Potential Revenue from Electrical Energy Storage in ERCOT: The Impact of Location and Recent Trends

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2015 DOE/OE Energy Storage Program Peer Review meeting
September 24, 2015
Project Goals

- Quantify the potential revenue from electrical energy storage in ERCOT
- Identify the impact of location
  - Analyzed all 8 load zones
- Identify trends
  - Analyzed 2011, 2012, and 2013 data
- Potential revenue streams:
  - Arbitrage
  - Frequency regulation

ACKNOWLEDGMENT: the authors would like to thank Dr. Imre Gyuk and his colleagues at the Energy Storage Program at the U.S. Department of Energy for funding this research.
Methodology

- Formulated the problem as a Linear Program (LP) optimization
  - Solved in MATLAB and Pyomo
  - Working to release the Pyomo code
  - Day ahead market data from ERCOT web site
  - Looked at the revenue opportunity (no cost data)
  - Optimization codes applicable to any market data

- Optimization objective function
  - Arbitrage
    \[
    \max \sum_{t=1}^{T} \left[ (P_t - C_d)q_t^D - (P_t + C_r)q_t^R \right] e^{-rt}
    \]
  - Arbitrage and frequency regulation
    \[
    \max \sum_{t=1}^{T} \left[ (P_t - C_d)q_t^D + (P_t^{RU} + \gamma_{ru}(P_t - C_d))q_t^{RU} + (P_t^{RD} - \gamma_{rd}(P_t + C_r))q_t^{RD} - (P_t + C_r)q_t^R \right] e^{-rt}
    \]
Methodology

- Energy storage model
  - Arbitrage
    \[ S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D \]
  - Arbitrage and frequency regulation
    \[ S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_{rd} q_t^{RD} - \gamma_{ru} q_t^{RU} \]

- \( q_t^R \): charge quantity in time period \( t \) (MWh)
- \( q_t^D \): discharge quantity in time period \( t \) (MWh)
- \( q_t^{RU} \): quantity bid into the regulation up market (MWh)
- \( q_t^{RD} \): quantity bid into the regulation down market (MWh)
- \( \gamma_{RU} \): fraction of regulation up bid that is accepted (%)
- \( \gamma_{RD} \): fraction of regulation down bid that is accepted (%)
- \( \gamma_S \): storage efficiency over one period (%)
- \( \gamma_C \): conversion efficiency (%)

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Methodology

- Handling frequency regulation
  - Make an assumption about the average fraction that is called
  - Sensitivity analysis shows that the results are not sensitive to this parameter
Methodology

- **Energy storage system constraints**
  - Arbitrage
    
    \[
    0 \leq S_t \leq \bar{S}, \; \forall t \in T \\
    0 \leq q_t^R \leq \bar{q}^R, \; \forall t \in T \\
    0 \leq q_t^D \leq \bar{q}^D, \; \forall t \in T
    \]

  - Arbitrage and frequency regulation
    
    \[
    0 \leq S_t \leq \bar{S}, \; \forall t \in T \\
    0 \leq q_t^R + q_t^{RD} \leq \bar{q}^R, \; \forall t \in T \\
    0 \leq q_t^D + q_t^{RD} \leq \bar{q}^D, \; \forall t \in T
    \]

  - Note: set up constraints so that you always have the charge available to provide frequency regulation (even though a fraction is modeled as called)
System Model

- Assumed perfect knowledge
  - Can recoup 85-90% of arbitrage maximum revenue with simpler algorithms
  - Can recoup 90-95% of arbitrage/frequency regulation maximum revenue with simpler algorithms
- Did not consider arbitrage between day ahead and real-time market

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$\bar{q}_D$</td>
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<tr>
<td>$\bar{q}_R$</td>
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<td>$\bar{S}$</td>
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<td>$\gamma_C$</td>
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</tr>
<tr>
<td>$\gamma_{rd}$</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Results - Arbitrage

- 2011 had significantly more potential revenue.
- Not a large difference by region, although the West Load zone had more opportunity.
Results – Arbitrage and Regulation

- Significantly more potential revenue in the frequency regulation market
- Once again 2011 had significantly more potential revenue
- Since there is one market for regulation, and has significantly more revenue => location not as important
- The West load zone had slightly higher revenue opportunity
Summary

- Increased potential revenue in 2011 can be explained by:
  - Ice storms in February
  - Record heat in August
  - 2012-2013 data probably more typical
- For arbitrage – West load zone has the highest potential revenue
- For arbitrage and regulation – the optimal policy is participate in the frequency regulation market
  - One market for regulation diminishes the impact of location on potential revenue
- Additional details: