Energy Storage Analysis Using the Battery Storage Evaluation Tool

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Monetize Energy Storage Benefits for Multiple Grid Applications

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Challenge - Over 3,000 utilities

- ✓ Different grid reliability, resiliency, flexibility, renewable integration challenges
- ✓ Different market structure
- ✓ Different cost of electricity
- ✓ Other competing solution approaches besides energy storage

What is needed

- ✓ Requires regional and local analysis of deployed storage technologies in diverse markets to develop full understanding of monetized and unmonetized benefits
- ✓ Development of industry standard design tools with fidelity to capture the multi-use value of storage in transmission, distribution, and behind the meter applications
- ✓ New business models

What We Have Learned – Need a Detailed Methodology for Assessing Energy Storage System (ESS) Value Proposition

Siting Energy Storage	Ability to aid in the siting of energy storage systems by capturing/measuring **location-specific benefits.**
Broad Set of Use Cases	Measure benefits associated with bulk energy, transmission-level, ancillary service, distribution-level and customer benefits **at sub-hourly level.**
Regional Variation	Differentiate benefits by region and **market structures/rules**.
Utility Structure	Define benefits for **varying types of utility** (e.g., PUDs, large utilities operating in organized markets and vertically integrated investor owned utilities operating in regulated markets).
Battery Characteristics	Accurately characterize **battery performance**, including round trip efficiency (RTE) rates across varying states of charge (SOC) and battery degradation caused by cycling.

Battery Storage Evaluation Tool (BSET) and Optimization Tool

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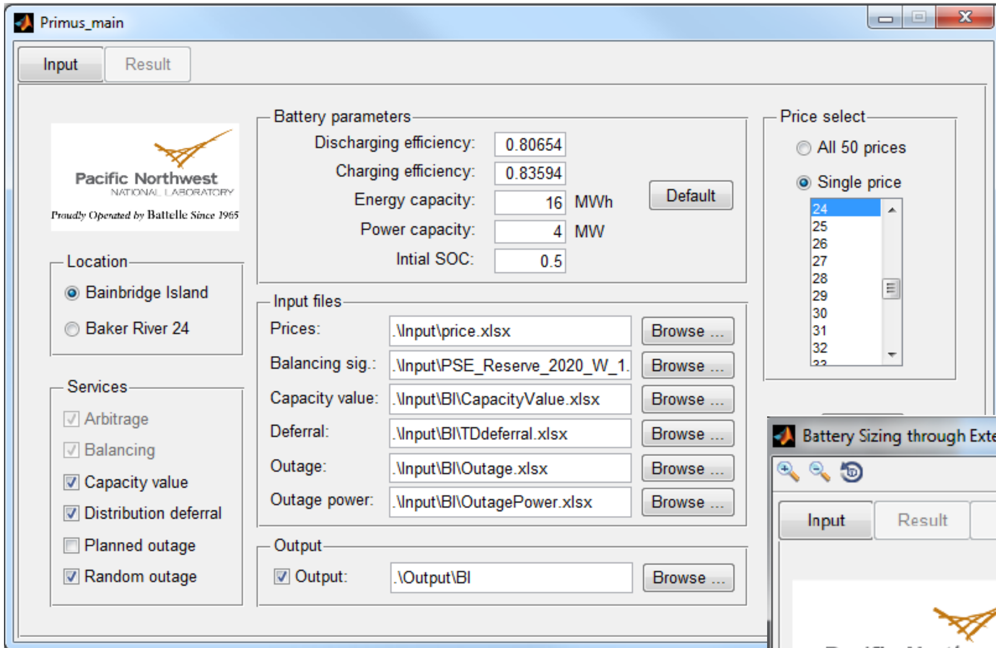

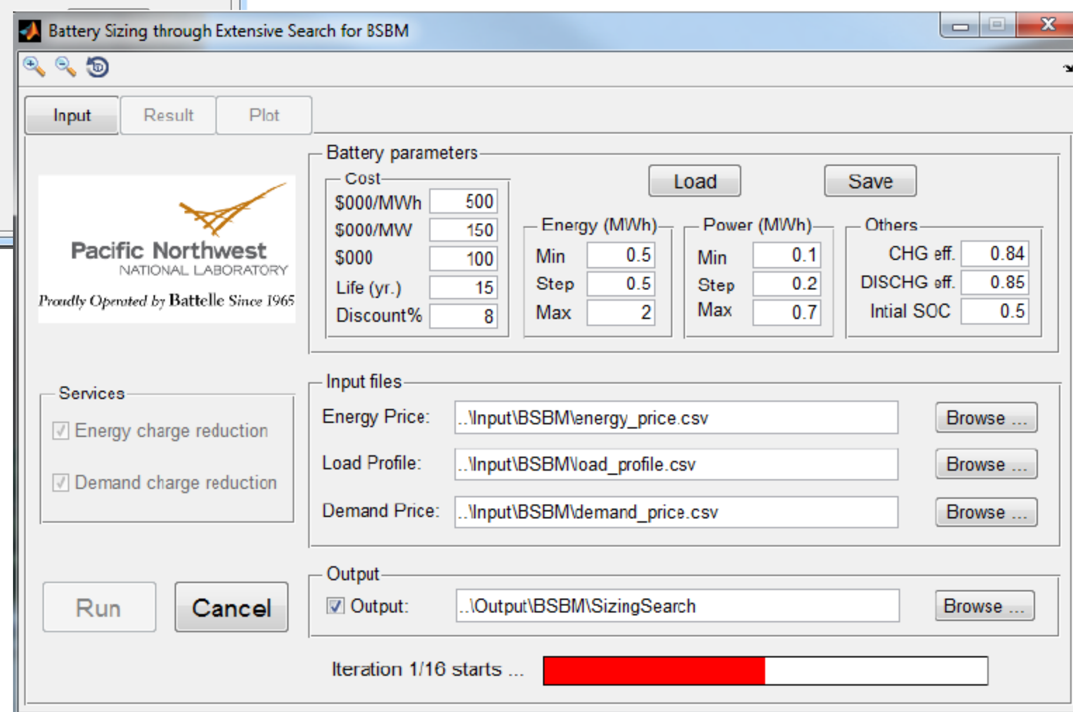

Energy Storage Bundled Services

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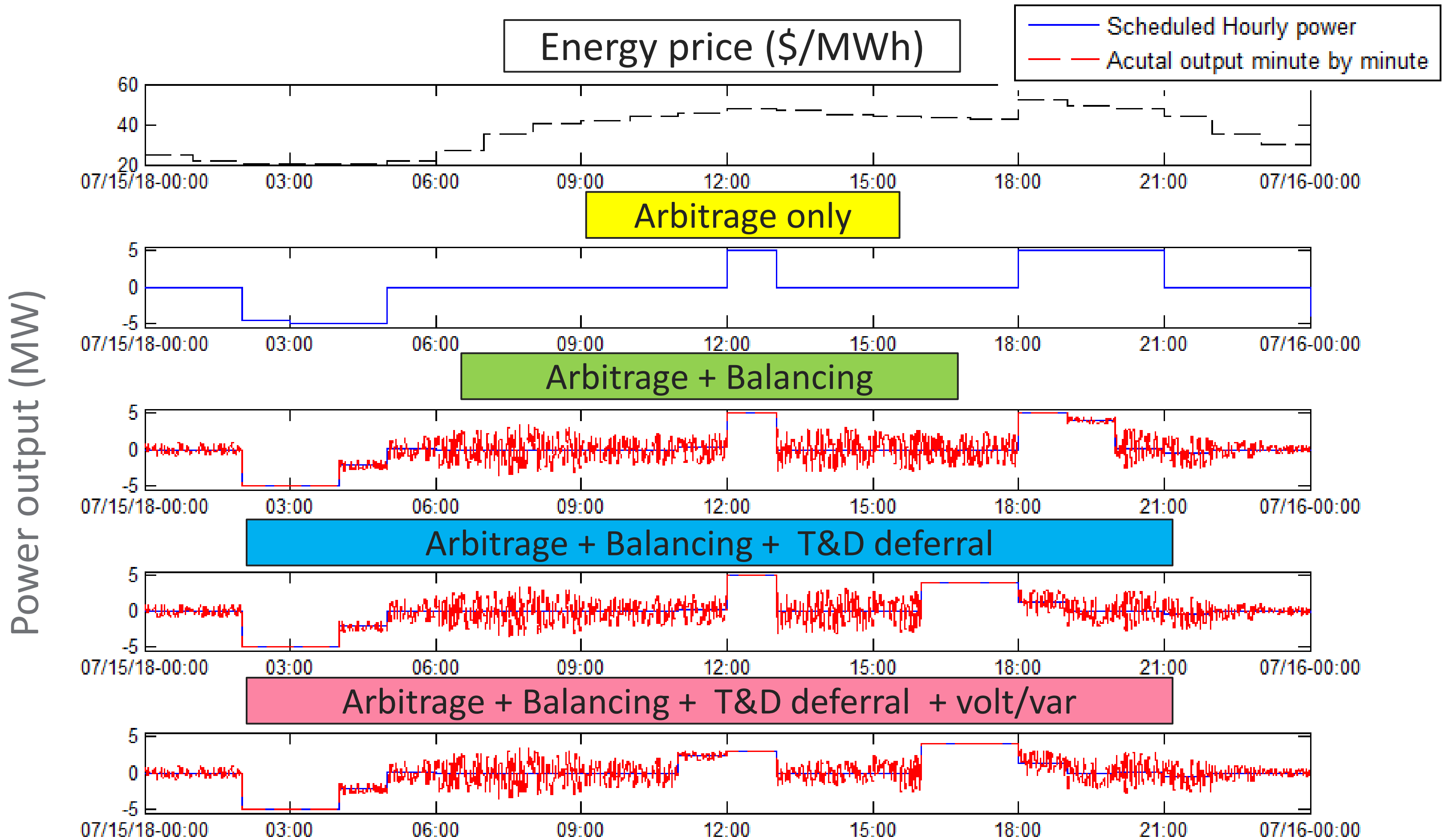

Eugene (OR) Water and Electric Board

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Microgrid Project

- 500kW energy storage + 125kW PV + diesel gen sets at three aggregated sites
- Benefits of energy storage:
  - Peak shifting
  - Transmission congestion relief
  - Minimizing balancing service payments to BPA
  - Energy arbitrage
  - Volt-VAR control
  - Outage mitigation
  - Capacity / resource adequacy
- EWEB working with Sandia National Laboratories and PNNL:
  - Define and monetize value of use cases
  - Evaluate design of planned microgrid
- Energy storage at the three sites can be aggregated to provide grid benefits

Partners

Sandia National Laboratories

Clean Energy States Alliance

EWEB

Northampton (MA) Microgrid Project

- Microgrid will bring multiple grid assets together in order to improve resiliency
  - Biomass
  - Photovoltaics
  - Diesel generators
  - Energy storage
- Microgrid would island three abutting campuses in the event of an outage
  - Northampton Dept. of Public Works
  - Smith Vocational and Agricultural High School
  - Cooley Dickinson Hospital
- Potential energy storage benefits:
  - Reduce energy and demand charges
  - Provide black start capability to the biomass facility, thereby allowing it to run during extended outages
  - Reduce diesel consumption during an outage and improve resiliency
  - Forward capacity market revenue
  - Regional network service revenue

Partners

Sandia National Laboratories
CleanEnergy States Alliance
Northampton

Salem (OR) Smart Power Center
GMLC Project

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- Salem Smart Power Center is comprised of a 5 MW – 1.25 MWh lithium-ion battery system built and managed by Portland General Electric (PGE)
- Recent demonstrations of value
  - Integration of renewables onto the grid (reduce intermittency of local 114-kW solar array)
  - Stabilization of grid frequency during recent power sag
  - Simulation of local microgrid, establishing a high-reliability zone
- Potential energy storage benefits:
  - Energy arbitrage
  - 400 kW of demand response capacity
  - 2-4 MW of real-time frequency and voltage regulation
  - kVAr support and control on the distribution feeder
  - Renewables integration
  - 5 MW of load response to under-voltage
  - Adaptive conservation voltage reduction
  - Emergency power for OR National Guard command
  - Intra-hour load balancing.

With DOE support, PNNL will model battery operations to determine the long-term financial benefits or value to PGE.

Partners

Clean Energy States Alliance
PGE
Sandia National Laboratories

Washington State Clean Energy Funds Energy Storage Projects

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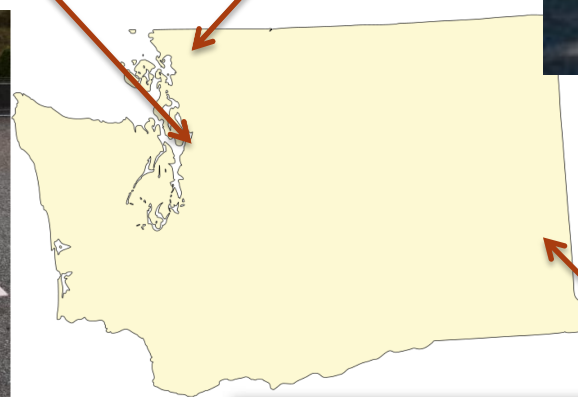
2 MW / 4.4 MWh li-ion/phosphate battery – Glacier, WA



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

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

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

DOE OE Funding PNNL to Analyze Broad Set of Use Cases

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Category	Services	Avista	PSE	SnoPUD
Bulk Energy Services	Electric Energy Time Shift (Arbitrage)	Y	Y	Y
	Electric Supply Capacity	Y	Y	Y
Transmission Infrastructure Services	Transmission Upgrade Deferral			
	Transmission Congestion Relief			
Distribution Infrastructure Services	Distribution Upgrade Deferral	Y	Y	
	Voltage Support	Y		Y
	Load Shaping Service	Y	Y	Y
Ancillary Services	Regulation Services	Y	Y	Y
	Load Following Services	Y	Y	Y
	Real-World Flexibility Operation	Y	Y	Y
	Black Start Capability	Y		
Customer Energy Management	Power Reliability	Y	Y	
	Demand Management			
	Retail Energy Time Shift			
	Power Quality			

Minimizing Bonneville Power Administration Energy Balancing Payments at SnoPUD

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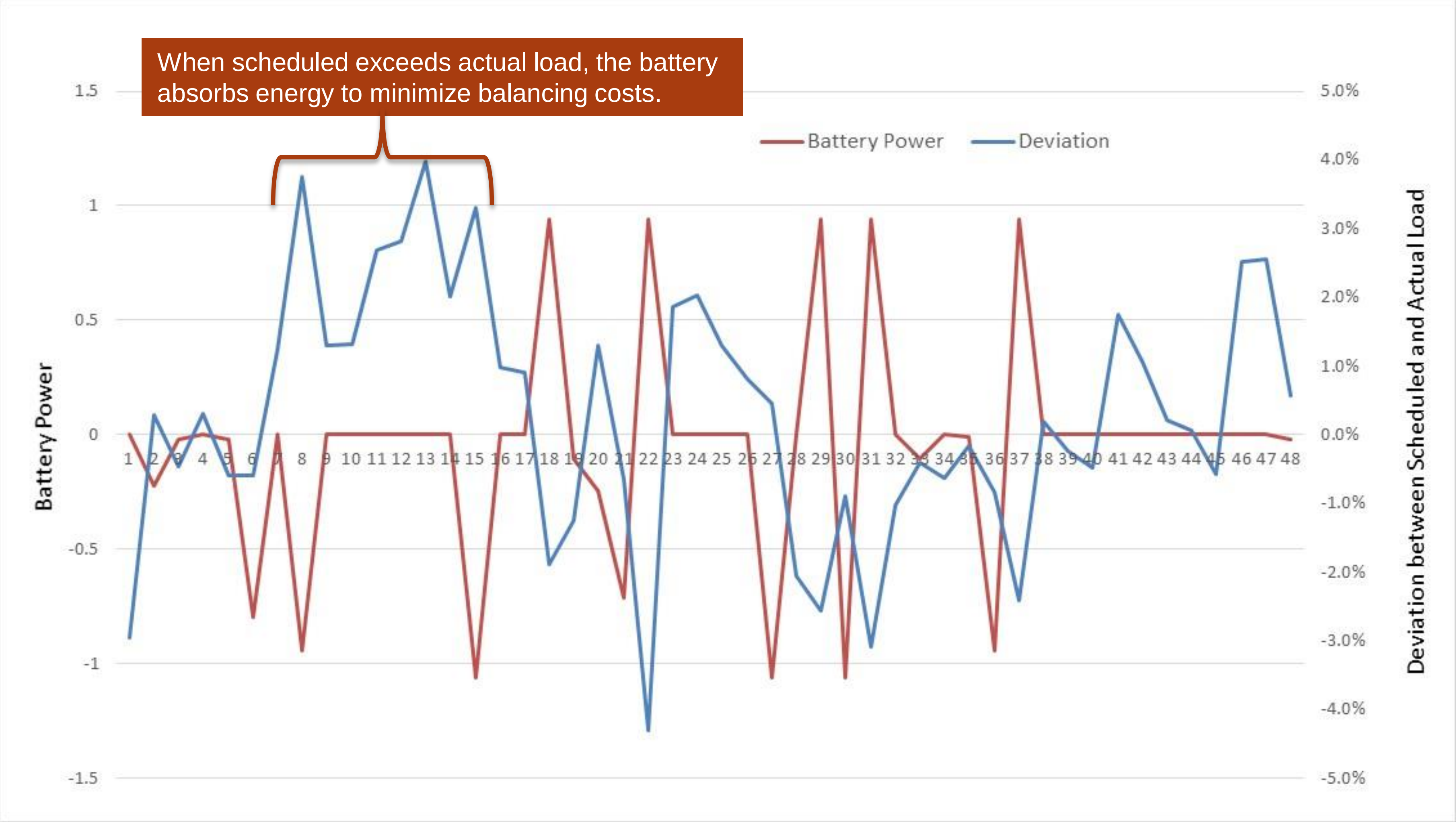
When scheduled exceeds actual load, the battery absorbs energy to minimize balancing costs.



DOE-OE Test Protocol Results for Vanadium Flow Battery (VFB) at Avista

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- Tested under capacity, frequency regulation, and peak shaving developed under DOE lead working groups[1]
- RTE (%) is AC-AC and includes DC battery, PCS, and auxiliary

Test	Test conditions	Discharge Energy kWh	RTE (%)	Normalized RMS
Baseline Capacity	Energy capacity at constant power of 520 kW / cumulative RTE 3 cycles	3200 kWh	71	
Frequency Regulation	Max power 800 kW		71	0.12
Peak Shaving	600 kW charge, 520, 740, 1000 kW discharge	3115, 2920, 1995	72, 65, 63	

- For peak shaving, RTE decreases for increasing power demand
- No degradation observed after baseline testing

(1) DR Conover et al, Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, PNNL-22010 Rev 2 / SAND2016-3078R

Arbitrage Use Case Testing (VFB at Avista)

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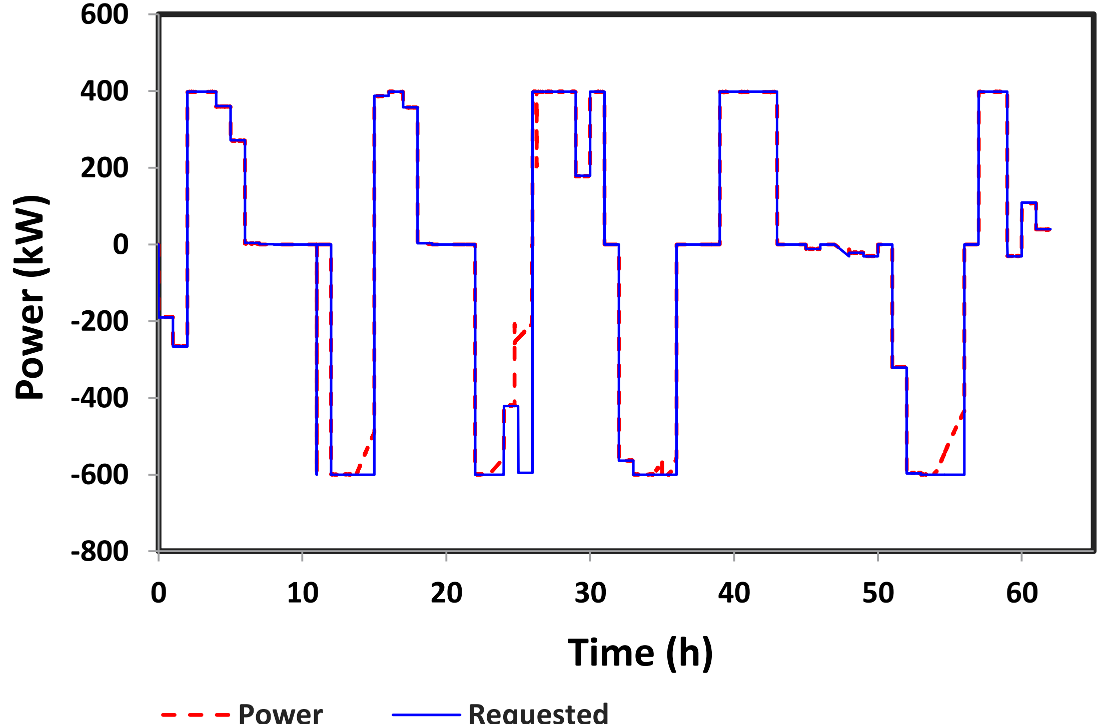
Date	RTE	RTE No Aux	Charge Power (kW)	Discharge Power (kw)	Strings Active
2016/01/20 02:00:00	74%	83%	600	520	2
2016/01/25 04:00:00	73%	82%	600	400	2
2016/01/26 04:00:00	74%	84%	600	400	2
2016/01/22 02:00:00	68%	78%	600	400	2
2016/01/19 18:00:00	67%	76%	600	520	2

- Discharging at 520 kw and 400 kW changes duration to 6 and 8 hour battery system.
- Modeled energy schedule based on historic data and applied to battery system.
- Variation in RTE may be due to:
  - Change in initial SOC
  - Change in temperature



Dispatch Controller Architecture

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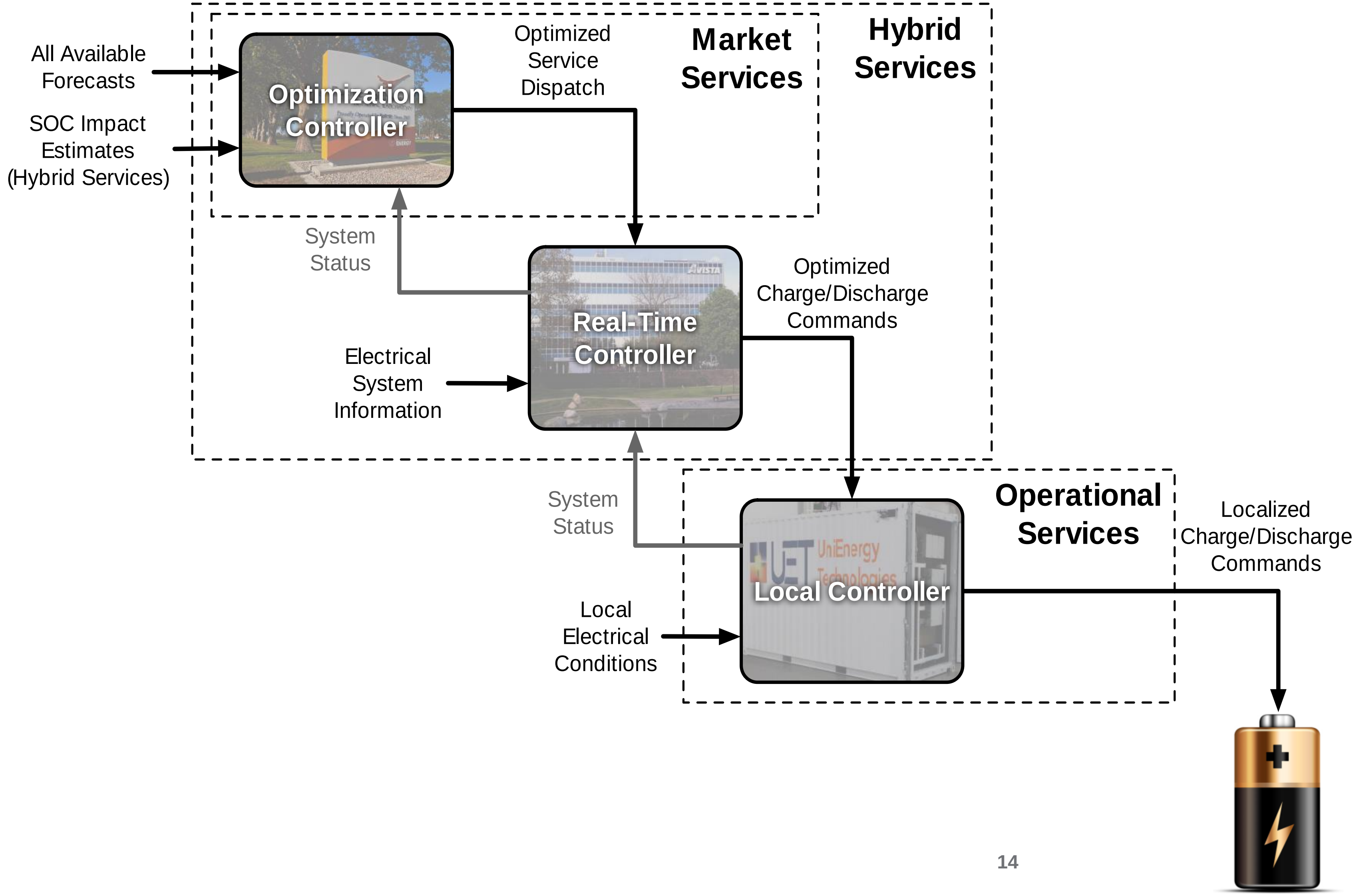

Conclusions

The potential market opportunity for energy storage is significant with two main challenges

- Reduce cost
- **Determine value for multiple grid applications across multiple utilities with varying grid challenges**

Take advantage of all Field Demonstrations by developing and sharing "use-case" analysis

- Ability to aid in the siting of energy storage systems by capturing/measuring **location-specific benefits**
- Differentiate benefits by region and **market structures/rules**
- Define benefits for **varying types of utility**
- Accurately characterize **battery performance**
- Develop **dispatch control architecture** to aid in improving economic operation of ESSs

Acknowledgments

Dr. Imre Gyuk - Energy Storage Program Manager, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy

Bob Kirchmeier - Senior Energy Policy Specialist, Clean Energy Fund Grid Modernization Program, Washington State Energy Office

More Information

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- PNNL:
  - National Assessment of Energy Storage:
    http://energyenvironment.pnnl.gov/pdf/National_Assessment_Storage_PHASE_II_vol_1_final.pdf
    http://energyenvironment.pnnl.gov/pdf/National_Assessment_Storage_PHASE_II_vol_2_final.pdf
  - Energy Storage Valuation for Distribution Systems
    http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23040.pdf
  - Codes and Standards for Performance Measurements
    http://energyenvironment.pnnl.gov/pdf/PNNL_22010_ESS_Protocol_Final.pdf
  - Optimization Tool
    http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23039.pdf
- DOE/EPRI Storage Handbook
  http://www.sandia.gov/ess/publications/SAND2013-5131.pdf