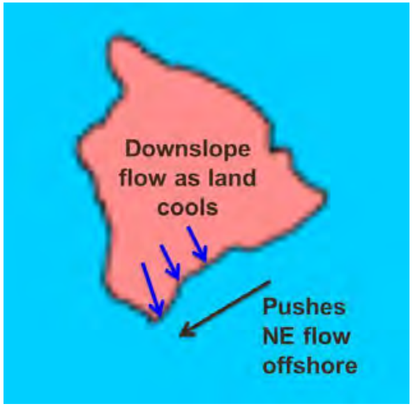
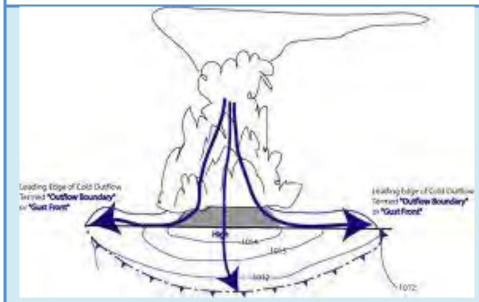
Figure 4.12 Comparison of December 19th measured ramp and rapid update NWP forecasts with and without WindNET data for South Point.

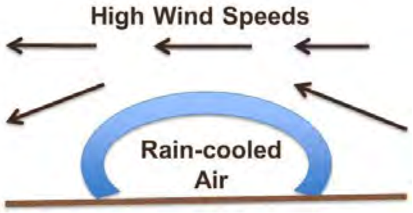
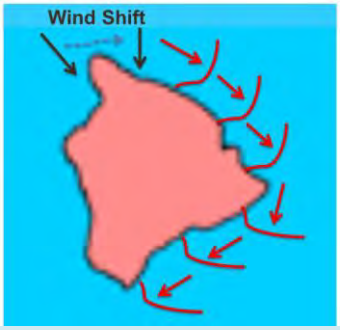
In addition to using WindNET remote sensors to capture new upper atmospheric data and vertical wind and temperature profiles for improving wind forecasting models, AWST reviewed historical event data that impacted the system and performed some initial validations using hind-casting techniques. AWST reviewed this information and provided probability statistics for ramp events whose variability thresholds (up and down events) were identified by HELCO operators to be of concern to the grid (i.e. ramps that cause frequency issues, time of day that the grid is more susceptible to variability) versus just looking at forecasting skill statistics (RSME, MAE) or “hit-miss” statistics. By combining the enhanced WindNET wind forecasts and grid conditions, AWST identified and categorized

- dominant weather and terrain interaction patterns observed through the field monitoring campaign,
- weather features and focused on times of day when atmospheric transitions were most likely to produce variability and/or ramps that could impact the grid.

Table 4.3 summarizes five of the predominant features identified for the wind facility known as Apollo on the southern tip of Hawaii. Descriptions include a visual display of the weather phenomenon, time and condition of likely occurrence and impact on the grid. Armed with detailed information for particular regions, HELCO operators can devise operational strategies and options to effectively prepare for prevailing conditions.

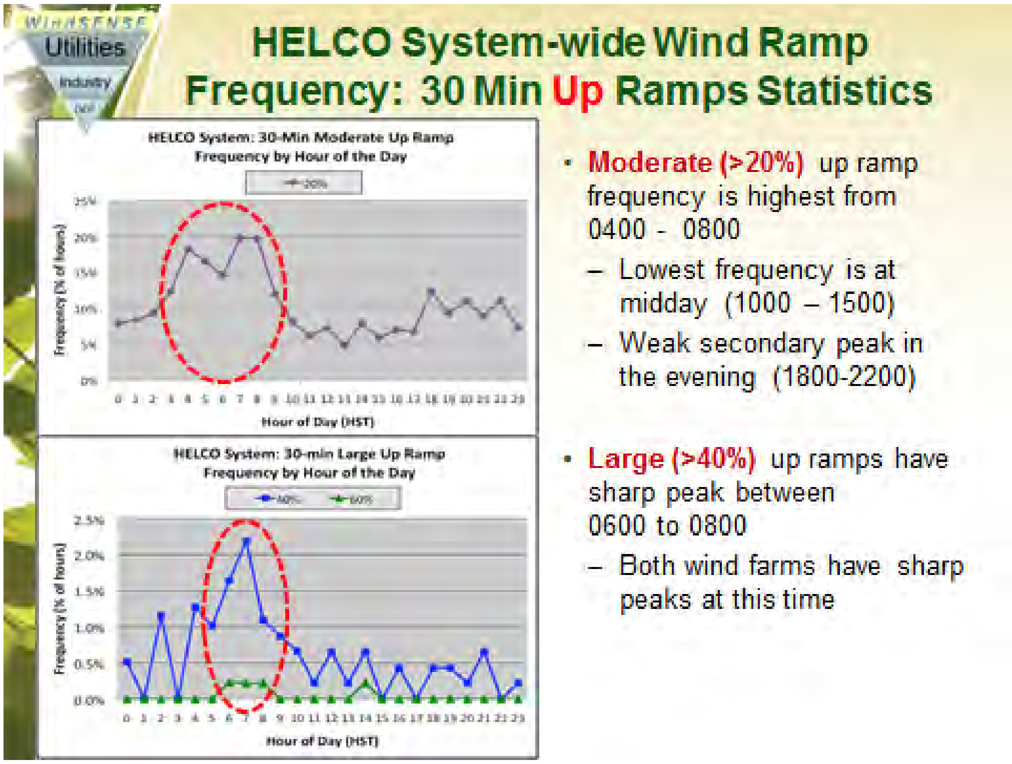
Table 4.3 Summary of 5 weather features and impacts on South Point wind facility.

Feature Detected	Description & Grid Impacts
Type A: Onshore Penetration of High Offshore Winds  	• Upward Ramps • Frequently occurs around sunrise and plays a big role in upward ramp frequency max 0500-0800 HST • Strong northeasterly flow channeled by the high terrain of the island is kept offshore by: - Nocturnal drainage flow/land breeze from the higher terrain - Increased blocking of the nocturnal lower atmospheric flow by terrain • With onset of daytime heating, after sunrise the drainage flow becomes upslope flow/sea breeze and blocking is reduced. This allows the jet to shift inland over southern wind farm.
Type B: Offshore Migration of High Winds  	• Downward Ramps • Frequently occurs around sunset and plays a big role in downward ramp frequency max in late afternoon and evening. • "Inverse" of Type A • Strong northeasterly flow is initially over Southern part of the island - Strong large scale NE trade winds - Unstable or neutral boundary layer which minimizes blocking effect of the terrain • With onset of nocturnal cooling (around sunset); a drainage flow (downslope flow of cool air) develops and blocking is increased. This pushes the strong NE flow offshore.
 	• Upward Ramps • Occurs when - Wind speeds are in the lower part of the power curve and power production is low - A shower (as opposed to large scale rain) moves into the wind farm area - Showers produce low level temperatures that are significantly cooler than the environment
Type D: Boundary Layer Stabilization from Rain	• Downward Ramps • Occurs when - Wind speeds are in the upper part of the

	power curve - Showers or larger scale rain begins • Evaporation from rain cools the boundary layer air and make its more stable • Greater stability inhibits turbulent mixing and high speed air from higher levels is cutoff from the near-surface layer •
Type E: Surge down W or E Coast 	• Upward Ramps • Occurs when large scale flow is northerly • Depending on the wind direction, Southern wind facility can be in - strong channeled flows down the east shore (NE flow at Apollo) - strong channeled flows down the west shore (NW flow at Apollo) - Weak flow between the two branches of strong channeled flow. • Downward, upward or downward spike type ramps occur as the wind shifts and Apollo shifts from one regime to another.

Similar to the western coast of California, Hawaii wind resources are predominately trade-wind and marine layer driven but unlike the west coast, tradewinds are relatively constant throughout the day except during storms or Kona conditions. However, due to thermal gradients and terrain interactions, the winds can become quite variable during the morning heating hours and evening cooling hours. Figure 4.13 and Figure 4.14 shows how the work to date translate to ramp rate frequencies (hours of occurrence) of 30-minute upward and downward ramp rates for moderate (20% of capacity) and large (40 to 60% of capacity) ramps.

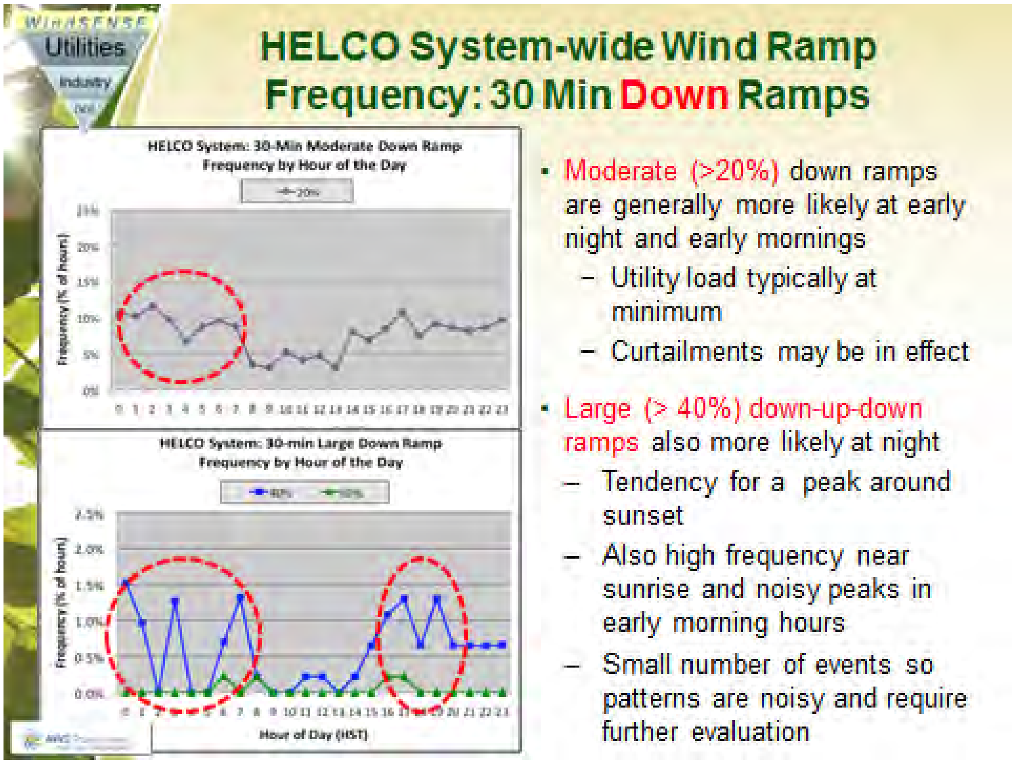
Based on this probabilistic information and improved forecasting capabilities, HELCO operations have made adjustments to current dispatching practices during the morning load rise and evening load drop hours compared to mid-day from 9-2 pm when the winds are statistically more stable. These practices improve utility management of regulating reserves and flexibility more dynamic dispatch based on resource availability and prevailing forecast conditions. Appendix I1-3 provides additional modeling and weather feature detection and categorization results.



HELCO System-wide Wind Ramp Frequency: 30 Min Up Ramps Statistics

- Moderate (>20%) up ramp frequency is highest from 0400 - 0800
  - Lowest frequency is at midday (1000 – 1500)
  - Weak secondary peak in the evening (1800-2200)
- Large (>40%) up ramps have sharp peak between 0600 to 0800
  - Both wind farms have sharp peaks at this time

Figure 4.13 Assessment of 30-minute upward ramp rate frequencies for moderate (20% of capacity) and large (40 to 60% of capacity) ramps.



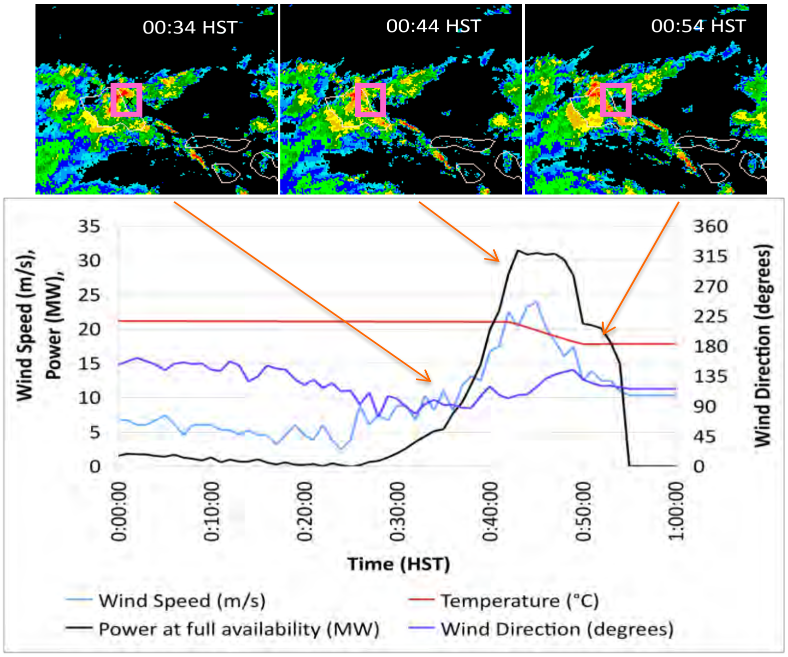
HELCO System-wide Wind Ramp Frequency: 30 Min Down Ramps

- Moderate (>20%) down ramps are generally more likely at early night and early mornings
  - Utility load typically at minimum
  - Curtailments may be in effect
- Large (> 40%) down-up-down ramps also more likely at night
  - Tendency for a peak around sunset
  - Also high frequency near sunrise and noisy peaks in early morning hours
  - Small number of events so patterns are noisy and require further evaluation

Figure 4.14 Assessment of 30-minute downward ramp rate frequencies for moderate (20% of capacity) and large (40 to 60% of capacity) ramps.

4.5 Wind Forecasting Results and Visualization for Operators

A key finding is that operators can do quite a bit with a consistent forecast that provides them a “heads-up” warning of prevailing conditions and the ability to “see” the resources. Additionally, they are more likely to rely on a forecasting tool if they understand the source and if it is highly consistent in identifying conditions for variability even if not 100% accurate. As grid operations rely heavily on situational awareness to inform decisions, establishing operator confidence and sense of understanding for prevailing conditions where renewables are likely to cause impacts will provide operators more options to effectively manage grid resources. Figure 4.15 shows how the weather features detection capability can be used to track ramp events and inform grid operators of potential variability impacts to a wind facility and thus the grid.



- **Condition:** Up ramp involving heavy precipitation and strong outflow
- **Impact:** Upward ramp or upward spike with downward ramp quickly following when prevailing flow returns
- **Timing:** Occurs most often at night and during early afternoon
- **Reason:** Related to moderate to strong outflow of rain-cooled air from the precipitation area

Figure 4.15 Evolution of a 30 MW up ramp event as tracked using Doppler radar and features detection capability.

Figure 4.16 and Figure 4.17 show screen shots from a preliminary pilot interface and wind forecasting visual display showing both actual and forecasted wind, ramp rate probabilities and confidence bands. Based on operator interviews, the ability to track the forecast performance throughout the day and the probability statistics provides some “sense” to inform actions.

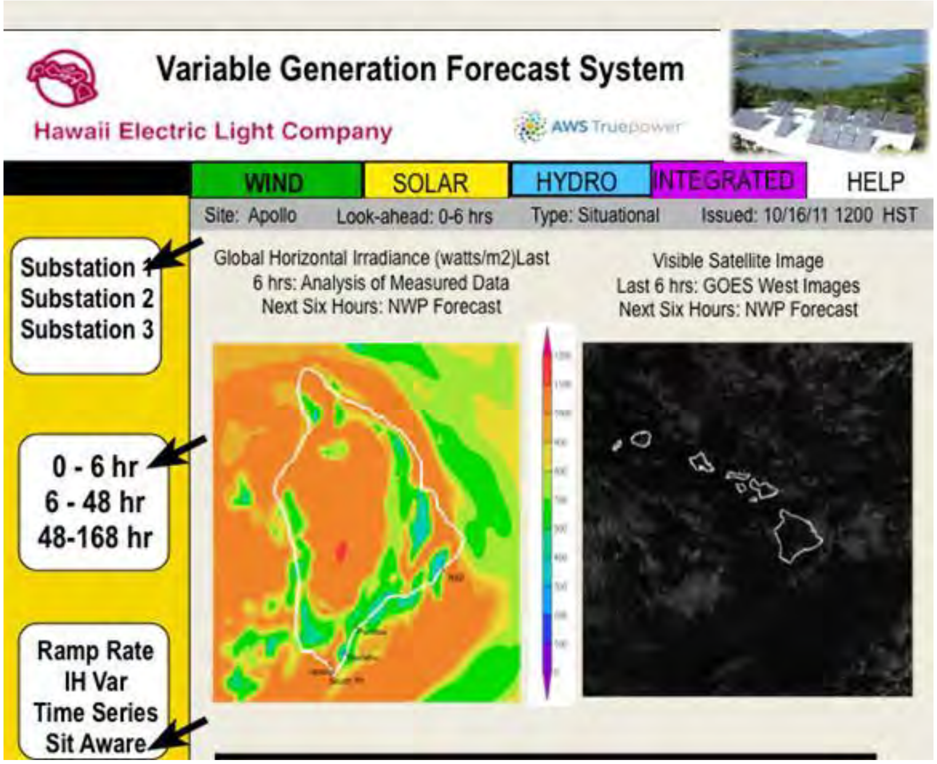


Figure 4.16 Pilot variable generation forecast interface for grid operators.

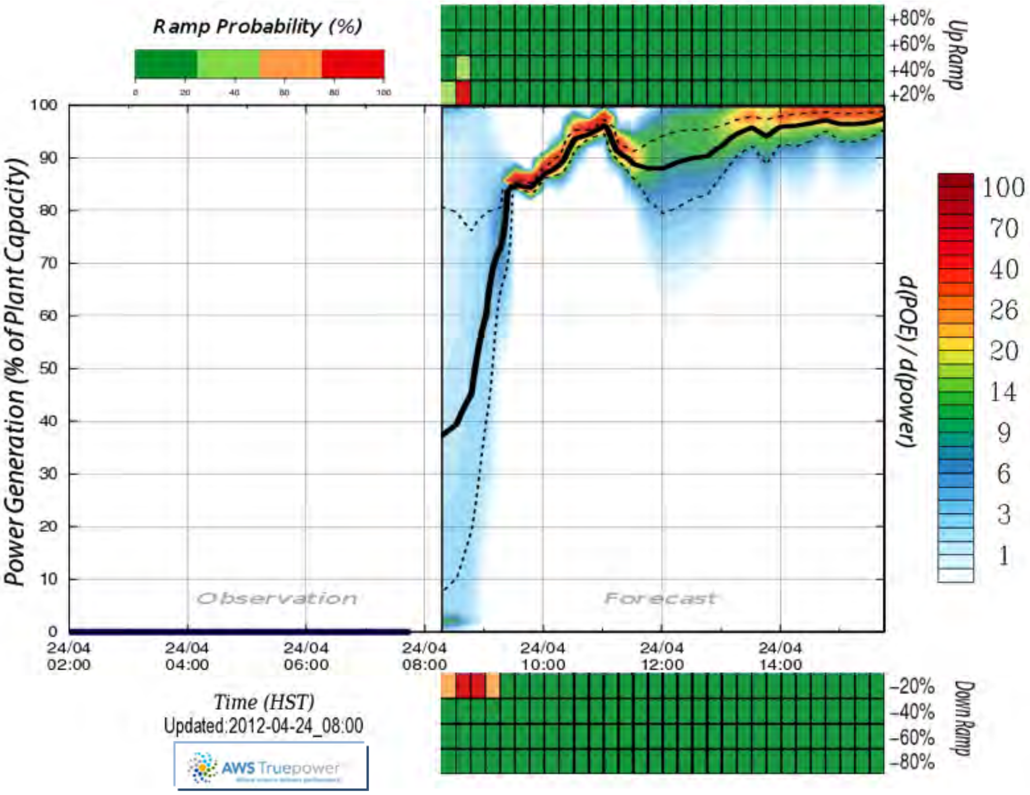


Figure 4.17 Pilot visual display integrating observed trends, forecast, ramp up and down statistics and probability confidence spectrum.

As more data is gathered from operational practice, the information can potentially be factored into more automated control logic such as the EMS to provide alerts and trending.

4.6 Outreach Activities and Accomplishments

Table 4.4 lists a number of the WindNET review meetings and outreach activities conducted as part of the project.

Table 4.4 WindNET outreach activities and accomplishments.

Topic	Accomplishment Delivered
Publications/Presentations	• ASM 2011 Proceedings Paper [22] • IEEE/IJCNN 2011 Proceedings Paper [26] • AWEA 2012 Conference Scientific Presentation [27] • IEEE PES 2012, Proceedings Paper [28] • July 2010 WindNET Kickoff Meeting & Field Siting and Onsite visit • September 2011 WindNET Utility Status Review Meeting • April 2012 WindNET Forecasting Review Meeting at HELCO, MECO and HECO
Collaborations Fostered	• Western utility collaboration on wind and solar forecasting • HECO participation in Wind Forecasting Improvement Program (WFIP) [19]
Techniques Demonstrated	• WindNET field deployment campaign • Observational Targeting • Pilot visualization screens
Training Conducted	• Internal Responsive and Dynamic (RAD) sessions on Wind Forecasting and SODAR devices for employee training – 2010 by AWST and ART • Summer interns supporting deployment and data monitoring efforts May through August 2011

Phase III Implementation efforts are currently being pursued by the Hawaiian Electric Companies to operationalize short-term wind ramp and wind forecasting capabilities for the Company's service territories. Early efforts investigating LIDAR (light detection and ranging) capabilities with OceanIT, a Hawaii-based technology company, were not pursued for the Big Island deployment due to timing and technology constraints. However, the information on LIDARs technologies is being utilized to deploy a scanning LIDAR for the Oahu WindNET deployments at the Kahuku Wind Facility. The Oahu efforts are outside of the DOE funded activities but build on the field deployment knowledge.

Successful deployment experiences and new real-time information for operators provided through the Wind HUI on the Big Island jumpstarted renewable forecasting efforts for Hawaiian Electric Companies with ongoing efforts on the Big Island, Maui and Oahu. Remote sensor deployment and monitoring campaigns are currently underway at MECO and HECO to operationalize forecasting capabilities by 2014.