ESS Testing and Modeling of Stacked Application Duty Cycles

2017 EESAT Presentation
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UC San Diego
Jacobs School of Engineering
Center for Energy Research
Motivation:
To provide economic valuation of energy storage benefits and testing protocols for performance of energy storage systems under conditions similar to how they would operate in the California markets.
Stacked Application Duty Cycles

Energy Storage Resources

Stacked Applications
- Demand Charge Management
- Energy Time Shifting (Day-ahead Market)
- Energy Time Shifting (Real-time Market)
- Flexible Ramping
- Frequency Regulation

Energy Markets
- Commercial & Industrial (Retail Market)
- California Independent System Operator (ISO) (Wholesale Market)

Economic Modeling and Valuation of wholesale and retail energy market using data from utilities or independent system operators and forecasting for real world economic valuation. Developing stacked application duty cycles to investigate better energy storage value proposition.
Stacked Application Duty Cycles

\[ P_{k,i} \]

\[ P_{k,i} \]
Stacked Application Duty Cycles

\[ p_{k,i} \]

- 1. Demand Charge Management
- 2. Day-Ahead Energy Time Shifting
- 3. Real-Time Energy Time Shifting
- 4. Flexible Ramping
- 5. Frequency Regulation
Stacked Application Duty Cycles

Wholesale Market
- Day Ahead Market
  - Frequency Regulation
  - Energy Time Shifting

Real-Time Market
- Flexible Ramping
- Energy Time Shifting

Retail Market
- Demand Charge Management
Stacked Application Duty Cycles

\[ P_{k,i} = t_1 \ t_2 \ t_3 \ \ldots \ \ t_n \]
Stacked Application Duty Cycles

\[ p_{k,i} \]

\[ p_{k,i}^o \quad p_{k,i}^+ \quad p_{k,i}^- \]
Stacked Application Duty Cycles

\[ p_{k,i} \]

\[ p_{k,i}^o, p_{k,i}^+, p_{k,i}^- \]

\[ 0 < p_{k,i}^+ < W_k \cdot \overline{p_k}, \]

\[ 0 < p_{k,i}^- < (1 - W_k) \cdot \overline{p_k}, \]
Stacked Application Duty Cycles

\[ p_{k,i} \]

\[ p^+_k, i \quad p^0_k, i \quad p^-_k, i \]

\[ p^0_k, i = p^+_k, i - p^-_k, i, \]
Stacked Application Duty Cycles

Mix Integer Linear Programming

\[
\begin{align*}
\text{minimize} & \quad J_{bat}(P, W) \\
\text{subject to} & \quad A(P, W) \leq B \\
& \quad A_{eq}(P, W) = B_{eq}
\end{align*}
\]

Revenue Model

\[
J_{bat}(P, W) = \sum_{i=1}^{N} \sum_{k=1}^{K} J_{ene, k, i}(p_{k, i}, w_{k, i}) + \sum_{i=1}^{N} \sum_{k=1}^{K} J_{app, k, i}(p_{k, i}, w_{k, i}).
\]
Stacked Application Duty Cycles

Mix Integer Linear Programming

\[
\begin{align*}
\text{minimize} & \quad J_{bat}(P,W) \\
\text{subject to} & \quad A(P,W) \leq B \\
& \quad A_{eq}(P,W) = B_{eq}
\end{align*}
\]

Power Constraints

\[
p_{k,i} = \{p_{k,i}^o, p_{k,i}^+, p_{k,i}^-\},
\]

\[
p_{k,i}^o = p_{k,i}^+ - p_{k,i}^-,
\]

\[
0 < p_{k,i}^+ < W_k \cdot \overline{p_k},
\]

\[
0 < p_{k,i}^- < (1 - W_k) \cdot \underline{p_k},
\]
Stacked Application Duty Cycles

Mix Integer Linear Programming

\[
\begin{align*}
\text{minimize} & \quad J_{bat}(P, W) \\
\text{subject to} & \quad A(P, W) \leq B \\
& \quad A_{eq}(P, W) = B_{eq}
\end{align*}
\]

SoC Constraints

\[
SoC_{bat,i} = SoC_0 + \sum_{i=1}^{n} \sum_{k=1}^{4} \left( \frac{\eta * p_{k,i}^+ - p_{k,i}^-}{Q} \right) \Delta t
\]

\[
= \eta * \left( \frac{1}{\gamma_i} p_{5,i}^+ - \frac{1}{\gamma_i} p_{5,i}^- \right) \frac{\Delta t}{Q} + \frac{\Delta t}{Q},
\]

\[
SoC_{bat} < SoC_{bat,i} < SoC_{bat}.
\]
Stacked Application Duty Cycles

Mix Integer Linear Programming

minimize \( J_{bat}(P, W) \)
subject to \( A(P, W) \leq B \)
\( A_{eq}(P, W) = B_{eq} \)

Demand Charge Revenue

\[
J_{1,\text{ene}} = \sum_{i=1}^{N} E_{tou}(p_{1,i}^o + L_i) \Delta t - \sum_{i=1}^{N} E_{tou}(Lr_i) \Delta t.
\]

\[
J_{1,\text{app}} = E_{dc} \max\{p_{1,i}^o + L_i - Lpk_i, 0\}, \quad i = 1, 2, \ldots, N
\]
Stacked Application Duty Cycles

Mix Integer Linear Programming

\[
\begin{align*}
\text{minimize} & \quad J_{bat}(P, W) \\
\text{subject to} & \quad A(P, W) \leq B \\
& \quad A_{eq}(P, W) = B_{eq}
\end{align*}
\]

Energy Time Shifting

\[
J_{2,ene} = \sum_{i=1}^{N} E_{da}(p_{2,i}^o) \Delta t,
\]
Stacked Application Duty Cycles

Mix Integer Linear Programming

\[
\begin{align*}
\text{minimize} & \quad J_{bat}(P, W) \\
\text{subject to} & \quad A(P, W) \leq B \\
& \quad Aeq(P, W) = B_{eq}
\end{align*}
\]

Ramping Revenue

\[
J_{4, app} = - \sum_{i=1}^{N} (E_{fr, down} \Delta p_{4,i}^{+} + E_{fr, up} \Delta p_{4,i}^{-}) \Delta t
\]

\[
\Delta p_{4,i}^{+} = \max\{(p_{4,i}^{o}) - (p_{4,i-1}^{o}), 0\}
\]

\[
\Delta p_{4,i}^{-} = \max\{-(p_{4,i}^{o}) + (p_{4,i-1}^{o}) , 0\}
\]
**Stacked Application Duty Cycles**

**Mix Integer Linear Programming**

\[
\begin{align*}
\text{minimize} \quad & J_{bat}(P, W) \\
\text{subject to} \quad & A(P, W) \leq B \\
& A_{eq}(P, W) = B_{eq}
\end{align*}
\]

**Regulation Revenue**

\[
J_{5, app} = \\
- (C_{FQ}^+ \sum_{i=1}^{N} \frac{1}{\gamma_i} P_{5,i}^+ + C_{FQ}^- \sum_{i=1}^{N} \frac{1}{\gamma_i} P_{5,i}^-) \Delta t \\
- (E_{FQ}^+ \sum_{i=1}^{N} M_i^+ \frac{1}{\gamma_i} P_{5,i}^+ + E_{FQ}^- \sum_{i=1}^{N} M_i^- \frac{1}{\gamma_i} P_{5,i}^-) \Delta t.
\]
Stacked Application Duty Cycles

Battery Specs:
1MW / 2MWh / 90% Eff.
Stacked Application Duty Cycles

Power Profile

Energy Throughput

Revenue Breakdown

Time [Day]

Power [MW]

Energy [MWh]

Revenue [$/Day]
Stacked Application Duty Cycles

Revenue Breakdown

Stacked Application Revenue

Stacked Application Revenue Without FQ
University of California, San Diego (UCSD) Microgrid Tour
Friday, October 13 | 9AM - 12PM

A tour of a 47MW peak load microgrid at the Center for Energy Research on the UCSD campus will be held on the last day of the conference. Busses will meet outside of the lobby of the Westin Hotel at 9am and will return attendees to the lobby of the Westin at Noon. Please dress comfortably as part of the tour is a walking tour.
Thank You

Project link
https://cer.ucsd.edu/research/energy-storage/ARPA-E_CHARGES.html

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