Optimal Investment Strategy in Grid-Scale Energy Storage Systems: A Real Options Analysis

Yiju Ma
Supervisors: Dr.Gregor Verbič
Dr.Arcie C.Chapman
• Renewable generation has increased significantly.
  • Total installed capacity of rooftop PV systems have increased from less than 200MW in 2009 to 1.1GW in 2017 [1].
  • Total rooftop solar capacity is expected to increase from 4.3GW in 2017 to 19GW in 2035 [1].

• Rising PV penetration has led to numerous technical problems [2].
  • Over voltages.
  • Thermal problems.
  • Phase unbalance.
• Network augmentation [3].
  • Upgrade transformer and line capacities.
  • Expensive and time-consuming.

• Grid-scale battery storage is an alternative option.
  • Mitigate the technical issues.
  • The cost of the technology is predicted to halve in the next decade [4].
Motivation

• Determining efficient and well-timed investment in large-scale batteries is challenging under uncertain electricity market environment.

• Traditional discounted cash flow (DCF) analysis.
  • It provides only deterministic decisions.
  • Distribution network investments are generally irreversible, and present many options (Defer, expand and abandon).
  • Investors have the flexibility to execute these options based on how future uncertainties are realised.
Real Options Valuation

- Real options valuation (ROV).
  - Highlights the value of the options under multiple uncertainties.
  - Mitigates the risk of financial losses and increase the investment value.
  - Optimal investment strategy.

- We propose a ROV framework, and demonstrate its characteristics by determining the optimal investment strategy of a grid-scale battery in a LV network.
  - Option to defer.
• Formulate a battery scheduling optimisation problem.
• Quantitatively incorporate the benefits from the battery within the ROV.
• Use the least square Monte Carlo (LSMC) approach to determine the deferral option value, and the corresponding investment strategy.

• The ROV uses the geometric Brownian motion (GBM) coupled with a Monte Carlo (MC) study to simulate possible paths of future uncertainties, including:
  • varying wholesale electricity price.
  • declining cost of battery system.
We formulate the battery scheduling optimisation as a *mixed integer linear programming* model.

Objective:
- Minimise the grid supply over 1 year.
- Minimise the size of the battery system.

Decision variables:
- Battery charging and discharging rates.
- Grid supply.
- Size of the battery system
• Translate the increase in network capacity into a monetary value.

\[ \Pi_{t,\omega} = c^B_{t,\omega} - c^\text{Aug}_t + c^g_{t,\omega}, \]  

(1)

where \( \Pi_{t,\omega} \) is the payoff, \( c^B_{t,\omega} \) is the cost of the battery, \( c^\text{Aug}_t \) is the augmentation cost, and \( c^g_{t,\omega} \) is the cost incurred by deferring the investment.
• The LSMC approach for determining the optimal investment strategy.
  • Calculate the *continuation value*, $\Phi_{t,\omega}$.
  • Decide the *optimal stopping time*, $\tau_\omega$.
  • The investment is executed as soon as $\Pi_{t,\omega}$ exceeds $\Phi_{t,\omega}$.
  • Calculate the *deferral option value*, $F_{\text{option}}$.

• The investment value considering the managerial flexibility is:

$$NPV_{\text{flexible}} = NPV_{\text{classic}} + F_{\text{option}}.$$ (2)
• Two LV test feeders are from Electricity North West Limited\(^1\).

### Table 1: LV Test Networks

<table>
<thead>
<tr>
<th></th>
<th>No. of consumers</th>
<th>Feeder length (km)</th>
<th>Transformer capacity (kVA)</th>
<th>Optimal battery size (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeder 1</td>
<td>98</td>
<td>10.2</td>
<td>1600</td>
<td>445</td>
</tr>
<tr>
<td>Feeder 2</td>
<td>41</td>
<td>4.3</td>
<td>800</td>
<td>174</td>
</tr>
</tbody>
</table>

\(^1\)A British distribution network operator.
Figure 1: Cost of the battery investment and the corresponding payoff on the test feeders.
# Table 2: ROV Table

<table>
<thead>
<tr>
<th>Feeder 1</th>
<th>$NPV_{\text{classic}}$ (k$)</th>
<th>$F_{\text{option}}$ (k$)</th>
<th>$NPV_{\text{flexible}}$ (k$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeder 1</td>
<td>-260</td>
<td>320</td>
<td>60</td>
</tr>
<tr>
<td>Feeder 2</td>
<td>50</td>
<td>55</td>
<td>105</td>
</tr>
</tbody>
</table>

**Figure 2: Optimal investment timing**

<table>
<thead>
<tr>
<th>Frequency (%)</th>
<th>Feeder 1</th>
<th>Feeder 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision Period (year)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
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</tbody>
</table>

**Figure 2: Optimal investment timing**
• We developed a ROV framework, and demonstrated its usefulness by determining the optimal investment strategy in grid-scale battery systems in two different LV networks.

• The framework incorporates battery schedules within its financial analysis.

• The results show that making contingent decisions based on how future uncertainties are realised increases the investment value, and mitigates the risk of financial losses.