Comparison Between Grid-Scale Batteries and Flexible Loads for Combined Value-Added Services

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Introduction and Motivation

- Battery costs are declining.
- Traditionally dormant demand-side of the grid is becoming more active due to various technological advancements and increasing energy awareness.
- Policies supporting participation of DERs in wholesale markets are gaining more traction e.g. FERC Order 841, FERC Order 2222 etc.
- Load Serving Entities (LSE) can use batteries and flexible loads for multiple services simultaneously.

Given favorable market conditions, policies and customer willingness, should an LSE invest in grid-scale batteries or the control of flexible loads (residential HVACs and water heaters) for multiple services?
Services of Interest

- **Peak Shaving**
  - Well studied and established concept
  - Directed at reducing electricity demand during peak hours
  - Results in reduced capacity charges for an LSE within a competitive market environment

- **Energy Arbitrage**
  - Similar to peak shaving
  - Increases consumption (or charges storage) when prices are low
  - Reduces energy consumption (or discharges storage) when prices are high
  - Results in reduced energy costs for LSE

- **Frequency Regulation**
  - Balances electricity supply and demand in real time
  - Most electricity markets have regulation markets
  - Batteries and aggregations of flexible loads can participate
  - Provides attractive extra renumeration for LSE
Methodology

Step 1: Establish capacity of flexible loads and grid-scale battery storage system using a cost-based equivalence approach.

\[
\text{Initial Cost} = N_{HVAC}(N_{EWH} + M_{HVAC}) + N_{EWH}(E_{EWH} + M_{EWH}) + PD_{EWH}(P_{r,EWH}) \\
+ PD_{HVAC}(P_{r,HVAC})
\]

\[
\text{Battery system size} = \frac{\text{Initial Cost}}{\lambda_{batt. system}}
\]

Where \( N_{HVAC(EWH)} = \text{number of HVACs/water heaters}, \ E_{HVAC(EWH)} = \text{equipment costs}, \ M_{HVAC(EWH)} = \text{marketing costs}, \ PD_{HVAC(EWH)} = \text{program development costs} \) and \( P_{r,HVAC(EWH)} = \text{unit power rating}, \ \lambda_{batt. system} = \text{battery system unit cost} \)

Step 2: Use novel mathematical optimization model to estimate annual profits from energy arbitrage and frequency regulation for each option (i.e. grid-scale battery and flexible loads) based on historical demand and electricity market price data.

Step 3: Estimate annual capacity charge savings from peak shaving depending on the wholesale market environment. Add to results from Step 2

Step 4: Use NPV analysis (and results from Step 3) to establish equivalent worth over the lifetime of each option (i.e. grid-scale battery and flexible loads)
Methodology – Optimization Model Structure

- A generic form of the novel optimization model for estimating annual profits for the flexible load option is as shown below.

\[
\text{Maximize } [\text{LSE's Revenue} - \text{LSE's Costs (including customer compensations)}] \\
\text{subject to} \\
\begin{align*}
\text{Peak Shaving Constraints} \\
\text{Energy Arbitrage Constraints} \\
\text{Frequency Regulation Constraints} \\
\text{Aggregated HVAC Unit Dynamics Constraints} \\
\text{Aggregated Water Heater Unit Dynamics Constraints}
\end{align*}
\]

- The optimization model is solved for each day of the year.

- For efficient computation, the residential HVAC units are grouped into different clusters and the thermal dynamics for the units within a cluster is represented by an equivalent HVAC model. A similar approach is also used for the water heating units.
Methodology – Optimization Model Structure

- A generic form of the novel optimization model for estimating annual profits for the grid-scale battery option is as shown below

\[
\text{Maximize} \ [LSE'\text{'s Revenue} - LSE'\text{'s Costs}] \\
\text{subject to} \\
\quad \text{Peak Shaving Constraints} \\
\quad \text{Energy Arbitrage Constraints} \\
\quad \text{Frequency Regulation Constraints} \\
\quad \text{Battery Storage System Constraints}
\]

- Customer compensation functions are not included in the model because the battery is owned by the LSE.

- The optimization model is also solved for each day of the year.
Case Study - Parameters

- The case study focuses on a hypothetical LSE operating within the New York City (N.Y.C) load zone of the NYISO wholesale market environment.
- Demand data was generated using the GridLAB-D software and electricity market prices (energy and regulation prices) were obtained from NYISO.
- Some of the parameters for the case study are shown in the table below.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{HVAC}$</td>
<td>42 (single cluster)</td>
<td>$P_{r,EWH}$</td>
<td>4.5 kW</td>
</tr>
<tr>
<td>$N_{EWH}$</td>
<td>42 (single cluster)</td>
<td>$P_{r,HVAC}$</td>
<td>4.2 kW</td>
</tr>
<tr>
<td>$M_{HVAC/EWH}$</td>
<td>$25$/participant*</td>
<td>Initial Cost</td>
<td>$28,248</td>
</tr>
<tr>
<td>$E_{EWH}$</td>
<td>$315$/unit*</td>
<td>$\lambda_{batt.system}$ ($/kWh)**</td>
<td>325, 300, 275, 250 and 200</td>
</tr>
<tr>
<td>$E_{HVAC}$</td>
<td>$215$/unit*</td>
<td>Battery sys. capacity (kWh)</td>
<td>87, 94, 103, 113 and 141</td>
</tr>
<tr>
<td>$P_{D,EWH}$</td>
<td>$12$/kW*</td>
<td>Flexible loads capacity (kW)</td>
<td>365</td>
</tr>
<tr>
<td>$P_{D,HVAC}$</td>
<td>$9$/kW*</td>
<td>Life span (years)</td>
<td>5 for battery; 10 for flexible loads</td>
</tr>
</tbody>
</table>

*Values obtained from [7].
**Values obtained from [8]. Five battery system cost scenarios were considered.
Case Study - Results

- **LSE's Estimated Annual Profits**
  - **Scenarios**
    - Base
    - Flexible Loads
    - Batt. (at $325/kWh)
    - Batt. (at $300/kWh)
    - Batt. (at $275/kWh)
    - Batt. (at $250/kWh)
    - Batt. (at $200/kWh)
  - **Profit ($)**
    - 500,000
    - 550,000
    - 600,000
    - 650,000
    - 700,000
    - 750,000
    - 800,000

- **Monthly Total Customer Compensations (for 84 customers)**
  - **Month**
    - Jan
    - Feb
    - Mar
    - Apr
    - May
    - June
    - July
    - Aug
    - Sept
    - Oct
    - Nov
    - Dec
  - **Compensation ($)**
    - 1000
    - 1500
    - 2000
    - 2500
    - 3000
    - 3500
    - 4000

- **NPV Estimates for Different Scenarios**
  - **Scenarios**
    - Flexible Loads
    - Batt. (at $325/kWh)
    - Batt. (at $300/kWh)
    - Batt. (at $275/kWh)
    - Batt. (at $250/kWh)
    - Batt. (at $200/kWh)
  - **NPV (%)**
    - $400,000.00
    - $500,000.00
    - $600,000.00
    - $700,000.00
    - $800,000.00
    - $900,000.00

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Conclusions

- Both control of flexible loads and grid-scale storage options provide more annual profits for the hypothetical LSE when compared with the base case.
- For the hypothetical LSE considered, the control of flexible loads is the best option considering a 10-year life span.
- Longer life span of flexible loads compared to batteries is a major factor.
- Average annual compensation for each flexible load is approximately $310 which is significantly higher than existing DSM programs.
- As battery costs decline, the total revenue from using battery storage resources for multiple services will increase.
- The developed optimization model and proposed approach can be employed by any other LSE interested in conducting a similar analysis.
Bibliography


