ELECTRIC POWER RESEARCH INSTITUTE

Energy Storage Demonstration Project Final Report

An EPRI Energy Storage Demonstration Report

2017 TECHNICAL REPORT

Energy Storage Demonstration Project Final Report

An EPRI Energy Storage Demonstration Report

3002011313

Final Report, June 2017

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Principal Investigator
S. Willard

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ABSTRACT

This report documents the Electric Power Research Institute (EPRI) Battery Storage Project structure, activities, researched performed, lessons learned, and related gaps exposed over the course of three years. The project was conceived over five years ago and was formally started in the summer of 2014. When this project was conceived, the capabilities of storage were becoming apparent, but there was much to be learned about how to best and most efficiently integrate it while extracting as much benefit as possible. The project involved the purchase and placement of a 1MW/2MWh Li-ion battery system, as well as research into already placed and similar sized systems. A variety of host utilities shared experiences and learned from other collaborators, and other entities joined as participants to learn from those with storage experience.

The collaboration centered on an iterative and somewhat circular project management model that identified gaps up front, engaged in research and tool development to find solutions, test these solutions in the real world, and reassess the gaps. Through information sharing and collaborative meetings the process was repeated, uncovering new gaps and solutions. Nine separate and distinct research reports (excluding this report) stemmed from this effort, and the learnings were also disseminated into other EPRI research efforts, such as the Energy Storage Integration Council (ESIC). Under this project many gaps relating to storage placement and operation were covered by new research that:

- Created new models for power conditioning systems and guidelines for storage grounding and scope of work development,
- Tested a recently enhanced optimization model that studies micro-grids and island grids and the placement of renewables and storage,
- Analyzed existing and new control systems from a formal Use Case documentation effort.

The lessons learned from this project are numerous and were documented in many of the reports. Special consideration on the lessons learned from the storage installation effort were documented in a risk analysis framework that also spoke to next step research needs. This report summarizes and categorizes the lessons learned and presents new material based on late stage learnings. Much has changed since the project's inception, and many challenges and grey areas are much clearer. However, new challenges emerged as the technology evolved, expectations of the technology became clearer, control systems became better understood, and codes and standards started to catch up to the wide variety of chemistries and systems related to energy storage.

Keywords

Energy storage	Microgrid
Storage optimization	Storage integration
Storage controls	Storage modeling

EXECUTIVE SUMMARY

Deliverable Number: 3002011313

Product Type: Technical Report

Product Title: Energy Storage Demonstration Project Final Report: An EPRI Energy Storage Demonstration Report

PRIMARY AUDIENCE: Funding entities of the Support, Analysis, and Modeling for a Substation-Size Energy Storage System Demonstration Project, and stakeholders interested in the integration issues, economics and demonstrated capabilities of utility-scale energy storage.

SECONDARY AUDIENCE: Utility personnel interested in understanding the roles and personnel required to manifest an energy storage system.

KEY RESEARCH QUESTION

What are the costs and integration issues prevalent with energy storage, and what additional development of storage technology is necessary to have a “plug-and-play” standardized product that utilities will know how to install with minimal special effort required?

RESEARCH OVERVIEW

This project entailed many parallel efforts centered on four Host Systems where utility scale storage was present, and installation of a new system at a 5th site. The efforts at the host systems included assessment of the current control systems, as well as modeling of overall economics for current and additional systems. The installation effort involved management of site development, system purchase and installation, as well as coordination of the commissioning effort. Detailed feeder modeling for the new installation was performed to best align the commissioning plan to the specified capabilities of the storage system. Lessons learned from the overall installation effort were documented in specific guidelines for various design elements, as well as overall project execution.

KEY FINDINGS

- Front end consideration of the intended storage applications needs to be formally conducted with as many stakeholders as possible at the beginning of any storage project design. Requirements documents (formal IT-type forms) should document with as much detail as possible the features of the controls needed to pursue the applications. The requirements documents should be repeatedly updated throughout the design effort.
- Aligned with controls requirements, front end effort is required to define specific roles and responsibilities within all organizations involved, including ownership of all aspects of the project life cycle from concept to decommissioning.
- Many new engineering models were developed or utilized in the course of this project. Each storage site had specific characteristics affecting how the system was modeled and operated in the real world. Design of storage still may require extensive modeling effort that should be reflected in preliminary budget projections.
- Storage technologies are rapidly advancing and many initial findings of this project had to be revisited throughout the project’s three year history. An iterative and circular project management approach was used to allow for initial models and findings to be retuned throughout the project. As new findings emerged, the technologies advanced and costs declined.

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EXECUTIVE SUMMARY

WHY THIS MATTERS

As energy storage systems become a more practical component of the emerging grid, documenting the experience of real world installations, as well as modeling field performance based on real world experience, highlights the true challenges of integrating storage systems to utility grids. This research benefits all stakeholders and the public in general by exposing development gaps and creating solutions to allow energy storage to be effectively and safely integrated to the energy grid.

HOW TO APPLY RESULTS

This report summarizes the research performed under this demonstration project and presents a compilation of lessons learned which can be used to guide future efforts. It also describes future research efforts that could further ease the integration of energy storage.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI Program 94: Energy Storage and Distributed Generation Program. By researching Distributed Energy Resources (DER) and energy storage technologies, Program 94 supports the integration of these systems into the grid, with the goal of improving overall reliability and reducing the environmental impacts of electric generation. http://www.epri.com/Our-Portfolio/Pages/Portfolio.aspx?program=053125
- Research results and pilot projects relevant to storage are active components of EPRI's collaborative direction featured in publicly available EPRI report 3002009917, *The Integrated Energy Network: Connecting Customers to Reliable, Safe, Affordable, and Cleaner Energy,* available at www.epri.com:

EPRI CONTACTS: S. Willard, Technical Executive, swillard@epri.com

PROGRAM: P94 Energy Storage and Distributed Generation

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1
INTRODUCTION

This report documents the overall activities and findings of the Energy Storage Demonstration Project. This multi-year project was aimed at bridging apparent weaknesses and to move energy storage offerings, namely Li-Ion technology, further down the path to a plug and play product where many benefits are available to appropriate stakeholders. This project combined the experiences of 4 host utilities and 7 participants to document current operational controls, identify gaps and create products and tools that bridge these gaps. A centerpiece installation at Southern Co/Georgia Power was developed through this project, including equipment installation.

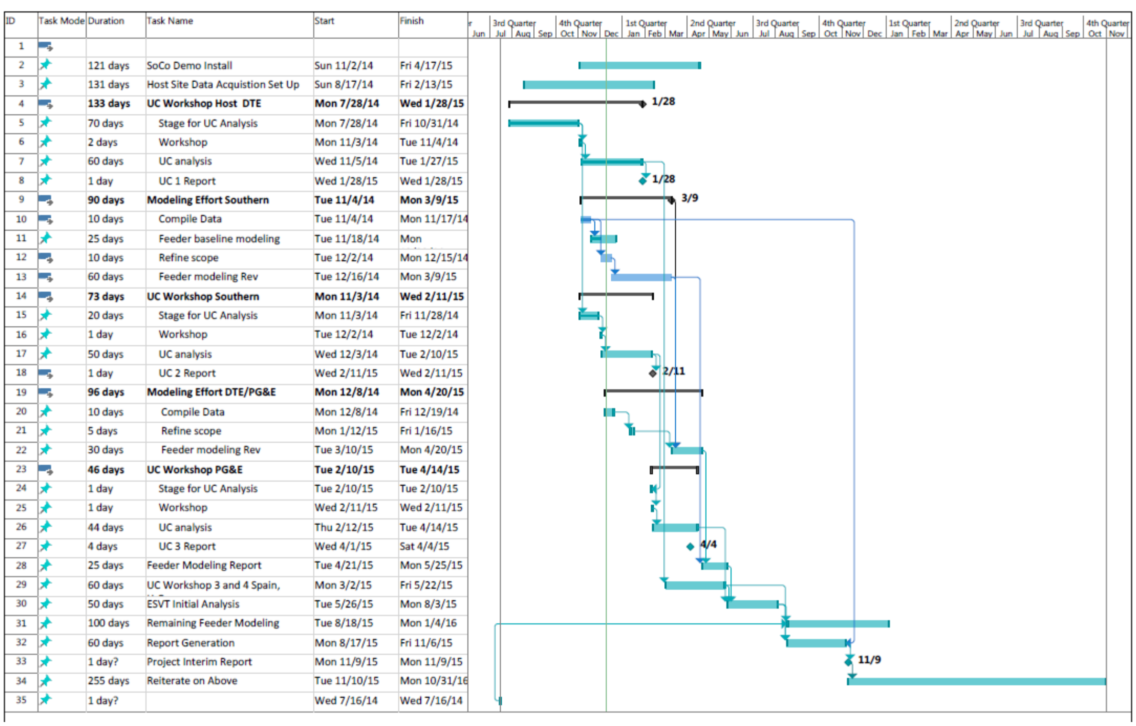
This report details the project history, key research questions answered, summary of the deliverables, status of the tasks in the project scope of work and a listing of the lessons learned, both for the specific deliverables and for the project overall. The report concludes with a narrative on key findings and future research directions that become evident through this effort.

2

PROJECT CHRONOLOGY

The overall project was launched, informally, in 2012 and subsequent years were spent enrolling members and negotiating the purchase of a battery system to serve as a centerpiece of the project. With assigned personnel, the project was formally launched in the summer of 2014. In parallel several tasks were initiated, including:

- Creation of project management plan with specific outcomes and goals that were targeted through ensuing efforts
- Creation of a project site web portal - detailed in the Deliverable Section below
- Alignment and scheduling for Use Case Studies/workshops
- Alignment of Southern storage site selection and engagement of an Engineer Procurement and Construction (EPC) contractor along with staging initial design meetings at Southern Company's Headquarters in Atlanta
- Many of the ensuing tasks were then scheduled and slated to run through late 2016 per the schedule below.



ID	Task Mode	Duration	Task Name	Start	Finish
1					
2		121 days	SoCo Demo Install	Sun 11/2/14	Fri 4/17/15
3		131 days	Host Site Data Acquistion Set Up	Sun 8/17/14	Fri 2/13/15
4		**133 days**	**UC Workshop Host DTE**	**Mon 7/28/14**	**Wed 1/28/15**
5		70 days	Stage for UC Analysis	Mon 7/28/14	Fri 10/31/14
6		2 days	Workshop	Mon 11/3/14	Tue 11/4/14
7		60 days	UC analysis	Wed 11/5/14	Tue 1/27/15
8		1 day	UC 1 Report	Wed 1/28/15	Wed 1/28/15
9		**90 days**	**Modeling Effort Southern**	**Tue 11/4/14**	**Mon 3/9/15**
10		10 days	Compile Data	Tue 11/4/14	Mon 11/17/14
11		25 days	Feeder baseline modeling	Tue 11/18/14	Mon
12		10 days	Refine scope	Tue 12/2/14	Mon 12/15/14
13		60 days	Feeder modeling Rev	Tue 12/16/14	Mon 3/9/15
14		**73 days**	**UC Workshop Southern**	**Mon 11/3/14**	**Wed 2/11/15**
15		20 days	Stage for UC Analysis	Mon 11/3/14	Fri 11/28/14
16		1 day	Workshop	Tue 12/2/14	Tue 12/2/14
17		50 days	UC analysis	Wed 12/3/14	Tue 2/10/15
18		1 day	UC 2 Report	Wed 2/11/15	Wed 2/11/15
19		**96 days**	**Modeling Effort DTE/PG&E**	**Mon 12/8/14**	**Mon 4/20/15**
20		10 days	Compile Data	Mon 12/8/14	Fri 12/19/14
21		5 days	Refine scope	Mon 1/12/15	Fri 1/16/15
22		30 days	Feeder modeling Rev	Tue 3/10/15	Mon 4/20/15
23		**46 days**	**UC Workshop PG&E**	**Tue 2/10/15**	**Tue 4/14/15**
24		1 day	Stage for UC Analysis	Tue 2/10/15	Tue 2/10/15
25		1 day	Workshop	Wed 2/11/15	Wed 2/11/15
26		44 days	UC analysis	Thu 2/12/15	Tue 4/14/15
27		4 days	UC 3 Report	Wed 4/1/15	Sat 4/4/15
28		25 days	Feeder Modeling Report	Tue 4/21/15	Mon 5/25/15
29		60 days	UC Workshop 3 and 4 Spain,	Mon 3/2/15	Fri 5/22/15
30		50 days	ESVT Initial Analysis	Tue 5/26/15	Mon 8/3/15
31		100 days	Remaining Feeder Modeling	Tue 8/18/15	Mon 1/4/16
32		60 days	Report Generation	Mon 8/17/15	Fri 11/6/15
33		1 day?	Project Interim Report	Mon 11/9/15	Mon 11/9/15
34		255 days	Reiterate on Above	Tue 11/10/15	Mon 10/31/16
35		1 day?		Wed 7/16/14	Wed 7/16/14

Figure 2-1
Battery Demo Project Timeline

The members of the along with their respective designation as participant (P) or self host (SH), along with size of host battery systems at the time of enrollment are:

- Southern Company (SH) – 1MW / 2MWH Li-Ion
- DTE (SH) 25 kW / 30 kWh – multiple sites totaling 1MW and 1 - 500 kW / 250kWh Li-Ion
- PG&E (SH) 2 MW / 12 MWh & 4 MW / 24 MWh NaS
- HydroOne (P)
- Red Electrica – Spain (SH) 1MW / 3MWH Li-Ion
- Endesa – Spain/Gran Canaria (SH) 1 MW /3 MWh Li-Ion
- ConEd (P)
- SRP (P)
- APS (P)
- LG& E and KU (P)
- Shell (P)

(It should be noted that almost all of the Project members have installed storage since the inception of this project)

3 PROJECT FRAMEWORK

The key research objectives of this demonstration are to:

- Bring together data and experiences from existing and new energy storage demonstrations, with a consistent approach to data analysis and understanding of integration efforts
- Develop and use standardized analytical tools and methodologies to determine the impacts that energy storage can make on the grid and the benefits that can be derived from its use;
- Understand the total cost of ownership for energy storage systems across the systems operational lifetime;
- Recognize and assess the differences in performance between different storage technologies;
- Explore how distribution-level storage can be used simultaneously to service multiple value streams, and how operation can be managed and prioritized to ensure optimal operation;
- Develop use cases for distribution-level storage applications that outline interface requirements with energy management systems (EMS), DMS and other utility systems to develop standardized interconnection and control requirements for integration of energy storage applications;
- Evaluation of new methods for scheduling and dispatching storage resources, as well as relative advantages of centrally (ISO) scheduled/dispatched storage in markets;
- Collect information that can be used to inform regulatory action that may ultimately make multiple value streams possible.

Project Management Framework – The overarching goal for this effort was to describe and specify how Energy Storage systems need to integrate in modern and emerging grids and the specification of the controls and technologies needed to perform optimized storage operation. To address this goal and the originally scoped research questions, an iterative framework was introduced to describe how the project was to evolve during its multi year scope. This structure was adopted to ensure that deliverables were informed by review and real world experience and hence refined as progress was made. - This framework centered on a repetitive learning cycle where an iterative process that started with 1) defining requirements through specific Use Case Analysis then 2) determining functional gaps followed by 3) modeling the systems in place and 4) determining needed technology improvement based on real world results through incorporation of field experience and data in second stage gaps analysis. The process was iterative and repeated allowing for refinement of Use Cases and models to further inform specifications and functional requirements needed to achieve the over-arching goal as shown in the figure below.

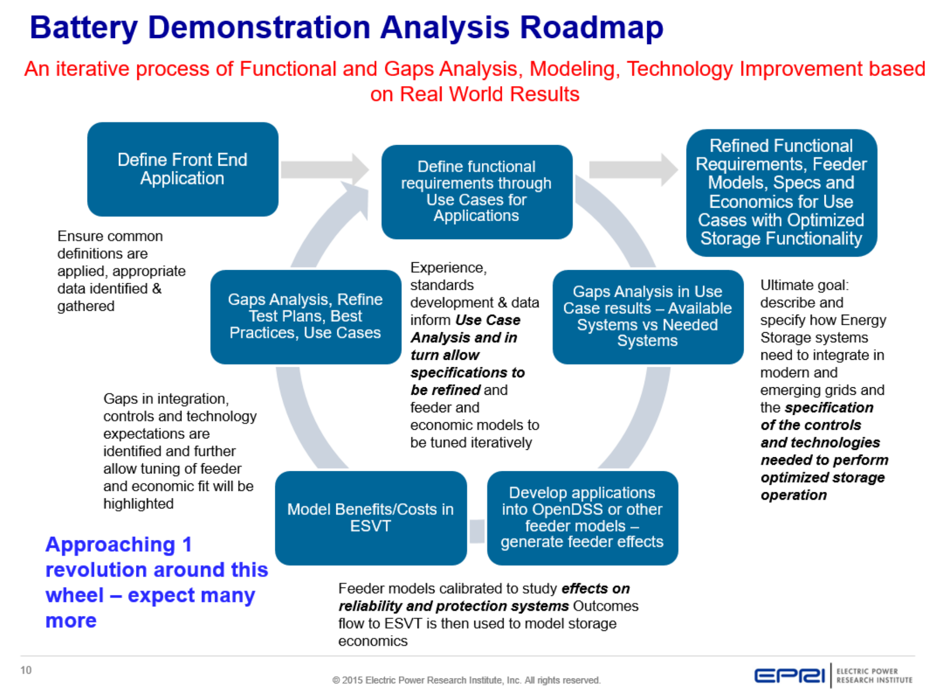


Figure 3-1
Batter Demonstration Analysis Roadmap

Specifically, this framework involved

1. An initial step of defining front end applications to ensure common definitions are applied, appropriate data identified & gathered. The ensuing circular steps where then pursued
2. Defining functional requirements through Use Cases for Applications
3. Performing a Gaps Analysis from the Use Case results based on features of the fielded or available systems vs whats needed in future systems to achieve the goal
4. Develop applications into OpenDSS or other feeder models to generate feeder effects and understand how new and existing storage systems impact the grid using Feeder models calibrated to study effects on reliability and protection systems. Outcomes flow to storage economics models like EPRI Energy Storage Valuation Tool (ESVT - since superseded by StorageVET^{TM})
5. Model Benefits/Costs in ESVT
6. Based on the outcome of the economic models perform and another Gaps Analysis, Refine Test Plans and Best Practices along with the Use Cases. specific focus was placed on gaps in integration and controls. Technology expectations were identified to allow tuning of feeder and economic models

Overall the project went through the framework cycle many times in terms of refining specific models and the project completed at least two revolutions in the learning cycle.

4
KEY QUESTIONS AND PROJECT FOCUS

The key questions posed in the project launch were presented as follows, noting the specific posture being taken to address the question

Validation of technical performance and durability – how are systems installed performing? What are the integration issues?

Project Focus: Most of the host systems experienced difficulties in terms of integration but once these issues were solved the systems for the most part operated at specified levels. Some host sites were hindered by vendor financial issues, others through control integration issues and some due to field conditions exceeding equipment capabilities.

Most of the integration issues centered on the controls and lack of maturity or capability of legacy control systems (SCADA) to interface with tkhe controls pertaining to the battery system. Many of these issues were documented for existing systems in the Endesa and DTE Energy Use Case studies and for a system in development in the case of the Southern Use Case study

What are the grid impacts and benefits of the energy storage systems in real application scenarios (realized and projected)?

Project Focus: Numerous modeling efforts were conducted that studied the impacts both in engineering and economic frameworks. These studies are highlighted in the Deliverables section below and furthered detailed in individual reports.

The most significant effort was expended on understanding the engineering characteristics of a battery/PCS performing fast acting duties such as voltage and frequency regulation. Prior to this development there was no true model that could integrate the sub-second responses with quasi-steady state, traditional feeder models, such as EPRI's OpenDSS. This effort was conducted in parallel with the Southern site development and the results of the model were used to PCS settings that could trigger voltage regulation from the storage system.

Detailed models were also created to allow economic optimization of storage and renewables for two separate islands in the Canaries Island chain; the La Palma Island system was studied for Red Electrica de España and the La Gomera system was studied for Endesa/Enel. Although the initial intent of these modeling efforts was to include power flow in the economic analysis that targeted numerous constraints, including operating cost and emissions, limitations were discovered in the program used that prevented correct understanding of the power flow within the optimization model. Commercial engineering software packages where then used to ensure proper power flow behavior separate from the optimization model.

A simple economic analysis was also conducted using EPRI's ESVT model for one of the hosts as part of their storage system analysis for the US DOE. These results are presented below.

What gaps need to be bridged to make storage efficient, responsive to utility needs, safe, reliable and cost effective?

Project Focus: This project focused heavily on understanding the requirements for back office controls necessary to allow for optimized storage operation where numerous applications can be operated, some simultaneously. The entailed numerous workshops with host utilities to document existing systems as well as the then in-development system at Southern. The workshops were conducted at the host utilities and involved input from numerous utility stakeholders. The format was driven by using established, uniform processes to define the goals of operation, the actors and systems involved, cyber security considerations, and envelopment of optimization algorithms.

The results of these Use Case analyses varied widely in terms of sophistication. All the systems studied relayed on internal development of back office control capabilities to some extent; the more sophisticated utilitized extensive efforts to tie to SCADA and real time feeder models while less sophisticated approaches created tie ins to simpler PCS vendor operating software packages. All systems struggled to adapt to legacy control systems, especially if fast acting feedback was needed to operate the storage system. The polling rates of legacy SCADA systems are too slow for these applications and effort needs to be made to determine downstream communication avenues to storage systems from sophisticated back office systems or provision of secure data on a real time basis to site specific controls.

There were numerous other gaps not associated with or tangential to control systems that were studied in the course of this project. These include, in part, grounding for storage and lack of uniform practices, lack of scope clarity between utility and vendor responsibilities, and the disparity of protection schemes between site and more broadly utilities.

What information/tools are necessary to enable informed investment and deployment decisions?

Project Focus: Within the confines of this project new tools were developed including guidelines for grounding and scope of work development, and a fast acting PCS model developed as a module to OpenDSS. Information gained from this project also informed numerous other tools developed within the EPRI Energy Storage Integration Council (ESIC) including, in part, standard specifications, safety guidelines and a RFP template.

5
DELIVERABLES

Web Portal Project Cockpit for the Demonstration Initiative

A web portal was created to share data, findings and reports for the project members. Each host had a limited access folder that was used to relay large data files and sensitive information and accessible only by assigned host personnel. The structure of the site folders is depicted in the screen shot below:

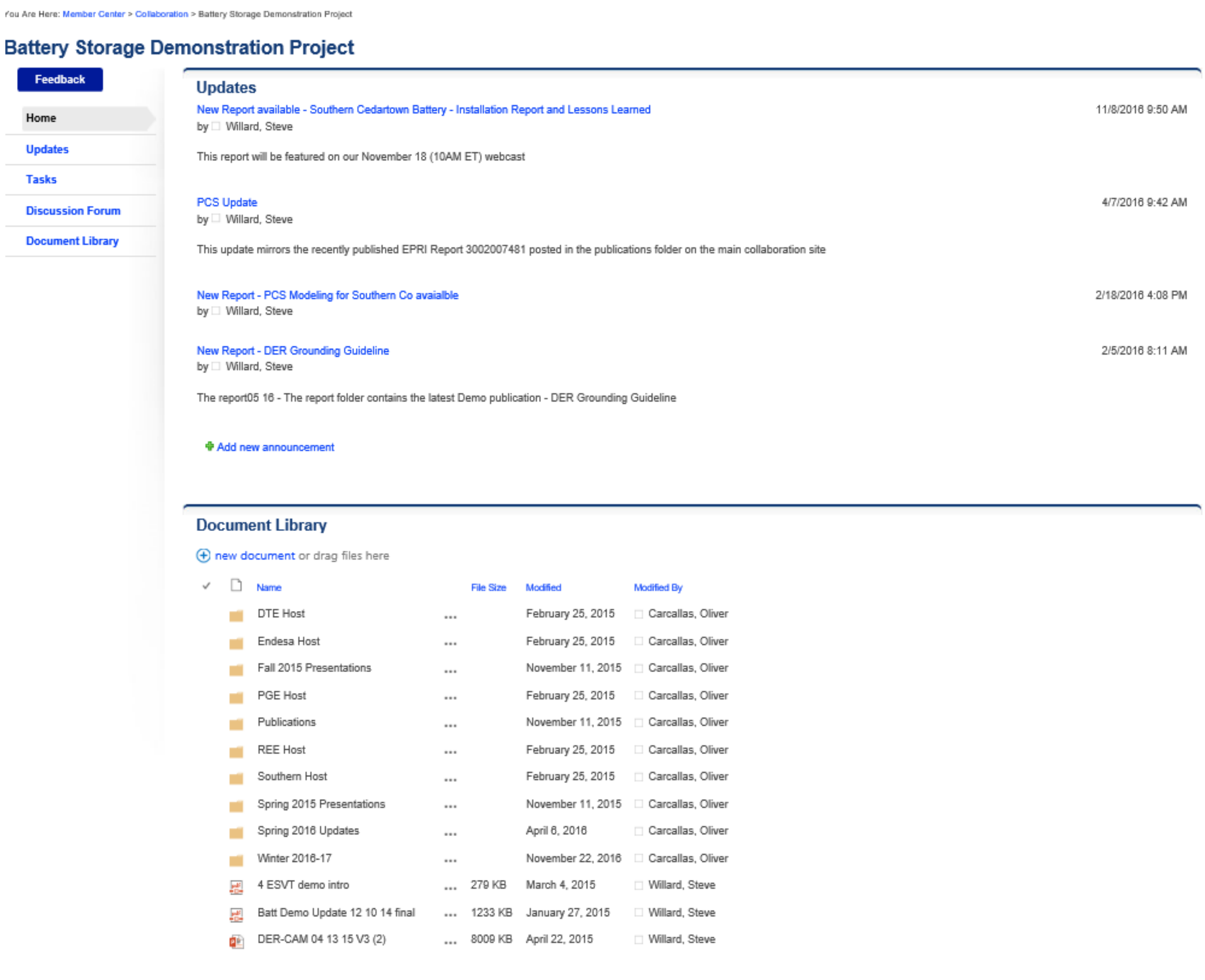


Figure 5-1
Battery Storage Demonstration Project Site Folder Structure

The document library was used to list the available reports

Document Library

⊕ new document or drag files here

Name		File Size	Modified
EPRI Report 3002005154 DTE Use Case Study	...	1748 KB	April 15, 2015
EPRI Report 3002005155 Batt Demo Scope Guidelin	...	743 KB	March 4, 2015
EPRI Report 3002006137 Southern Use Case Study	...	2717 KB	June 2, 2015
EPRI Report 3002006891 Endesa Use Case Study	...	1574 KB	A few seconds ago
EPRI Report 3002007313 DER Grounding Guideline	...	4129 KB	February 5, 2016
EPRI Report 3002007481 Modeling PCS	...	4695 KB	February 18, 2016
EPRI Report 3002009415 Southern Cedartown Battery - Installation Report and Lessons Learned	...	1010 KB	November 8, 2016
EPRI Report 3002009920 La Gomera Island Optimized DER Modeling for Endesa	...	1481 KB	Yesterday at 12:26 PM

Figure 5-2
Document Library

Note that an attempt to connect direct feeds to existing host project data acquisition system was attempted but abandoned due to data security issues.

Southern Host Site Construction/Installation of 1MW/MWH Battery System - In parallel to the overall project set up a site was chosen for battery at Southern/Georgia Power service territory and design and installation were instigated. Efforts under this task included

- The battery system PO was executed in late 2013 and the battery modules were shipped from the vendor in early 2014 and subsequently held in an environmentally controlled warehouse until installation in 2015
- Review of the site including analysis of the feeder loads and development of software to model and determine PCS settings to allow voltage regulation. Under this effort extensive power quality level data sets were recorded and used to calibrate the new model. Additionally, the feeder was modeled in OpenDSS to ensure proper operation and ability to pursue the stated functions desired by the battery system
- A solicitation was issued to engage a EPC. Once engaged the activities of the EPC, Southern and the storage vendors was coordinated to ensure a correct design, alignment of the construction schedules and delivery of the equipment and ensuing commissioning activities
- In parallel numerous design meetings were held to accommodate the issues that stemmed from the unique ownership by EPRI of the equipment. The site was considered a customer owned site due to this ownership provision and this stance impacted the design due to:
  - Need to place a second set of line side potential transformers (PTs) for relaying the site meter signal to the PCS because the local utility does not allow sharing of PT signals from their site meter.
  - Development of a radial feed on the distribution system due to protection requirements. It was deemed less costly to run the radial feed from upstream rather than tie the storage system to the loop containing an adjacent ~1MW PV farm. Tying to the loop would have

incurred additional protection equipment and coordination, above and beyond the protection required.

  - It was determined non-feasible to tie to the local utility SCADA system. This then prevented the ability for the storage system to read signals from the local substation or feeder head and perform peak shaving. It is non-sensical to use the site meter to peak shave.

- Site construction required extensive dirt work since the storage system was sited on unsuitable for compaction soil. Construction also entailed development of an extensive grounding and lightning protection system. This was due to lack of identifiable grounding standards that apply to customer owned storage. Hence traditional utility substation standards were used.
- Construction was completed in August 2015. Gaps, solutions found and lessons learned were documented in the Southern Lessons Learned report

Reports - The following reports were developed under the auspices of the project.

Southern Cedartown Construction Specific Reports

Southern Cedartown Battery - Installation Report and Lessons Learned - EPRI TR 3002009415

This report, centered on the Southern host project, documents the chronology of the site build out, system description and features as well as a risk assessment and potential research areas that could bridge identified gaps

Battery Storage Installation Scope of Work Guideline - EPRI TR3002005155

This study serves to inform utility decision makers on the processes and timing pertinent to storage system siting. It focuses on ensuring proper project timing and scope development including correct assignment on roles and duties with respect to utility obligations and integrator obligations

DER Equipment Grounding Practice and Recommendations - EPRI TR3002007313

This study stems from disparities seen in grounding systems located on utility distribution grids. In many cases the grounding system can be different from utility to utility, presenting a wide spectrum of costs to a typical storage project. This is due, in part, to different standards and codes being applied at different sites.

General Controls Integration Analysis

Use Case Development - Southern Company Battery Control - EPRI TR 3002006137

This study investigated the platform being developed for the Southern Cedartown project and contrasted it to the controls and signals necessary to establish true optimal functionality

DTE Energy – Use Case Development - Storage Optimization Engine - EPRI TR 3002005154

This study investigated and documented the sophisticated back office control system developed in house be DTE Energy that incorporates on the fly distribution analysis with an accompanying commercial feed modeling package

Use Case Development—Endesa Battery Control - EPRI TR3002006891

This study documented the remote control system used at the Gran Canaria island based system in the Canary Islands under the auspices of Endesa

Modeling/Simulation of Grid Effects and Economics

Modeling of a Battery Storage System for Southern Co: Application of Smart Inverter Functions for Energy Storage in OpenDSS - EPRI TR3002007481

Extensive effort was placed on developing a model for a fast-acting PCS providing voltage and frequency report. This filled a large gap in the capabilities of existing feeder and other engineering models. It allows for very granular data to drive into the model and, based on specific PCS characteristics (including droop curve and responses??) determine how the PCS provides voltage regulation and what settings need to be for the inputs to the PCS operating firmware. In the case of Southern Co, extensive data was gathered (during construction of the site) to understand the detailed characteristics of the feeder and the loads (mostly industrial) place on the feeder. The model was then used to predetermine the voltage regulation settings needed for the Cedartown PCS to perform voltage regulation on the adjacent feeder. Note it was found that the feeder was well within ANSI Range A voltage parameters so the model was used to define a narrower bandwidth of voltage stability settings that would allow finely tuned voltage regulation at the site. This model, developed in MATLAB is now being incorporated in to a broader tool set that will allow its functionality to applied to numerous tools like OpenDSS and other commercial based feeder analysis platforms

La Gomera Island - Optimized DER Modeling for Endesa - EPRI TR 3002009920

This modeling effort utilized DER-CAM, developed by Lawrence Berkeley National Labs (LBNL) to determine the optimal mix of renewable energy and storage for the La Gomera Island in the Canaries. DER-CAM uses the General Algebraic Modeling System (GAMS) to find the solution by allowing for constraints such as annual operating cost or annual emissions to determine the optimal mix. DER-CAM can model in investment (determining optimal investments) or operation (determining optimal schedules) modes. In this case the investment mode was used. Within the investment mode DER-CAM has newly added capabilities of power flow modeling or the aggregated load approach (where the power flow effects are ignored). Due to limitations of applying the actual network on La Gomera into the power flow model (discussed further in TR 3002009921 below) the aggregated load approach was pursued. The effort found that storage was nominally effective when used to minimize part load operation of the existing fossil based generation fleet.

La Palma Island - Optimized DER Modeling for Red Electrica de España – EPRI TR 3002009921

Similar to the La Gomera Island, also in the Canaries Island chain, this effort utilized DER-CAM to analyze the placement of storage and renewables into the current generation mix. In this effort, the power flow capabilities, recently added by LBNL to the DER-CAM model, were tested. Initial attempts showed that the power flow portion of the model was not producing accurate results when validation with other discrete power flow models were used. Input and software were modifications were tried to improve the output of the power flow portion of the model but none achieved acceptable results. As such, similar to the La Gomera analysis (TR 3002009920), the aggregated load approach was used and similar to that report storage was found to be nominally effective in reducing part load operation of the fossil based fleet currently in place. Other interesting facets of this analysis included a limitation placed in the model to reflect the lack of flat land available for PV placement and some discovered limitations on modeling fossil generator part load efficiencies

DTE Energy Economics Analysis using ESVT

This effort encompassed an economic evaluation of storage at DTE Energy using ESVT. This analysis included assessment of a total of 1 MW total of energy storage systems (20 – 25kW Community Energy Storage and 1 – 500kW utility sized) . The ESVT analysis examined and performed sensitivity analysis around the current applications being pursued including regulation services, deferring capital (substation or distribution upgrade deferral) and some arbitrage based on an MISO LMP price. There was no current prioritization of these applications, though efforts were document in the DTE Energy Use Case Analysis to this capability internally.

The sensitivities considered battery price, a range of low, medium and high capacity market costs and financial inputs that considered both regulated and de-regulated standpoints.

DTE ESVT Assumptions

- The DTE CES storage systems were modeled as a group, acting as a single 1 MW system with agreed upon operating characteristics defined prior to modeling. To model different capacity market scenarios ESVT uses an annual capacity value and 8760 hour system load data for this service. Capacity wasn't included in initial analysis but added in a second phase. Frequency regulation used 2014 MISO data and arbitrage used 8760 LMP price data from MISO. The DTE applications run in ESVT were prioritized as follows:
  - Substation deferral
  - Capacity market
  - LMP based arbitrage
  - Regulation service

DTE ESVT Approach

The modeling effort first analyzed scenarios that iterated on the load growth rate on the feeder, capital cost and deferral upgrade cost as shown in the following Table 5-1.

Table 5-1
DTE Modeling Scenarios

Run	Dist Def	Arbitrage	Freq Reg	Growth Rate	Capital Cost	Upgrade Cost	RT Price
1	Yes	Yes	Yes	1%	1000$/kwh	5M	Avg
2	Yes	Yes	Yes	1%	1500$/kwh	5M	Avg
3	Yes	Yes	Yes	1%	1000$/kwh	Target to B/C~1	Avg
4	Yes	Yes	Yes	1%	Target to B/C~1	2M	Avg
5	Yes	Yes	Yes	2%	1500$/kwh	5M	Avg

The model targeted a benefit cost ration of ~1 by::

- Iterating the upgrade cost until the B/C ratio ~1 or assessing a variety of capital costs ($1000-$1500/kWh) and changing Upgrade Cost – holding growth at 1%
- Using a low end Upgrade Cost and changing Capital Cost – holding growth at 1%

A subsequent analysis incorporated refined financial inputs and added system capacity application to benefits pursued

DTE ESVT Results

Some of the initial results are presented below in Figure 5-3. Run 1 showed that stacked benefits exceeded costs when the distribution investment deferral was raised to $2.2M, allowing for arbitrage and frequency regulation to also incur benefits based on the input market data.

Run 1		
	Cost	Benefit
Utility Rev. Requirement (Variable)	$ 440,235.01	$ -
Utility Rev. Requirement (Fixed)	$ 2,387,745.67	$ -
Electricity Sales	$ -	$ 406,876.40
Distribution Investment Deferral	$ -	$ 2,213,116.31
Frequency Regulation	$ -	$ 971,096.75
Total	$ 2,827,980.68	$ 3,591,089.46

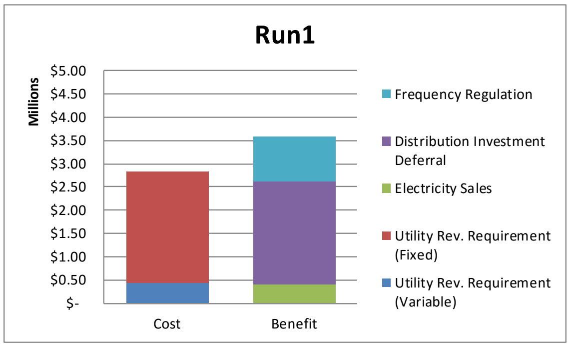


Figure 5-3
Initial Results

Run 2, with a higher capital cost and other variables static, had a negative C/B ratio

Run 2		
	Cost	Benefit
Utility Rev. Requirement (Variable)	$ 440,235.01	$ -
Utility Rev. Requirement (Fixed)	$ 3,549,609.01	$ -
Electricity Sales	$ -	$ 406,876.40
Distribution Investment Deferral	$ -	$ 2,213,116.31
Frequency Regulation	$ -	$ 971,096.75
Total	$ 3,989,844.02	$ 3,591,089.46

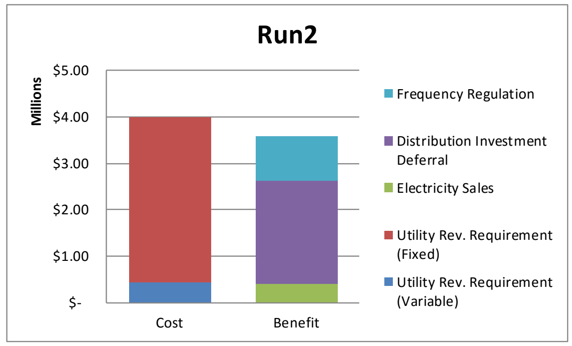


Figure 5-4
Run 2 Results

Run 3, with the lower capital cost, targeted a C/B ratio of ~1 by iterating the deferral cost down to $1.4M

Run 3		
	Cost	Benefit
Utility Rev. Requirement (Variable)	$ 440,235.01	$ -
Utility Rev. Requirement (Fixed)	$ 2,387,745.67	$ -
Electricity Sales	$ -	$ 406,876.40
Distribution Investment Deferral	$ -	$ 1,460,656.77
Frequency Regulation	$ -	$ 971,096.75
Total	$ 2,827,980.68	$ 2,838,629.91

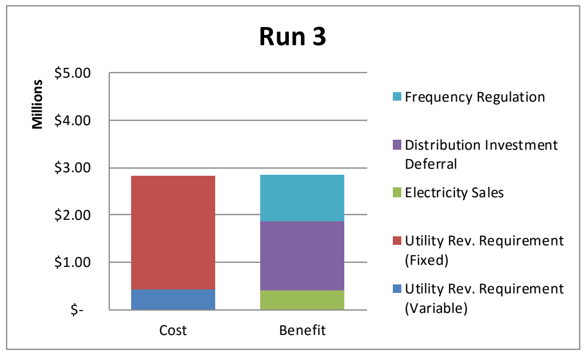


Figure 5-5
Run 3 Results

Run 4, with a set $2M deferral benefit, iterated the capital cost down to a C/B ratio ~1 and results in an allowed capital cost of $705/kWH.

run4		
	Cost	Benefit
Utility Rev. Requirement (Variable)	$ 440,235.01	$ -
Utility Rev. Requirement (Fixed)	$ 1,702,246.30	$ -
Electricity Sales	$ -	$ 406,876.40
Distribution Investment Deferral	$ -	$ 885,246.52
Frequency Regulation	$ -	$ 971,096.75
Total	$ 2,142,481.31	$ 2,263,219.67

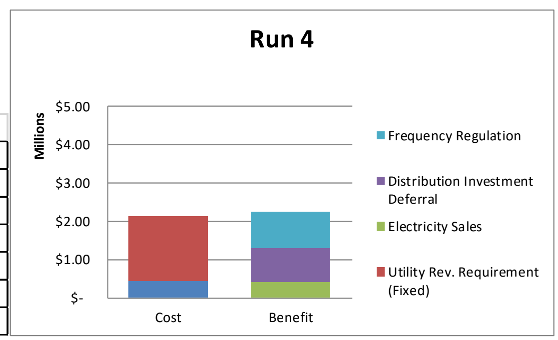


Figure 5-6
Run 4 Results

Run 5 repeated Run 2 but raised the load growth rate to 2%, effectively driving a $5M upgrade deferral to earlier in the project life and hence lowering reducing the benefits.

RUN5		
	Cost	Benefit
Utility Rev. Requirement (Variable)	$ 443,045.47	$ -
Utility Rev. Requirement (Fixed)	$ 3,549,609.01	$ -
Electricity Sales	$ -	$ 409,520.23
Distribution Investment Deferral	$ -	$ 1,235,237.30
Frequency Regulation	$ -	$ 974,215.88
Total	$ 3,992,654.49	$ 2,618,973.41

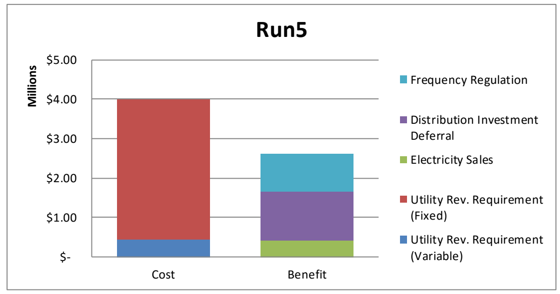


Figure 5-7
Run 5 Results

The second effort used refined financials to model the economics in an unregulated environment and adding capacity as an application. This showed a reduced benefit level given the inputs used.

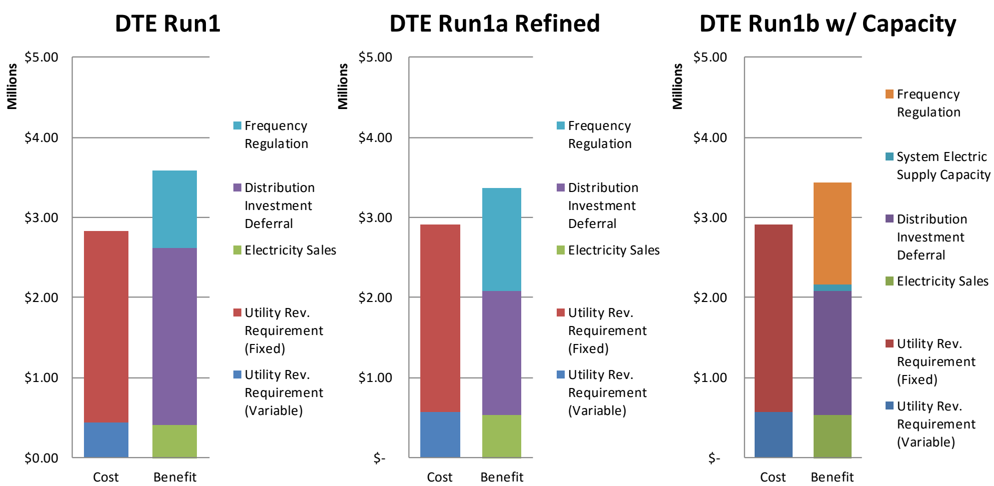


Figure 5-8
DTE ESVT Output Comparison

The final results of the initial runs are tabulated below in Table 5-2.

Table 5-2
Final Results

Run	Dist Def	Arbitrage	Freq Reg	Growth Rate	Capital Cost	Upgrade Cost	RT Price	B/C
1	Yes	Yes	Yes	1%	1000$/kwh	5M	Avg	1.3
2	Yes	Yes	Yes	1%	1500$/kwh	5M	Avg	0.9
3	Yes	Yes	Yes	1%	1000$/kwh	3.3M	Avg	1.0
4	Yes	Yes	Yes	1%	705$/kwh	2M	Avg	1.1
5	Yes	Yes	Yes	2%	1500$/kwh	5M	Avg	0.7

DTE Energy ESVT Conclusions

- A high sensitivity of deferral benefits to the growth rate was noted; the higher growth rate diminishes benefit on deferral ($2.2M benefit for 1% growth vs $1.2M for 2% growth, Run 2 vs Run 5)
- Substantial deferment is needed to justify cost of storage (keeping the other benefits constant)
- Frequency Regulation used MISO 2014 historical prices and contributed ~$409k benefit over life
- Arbitrage used MISO prices and contributed ~$970k life benefit
- Added System Capacity capability didn't substantially help benefits
- Little change noticed with revised financial parameters

In the second iteration, a large decrease in deferral due benefits appeared due to a lowered discount rate. This was made up for in part by increase in frequency regulation benefits but a slight erosion of overall benefits was noted in the deregulated model.

6
PROJECT TASK SUMMARY AND STATUS

Task 1: Energy Storage System Procurement and Risk Management

Completed in August 2015. This task was centered on the installation of the Cedartown Project for Southern Co. It involved guidance on site selection, development of a project scope on installation, engagement with an Engineer Procure Construct (EPC) entity, coordination of construction and delivery of equipment, development of project commissioning plan and coordination of commissioning activities as well as overall project management of associated research activities including feeder and PCS modeling exercises which influenced the commissioning plan.

Site installation was completed through adherence to project management tools including weekly meeting with all stakeholders (utility groups, vendor and subcontractors, EPC firm and other EPRI supporting groups). Each meeting was documented in a risk framework matrix to specific risks were identified classified assigned mitigation and tracked. Samples of weekly meeting minutes and specific issues follow:

Table 6-1
Samples of Weekly Meeting Minutes and Specific Issues

Item/Issue/Logistics	Resolution	Responsible Party/Date Due
Shipping quote for PCS, battery container, transformer, battery modules	Need quote – shipping arrival will have to be closely coordinated with craning and other off loading equipment – update – Vendor has quotes PCS, transformer, racks, waiting on batteries, batt container finalizing on HVAC (Sub will let Vendor know tomorrow) - Does Vendor need refrigerated containers? Current delivery dates need definition • PCS – January • Batt Container – May – mtg Weds this week • Transformer – January	1/23/15 Vendor Update: Vendor was able to establish dialogue with a more responsive logistics contact. For the battery modules, a reefer trailer can be available, but it requires live unload and there is no drop service. It is likely that staged deliveries of the battery modules are needed. Vendor and EPC targeting a conference call for 1/29/15 to discuss site resources and delivery schedule. After the delivery schedule is set, Vendor will go back to the logistics company to request a quote. 1/23/15 Vendor Update: Vendor sent installation manual for battery modules and wiring to EPC as part of initiating a dialogue on site details. 2/3/15 still detailing based on field eqpt available EPC will talk with City on parking 53' container on "milk run"

Table 6-1 (continued)
Samples of Weekly Meeting Minutes and Specific Issues

Item/Issue/Logistics	Resolution	Responsible Party/Date Due
Need to start Utility line extension scheduling – finalize BOM and order eqpt	Trigger needs to be defined and dated Need agreement on scope in order for line extension eqpt to be ordered. Also need to schedule line extension construction	Utility by 12/31/14 Doing cost estimate 12/15/14 Received information from Utility/ Cedartown et al 01/05/15 – have initial estimate – looking for budget approval this week 01/12/15 still pursuing 01/22/15 this week got added estimate for things in the fence 1/26/15 budget tied in – talked with Utility in Cedartown 2/3/15 Utility has authorization to move ahead – crew is scheduled

Task 2. Modeling and Simulation of Distribution Feeder and Energy Storage Economics

This involved development of an OpenDSS feeder model and development of a PCS fast acting model that could be run in concert with OpenDSS - completed through efforts in OpenDSS and development of the new fast acting PCS model in MATLAB as well as the DERCAM modeling efforts conducted for Red Electrica and Endesa as well as the economic modeling for DTE Energy

Task 3. Installation, Interconnection and Data Acquisition

The Southern/Cedartown system installation was completed in August 2015 and the associated interconnection process and lessons learned were documented in the Southern Lessons Learned Report

- The EPRI data collection system installed at the Cedartown site operated successfully and subsequent data collected from Cedartown showed all meters and points reporting. Subsequently, issues occurred with a Wi-Fi modem sending signals to the data collection platform from the adjacent PV site. The monitoring system collects the data shown in Appendix A. All power based points are collected on a 1 second interval, the remaining points on a 15 minute interval. .
- A variety of data was also posted to the collaboration site for modeling purposes from a variety of hosts, including high resolution power quality meter data for the associated feeder and nearby industrial loads from the Cedartown associated feeder as well as pertinent data for DER CAM and economic modeling purposes.

Task 4. Testing, Monitoring, and Documentation of Technical System Performance

A commissioning and test protocol was developed for Southern/Cedartown . Technical issues with the PCS firmware, miswiring, scheduling, metering and overall control issues delayed the commissioning of all applications specified for the system. The commissioning plan incorporated a modification of the PNNL Commissioning Protocol as well as vendor specific steps of bringing the system on line. Initial results are and details of the Cedartown commissioning effort are presented in EPRI TR 3002009415.

Task 5. Analysis of Grid Operational Impacts & Benefits and Site-Specific Application Benefit Analysis

This task was accomplished through:

- PCS and feeder modeling for Southern/Cedartown site and associated feeder presented in EPRI TR3002007481.
- DER CAM studies for Endesa/Enel and Red Electrica presented in EPRI TR 3002009920 and TR3002009921 respectively.
- Economic analysis of DTE Energy's storage – presented above in this report.

Task 6. Reporting and Technology Transfer Activities

A series of webcasts and face to face meetings including web based updates and face to face meetings, which included

- Southern Construction Kick Off meeting 5/28/2014
- General Project Kick Off Webcast 8/28/2014
- Project Update Webcast 11/4/2014
- DTE Energy and Southern Co Workshop Sessions November 2014
- Project Update Webcast 12/11/2014
- Face to Face Meeting (PDU – Phoenix AZ) 3/4/2015
- Endesa and Red Electrica Workshop Sessions April 2015
- Face to Face Meeting (DTE Energy Host – Detroit MI) – 9/14/2015
- Project Update Webcast 12/9/2015
- Project Update Webcast 4/6 /2016
- Project Update Webcast 11/18/2016
- Numerous other host specific meetings were also held throughout the course of the project

7
LESSONS LEARNED/CONCLUSIONS AND NEXT STEP RESEARCH NEEDS

IT/OT Requirements Documentation

One of the key learnings evidenced by project activities was the need to develop requirements documents to detail the features of the storage control system in the early stages of project development. The following Figure 7-1 displays a model control/communication architecture for a utility based storage system. In this model the storage system is controlled from a contemplated back office system that utilizes SCADA (or some form of communication, polling and control platform) and data inputs from a variety of external and internal sources to control the storage, perhaps as a part of a fleet of DER with optimization of each determined in the back-office platform.

From the experiences of this and similar projects, key questions are posed that necessarily need to be addressed (amongst many other questions) in requirements documentation to ensure successful operation. Each of these questions is analyzed further below in Figure 7-1.

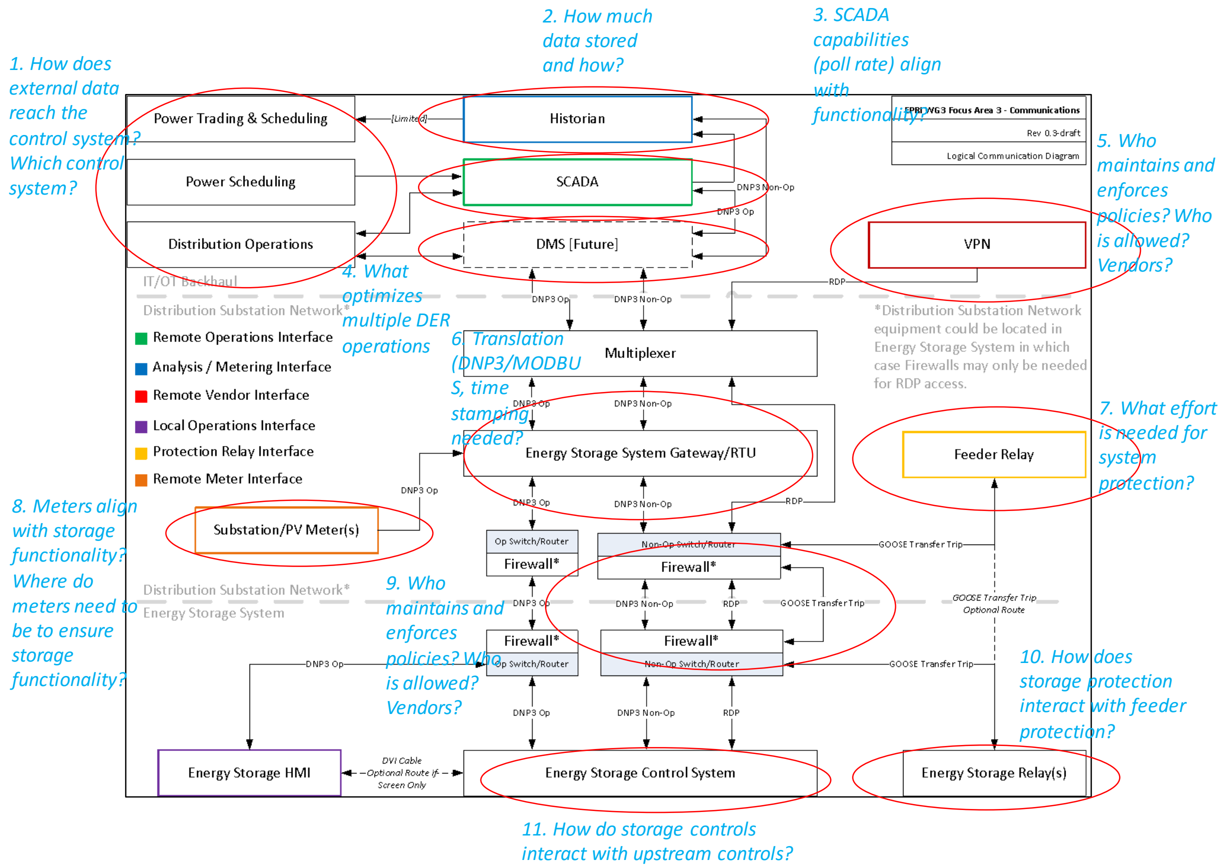


Figure 7-1
Key Questions

How does external data reach the control system? Which control system? Many applications require data from external sources. Consideration needs to be given on how this data gets into the enterprise bus in the back office or down to control system utilizing the data and any associated security requirements and verification methods.

How much data stored and how? If granular data is captured the amount of data compiled and the database architecture and development effort can be significant. Requirements need to address not only the architecture but also the maintenance of the database. Time stamping consideration and the communication protocol used influence the database requirements as well.

SCADA capabilities (poll rate) align with functionality? If a legacy SCADA system is integrated into the storage control/communication architecture consideration needs to be given on the ability to control with SCADA versus the polling rate. Additional thought needs to address the SCADA system operators and their ability to control a new, non-traditional asset

What optimizes multiple DER operations? With multiple storage assets in place, each having the ability to perform multiple functions, it becomes necessary to optimize the storage acting as a group in unison or individually or both. The optimization capabilities may need to depend on numerous inputs and the algorithms may require a powerful computing capability

Who maintains and enforces (cyber-security) policies? Who is allowed? Vendors? (VPN) Vendor remote access needs to be addressed in the Requirements in order to define the level that the vendor can see the system in the field, whether or not vendor remote control or firmware upgrades are allowed. Additional effort needs to address maintenance of security policies and firewall access.

Translation (DNP3/MODBUS, time stamping needed? Most storage control systems are developed with MODBUS used to communicate between storage system components but most utilities use DNP3 or IEC61850 platforms to communicate. Therefore, translation needs to happen at some point in order for the utility to interact with the storage system. Additionally, time stamping of storage system MODBUS based data may be needed when translated. Control system register mapping also needs to be done in all protocols being spoken.

What effort is needed for system protection? Traditionally protection settings and communication were the domain of utility OT groups. With the extension of IT type functions into distributed equipment the clarity is eroded on the IT/OT divide. Protection gear may need to be linked to the storage device (permission to run signal) and many new systems may need to monitor protection gear status.

Meters align with storage functionality? Where do meters need to be to ensure storage functionality? Accurate metering is necessary for most storage installations and the Requirements of the meters need to be defined as to the granularity of measurement and how data is exported from the meter, the language spoken and the number of points. If power quality level metering is needed for fast acting applications like frequency support the Requirement need to address the meter capabilities.

Who maintains and enforces policies? Who is allowed? Vendors? (Field based firewalls) Security strategies may dictate placement of field based firewalls. Responsibility for the settings of these and their operation and maintenance needs to be clear to avoid situations where parties needed remote or local access are denied.

How does storage protection interact with feeder protection? Requirements need to focus on the settings of the protective gear within the storage system and how these relate and communicate with any external protection gear.

Other Lessons Learned

- A thorough communication/control design effort, manifested through standard IT requirements documentation is needed either in parallel to, or preferably preceding, site civil and electrical design. Even more preferable, would be a standardization of the communication control interface prior to solicitation of future storage systems.
- By standardizing the communication interface between the utility and storage systems (and other distributed resources) all control intents, use cases needed, physical characteristics and cyber security issues, policies, constraints and dictates are clear when the vendor is specifying the system. To create a workable utility standard, the control intent and associated communication bandwidths required need to be clearly identified from a strategic standpoint and potentially accommodate single or multiple distributed resources (grouped resource perspective)

- Most of the offerings apparent through the course of this project and even at present are an assembly of components, each needing to be integrated into a storage system and then, as an assembled system, into the utility grid and its attendant controls.
- There is a mismatch between the capabilities of new storage systems and the legacy controls or SCADA systems used to operate distribution grids. SCADA systems poll the points reporting on a time interval that is too slow for fast acting storage applications such as voltage or frequency control or PV ramp/smoothing. Even though these controls can be set up on a autonomous basis, with this mismatch the SCADA system or its operators can't really see granular operation. Additionally, it is difficult to push storage operations onto a legacy platform both from a logistical software development basis but also from a human operator basis; the legacy platforms weren't designed for operation of distributed resources on a command/control basis and the operators themselves are used to the role of controlling distributed resources, especially if external control signals such as price or weather are involved
- Cyber security and vendor remote access remain a challenge. Due to lack of standardized design and communication methods, as well as disparate cyber security policies, every utility and storage vendor combination results in a unique approach. In many cases these leave gaps in terms of the amount of information a vendor can remotely access or, on the other end of the spectrum, place a large amount of command and control in the hands of the vendor with little utility oversight.

Storage Modeling

DER-CAM

- DER-CAM is a powerful tool for performing optimization of the operating schedule or annual operating costs. In this project the tool was used for two different island grids, La Palm and La Gomera island in the Canaries chain. The annual operating costs were determined with numerous inputs and specific constraints that included limitation on PV (due to land limitations) and emissions to name a few.
- DER-CAM is not currently capable of accounting for part load efficiencies of the generators and the average efficiency was used. When attempted the program did not reach a solution even though it has input parameters to adjust for varying efficiencies at different loadings of the fossil fuel based generators.
- Even though new versions of this model have purported capability to include power flow analysis, this feature did not produce feasible results and the power flow option was ultimately disabled. The ensuing approach then used an aggregated load method to determine the amount PV and storage suitable to minimize the annual operating costs.
- The end results did not clearly indicate that adding storage would save much on the annual operating costs, rather, the addition of storage roughly produced the same operating cost results as did the case without storage. This occurred even when storage was priced at $400/kWH.

- The model was staging storage to prevent operation of low efficiency generators through a combination of PV and storage in some iterations. It can reasonably be assumed that enabling this feature would further drive storage as a solution.
- Resilience could also become an important parameter in the value stream that must be valued properly.

PCS Modeling

- A tool for sizing a PCS for voltage regulation purposes has been developed, leading to a new approach of sizing storage systems compared to the traditional approach based on energy and power requirements for other applications.
- Accurate and granular data as well as characteristics of the PCS will be required to thoroughly analyze voltage regulation functionality with this model. The data will need come from the feeder head and large customer meters that comprise a majority of the feeder load. The location of the storage will also dictate the appropriate level of baseline data needed.
- PCS vendors will need to supply information describing transfer functions and response curves for the model to accurately predict how it will respond to grid conditions.
- The model has been applied to a module and adapted to OpenDSS – this gives OpenDSS a new ability to model PCS functions that wasn't previously available
- This tool will enable further research on the detailed interactions of a PCS with the batteries when fast acting applications are pursued and help determine how or if the batteries are impacted in pursuit simultaneous use cases.

Southern Cedartown specific learnings (detailed also in the Southern Lessons Learned document in a risk analysis framework

- Ownership and associated source and applicability of grounding and lightning standards needs to be clarified with all stakeholders on the front end of the project. If substation standards are to be applicable, the budget needs to reflect as these standards may invoke higher cost systems.
- Before engaging vendors or initiating design at least 2 sites should be selected and risk analyzed for ownership, permitting and reason for installing storage The lowest risk site should then be pursued with a second site as a contingent location
- Communication with local permitting authorities should be part of site selection process to identify all site civil upgrades needed, applicable codes and standards and their associated cost impacts
- Protection engineering needs to be involved in front end site selection and costs of protection added to decision making process - To the extent possible recloser settings should be documented for initial sites to allow for quicker commissioning in future sites. Standard specifications should be developed for battery based protection gear to allow for efficient placement in future sites.
- To enable peak shaving for this project communication directly from feeder head meter to the battery PCS is needed. This would also necessitate protocol translator (DNP3 to Modbus)

and/or means of timestamping the data, which implies incorporating a substation gateway type device

- Equipment solicitations should clearly call for and vendors should clearly define the nature of their subcontracting relationships, maturity of these relationships and clear listing of past efforts that are similar in size and scope to solicited effort. More importantly clear terms and conditions should be applied to the procurement that place the risk of untenable equipment design and manufacturing impacts (both cost and schedule) clearly on the vendor.
- Factory Acceptance Test (FAT) needs to test as many external control and communication inputs or interfaces as possible. Commissioning test needs to thoroughly vetted by all parties with wiring responsibility to ensure fielded equipment is correctly wired. Phase rolling on utility feed should be clearly vetted and addressed in the commissioning plan.
- Vendor scope of work should clearly indicate that any firmware correction be made within a specified short timeframe during commissioning. Terms and conditions should place risk of firmware shortcomings fall on the vendor. Additionally vendor should be responsible for setting up a production environment that displays proper interaction of software operating on all components that are interacting, prior to shipment in the field, perhaps as part of the FAT
- Data signaling with wireless modems for short hops needs to be set up such that the meter and modem can transport the data without interference. Different transport frequencies may have to be investigated (2.4GHz vs 913MHz)

Codes, Standards and Regulations

- At the start of this project there were only legacy codes and standards available to specify storage systems. The guiding specification for the Cedartown project was EPRI Report 1025573, Technical Specification for a Transportable Lithium-Ion Energy Storage System for Grid Support Using Commercially Available Lithium-Ion Technology. This report listed 54 different primary codes and standards. This comprehensive list covered numerous aspects of a storage installation including construction, materials, grid integration and operation. Very few of these standards that pertained to batteries contemplated Li-Ion technology and stemmed from other chemistries.
- Throughout the course of this project there have been developments both in the grid integration through IEEE1547 based standards as well as new standards relating to Li-Ion technologies such as UL 9540 and IFC18. Other efforts are in draft form at the time of this writing such as NFPA855 and revisions to NFPA1. While these new CSRs address Li-Ion installation and operation, many stakeholders point to a lack of research on the best methods for preventing and/or containing thermal incidences with Li-Ion.
- EPRI research in this area will entail enhancing the communication between all stakeholders relating to the evolution of these CSRs through EPRI ESIC. The goal of this effort is to clarify the CSR development process and ensure awareness of and input to the standard making process is substantive. It is important to note that storage technologies are rapidly evolving but the standard making process is typically born on a 3 to 5-year update cycle.

Future Research Needs

- Anonymized and non-confidential standard requirements document templates need to be generated and distributed.
- Workshops need to be staged to determine how to bridge the IT/OT gap and further align standardized control design, addressing an efficient approach that accommodates
  - Cyber security – Addressing the need for secure control and data acquisition but also recognizing the potential need for vendor remote access and evolving rules and policies.
  - Vendor remote access needs
  - Alignment to future back office control systems such as DERMS - , the back office architecture for a future, mature setting, where many distributed resources are utilized, needs to be capable of accommodating resources placed in the near future since the mature view will require a substantial investment and time to build. Hence the standardization effort needs to address, at a minimum:
  - Device and back office control system interoperability – Ensuring that what is installed now can be forward compatible to future systems like Distributed Energy Resource Management Systems
  - Front end definition of Control Intent –initial efforts are need to define:
  - Scalability and flexibility – does the architecture allow for straightforward expansion to allow many units to operate as an aggregated resource?

A
CEDARTOWN POINTS LIST

System Node Type	System Node Name	Parent System	Channel Type	Channel Type Unit
PV System	833kW PV Plant	Cedartown Demonstration	State.AcquiSuite.Err	
PV System	833kW PV Plant	Cedartown Demonstration	AC.Current.A	A
PV System	833kW PV Plant	Cedartown Demonstration	AC.Current.B	A
PV System	833kW PV Plant	Cedartown Demonstration	AC.Current.C	A
PV System	833kW PV Plant	Cedartown Demonstration	AC.Frequency	Hz
PV System	833kW PV Plant	Cedartown Demonstration	AC.Voltage.AN	V
PV System	833kW PV Plant	Cedartown Demonstration	AC.Voltage.BN	V
PV System	833kW PV Plant	Cedartown Demonstration	AC.Voltage.CN	V
PV System	833kW PV Plant	Cedartown Demonstration	AC.Voltage.AB	V
PV System	833kW PV Plant	Cedartown Demonstration	AC.Voltage.BC	V
PV System	833kW PV Plant	Cedartown Demonstration	AC.Voltage.CA	V
PV System	833kW PV Plant	Cedartown Demonstration	AC.Power	kW
PV System	833kW PV Plant	Cedartown Demonstration	AC.Power.Q	kVAR
PV System	833kW PV Plant	Cedartown Demonstration	AC.Power.S	kVA
PV System	833kW PV Plant	Cedartown Demonstration	AC.Energy.Cum.Pos	kWh
PV System	833kW PV Plant	Cedartown Demonstration	AC.Energy.Cum.Neg	kWh
PV System	833kW PV Plant	Cedartown Demonstration	AC.Energy.Cum.Q.Pos	kVARh
PV System	833kW PV Plant	Cedartown Demonstration	AC.Energy.Cum.Q.Neg	kVARh
PV System	833kW PV Plant	Cedartown Demonstration	AC.PF.True	
PV System	833kW PV Plant	Cedartown Demonstration	State.AcquiSuite.Err	
PV System	833kW PV Plant	Cedartown Demonstration	Irradiance.POA	W/m^2
PV System	833kW PV Plant	Cedartown Demonstration	Irradiance.POA	W/m^2
PV System	833kW PV Plant	Cedartown Demonstration	Temp.Air.DAQ.Enclosure	°C
Electric Load	Auxiliary Load	Cedartown Demonstration	State.AcquiSuite.Err	
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Current.A	A

System Node Type	System Node Name	Parent System	Channel Type	Channel Type Unit
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Current.B	A
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Current.C	A
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Frequency	Hz
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Voltage.AN	V
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Voltage.BN	V
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Voltage.CN	V
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Voltage.AB	V
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Voltage.BC	V
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Voltage.CA	V
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Power	kW
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Power.Q	kVAR
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Power.S	kVA
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Energy.Cum.Pos	kWh
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Energy.Cum.Neg	kWh
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Energy.Cum.Q.Pos	kVARh
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.Energy.Cum.Q.Neg	kVARh
Electric Load	Auxiliary Load	Cedartown Demonstration	AC.PF.True	
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	State.AcquiSuite.Err	
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Current.A	A
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Current.B	A
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Current.C	A
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Frequency	Hz
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Voltage.AN	V
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Voltage.BN	V
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Voltage.CN	V

System Node Type	System Node Name	Parent System	Channel Type	Channel Type Unit
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Voltage.AB	V
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Voltage.BC	V
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Voltage.CA	V
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Power	kW
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Power.Q	kVAR
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Power.S	kVA
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Energy.Cum.Pos	kWh
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Energy.Cum.Neg	kWh
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Energy.Cum.Q.Pos	kVARh
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.Energy.Cum.Q.Neg	kVARh
Battery	1MW Li-Ion ESS (2MWh)	Cedartown Demonstration	AC.PF.True	
Site	Cedartown Demonstration		State.AcquiSuite.Err	
Site	Cedartown Demonstration		Wind.Speed	m/s
Site	Cedartown Demonstration		Wind.Speed	m/s
Site	Cedartown Demonstration		Wind.Direction	° from N
Site	Cedartown Demonstration		Temp.Air.Outdoor.Duct	°C
Site	Cedartown Demonstration		Temp.Air.Outdoor.Amb	°C
Site	Cedartown Demonstration		Rel.Humidity.Outdoor.Duct	%
Site	Cedartown Demonstration		Rel.Humidity.Outdoor.Amb	%

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