Hawaiian Electric Company

Hawaii Utility Integration Initiatives to Enable Wind (Wind HUI)

Final Technical Report DOE/EE0001379-1

Dora Nakafuji
7/15/2012

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Submitted by

Hawaiian Electric Company

to

U.S. Department of Energy

DOE Award Number:	**EE0001379**
Project Period:	**November 2009 - April 2012**

Principal Investigator:	**Dr. Dora Nakafuji, (808) 543-7597, dora.nakafuji@heco.com**
Co-Principal Investigators:	**Lisa Dangelmaier, lisa.dangelmaier@helcohi.com**
	Chris Reynolds, chris.reynolds@mauielectric.com
Organization Name:	**Hawaiian Electric Company**
Address:	**P.O. Box 2750**
	Honolulu, HI 96840
Subrecipients:	**AWS Truepower, LLC**

Date of Report:	**July 15, 2012**

Acknowledgements

The Hawaiian Electric Companies would like to thank the U.S. Department of Energy for their sponsorship of Wind HUI Initiatives. This report is based upon the work supported under U.S. Department of Energy Award No. EE0001379. We would like to extend our appreciation to our project sponsors, Mr. Stanley Calvert (previously with the DOE RSI Wind Program), Mr. William Parks, Mr. Steve Lindenberg and especially, Mr. Nicholas Johnson, our Wind HUI project officer. Our efforts also built upon the research efforts of Dr. Marc Schwartz (retired from the National Renewable Energy Laboratory).

Our vendor partners were instrumental in helping us achieve the success under the Wind HUI Initiatives. We would like to extend our appreciation to our industry collaborators: Dr. John Zack, Dr. Deborah Hanley, Dr. Jeffrey Freedman and the AWS Truepower field deployment team; Dr. Barry Neal, our resident SODAR expert in Hawaii at Atmospheric Research and Technology; and the Accenture consulting team. Special recognition is extended to Dr. John Zack at AWS Truepower, whose expertise, patience and guidance kept the project on track.

The Wind HUI team would like to acknowledge our western utility partners: Dr. Robert Farber and Mr. Jack Peterson at Southern California Edison, Mr. John Pease at Bonneville Power Administration, Ms. Elaine Sison-Lebrilla at Sacramento Municipal Utility District and Mr. Jim Blatchford at the California ISO. Their candid feedback, support and participation in review of the results of the Hawaii wind forecasting efforts improved the robustness of modeling and field deployment activities not only for Hawaii but for the mainland utilities. These western utilities partnerships have truly advanced 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 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**).

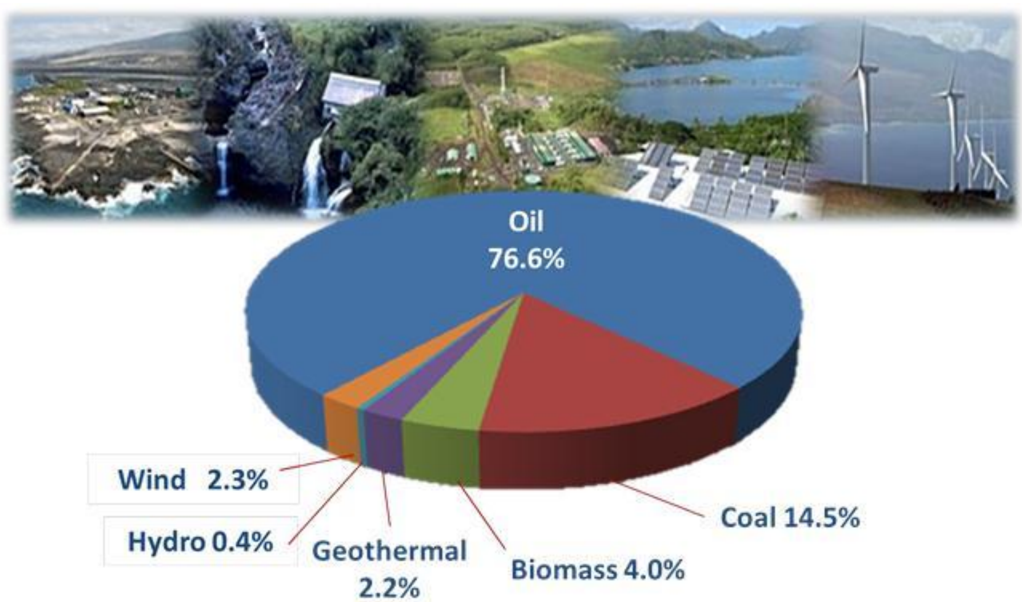


Figure 2.1 Hawaii energy resources (HECO 2007)

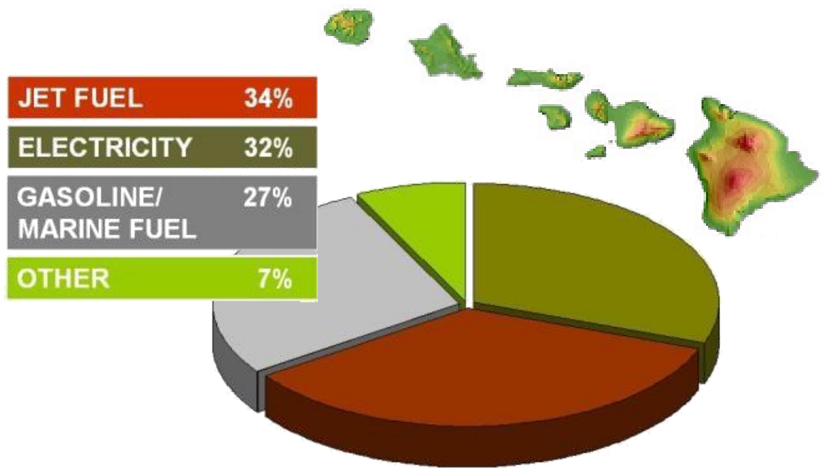


Figure 2.2 Hawaii energy use. (Source: DBEDT 2008)

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.

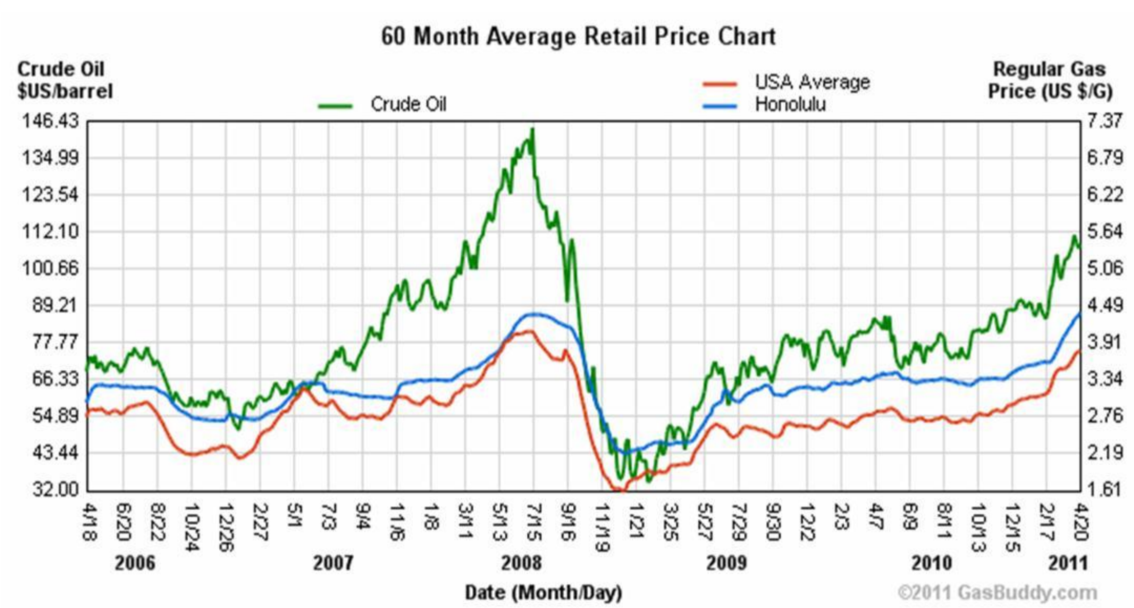


Figure 2.3 Comparison of fuel price volatility on Hawaii and average U.S. Mainland when crude oil soared over $144 per barrel in the summer of 2008. (Source: UHERO)

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:

> <u>Phase 1 Planning</u> - 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.
>
> <u>Phase 2 Deployment</u> - 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/CalSO 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.

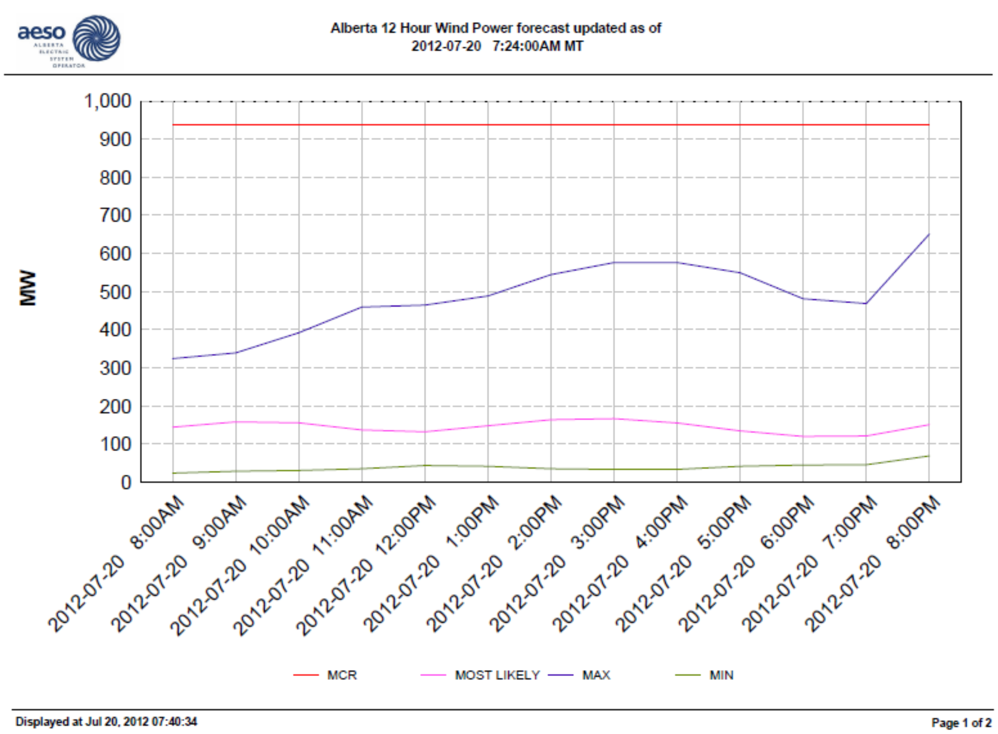


Figure 3.1 Example of current short-term wind forecasting information used by the Alberta Electric System Operator (AESO).

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.

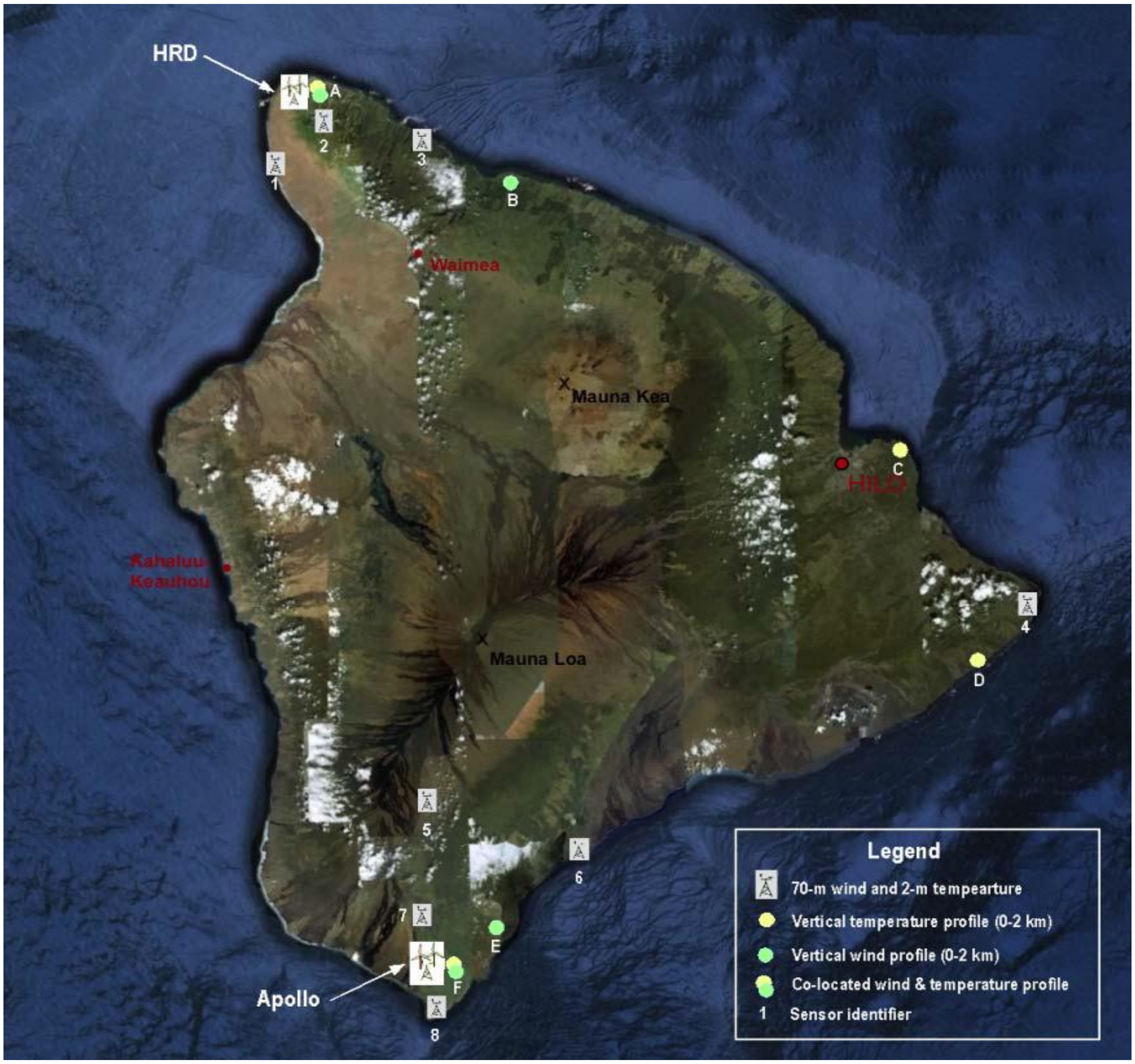


Figure 3.2 Observational Targeting analysis candidate locations and measurement parameters for the Big Island of Hawaii.

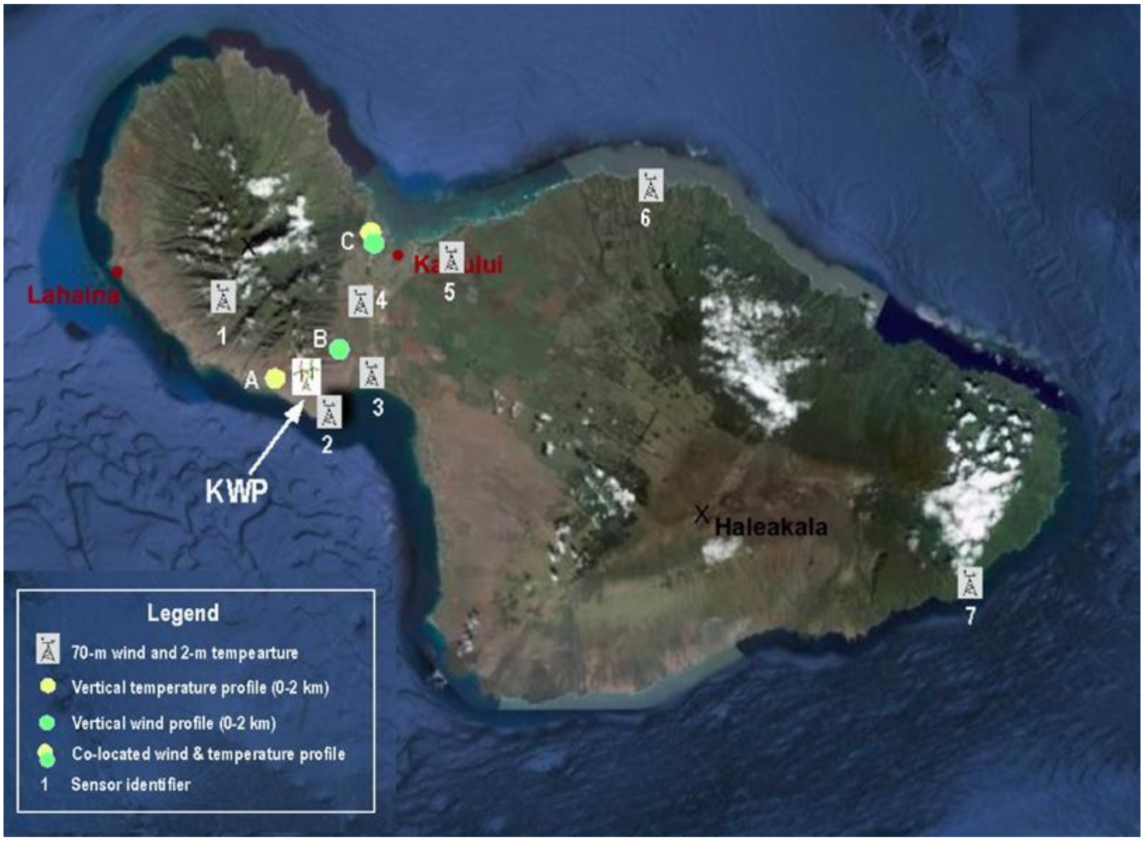


Figure 3.3 Observational Targeting analysis candidate locations and measurement parameters for Maui.

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.

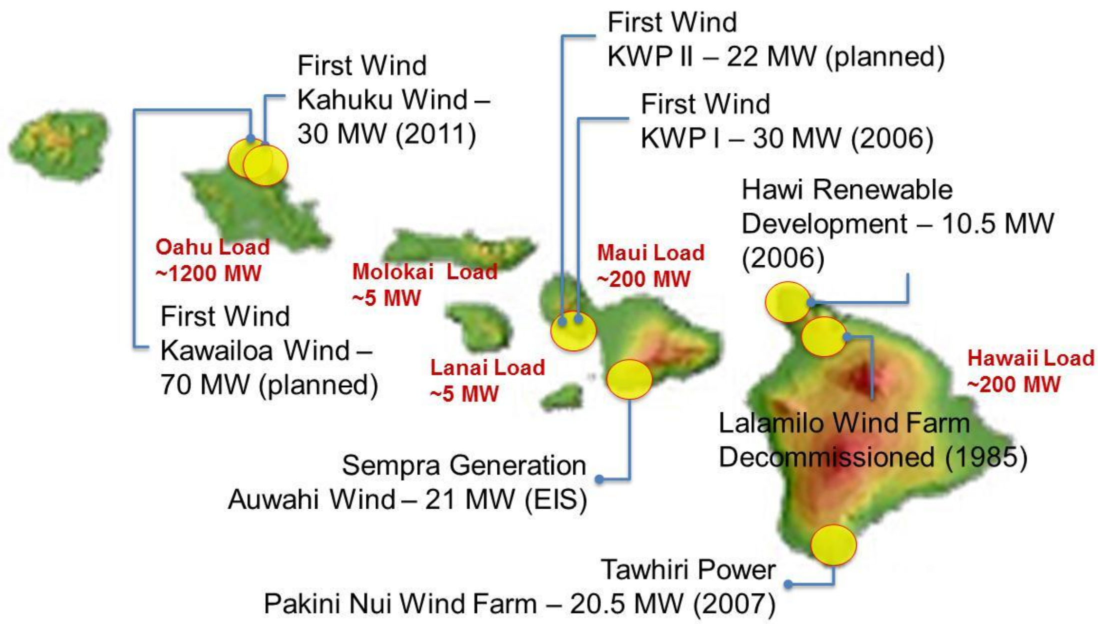


Figure 3.4 Existing and in construction wind facilities in Hawaii.

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.

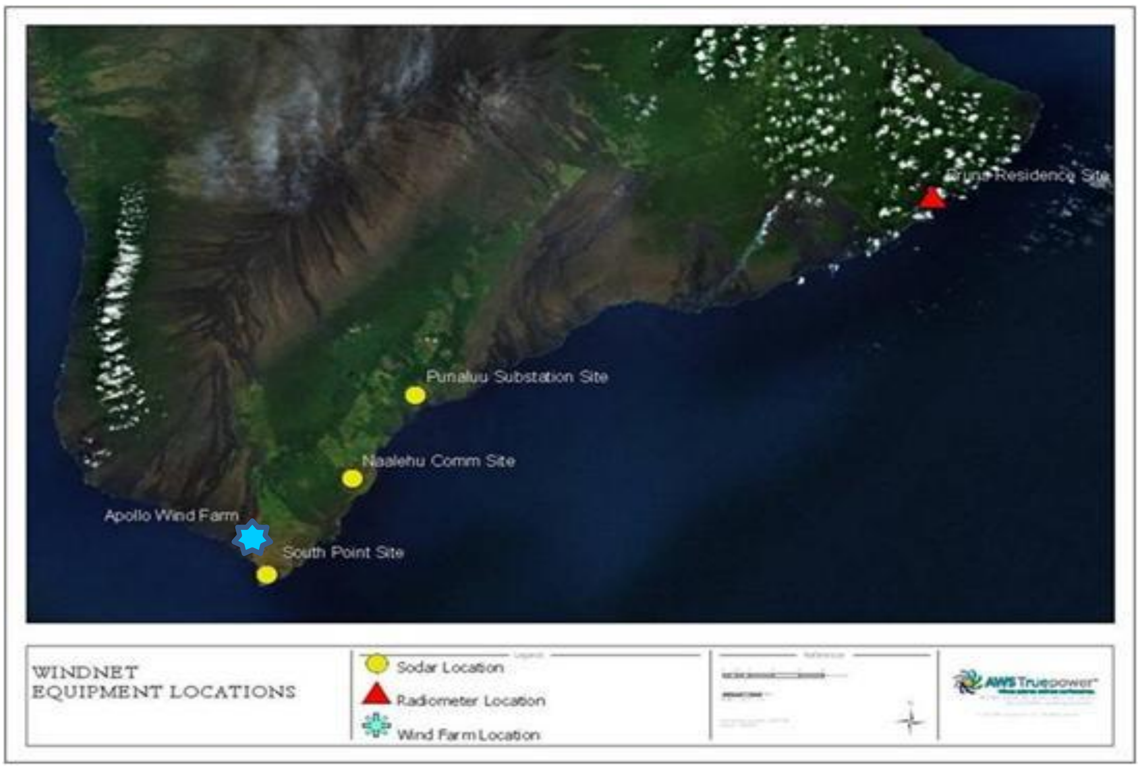


Figure 4.1 Deployment locations for WindNET sensors on the Big Island of Hawaii.

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.

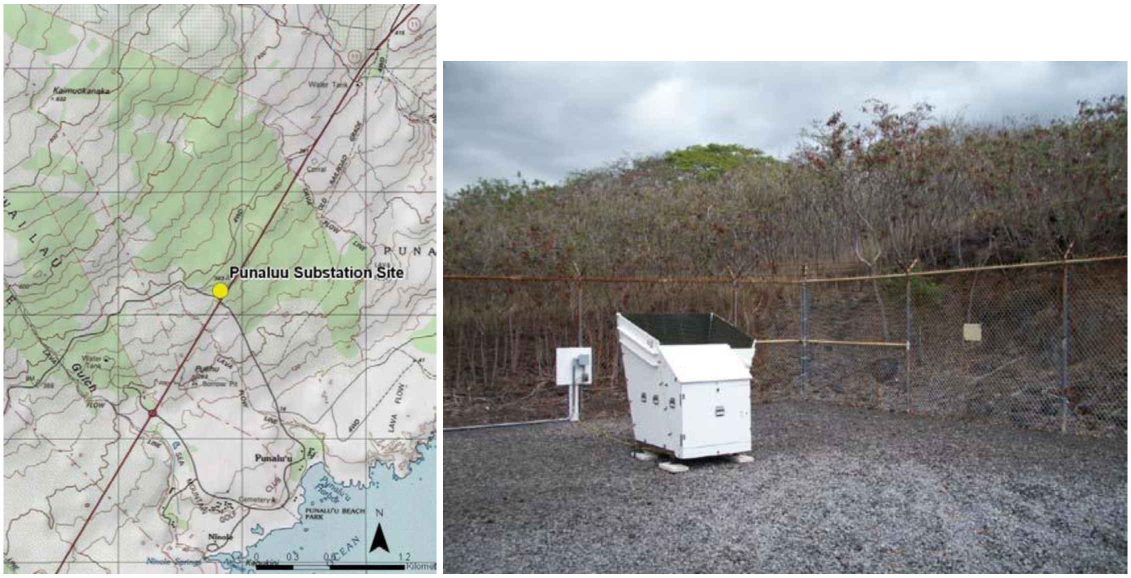


Figure 4.2 Utility powered SODAR at Punaluu.

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

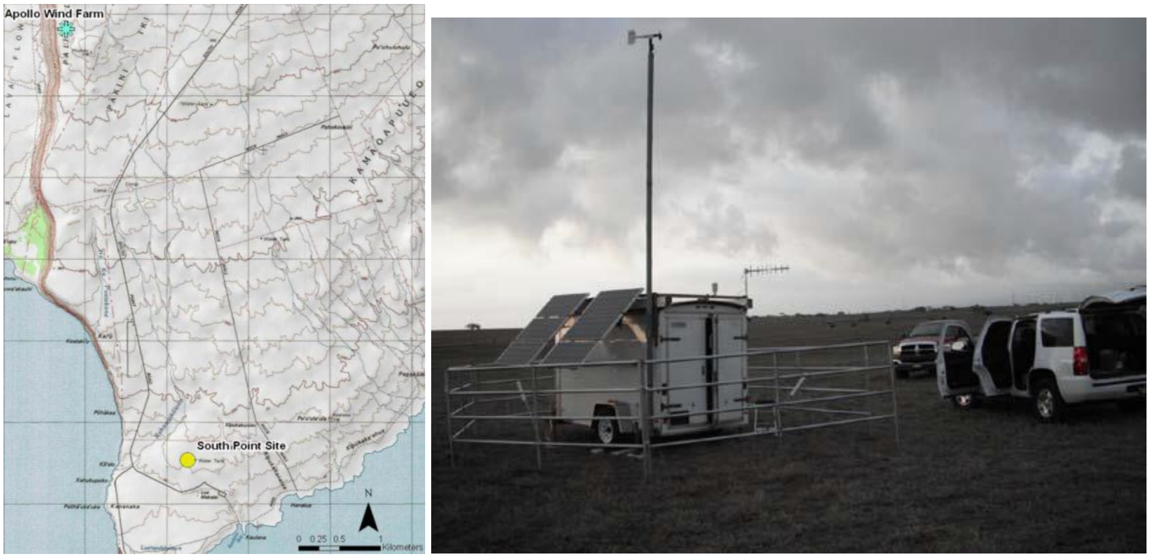


Figure 4.4 Solar powered, mobile SODAR with met-mast at South Point.

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.

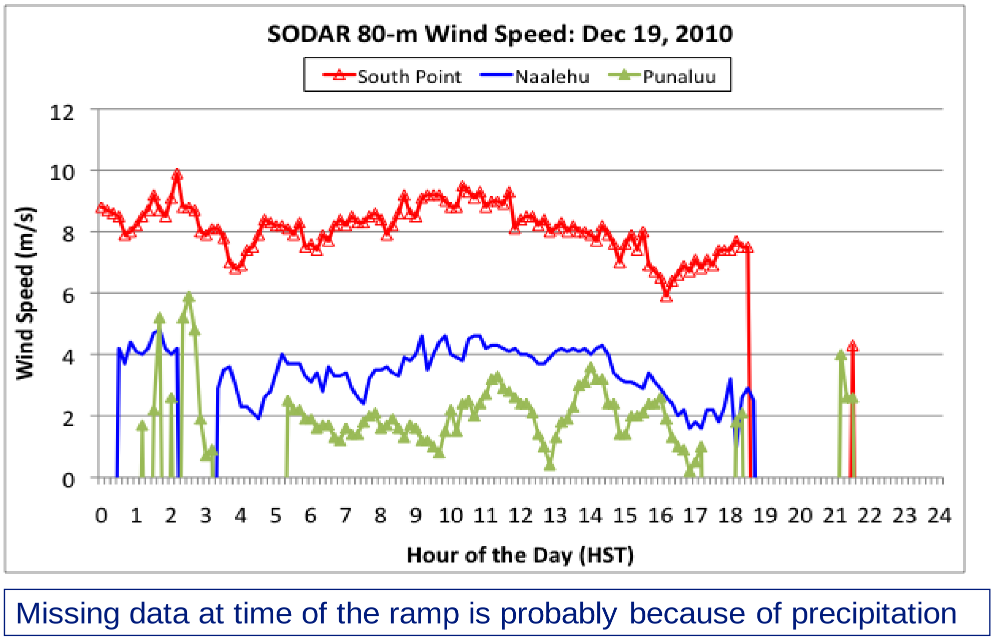


Figure 4.6 80m level SODAR wind data.

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.

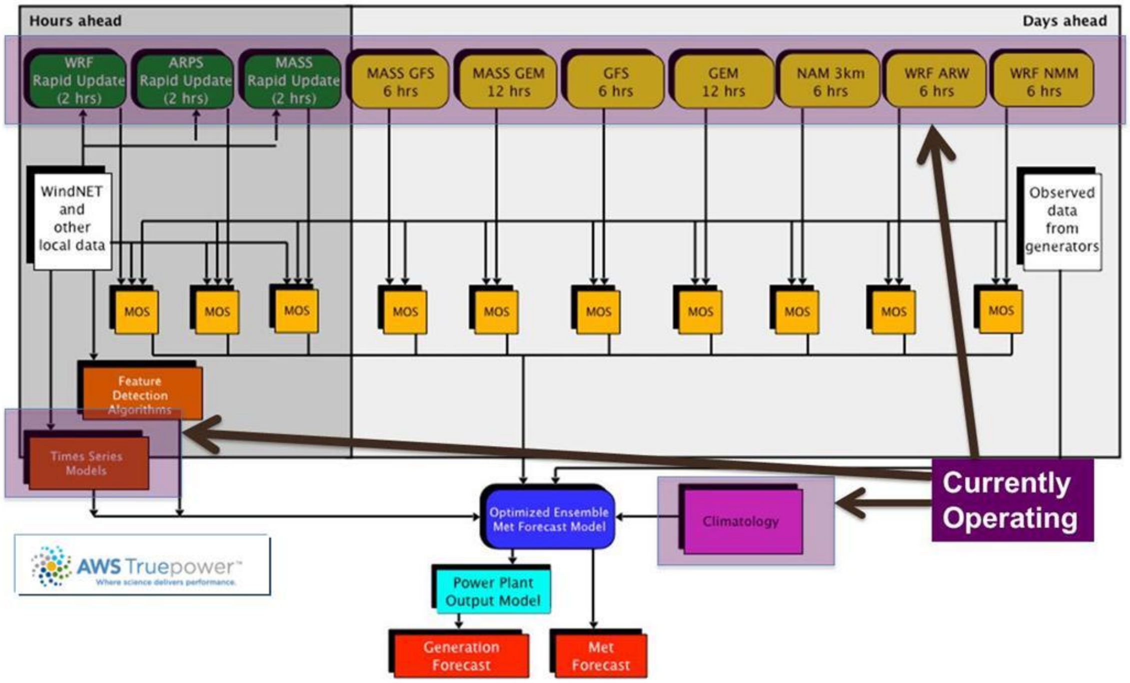
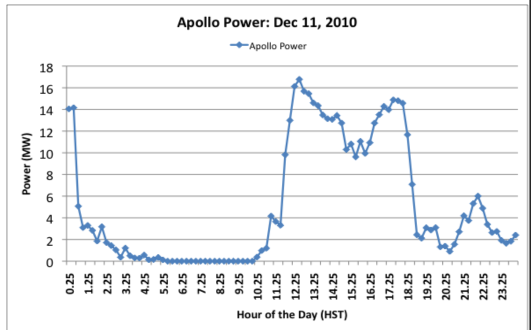


Figure 4.7 AWST Integrated WindNET Forecasting System developed for Hawaii.

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



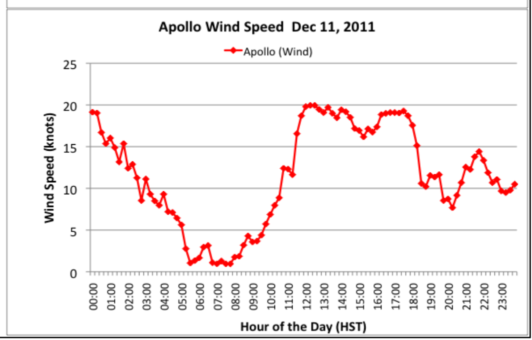
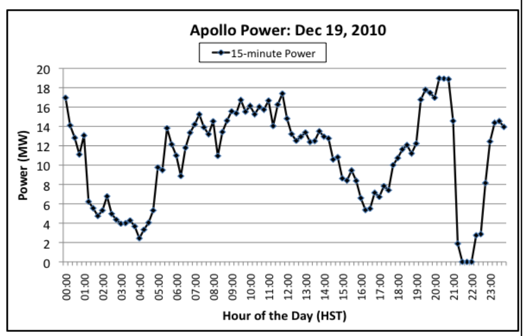


Figure 4.8 December 11, 2010 ramp event conditions.

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



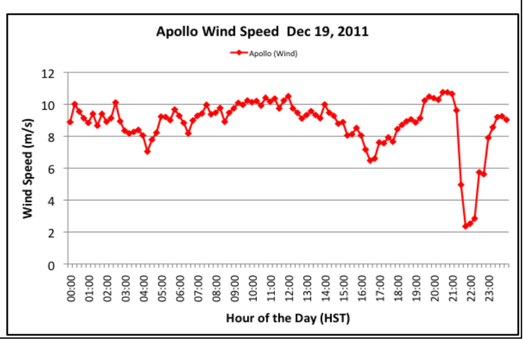


Figure 4.9 December 19, 2010 ramp event conditions.

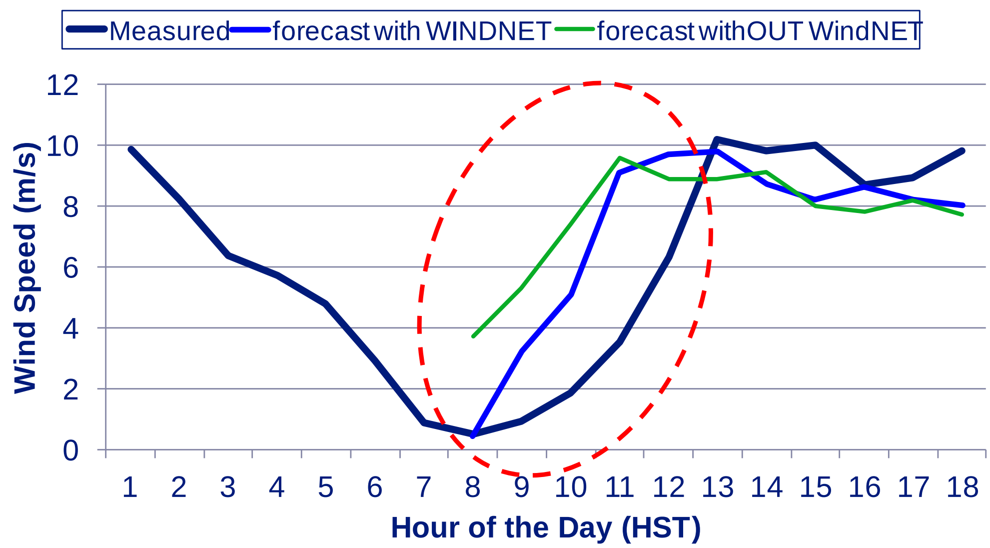


Figure 4.10 Comparison of December 11th measured ramp and rapid update NWP forecasts with and without WindNET data for South Point.

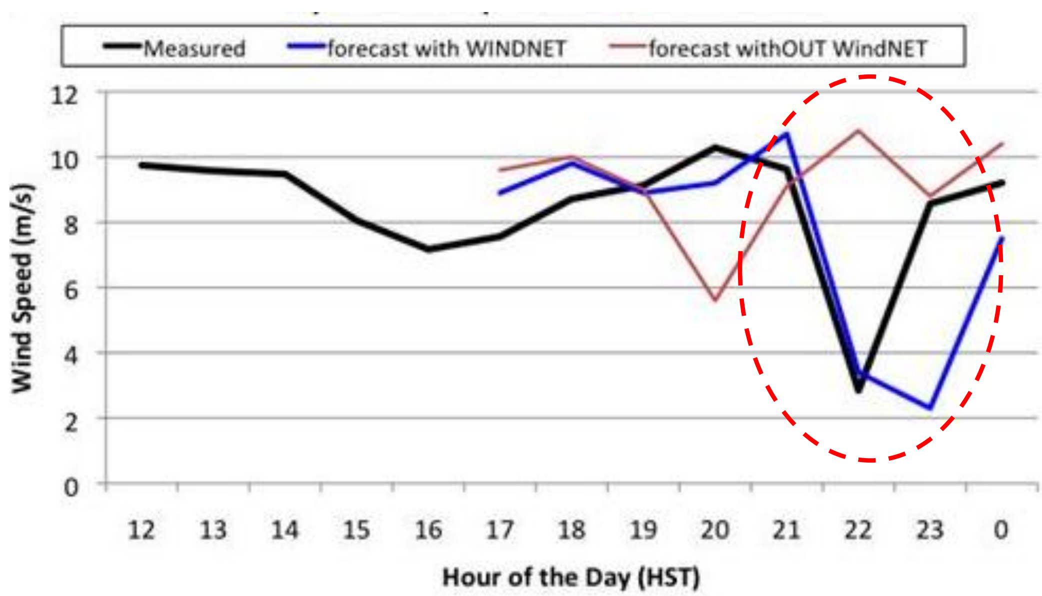


Figure 4.11 Comparison of December 19th measured ramp and rapid update NWP forecasts with and without WindNET data for South Point.

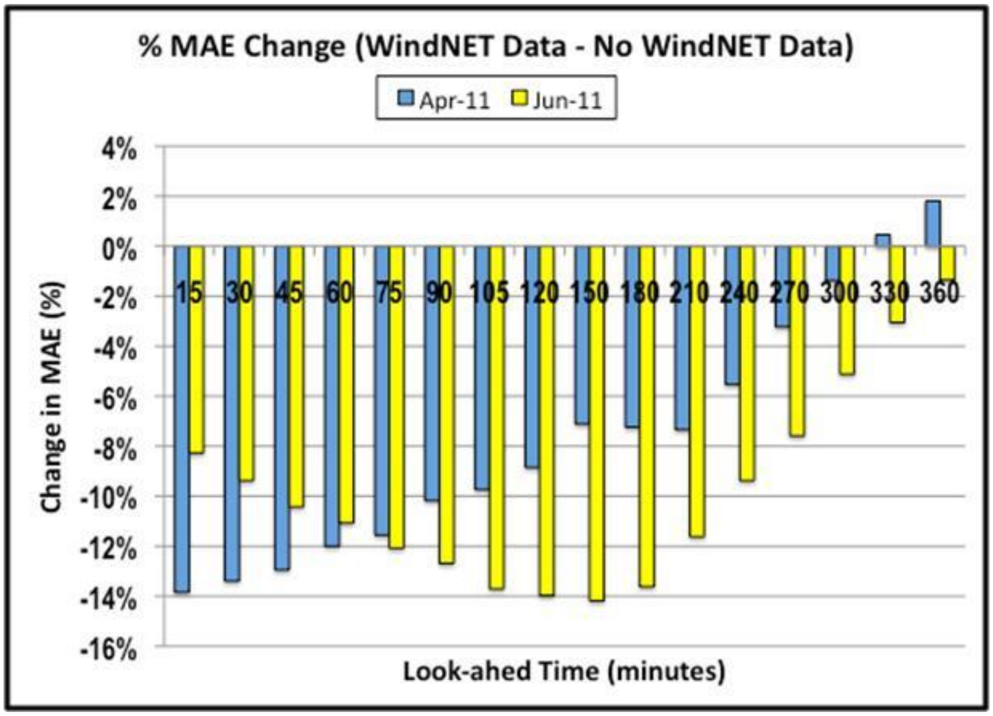


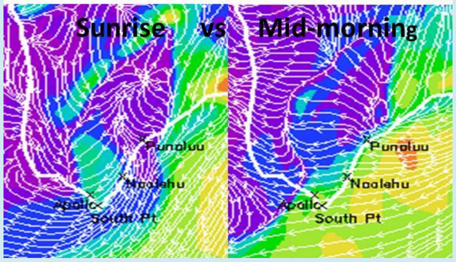
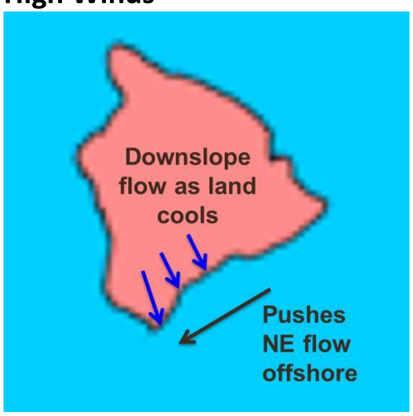
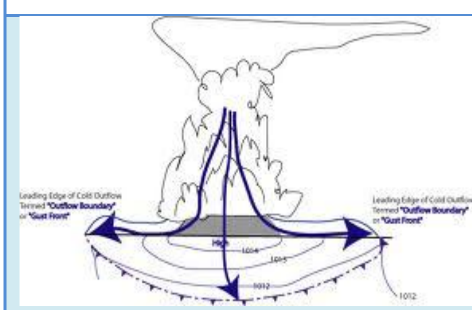
Figure 4.12 Comparison of December 19th measured ramp and rapid update NWP forecasts with and without WindNET data for South Point.

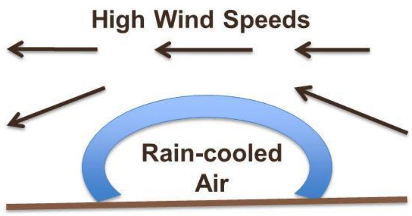
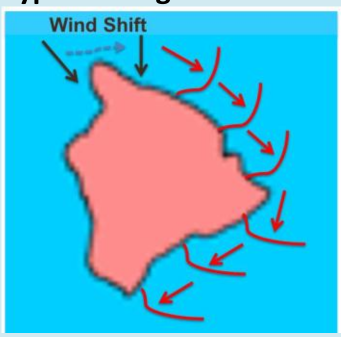
In addition to using WindNET remote sensors to capture new upper atmospheric data and vertical wind and temperature profiles for improving wind forecasting models, AWST reviewed historical event data that impacted the system and performed some initial validations using hind-casting techniques. AWST reviewed 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.

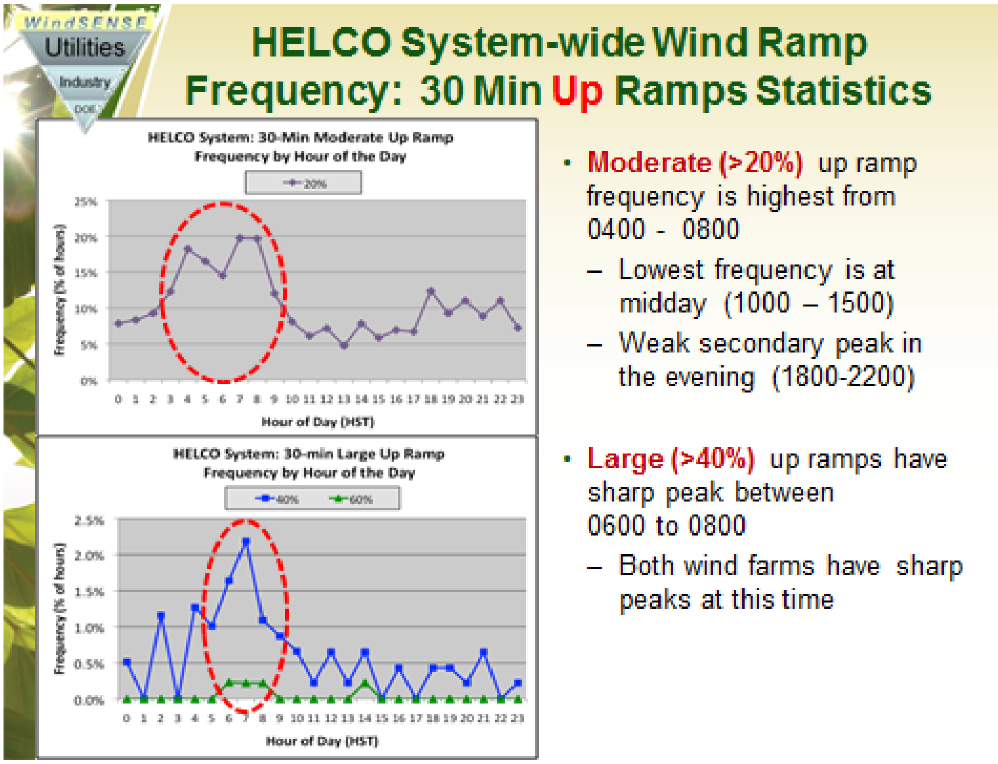


Figure 4.13 Assessment of 30-minute upward ramp rate frequencies for moderate (20% of capacity) and large (40 to 60% of capacity) ramps.

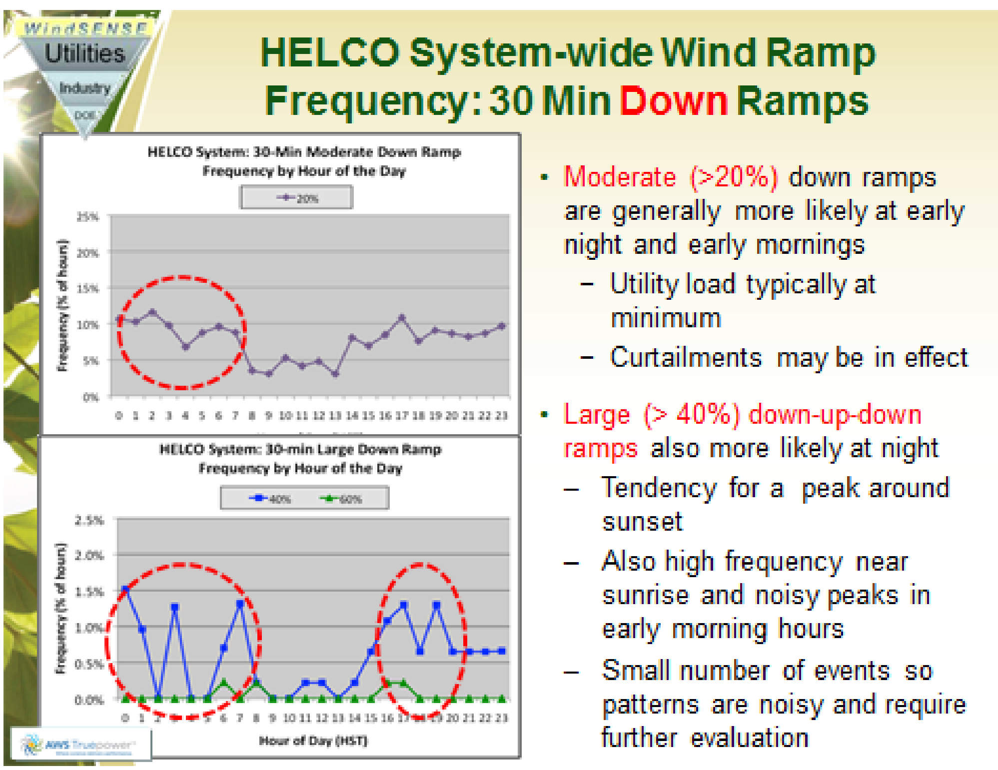
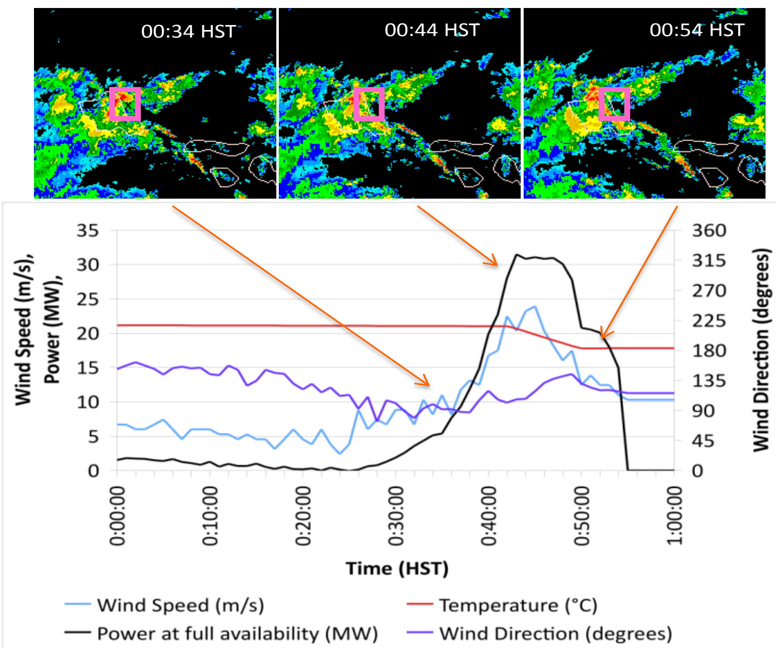


Figure 4.14 Assessment of 30-minute downward ramp rate frequencies for moderate (20% of capacity) and large (40 to 60% of capacity) ramps.

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.

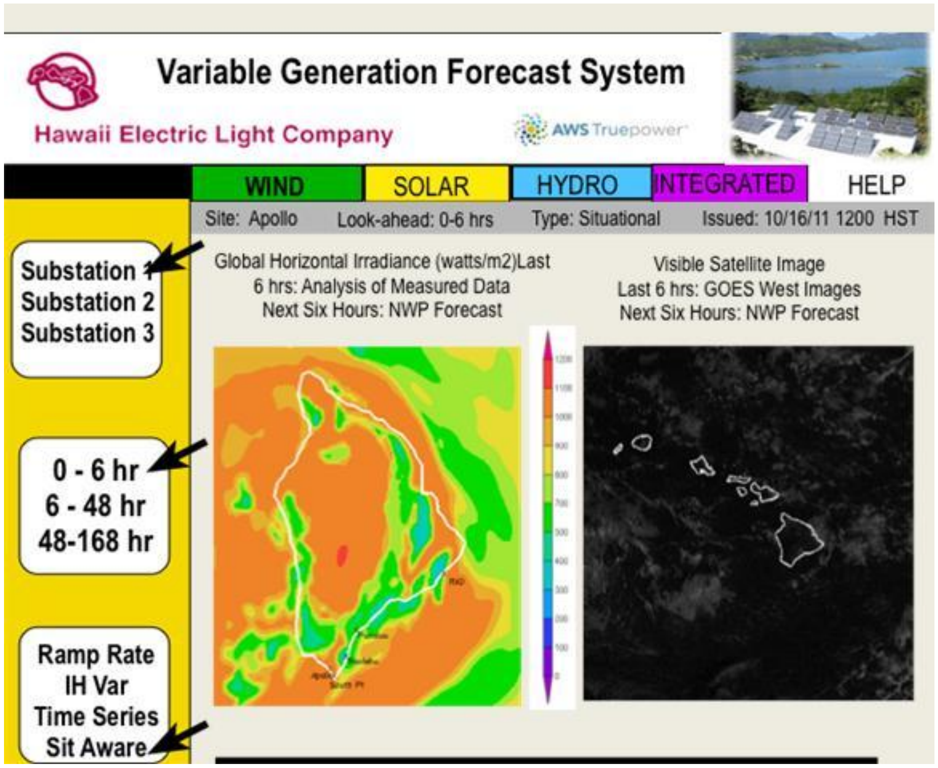


Figure 4.16 Pilot variable generation forecast interface for grid operators.

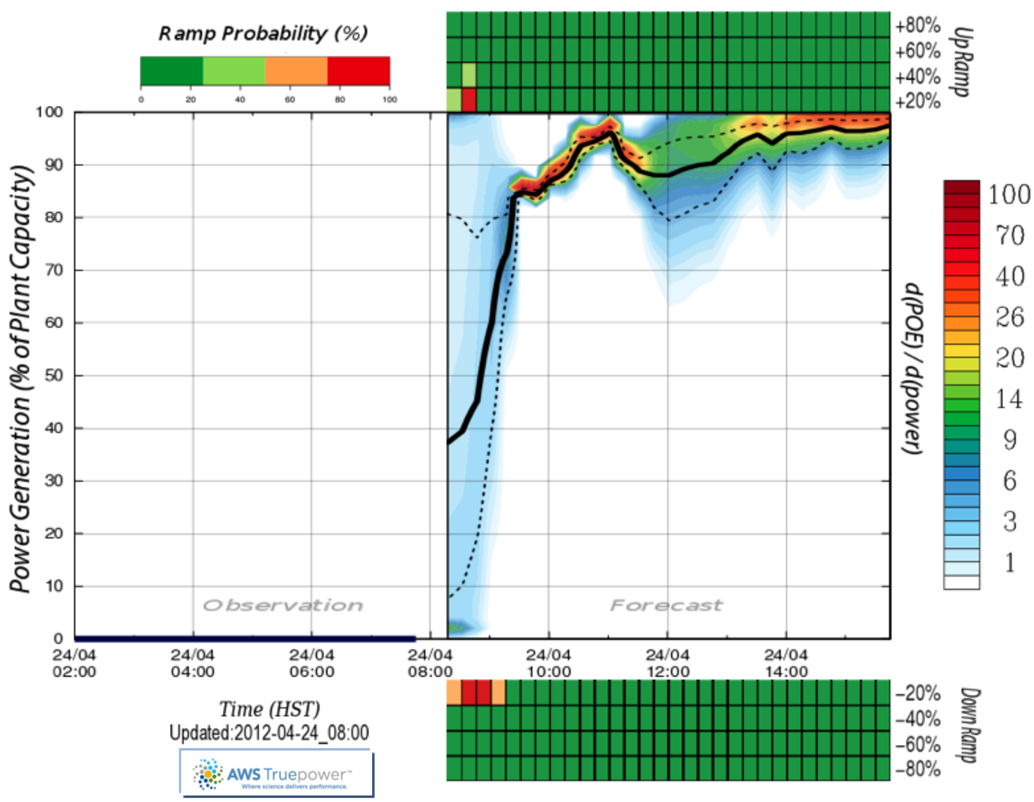


Figure 4.17 Pilot visual display integrating observed trends, forecast, ramp up and down statistics and probability confidence spectrum.

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.

5.0 Initiative 2: PMU Deployments Experiences & Findings

Initiative 2 provided utilities hands-on experience to using high resolution, high frequency information from PMU devices, to begin to define how best to gather more grid intelligence and to evaluate more automated control schemes and other T&D automation to increase visibility of system conditions and management of high levels of variable resources (i.e. wind, solar and distributed generation) [26].

During the Phase 1 – Planning, HELCO and HECO staff investigated sites on the HELCO system where PMU data would be useful and inventoried existing locations for space to install PMU devices. During this process, a number of PMU-ready Schweitzer SEL-351 (Figure 5.1a) devices were identified on HELCO's system. Originally, the idea was to activate the PMU functions on the SEL-351 devices in addition to installing new SEL-351 devices since these devices were compatible with existing inventory and hardware. However, upon further investigation, the existing SEL-351 were dedicated protection/control devices, and it was recommended that for purposes of this initiative, separate devices be procured to minimize any risk of interference between the protection/control function and the PMU data collection/communication function. Ultimately this decision to separate the devices proved to be the most advantages for the project for the following reasons:

- Issues were encountered when using the SEL-351 and the data concentrators. SEL-451 had no issues interfacing the SEL data concentrators and communication equipment
- Due to manufacturer hardware upgrades, SEL-451 units with expanded I/O functionality was recommended by Schweitzer for installation as PMU devices
- SEL-451 were comparable in price to the older SEL-351 model and affords future expansion ports for new data and automation needs
- SEL-451s offered additional data features found in Schweitzer's SYNCHROWAVE® Central Visualization Analysis Software

In Phase 2 – Deployment, HELCO and HECO staff worked to identify and finalize sites on the HELCO system that could accommodate the SEL-451 (Figure 5.1b).

(a)

(b)

Figure 5.1 SEL-351 (a) and SEL-451 (b) for rack mount installations.

Seven PMUs were procured along with corresponding Synchorphasor Vector Processors (SEL-3378), a central phasor data concentrator software (SEL-5073), communication equipment and other hardware to install at existing substation switchgears. Table 5.1 lists the locations and coverage on the Big Island.

Table 5.1 Initiative 2 Project Relays designated for PMU data collection.

ID No.	Type	Manufacturer	Location	Notes
2959	SEL-451	Schweitzer	Haina Sw Stn	Near Hamakua Energy Partners
2960	SEL-451	Schweitzer	Haina Sw Stn	Near Hamakua Energy Partners
3026	SEL-451	Schweitzer	Keahole CT-4	At HELCO Keahole plant
3027	SEL-451	Schweitzer	Keahole CT-5	At HELCO Keahole plant
3028	SEL-451	Schweitzer	Keahole ST-7	At HELCO Keahole plant
3029	SEL-451	Schweitzer	Kanoelehua HILL 5	At HELCO Hilo Hill plant
3030	SEL-451	Schweitzer	Kanoelehua HILL 6	At HELCO Hilo Hill plant
3010	SEL-451	Schweitzer	STOCK (C11,S4)	Spare

Figure 5.2 shows the SEL's recommended configuration used to interconnect the PMUs for real-time synchronized monitoring. All PMU units were located on HELCO's 69 kV transmission system close to generators to assess impact on the system due to plant and also impacts on the plants due to induced variability elsewhere on the grid. The deployment strategy enables operations and engineering to track and reconstruct events using high quality PMU data, as illustrated in Figure 5.3.

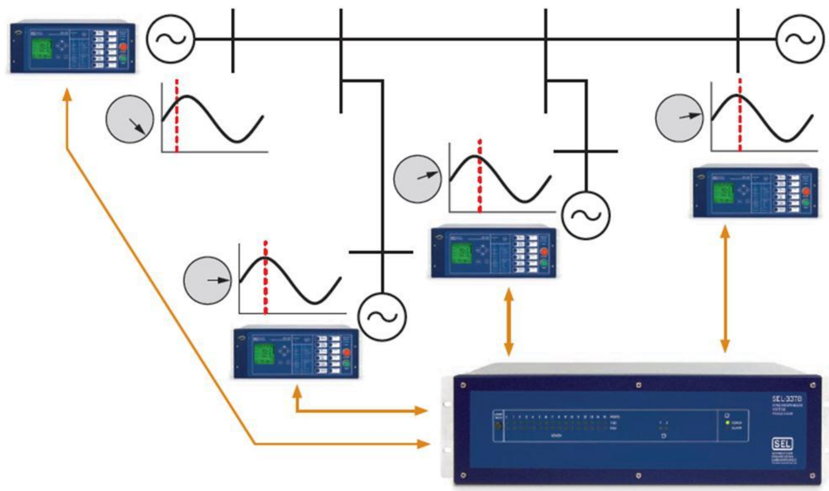


Figure 5.2 Typical configuration using wide-area generation control (SEL-3378) and remote PMUs (SEL-451). (Source: SEL)

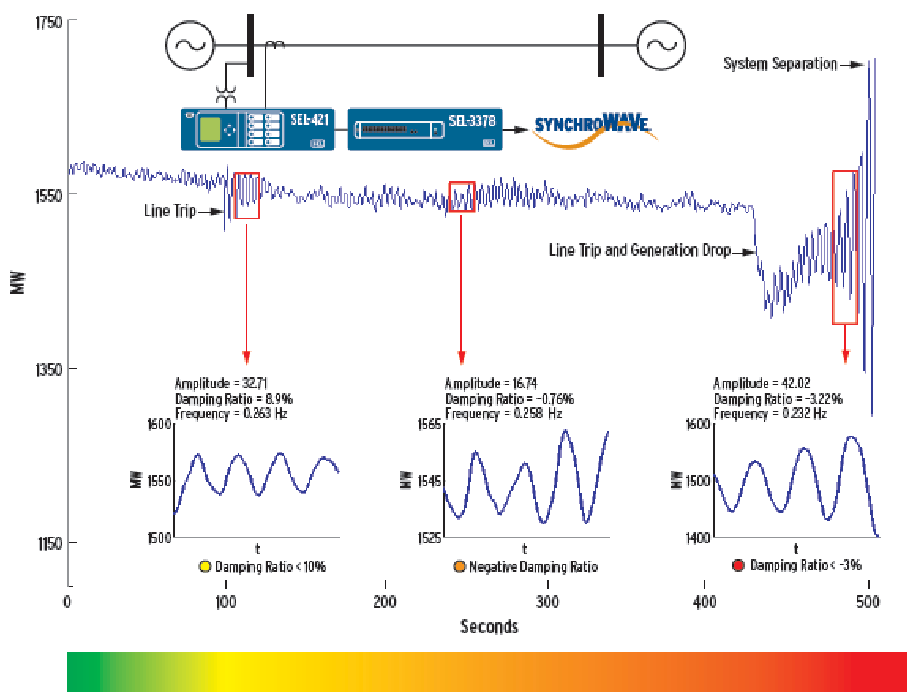


Figure 5.3 Desired future capability to detect and capture unstable operations to validate model predictions. (Source: SEL)

Complexities arose during utility deployment efforts. Due to the limited timing of the Wind HUI project and project funding period, deployments had to be coordinated with existing utility work load and crew schedules. HELCO engineering staff supported a number of the deployments in order to help expedite installations to complete deployments and allow for follow-in data collection. In total, 7 PMUs were deployed in the field and are currently in operations. Insights gain would inform future deployments of PMU devices on

HELCO/MECO/HECO systems and inform data management and data analysis tools that offer more grid intelligence for the Hawaiian utilities. Information would further support variability management needs at high penetration levels not only in Hawaii but in support of national efforts.

As installations were completed, staff began configuring the software and retrieving data for analysis purposes. Schweitzer staff came on site in April of 2011 to provide onsite technical support and training on the SYNCHROWAVE® software tool [29]. Initial software deployments ran into version control issues and several months of data collected were over written. During that period, a system voltage anomaly was captured but as the PMU data was over written, no analysis could be conducted. System SCADA information detected depressed voltage levels spreading across a significant portion of the HELCO system, however within the one to two SCADA 2-second scan cycle, the system recovered. Since that event the PMUs have been collecting data but the voltage sag has not reoccurred.

Phase 3 efforts, ongoing data collection and analysis is proceeding with no further software or version control issues. Over the course of the last several months, utility staff has been working to resolve ITS and cyber security issues associated with the sending of system information over the network. Internal resources are working to resolve this standards and procedures issue to facilitate real-time use of information for operations and planning.

Figure 5.4 are snapshots from the SYNCHROWAVE® software showing the PMU outputs capturing a unit outage April event. Detailed event data on unit response, phase angles and frequencies has been gathered and used for analysis; however, significant events of interest related to variability of renewables have yet to be captured. Data gathered thus far has been valuable and plans are to continue evaluation of SEL analysis software features, provide staff training on PMU capabilities and continue PMU site evaluation and deployment on HELCO system in consultation with System Operations.

Based on the findings and capabilities jumpstarted in this initiative, HELCO is pursuing additional sites for PMU deployment and data collection (Table 5.2) and shows utility commitment to enhance existing infrastructure and prepare the system for more grid automation and intelligence. Onsite training support by SEL will also be continued.

Table 5.2 Ongoing PMU data collection as part of continuing HELCO efforts.

ID No.	Type	Manufacturer	Location	Notes
2858	SEL-421	Schweitzer	Kamaoa 6602 Line	Near South Point wind farm
2862	SEL-421	Schweitzer	Kamaoa 9601 Line	Near South Point wind farm
2957	SEL-451	Schweitzer	Puna Plant GSU	At HELCO Puna plant

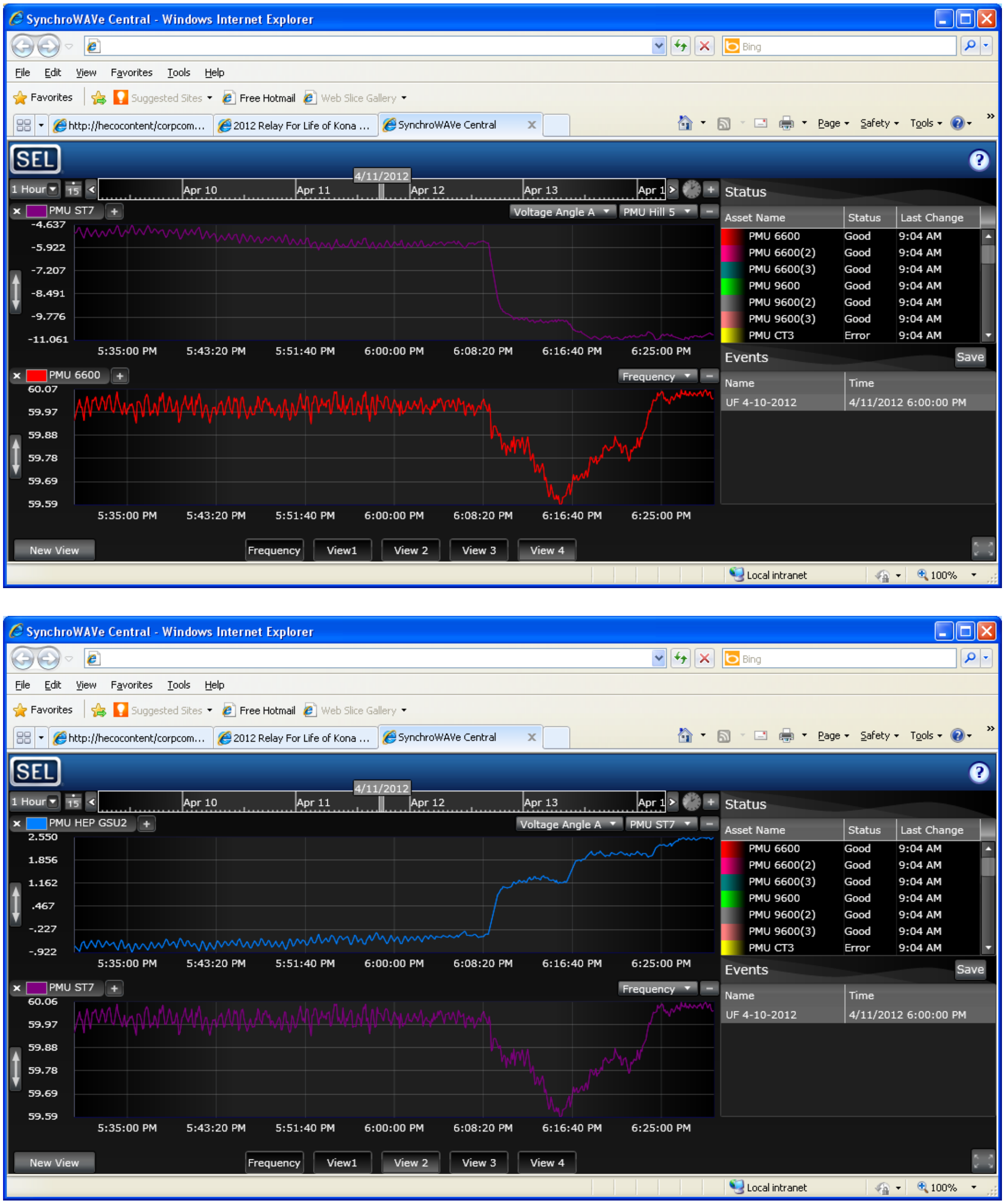


Figure 5.4 Screenshots of PMU from the SYNCHROWAVE® software.

6.0 Initiative 3: GSG Framework Development Experiences & Findings

Initiative 3 efforts were the first to kick-off as part of Wind HUI initiatives as the utilities were already investigating grid automation options using smart technologies. In response to the HCEI Energy Agreement, HECO/HELCO/MECO already organized a Smart Grid Task Force. The task force meetings provided a forum to gather input from a diverse group of subject matter experts across all three companies with mission to

- Create an initial Corporate Road Map for smart grids which shapes the HECO, HELCO, and MECO grids towards the integration of renewable energy;
- Develop a detailed cost effective path towards implementing a smart grid on the Hawaiian Electric Companies' systems;
- Keep abreast of, and if possible participate in, forums for developing smart grid solutions such as standards for communication, cyber security developments, intelligent electronic device capabilities, etc.
- Keep abreast of the Hawaiian Electric Companies' smart grid project implementations;
- Establishing a smart grid road map and blueprint for the smart grid effort.

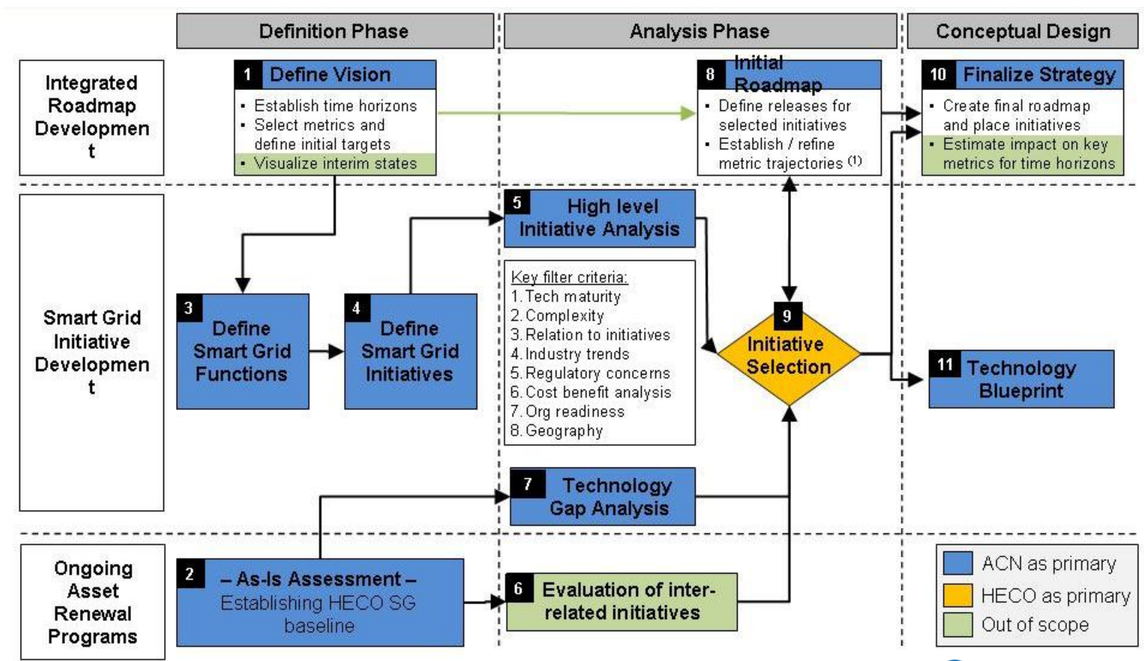
Table 6.1 captures the Smart Grid Task Force's preliminary, high level perspective and approach on developing a roadmap. This summary incorporated both internal and external factors affecting the operation of the Hawaiian Electric Companies and provided background information for the smart grid visioning and approach introduced by Accenture (ACN) for the GSG Framework development. Initiative 3 efforts complemented the mission of the Smart Grid Task Force and introduced industry "best-practices" and tools to develop an initial GSG Framework. Efforts also provided new expertise on smart grid architecture that was not found within the traditional utility environment.

As Phase 1 – Planning for Initiative 3 kicked off, Accenture reviewed existing information provided on the Smart Grid Task Force and continue to leverage task force members to provide input and review progress. The new GSG Task Force was comprised of utility staff across the company supporting renewables initiatives and included operations, renewable energy planning, T&D planning, AMI and customer programs on load control and later augmented to include other areas such as communication, ITS and asset management. Well over 40 staff was involved in the GSG Task Force providing input and expertise to help shape future infrastructure needs.

Table 6.1 Preliminary HECO Smart Grid Task Force Purpose and Objectives

Time Frame	Mobilization/Preparation/RoadMap	Solidification of Smart Grid Methodology	Full Deployment of Smart Grid Methodology	Optimization of the Installed Technology
Objectives	• Mobilize Smart Grid Transformation Process • Identify/Verify Key Design/Deployment Methodologies and Supporting Technologies • Establish Plan for Multi-company Common Technology Convergence/Leverage • Execute Prioritized High Value Programs	• Refine Design/Deployment Methodologies, Course Correct • Verify Key Technology and Solution Scalability • Incorporation of significant DER in Distribution System • Prioritized Rollout by Value Assessment • Expand on Transmission System Preparation and Renewable Energy Resource Integration	• Full Deployment of Established Technologies and Processes • Verification/Integration of Initial Large Scale Renewable Energy Resources (Target 30% of 2030) • Assess Management of Combined Aggregate Load and DER reserve • Expand Distribution DER and aggregate demand management/response	• Rollout of Integrated Renewable Energy Resources to Achieve 2030 targets • Expand Demand Management and Response Programs • PHEV Expansion • Fully Integrated Island Utility Systems
Capabilities	• Subset of staff retrained in new paradigm • Change Management know-how and plan • T&D O&M Process Changes • Prepared for Transformation to Smart Grid paradigm	• Strengthened Distribution and Transmission Grid • Integration of Distributed Energy Resources • Pervasive and secure communications established • Change Management process on-going	• Ability to incorporate large variable generation into network • Ability to Model and Manage more dynamic stability issues • Integrated Transmission and Distribution Demand Management (Surgical) • Microgrid management and PHEV Integration	• Fully integrated Operations and Maintenance Processes and Systems with Large Scale Renewable Energy Resources • Broad integrated DER • PHEV integration on community scale
Value	• Initial reliability, efficiency, and safety gains acquired in Distribution • Initial gains quantifiable and demonstrable to PUC • Related initial cost savings achieved and prioritized next steps	• Scaling of reliability, efficiency and safety gains • Consumer participation established • Prepared to Incorporate Large Scale Renewable Resources • Improved Asset Utilization/Management	• Reduction in dependency on non-renewable energy resources (reduced fuel costs) • Direct access to Demand and Demand offset to compensate variability of generation • Continued gains in asset utilization and efficiency	• Adherence to governmental renewable objectives • Managed reduction in non-renewable fuel costs and dependencies • Reliability and efficiencies maintained or improved • Transmission Stability • DER, DSM/R/PHEV established
Key Technology Area Focus	<u>DISTRIBUTION/CONSUMER</u> • Transmission Stability/PMUs, Data Collectors, EMS Upgrades • Preparing Central Station Generation (Unit tuning, AGC tuning, EMS interface upgrades) • Distribution Reliability/Operations (DMS, SA, DA, Design/Planning, Fault Location) • Crew Efficiency/Metering (AMI, MDMS) • Customer Interface/Demand Management/Response • Communications/SCADA and Security • Standards and Solution Integration	<u>TRANSMISSION/DER</u> • Real-time Information Filtering and Large Scale Visualization • Real-time Transmission Dynamic Stability on the Transmission System • Complete Central Station Improvements • Transmission Reliability/Operations • Micro-Grid Protection and Control • Consumer Demand Management and Response • Wind Forecasting and Capacity Alternative Planning • PHEV Technology and Analysis Modeling	<u>RENEWABLES - DSM/DER</u> • DC Cable/Station Modeling and EMS Application Enhancement • Large Scale Variable Generation Dispatch and Management • Demand Reduction/Offset Capacity Assessment and Management • PHEV Operations Analysis Applications	<u>RENEWABLES/ DSM/DER / PHEV</u> • Large Scale Wind and Dispatch Analysis • Demand Resource Optimization

In Phase 2, Accenture staff introduced a more systematic approach and facilitated several meetings to introduce utility management and GSG Task Force on the assessment framework and a set of “best-practices” performance tools [Appendix I3-1]. A series of information workshops were scheduled to first inform management and GSG Task Force staff on the process. Next, site visits and inventory review meetings were conducted with subject matter experts (SMEs) from each utility on current practices for equipment procurement, maintenance, equipment selection and replacement evaluation. Site visits and surveys were critical and had to be conducted with Accenture team and utility SMEs to identify unique infrastructure and limitations on each of the island grids. Interactions provided the Accenture team perspective on each of the island grid’s operational conditions/resources/challenges. Findings including limitations, gaps, challenges and results were reviewed in workshops with GSG Task Force so there was opportunity for further feedback from staff on next steps and recommendations.



Source: 2010, GSG visioning process for HECO by Accenture.

Hawaiian Electric Company

Figure 6.1 Overview of GSG visioning process.

The overall visioning process is depicted in Figure 6.1 and illustrates the systematic evaluation and development approach used by Accenture to guide the process in developing the baseline, vision, focus initiatives and arriving at recommended implementation plans or “blueprint” for each of the utilities (HECO/MECO/HELCO). This was followed by a series of interviews and meetings with personnel from throughout the Companies’ operating and business departments.

The initial products of the GSG framework process was the completion of individual "as-is" documents for each of the operating companies, which served as the reference point for defining gaps between the current state of each company and a future vision of the smart grid. Rather than focusing on specific technologies or features [30] of a particular technology right at the beginning, Accenture staff focused on defining value added across the enterprise given a particular enhancement feature or lack thereof.

During Phase 2 – Deployment, Accenture staff provided an initial technology framework with "typical" layers of technology to begin discussions with guidance on down selecting to a set of priority layers to focus on. Figure 6.2 shows the initial GSG technology framework.

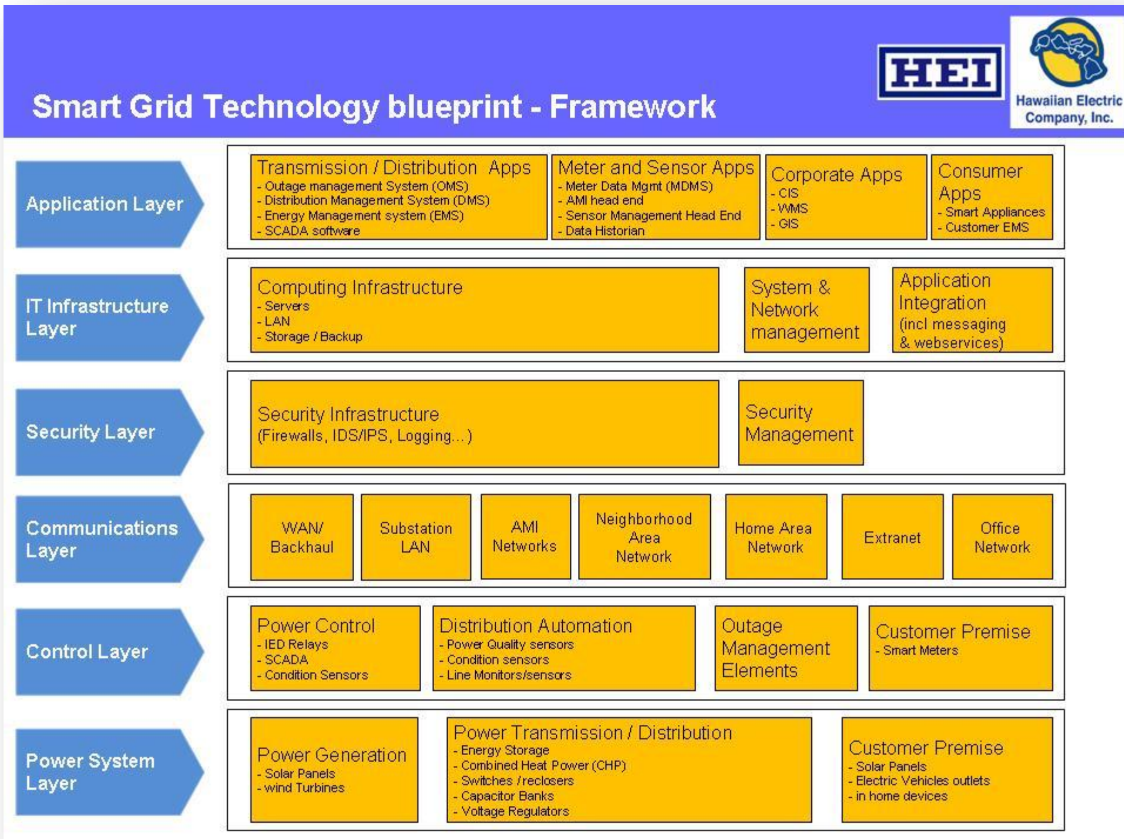


Figure 6.2 Initial GSG Technology Framework for Hawaii utilities.

Identified gaps were documented for each layer in the technology framework and assigned a value of High, Low and Medium priority and complexity for each of the operating companies (Figure 6.3). The assignments varied across the operating companies but there were commonalities amongst the priority issues. Based on their interviews and discussions with SME and use of their performance tools, technology layers were then filtered based on readiness levels and risk posture of the utilities. For example, if organizational resources were not available to implement a technology, were there alternative technologies to implement first then build capabilities and expand organization. Identified gaps, priority and other factors identified in Figure 6.3 played into the analysis but matching the readiness level of technologies to the readiness of utility resource capabilities ensured that recommended options and down selected priorities were of value and could be sustainably implemented.

Application Layer Gaps

HEI — Hawaiian Electric Company, Inc.

Gap	Description	Priority	Complexity
The need for an AMI head end system	AMI system head end to manage the new network of smart meters to support sensor telemetry and control	H	H
Meter data management system	The meter data management system (MDMS) will be used as a central depository for meter data to complement the new AMI system	H	H
Customer energy management system	This system is intended to store customer data for energy management such as in premise device inventory, registration and commissioning	L	M
Distribution management system	A suite of application software that support electric system operations and is an enabler for utilizing many new smart grid monitoring and controls. This could be an extension of the current EMS. One consideration could be to have a single DMS/OMS solution to allow for native integration between the two, fewer versions of the real-time grid state model, and more efficient distribution operations.	H	H
Demand side management system	System to manage peak demand and shape load throughout the distribution system via prediction algorithms, automated scheduling and advanced measurement and verification tools. High priority due to the PUC's loading order (HCEI Agreement)	H	M
Sensor management system	This system will manage the remote measurement and reporting of information that the new smart grid sensors provide	H	H
Data warehouse/portal	The customer portal to visualize the customer energy usage, meter sates, rates and tariffs	M	M
Enhanced CIS	Enhanced customer information system that supports new smart grid functionalities	H	H
Enhanced WMS	Enhance work management system to support the new grid intelligence	H	H
Data Historian	Enhancements are required to accommodate all the new systems and interfaces	H	H

Figure 6.3 Identified gaps by technology layer and readiness levels.

In Phase 3 – Implementation, final technology frameworks or "blueprints" were provided by Accenture. Figure 6.4 shows the high level consolidated roadmap for the Companies. Figure 6.5 shows the same information but grouped by short-term, medium-term and long-term initiatives over a 20 year outlook. As shown, the roadmap organized the proposed initiatives and capabilities into six layers:

- Feasibility Assessments
- Foundational Infrastructure and Applications
- Transmission Automation
- Distribution Automation

- Renewable Energy/DG/PHEV Integration
- Customer Enablement and Metering

As regulated utilities, it should be noted that the Companies' efforts must also be reviewed by the Hawaii Public Utility Commission; therefore, all timelines on possible projects included in this report for planning must be viewed solely as best estimates. Efforts pursued in Initiative 3 assist the Companies in responding to recent Hawaii Public Utilities Commission request that the Companies develop an overall smart grid plan which include the Companies' AMI initiatives.

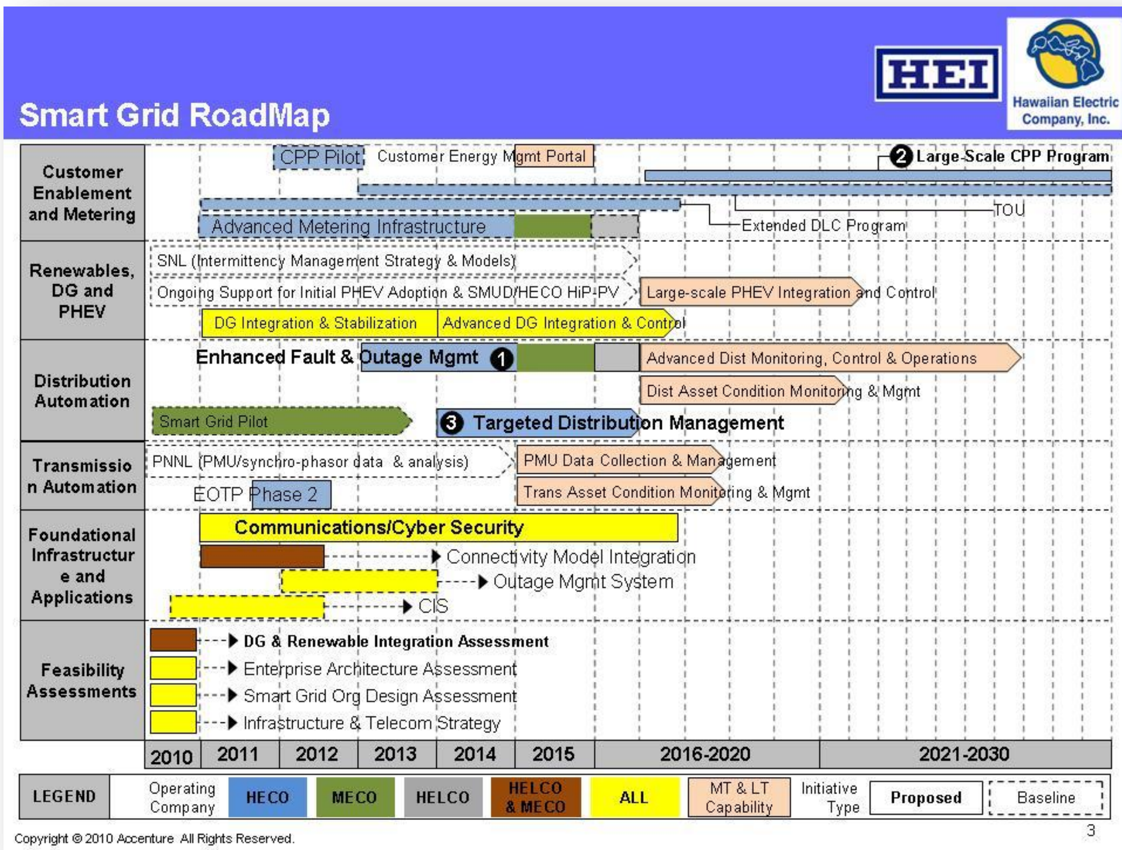


Figure 6.4 Consolidated GSG Roadmap color coded by Company.

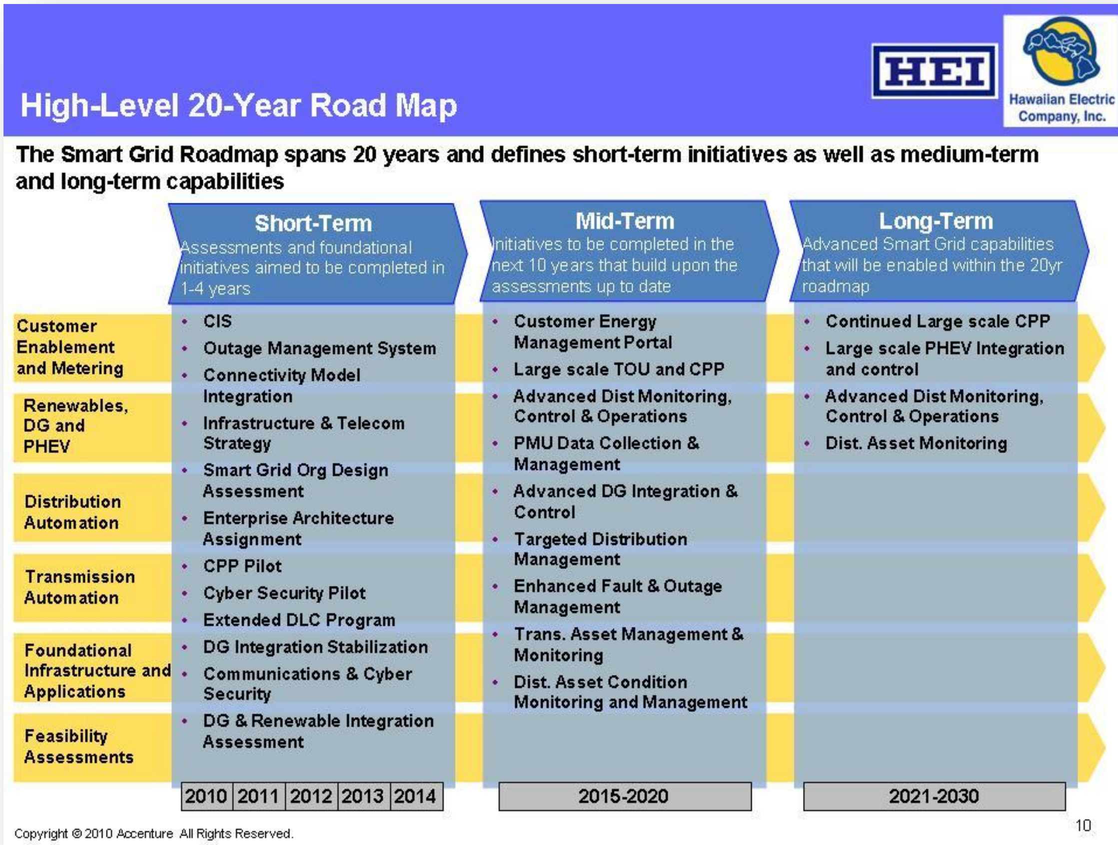


Figure 6.5 20- year consolidated GSG roadmap by short, medium and long term initiatives.

Recommendations on mid-term and longer-term priority initiatives for investment and rationale are summarized in Figure 6.6 and Figure 6.7. Figure 6.6 lists three candidate initiatives and seven capabilities in the medium and long term identified as drivers for utilities' smart grid development needs. These initiatives and capabilities are identified along with their estimated readiness impacts, in the areas of reliability, grid stability, cost to serve and safety. **Figure** 6.7 provides rationale to pursue these initiatives based on the utility GSG needs along with required short-term supporting activities to ensure successful implementation.

Figure 6.8 provides a suggested list of the required near-term activities and estimated costs for addressing these critical building blocks. These building blocks provide preparatory steps toward longer term GSG initiatives. Note, *DG and Renewable Integration* (**Figure** 6.7) consistent with Initiative 1.0 activities and *PMU data collection and management* (Figure 6.6) pursued in Initiative 2.0 were both identified as priorities initiatives and capabilities in supporting the GSG.

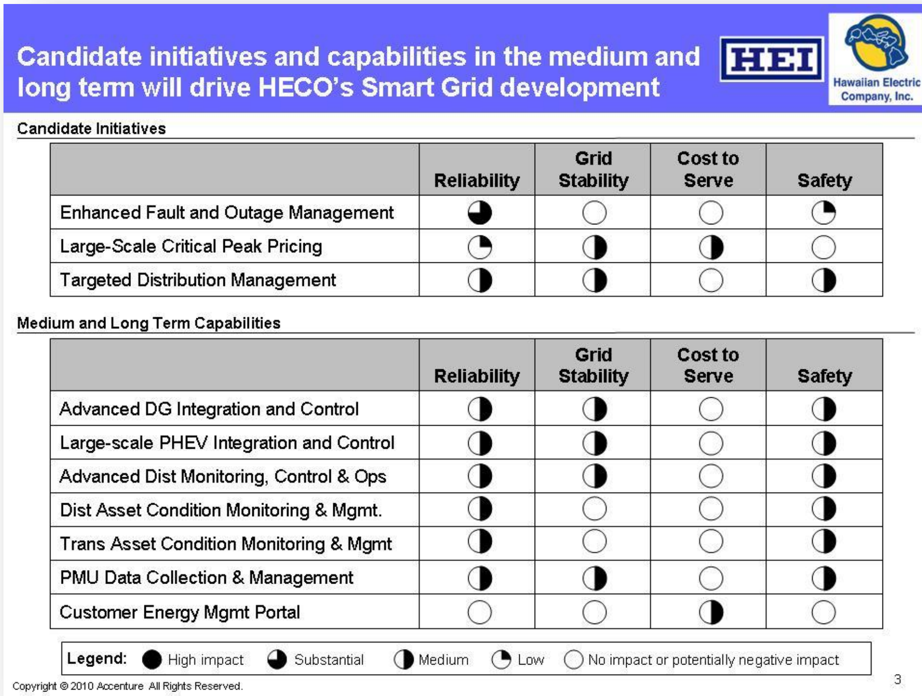


Figure 6.6 Recommended candidate initiatives and capabilities driver for GSG efforts.

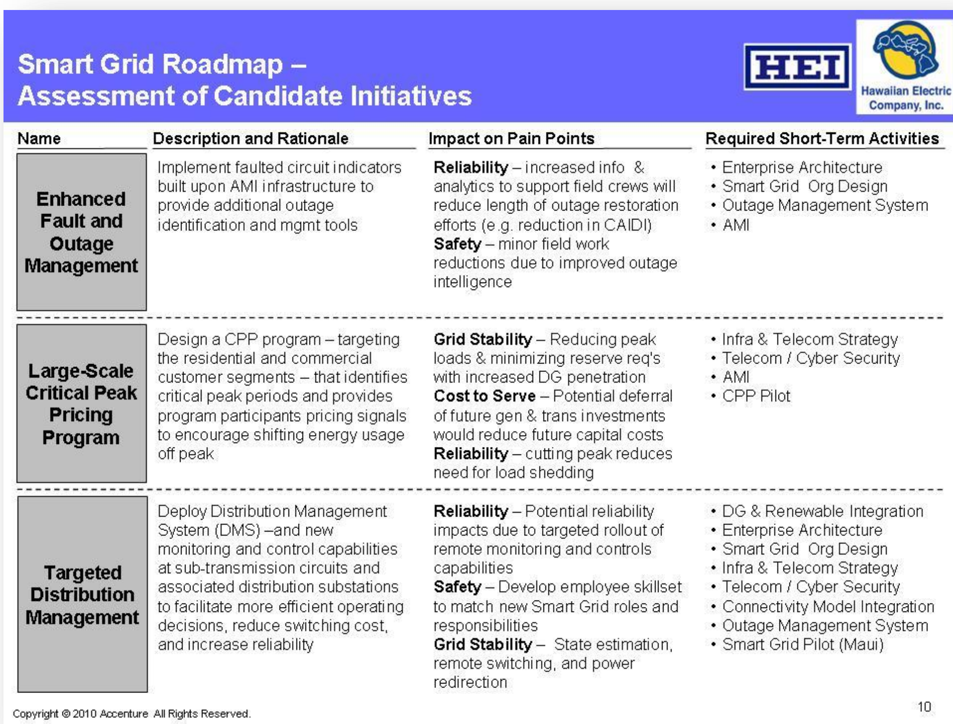


Figure 6.7 Three candidate initiatives.

Smart Grid Roadmap –
Cost Assessments for Proposed Activities (2011-2013)

HEI — Hawaiian Electric Company, Inc.

Activity Name	Description of Initiative / Assessment	Cost Requirements	Cost Estimates (1)
DG & Renewable Integration Assessment	• Assess integration of renewables, DG, energy storage & DSM into T&D grid / system ops and assess how it relates to SG	• 4-6 month effort with 5-6 fulltime resources • Solution sessions and detailed cost analysis • Engage vendors for short -long term solutions	$750K-$1M*
Enterprise Architecture Assessment	• Identify and align enterprise activities and investments across the operating companies	• 4-5 month effort with 4-5 fulltime resources • Define bus capabilities and requirements • Detailed cost analysis & vendor assessment	$600K-$800K*
Smart Grid Org Design Assessment	• Define organizational structure, reporting relationships, and job roles & responsibilities required for Smart Grid capabilities	• 4-5 month effort with 4-5 fulltime resources • Define high-level solution definition • Assess role and head count implications	$600K-$800K*
Infra & Telecom Strategy Assessment	• Facilitate & guide the development of a detailed telecom strategy and assessment across the operating companies	• 4-6 month effort with 6-7 fulltime resources • Detailed as -is and to-be analysis • Vendor assessment & detailed cost analysis	$1M-$1.5M*
Telecom / Cyber Security	• Design and implement enterprise-wide comms infrastructure to provide a backbone and support for future Smart Grid initiatives	• Costs spanning from 2011 - 2016 not included. This will be defined by the Infrastructure & Telecom Strategy	$TBD
Connectivity Model Integration	• Enhance / design / complete connectivity model integration	• Completing MECO and HELCO GIS efforts • Upgrading HECO GIS if needed • System integration	$4M-$7M*
Outage Management System	• Provide integrated application that provides real-time info and analytics to support fault ID and outage restoration efforts	• New OMS for HELCO and MECO • Updated OMS for HECO • Includes system integration	$5M-$8M*

Note (1): Cost estimates are indicative of potential ranges only. Further cost analysis needed to validate above estimates

Note (2): First 4 are assessments that are primarily O&M expenditures; last 3 are potentially capital projects

*Cost includes all three companies

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Figure 6.8 Required short-term activities needed to support mid- to longer-term GSG initiatives.

The overall Initiative was completed on time and within budget despite a very aggressive timetable of 6 months from project initiation to final presentations and project closeout. The communication effort for Initiative 3.0 was considerable and required dedicated staff time to complete. However, the process effectively demonstrated how communication and involvement across the companies provided overarching benefits. Some of benefits included

- An organized and systematic process for evaluating need based on several factors including resource readiness, cost, gaps and technology maturity
- Use of simple readiness levels as a gauge for utilities to evaluate and improve
- Recognition of both outside and internal expertise (SMEs)
- Involvement and interaction of staff across departments and across the Companies
- Recommendation of actionable options, steps, rationale with pathway and phased approach (near-, mid- and longer-term building blocks)

It is clear that significant investments and resources are necessary even in the initial stages of the Companies' smart grid planning efforts. These efforts probably would not have the same level of success or perspective without outside consultants supported via the Wind HUI. Even more important is the realization that the smart grid is an enterprise-wide endeavor that will require collaboration within and across all of the Companies. Figure 6.9 and Figure 6.10 were provided by Accenture to provide future potential perspectives on applications and architectures for a GSG.

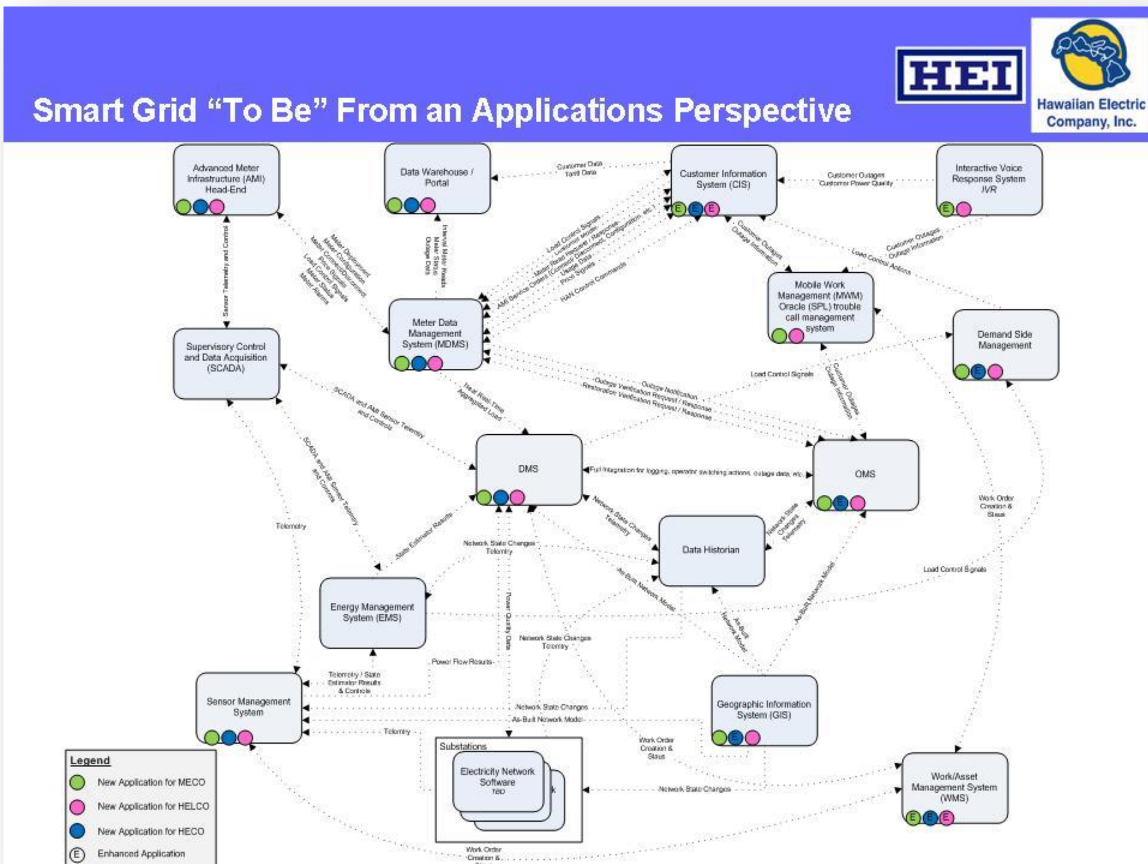

Figure 6.9 A Potential Future GSG Application Perspective.

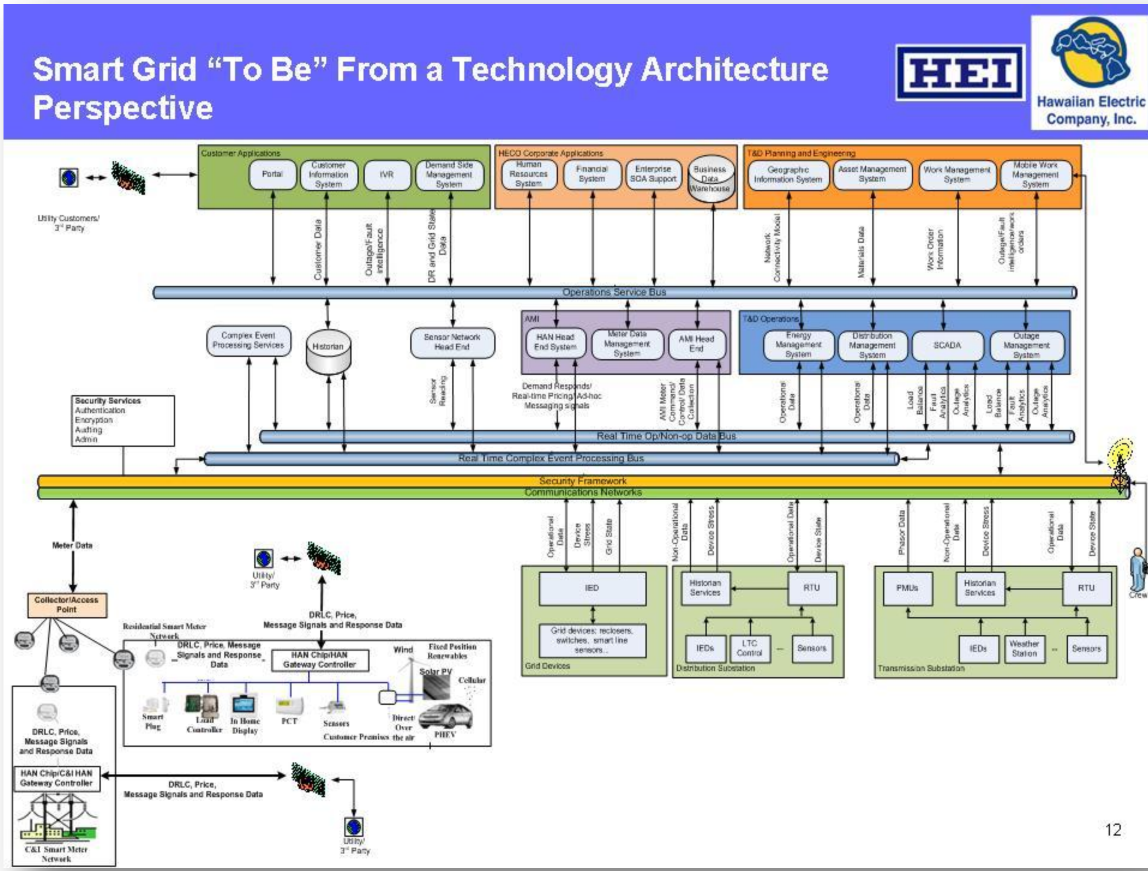

Figure 6.10 Potential Future GSG Architecture Perspective.

Since the initial recommendations and GSG blueprints were completed, the Companies have initiated a number of strategic assessments to support transformations toward greener, smarter grids. Though not part of the Wind HUI efforts, these efforts are currently underway and align with the recommendations provided as part of Initiative 3.0. The efforts include

- Development of a master communication infrastructure plan for the Companies
- Development of a master distribution automation plan for the Companies
- Support for dedicated resources, such as the Renewable Energy Planning Division within the Operations Integration Department to proactively pursue enterprise-level building blocks necessary to support the future grid.

7.0 Summary & Recommendations

Three priority utility integration efforts were initiated with funding provided by the ARRA Stimulus funds. Each initiative responded to addressing priority needs to further enhance technologies, develop "lessons learned", build experience through pilots and engage utility staff to solicit feedback. Overall the project is a success as it provided considerable feedback for utilizes involved and developed lasting relationships with industry partners. All three priority initiatives have made impacts on the current operations of the companies with

- Follow-on project initiatives that extend the initial demonstrations into full implementation
- Dedicated staff and organizational support to further develop work
- In-field equipment to continue data collection and improved situational awareness
- Technical outreach literature enhancing collaboration and informing industry knowledgebase (i.e. conference papers, presentations, progress reports)

In all instances, the Initiatives progressed to some level of Phase 3 – Implementation within the project period. For Initiatives 1 and 2, considerable progress was made in light of the regulated environment, staffing and workload schedules, land use and permitting needs, community interactions and new technology deployment issues. All planned objectives were achieved and in some instances surpassed. Project provided significant contributions toward advancing Hawaii's renewable integration initiatives. Efforts have lasting impacts as highlighted below:

For Initiative 1 – WindNET,

- Demonstrated value added using remote sensing WindNET monitoring improving state-of-the-art wind forecasting accuracies by up to 15%
- Successful deployment of one of the first utility network of advance remote sensing capability (fleet of SODARs and radiometer) and operational experience
- Successful collaborative development and demonstration of a probabilisitc short-term ramp event forecasting capability and decision-oriented visualization screen for operators
- Jumpstarted utility regional forecasting capability and solar forecasting capabilities
- Developed lasting western utility collaborations and involvement in the WFIP efforts to continue sharing of utility operational and field deployment "lessons learned" with mainland utilities
- Launched corporate wind forecasting and WindNET Phase II efforts on Maui and Oahu
- Utility WindNET sensors contributing to the national NOAA MADIS for wind and weather forecasting

For Initiative 2: Smart Grid Prep

- Successful deployment of "smart" monitoring architecture and wide-area network communication devices at utility substations
- Addressed legacy and integration challenges
- Enabling real-time monitoring and synchronized visibility to system previously not available to system Operators and Planners
- Jumpstarting utility adoption of new synchrophasor technologies and building utility staff confidence and capabilities through vendor training and hands on experience
- Enabled supported learning and use of new technologies

For Initiative 3: GSG Framework

- Employed more systematic approach and industry expertise to review and assess new technologies, value benefit and utility readiness levels
- Completed comprehensive inventory and assessment of utility smart grid readiness levels
- Developed initial smart grid roadmap (blueprints) with utility SMEs
- Developed detailed next step and cost projections for priority focus
- Information contributing to continuing utility strategic efforts to develop a Communication, Distribution Automation and Smart Grid Strategic Plans.

While Hawaii systems can offer a fertile testing and demonstration platform 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. Hawaii is well poised to attain aggressive RPS goals by 2030. Continuing utility leadership in proactively pursuing GSG initiatives, dedicating resources and staff to focus on priority renewable integration needs will pave the pathway forward to a more sustainable and economic grid that is less reliant on fossil-based fuels. The multi-phased approached developed in each of the Initiatives provide a flexible and robust template for Hawaiian utilities to use in pursuing future Initiatives and application of new technologies.

Adoption of any new technology infrastructures, such as communication networks and transfer protocol between databases, smart systems and other critical systems, will require continuing vigilance and review to manage risks and avoid operational consequences. Continuous review and centralize oversight on process interdependencies and infrastructure retrofits will help minimize unintended consequences as the electrical systems continue to evolve. Thus, change impacts affecting the existing system including electrical hardware, interface components, operating procedures, reliance/impact on other systems (i.e. water, telecom, emergency response), existing policies/regulatory constraints, timing and markets must also be carefully reevaluated as part of ongoing efforts to avoid costly and unintended consequences as a result of changing system architecture and performance boundaries.

8.0 Conclusions

Wind HUI Initiatives were pursued to inform and engage Hawaiian utilities to proactively gain experiences proving out new technologies and exploring new practices to better manage high levels of variable renewables. The word "hui" in Asian and Hawaiian cultures means a meeting of the minds in conference on a topic of importance.

Three specific integration initiatives were identified to support Hawaii utilities readily adopt and manage increasing variability and diverse renewable resources such as wind onto the island grids. These initiatives and the results were envisioned to provide actionable strategies to inform future utility investments and teaming strategies. Funded initiatives jumpstarted review efforts to assess state-of-the-art technologies and also created new teaming opportunities with support industries (vendors, equipment providers) that under traditional cost regulated utility environments would likely not have occurred or advanced as quickly. Insights gained from these initiatives will greatly inform ongoing Hawaiian utility efforts and utilities all over the world integrate wind and manage a diverse variable generation resource mix, including solar and demand side management (DSM) resources.

Project achievements as summarized in this final report met intended objectives and in some instances, spawned new initiatives that will have lasting benefits not only for Hawaii but for the nation. Recently, NOAA confirmed that the Hawaii WindNET information from the radiometer and SODARs will be added to the national Meterological Assimilation Data Ingest System (MADIS) in support of real-time National Weather Service weather forecasting and weather prediction models [31]. Modeling improvement results and data have also already been incorporated into a number of state and federally supported Hawaii Clean Energy Initiatives (HCEI) renewable integration planning efforts [32] to look at impacts of nearly 80% solar PV generation for the islands and benefits of interconnecting the islands via AC and HVDC cables [33].

Ongoing resources and commitment will be needed to advance the energy sector toward cleaner, alternatives that are less fossil-fuel dependent. The work completed to date has provided foundational information to jumpstart initiatives and established some pathways for future utility initiatives toward meeting Hawaii and national energy goals.

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10.0 Appendices

Initiative 1 Appendices

Appendix I1-1: Model VT-1 Sodar System Specifications from Atmospheric Research & Technology, LLC

Appendix I1-2: Field Campaign Report, AWS TruePower, LLC, Technical Report, DOE/EE0001379-2, November 2011

Appendix I1-3: WindNET-Phase 1: Final Report, AWS TruePower, LLC, Technical Report, DOE/EE0001379-3, March 6, 2012.

Appendix I1-1: Model VT-1 Sodar System Specifications from Atmospheric Research & Technology, LLC

Technical specification sheet on Model VT-1 SDOAR from ART.

Model VT-1 Phased-Array Doppler Sodar System

Atmospheric Research & Technology, LLC

P. O. BOX 1808 • KAILUA-KONA, HAWAII 96745 USA • TELEPHONE: (808) 329-1627

FAX: (808) 331-8428 • E-MAIL: sales@sodar.com • WEB: http://www.sodar.com

The **Model VT-1 sodar** developed by Atmospheric Research & Technology (ART) provides a "virtual tower" for obtaining remote measurements of the wind profile up to a maximum height of approximately 300 m (1000 ft).

This self-contained, portable system includes a phased-array acoustic transmitter and receiver with supporting electronics, a notebook computer, and software for system configuration, operation, and data storage. The entire system can be assembled without tools in a matter of minutes.

The unit is designed for both durability and versatility. All cabinet components are stainless steel or PVC plastic. The Model VT-1 is powered by a 12 VDC power supply or battery, drawing only about 40 watts. Thus the unit can be used even at isolated locations lacking support facilities.

Model VT-1

Parameter	Specification
Maximum height	300 m (1000 ft)
Minimum height	15 m (50 ft)
Range gates	25 maximum
Effective sampling depth	10 to 40 m (30 to 130 ft)
Transmit frequency	4504 Hz
Pulse duration	10 to 200 ms (adjustable)
Averaging interval	2 to 60 minutes (adjustable)
Wind speed range	0 to 25 m/s (0 to 55 mph)
Wind speed accuracy	±0.25 m/s (±0.55 mph)
Wind direction accuracy	±2 degrees
Power requirement	40 watts (without heater)
Voltage input (nominal)	12 VDC
Weight (w/o batteries)	135 kg (300 lbs.)
Dimensions (w, l, h)	1.5 m (5 ft), 1.8 m (6 ft), 1.5 m (5 ft)

Features

- Phased-array antenna for high performance
- Single-frequency operation for simplicity and accuracy
- High-quality construction for durability and dependability
- Simplified design uses Windows® notebook computer for system configuration, operation, and data storage
- Remote site friendly: portable, self-contained, battery-powered, and reliable
- Optional software for calibration and data processing
- Optional hardware for snow melting, external sensors and trailer mounting
- Competitively priced with excellent service & support

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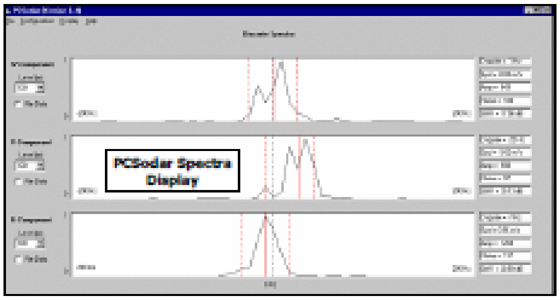
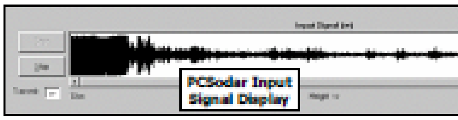
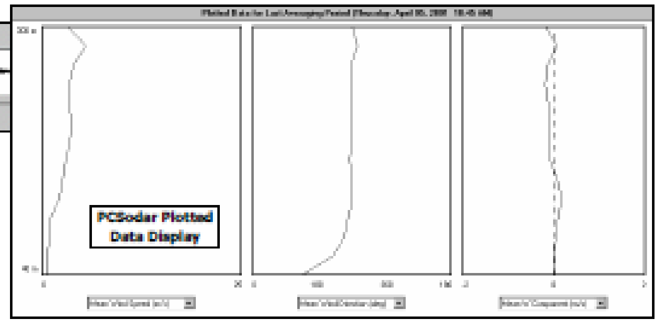


PCSodar

Operation of the Model VT-1 sodar is easy using ART's **PCSodar** software to configure and control the Model VT-1 from a familiar Windows® graphical interface. Several wind data display modes are provided, including tabular and plotted profiles for each of the three wind components plus the vector wind speed and direction.





Other screens display spectra of the incoming signals, graphical representations of the raw input and output signals, an intensity facsimile, and values received from any optional external sensors in use.

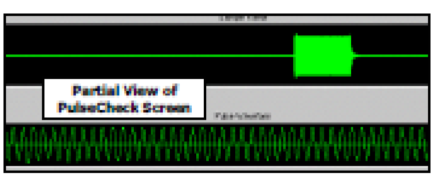
Software Options

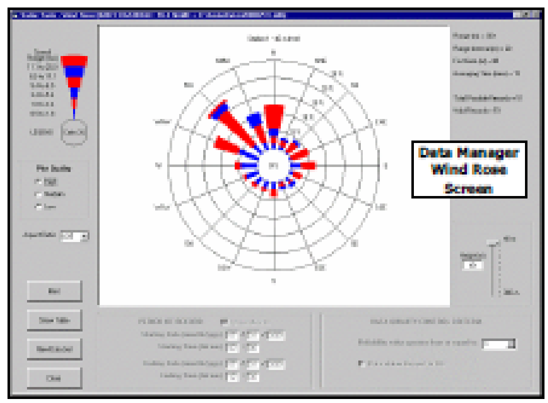
Data Manager: The SodarTools Data Manager provides a convenient way to manage the large amount of data generated by the Model VT-1. This application reads the daily wind data files created by the VT-1 into a database and provides a variety of tools to view, plot, edit, combine, validate, export, and archive the data.

Calibration System: The SodarTools Calibration System (CalSys) includes three modules.

- *PulseCheck* measures the frequency of the sodar transmit pulse.
- *MakeTone* generates constant tones to test the unit's frequency response.
- *Transpond* assesses the accuracy of the sodar timing and signal processing using generated test signals to simulate specific wind conditions.

Both the Data Manager and CalSys run under the Microsoft® Windows® 98SE, 2000, and XP operating systems.





Hardware Options

- Snow-melting system
- Trailer mounting
- External sensors for:
  - — Wind (anemometer)
  - — Temperature
  - — Relative humidity
  - — Precipitation
  - — Solar radiation

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Appendix I1-2: Field Campaign Report, DOE/EE0001379-2

Document is an Interim Project report documenting field deployment campaign experiences. Submitted as separate document DOE/EE0001379-2 entitled Appendix I1-2 to Wind HUI.

PREPARED FOR

HAWAIIAN ELECTRIC CORPORATION

Appendix I1-2 to Wind HUI DOE/EE0001379-2

Field Campaign Report

NOVEMBER 22, 2011

Submitted by:

Deborah Hanley
AWS TRUEPOWER, LLC
263 NEW KARNER ROAD
ALBANY, NEW YORK

463 NEW KARNER ROAD | ALBANY, NY 12205
awstruepower.com | info@awstruepower.com

Appendix I1-3: WindNET-Phase 1: Final Report, AWS TruePower, LLC, DOE/EE0001379-3

Document is the final project report from AWS summarizing progress to date inclusive of the modeling and forecast screen interface development. Submitted as separate document DOE/EE0001379-3 entitled Appendix I1-3 to Wind HUI.

AWS Truepower™
Where science delivers performance.

PREPARED FOR
HAWAIIAN ELECTRIC CORPORATION
Appendix I1-3 to Wind HUI DOE/EE0001379-3

AWST-WindNET-Phase 1: Final Report

MARCH 6 , 2012

Technical Report

Submitted by:

AWS TRUEPOWER, LLC
263 NEW KARNER ROAD
ALBANY, NEW YORK

AWS Truepower™
Where science delivers performance.

463 NEW KARNER ROAD | ALBANY, NY 12205
awstruepower.com | info@awstruepower.com

Appendix I2-1: SEL-451 Data Sheet, Schweitzer Engineering Laboratories, Inc.

Technical specs on the SEL-451. Sourcehttp://www.selinc.com/sel-451/

SEL-451 Protection, Automation, and Control System

Major Features and Benefits

The SEL-451 Protection, Automation, and Control System combines directional overcurrent protection with complete control for a two-breaker bay.

- **Protection.** Use multiple instantaneous and time-overcurrent elements with SELOGIC® control equations to customize distribution protection. Best Choice Ground Directional Element™ logic optimizes directional element performance and eliminates the need for many directional settings. Protect two breakers with one relay.
- **Automation.** Take advantage of enhanced automation features that include 32 programmable elements for local control, remote control, protection latching, and automation latching. Local metering on the large format front-panel Liquid Crystal Display (LCD) eliminates the need for separate panel meters. Use serial and Ethernet links to efficiently transmit key information, including metering data, protection element and control I/O status, IEEE C37.188 Synchrophasors, IEC 61850 GOOSE messages, Sequential Events Recorder (SER) reports, breaker monitor, relay summary event reports, and time synchronization. Use expanded SELOGIC control equations with math and comparison functions in control applications. High-isolation inputs have settable assertion levels to easily combine inputs from different systems. Incorporate up to 1000 lines of automation logic to speed and improve control actions.
- **High-Accuracy Time-Stamping.** Time-tag binary COMTRADE event reports with real-time accuracy of better than 10 µs. View system state information to an accuracy of better than 1/4 of an electrical degree.
- **Synchrophasors.** Make informed load dispatch decisions based on actual real-time phasor measurements from across your power system. Use synchrophasors to determine actual stability margins with standard spreadsheet, graphics program, or data management system.
- **High-impedance Fault Detection.** The optional high-impedance fault (HIF) detection element operates for small current ground faults typically caused by downed conductors on ground surfaces such as earth, concrete or other poorly conductive materials. HIF event data are made available in standard COMTRADE format.
- **Digital Relay-to-Relay Communications.** Use Enhanced MIRRORED BITS® communications to monitor internal element conditions between relays within a station, or between stations, using SEL fiber-optic transceivers. Send digital, analog, and virtual terminal data over the same MIRRORED BITS channel.
- **Ethernet Access.** Access all relay functions with the optional Ethernet card. Interconnect with automation systems using IEC 61850 or DNP3 protocol directly. Optionally connect to DNP3 networks through an SEL-2032 Communications Processor. Use file transfer protocol (FTP) for high-speed

Schweitzer Engineering Laboratories, Inc. SEL-451 Data Sheet

Initiative 3 Appendices

Appendix I3-1: Summary of Accenture "best-practices" performance tools, Accenture

Appendix I3-2: Additional GSG Framework slides and detailed example of targeted initiative

Appendix I3-1: Summary of Accenture "best-practices" performance tools

Accenture's High Performance Utility Model (HPUM)

Our High Performance Utility Model (HPUM) is based on the knowledge of business processes collected through more than 40 years of working with more than 400 utilities globally, implementing distribution grid strategy, re-engineering processes and organization structures, and developing new capabilities. This High Performance Utility Model is a capability model that describes every function of a utility business, including smart-grid capabilities, meter data management and demand response. Business processes are mapped to each capability area and allow us to assess a client's current business model and process maturity along with supporting applications and critical integrations that enable the business to assimilate information and execute work across the enterprise. These business processes would be leveraged during the examination of HECO's current state, as well as during the future vision exercise, through which specific impacts related to smart grid processes and capabilities could be assessed. Each component of the model has the following key areas of focus:

- Documented process descriptions, process decompositions, and scope definitions
- Documented levels of mastery, which are used to assess lagging or leading capability relative to industry peers
- Identified key performance indicators, value levers, and outcomes
- Direct links to Accenture's Global Utility Benchmark Repository
- Identified cross-process and capability dependencies and impacts

The effective use of Accenture's HPUM would enable us to create a pragmatic Distribution Grid and AMI Operations Strategy. It is a valuable asset to help facilitate discussions by bringing a fresh perspective to complex requirements, enabling Accenture and all of the HECO companies to understand the impacts of the distribution grid and AMI operations strategy on business processes that need to deliver targeted benefits as well as mitigate risk.

Intelligent Networks Data Enterprise (INDE)

INDE is a set of tools, accelerators, and implementation components for the definition, design, and implementation of end-to-end-smart grid data management. This includes data acquisition and transport, data storage, the transformation of raw grid data into usable information via technical analytics in both real time and transactional modes, and integration into utility processes and systems. DE effectively provides a smart grid middleware that enables a utility to:

- Obtain maximum value from deployed smart grid infrastructure quickly
- Accelerate the process of deploying smart grid functionality
- Reduce the risk associated with custom smart grid data management implementations

- INDE includes databases, analytics and visualization platforms and implementations, services and applications for key smart grid processes, and an advanced integration platform. INDE also provides tools, accelerators, and processes for the development of smart grid strategies and high level blueprints. These include:
  - Smart grid use case scenario catalogue with over 100 use cases
  - Smart grid technical analytics catalogue with over 200 analytics
  - Smart grid value proposition catalogue with over 60 value propositions
  - Smart grid Reference Architecture providing a reference model for grid data management, analytics/visualization, and integration with utility Operations and Enterprise systems
  - Smart grid sub-architectures for specialty applications such as Demand Response including virtual Power Plant dispatch with optimization for feeder loss minimization and distributed analytics for real time grid fault analysis
  - Reusable code elements, including databases, analytics implementations, SOA services and process modules that accelerate the development of smart grid solutions while reducing risks associated with custom development
  - Deployment of functionality (e.g., outage intelligence, on-line circuit impedance measurement)
  - An extensive and comprehensive set of procedures and methods for applying the INDE tools and accelerators to specific utility requirements
  - The INDE asset base is supported by the first-of-its-kind INDE Smart Grid Architect's Workbench. The Workbench provides access to the various catalogues and design elements from INDE and also encapsulates best practice information on smart grid architecture and design.

Accenture Smart Grid Financial Modeling Tool

Accenture has developed a proprietary Smart Meter / Smart Grid Financial Model to provide the quantitative rigor for Smart Grid strategy or implementation initiatives. It provides a strong basis for:

- Selecting smart grid technologies and functions that may have value for each of the HECO operating companies
- Evaluating the impact of these smart technologies and functions on the utility value chain
- Quantifying the cost of these smart grid technologies and functions for a given utility using both system attributes and industry estimates
- Providing detailed financial analysis – including, but not limited to, cost benefit analysis, rate impact assessment, and sensitivity analysis.

Appendix I3-2: Additional GSG Framework Slides

This section contains excerpts from a business proprietary/confidential presentation on setting priority initiatives and an example targeted initiative.

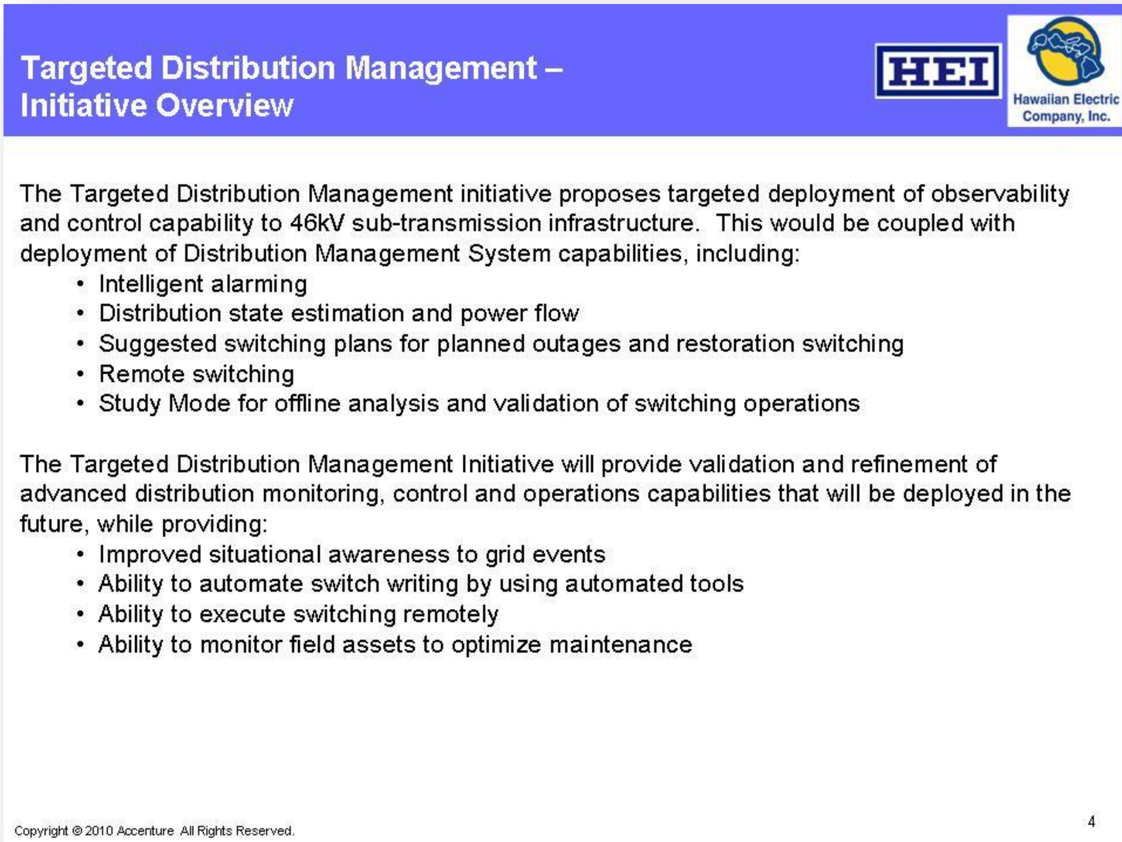

Figure Appendix 3.1. Example GSG Action (Targeted Distribution Management)

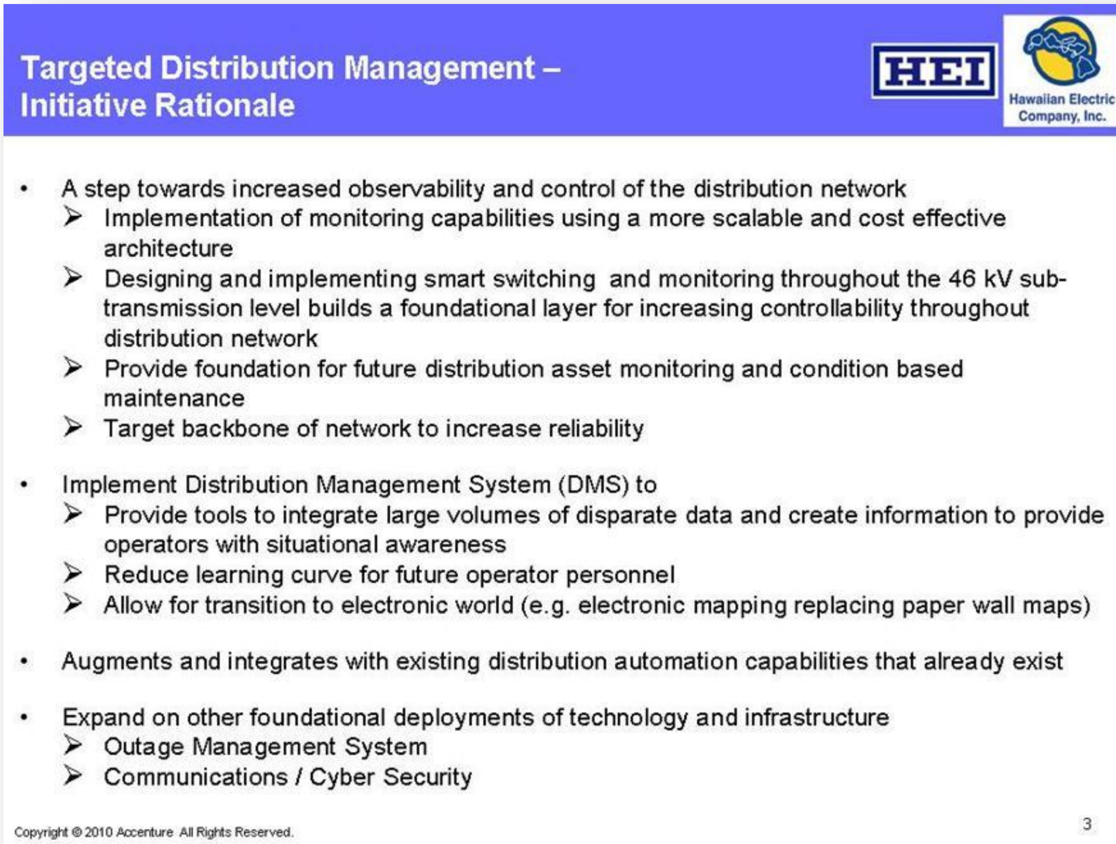

Figure Appendix 3.2. Example of Initiative Rationale (Targeted Distribution Management

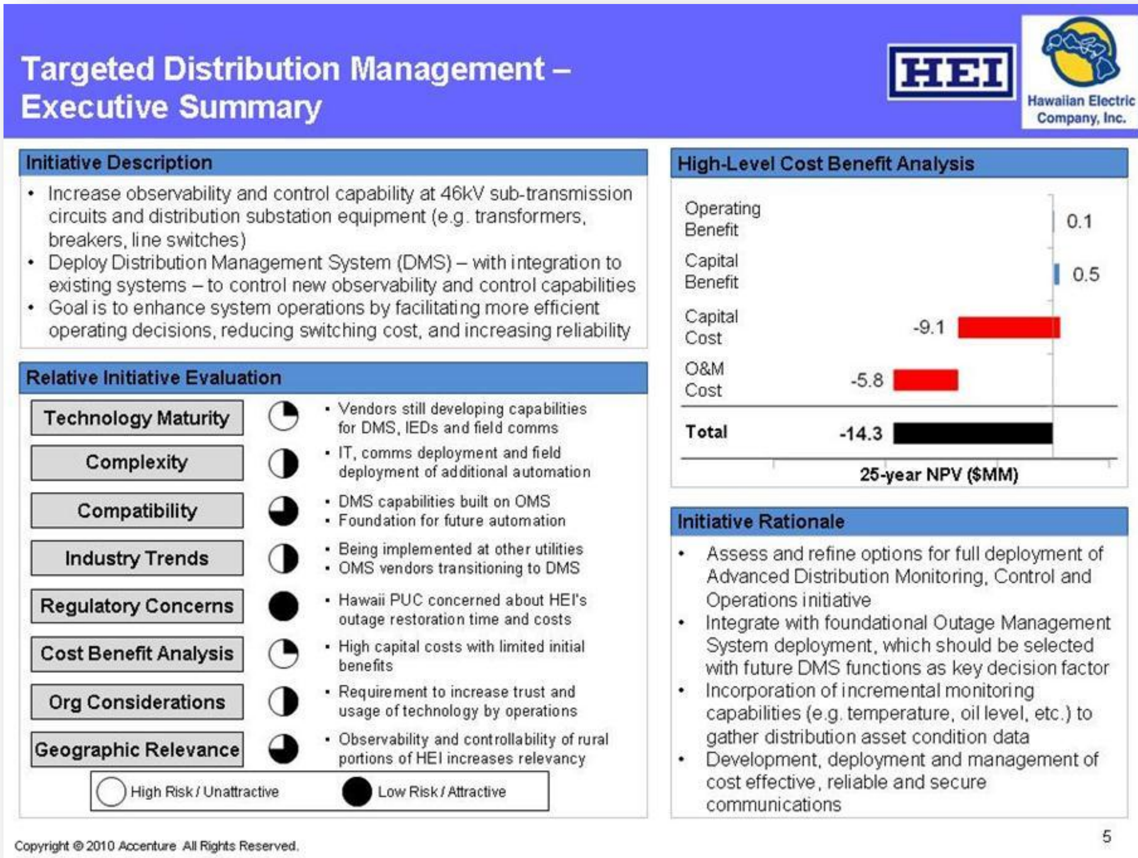

Figure Appendix 3.3. Example of Initiative Rationale (Targeted Distribution Management) and high-level cost considerations.