Energy storage price targets to enable energy arbitrage in CAISO

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Abstract – The potential annual revenue of a generic battery energy storage system (BESS) participating in the CAISO day-ahead energy market was analyzed for 2,145 nodes over a seven year period (2014-2020). This data was used to estimate the break-even capital cost for each node as well as the cost requirements for several internal rate of return (IRR) scenarios.

Revenue optimization formulation:

\[
\max \sum_{t=1}^{T} \left[ (P_t - C_d) - (P_t + C_r) q^D_t \right] e^{-r_t t}
\]

where

- \( S_t = \gamma_t S_{t-1} + \gamma_t q^D_t - q^R_t \)
- \( q^D_t \) is the quantity of energy discharged at time \( t \)
- \( q^R_t \) is the quantity of energy recharged at time \( t \)
- \( \gamma_r \) is the conversion efficiency
- \( P_t \) is the price of electricity (LMP) at time \( t \)
- \( C_d \) is the cost of discharging at time \( t \)
- \( C_r \) is the cost of recharging at time \( t \)
- \( r_t \) is the interest rate over one time period

The break-even cost formulation for each node:

\[
\text{NPV[revenue]} = \text{NPV[total cost]}
\]

\[
\text{CAP} = \frac{\text{GAF} \times \text{REV}}{1 + k \times \text{AF}^2}
\]

where

- \( \text{GAF} \) is the geometric average factor
- \( \text{REV} \) is the revenue
- \( k \) is the discount rate
- \( \text{AF} \) is the arithmetic factor

System parameters and case studies:

<table>
<thead>
<tr>
<th>Value</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( P_{\text{max}} ), maximum power rating (MW)</td>
</tr>
<tr>
<td>( S )</td>
<td>maximum state of charge (MWh)</td>
</tr>
<tr>
<td>( q^R )</td>
<td>maximum quantity that can be bought/recharged in a period (MWh)</td>
</tr>
<tr>
<td>( q^D )</td>
<td>maximum quantity that can be sold/discharged in a period (MWh)</td>
</tr>
<tr>
<td>( \Delta t )</td>
<td>(hours)</td>
</tr>
<tr>
<td>1.0</td>
<td>( \gamma_r ), storage efficiency (fraction)</td>
</tr>
<tr>
<td>0.85</td>
<td>( \gamma_c ), conversion efficiency (fraction)</td>
</tr>
<tr>
<td>1</td>
<td>( C_d ), cost of discharging at time ( t ) (SMWh)</td>
</tr>
<tr>
<td>0</td>
<td>( C_r ), cost of recharging at time ( t ) (SMWh)</td>
</tr>
<tr>
<td>( r_t )</td>
<td>interest rate over one time period (percent)</td>
</tr>
</tbody>
</table>

IRR = 2.5%, 5%, 7.5%, 10%
Annual revenue growth rates (g) = 0%, 3%, 6%
Project lifetimes (T) = 10 and 15 years
\( k = 2\%

Conclusion:

Using arbitrage as the only revenue stream for the BESS, capital costs need to be reduced by about 80% of the current cost for a battery system of the same type in order to make a reasonable rate of return.

Future work:

We are currently looking at additional revenue sources (i.e. frequency regulation, spinning and non-spinning reserves, as well as flexible ramping product) for the BESS in order to increase its revenue streams.

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