Energy Storage Technology Advancement Partnership (ESTAP) Webinar:

Optimizing Energy Storage Sizing, Location and Operation: Current R&D Efforts at Sandia National Laboratories

February 25, 2016

Hosted by Todd Olinsky-Paul
ESTAP Project Director
Clean Energy States Alliance
Housekeeping

All participants are in “Listen-Only” mode. Select “Use Mic & Speakers” to avoid toll charges and use your computer’s VOIP capabilities. Or select “Use Telephone” and enter your PIN onto your phone key pad.

Submit your questions at any time by typing in the Question Box and hitting Send.

This webinar is being recorded.

You will find a recording of this webinar, as well as all previous CESA webcasts, archived on the CESA website at www.cesa.org/webinars
State & Federal Energy Storage Technology Advancement Partnership (ESTAP)

Todd Olinsky-Paul
Project Director
Clean Energy States Alliance (CESA)
Thank You:

Dr. Imre Gyuk
U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability

Dan Borneo
Sandia National Laboratories
ESTAP is a project of CESA

Clean Energy States Alliance (CESA) is a non-profit organization providing a forum for states to work together to implement effective clean energy policies & programs:

State & Federal Energy Storage Technology Advancement Partnership (ESTAP) is conducted under contract with Sandia National Laboratories, with funding from US DOE.

ESTAP Key Activities:

1. Disseminate information to stakeholders
   - ESTAP listserv >3,000 members
   - Webinars, conferences, information updates, surveys.

2. Facilitate public/private partnerships to support joint federal/state energy storage demonstration project deployment

3. Support state energy storage efforts with technical, policy and program assistance

ESTAP Project Locations

- Oregon: Energy Storage RFP
- New Mexico: Energy Storage Task Force
- Kodiak Island Wind/Hydro/Battery & Cordova Hydro/flywheel projects
- New York: $40 Million Resilient Power/Microgrids Solicitation; $10 Million energy storage demonstration program
- Connecticut: $45 Million, 3-year Microgrids Initiative
- Pennsylvania Battery Demonstration Project
- Massachusetts: $40 Million Resilient Power/Microgrids Solicitation; $10 Million energy storage demonstration program
- New Jersey: $10 million, 4-year energy storage solicitation
- Northeastern States Post-Sandy Critical Infrastructure Resiliency Project
- Vermont: 4 MW energy storage microgrid & Airport Microgrid
- Maryland Game Changer Awards: Solar/EV/Battery & Resiliency Through Microgrids Task Force
- Oregon: Energy Storage RFP
- New Mexico: Energy Storage Task Force
- Kodiak Island Wind/Hydro/Battery & Cordova Hydro/flywheel projects
- New York: $40 Million Resilient Power/Microgrids Solicitation; $10 Million energy storage demonstration program
- Connecticut: $45 Million, 3-year Microgrids Initiative
- Pennsylvania Battery Demonstration Project
- Massachusetts: $40 Million Resilient Power/Microgrids Solicitation; $10 Million energy storage demonstration program
- New Jersey: $10 million, 4-year energy storage solicitation
- Northeastern States Post-Sandy Critical Infrastructure Resiliency Project
- Vermont: 4 MW energy storage microgrid & Airport Microgrid
- Maryland Game Changer Awards: Solar/EV/Battery & Resiliency Through Microgrids Task Force

Hawaii: 6MW storage on Molokai Island and 2MW storage in Honolulu
ESTAP

Project Director: Todd Olinsky-Paul
Contact: Todd Olinsky-Paul, Todd@cleangroup.org

The Energy Storage Technology Advancement Partnership (ESTAP) is a federal-state funding and information sharing project, managed by CESA, that aims to accelerate the deployment of electrical energy storage technologies in the U.S.

The project’s objective is to accelerate the pace of deployment of energy storage technologies in the United States through the creation of technical assistance and co-funding partnerships between states and the U.S. Department of Energy.

ESTAP conducts two key activities:

1) Disseminate information to stakeholders through:
   - The ESTAP listserv (>2,000 members)
   - Webinars, conferences, information updates
Today’s Guest Speakers

• **Dr. Cesar Silva-Monroy**, Senior Member of Technical Staff, Electric Power Systems Research Group, Sandia National Laboratories

• **Dr. Raymond Byrne**, Distinguished Member of Technical Staff, Energy Storage and Transmission Analysis Department, Sandia National Laboratories

• **Daniel Kirschen**, Close Professor of Electrical Engineering, University of Washington Graduate Research Assistant, University of Washington

• **Yury Dvorkin**, Graduate Research Assistant, University of Washington

• **Dan Borneo**, Senior Electrical Engineer, Sandia National Laboratories
Acknowledgment: this research was funded by Dr. Imre Gyuk from the DOE Energy Storage Program.

Cesar A. Silva-Monroy, Ph.D.
casilv@sandia.gov
Feb. 26, 2015
Optimize What?

- Find the size (MW/MWh) and location (electrical bus) at which the **value** of energy storage is maximized.

- "**Value** is in the eye of the beholder"

- Regulated markets – utilities seek to minimize their costs
- Deregulated markets – system operators seek to maximize social welfare and support/improve reliability
- Merchant energy storage plants – owners seek to maximize their profits
Optimization Approaches

- Simulation-based approaches
  - Heuristic rule for operation of energy storage or optimize daily operations
  - Use historical load/price data (to create projections)
  - Perform rolling horizon simulations (e.g., production cost model)

- Mathematical programming
  - Formulate optimal size/location as a mathematical program
  - Use historical load/price data (to create projections) as inputs
  - Solve using power computer/algorithms – wait for a few days
  - Information about the quality of the solution is available

- Hybrid
  - Formulate optimal location for single day horizon, solve for multiple days
  - Use historical load/price data (to create projections) as inputs
  - Use results as input to optimal sizing problem, solve for multiple days
  - Use results as input to optimal operation problem, solve for multiple days

- They all follow the universal principle: “Garbage in, garbage out”
Stochastic Production Cost Modeling

- We have developed a stochastic production cost model (PRESCIENT) and added energy storage models.
- Stochastic Unit Commitment - schedule generation resources (ON/OFF) such that *expected* generation costs are minimized *under several load and renewable generation scenarios*
Future Work

- Comparing benefits of stochastic unit commitment with deterministic + storage
- Modifying the code to directly calculate optimal size/location of energy storage for a given budget.
- PRESCIENT code to be released as open source (working through copyright now)

- We are always happy to discuss potential uses of our computational tools with utilities, ISOs, industry, and other researchers!
Optimal Operation of Energy Storage

Acknowledgment: this research was funded by Dr. Imre Gyuk from the DOE Energy Storage Program.

Ray Byrne, Ph.D.
Cesar A. Silva-Monroy, Ph.D.
Ricky Concepcion
Optimal Operation of Energy Storage

- Two prevalent “goals” with energy storage
  - Maximize revenue or return-on-investment
  - Maximize benefit to the grid
  - Often, these do not align ....
    but that is a policy issue

- Two different use cases or applications
  - Vertically integrated utility
  - Market area

- This portion of the webinar will focus on:
  - Maximizing revenue in a market area
Maximizing Revenue - Market Area

- Linear Program Optimization
  - MATLAB
  - Python/Cooper

- Typically look at the following revenue streams
  - Arbitrage
  - Arbitrage + Regulation
  - Allocate charge to avoid double counting

- Typically look at maximizing revenue

- Can incorporate cost data (if available)
  - Penalty for charge/discharge
  - Variable O&M costs

- Optimization assumes perfect knowledge – best you can do
  - Serves as a benchmark for other trading algorithms
ERCOT Results

- Looked at every load zone
  - Arbitrage
  - Arbitrage + frequency regulation
  - 2011, 2012, 2013 data

### ENERGY STORAGE SYSTEM PARAMETERS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q^D$</td>
<td>8 MWh</td>
</tr>
<tr>
<td>$q^R$</td>
<td>8 MWh</td>
</tr>
<tr>
<td>$S^*$</td>
<td>32 MWh</td>
</tr>
<tr>
<td>$\gamma_S$</td>
<td>1.0</td>
</tr>
<tr>
<td>$\gamma_C$</td>
<td>0.8</td>
</tr>
<tr>
<td>$\gamma_{ru}$</td>
<td>0.5</td>
</tr>
<tr>
<td>$\gamma_{rd}$</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- Regulation -> more $$$
- Not location dependent (1 market)

---

PJM Results

- Looked at 1-year of PJM data (June 2014-May 2015)
- Plant modeled on Beacon Flywheel
- Incorporated pay for performance in model
  - Regulation data on PJM website -> calculate $\gamma_t^{RD}, \gamma_t^{RU}$

<table>
<thead>
<tr>
<th>Month</th>
<th>RMCCCP Credit</th>
<th>RMPCP Credit</th>
<th>Arbitrage Credit</th>
<th>Total Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/14</td>
<td>$356,412.73</td>
<td>$130,286.06</td>
<td>$487.16</td>
<td>$487,185.94</td>
</tr>
<tr>
<td>07/14</td>
<td>$351,131.53</td>
<td>$135,123.18</td>
<td>-$1,759.82</td>
<td>$484,494.90</td>
</tr>
<tr>
<td>08/14</td>
<td>$231,708.06</td>
<td>$124,760.87</td>
<td>-$2,057.32</td>
<td>$354,411.61</td>
</tr>
<tr>
<td>09/14</td>
<td>$280,496.49</td>
<td>$121,979.31</td>
<td>-$1,398.84</td>
<td>$401,076.97</td>
</tr>
<tr>
<td>10/14</td>
<td>$389,520.38</td>
<td>$148,445.40</td>
<td>-$2,671.94</td>
<td>$535,293.84</td>
</tr>
<tr>
<td>11/14</td>
<td>$315,773.83</td>
<td>$117,698.79</td>
<td>-$2,366.21</td>
<td>$431,106.41</td>
</tr>
<tr>
<td>12/14</td>
<td>$250,525.71</td>
<td>$92,077.48</td>
<td>-$1,321.73</td>
<td>$341,281.46</td>
</tr>
<tr>
<td>01/15</td>
<td>$355,093.93</td>
<td>$102,707.75</td>
<td>$5,634.43</td>
<td>$443,436.10</td>
</tr>
<tr>
<td>02/15</td>
<td>$837,537.28</td>
<td>$141,229.67</td>
<td>$19,625.70</td>
<td>$998,392.65</td>
</tr>
<tr>
<td>03/15</td>
<td>$561,451.79</td>
<td>$160,354.43</td>
<td>$1,886.07</td>
<td>$723,692.29</td>
</tr>
<tr>
<td>04/15</td>
<td>$373,388.33</td>
<td>$155,942.07</td>
<td>-$1,894.29</td>
<td>$527,436.11</td>
</tr>
<tr>
<td>05/15</td>
<td>$337,115.47</td>
<td>$129,786.70</td>
<td>-$611.47</td>
<td>$666,290.70</td>
</tr>
<tr>
<td>Total</td>
<td>$4,820,155.53</td>
<td>$1,560,391.71</td>
<td>$13,551.74</td>
<td>$6,394,098.97</td>
</tr>
</tbody>
</table>

ISO-NE

- We’ve been looking at several projects in ISO-NE
- Potential revenue streams
  - Arbitrage
  - Reduction in monthly network load (Regional Network Services – RNS)
  - Reduction in capacity payments to ISO-NE (annual peak)

- Additional capacity hours don’t increase max revenue -> increases your odds of hitting peak hours
Future Work

- Look at pay-for-performance models in other ISOs
- Incorporating cost of degradation based on charge/discharge profile
- Development of algorithms that do not rely on perfect knowledge
- Add additional revenue streams to the optimization
- Pyomo code published on SNL web site (working through copyright now)
Backup Slides
Maximizing Revenue - Market Area

- Assume price insensitive to supply (if not \( \rightarrow \) production cost modeling)
- Typically use 1 hour data
- Energy storage model – arbitrage

\[
S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D \quad \forall t \in T
\]

**Decision Variables**
- \( q_t^D \): quantity of energy sold (Discharged) at time \( t \) (MWh)
- \( q_t^R \): quantity of energy purchased (Recharged) at time \( t \) (MWh)

- Constraints on:
  - Total capacity
  - Maximum hourly charge/discharge quantity

\[
0 \leq S_t \leq \bar{S}, \quad \forall t \in T
\]
\[
0 \leq q_t^R \leq \bar{q}^R, \quad \forall t \in T
\]
\[
0 \leq q_t^D \leq \bar{q}^D, \quad \forall t \in T
\]

\[
\max \sum_{t=1}^{T} \left[ (P_t - C_d)q_t^D - (P_t + C_r)q_t^R \right] e^{-rt}
\]
Maximizing Revenue - Market Area

- Assume price insensitive to supply (if not \(\rightarrow\) production cost modeling)
- Typically use 1 hour data
- Energy storage model – arbitrage + regulation

\[
S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_r d q_t^{RD} - \gamma_r u q_t^{RU}
\]

**Decision Variables**

- \(q_t^D\): quantity of energy sold (Discharged) at time \(t\) (MWh)
- \(q_t^R\): quantity of energy purchased (Recharged) at time \(t\) (MWh)
- \(q_t^{RU}\): quantity of energy offered into the regulation up market at time \(t\) (MWh)
- \(q_t^{RD}\): quantity of energy offered into the regulation up market at time \(t\) (MWh)

\[
\max_{t=1}^{T} \sum [(P_t - C_d)q_t^D + (P_t^{RU} + \gamma_r u (P_t - C_d))q_t^{RU} + (P_t^{RD} - \gamma_r d (P_t + C_r))q_t^{RD} - (P_t + C_r)q_t^R]e^{-rt}
\]

- \(0 \leq S_t \leq \bar{S}, \forall t \in T\)
- \(0 \leq q_t^R + q_t^{RD} \leq \bar{q}^R, \forall t \in T\)
- \(0 \leq q_t^D + q_t^{RU} \leq \bar{q}^D, \forall t \in T\)
Maximizing Revenue - Market Area

- Modeling regulation – need to assume fraction that is assigned

\[ S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_{rd} q_t^{RD} - \gamma_{ru} q_t^{RU} \]

Account for fraction called
Optimizing Energy Storage Sizing, Location and Operation

Prof. Daniel Kirschen
Yury Dvorkin
Energy Storage for Electrical Grids

Services

Energy Arbitrage
Congestion Relief
Ancillary Services
Contingency Mitigation
Energy Storage for Electrical Grids

- Services:
  - Energy Arbitrage
  - Congestion Relief
  - Ancillary Services
  - Contingency Mitigation

- Perspective:
  - System Operator (SO)
  - Energy Storage Owner (ESO)
Energy Storage for Electrical Grids

<table>
<thead>
<tr>
<th>Services</th>
<th>Energy Arbitrage</th>
<th>Congestion Relief</th>
<th>Ancillary Services</th>
<th>Contingency Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perspective</td>
<td>System Operator (SO)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Objective</td>
<td>Support Reliability</td>
<td>Maximize Welfare</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy Storage Owner (ESO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximize Profit</td>
</tr>
<tr>
<td>Recover Investments</td>
</tr>
</tbody>
</table>
Energy Storage for Electrical Grids

Services
- Energy Arbitrage
- Congestion Relief
- Ancillary Services
- Contingency Mitigation

Perspective
- System Operator (SO)

Objective
- Support Reliability
- Maximize Welfare
- Maximize Profit
- Recover Investments
- Expansion planning
- Undefined revenue streams

Barriers
- Undefined value
Case I: Centralized (SO) Perspective

- **Site** and **size** energy storage (ES) to reduce the operating cost
- **Minimize:**
  - Operating cost
  - + Investment cost in energy storage
- **Subject to constraints:**
  - System operation: generation and transmission
  - Operation of energy storage
  - Investment in energy storage
- Consider stochastic nature of renewable generation
- Tested on a model of the WECC system
Case I: Key Results

- Installing ES at more buses affects power and energy ratings
- The total power rating gradually saturates
Case I: Key Results

- The investment cost is the primary driver of sizing decisions
  - As the capital cost increases, the total rating of ES installed reduces
Case II: Mixed TSO+DSO Perspective

- Distribution System Operator (DSO)
  - Owns and operates batteries
  - Willing to “share” with the TSO
- Transmission System Operator (TSO)
  - Interested in using batteries for congestion relief
- How to structure the TSO-DSO coordination?

Diagram:

- BPA
  - Transmission level
  - Preferred Actions
  - Availabilities
  - Net load injections
- SnoPUD
  - Distribution level
Case III: Mixed SO+ESO Perspective

• How to site and size merchant-owned energy storage?
  – Energy Storage Owner (ESO) must make a profit on its investment
  – Balance SO’s cost savings and ESO’s profits

• Minimize
  Operating cost
  + Cost of investment in energy storage

• Subject to constraints:
  – System operation: generation and transmission
  – Operation of energy storage
  – Investment in energy storage
  – Minimum profit constraint
    • Lifetime Profit ≥ χ ⋅ Investment Cost
    • χ is the rate of return
Case III: Key results

Lifetime Profit $\geq \chi \cdot \text{Investment Cost}$

- Profit constraints drives both the siting and sizing decisions
  - Reduction in the cumulative rating
  - More diversity in locations
  - Results are strongly affected by the capital cost (Low, Medium, High)

Case IV: Merchant ESO Perspective

• How to site and size merchant-owned energy storage?
  – Energy storage owner aims to maximize its profit
  – System operator must minimize the overall cost

• Bi-level problem:
  – ESO maximizes (Lifetime net revenue of ES – Cost of investment in storage)
  – SO minimizes (Operating cost + Cost of investment in transmission expansion)

• Constraints
  – Minimum profit constraint, i.e. Lifetime Profit ≥ 𝜒 · Investment Cost
  – System operation: generation and transmission
  – Operation of energy storage
  – Investment in energy storage

• Siting and sizing decisions for a profit-seeking ESO
  – Robust to transmission expansion decisions
Summary

Case I: SO Perspective

Case II: SO Mixed (TSO+DSO) Perspective

Case III: Mixed (SO+ESO) Perspective

Case IV: ESO Perspective & Transmission Expansion

ESO Perspective

Economic Sustainability

Applicability to a market environment (CAISO)

Modeling complexity
Conclusion

- Compare siting of 10 batteries for cases I, III, and IV:

- Only 3 locations are the same for all three cases
- Cases III and IV have 7 out of 10 common locations
- It is thus essential to take the right perspective when exploring potential locations
Contact Info

CESA Project Director: Todd Olinsky-Paul
(Todd@cleanegroup.org)

Sandia Project Director: Dan Borneo
(drborne@sandia.gov)

Webinar Archive: www.cesa.org/webinars
ESTAP Website: http://bit.ly/CESA-ESTAP
Upcoming Webinars

• Resilient San Francisco: How to Develop a Citywide Solar+Storage Disaster Plan, March 7

More information at www.cesa.org/webinars