Overview and Lessons Learned from Snohomish County PUD's First Energy Storage Project

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***Abstract* - Over the past two years the Snohomish County Public Utility District No. 1 (District) planned and engineered its first energy storage system installation. The system is a 1MW/0.5MWh lithium-ion battery energy storage system built on the Modular Energy Storage Architecture (MESA). The system is electrically connected into a distribution substation 12kV bus and communicates with the substation data network allowing it to be dispatched from the Energy Control Center and Power Scheduling. The system is fully commissioned and tested.**

MESA is an open standard for energy storage that focuses on the physical, electrical, and communication interconnection of components in an energy storage system. The District views MESA as a way to reduce the complexity of energy storage systems, enable compatibility of various system components, and significantly reduce non-recurring engineering costs.

The energy storage project team includes groups from across the District including Substation Engineering, Planning and Protection, Environmental, Safety, Construction, IT, SCADA, Telecommunications and Public Relations. In addition, multiple contractors have been involved in development of the system.

This paper explains why Snohomish County PUD is installing energy storage, gives an overview of MESA and the benefits the District sees in its approach, and provides lessons learned during the engineering, manufacturing, testing, site construction, installation, and commissioning.

I. Introduction

The Snohomish County Public Utility District No. 1 (District) is the second largest publicly owned utility in Washington. It is located approximately 20 miles north of Seattle and serves over 327,000 electric customers and 19,000 water customers. The service territory covers over 2,200 square miles, including all of Snohomish County and Camano Island.

The District receives the majority of its power from the Bonneville Power Administration. It also has 120MW of its own hydroelectric generation. The District operates its transmission system at 115kV and its distribution system at 12.47kV. The distribution system is a mix of overhead and underground conductors.

The District first started looking into battery energy storage systems in 2011. The District became interested in the technology as it looked for additional ways to integrate renewable generation resources, such as wind, into its resource portfolio. Battery energy storage technology was attractive to the District compared to other storage technologies because of its relatively small physical footprint, small upfront capital investment requirement, and minimal permitting requirements. The District's first energy storage project is a 1MW/0.5MHh lithium-ion battery energy storage system (Project) installed in a distribution substation. This paper discusses what it took to go from concept to reality on the Project, including the engineering, testing, site construction, installation, training and commissioning processes. It also discusses the MESA standards that the system is designed around and lessons learned.

A. History of Technology Investment at the District

The District has a history of exploring new technologies in its generation portfolio and electrical system. In 2011 the District completed the Youngs Creek run-of-the-river hydroelectric project. This was the first hydroelectric project completed in Washington State in nearly 20 years. It has a rating of approximately of 7.5MW and an annual production of 18,000MWh. The District is currently in the process of engineering two more run-of-the-river hydroelectric projects, each with a rating of approximately 6MW.

The District also has an aggressive smart grid program that was partially funded by the American Recovery and Reinvestment Act (ARRA). In 2010 the District was awarded a Smart Grid Investment Grant (SGIG) of $15 million through ARRA. The SGIG funded the build out of the following five foundational components of the District's Smart Grid:

(1) Digital Communications – installation of an integrated, high capacity, and secure fiber optic communication network to connect all of the District's substations and other critical facilities.

(2) Substation Automation - upgrading existing legacy substations with high-tech digital meters, relays, and other control equipment, and establishing communication nodes to enable a fully functional SCADA system for both substations and distribution circuits. The Smart Grid Test Lab subproject is also incorporated into the Substation Automation project;

(3) Distribution Automation – automation of the distribution system by installing automatically and/or remotely operable devices and sensors on a portion of the electrical distribution system. Included is the design and installation of a Field Area Network (FAN) communication system.

(4) Distribution Management System (DMS) - install software and hardware systems that enable automated control of the electrical distribution system.

(5) Cyber Security – development of a Cyber Security Plan and implementation of a Cyber Security Program that secures cyber assets included in the SGIG.

The energy storage system leverages the substation automation and fiber optic network investments by the District for integration into its Supervisory Control and Data Acquisition (SCADA) and power scheduling software systems. The District sees battery energy storage as one of the next steps in its smart grid investments and enabling further growth of its renewable resource portfolio.

B. The Origins of Modular Energy Storage Technology

When the District began exploring storage technology in 2011, it had several goals for the energy storage system. First, integrate it into an existing substation yard and avoid costly and lengthy site development and permitting processes. A substation site also provides a secure location for the District to become familiar with storage technology. Second, install storage technology that fully integrates with the District's software systems for managing the electrical grid. This includes the Supervisory Control and Data Acquisition (SCADA) system used by Dispatchers to monitor and control the electrical system, power scheduling software, and future integration with distribution management software. The final goal was to install energy storage technology with a software platform that had the ability to implement multiple customizable operating modes for various use cases. This goal was extremely important to the District in order to maximize the benefits of the system across multiple value streams not only today, but also in the future.

Lithium-ion batteries were evaluated as the best storage technology based on the price and size requirements of the District. This paper doesn't go into detail on the battery selection process, but it is recommended that any utility exploring the possibility of installing a battery energy storage system first define its use cases and then select a battery that best satisfies the use case requirements. Lithium-ion batteries supplied by different vendors can have very different charge/discharge characteristics and power to energy ratios. Different battery types such as flow batteries and lithium-ion batteries vary in similar ways as well. A thorough investigation of these characteristics would be prudent before selecting a product.

As the District explored the different battery energy storage systems available on the market it didn't find a solution that satisfied its software integration and control system goals using open standards. The District found that very few standards for utility battery energy storage systems existed. Typically when a utility goes out to procure electrical equipment, such as a breaker or transformer, the utility will write a specification based on IEEE standards. The IEEE standards allow the utility and vendor to come to a common understanding of what is required in the design and manufacturing of the equipment. Due to the lack of existing standards it was not easy to create a specification for the battery energy storage system.

For this reason the District began to work on the Modular Energy Storage Architecture (MESA) standards. The very basic components of a battery energy storage system are batteries, a power conversion system, used to convert direct current (DC) battery power to alternating current (AC) grid power and a control system. The lack of standards has led to battery energy storage system components being electrically connected in a variety of different ways. Different battery vendors have different DC voltage output levels. Power conversion system manufactures have various DC and AC voltage output levels, restricting battery compatibility and requiring various transformer configurations. Furthermore, the batteries and power conversion systems can tolerate different levels of ripple on the DC voltage. If the ripple is greater than one device's tolerance it may not operate correctly. The lack of standardization in these areas has led to many integration issues and limited the ability of different venders to work together on projects. Ultimately, this drives up the system cost for utilities.

Battery energy storage system standards are also lacking in the area of communications. As the District learned about different energy storage products it found that the communications between the system components was done in many different ways and used multiple different communication protocols. Majority of battery energy storage systems were designed for a specific purpose with each system requiring a significant amount of recurring engineering. Vendors would pair up on a project and engineer a specific solution for a specific need but there was no consistency between vendors or projects. Additionally, some vendors would attempt to engineer and manufacture a complete system by themselves and this led to companies performing outside of their core competencies. This drove up the overall battery energy storage system cost and reduced its ability to meet a utility's needs.

As a result of these findings the District began developing the MESA standards with industry partners. The goal of MESA is to create open electrical interconnection and communication standards around battery energy storage systems. The long range goal of these standards is to create a marketplace where the battery energy storage system components become modular, reduce recurring engineering costs and ultimately drive down prices.

Figure 1 gives a visual representation of a battery energy storage system and the different control and monitoring systems that must communicate with each other. The MESA standard specifies how these communications will take place between the batteries, power conversion system, and utility.

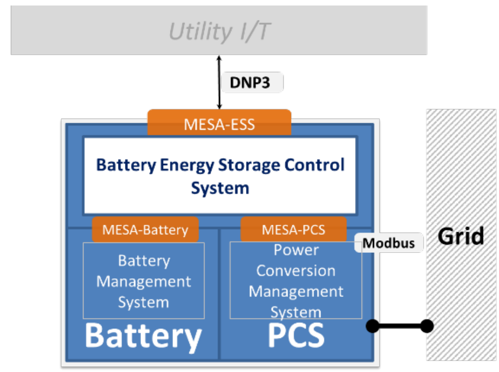


Figure 1

The District's system integrator for the Project is also a MESA strategic partner tasked with developing the foundation for the MESA standards with the District. The District decided early on to only pursue projects that complied with the MESA standards. Today the standards are managed by an independent organization made up of utilities and industry leaders for further development and publishing.

II. Contracting

The District contracted with a single company to deliver the Project and act as the overall system integrator. One reason the District did this was to avoid being in a position of resolving conflicts between different component suppliers. The system integrator was responsible to deliver the system in whole. Ultimately, the District did have contact with the vendors throughout the design and was involved in resolving some conflicts. The District also contracted with an engineering firm to act as an owner's engineer. This proved to be extremely helpful in the design review process. Due to the lack of standards the first step the District took was to require the development of a System Design and Project Plan (SD&PP). The SD&PP included specifications, performance requirements, engineering drawings, bill of materials, system integration plans, hazard analysis, system testing and verification plans, material safety data sheets, manuals, and training plans. It was required that the SD&PP be completed and approved by the District before any system manufacturing started for the Project.

III. Design of the System

A. System Overview

The battery energy storage system the District installed is a 1MW/0.5MHh system utilizing ithium-ion batteries. A second storage project is planned to be installed adjacent to the first system in the near future. The system contains a battery container, a power conversion system, an AC disconnect switch for visible isolation, an auxiliary power transformer, an interconnection transformer and a control cabinet. The interconnection transformer is connected to a dedicated feeder breaker in the substation switchgear. A one-line of the battery energy storage system is shown in **Figure 2**. The substation is a distribution substation stepping down the transmission voltage from 115kV to 12kV. The substation is designed for two power transformers and switchgear. The second transformer is not planned for installation in the near future (10+ years). The substation is conveniently located approximately a mile from the District's engineering and operations headquarters. Coupled with the fact that the substation is fully automated, made it an ideal candidate for the District's first battery energy storage system installation.

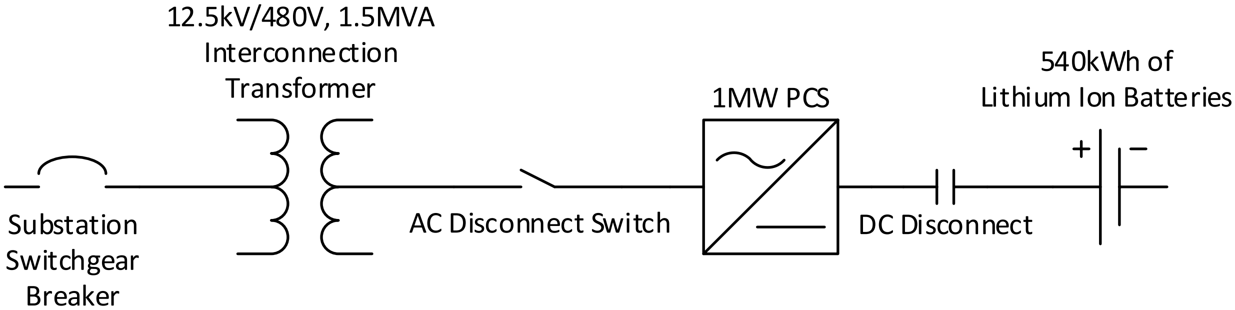
The purpose of the power conversion system is to convert the DC battery power to AC grid power and vice versa. Its primary components are Integrated Gate Bipolar Transistors for power conversion switching, electrical filters made up of capacitors and inductors to reduce harmonics, and a Programmable Logic Controller (PLC). The power conversion system weights approximately 8,800 lbs. and is shown in **Figure 3.** The PLC must communicate with the site control system that runs algorithms to implement the utility use cases. This communication is done using Modbus/TCP protocol in compliance with the MESA standard. The power conversion system has electrical bus and ambient temperature monitors throughout it to ensure it doesn't overheat. It also has two large and very quiet fans located on the top of the unit for cooling the condenser.

Figure 3

The design of the interconnection transformer required the District to work closely with the system integrator and power conversion system manufacture to ensure it would be compatible with the power conversion system output. The exact winding ratio was specified such that as the substation 12kV bus voltage varied, the voltage on the low side of the interconnection transformer would stay in the necessary range for the power conversion system to function properly while utilizing the full battery capacity. The interconnection transformer was also designed as a part of the power conversion system harmonic filtering. The District worked with the power conversion system vendor to ensure the transformer had the appropriate impedance, K factor, and static shielding to withstand and filter any harmonic output of the power conversion system. This drove up the price of the interconnection transformer but eliminated the need for an additional 1:1 isolation transformer in the power conversion system for harmonic filtering. As a part of the commissioning tests, the Project electrical output at the interconnection breaker was tested to ensure compliance with IEEE 519 and 1547 power quality standards.

The power conversion system vendor also provided the lithium-ion battery container design and manufacturing. The battery container houses the

Figure 2



batteries, a heating and cooling system that includes a chiller and air handler, a fire suppression system, DC conductor termination paddles, visible main DC disconnect switch, DC contactors and fuses for each individual battery string, and all of the battery and container monitoring and controls. The battery system consists of 12 strings of batteries, each string containing 20 battery modules, and each module contains 12 battery cells. This makes for a total of 2880 battery cells. Each battery cell has a maximum voltage of 4.1 volts and a minimum voltage of 3.08 volts. The battery modules are approximately 8.5" wide, 24" deep, 5" high and weight 60 lbs. A picture of the battery modules in the container racks is shown in **Figure 4.** Each battery module has a battery management system that reports to a string battery management system. There is also an overall container battery management system. The battery management system ensures the state of charge between the batteries is balanced, monitors the battery voltage, temperature, and current among other things.

Figure 4

The District worked closely with the system integrator to ensure the battery energy storage system was designed to be utility grade. The vendors had to be educated on various utility requirements to ensure the systems would withstand the substation electrical environment and would meet the operational and maintenance requirements of the District. Visible, lockable disconnect switches were integrated into the system between the interconnection transformer and PCS and between the PCS and battery container. This allows District electrical workers to safely isolate any energy sources while performing maintenance on the system. The system design was reviewed by the Districts' Switching and Clearance Committee, Safety Department, Energy Control Center, and Substation Construction Department to ensure the system met all operational requirements.

Edits were made to the Districts Switching and Clearance manual to further define how to take an electrical clearance on the system and isolate the DC batteries which always contain some level of charge. The District also specified utility grade protective relays for overcurrent protection and arc flash protection. Arc flash sensors were installed throughout the power conversion system, battery container and at all switching devices. In the case of an arc flash the relays trips both the utility interconnection breaker and the power conversion system breaker, stopping operation of the battery energy storage system immediately. This arc flash protection scheme significantly reduced the amount of incident energy on the low-voltage AC bus, improving safety.

B. Battery Container Auxiliary Systems

Lithium-ion batteries do have a risk of going into thermal runaway due to thermal or electrical abuse such as internal or external short circuit, heating, overcharging/discharging, or physical damage. For this reason the battery container is equipped with a FM-200 fire suppression system that fills the battery container with a Heptafluoropropane gas agent designed to extinguish the fire primarily by disrupting the chemical process of fire and absorbing the heat as it changes from a liquid to a vapor during discharge. It is an odorless, colorless, liquefied compressed gas that is electrically non-conductive. The fire suppression system was reviewed by the District's insurance company. It is highly recommended that utilities keep their insurance vendors up to date on new battery energy storage system installations to ensure they meet the necessary insurance requirements. Fire alarms indicating activation of the system are hardwired from the battery container to the annunciator in the substation switchgear. Additionally, the alarm is brought back to SCADA for monitoring by Energy Control Center dispatchers. There are a total of four fire detectors in the container and at least two must activate to trigger the system. The container also has an audible alarm and a flashing light to alert personnel if the fire suppression system has been activated. Finally, hard-wired resistance temperature detectors (RTDs) inside the battery container provide insight into the status of the fire through SCADA even when auxiliary power to the container is lost.

The battery container is also equipped with a closed loop controlled cooling system that consists of a chiller and air handling system. This cooling system keeps the container at approximately 72˚F. This is important for battery performance and life. The chiller is industrial grade and provides cold water to the air handler at a temperature in the range of 50 to 54˚F. The air handler includes a liquid to air heat exchanger, fans, and heating coils. Air exits the air handler into a large air plenum that distributes the air down the center of the container and out through the battery racks cooling the batteries. The air then returns back to the air handler along the outer walls of the container. Return air is cleaned by internal air filters. The vendor originally recommended an antifreeze for the chiller that required a high degree of personal protective equipment (PPE) for maintenance personnel. The District worked with the vendor to change to a more common antifreeze that it was already trained to handle. A thorough review of all Material Safety Data Sheets is recommended for any utility installing a battery energy storage system.

C. Hazard Analysis

As described above, the battery energy storage system contains multiple subsystems with various chemicals involved. For this reason the District prepared a Hazardous Material Management Plan (HMMP) to detail how to store, transport, monitor, and respond to emergencies related to the batteries and other systems. The engineering firm the District hired to review the design was extremely helpful in preparing and providing expertise for this document. The plan includes Material Safety Data Sheets for all material in the battery energy storage system. It also includes an emergency response chart detailing how to respond to different emergencies, a site layout with pertinent emergency information, an emergency call-out list, hazard recognition information, a Health and Safety Plan and appropriate evacuation zones in case of a large fire. The U.S. Department of Transportation's 2012 Emergency Response Guide provided valuable input to the HMMP on recommended evacuation distances and fire response procedures. A complete copy of the Hazardous Material Management Plan was submitted to the city and fire department for review during the project permitting.

In addition to the chemical hazards identified in the HMMP, the system integrator performed a detailed arc flash study in order to identify electrical hazards and PPE requirements for the system. The initial arc flash study made assumptions on the protective relay settings as they were not finalized early on in the project design. Regardless, the results of the study gave good insight into the likely incident energy levels throughout the system and validated that existing PUD crew PPE met the hazard risk category (HRC) 2. The arc flash study was updated after final protective relay settings were determined, then each compartment door was labelled with detailed arc flash information including voltage, approach distances, incident energy, and HRC.

D. Communications and Control

The communications between the power conversion system, battery container, and control system were designed around the MESA standard. The power conversion system and battery container vendors for the Project made modifications to their systems to make them MESA compliant. The integration of the battery energy storage system into the District's SCADA system was done through the substation data network in a MESA compliant fashion using Distributed Network Protocol 3. This is the same communication protocol the District uses for all of its substation communications. Additionally, engineering data from the battery energy storage system is fed through the substation data network back into the District's data historian. This feature will be extremely useful while assessing the systems performance. Future energy storage systems that the District installs will be integrated in a similar fashion and use the MESA standards, reducing the amount of recurring engineering from project to project.

Cyber security is a high priority at the District and was integrated into the design. The system integrator and control system provider worked closely with the District's Information Technology Department. The battery energy storage system was designed to report data over three different channels, a SCADA data channel, an engineering data channel, and a third party vendor channel. All of these channels pass through the substation networking equipment and had to be properly secured. The third party vendor channel allows the vendors to remotely access the battery energy storage system for monitoring purposes. No control is permitted over this channel. The District has found that a majority of battery energy storage system vendors require access of this kind, with many wanting a separate channel such as a cellular modem. The District does not allow such a separate channel as it could potentially be a back-door from the internet to the operational SCADA network. Vendor data collection and remote access requirements should be identified up front in a project so that it can be evaluated and integrated into the design. The overall data network for the energy storage system became rather complicated due to cyber security requirements and this is something the District will work to simplify for future installations.

The battery energy storage control system has eight control modes including Limited Watts, Charge/Discharge, Fixed Power Factor, Power Factor Limiting, Load and Generation Following, Peak Power Limiting, Real Power Smoothing, and Dynamic Volt-Watt mode. Additionally, the Limited Watts, Charge/Discharge, and Fixed Power Factor modes can be scheduled and operate autonomously for up to 50 hours, at which point the schedule can then repeat itself. The control system allows for customization of the algorithms, although in its current state programming knowledge is required. The overall control system is MESA compliant. The battery energy storage system has hundreds of alarms associated with it. The District combined these alarms into three actionable alarms with varying levels of response required. The purpose of doing this was to ensure that District Energy Control System Dispatchers would not be overwhelmed but rather have three simple alarms with actionable responses.

E. Site Design

The site design required each container's dimensions, weight, center of gravity and conduit entry locations among other things. The containers were all set on slab foundations. The battery container weighs approximately 47,000lbs with batteries and thus required a fairly thick slab with rebar reinforcements. All electrical connections between the battery containers, power conversion system, disconnect switch, interconnection transformer, and switchgear were made with cables installed in either conduit or trench. Trench was utilized between the battery container and power conversion system to provide improved cooling over buried conduit and reduce the total number of conductors. The District worked with the local city to amend an existing Special Property Use permit for the project. This required a new sound study for the site. Detailed noise emission data was gathered for each component and with the proposed site layout, a model was generated to ensure the total audible noise met the permit requirements. The fire department was also involved in the permitting process and made additional requirements on signage in order for responders to adequately identify that the system contains lithium-ion batteries.

IV. Manufacturing, Installation, and Testing

A. Factory Acceptance Testing

The design also included the development of Factory Acceptance, Commissioning, and Acceptance Testing documents and test procedures. This was very important and helped ensure the District would get the product it was expecting. The battery energy storage system design phase was a difficult process that took much longer than expected. The District was as thorough as possible during the design while trying to maintain the project schedule.

Oversight of the manufacturing was largely left up to the system integrator. Regular reports were given to the District on the progress and any design changes were presented to the District. The batteries were the first component to complete manufacturing. The battery container and power conversion system were manufactured by the same vendor. Once all manufacturing was complete the system integrator went to the main manufacturing location to perform initial factory acceptance testing on the system. The District insisted on a complete test of the entire battery system before shipment. This is highly recommended as a test of only a subset of the batteries connected to the power conversion system may not reveal all potential issues. All the batteries were installed in the battery container and connected to the power conversion system prior to shipping. The batteries were not removed from the container for shipping. This required some additional permitting on the part of the vendors.

Thorough factory testing was a high priority of the District's. The District's goal was to discover and correct as many issues as possible in the factory before shipping the devices to the field where it would be much more difficult to make modifications. The factory acceptance test took approximately two weeks to complete. The District was on sight for the final two and a half days. During this time the District witnessed a complete system start up and shut down, emergency shutdown via multiple mechanisms, charge/discharge of the system at full capacity, reactive power tests, round trip efficiency tests, multiple Failure Modes and Event Analysis tests including loss of communications between systems, inadvertent trip of a system, control system failure and major component failure. Overall the factory acceptance test went well. Several issues were discovered and the vendor and system integrator took quick action to correct them. It is highly recommended to any utility installing a battery energy storage system to require thorough Factory Acceptance Testing of the complete system.

B. Electrical Assembly

The Electrical Assembly work consisted of placing and anchoring all the equipment, grounding, pulling and terminating the electrical cables, pulling and terminating the electrical control wiring, connecting communication wires, cables, and fiber. The entire electrical assembly took approximately five weeks, working an average of five ten-hour days per week. The control cabinet, disconnect switch, power conversion system, and battery container all required some modifications or corrections during the electrical assembly. Majority of the corrections where with the control cabinet wiring and communication cables. It is highly recommended to perform thorough testing of all equipment before it is shipped from the factory. The District didn't perform any factory acceptance testing on the control cabinet as it did with the power conversion system, batteries and battery container. The result was evident during electrical assembly.

C. Substation Data Network and SCADA Integration

The District installed a Smart Grid Test Lab at its engineering and operations headquarters with funding from the SGIG. The Smart Grid Test Lab is a complete mockup of a substation data network including relays, a gateway (data concentrator and protocol converter), communications equipment, and a fiber connection into a test SCADA system. The District is committed to using this resource to test any new equipment, control schemes, or communication before deploying them in the field.

A new room was added to the Smart Grid Test Lab specifically for the purpose of testing the battery energy storage control system and communications. The power conversion system Programmable Logic Controller, battery management system, battery energy storage control system and Human Machine Interface (HMI) were all installed in the test lab for a communications test before any of the equipment arrived on site. The battery energy storage system network was assembled and communications were tested all the way back to the test SCADA system. All components were connected identical to the field design and used the same networking equipment. The equipment was purchased and installed permanently so that any future software/firmware patches or upgrades can also be tested before being deployed to the field. An additional benefit to having identical equipment in the test lab is emergency spare parts. With identical configurations a component could be borrowed from the test lab to facilitate immediate field replacement, avoiding procurement delays. Many bugs were worked out in the software prior to and throughout deployment. Once the system was installed in the field, integration into the substation data network went smoothly.

D. Commissioning

The commissioning process and initial start-up of the system was quite successful. The system integrator and power conversion system vendor were on-site and the system was charging/discharging at full capacity within a week. Commissioning included equipment inspections, testing of all electrical and communications connections, testing of cooling and fire suppression systems, pump rotation checks, full discharge/charge tests, round trip efficiency tests, control system tests, system emergency stop tests and many others. No issues were found with the batteries during commissioning. The biggest issues were the failure of a Human Machine Interface and several communications cards/equipment. Some fine tuning was done to the overall control system as this was its first installation. The District does anticipate some level of on-going issues as this is a first of its kind system.

V. Training

The District and system integrator provided training on the energy storage system to relay technicians, wiremen, servicemen, Energy Control Center dispatchers, and firefighters. For the field personnel the training consisted of a technical overview of the system, operation of the system, troubleshooting, maintenance, and emergency response. Energy Control Center dispatchers were given an overview of the system and instructed on how to respond to various alarms surfaced in SCADA. The battery energy storage system itself has hundreds of alarms. These alarms were summarized into three actionable alarms for Dispatchers. Training for the firemen consisted of an overview of the system, how to respond to major emergencies, and chemicals in the container.

VI. Conclusion

Overall the installation of the District's first MESA based energy storage system was a success. It was a team effort involving groups from across the District including: Substation, Planning and Protection, Environmental, Safety, Construction, IT, SCADA, and Communications. Additionally, multiple contractors were involved in development of the system. The District is hopeful that the MESA standard will continue to be adopted by vendors and required by utilities in energy storage system specifications. These standards will help system vendors and utilities better understand each other, make the systems easier to install and maintain, drive down costs, and make the systems more useful in the long run. Storage technology has the ability to enable the additional integration of renewable energy and decrease the electricity sectors dependence on carbon based energy resources.

VII. Biographies

Jason Zyskowski received his B.S. in electrical engineering from the University of Washington in 2004. He has worked at the Snohomish County PUD #1 since graduating. He has experience in transmission, protection, and substation engineering and is the manager of the Substation Engineering Department. He is a member of IEEE and a registered Professional Engineer in the state of Washington.