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.

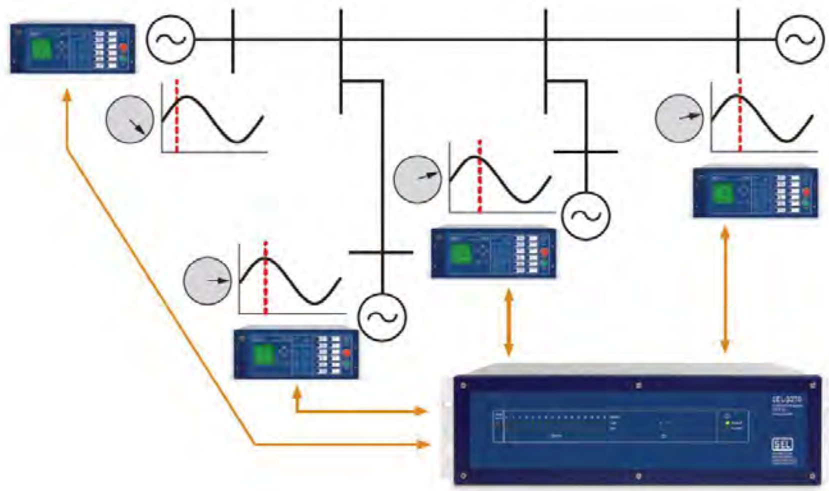


Figure 5.2 Typical configuration using wide-area generation control (SEL-3378) and remote PMUs (SEL-451). (Source: SEL)

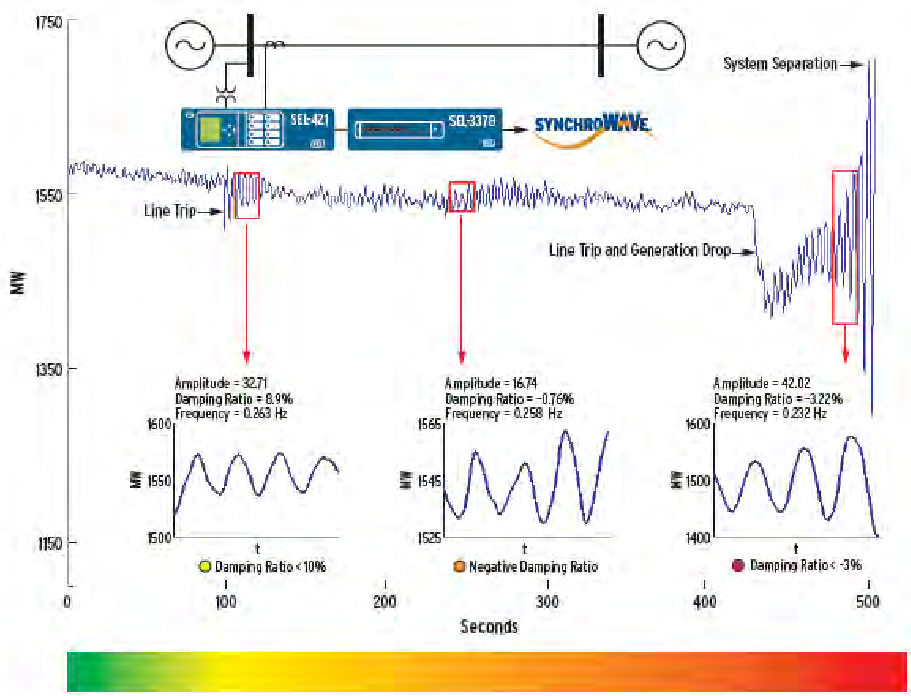


Figure 5.3 Desired future capability to detect and capture unstable operations to validate model predictions. (Source: SEL)

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

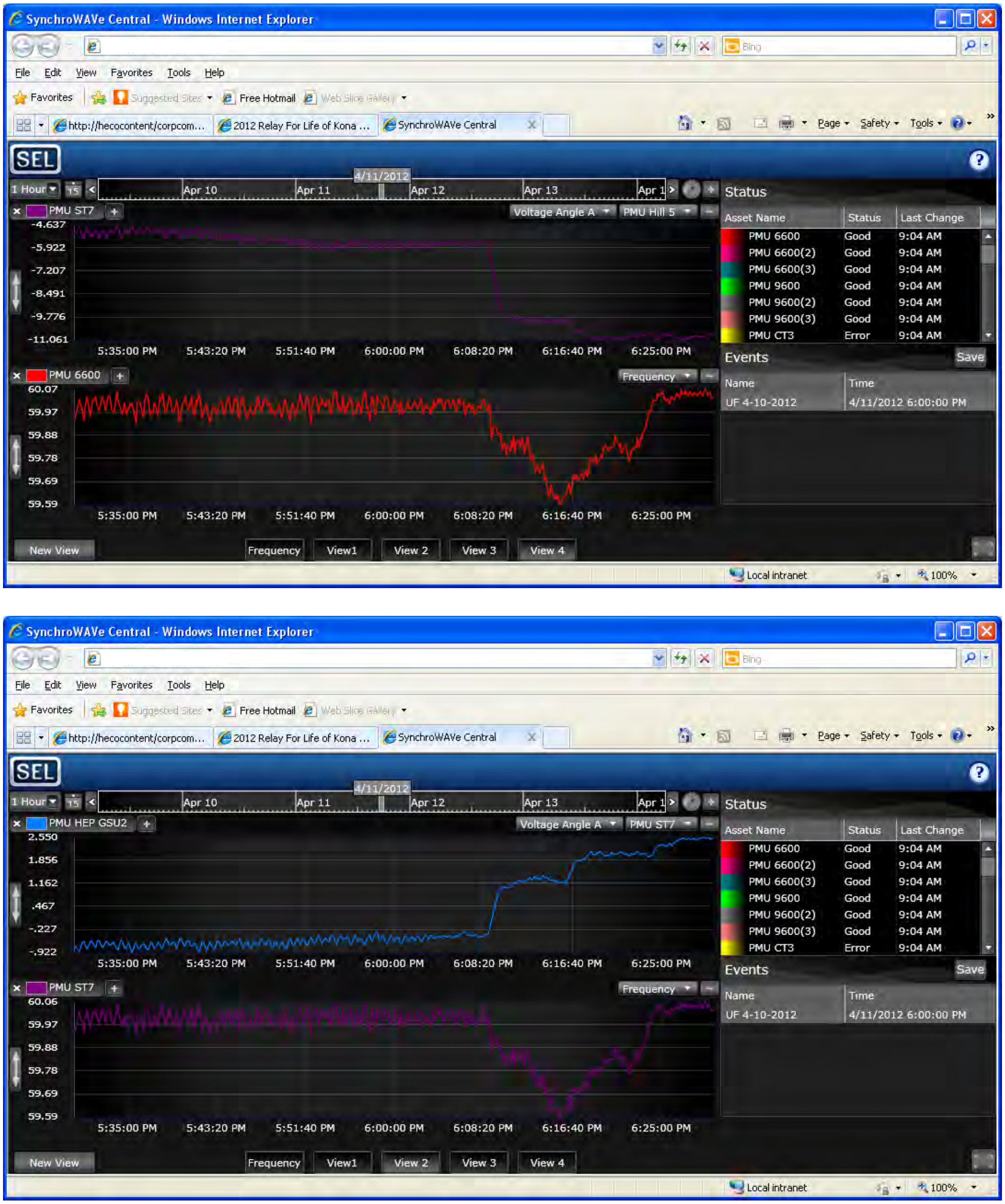


Figure 5.4 Screenshots of PMU from the SYNCHROWAVE® software.

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.

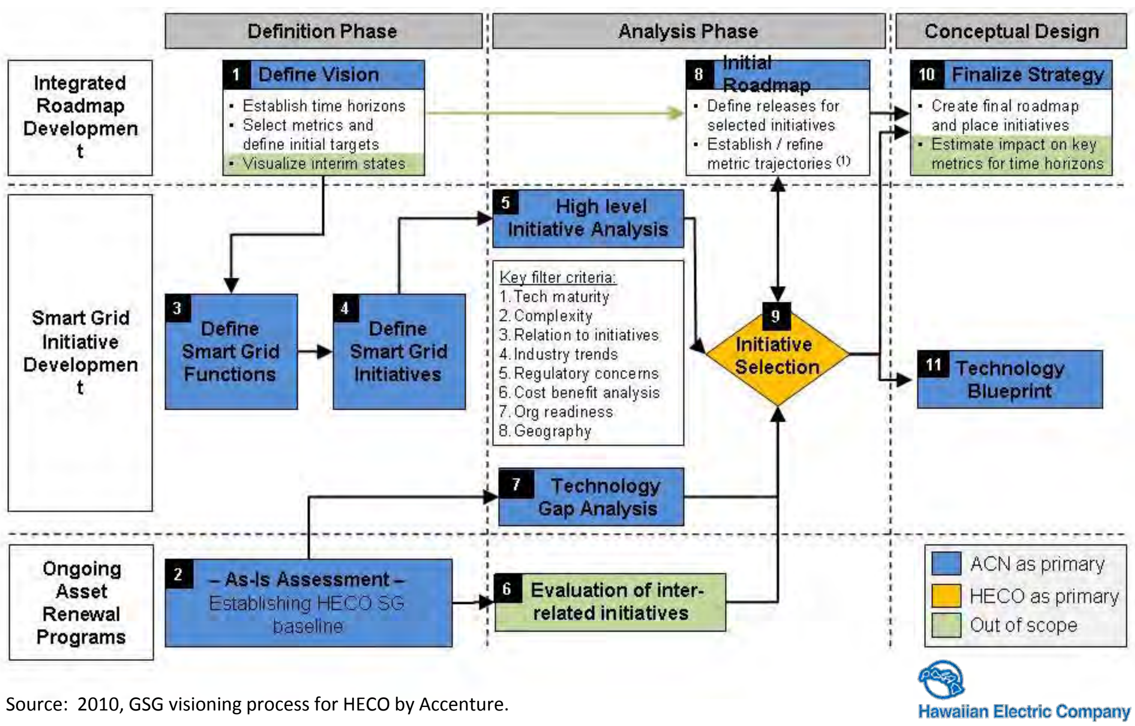
Table 6.1 captures the Smart Grid Task Force's preliminary, high level perspective and approach on developing a roadmap. This summary incorporated both internal and external factors affecting the operation of the Hawaiian Electric Companies and provided background information for the smart grid visioning 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.

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.

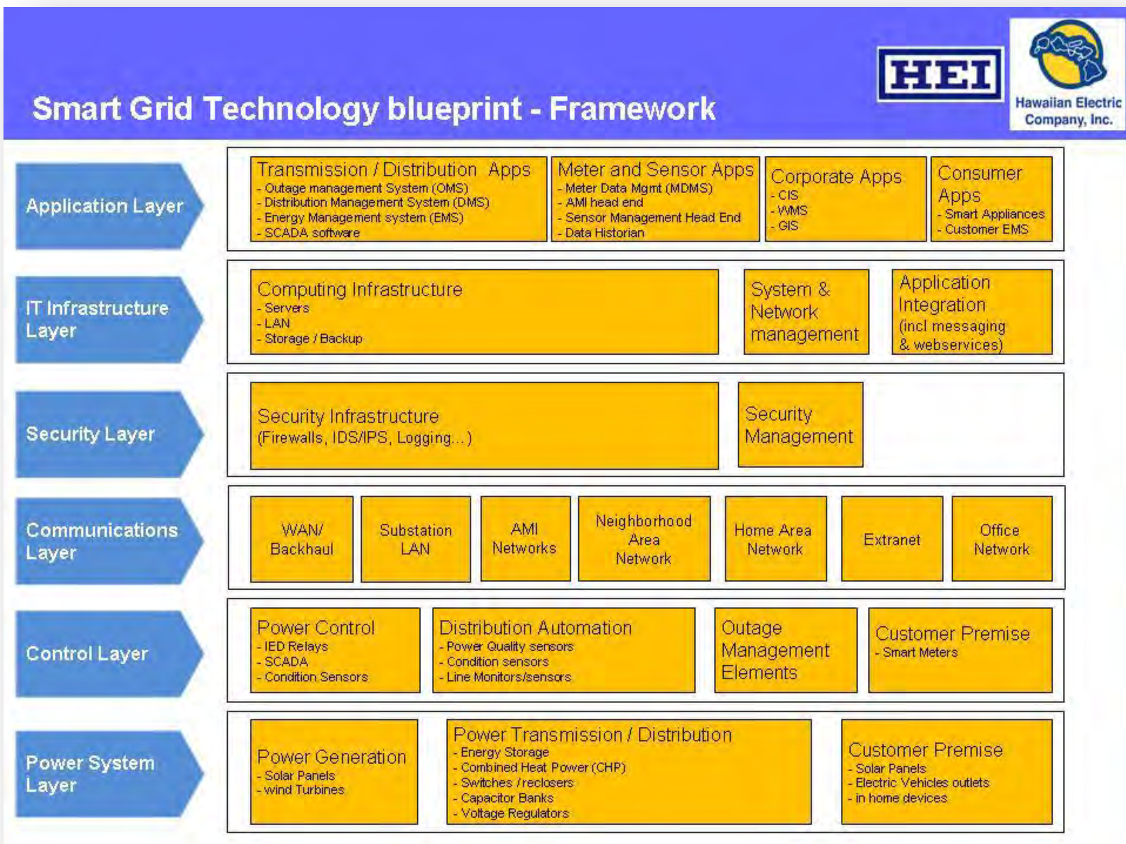


Figure 6.2 Initial GSG Technology Framework for Hawaii utilities.

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

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.

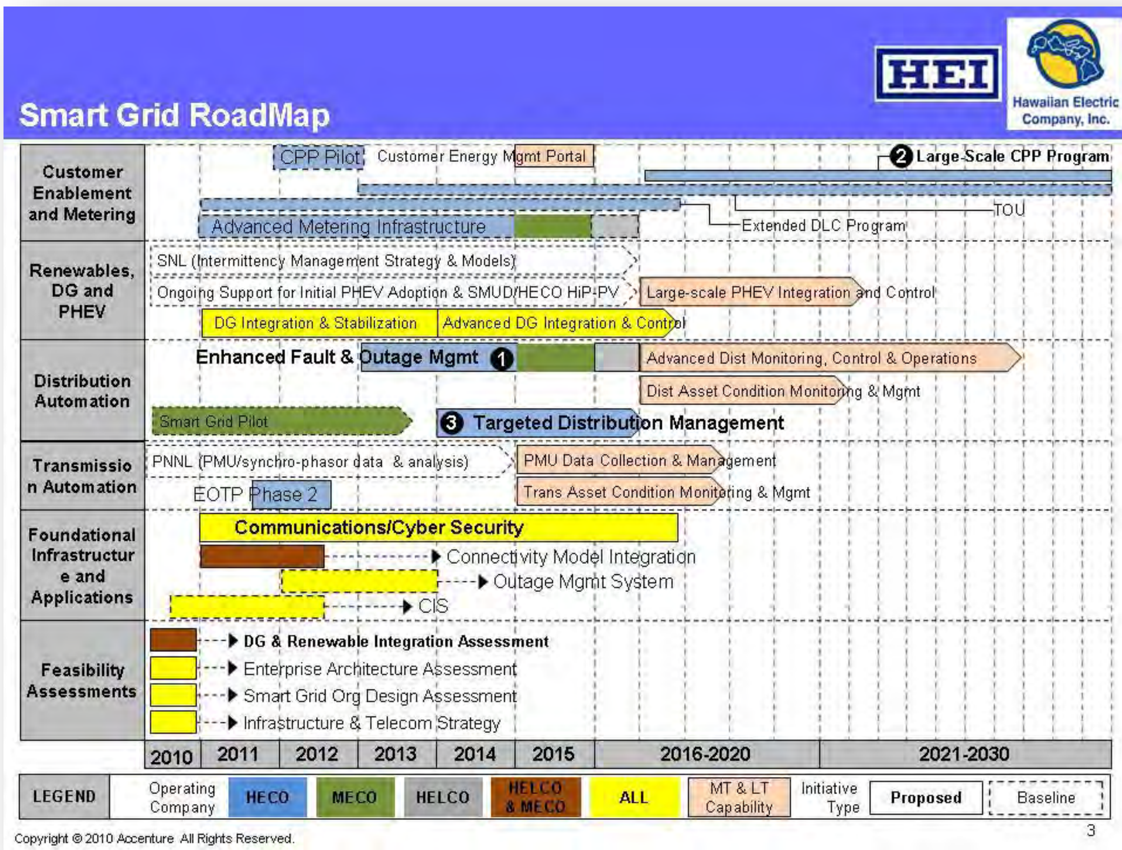


Figure 6.4 Consolidated GSG Roadmap color coded by Company.

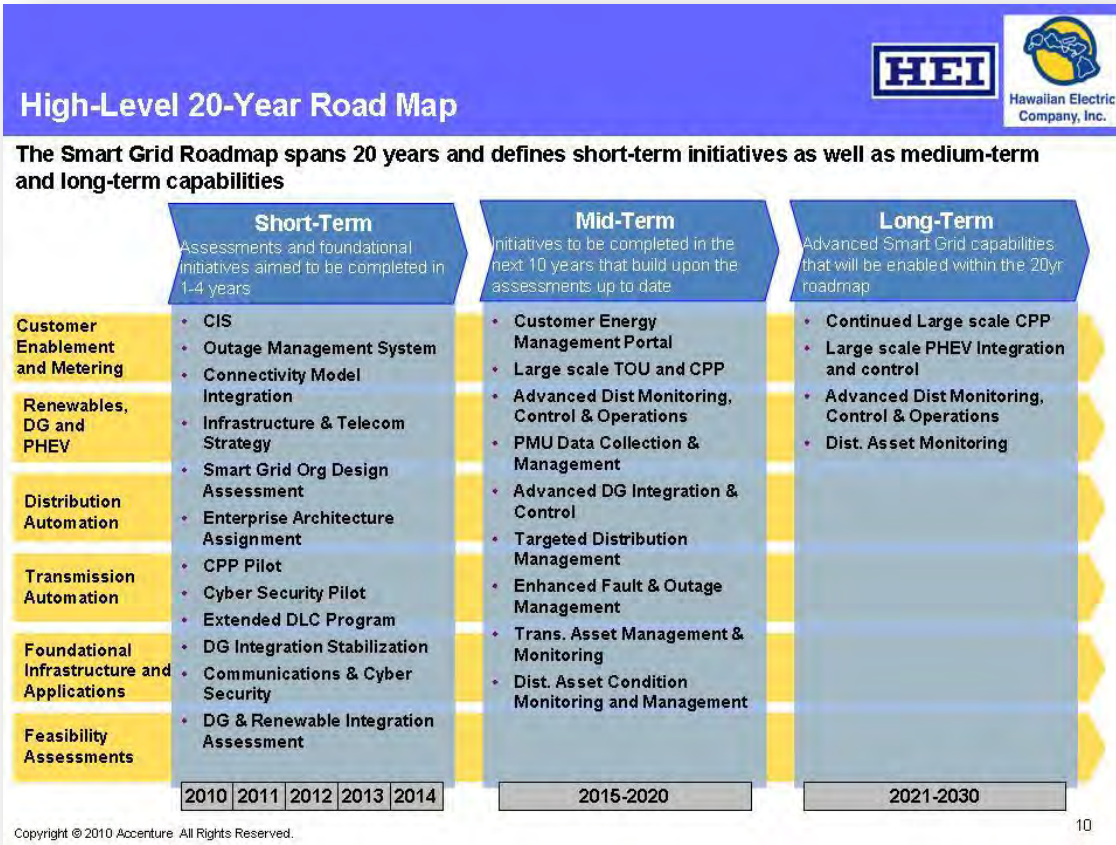


Figure 6.5 20- year consolidated GSG roadmap by short, medium and long term initiatives.

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.

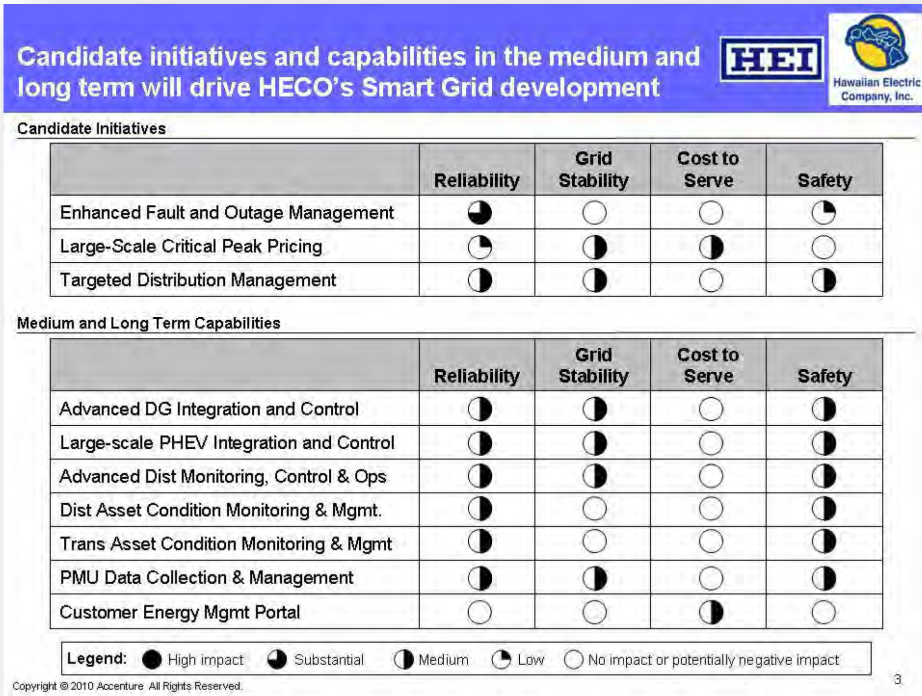


Figure 6.6 Recommended candidate initiatives and capabilities driver for GSG efforts.

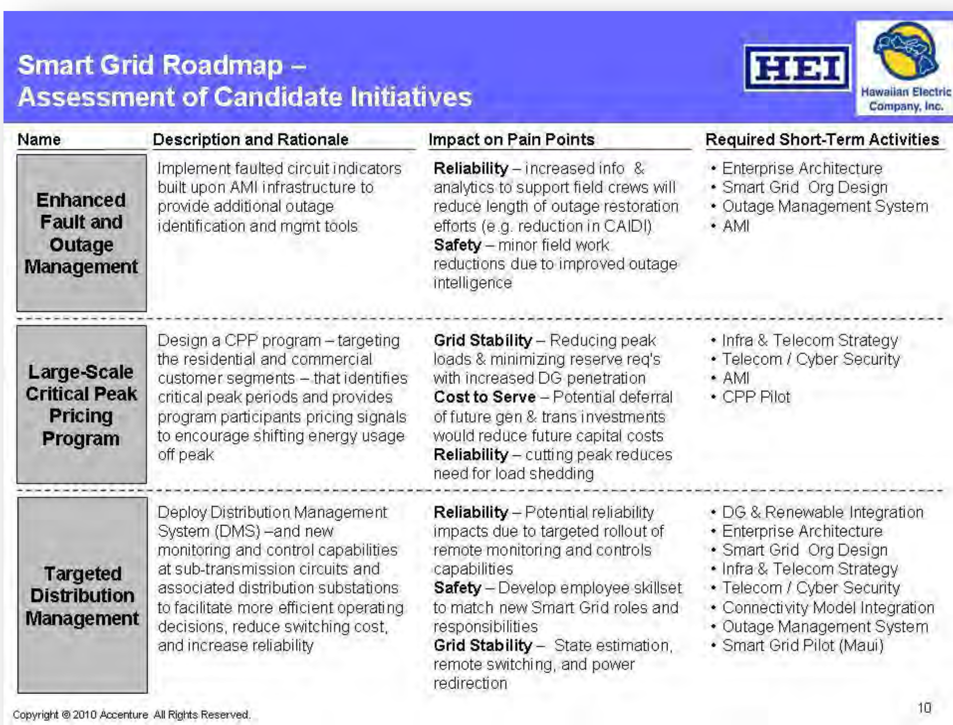


Figure 6.7 Three candidate initiatives.

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.

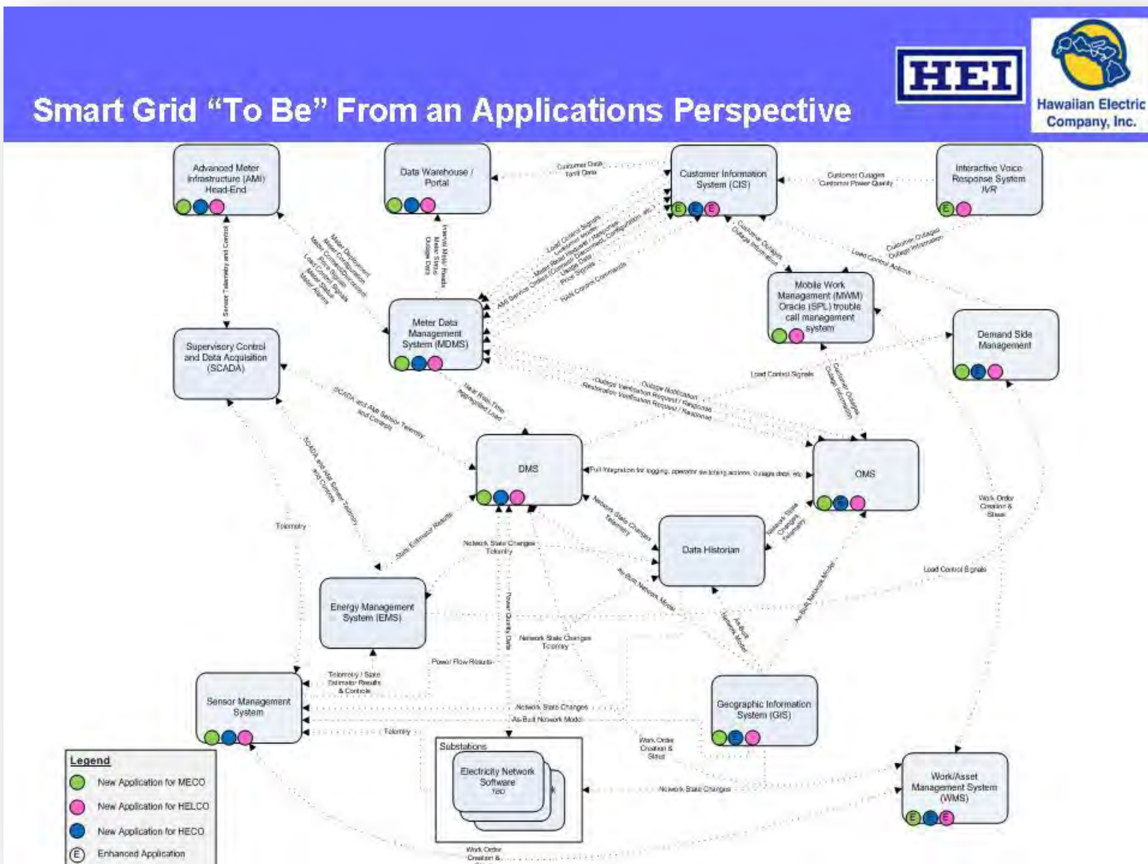

Figure 6.9 A Potential Future GSG Application Perspective.

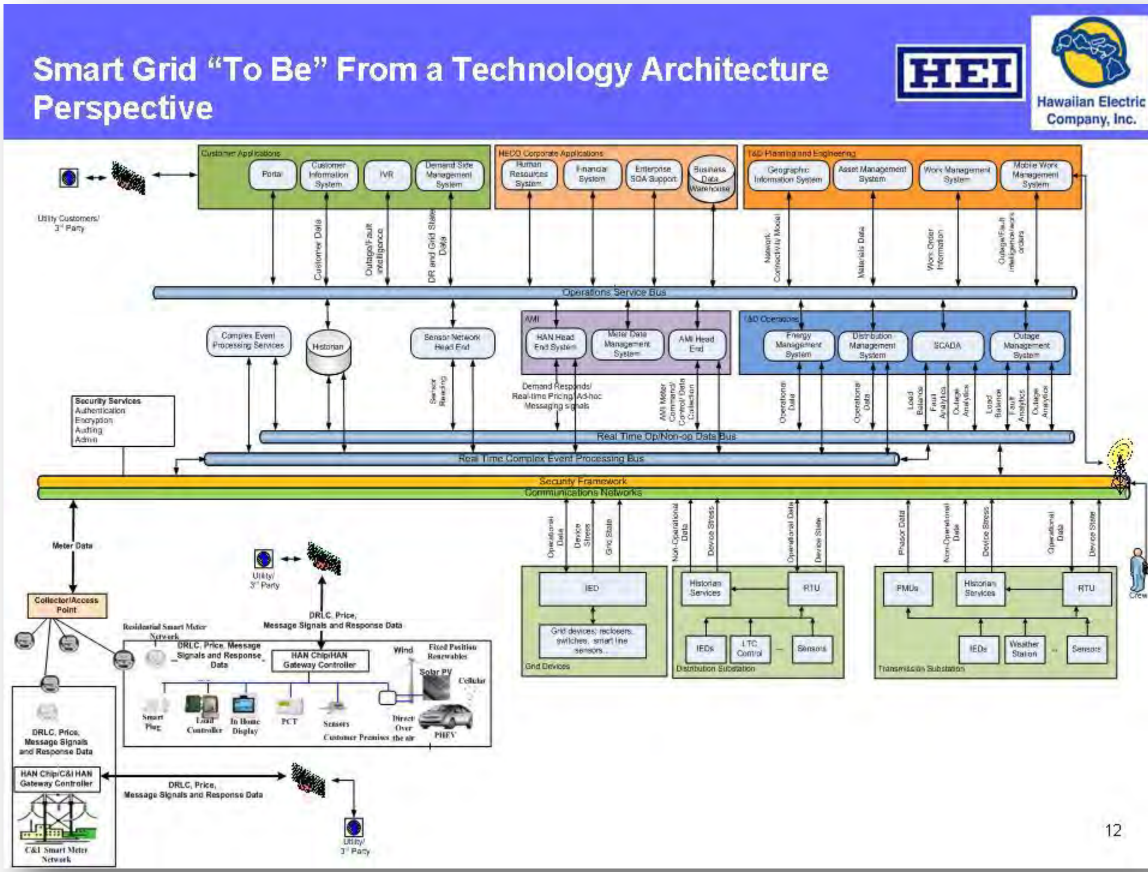

Figure 6.10 Potential Future GSG Architecture Perspective.

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.

9.0 References

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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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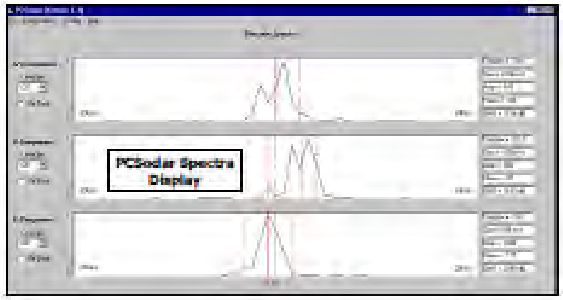
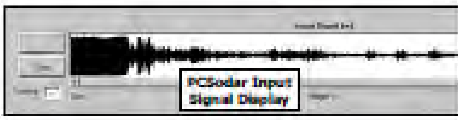
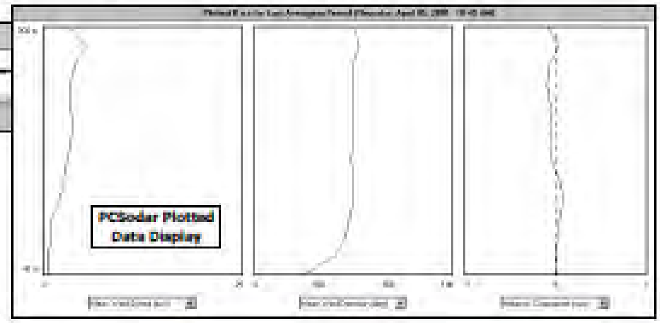


PCSodar

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.

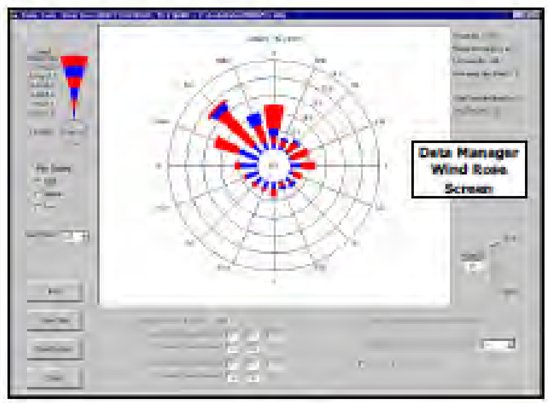
Software Options

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.

AWS Truepower

PREPARED FOR

HAWAIIAN ELECTRIC CORPORATION

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

Field Campaign Report

NOVEMBER 22, 2011

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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.

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

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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.

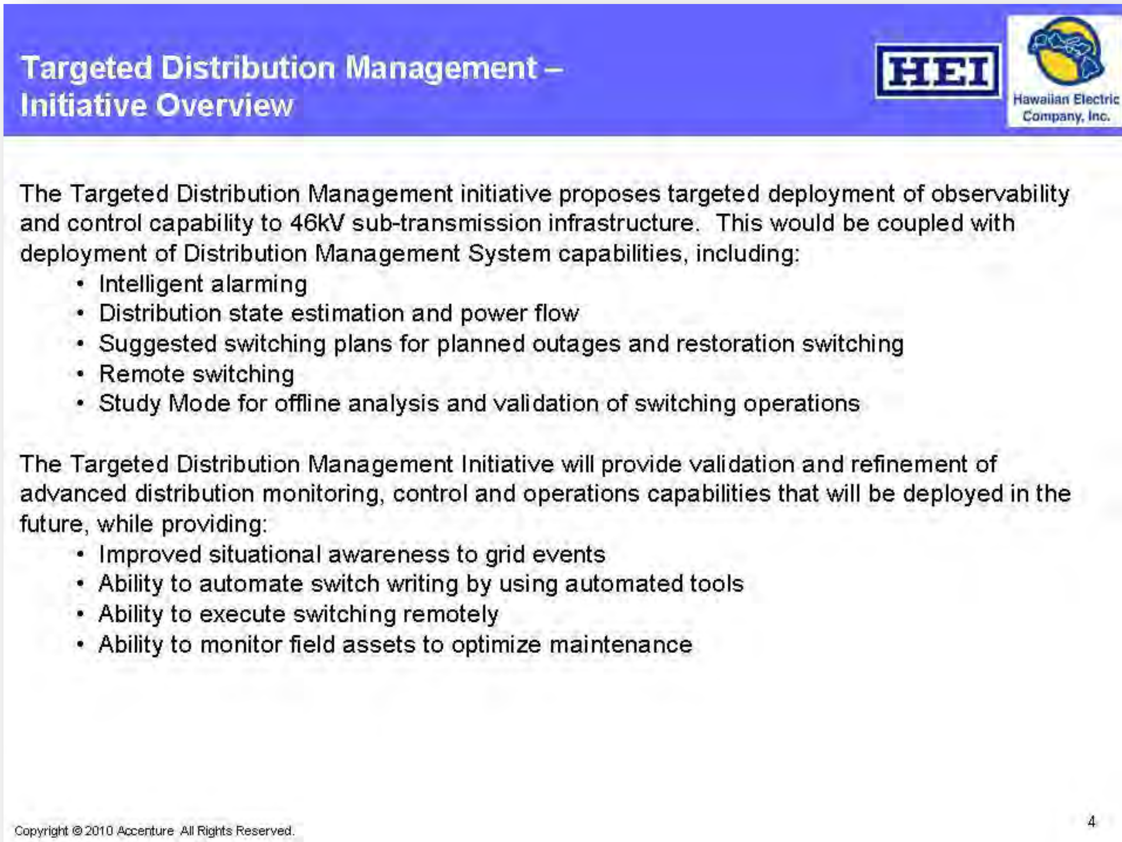

Figure Appendix 3.1. Example GSG Action (Targeted Distribution Management)

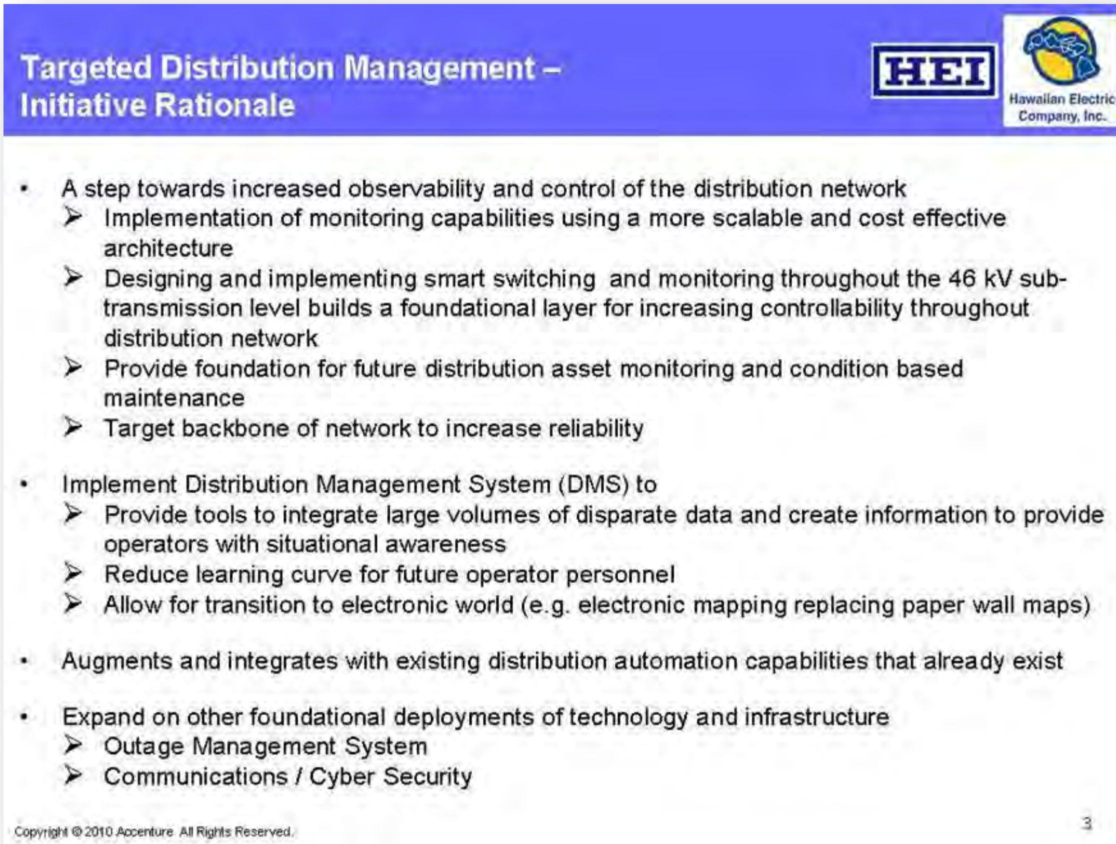

Figure Appendix 3.2. Example of Initiative Rationale (Targeted Distribution Management

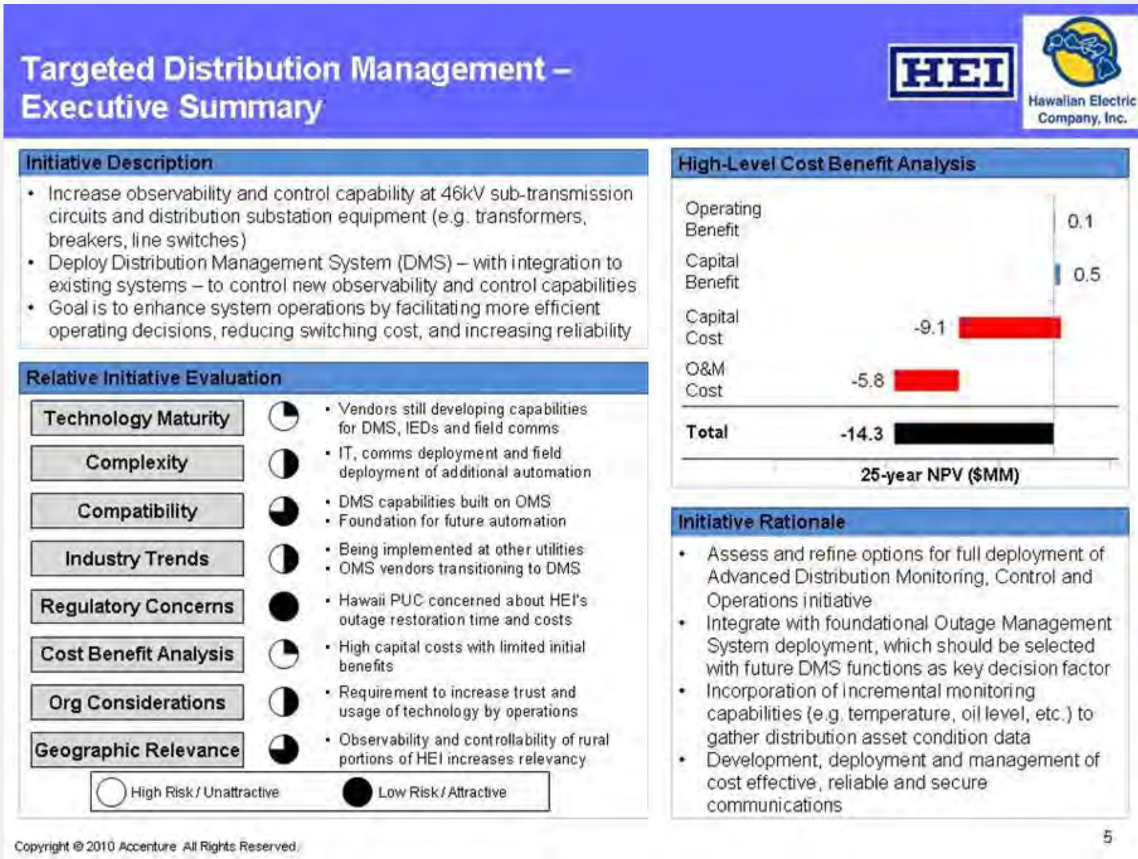

Figure Appendix 3.3. Example of Initiative Rationale (Targeted Distribution Management) and high-level cost considerations.