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

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ENERGY STORAGE PROGRAM
RPS expansion requires balancing resources.

Legacy hydro cannot meet all our growing regional needs for service.

**Energy Storage Critical for Flexible, Efficient Grid of the Future**

**Electric Power Grid**

- **RTO/ISOs** Coordinates, controls and monitors transmission grid and wholesale market.
- **State Regulators** Regulation of vertically integrated utilities.
- **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.
- **Electric Utilities** Monitor and operate distribution network.
- **Communities**
- **States/Territories**
- **Distributed Energy Resources**

**Centralized Electricity Producers**

**Electricity Consumers**

**Legacy hydro** cannot meet all our growing regional needs for service.
Energy Storage Demonstration Project Assessments as PNNL

PNNL Storage Analytics Program

- 26 MW
- 103 MWh at 14 Sites

PNNL Analytics Task-flow

- Preliminary Economic Analysis and Identification of Use Cases
- Baseline Testing to Evaluate Ratings etc.
- Use Case Testing and Analysis
- 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
Richland, WA: 1 MW / 4 MWh VFB
Salem, OR: 5 MW / 1.25 MWh Li-ion
California ISO Territory: 5 MW / 30 MWh PSH
Nantucket Island, MA: 6 MW / 48 MWh Li-ion
New York ISO Territory: >5 MW / 30 MWh PSH
Northampton, MA: 5 MW / 5 MWh Li-ion; 386 MW Photovoltaics
Hawaii: 5 MW / 30 MWh PSH
Defining and Monetizing the Value of Energy Storage and DERs More Broadly

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) LMPs 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, and
  - 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

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

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

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

• 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

<table>
<thead>
<tr>
<th>Duration</th>
<th>Residential</th>
<th>Small C + I</th>
<th>Large C + I</th>
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<tbody>
<tr>
<td>Momentary</td>
<td>$2</td>
<td>$210</td>
<td>$7,331</td>
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<tr>
<td>Less than 1 hr</td>
<td>$4</td>
<td>$738</td>
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<tr>
<td>2-4 hours</td>
<td>$7</td>
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<tr>
<td>8-12 hours</td>
<td>$12</td>
<td>$3,996</td>
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Transmission and Distribution Deferral

- Energy storage used to defer investment; impact of deferment measured in present value (PV) terms
- Net present value of deferring a $1 million investment for one year estimated at $90,000 or $10,400 annually over economic life of battery

\[ PV = \frac{FV}{1+i^n} \]

\( PV \) = Present value
\( FV \) = Future value
\( i \) = Cost of capital
\( n \) = Number of years

Assuming an 8% cost of capital (discount rate) and 3% cost inflation, distribution deferral of six years for a $10 million substation would be valued at $2.5 million – PV = $10 million*1.03^6 / (1+.08)^6 = $7.5 million.
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
(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
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.

- By upsizing the energy storage capacity to 10 MWh, the return on investment ratio yields a positive result at 1.24.
Optimal Microgrid Scale Required to Achieve Energy Security and Operational Goals:
Gen Set – 1,150 kW
PV – 1,224 kW
Energy storage – 408 kW / 510 kWh
Importance of Operational Knowledge in Defining Value for Energy Storage and Capturing it in Real Time

• Results
  • Flow battery power and energy capacity ratings can be confusing; 1 MW / 3.2 MWh battery provides ~ 2 MWh of energy when discharged at 1 MW
  • Battery performance, measured in round-trip efficiency (RTE) varies based on power output level, state of charge (SOC) operating range, and temperature
  • Li-ion batteries provide RTEs in the 70-87% (83-91% w/o aux) for C/6 to C/2 cycling range; flow battery RTEs in the 58-65% range (66-75%) for C/9 to C/3 cycling

• Non-linear Performance Modeling
  • Model allows estimation of SOC during operation taking into account operating mode, power, SOC, and temperature
  • Model has been validated with data
  • Actual battery performance can be anticipated, thus providing a high degree of flexibility to the BESS owner/operator
  • Self-learning model applicable to energy type of storage system

• PNNL Building a Battery State of Health Model using CEF Data
Energy Storage Control Algorithms

- Development of control strategies
  - Outline control strategies
  - Develop detailed design of control functions and reporting
  - Simulation/implementation of control functions.

- Optimization Performance Enhancement Tool (OPET): Tool for evaluating commercial energy storage controllers operating at utility sites. OPET goals:
  - Enhance learning of the inputs for consideration in developing storage control strategies that could achieve targeted economic values in real-world situations
  - Enhance performance by finding logic errors in control strategies
  - Evaluate impacts of forecast error on control strategies.

Key Lesson: Development of control strategies is required to obtain value in real-time. We should not compete in developing real-time control systems; rather, we should propel the industry forward through development of advanced algorithms and OPET.
What We Have Learned – Numerous Factors Determine an Energy Storage System’s Value Proposition

**Siting/Sizing 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 different types of utilities (e.g., PUDs, co-ops, 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 rates across varying states of charge and battery degradation caused by cycling.
Acknowledgments

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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
Q/A and Further Information

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