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U.S. Efforts Related to Energy Storage Systems:

Overview, Economics of Applications, Safety, Interconnection and Utility Implementation, and System Performance

U.S.-South Africa Workshop
Energy Storage Standards, Conformance and Technology

February 21, 2019

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Agenda

- Overview of Energy Storage in the U.S. - David Conover
- Energy Storage Valuation and Analytics: Lessons, Methods, and Models Resulting from Recent - Patrick Balducci
- Reliability and Connecting ESS to the Grid - Charlie Vartanian
- Energy Storage System Safety – David Conover
- AEP Chemical Substation BESS Example – Charlie Vartanian
- Measuring and Expressing ESS Performance – Vish Viswanathan
- Summary and Wrap Up – David Conover

Grid Scale Energy Storage – An Overview

David Conover

Pacific Northwest National Laboratory

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PNNL Energy Storage Activity

U.S. DEPARTMENT OF ENERGY | Electricity Delivery & Energy Reliability

Grid Scale Storage

- *Development of next generation grid scale energy storage technologies*
- *Improved Safety and Reliability of storage systems*
- *Modeling regulatory impacts of storage policy*
- *Independent validation and analysis of deployed storage systems.*

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
VEHICLE TECHNOLOGIES OFFICE

Consortium
Battery 500

- *PNNL Leads DOE's Battery 500 Consortium*
- *Goal to double energy density (to 500 WH/kg) relative to today's battery technology while achieving 1,000 electric vehicles cycles*

Materials	Architectures	Integration
The University of Texas at Austin Pacific Northwest National Laboratory Stanford University Binghamton University	University of California San Diego INL Idaho National Laboratory Pacific Northwest National Laboratory SLAC National Accelerator Laboratory	University of Washington Brookhaven National Laboratory Pacific Northwest National Laboratory

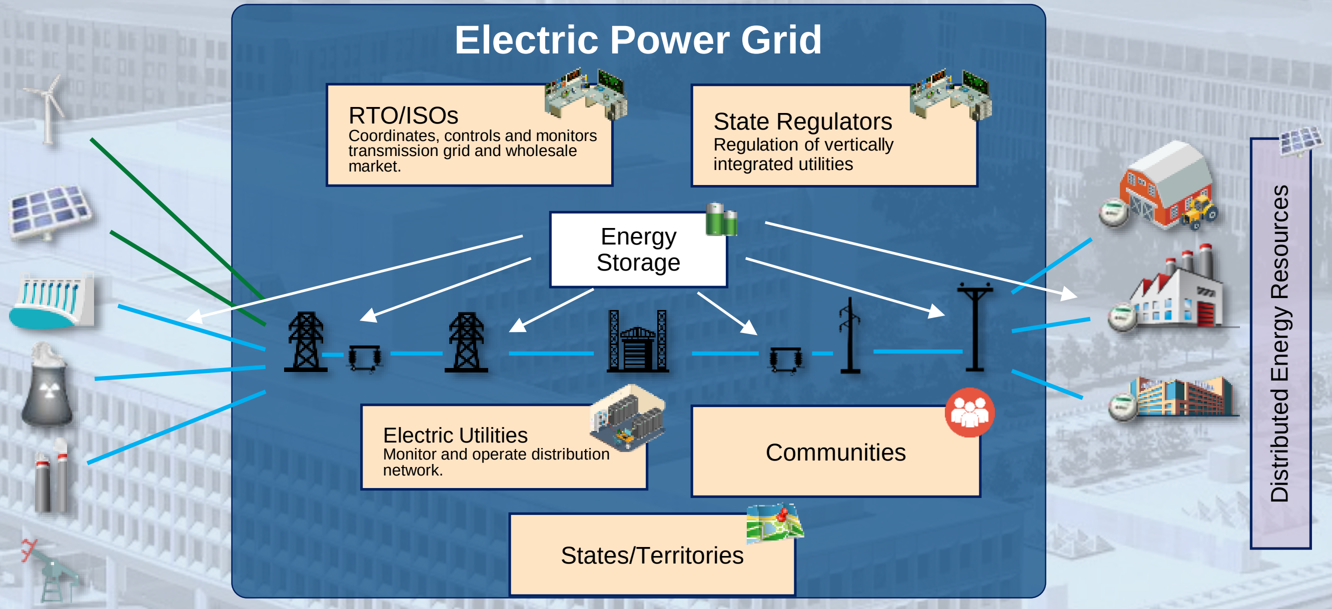
U.S. DEPARTMENT OF ENERGY | Office of Science

JCESR Joint Center for Energy Storage Research

Discovery Science

arpa·e
U.S. DEPARTMENT OF ENERGY

Energy Storage - Critical for a Flexible and Efficient Grid



Electric Power Grid

RTO/ISOs
Coordinates, controls and monitors transmission grid and wholesale market.

State Regulators
Regulation of vertically integrated utilities

Energy Storage

Electric Utilities
Monitor and operate distribution network.

Communities

States/Territories

Distributed Energy Resources

Centralized Electricity Producers

Electricity Consumers

Electrical Energy Storage –bi-directionally capable of ***consuming*** and ***producing*** specific amounts of electric power as it is made available at specific times; e.g batteries, flywheels, supercapacitors, pumped hydro, etc.

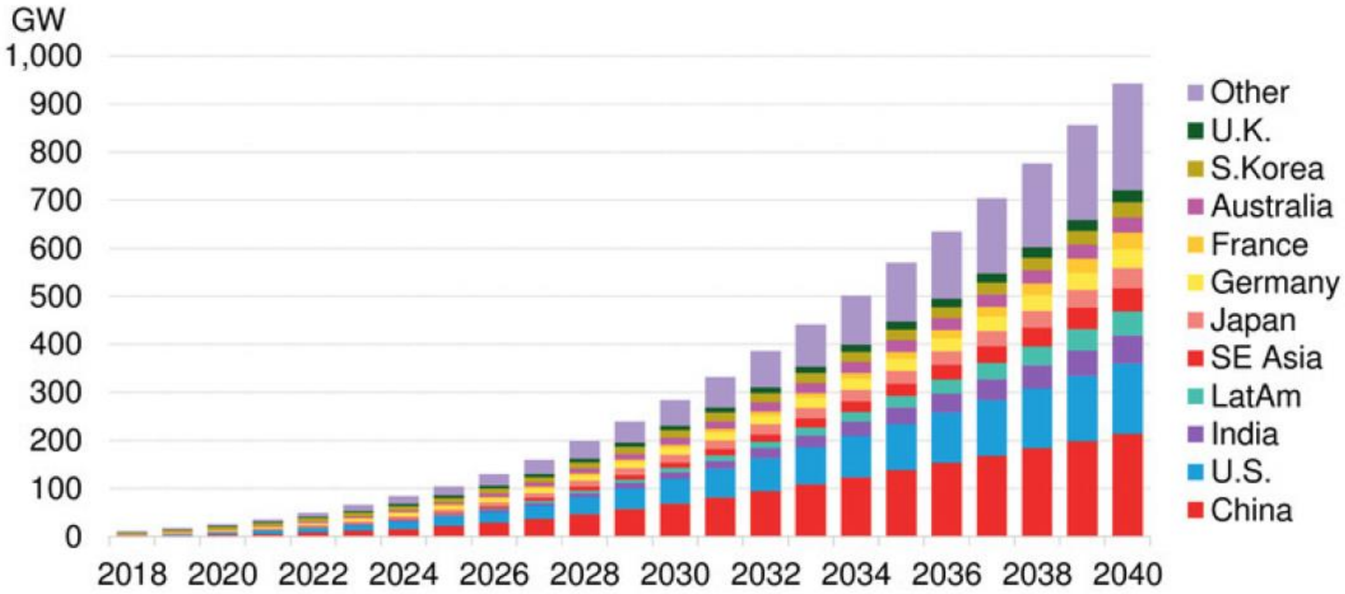
U.S. DEPARTMENT OF ENERGY | Electricity Delivery & Energy Reliability

Advanced Grid Research
OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY

Strong Projections for Global Growth in Grid Scale Battery Energy Storage

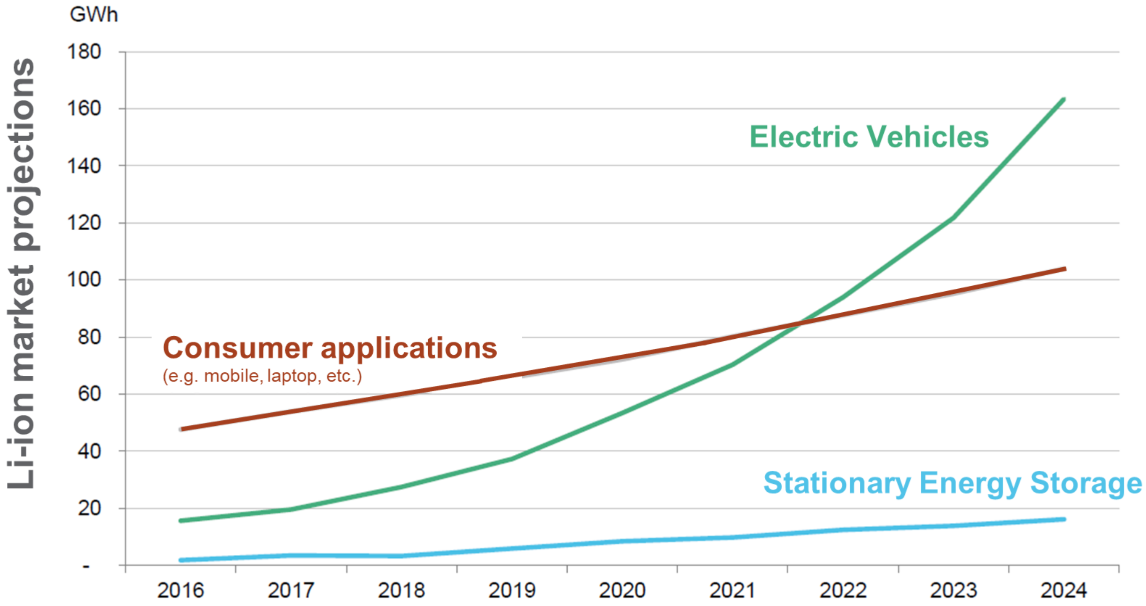
South Africa makes huge distributed energy storage commitment - 1,400 MWh

Figure 1: Global cumulative storage deployments



Source: Bloomberg NEF

Grid Scale Storage Still Represents Small Percentage of Overall Storage Market



Source: Bloomberg New Energy Finance

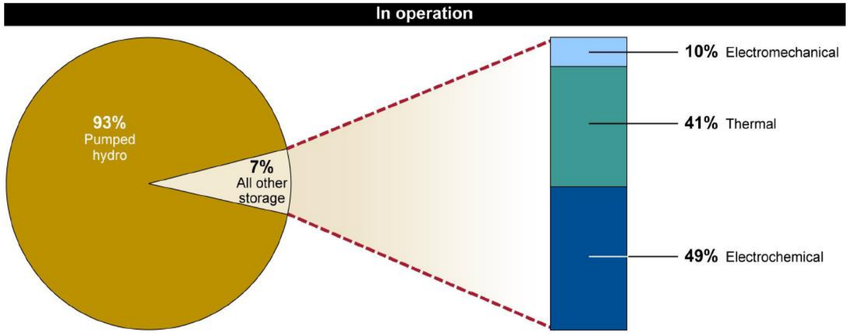
- Grid-Scale Energy Storage still < 0.1% of U.S. Generation Capacity
- EV’s < 1% of vehicles sold in U.S.

Current State Grid Scale Energy Storage in US

- 0.4GW Battery Storage on grid end of 2018
- Compared to 22GW Pumped Hydro Resources installed

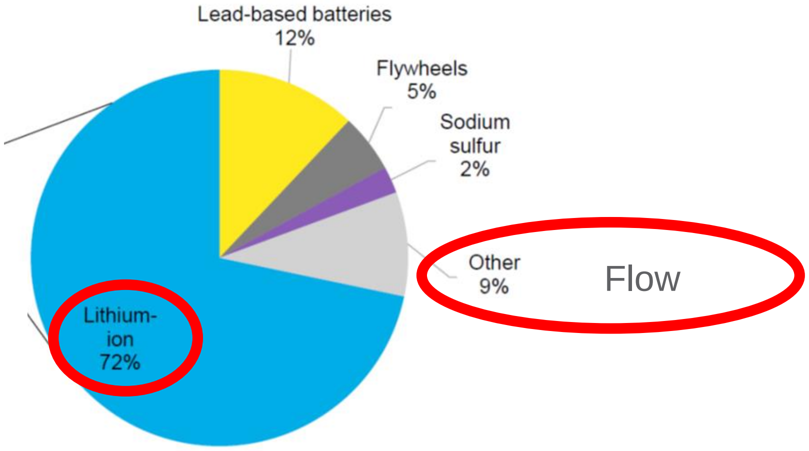
GAO 2018 from DOE Energy Storage Database

Figure 2: Capacity of Energy Storage in Operation and Under Development by Technology Type



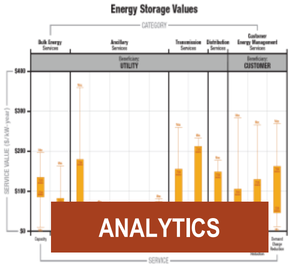
Source: GAO analysis of Department of Energy (DOE) data. | GAO-18-402

Note: The data are from the Department of Energy's (DOE) Global Energy Storage Database, as of March 20, 2018, and include projects in operation (operational and offline or under repair) or under development (under signed contract to be built or under construction). Electromechanical storage includes technologies such as flywheels (devices that harness rotational energy to store and deliver energy) and compressed air energy storage (that uses electricity to compress air, then release it through a turbine to generate electricity later). Electrochemical storage includes technologies such as batteries (lead acid, lithium ion, sodium sulfur, and flow).



Bloomberg New Energy Finance Dec 2018

The Future of Energy Storage at Pacific Northwest National Laboratory



ANALYTICS

- ▶ Expanding models to include non-battery storage, including pumped storage hydro and power to gas
- ▶ Industry standard valuation model in collaboration with other national laboratories and industry groups
- ▶ Tools for defining market penetration of storage by region at various cost targets
- ▶ Expanded distribution system integration, performance characterization, and control systems capabilities

RESEARCH AND DEVELOPMENT

- ▶ Increase the performance, safety, and reliability of grid-scale storage
- ▶ Reduce costs of energy storage technologies
- ▶ Accelerate design, prototype, and testing of new grid-scale batteries
- ▶ Provide independent validation of the lifetime and performance of new technologies

REGULATORY TREATMENT

- ▶ Removing market and regulatory barriers to energy storage adoption; (projects with HI, NV, OR, and WA)
- ▶ Industry-accepted integrated resource planning model
- ▶ Expand and raise profile of the DOE Energy Storage Policy Database
- ▶ Develop valuation handbook

Grid Scale Energy Storage Summary

- While > 2% of worldwide stored electrical energy capacity is currently served by battery technology, market is experiencing significant growth due to decreasing costs and ability of systems to be readily dispatchable.

- Li-ion technology will continue current dominance for grid scale storage but is being developed to serve consumer electronics and then EV/PHEV markets. Cell costs approaching materials costs, how much lower can costs go?

- Next generation of DOE technologies like Aqueous Soluble Organics (ASO) redox flow batteries (RFB) being developed to eliminate commodity mineral volatility. RFB may be able to beat Li-ion cost targets at ~ 100X lower production volumes.

Energy Storage Valuation and Analytics: Lessons, Methods, and Models Resulting from Recent Experience

Patrick Balducci

Chief Economist

Pacific Northwest National Laboratory

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Learning Objectives

- Understand the basis of energy storage valuation and the associated taxonomy of benefits
- Learn the definition of grid services provided by energy storage systems (ESSs) and the bases of monetization
- Review a number of recent assessments of energy storage projects and draw conclusions regarding what worked and how improvements could be made
- Review our recent findings associated with grid-connected energy storage performance and how enhanced operational knowledge affects value
- Understand the importance of energy storage controls system logic in obtaining real-time benefits

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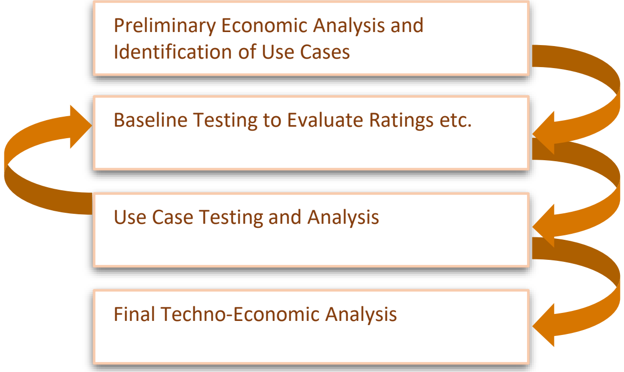
Energy Storage Demonstration Project Assessments at PNNL

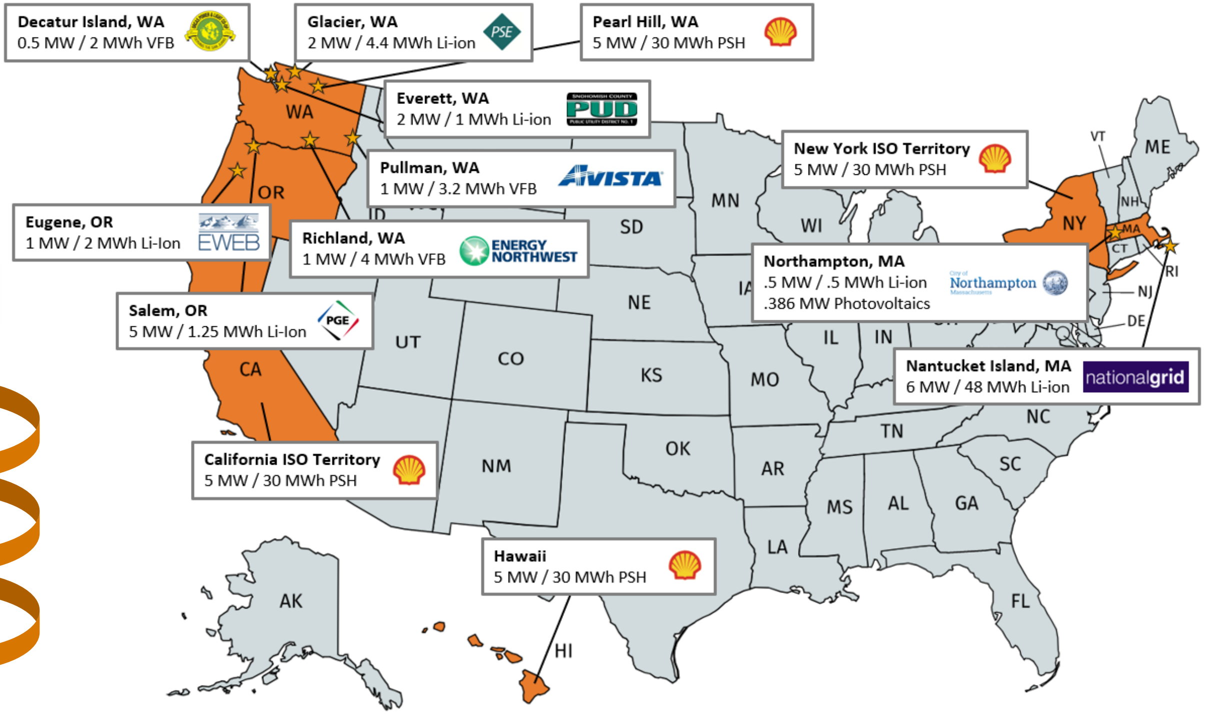
PNNL Storage Analytics Program

26 MW | 103 MWh at | 14 Sites

PNNL Analytics Task-flow



1. Preliminary Economic Analysis and Identification of Use Cases
2. Baseline Testing to Evaluate Ratings etc.
3. Use Case Testing and Analysis
4. Final Techno-Economic Analysis



Decatur Island, WA
0.5 MW / 2 MWh VFB

Glacier, WA
2 MW / 4.4 MWh Li-ion

Pearl Hill, WA
5 MW / 30 MWh PSH

Everett, WA
2 MW / 1 MWh Li-ion

Pullman, WA
1 MW / 3.2 MWh VFB

Eugene, OR
1 MW / 2 MWh Li-Ion

Richland, WA
1 MW / 4 MWh VFB

Salem, OR
5 MW / 1.25 MWh Li-Ion

California ISO Territory
5 MW / 30 MWh PSH

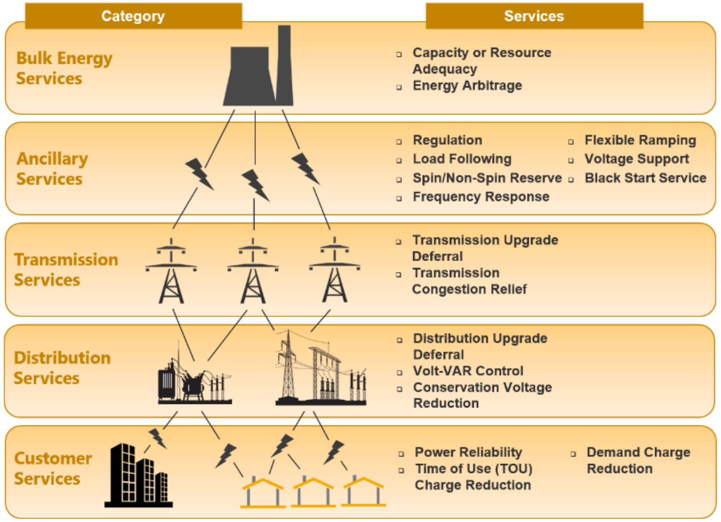
Hawaii
5 MW / 30 MWh PSH

New York ISO Territory
5 MW / 30 MWh PSH

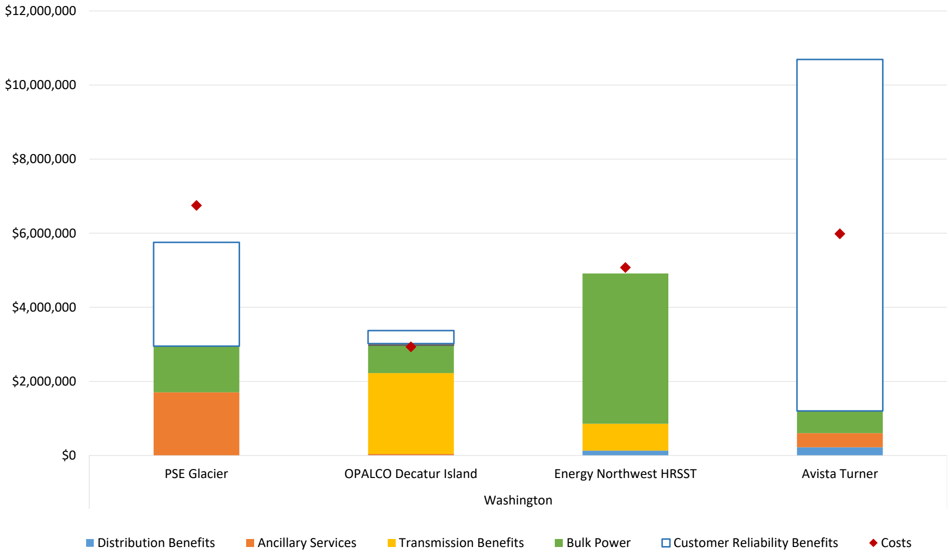
Northampton, MA
.5 MW / .5 MWh Li-ion
.386 MW Photovoltaics

Nantucket Island, MA
6 MW / 48 MWh Li-ion

Defining and Monetizing the Value of Energy Storage and DERs More Broadly



Category	Services
Bulk Energy Services	▫ Capacity or Resource Adequacy ▫ Energy Arbitrage
Ancillary Services	▫ Regulation ▫ Load Following ▫ Spin/Non-Spin Reserve ▫ Frequency Response ▫ Flexible Ramping ▫ Voltage Support ▫ Black Start Service
Transmission Services	▫ Transmission Upgrade Deferral ▫ Transmission Congestion Relief
Distribution Services	▫ Distribution Upgrade Deferral ▫ Volt-VAR Control ▫ Conservation Voltage Reduction
Customer Services	▫ Power Reliability ▫ Time of Use (TOU) Charge Reduction ▫ Demand Charge Reduction

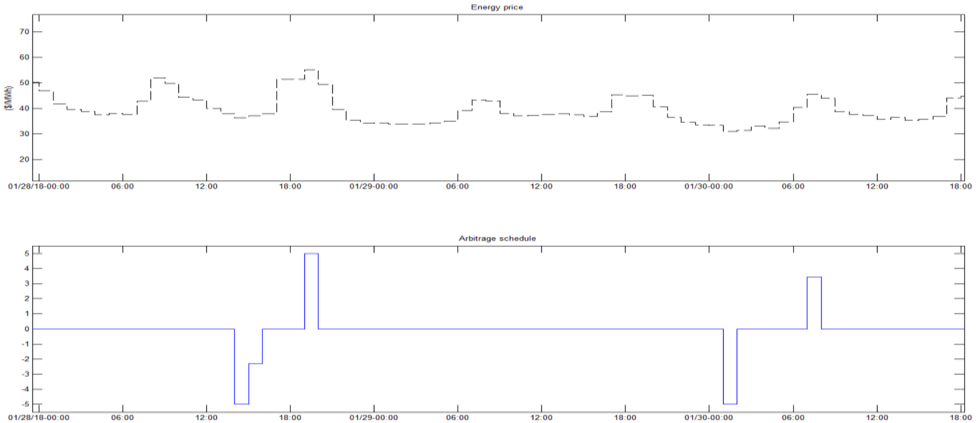


Key takeaways:

- ❑ We have developed a broad taxonomy and modeling approach for defining the value of distributed energy resources (DER)
- ❑ Economic value is highly dependent on siting and scaling of energy storage resources; many benefits accrue directly to customers
- ❑ Benefits differ based on utility structure (e.g., PUDs, co-ops, vertically integrated investor-owned utilities) and market participation
- ❑ Accurate characterization of battery performance, and development of real-time control strategies, are essential to maximizing value to the electric grid

Energy Arbitrage

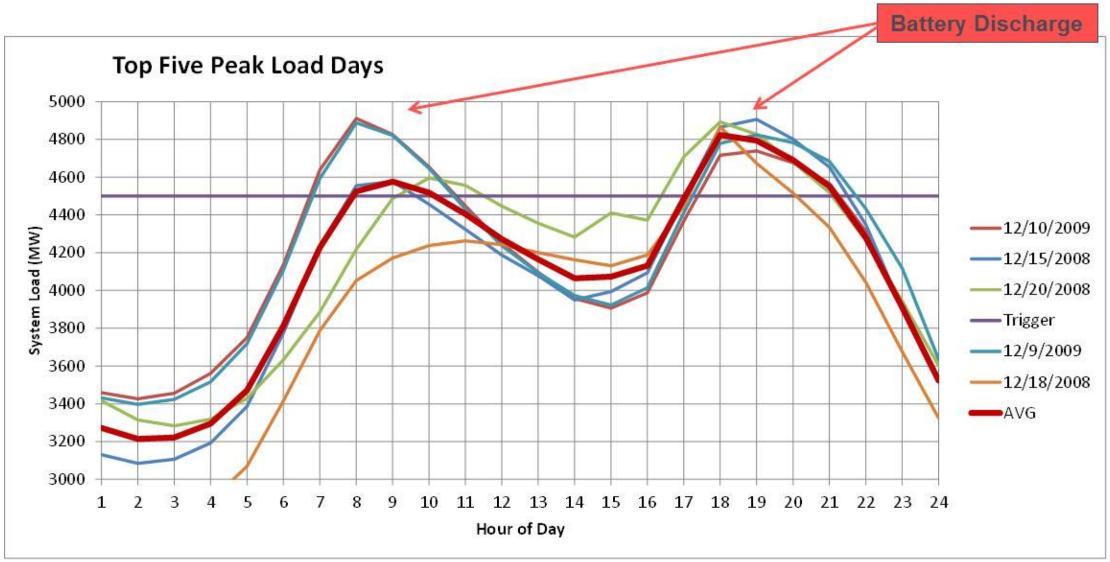
- Hourly wholesale energy market used to determine peak / off-peak price differentials (e.g., Mid-C prices in Pacific NW or California Independent System Operator (ISO) locational marginal prices in California)
- Value obtained by purchasing energy during low price hours and selling energy at high energy price hours – efficiency losses considered
- Energy time shift still generates value even in the absence of markets
- 85% efficiency => 117.6% price difference
- 65% efficiency => 153.8% price difference



Key Lesson: While one of the first recognized use cases for energy storage, arbitrage typically yields a small value.

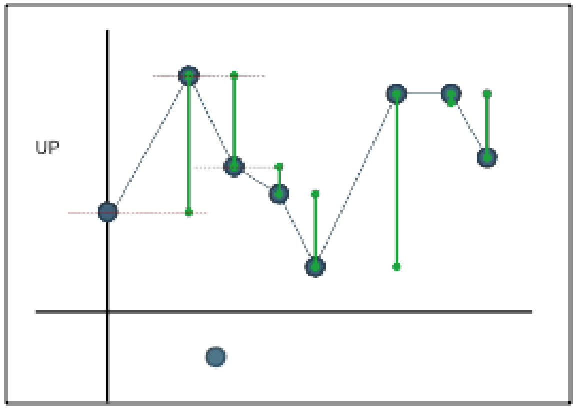
Capacity / Resource Adequacy

- Capacity markets have been established in regions throughout the United States with value based on forward auction results and demonstrated asset performance
- For regulated utilities, capacity value based on the incremental cost of next best alternative investment (e.g., peaking combustion turbine) with adjustments for:
    - energy and flexibility benefits of the alternative asset
    - the incremental capacity equivalent of energy storage
    - line losses



Frequency Regulation

- Second by second adjustment in output power to maintain grid frequency
- Follow automatic generation control (AGC) signal
- Value defined by market prices or avoiding costs of operating generators

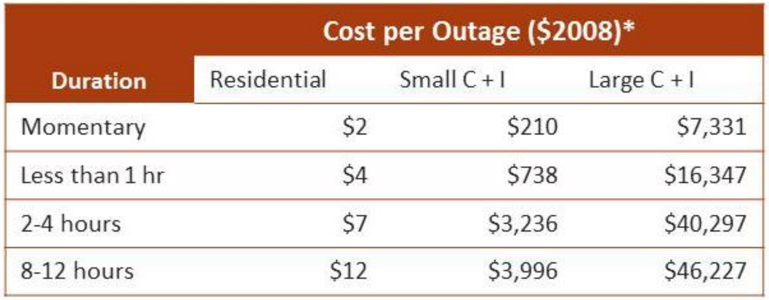


Mileage definition is the sum of all green bars in 15 min. intervals

Capacity Payment = Regulation Capacity Clearing Price
Service Payment = Mileage (AGC Signal Basis)
Performance = Regulation Service Performance Score

Key Lesson: Performance of battery storage in providing frequency regulation is exceptionally high. Batteries represent an efficient resource for providing frequency regulation; however, market prices can be driven downward as a result, undermining the profit potential to storage operators in the process.

Outage Mitigation

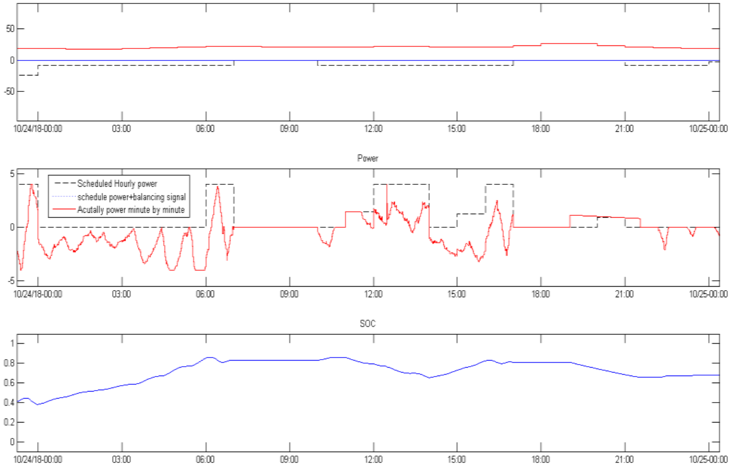


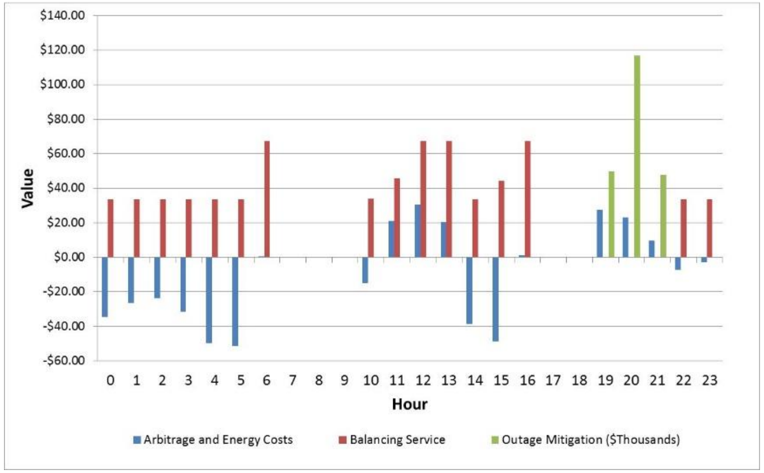
Duration	Cost per Outage ($2008)*		
	Residential	Small C + I	Large C + I
Momentary	$2	$210	$7,331
Less than 1 hr	$4	$738	$16,347
2-4 hours	$7	$3,236	$40,297
8-12 hours	$12	$3,996	$46,227

Source: Sullivan, M., Mercurio, M., and J. Schellenberg. 2009. "Estimated Value of Service Reliability for Electric Utility Customers in the United States." Prepared for U.S. Department of Energy by Lawrence Berkeley National Laboratory. Berkeley, CA.

- Outage data
  - Outage data obtained from utility for multiple years
  - Average annual number of outages determined and outages randomly selected and scaled to approximate average year
  - Outage start time and duration
- Customer and load information
  - Number of customers affected by each outage obtained from utility
  - Customer outages sorted into customer classes using utility data and assigned values
  - Load determined using 15-minute SCADA information
- Alternative scenarios
  - Perfect foreknowledge – energy storage charges up in advance of inclement weather
  - No foreknowledge – energy on-hand when outage occurs is used to reduce outage impact

Bundling Services: How To Do It Optimally





Key Lesson: A valuation tool that co-optimizes benefits is required to define technically achievable benefits.

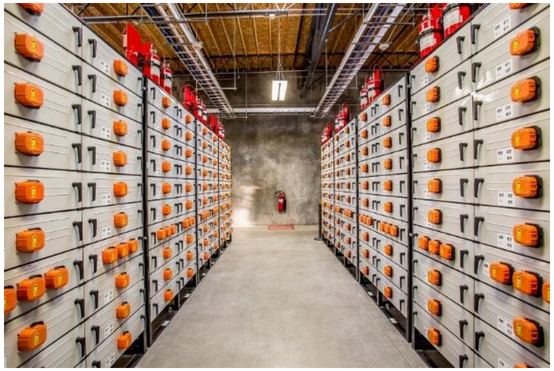
- Multi-dimensional co-optimization procedures required to ensure no double counting of benefits
  - ESSs are energy limited and cannot serve all services simultaneously
  - By using energy in one hour, less is available in the next hour
- Energy storage valuation tools are required

Example Energy Storage Projects

1. Portland General Electric – Salem Smart Power Center
2. U.S. Department of Defense – Joint Forces Training Base Los Alamitos

(1) Portland General Electric (PGE) Salem Smart Power Center (SSPC)

- Developed as an R&D project under the Pacific Northwest Smart Grid Demo as part of the American Recovery and Reinvestment Act of 2009
- The U.S. Department of Energy (DOE) provided half of the funding
- 5 MW – 1.25 MWh lithium-ion battery system built and managed by PGE



Potential energy storage benefits:

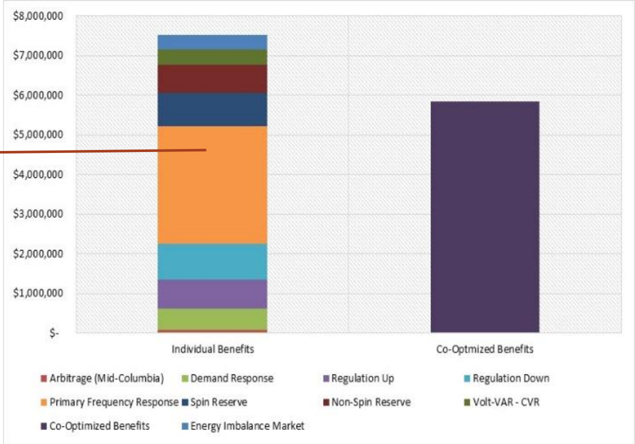
- Energy arbitrage
- Participation in the Western Energy Imbalance Market (EIM)
- Demand response
- Regulation up and down
- Primary frequency response
- Spin reserve
- Non-spin reserve
- Volt-VAR control
- Conservation voltage reduction

Western Energy Imbalance Market

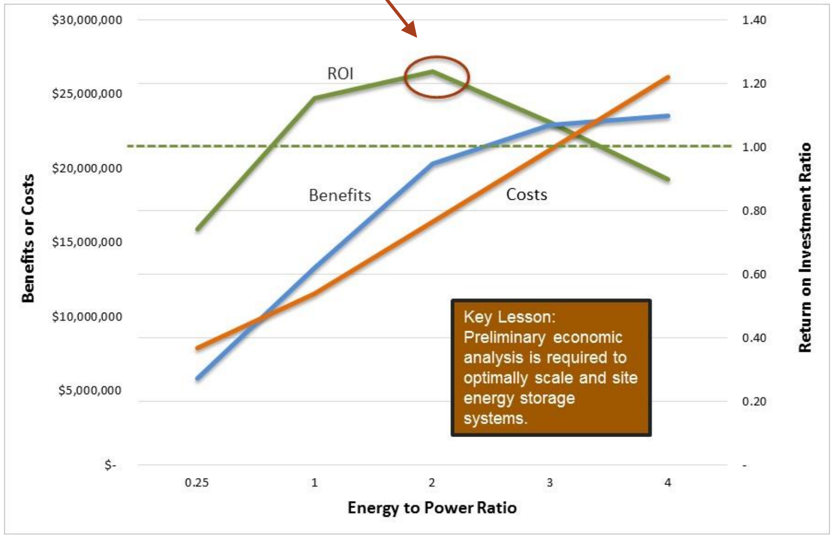
Optimal Scaling of the SPCC

- Evaluated individually the total 20-year value of SSPC operations exceeds $7.5 million in PV terms. When co-optimized, revenue falls to $5.8 million
- At an energy to power ratio of 0.25, the SSPC is not well suited to engage in most energy-intensive applications, such as arbitrage and ancillary services, so revenue is lost during the co-optimization process.

Technically Unachievable



- By upsizing the energy storage capacity to 10 MWh, the return on investment ratio yields a positive result at 1.24

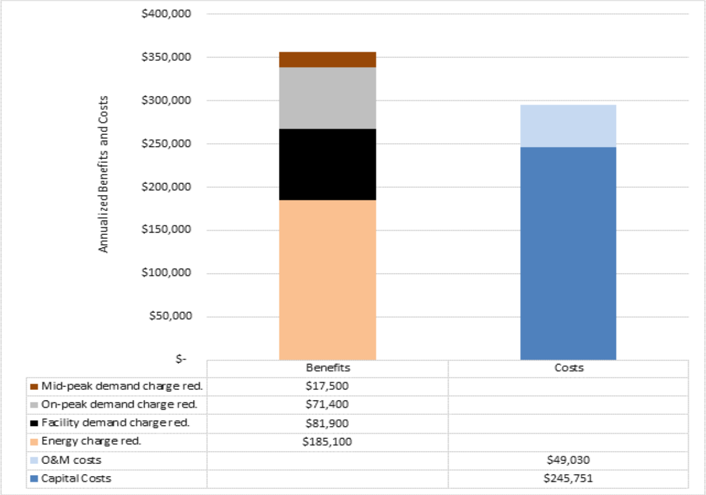


Key Lesson: Preliminary economic analysis is required to optimally scale and site energy storage systems.

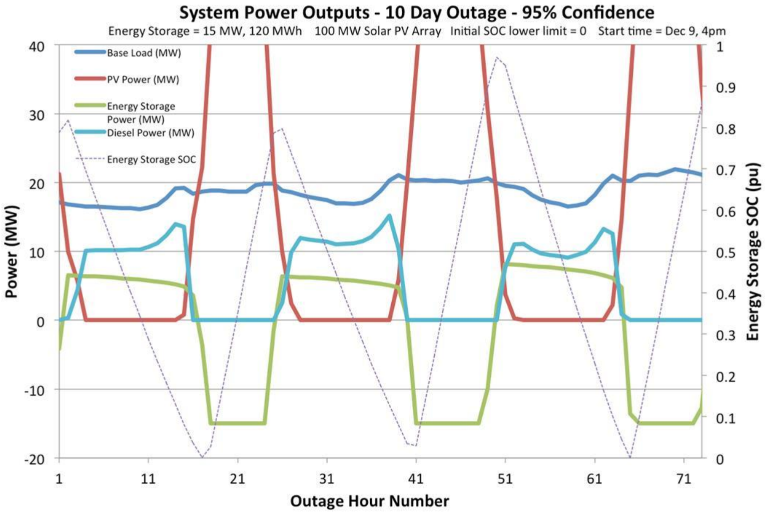
(2) Joint Forces Training Base Los Alamitos, CA.

JFTB Los Alamitos Microgrid Assessment

- Resiliency goal – 90% survivability rate for a two-week outage
- Energy assets – Photovoltaics, diesel gen sets, energy storage
- Charge to analysts – Meet resiliency goal and maximize economic benefits given fixed budget



	Benefits	Costs
■ Mid-peak demand charge red.	$17,500	
■ On-peak demand charge red.	$71,400	
■ Facility demand charge red.	$81,900	
■ Energy charge red.	$185,100	
■ O&M costs		$49,030
■ Capital Costs		$245,751

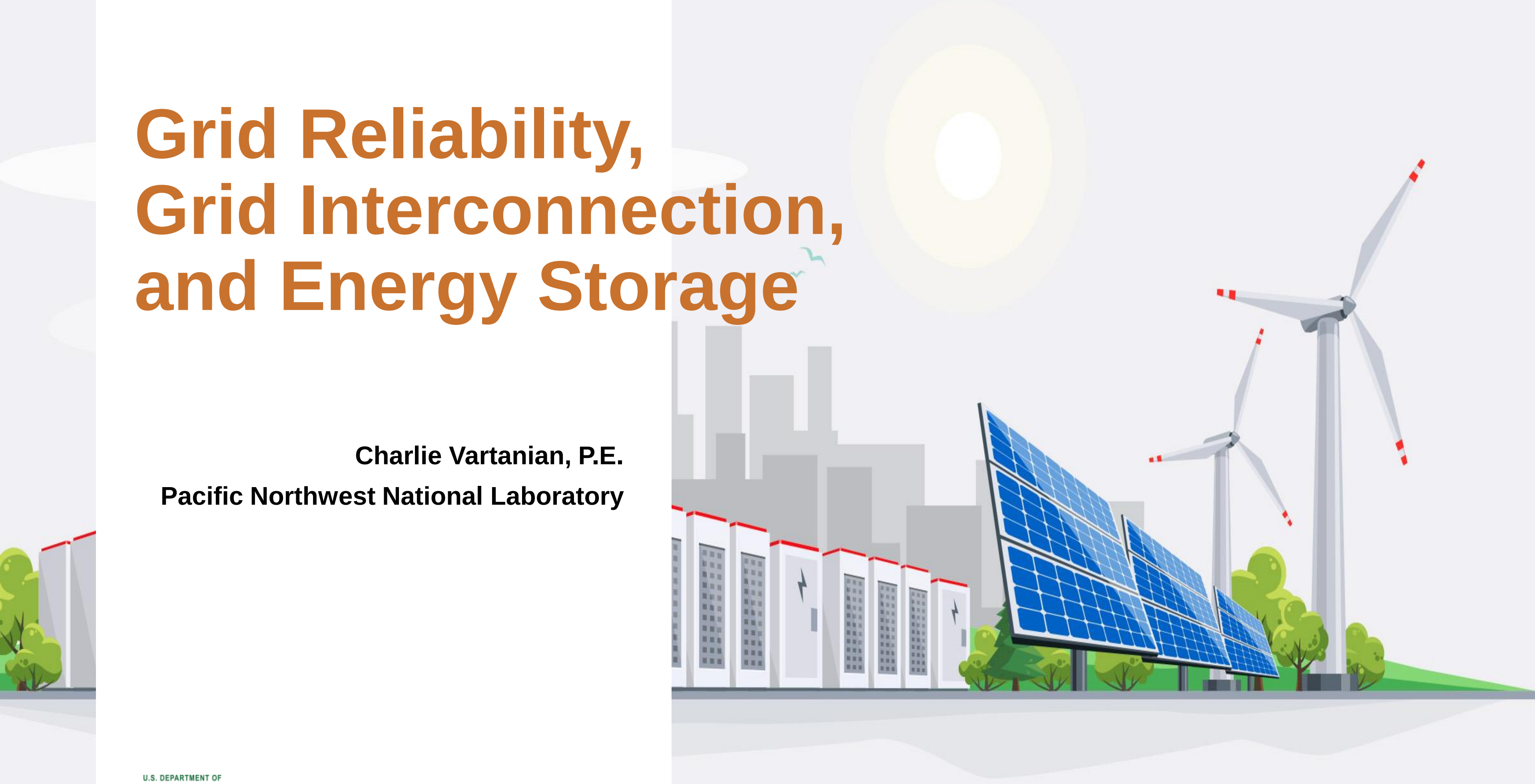


Optimal Microgrid Scale Required to Achieve *Energy Security* and *Operational Goals:*
Gen Set – 1,150 kW
Photovoltaics – 1,224 kW
Energy storage – 408 kW / 510 kWh

Summary and Key Takeaways

Siting/Sizing Energy Storage	Models can aid in the siting/sizing of energy storage systems by capturing/measuring location-specific benefits
Broad Set of Use Cases	The unique attributes of energy storage can produce benefits associated with bulk energy, transmission-level, ancillary service, distribution-level, and customer benefits on a sub-hourly basis
Regional Variation	Models are required to differentiate benefits by region and market structure/rules
Utility Structure	Benefits differ by utility structure (e.g., PUDs, co-ops, large utilities operating in organized markets, and vertically integrated investor-owned utilities operating in regulated markets)
Battery Characteristics	The accurate characterization of battery performance, including round trip efficiency rates across varying states of charge and battery degradation caused by cycling, is essential to the modeling of benefits.

Grid Reliability, Grid Interconnection, and Energy Storage



Charlie Vartanian, P.E.

Pacific Northwest National Laboratory

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Purpose and Expected Outcome

Purpose – To provide an introductory level overview of selected grid reliability concerns and relevant interconnection standard updates, in context of energy storage technology (EST)

Expected Outcomes

- Awareness of emerging grid reliability risk exposures associated with the increased penetration of distributed energy resources (DER), including PV
- Awareness of the EST characteristics that mitigate these risks
- Knowledge about key updates to the IEEE 1547 DER grid interconnection standard
- Awareness of how updates to IEEE 1547 enable grid supportive capabilities
- Awareness of pending standards development activity to add guidance for interconnection of EST
- Ability to benefit from U.S. experiences related to key technical insights on DER impact and interconnection challenges, and relevant EST performance characteristics

Expected DER/Inverter-Based Resource Impacts

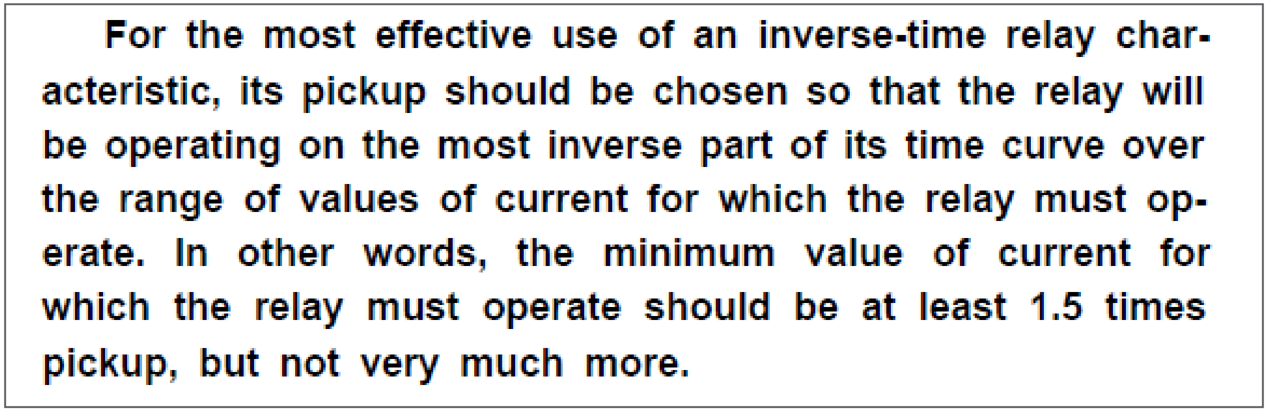
1. "Generators that use inverters to interface to the grid … can only supply relatively small amounts of short circuit current. Typically, inverter short circuit current is limited to a range of 1.1 to 1.4 per unit. As the penetration levels of these generators increases and displaces conventional synchronous generation, **the available short circuit current on the system will decrease. This may make it more difficult to detect and clear system faults.** "

2. "… as DER displaces synchronous generation, **there may be times when there is insufficient system inertia and primary frequency response to arrest frequency decline** and stabilize the system frequency following a contingency."

(**emphasis** added)

From "Potential Bulk System Reliability Impacts of Distributed Resources", NERC, August 2011

Impact 1: How Much Short Circuit Current Is Needed?



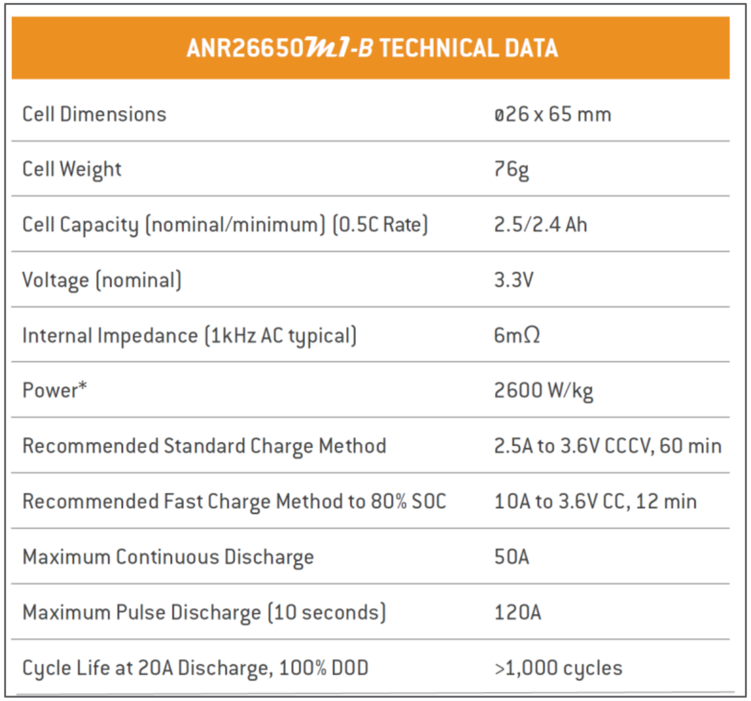
For the most effective use of an inverse-time relay characteristic, its pickup should be chosen so that the relay will be operating on the most inverse part of its time curve over the range of values of current for which the relay must operate. In other words, the minimum value of current for which the relay must operate should be at least 1.5 times pickup, but not very much more.

From “Distribution System Feeder Overcurrent Protection”, GET-6450, GE

Impact 1: Short Circuit Current Delivery from EST, 2X+?

BESS Inverters' SCD Capability?

PV SCD Capability?



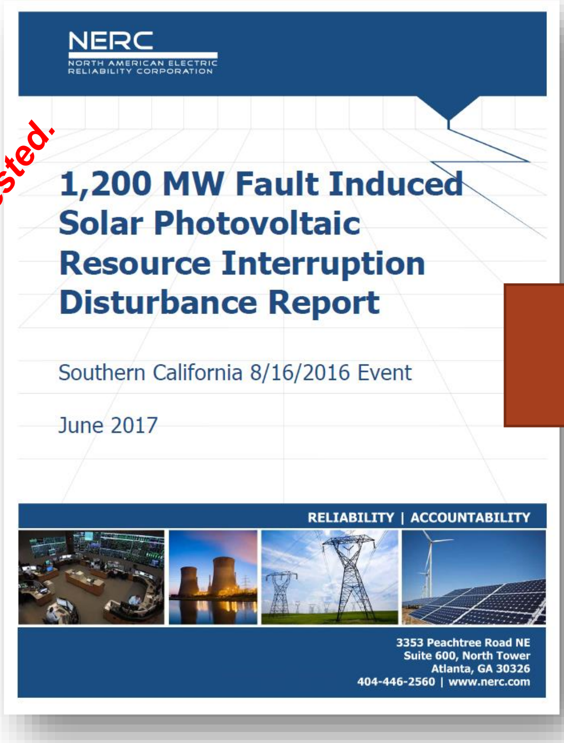
ANR26650m1-B TECHNICAL DATA	
Cell Dimensions	ø26 x 65 mm
Cell Weight	76g
Cell Capacity (nominal/minimum) (0.5C Rate)	2.5/2.4 Ah
Voltage (nominal)	3.3V
Internal Impedance (1kHz AC typical)	6mΩ
Power*	2600 W/kg
Recommended Standard Charge Method	2.5A to 3.6V CCCV, 60 min
Recommended Fast Charge Method to 80% SOC	10A to 3.6V CC, 12 min
Maximum Continuous Discharge	50A
Maximum Pulse Discharge (10 seconds)	120A
Cycle Life at 20A Discharge, 100% DOD	>1,000 cycles

Source, A123Systems, https://a123batteries.com/product_images/uploaded_images/26650.pdf

Impact 2: DER & Frequency Decline, Early Recorded Event

System frequency deviation due to inadvertent PV loss.

This time, the decline was arrested.



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

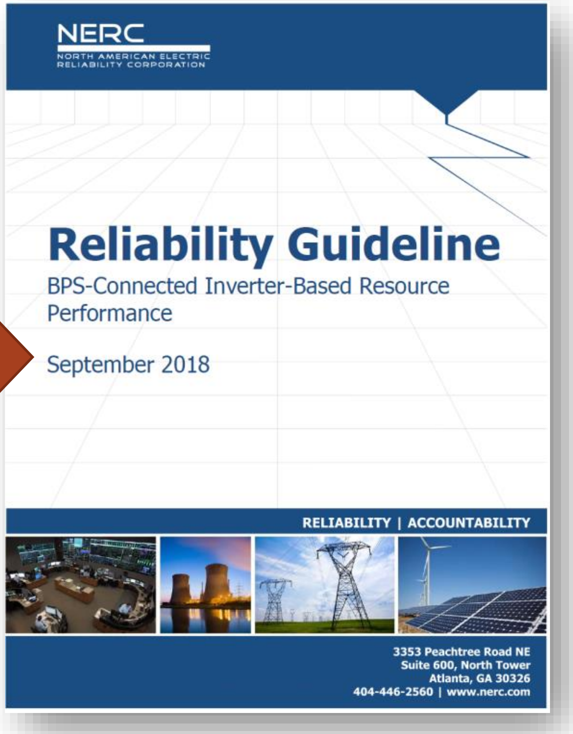
1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

Southern California 8/16/2016 Event

June 2017

RELIABILITY | ACCOUNTABILITY

3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Reliability Guideline

BPS-Connected Inverter-Based Resource Performance

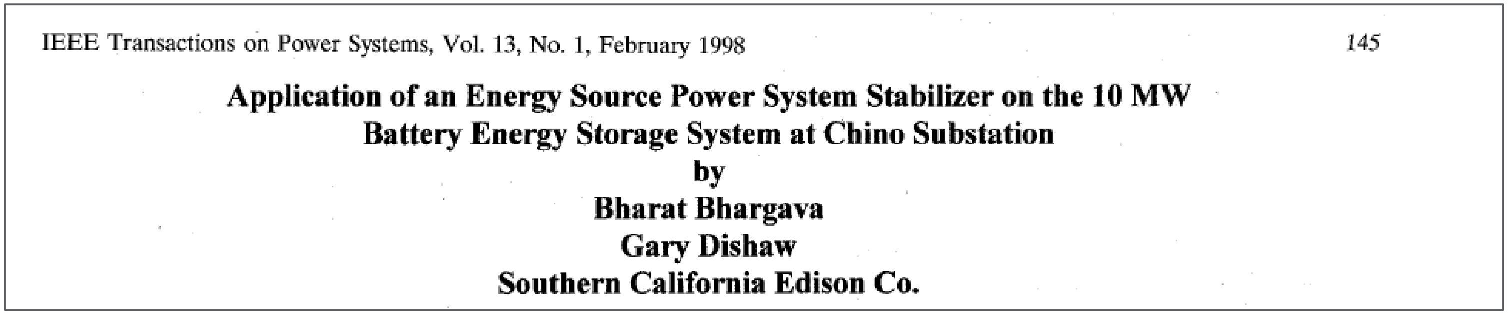
September 2018

RELIABILITY | ACCOUNTABILITY

3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com

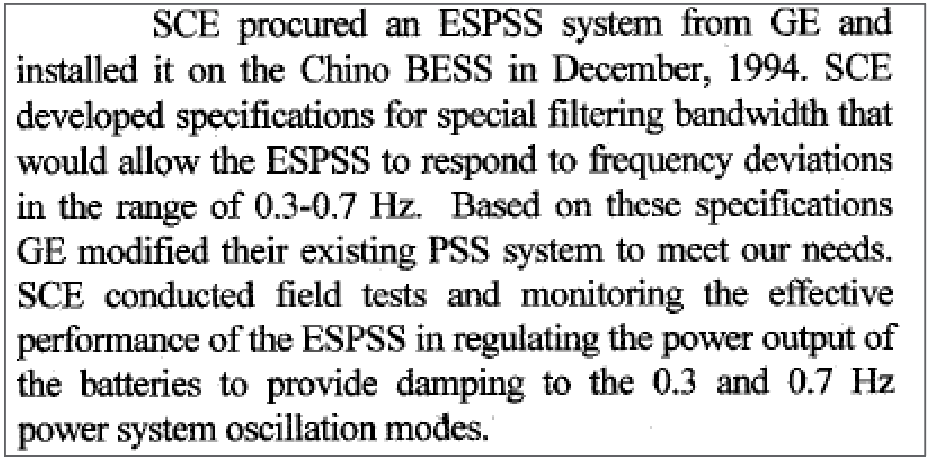
Source - NERC
See https://www.nerc.com/comm/OC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf

Impact 2: Early Solution Based on EST



IEEE Transactions on Power Systems, Vol. 13, No. 1, February 1998 145

Application of an Energy Source Power System Stabilizer on the 10 MW
Battery Energy Storage System at Chino Substation
by
Bharat Bhargava
Gary Dishaw
Southern California Edison Co.



SCE procured an ESPSS system from GE and installed it on the Chino BESS in December, 1994. SCE developed specifications for special filtering bandwidth that would allow the ESPSS to respond to frequency deviations in the range of 0.3-0.7 Hz. Based on these specifications GE modified their existing PSS system to meet our needs. SCE conducted field tests and monitoring the effective performance of the ESPSS in regulating the power output of the batteries to provide damping to the 0.3 and 0.7 Hz power system oscillation modes.

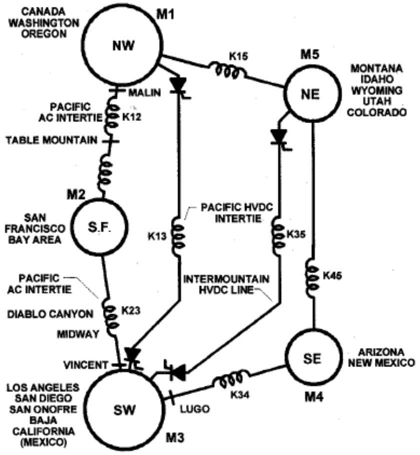
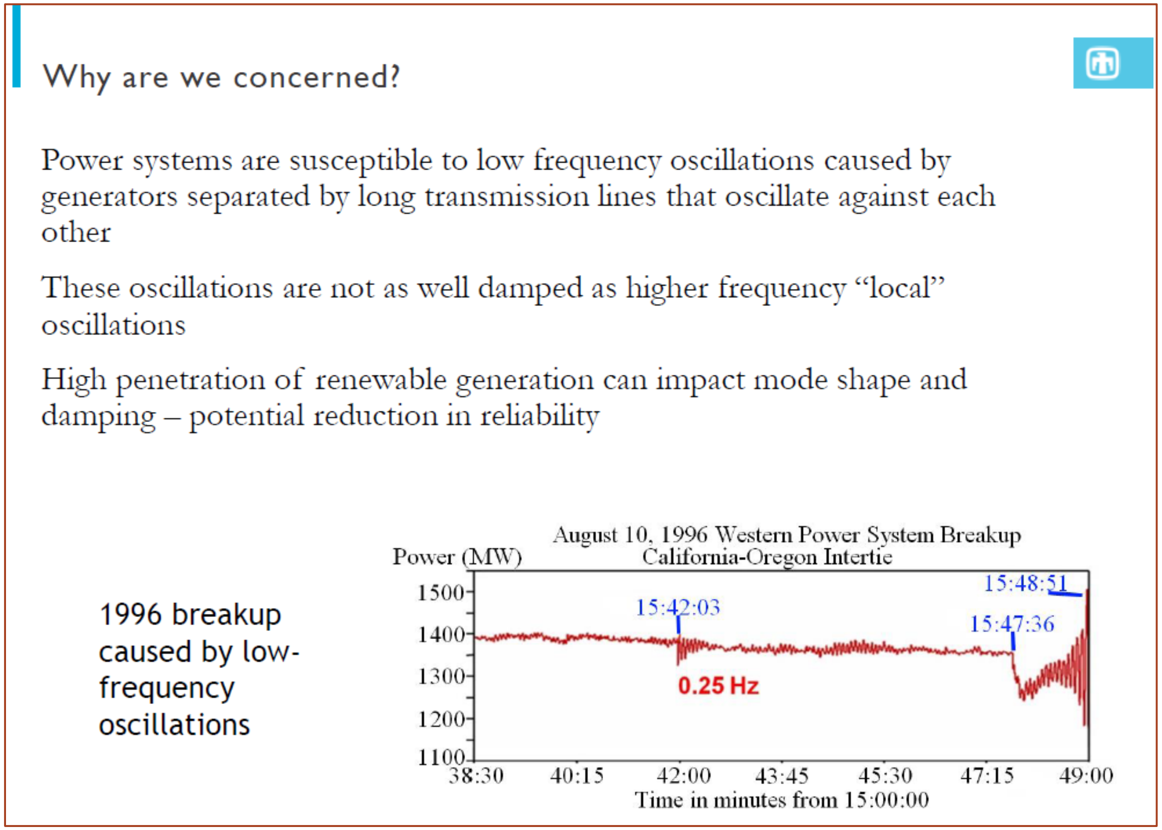


Figure 3. Equivalent Mass - Spring representation of the WSCC system.

Source, Southern California Edison

Impact 2: Next Generation Solution Based on EST



Why are we concerned?

Power systems are susceptible to low frequency oscillations caused by generators separated by long transmission lines that oscillate against each other

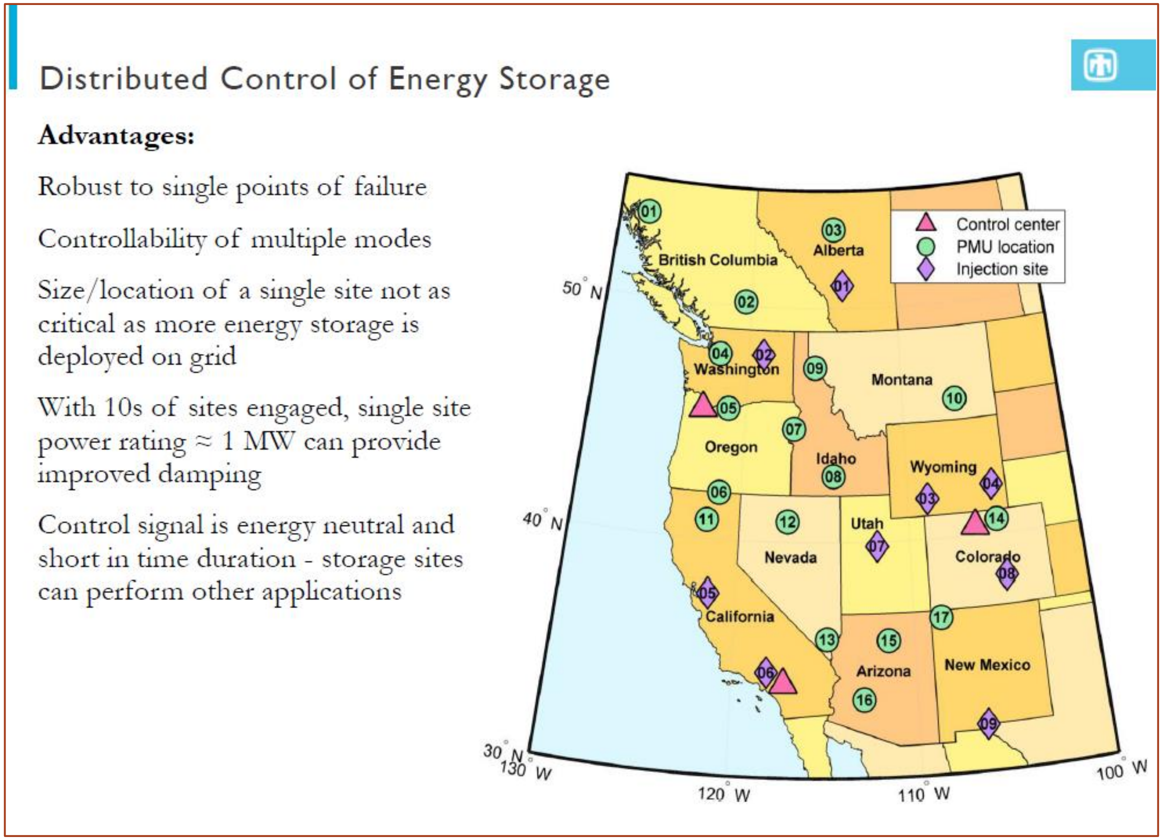
These oscillations are not as well damped as higher frequency “local” oscillations

High penetration of renewable generation can impact mode shape and damping – potential reduction in reliability

1996 breakup caused by low-frequency oscillations

Source, R. Byrne, Sandia National Laboratory

Impact 2: Next Generation Solution Based on EST (continued)



Distributed Control of Energy Storage

Advantages:

Robust to single points of failure

Controllability of multiple modes

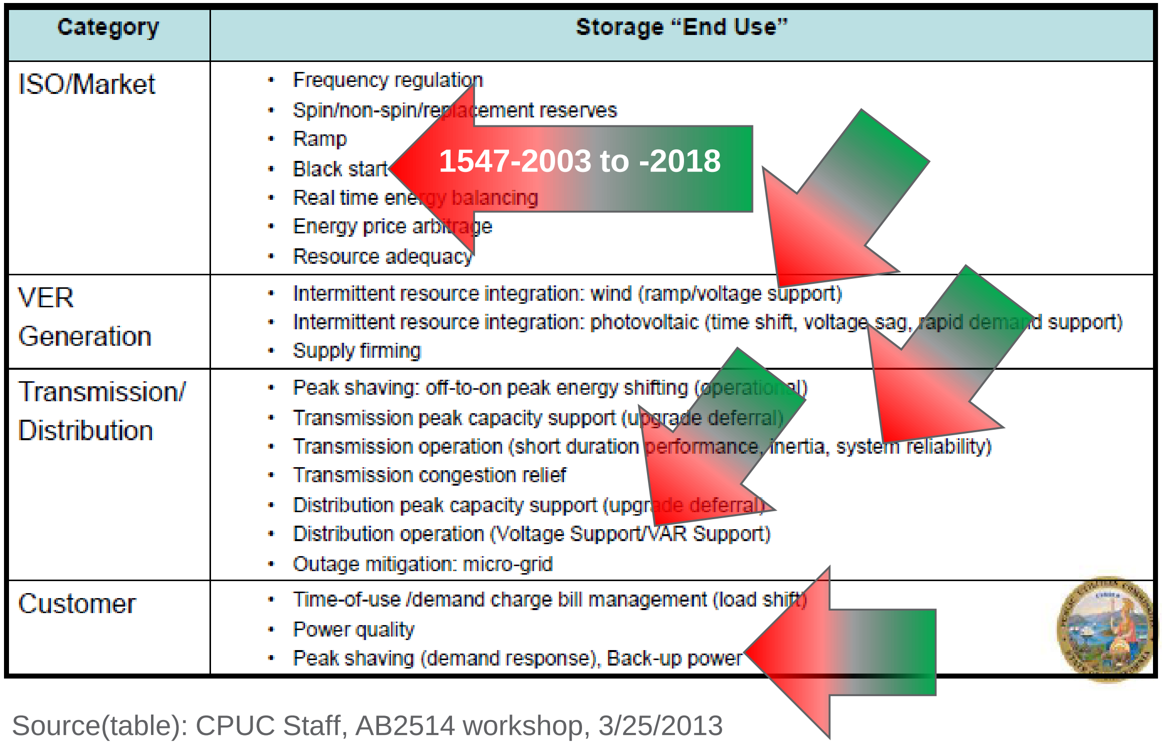
Size/location of a single site not as critical as more energy storage is deployed on grid

With 10s of sites engaged, single site power rating ≈ 1 MW can provide improved damping

Control signal is energy neutral and short in time duration - storage sites can perform other applications

Source, R. Byrne, Sandia National Laboratory

‘Smart’ ES Applications – from California’s ES Procurement Mandate



Category	Storage “End Use”
ISO/Market	• Frequency regulation • Spin/non-spin/replacement reserves • Ramp • Black start • Real time energy balancing • Energy price arbitrage • Resource adequacy
VER Generation	• Intermittent resource integration: wind (ramp/voltage support) • Intermittent resource integration: photovoltaic (time shift, voltage sag, rapid demand support) • Supply firming
Transmission/ Distribution	• Peak shaving: off-to-on peak energy shifting (operational) • Transmission peak capacity support (upgrade deferral) • Transmission operation (short duration performance, inertia, system reliability) • Transmission congestion relief • Distribution peak capacity support (upgrade deferral) • Distribution operation (Voltage Support/VAR Support) • Outage mitigation: micro-grid
Customer	• Time-of-use /demand charge bill management (load shift) • Power quality • Peak shaving (demand response), Back-up power

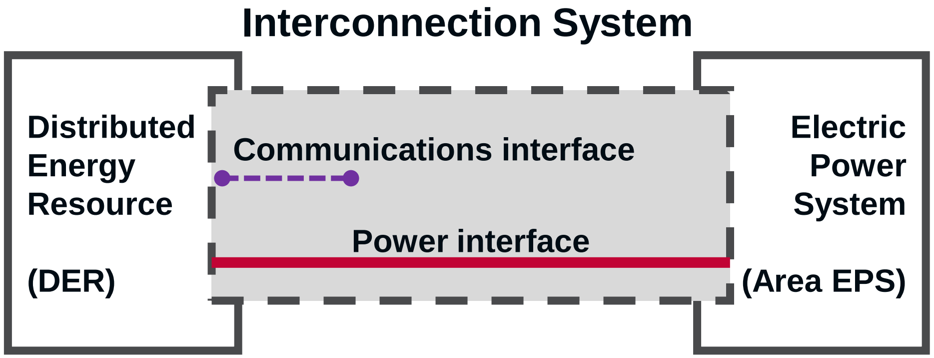
1547-2003 to -2018

Source(table): CPUC Staff, AB2514 workshop, 3/25/2013

IEEE 1547-2018 Scope and Purpose

Title: *Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

Scope: *This standard establishes criteria and requirements for interconnection of distributed energy resources (DER) with electric power systems (EPS), and associated interfaces.*



Purpose*: This document provides a uniform standard for the interconnection and interoperability of distributed energy resources (DER) with electric power systems (EPS). It provides requirements relevant to the interconnection and interoperability performance, operation, and testing, and, safety, maintenance and security considerations.*

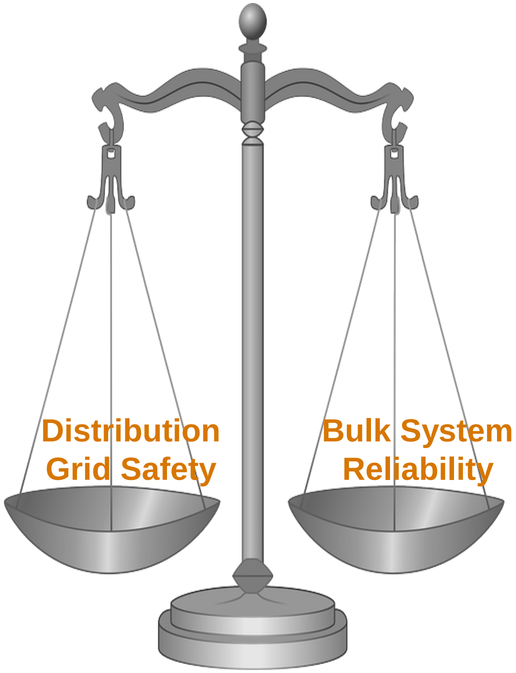
Interconnection system: The collection of all interconnection equipment and functions, taken as a group, used to interconnect DERs to an area EPS. Note: In addition to the power interface, DERs should have a communications interface.

Interface: A logical interconnection from one entity to another that supports one or more data flows implemented with one or more data links.

Source: IEEE P1547 Working Group

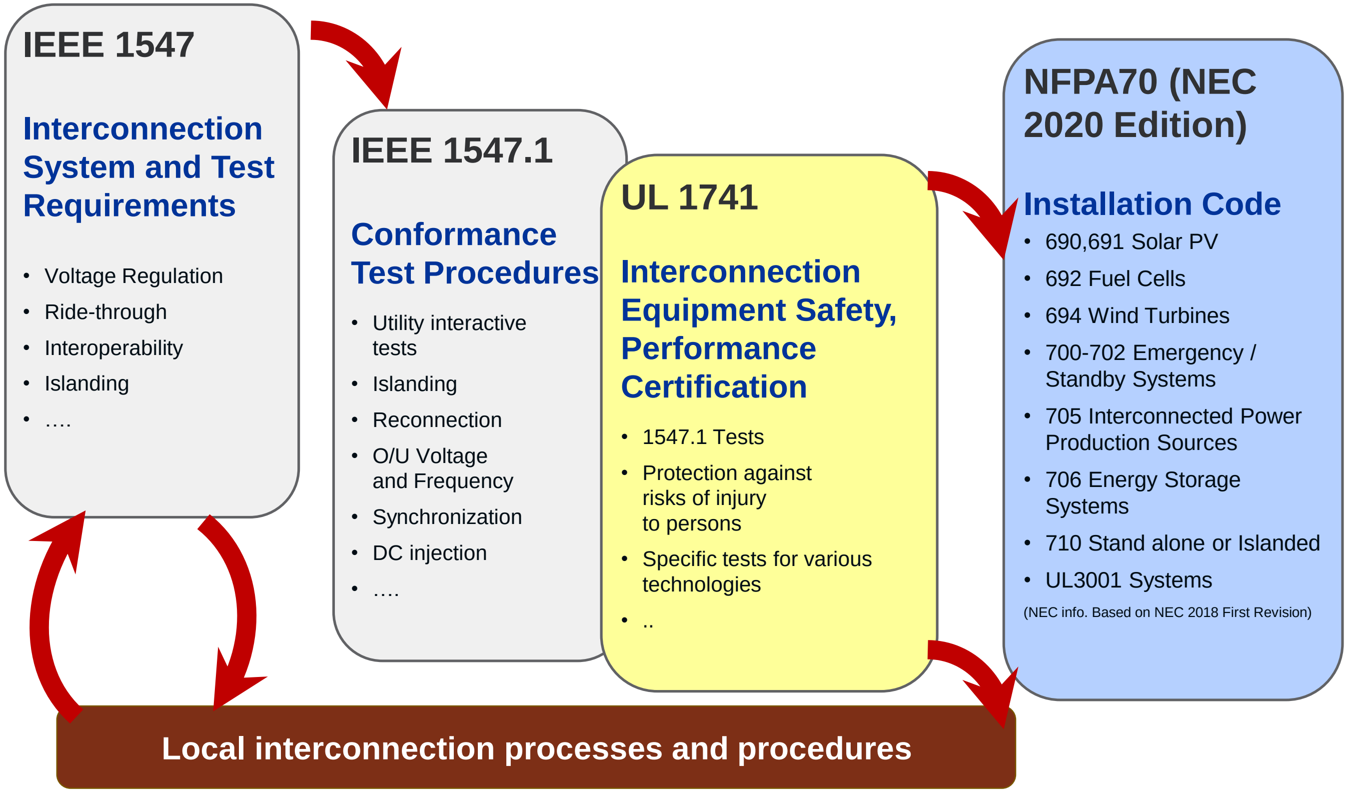
IEEE 1547-2018 Strikes a New Balance

- IEEE 1547-2018 mandates BOTH:
  - Tripping requirements, and
  - Ride-through requirements
- Ride-through is not a “setting”, it is a minimum *capability* of the DER
  - *“shall ride through <u>for at least</u> … seconds”*
  - I.e., it is the minimum required DER robustness to withstand voltage and frequency disturbances
  - May or may not be fully utilized, or it may be exceeded
- Trip thresholds and clearing times are maximum operational *settings*
  - *“shall trip <u>at latest by</u> … seconds”*
  - May differ from *default settings* and are adjustable over a ‘range of allowable settings’
  - Specified ranges do not allow DER tripping to seriously compromise bulk power system reliability
  - Tripping points specified by the distribution utility may account for utility-specific practices but may also be constrained by the ***regional reliability coordinator***



Source: IEEE P1547 Working Group

IEEE 1547-2018 Used By Reference in the U.S.



IEEE 1547

Interconnection System and Test Requirements

- Voltage Regulation
- Ride-through
- Interoperability
- Islanding
- ….

IEEE 1547.1

Conformance Test Procedures

- Utility interactive tests
- Islanding
- Reconnection
- O/U Voltage and Frequency
- Synchronization
- DC injection
- ….

UL 1741

Interconnection Equipment Safety, Performance Certification

- 1547.1 Tests
- Protection against risks of injury to persons
- Specific tests for various technologies
- ..

NFPA70 (NEC 2020 Edition)

Installation Code

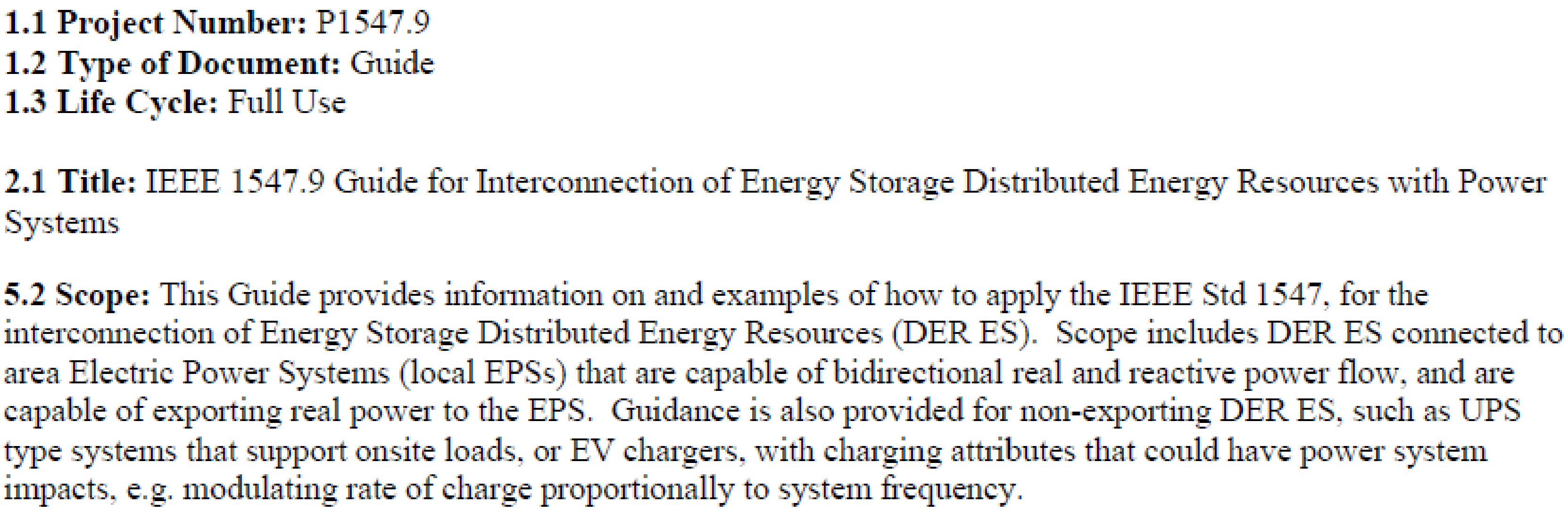
- 690,691 Solar PV
- 692 Fuel Cells
- 694 Wind Turbines
- 700-702 Emergency / Standby Systems
- 705 Interconnected Power Production Sources
- 706 Energy Storage Systems
- 710 Stand alone or Islanded
- UL3001 Systems

(NEC info. Based on NEC 2018 First Revision)

Local interconnection processes and procedures

Source: IEEE P1547 Working Group

New IEEE ‘PAR’ Project:
Guide for ES-DER Interconnection



1.1 Project Number: P1547.9
1.2 Type of Document: Guide
1.3 Life Cycle: Full Use

2.1 Title: IEEE 1547.9 Guide for Interconnection of Energy Storage Distributed Energy Resources with Power Systems

5.2 Scope: This Guide provides information on and examples of how to apply the IEEE Std 1547, for the interconnection of Energy Storage Distributed Energy Resources (DER ES). Scope includes DER ES connected to area Electric Power Systems (local EPSs) that are capable of bidirectional real and reactive power flow, and are capable of exporting real power to the EPS. Guidance is also provided for non-exporting DER ES, such as UPS type systems that support onsite loads, or EV chargers, with charging attributes that could have power system impacts, e.g. modulating rate of charge proportionally to system frequency.

First P1547.9 Working Group was held at NERC, in February 2019.
Please use IEEE MyProject to ID your interest.
Or, contact Charlie.Vartanian@pnnl.gov

Source: IEEE P1547.9 Working Group

Summary and Key Takeaways

- Common interconnection criteria across fragmented jurisdictions (e.g. U.S. States) saved all stakeholders time and money, thus accelerating DER and ES adoption
- Inverter connected BESS have unique operating characteristics that should be considered when developing and updating grid-facing performance and reliability standards
- Distributed/multi-island electric service models will have performance attributes and needs compatible with 1547-2018’s newly added performance requirements for VAR capabilities, grid event ride thru, and inertial equivalent controlled power modulation

Pacific Northwest
NATIONAL LABORATORY

Energy Storage Technology Safety Overview

David R. Conover
Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Purpose and Expected Outcome

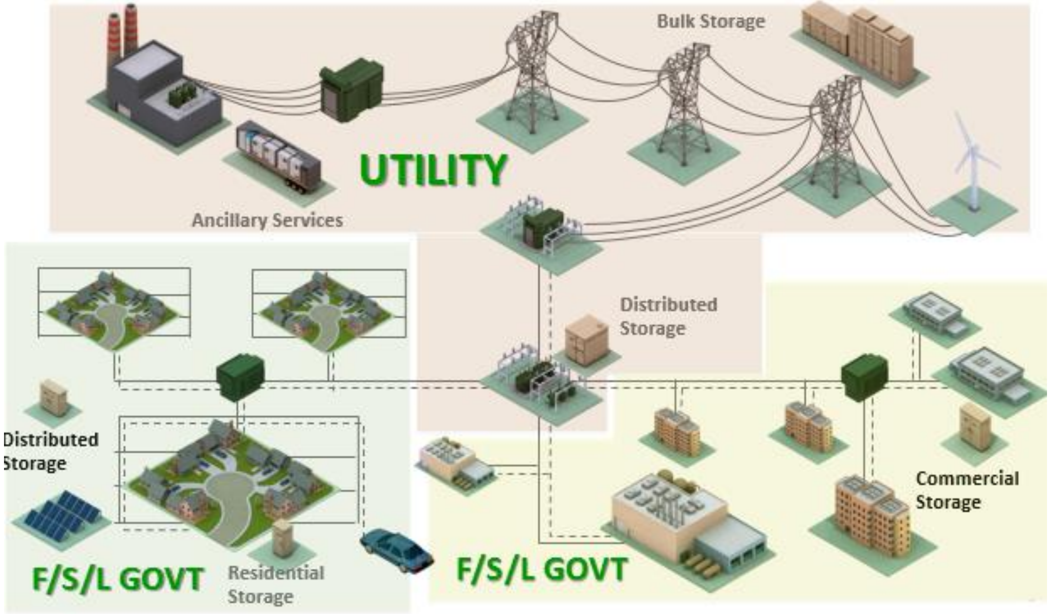
Purpose – To provide an overview of challenges and responses to ensuring timely deployment of safe energy storage technology (EST)

Expected Outcomes

- An awareness of safety issues associated with EST
- Recognition of the challenges faced by those responsible for public safety
- Knowledge of key safety-related questions that need answers
- Consideration of the myriad of variables involved in addressing safety
- Recognition that codes and standards provide a foundation to support timely application of safe EST
- Awareness of EST safety issues and U.S. codes and standards that address them
- Ability to benefit from U.S. experiences related to public safety and consider them in addressing EST deployment activities in South Africa

Key Variables Impacting Safety

Continuity	Location	Load	Ownership/Operation
Portable	Inside	**Grid**	**Utility**
Mobile	**Outside**	Commercial/Industrial	F/S/L Government
Stationary	Rooftop	Residential	Private Sector



ESA Basics of Energy Storage Workshop 2011/ SNL-EPRI

- **X Technologies**
- **Y Chemistries**
- **Z Size/Capacity**

$[3^4$ x $(X·Y·Z)]$ Possible Scenarios

if X=3, Y=5 and Z=5 then 6,000 possible scenarios

If the scope includes only red items targeted at only the grid the problem is simplified

$[1^4$ x $(X·Y·Z)] = 75$ (or less if X, Y or Z are reduced)

Safety Issues

- Fire, smoke and gas detection and fire suppression
- Impact of an incident on other construction and systems
- Thermal management, ventilation and exhaust
- Explosion potential and control
- Support and protection from natural and man-made disasters/incidents
- Access for facility O&M and first responders/fire service
- Proper operation of control systems
- Spill containment and/or neutralization
- Continuing safety after repair, retrofit, replacement, renovation or addition
- Security of systems

The size, type, chemistry, location and ownership/operation of the EST has a major impact on how serious (or not) these issues are

The cause of safety incidents is ‘blind’ as to the county where an EST is located

Key Questions

- What is safe (or not safe)?
- How does one assess if something is or is not safe?
- What criteria are used to make an assessment?
- How are criteria developed, adopted and applied?
- When is an assessment needed?
- Who can perform an assessment?
- Who can designate something as safe?
- How can they apply the results of an assessment?
- Can the answers change over time?
- Why would the answers change?
- How are new answers developed and implemented?

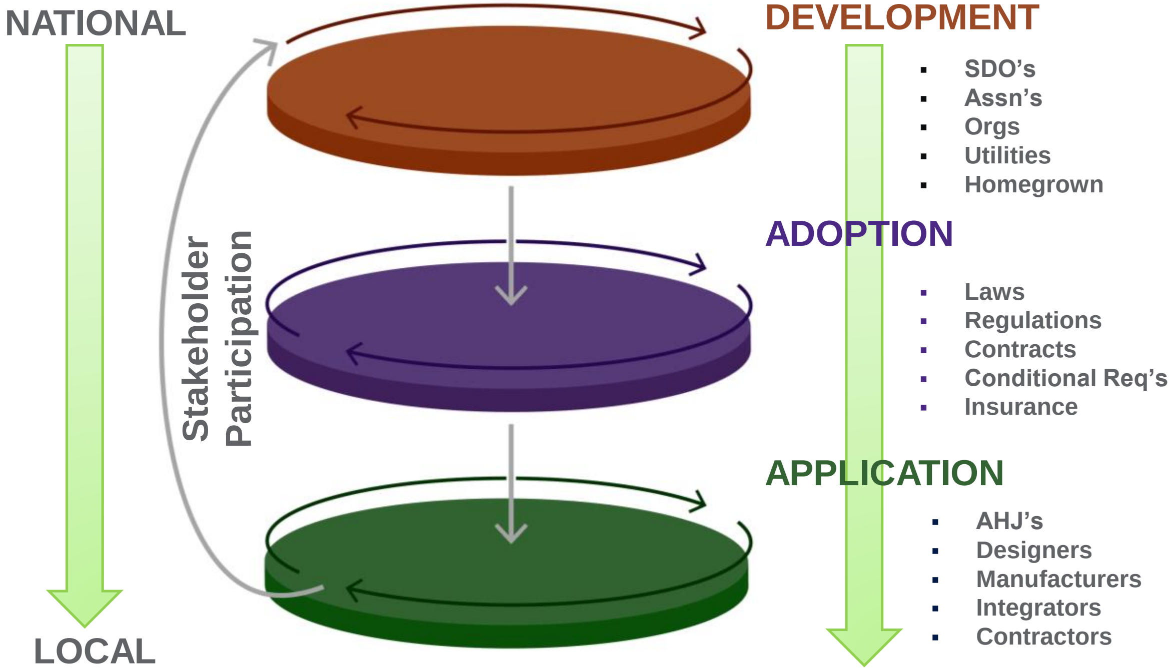
Do these also apply in South Africa and if so how might they be best addressed using U.S. experiences OR how might plans to implement EST in South Africa change the answer or render the question moot?

Challenges in the U.S.

- Increasing number of EST and battery chemistries
- Growing range of EST uses and application scenarios
- Varying needs and stakeholders over time (design, installation, commissioning, O&M, post-incident response, decommissioning)
- Ability of relevant stakeholders to keep up with change
- Lack of answers to key questions
- Desire to deploy EST in a timely manner
- Lack of updated codes and standards that provide a basis for approval
- Policies that can accelerate deployment too fast in relation to needed safety guidance
- A safety incident that has a major impact on progress

Do these also apply in South Africa and if so how might they be best addressed using U.S. experiences OR how might plans to implement EST in South Africa minimize or eliminate one or more challenges?

Overview - Standards and Model Codes Development, Adoption and Application in the U.S.



NATIONAL

LOCAL

Stakeholder Participation

DEVELOPMENT

- SDO’s
- Assn’s
- Orgs
- Utilities
- Homegrown

ADOPTION

- Laws
- Regulations
- Contracts
- Conditional Req’s
- Insurance

APPLICATION

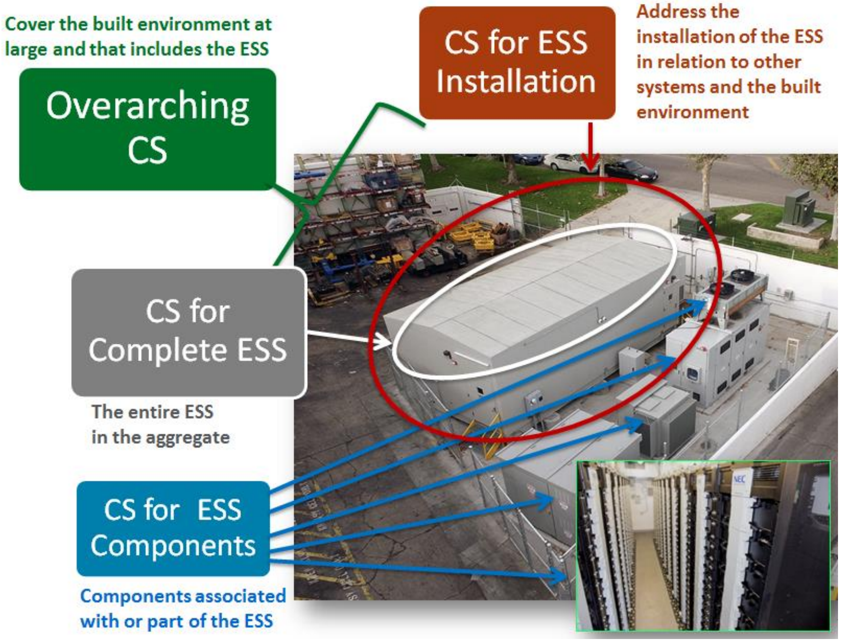
- AHJ’s
- Designers
- Manufacturers
- Integrators
- Contractors

Timely deployment of safe EST

- *Standards and model codes are developed in the U.S. at the national level by the voluntary (e.g. non-governmental) sector*
- *They are adopted by and applied in the public and private sector*
- *When adopted they form the basis for technical communication between all stakeholders involved developing and deploying energy storage technology*
- *As lessons are learned in the field and energy storage technology evolves these documents can be updated and revised*

Safety-Related Topics – Codes and Standards Perspective

- Siting (location, loads, protection, egress/access, maximum quantities of chemicals, separation, etc.)
- System age (new, existing, renovated/recycled)
- New versus existing building/facility applications
- Continuity (stationary, mobile, and/or portable)
- Ventilation, thermal management, exhausts (when necessary, flow rates, how controlled, etc.)



Cover the built environment at large and that includes the ESS

Overarching CS

CS for ESS Installation

Address the installation of the ESS in relation to other systems and the built environment

CS for Complete ESS

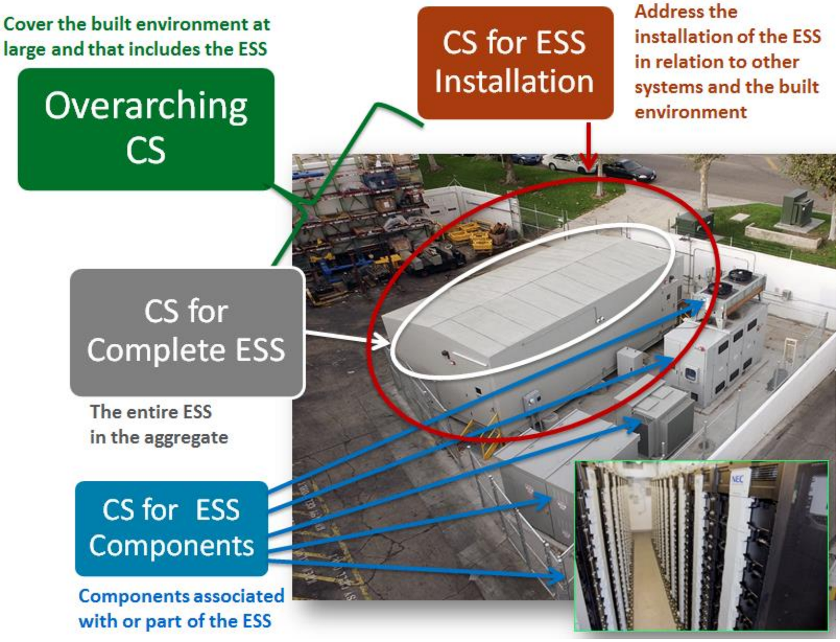
The entire ESS in the aggregate

CS for ESS Components

Components associated with or part of the ESS

Safety-Related Topics (cont.)

- Interconnection with other systems (energy sources, communications, controls, etc.)
- Fire protection (detection, suppression, containment, smoke removal, etc.)
- Containment of fluids (from the ESS and from incident response)
- Signage, markings, and security
- Identification of the applicable authorities having jurisdiction (utility, federal, state, or local government, etc.)
- How to document safety, who can do that and the scope of their activity (e.g., third-party testing, FEMA, HMA, product certification, etc.)



Cover the built environment at large and that includes the ESS

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CS for ESS Installation

Address the installation of the ESS in relation to other systems and the built environment

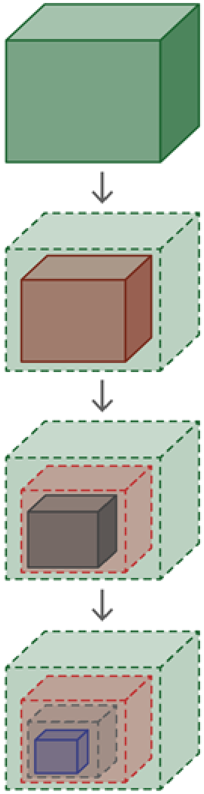
CS for Complete ESS

The entire ESS in the aggregate

CS for ESS Components

Components associated with or part of the ESS

Standards and Model Codes Adopted and Applied in the U.S.



BUILT ENVIRONMENT

- ICC International Residential Code and International Fire Code
- NFPA 1 (Fire Code)

INSTALLATION / APPLICATION

- IEEE C2 National Electrical Safety Code
- IEEE 1635/ASHRAE 21 Guide for Ventilation and Thermal Management of Stationary Batteries
- NFPA 855 Standard for the Installation of ESS
- NFPA 70 National Electrical Code
- NECA 416 Recommended Practice for Installing Stored Energy Systems

ENERGY STORAGE SYSTEMS

- ASME TES-1 Safety Standard for Thermal (molten salt ESS
- UL 9540 Energy Storage Systems and Equipment
- UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery ESS
- NFPA 791 Recommended Practice and Procedures for Unlabeled Electrical Equipment

SYSTEM COMPONENTS

- CSA C22.2 No. 340 Battery Management Systems
- UL 810A Electrochemical Capacitors
- UL 1973 Standard for Batteries for Use in Stationary Applications
- UL 1974 Evaluation for Repurposing Batteries

IEC TC 120

Develops standards for ESS performance, grid integration, safety and environment

Scope “Electrical Energy Storage (EES) Systems are becoming key components of the grid. TC 120 describes and defines system aspects of EES systems which are grid connected AND operated as both an energy source and sink with respect to the grid.” Grid includes utility, commercial/industrial and residential.

Principles:
- No duplication of existing IEC TC activities
- Establish liaisons with appropriate TCs
- Perform gap analysis to determine gaps in ESS standards
- Consider storage system as a black box

Safety approach
- Identify hazards
- Perform risk analysis
- Develop risk mitigation measures

Key Takeaways - Considerations

- Constant evolution on many fronts involving many variables
- There are many challenges, issues and questions to be addressed
- Those who adopt or apply C/S can be challenged to keep up with EST evolution
- All stakeholders need to collaborate
- Policies and supporting resources are needed and can help
- There are limits - you can only run so fast and do it safely

The situation in South Africa with respect to the scope of EST deployments, the manner in which standards are developed and adopted and the manner in which projects are documented and verified as safe presents a less complicated challenge than in the U.S.

Is it possible to standardize EST deployment scenarios to yield a small set of pre-approved technologies and installations that can be readily replicated throughout South Africa and commissioned, operated, maintained and decommissioned using a standardized set of guidelines and trained personnel?

What information and experiences can be gleaned from the U.S. and than adapted to best fit with the safety infrastructure in South Africa?

Moving Forward

DOE OE Energy Storage Systems Safety Roadmap

Goal - to foster confidence in the safety and reliability of energy storage systems

Objectives address….

1. R&D
2. Codes and Standards
3. Collaboration

Updated guidance to facilitate more uniform and timely documentation and verification of safety as the EST evolves and EST applications increase

Highlights

Final actions on proposed changes to the ICC 2018 International Fire Code (IFC) that will be included in the 2021 IFC have been approved.

The public review of ASME TES-1 is open and will close January 8, 2019.

The second draft report on NFPA 855 is scheduled to be posted in January 2019.

ESS-1-2019 Standard for Uniformly Measuring and Expressing the Performance of Electrical Energy Storage Systems is expected to be published by NEMA in January 2019.

A fourth ballot for NECA 417 Recommended Practice for Designing, Installing, Maintaining, and Operating Micro-grids closes on January 25, 2019.

IEEE P1679.2-18, Guide for the Characterization and Evaluation of Sodium-Beta Batteries in Stationary Applications was published December 21, 2018.

CODES AND STANDARDS UPDATE
DECEMBER 2018

ENERGY STORAGE SYSTEM SAFETY

Development and Adoption of Codes and Standards

ENERGY STORAGE SYSTEM SAFETY

Documenting and Validating Compliance with Codes and Standards

AEP Chemical Substation BESS Example

Charlie Vartanian, P.E.

Pacific Northwest National Laboratory

PNNL is operated by Battelle for the U.S. Department of Energy

Project Plot Plan

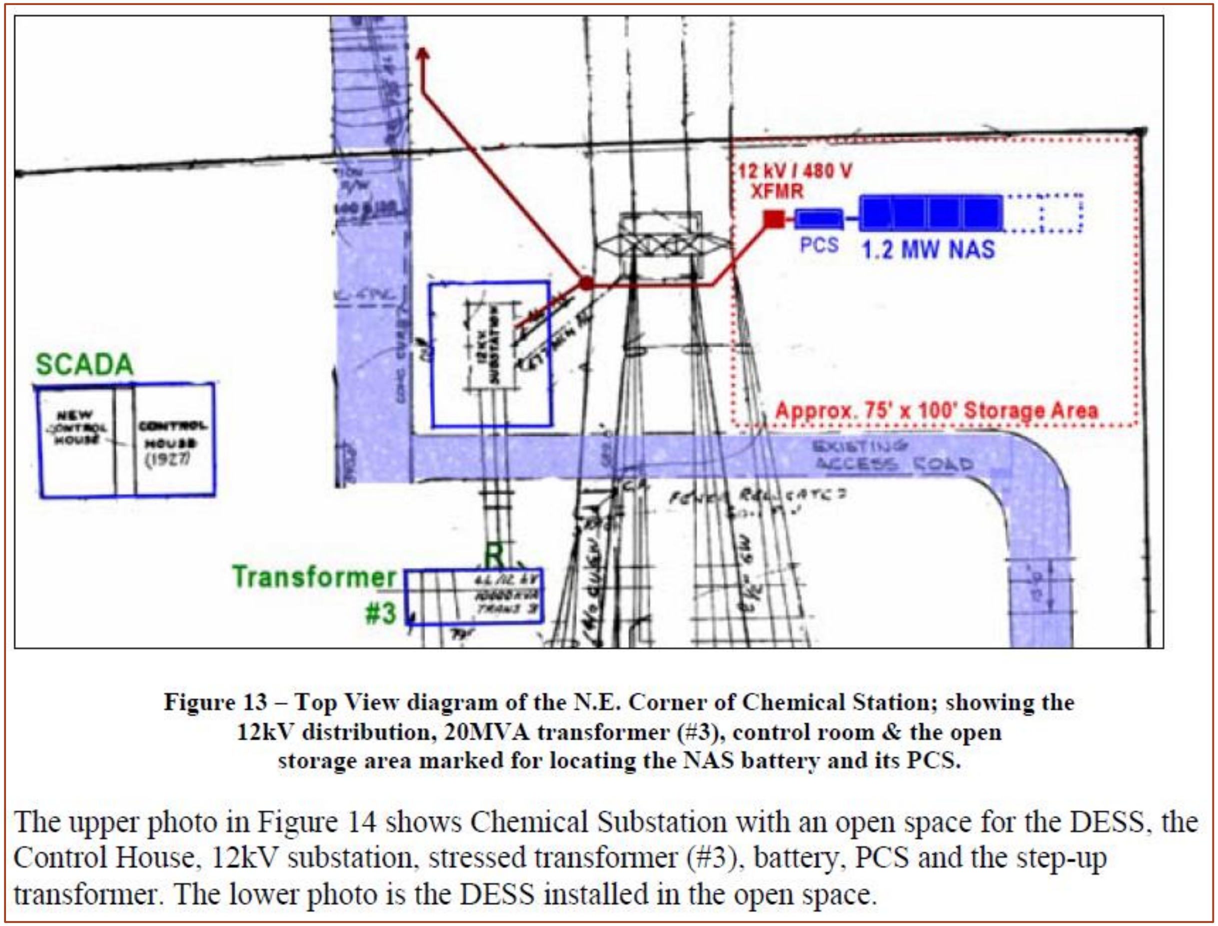


Figure 13 – Top View diagram of the N.E. Corner of Chemical Station; showing the 12kV distribution, 20MVA transformer (#3), control room & the open storage area marked for locating the NAS battery and its PCS.

The upper photo in Figure 14 shows Chemical Substation with an open space for the DESS, the Control House, 12kV substation, stressed transformer (#3), battery, PCS and the step-up transformer. The lower photo is the DESS installed in the open space.

Source, SNL/DOE, https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2007/073580.pdf

Project Layout Photo

Once users get past the apparent ‘exotic’ aspect of EST as prime mover they find …..

- They are generally like any other resource from a power systems integration and controls interface standpoint
- Power systems personnel find that most if not all the pieces and parts of an ES project are familiar to once they are walked thru a project

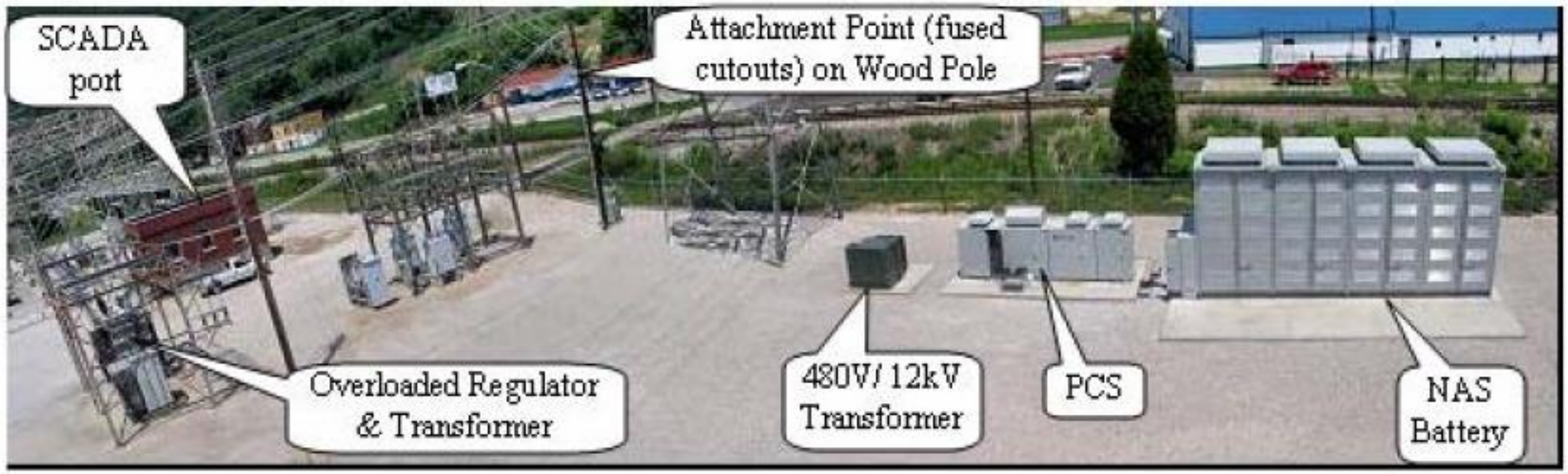


Figure 32 – Layout of a 1.2 MW, 7.2 MWh DESS at Chemical Station in Charleston

Source, SNL/DOE, https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2007/073580.pdf

Project Electrical Single Line Drawing

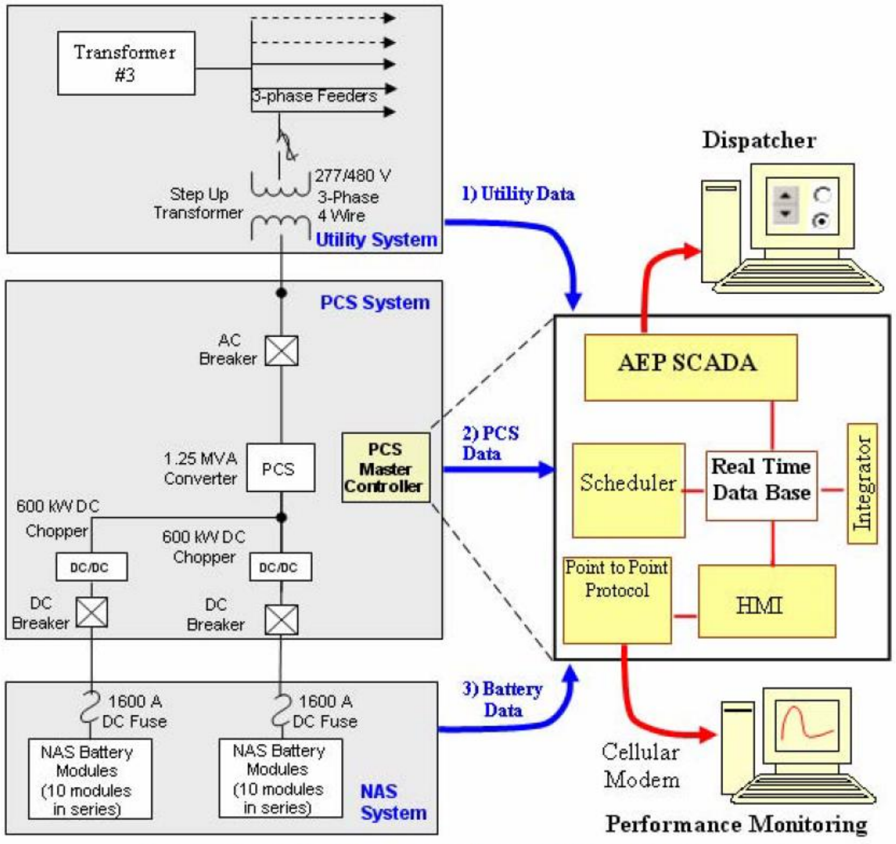


Figure 34– Layout of DESS and its PCS Master Controller with different data

Source, SNL/DOE, https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2007/073580.pdf

Project Description and Setting

Chemical Station is a combination of transmission (138kV) and distribution (12kV) substations. The 20MVA, 46kV/12kV distribution transformer and the voltage regulator that supply the three 12kV feeders out of this station were very close to their limits during the 2005 summer peak (June through August) and were very likely to surpass them during that period. AEP decided to install a 1.2 MW DESS to mitigate this problem for a few years, until a new substation could be justified.

Figure 11 is a one-line diagram of the distribution substation in Chemical Station, indicating the location of a 1.2 MW NAS battery that would be connected to one of the three 12kV feeders (West Washington Street).

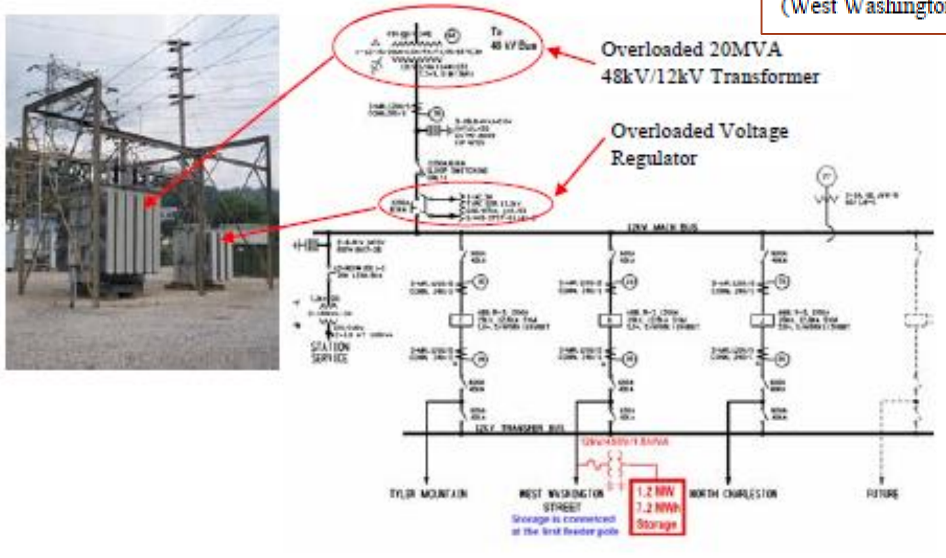
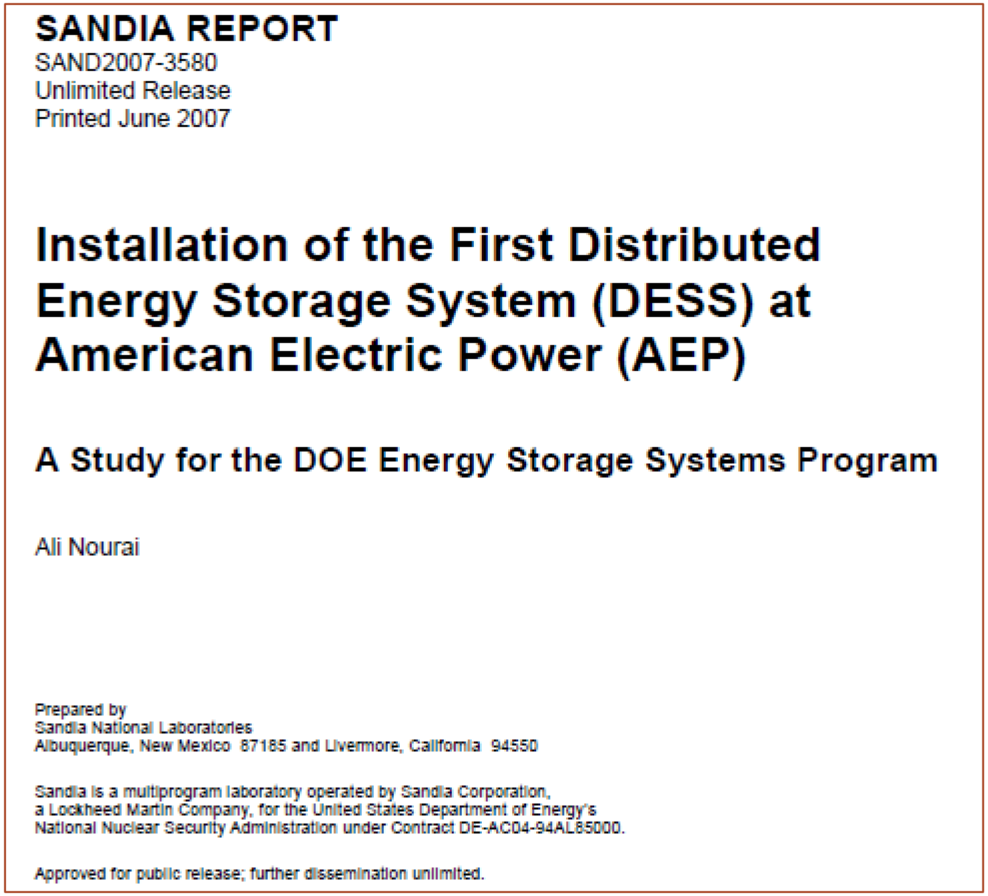


Figure 11 – One-line diagram of the Chemical Distribution Substation in Charleston WV, with a photo of its overloaded voltage regulator and transformer.

Source, SNL/DOE, https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2007/073580.pdf

Project Report Information



SANDIA REPORT
SAND2007-3580
Unlimited Release
Printed June 2007

Installation of the First Distributed Energy Storage System (DESS) at American Electric Power (AEP)

A Study for the DOE Energy Storage Systems Program

Ali Nourai

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Energy Storage Measuring and Expressing System Performance

Vish Viswanathan

Pacific Northwest National Laboratory

Energy Storage Measuring and Expressing System Performance

Purpose

Provide an overview of the Protocol for Measuring and Expressing Energy Storage System Performance

Expected Outcome

An understanding of the metrics and applications for possible use in South Africa

Applications Covered

- Peak shaving
- Frequency regulation
- Islanded microgrids
- Volt/var support
- Power quality
- Frequency control
- PV Smoothing
- Renewables (solar) firming

Protocol Overview

- Describe ESS (boundary and system content)
- Identify ESS Application(s)
- Specifications and Duty Cycle and Performance Metrics as a Function of Application
- Measurements and Determination of Performance Metrics
- Reporting of Results

General Information and Technical Specifications

- Enclosure type
- Equipment footprint
- Height and weight
- Grid communication mechanism
- General description of the ESS
- Warranty and replacement schedule
- Expected availability of the ESS
- Rated continuous discharge power
- Rated apparent power
- Rated continuous charge power
- Rated continuous AC current (discharge and charge)
- Output voltage range
- Rated discharge energy
- Minimum charge time

Reference and Duty Cycle Performance

Reference

- Stored energy capacity
- Round trip energy efficiency
- Response time
- Ramp rate
- Reactive power response time
- Reactive power ramp rate
- Internal resistance
- Standby energy loss rate
- Self-discharge rate

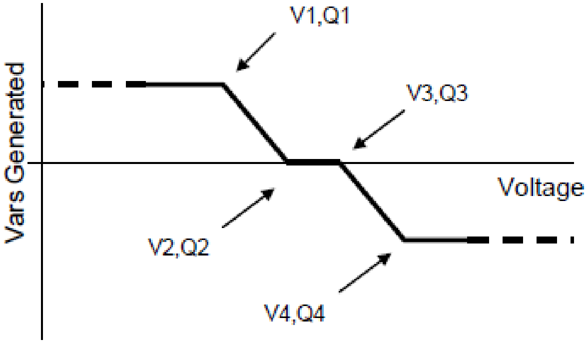
Duty Cycle

- Duty cycle round trip efficiency
- Reference signal tracking
- State of charge excursions
- Energy capacity stability
- Peak power

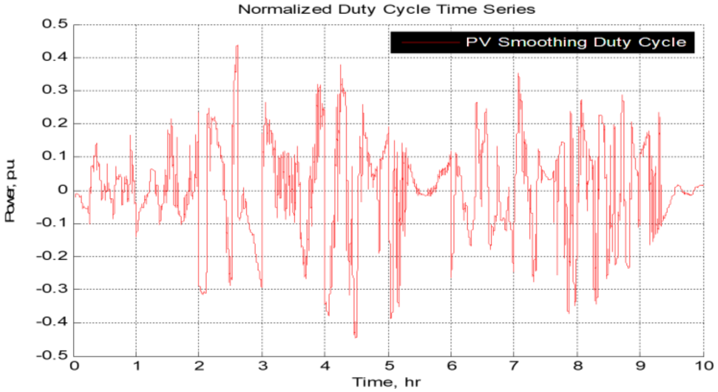
Duty Cycles Developed to Support ESS Applications

- Each application has a specific duty cycle that is intended to be representative of what an ESS will experience in the field
- Metrics associated with performance under a specific application are then comparable from system to system
- One or more additional duty cycles can be developed if desired and must be described
- Documentation on and the details associated with each duty cycle are published and available for use

Volt-var Support

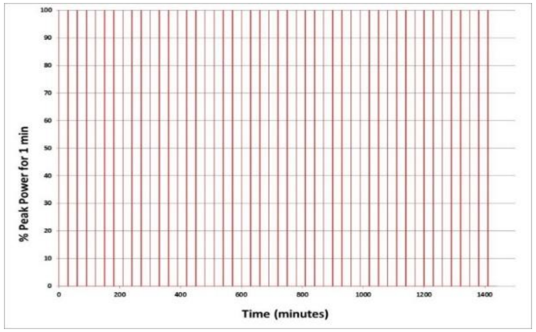


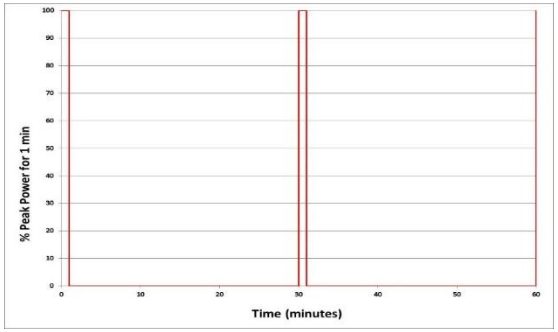
PV Smoothing

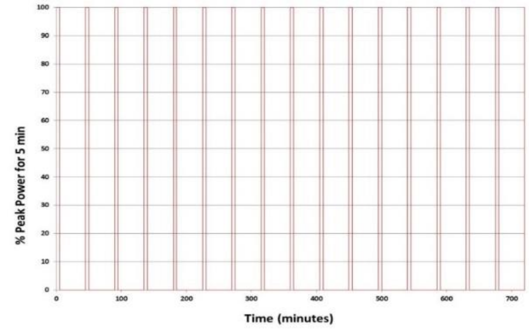


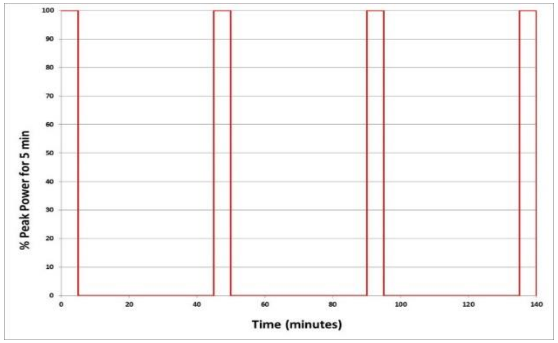
Duty Cycles Developed to Support ESS Applications

Power Quality

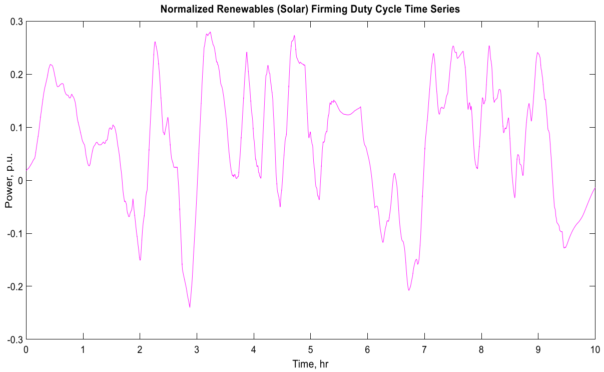






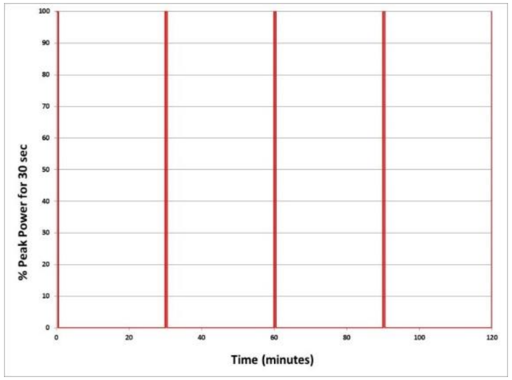


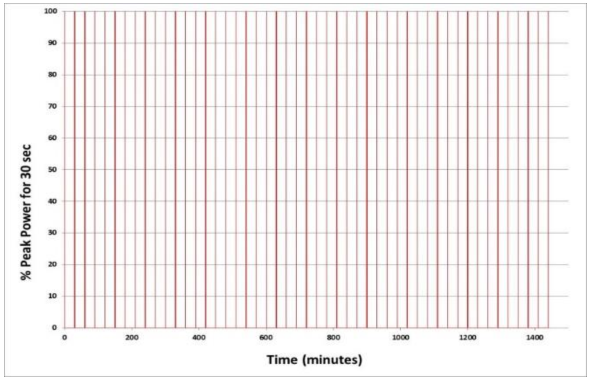
Renewables (solar) Firming

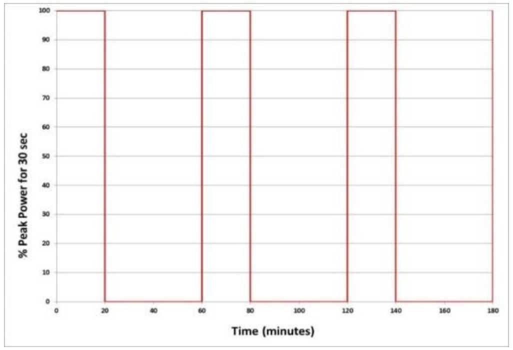


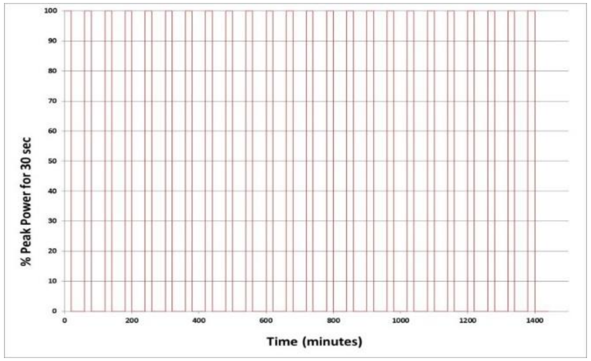
Duty Cycles Developed to Support ESS Applications

Primary and Secondary Frequency Control



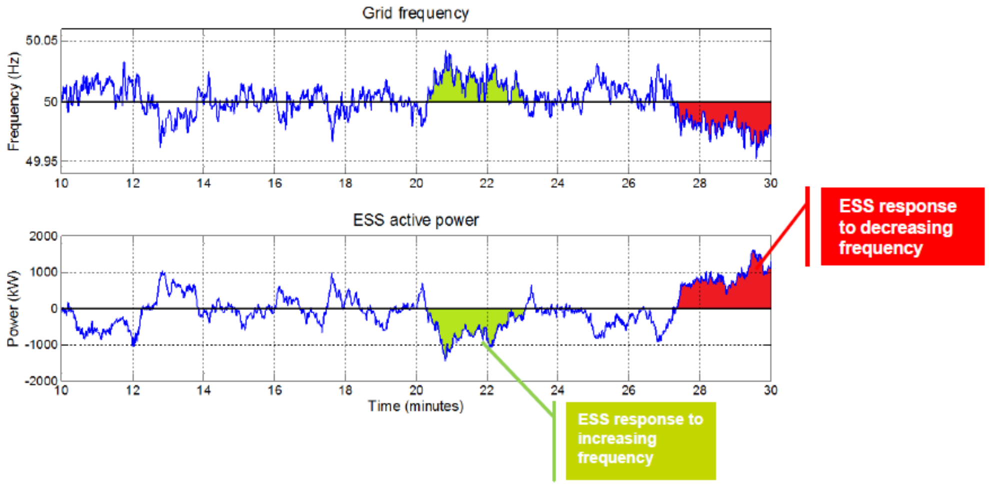






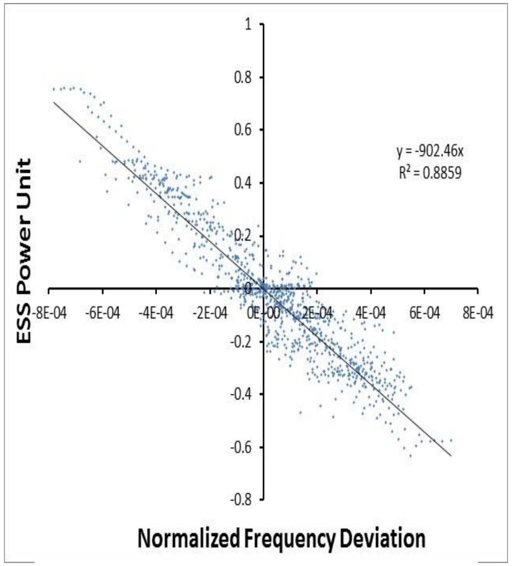
Dynamic Frequency control Additional Duty Cycles

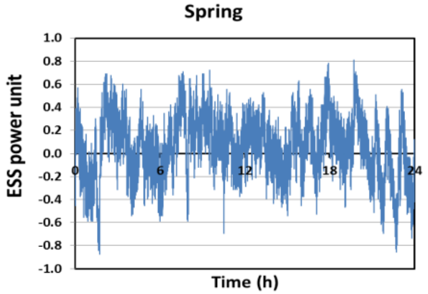
EXAMPLE: PRIMARY FREQUENCY CONTROL



ESS response to decreasing frequency

ESS response to increasing frequency





Applied the response signal to a US grid for Spring season

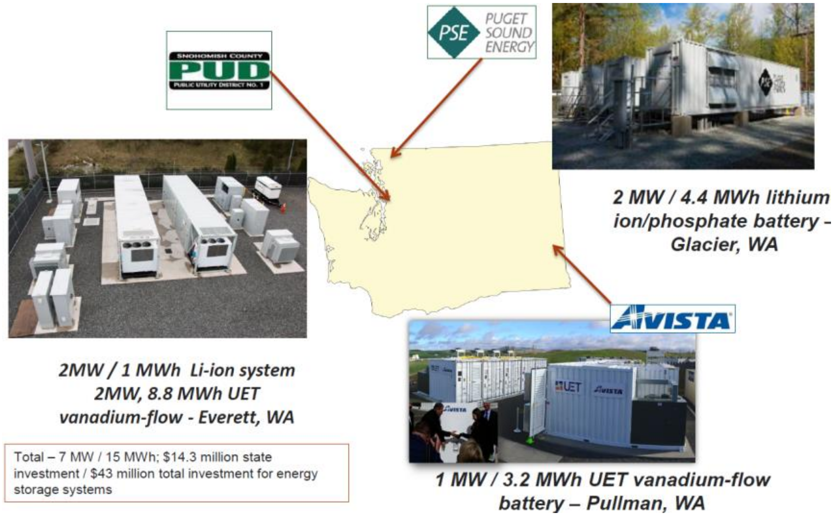
FIELD TESTS: May 2015 to May 2016
GOAL: analyze impacts of seasonal variations of wind generation and load on the operation of the storage system (benefits, grid constraints, etc.)

Bruno Prestat (EDF), Chair EPRI-ESIC WG4 Grid Integration. July 10, 2015 presentation

Didier Colin et al ERDF/SAFT/Schneider Electric and others – Venteea 2 MW 1.3 MWh battery system. Lyon France 15-18 June 2015

Grid Scale Energy Storage Performance Testing

- Washington clean energy funds and US DOE-OE sponsored ESS integration with grid at 3 utilities
- Li-ion Systems 1 to 5 MWh; 2 to 4 MW
- Flow Battery Systems 1 to 2 MW, 4 to 8 MWh
- Used US DOE-OE Performance Protocol (Sandia-PNNL led) for Reference Performance Tests
- Developed duty cycles for various use cases
    - Energy shifting
    - Grid Flexibility
    - Outage Mitigation
    - Microgrid
    - Conservation Voltage Reduction
    - Volt-var



2 MW / 4.4 MWh lithium ion/phosphate battery - Glacier, WA

2MW / 1 MWh Li-ion system 2MW, 8.8 MWh UET vanadium-flow - Everett, WA

Total – 7 MW / 15 MWh; $14.3 million state investment / $43 million total investment for energy storage systems

1 MW / 3.2 MWh UET vanadium-flow battery – Pullman, WA

Performance Testing Metrics and Lessons Learned

Metrics

- Round Trip Efficiency
  - With Auxiliary consumption
  - Without Auxiliary consumption
- Response Time
  - Communication lag
  - Hardware lag
  - Time to target power
- Ramp Rate – from time to rated power
- Internal Resistance as f(SOC)
  - Go under the hood delta V/delta I (delta SOC < 0.1%)
    - ✓does ramp rate depend on this parameter?
- Signal Tracking
  - Tracking at grid level different from tracking at inverter level
    - ✓Need to ensure ESS tracks command signal at grid level

Lessons Learned

- No one size fits all
- Different energy to power ratio of BESS applicable for different use cases
- RTE important for arbitrage
  - Depends on power as percent of rated power
  - Auxiliary consumption
  - Inverter efficiency at various power levels
  - For some applications, RTE may be 0
- Signal tracking important for volatile applications
- Performance model to predict performance
  - Being modified to predict degradation

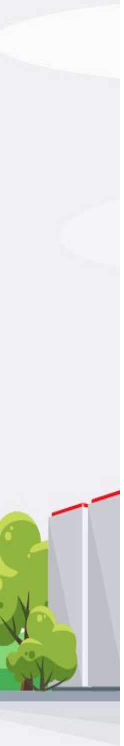
Summary and Wrap UP

David R. Conover

Pacific Northwest National Laboratory

PNNL is operated by Battelle for the U.S. Department of Energy

Summary



- As South Africa develops and implements actions to develop and deploy energy storage systems the experiences gained in and resources available from the U.S. can be of value
- The work done on valuation and associated analytics provides a foundation to value energy storage systems in South Africa and how to best bundle services provided
- Reliability of energy storage systems can be addressed through application of US experiences that are enhanced as warranted to cover South Africa’s reliability needs
- Grid Interconnection can benefit from the content of and experiences associated with IEEE 1547
- The safety-related performance of an energy storage system is the same regardless of the country where it is installed that allows U.S. experiences to be directly applied
- The performance of energy storage systems can be measured and expressed in a manner that is directly applicable in or at least can serve as a foundation for similar efforts in South Africa

Acknowledgment

Dr. Imre Gyuk, DOE – Office of Electricity Delivery and Energy Reliability

Mission – to ensure a resilient, reliable, and flexible electricity system through research, partnerships, facilitation, modeling and analytics, and emergency preparedness.

https://www.energy.gov/oe/activities/technology-development/energy-storage

Thanks and for Further Information

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