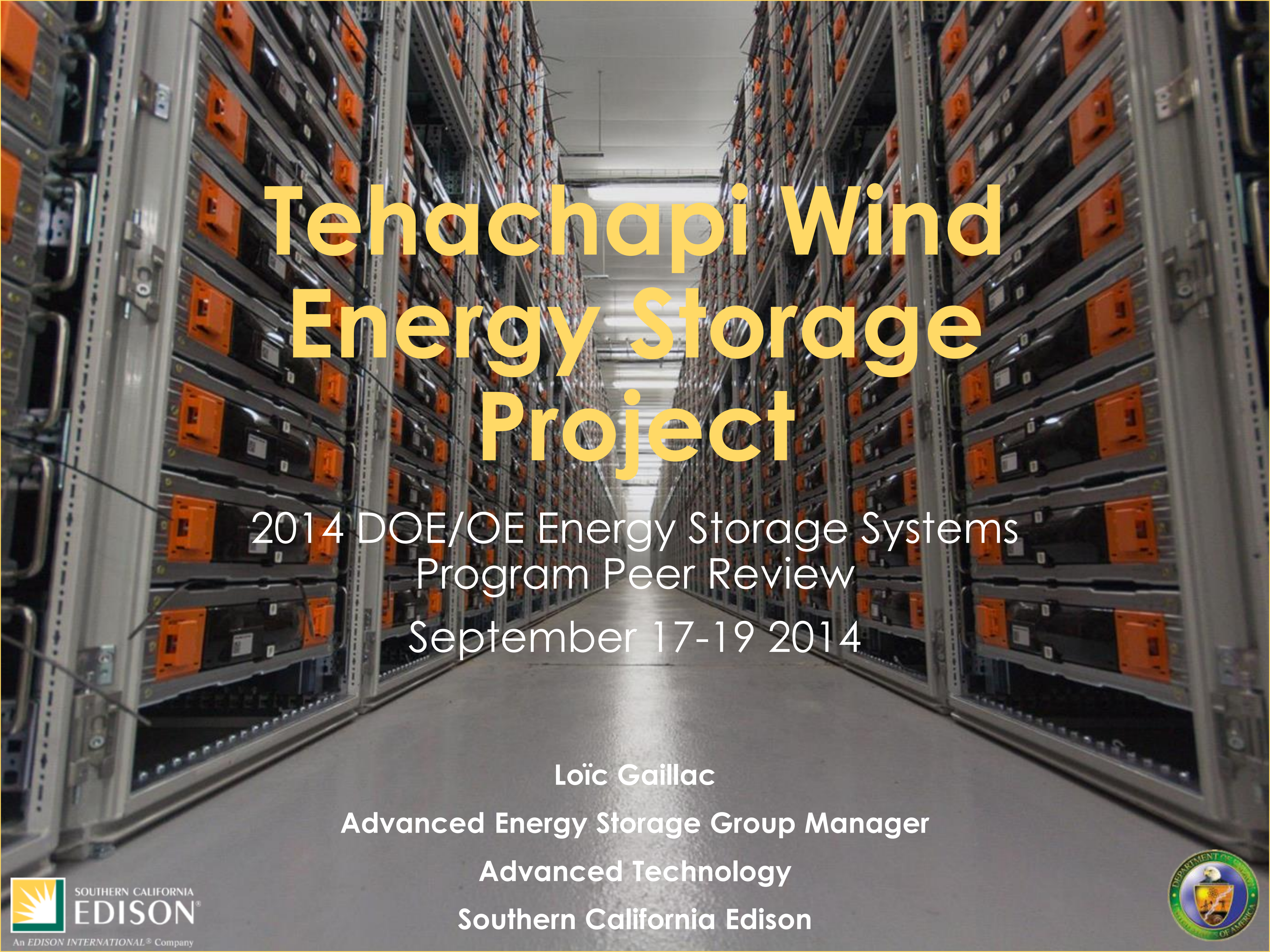

Tehachapi Wind Energy Storage Project

2014 DOE/OE Energy Storage Systems Program Peer Review

September 17-19 2014

Loïc Gaillac

Advanced Energy Storage Group Manager

Advanced Technology

Southern California Edison

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Southern California Edison

- 14 million customers: one of the largest utilities in US
- 125 years of service
- Award-winning energy efficiency and demand response programs

Committed to safely providing, reliable and affordable electric service

SCE Advanced Technology Focus

- Implementing government policies and regulations and improving current utility operations
- Enabling customer adoption of new energy technologies
- Acquiring a deep understanding of the performance and controls of distributed resources
- Investing in next generation infrastructure to enable utilities to be the “optimizer” of distributed resources

Project Objectives

- Test Battery Energy Storage System as a system reliability and/or market driven device
  - Demonstrate the performance of a lithium-ion Battery Energy Storage System (BESS) for 13 specific operational uses, both individually and bundled
  - Share data and results with CAISO, CEC, CPUC, DOE, and other interested parties
  - Assist in the integration of large-scale variable energy resources
- Integrate battery storage technology into SCE's grid
  - Test and demonstrate smart inverter technology
  - Assess performance and life cycle of grid-connected lithium-ion BESS
  - Expand expertise in energy storage technologies and operations

Tehachapi Storage Project (TSP) Facility

BESS facility at Monolith Substation

BESS facility and 12kV/66kV transformer

- Located in the Tehachapi area, California's largest wind resource
- Massive wind development potential (up to 4,500MW) driving grid infrastructure
- Installed at SCE's Monolith Substation
- 6,300 ft^2 building
- Connected at sub-transmission level through a 12/66kV transformer

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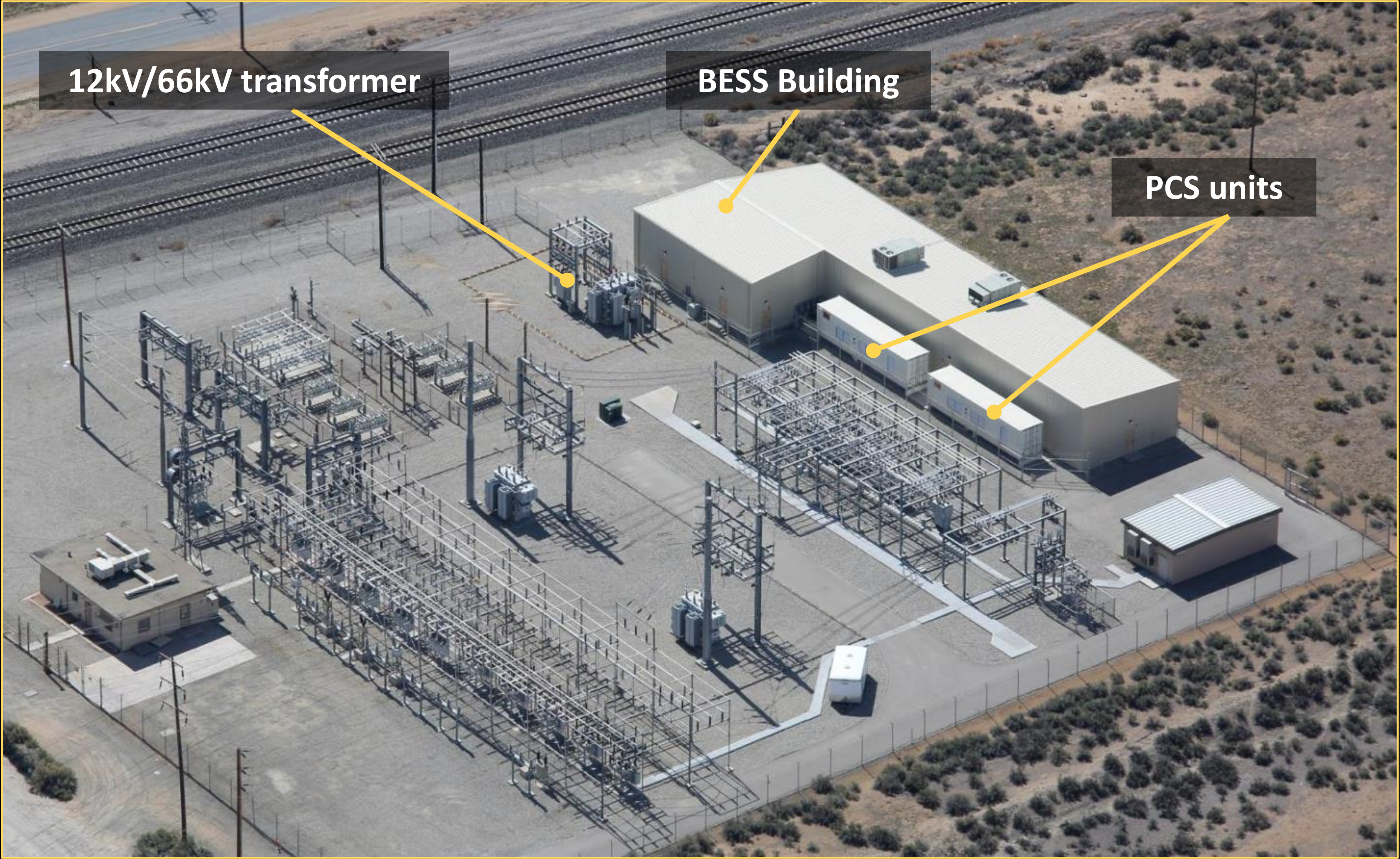
TSP Layout



Project Timeline

02/09/2010 – Project Started

10/13/2010 – DOE Contract Signed

02/28/2011 – Original Vendor Contract Signed

10/16/2012 – Original Vendor Filled for Bankruptcy

03/27/2013 – New Vendor Contract Signed

07/18/2014 – System Commissioning/Acceptance Completed

System Specifications

- Battery Storage System
  - Li-Ion
  - Manufactured by LG Chem.
  - 32MWh usable
- Power Conversion System
  - 9MVA
  - 12kV connected
  - Manufactured by ABB

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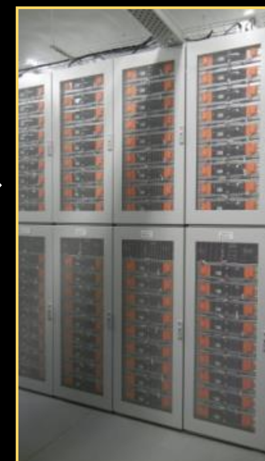
System Configuration

How to get 32MWh from 60Wh battery cells?

x 56

x 18

x 151



x 4

	Cell	Module	Rack	Section	System
Quantity	609 k	10,872	604	4	1
Voltage	3.7 V	52 V	930 V	930 V	930 V
Energy	60 Wh	3.2 kWh	58 kWh	8.7 MWh	32 MWh
Weight	380 g	40 kg	950 kg	N/A	N/A

13 Operational Uses

- Transmission
  - Provide voltage support/grid stabilization
  - Decrease transmission losses
  - Diminish congestion
  - Increase system reliability
  - Defer transmission investment
  - Enhance value and effectiveness of renewable energy-related transmission
- System
  - Provide system capacity/resource adequacy
  - Integrate renewable energy (smoothing)
  - Shift wind generation output
- Market
  - Frequency signal/response
  - Spin/non-spin/replacement reserves
  - Ramp management
  - Energy price arbitrage

8 Core Tests

1) Provide steady state voltage regulation and dynamic voltage support at the local 66 kV bus
2) Perform Test 1 while operating under any mode and performing real power injection/absorption required under such mode
3) Charge during periods of high line loading and discharge during low line loading under SCE system operator control
4) Charge during off-peak periods and discharge during on-peak periods under SCE system operator control
5) Charge and discharge seconds-to-minutes as needed to firm and shape intermittent generation in response to a real-time signal
6) Respond to CAISO control signals to provide frequency regulation
7) Respond to CAISO market awards to provide energy and spin/non-spin reserves
8) Follow a CAISO market signal for energy price

Deployment Challenges

<table>
<tr><th>Challenges</th><th>Resolutions</th></tr>
<tr><td>Construction & Site Constraints
  </td><td>• Made scheduling a priority; deliveries, tasks, crew sizes, and trash disposal</td></tr>
<tr><td>Insects and Rodents
 </td><td>• Installed extra door seals
• Installed traps
• Installed sonic repellers</td></tr>
<tr><td>Weather Conditions & Schedule Impacts


 
</td><td>• Checked weather forecasts daily and scheduled travel, construction crews, & tasks accordingly</td></tr>
</table>

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Deployment Challenges (cont.)

Challenges	Resolutions
Scale and Complexity of System  	• Managed project onsite, real-time, in-person • Communicated continually across teams • Implemented additional training, quality inspections and checks
Number and Breadth of Stakeholders	• Continued constant stakeholder engagement and collaborative efforts
Complexity of Interconnection Process	• Remained flexible, engaged, & supportive

System Validation Challenges

- Large energy storage systems are modular
  - Comprised of AC and DC subsystems
  - Scaled by adding additional components in series/parallel
  - Multiple manufacturers
  - Requires integration
  - Increased likelihood of problems
- Utilities need to assess safety and reliability prior to field deployment
- Issues with testing large systems in the field
  - Grid/personnel safety
  - Geographic distance
  - Need to exchange significant power at will
  - Hardware/firmware/software problems can take many months to solve

System Validation Approach: Mini-System Lab Testing

Mini-System enables subscale testing in the lab before full-scale operation of the BESS at Monolith Substation

	Mini-System	Full System
Footprint	77 ft^2	6300 ft^2 building
Power	30 kW	8 MW
Energy	116 kWh	32 MWh
Power Conversion System	One Mini-Cabinet	Two 40-foot containers
Sections	1	4
Banks	1	32
Racks	2	604
Modules	36	10,872
Cells	2,016	608,832

Mini-System for Subscale Testing

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Mini-System Testing Key Findings

Key Findings	Benefits
Discovered and resolved critical operation aspects regarding the battery system and PCS	Enabled operational aspects to be resolved quickly
Several iterations of software/firmware upgrades were required	Significant time and resources saved due to upgrades performed in the lab at subscale level versus full-scale at remote substation location
24/7 operation for more than 4 months prior to full system commissioning yielded feedback to implement many additional functional upgrades	System operation and features have been enhanced (optimized control algorithms & graphic user interface)

Pre-Operation Challenges

Challenges	**Resolutions**
System integration between all components; Sub-components may be mature but system integration is not	Assess safety and reliability prior to field deployment
System Acceptance Testing (SAT) is impractical on site	Introduced multi-step Acceptance Testing based on lab evaluation of: • Communication system by SCE IT group • PCS controller on the RTDS (Real Time Digital Simulator) • Mini-system
Framework around control ownership in a non-vertically-integrated utility: • Generator controlled by Power Supply Group • Grid reliability asset controlled by Grid Control Center • Shared optimized asset	Engage stakeholders and identify requirements to be completed for (inter)connection and deployment

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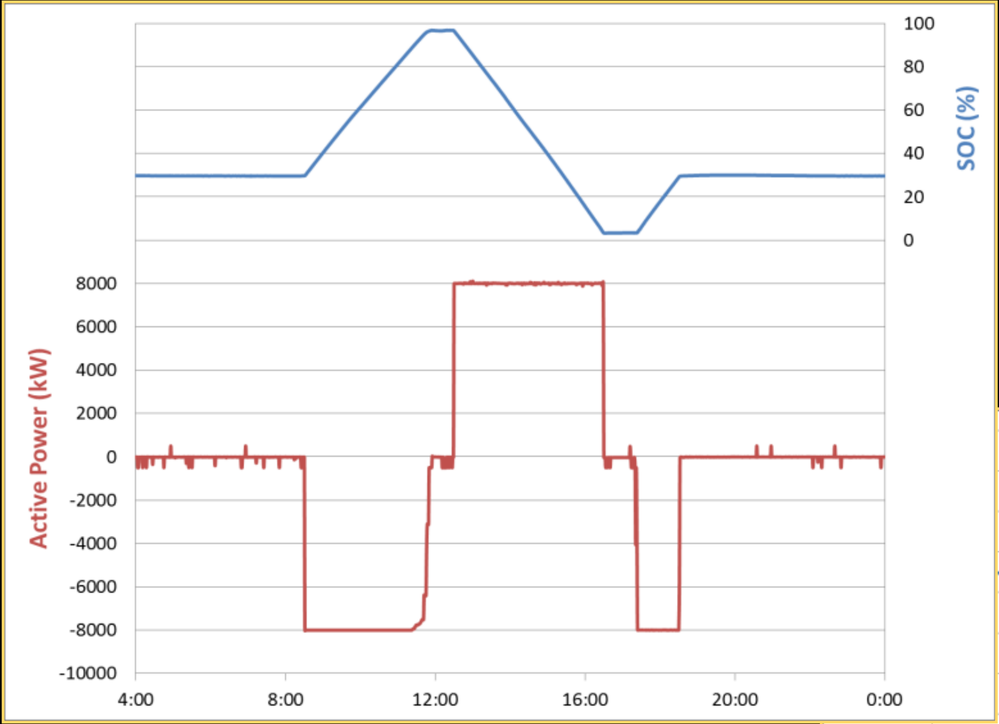
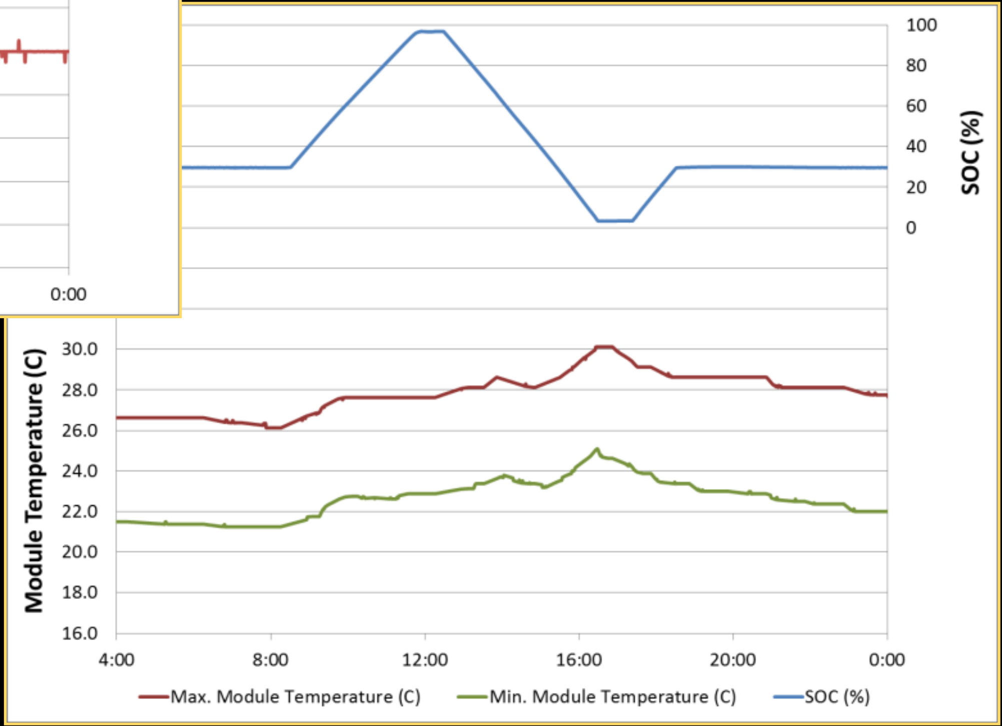
Initial Operation



Full Discharge:

- 8MW - 4 hours
- 32MWh



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Final Thoughts

- Installation, deployment and initial operation of large-scale ESS has:
  - Provided key learning to facilitate future deployments
  - Demonstrated the benefits of Mini-System testing

- Close collaboration between utility and turnkey system provider has accelerated lessons learned

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Questions?