Economics of Energy Storage

Travis Simpkins, PhD

June 8, 2016
Goals for this Talk

• **We’ll talk about:**
  - How battery systems are specified
  - How batteries make / save money
  - Where batteries are likely to be most cost effective
PV vs. Batteries

• **PV is simple**
  - Put it on the roof
  - The sun shines
  - Electricity is produced
  - Your utility bill is lowered

• **Batteries are complicated**
  - Put one in the basement or in a shed
  - Nothing happens
Energy Storage Economics in a Nutshell

Energy storage: A bucket that moves energy from one time period to another

- **Need to decide:**
  - When to fill the bucket
  - When to empty the bucket
  - How big of a bucket to buy

- **Factors to consider:**
  - How fast can the bucket be filled or emptied?
  - How much does the bucket cost?
  - How long will the bucket last?
  - Will using the bucket in a certain way cause it to fail faster?

The value of the energy must be worth more at the time you empty the bucket than it was at the time you filled the bucket.
Power vs. Energy Capacity

- **Power**
  - How fast you can charge or discharge the battery
  - Measured in kW or MW

- **Energy Capacity**
  - How much energy you have available
  - Measured in kWh or MWh

- **Power : Energy ratio is primary specification for battery**
  - Can generally specify the power : energy ratio

- **Common configurations**
  - 1 MW : 3 MWh (C/3)
  - 4 MW : 2 MWh (2C)

- **Which of these buckets is more useful?**
Energy Storage Value Streams

• **Behind-the-Meter (client side)**
  - Demand management – “peak shaving”
    - Reducing peak demand charges on utility bill, client driven
  - Energy arbitrage
    - Shifting energy from off-peak hours to peak hours
  - Demand response
    - Utility program that pays you to lower demand
  - Resiliency
    - Using battery to sustain load during grid outages

• **Front-of-the-Meter (grid side)**
  - Ancillary services
    - Providing grid support
  - Transmission / Distribution upgrade deferral
    - Use storage to meet power quality during peak days, thus not having to upgrade infrastructure
  - Capacity markets
    - Bid batteries into reserve markets
Application Stacking Challenge

• **Batteries can usually only do one thing at a time**
  o But each use may only require a few hours per year

• **To maximize Return on Investment (ROI), must determine:**
  o What application battery should serve
  o When it should serve it

• **Requires an optimization model**
REopt: Platform for Energy Integration and Optimization

• Techno-economic decision support model
• Integration & Optimization
  o Considers interactions between multiple technologies
• Solves energy balance at every time-step
  o Does not consider powerflow
• Mixed-integer linear program
  o Objective function: minimize life cycle cost of energy
  o Subject to constraints: resource, operating, load, policy, etc
• Assumes perfect prediction
• Used to analyze 8000+ sites
• NREL-internal tool for now
Case Study: Peak Shaving in CA
Example: Behind the Meter in CA

- Midsize office building in LA
- Considering installation of a battery
- Value streams considered
  - Peak demand charge reduction
  - Energy arbitrage
Batteries Like Complicated Tariffs

- Southern California Edison Time of Use GS 3

<table>
<thead>
<tr>
<th>Energy Charge</th>
<th>Times (weekdays only)</th>
<th>Delivery</th>
<th>Generation</th>
<th>Total Usage</th>
<th>Arbitrage (to high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer - On-Peak</td>
<td>12 pm - 6 pm</td>
<td>$0.02664</td>
<td>$0.11955</td>
<td>$0.14619</td>
<td>-</td>
</tr>
<tr>
<td>Summer - Mid-Peak</td>
<td>8 am - 12 pm &amp; 6 pm - 11 pm</td>
<td>$0.02664</td>
<td>$0.06455</td>
<td>$0.09119</td>
<td>$0.05500</td>
</tr>
<tr>
<td>Summer - Off-Peak</td>
<td>11 pm - 8 am (&amp; all weekend)</td>
<td>$0.02664</td>
<td>$0.03837</td>
<td>$0.06501</td>
<td>$0.08118</td>
</tr>
<tr>
<td>Winter - Mid-Peak</td>
<td>8 am - 9 pm</td>
<td>$0.02664</td>
<td>$0.06636</td>
<td>$0.09300</td>
<td>-</td>
</tr>
<tr>
<td>Winter - Off-Peak</td>
<td>9 pm - 8 am (&amp; all weekend)</td>
<td>$0.02664</td>
<td>$0.04376</td>
<td>$0.07040</td>
<td>$0.02260</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand Charges</th>
<th>Facility</th>
<th>Time Related</th>
<th>Total Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer - On-Peak</td>
<td>12 pm - 6 pm</td>
<td>$15.77</td>
<td>$20.36</td>
</tr>
<tr>
<td>Summer - Mid-Peak</td>
<td>8 am - 12 pm &amp; 6 pm - 11 pm</td>
<td>$15.77</td>
<td>$5.97</td>
</tr>
<tr>
<td>Winter</td>
<td>any time</td>
<td>$15.77</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

Customer Charge: $432.01

Summer rates from June 1 - Sept 30 (4 months)
Winter rates from Oct 1 - May 31 (8 months)
Dispatch Strategy, 1 Week In July
## Results

<table>
<thead>
<tr>
<th></th>
<th>No Batt</th>
<th>With Batt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year Total [$]</td>
<td>257,710</td>
<td>221,608</td>
</tr>
<tr>
<td>Energy [$]</td>
<td>149,443</td>
<td>148,253</td>
</tr>
<tr>
<td>Demand [$]</td>
<td>103,067</td>
<td>68,159</td>
</tr>
<tr>
<td>Fixed [$]</td>
<td>5,184</td>
<td>5,184</td>
</tr>
<tr>
<td>Savings</td>
<td>36,102</td>
<td>14.0%</td>
</tr>
</tbody>
</table>
Economic Drivers of Batteries in Commercial Buildings

- Created large sample population of buildings
  - 16 building types
  - 15 climate zones
  - Randomized economic parameters (discount rate, escalation rate, battery cost)
- Used REopt to determine optimal battery size and NPV
- Found batteries most economical when
  - Peak demand charges are high
  - Battery prices are low
- Precursor to a larger ongoing Sunlamp project

“With the right market structures and incentives, solar+storage systems can provide an economic return while making affordable housing energy resilient by powering critical loads like common area lighting, water, and communications—protecting vulnerable residents at little to no net cost: resilience for free.”

Seth Mullendore, Robert G. Sanders, Lewis Milford, with Henry Misas and Adje Mensah. “Resilience for Free: How Solar+Storage Could Protect Multifamily Affordable Housing from Power Outages at Little or No Net Cost” October 2015
Solar + Storage Resiliency is Probabilistic

• The duration of an outage for which a solar + storage system can sustain the critical load is a function of
  o Solar resource
  o State of charge of battery
  o Critical load

when the outage begins.

An outage on April 8th at 2 pm is different than an outage on July 15th at 8pm.

• Resiliency is always probabilistic
  o Generators fail to start, fuel runs out, etc.
Behind The Meter Energy Storage In NYC
Improving Resiliency With S+S in NYC

- Firehouse in New York City
- Considering installation of a battery
- Value streams considered
  - Peak demand charge reduction
  - Energy arbitrage
  - Resiliency during grid outages

In collaboration with CUNY. Report to be published soon.
## FDNY Results Summary

<table>
<thead>
<tr>
<th>Scenario Number</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario Description</strong></td>
<td>Base case</td>
<td>PV and Battery</td>
</tr>
<tr>
<td><strong>PV Size</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Battery Size</strong></td>
<td>26 kWh/ 9 kW</td>
<td></td>
</tr>
<tr>
<td><strong>Diesel Generator Size</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>PV Cost</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>PV Cost Less NY-Sun Incentive</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Battery Cost</strong></td>
<td>$22,520</td>
<td></td>
</tr>
<tr>
<td><strong>Generator Cost</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Total Capital Cost</strong></td>
<td>$22,520</td>
<td></td>
</tr>
<tr>
<td><strong>Year 1 Electric Savings</strong></td>
<td>-$11</td>
<td></td>
</tr>
<tr>
<td><strong>Year 1 Demand Savings</strong></td>
<td>$2,310</td>
<td></td>
</tr>
<tr>
<td><strong>Life Cycle Cost</strong></td>
<td>$371,141</td>
<td>$348,594</td>
</tr>
<tr>
<td><strong>Net Present Value</strong></td>
<td>$22,547</td>
<td></td>
</tr>
<tr>
<td><strong>Simple Payback Period</strong></td>
<td>10.8 years</td>
<td></td>
</tr>
</tbody>
</table>

The battery is strategically charged and discharged to reduce peak demand.

The cost optimal solar + storage system can sustain the critical load for 2-4 hours on average. This is free resiliency.
Quantifying and Valuing the Resiliency Benefit of S + S Systems

- Use regression analysis to estimate amount of resiliency a S+S system would provide for a
  - specific load profile
  - at a specific location
- Allows value of incremental resiliency to be incorporated during design and planning

DER Scenario Analysis Example: Microgrids

Base case: 2.5 MW diesel w/ 4,000 gal fuel storage

Evaluated two different DER scenarios

- Scenario 1: 625 kW PV with battery (model optimized battery size)
- Scenario 2: 2,000 kW PV with battery (model optimized battery size)

<table>
<thead>
<tr>
<th></th>
<th>LCC ($MM)</th>
<th>Outage Survivability (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>20.0</td>
<td>5</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>19.5</td>
<td>6</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>20.1</td>
<td>9</td>
</tr>
</tbody>
</table>

**Diagram:**
- Probability of Surviving Outage [%]
- Length of Outage [Days]
- Base Case + 2.0 MW PV, 500 kWh Batt
- Base Case + 625 kW PV, 175 kWh Batt
- Base Case
Community Solar + Storage

• May appear more like a utility-scale project
• No customer load, no peak shaving potential
• Possible value streams
  o TOU arbitrage – charge with PV during low TOU rates, discharge during high periods
  o Ancillary services
  o T&D deferral – can reduce interconnection costs
• Worked with CEC to analyze business case
• Conclusion – not a great opportunity today, need lower battery costs
Questions? Please contact:
Travis Simpkins, PhD
Travis.Simpkins@nrel.gov
303-275-4242