Use of Operating Agreements and Energy Storage to Reduce Photovoltaic Interconnection Costs

March 23, 2022
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Webinar Speakers

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- **Shauna Beland**, Rhode Island Office of Energy Resources
- **Joyce McLaren**, National Renewable Energy Laboratory
- **Ryan Constable**, National Grid
- **Naim Darghouth**, Lawrence Berkeley National Laboratory
- **Sydney Forrester**, Lawrence Berkeley National Laboratory
- **Todd Olinsky-Paul**, Clean Energy States Alliance (moderator)
Operating Envelope Agreement

A contractual agreement between the utility and the system owner that defines a mutually agreeable set of time-based technical operating requirements (an “Operating Envelope”) for a PV and storage system that limits risk to neighboring customers and the utility’s infrastructure and provides certainty to both the utility and PV system owner.
Conditions that can Trigger Grid Violations

![Graph showing PV generation and load on feeder by month of the year. The graph indicates a peak in June and July, and a dip in August.](image-url)
Conditions that can Trigger Grid Violations
One Way to Remedy Grid Violations
Overview of the Analysis

**Technical Analysis**
1. **Identify** grid violations
   - Overvoltage
   - Undervoltage
   - Line overloads
   - Transformer overloads
2. **Mitigate** grid violations
   - Infrastructure upgrades
   - Reduction in PV system size
   - Curtailment of PV
   - Battery storage
3. **Technical Parameters** of the OEA
   - Maximum export for each hour of the year

**Economic Analysis**
1. **Compare** the cost and revenue from the strategies that mitigate violations
2. **Conduct** sensitivity analyses
   - Battery sizes
   - Battery prices
   - Future electricity market scenarios
3. **Select** economically preferred system design
   - Net Present Value;
   - Break-even infrastructure upgrade costs
   - Break-even battery storage costs
IEEE Feeder Model Used in the Analysis

Identify violations for originally proposed PV size
Identify PV size that does not cause violations
Identify an export level that does not cause violations
Define OEA technical parameters
# Output Metrics from Time-Series Analysis

<table>
<thead>
<tr>
<th>Time-Series Output Metrics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M1</strong> Maximum voltage (per unit)</td>
<td>Maximum voltage magnitude across all nodes in the network that experience overvoltage violations</td>
</tr>
<tr>
<td><strong>M2</strong> Minimum voltage (per unit)</td>
<td>Minimum voltage magnitude across all nodes in the network that experience undervoltage violations</td>
</tr>
<tr>
<td><strong>M3</strong> Maximum transformer loading (per unit)</td>
<td>Maximum loading observed across all transformers in the network that experience overloading</td>
</tr>
<tr>
<td><strong>M4</strong> Maximum line loading (per unit)</td>
<td>Maximum loading observed across all lines in the network that experience overloading</td>
</tr>
<tr>
<td><strong>M5</strong> Duration of occurrence of violations for each month in a year</td>
<td>This metric gives the total number of hours that the system experienced different kinds of violations for every month</td>
</tr>
<tr>
<td><strong>M6</strong> Duration of occurrence of violations for each week in a year</td>
<td>This metric gives the total number of hours that the system experienced different kinds of violations for every week</td>
</tr>
<tr>
<td><strong>M7</strong> Duration of occurrence of violations by hour of day</td>
<td>This metric gives the total number of hours that the system experienced different kinds of violations for every hour of the day, across the whole year</td>
</tr>
</tbody>
</table>
## Power-Flow Modeling Scenarios

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>Description/Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 Load-only</td>
<td>Tests the feeder model to ensure that there are no pre-existing violations or errors prior to beginning scenario analysis.</td>
</tr>
<tr>
<td>S2 Originally proposed PV size</td>
<td>Tests for violations due to the originally proposed PV system size, which represents the system as originally proposed by a PV developer in the interconnection request. For the purposes of this analysis, this scenario is designed to result in violations.</td>
</tr>
<tr>
<td>S3 Originally proposed PV size with smart inverter controls</td>
<td>Tests for violations due to the originally proposed PV system size, with advanced inverter controls enabled (volt-VAR), in accordance with IEEE Standard 1547. For this analysis, this scenario is designed to result in violations. The goal is to quantify the impact of advanced inverter controls in alleviating violations.</td>
</tr>
<tr>
<td>S4 Downsized PV system</td>
<td>This scenario is used to identify and verify the PV system size that does not cause violations on the feeder. A downsized PV system size is estimated, based on the violations from scenarios 2 and 3. An iterative process is used to identify and confirm the system size that does not cause violations in any hour of the year.</td>
</tr>
<tr>
<td>S5 Constant injection of generation to simulate a battery energy storage discharge to the grid</td>
<td>This scenario is used to ensure that the addition of a battery to mitigate PV violations will not cause additional violations by discharging to the grid (e.g., in hours of low PV production). It determines the maximum allowable constant injection at the point of interconnection. An iterative process identifies and confirms the battery size that does not cause violations in any hour of the year, despite when the battery is discharged.</td>
</tr>
<tr>
<td>Derived Operating Envelope (max allowable kW export)</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Table" /></td>
<td></td>
</tr>
</tbody>
</table>
# Variations of Operating Envelope Agreement

<table>
<thead>
<tr>
<th></th>
<th>Simple OEA</th>
<th>Complex OEA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Month of Violation</strong></td>
<td>Enforcement during entire year</td>
<td>Enforcement during certain season(s)</td>
</tr>
<tr>
<td><strong>Analysis Indicators</strong></td>
<td>Violations occur in most months</td>
<td>Violations occur regularly during certain seasons</td>
</tr>
<tr>
<td><strong>Hours of Violation</strong></td>
<td>Enforcement 24-hours/day</td>
<td>Enforcement sunrise to sunset</td>
</tr>
<tr>
<td><strong>Analysis Indicators</strong></td>
<td>Violations occur in most months</td>
<td>Violations occur throughout day</td>
</tr>
<tr>
<td><strong>Magnitude of Violation</strong></td>
<td>Zero export to grid during enforcement</td>
<td>Single maximum export during enforcement</td>
</tr>
<tr>
<td><strong>Analysis Indicators</strong></td>
<td>Violations are large in magnitude</td>
<td>Violations are consistent in magnitude</td>
</tr>
</tbody>
</table>
Terms and Conditions

Performance validation and data reporting

Term of the agreement and changes to the agreement

Non-compliance, enforcement, liability, and dispute resolution

Changes in ownership
Performance Validation

• How will performance be verified?

• Why, how, and when are systems treated differently?

• Must positively demonstrate compliance

• What are current and anticipated standards for inverters?

• If backstop compliance is needed, which technology is appropriate?

• What level of monitoring is appropriate?
Term and Changes

• Similar to ISA, OEA term is lifetime of system
• Changes may necessitate a restudy

• The utility can **require** a change if:
  • System size or components change
  • Repeat non-compliance

• The utility can **request** a change if:
  • Mutual benefit and system owner agrees (default to original OEA otherwise)

• The system owner can **request** a change if:
  • Changes in market conditions
  • Considering changes to the system
  • Changes in technology or resources
Non-Compliance

• Non-compliance
  • Discovered via investigation of a grid violation or through performance validation
  • Mis-operation
  • Inadvertent export
• Enforcement through disconnection
  • Immediate or planned, coupled with financial penalty for gross violations

• How will liability for damages will be assessed and compensated?

• How will dispute resolution be handled?
Changes in Ownership

• What are expectations and process for a change in system ownership?

• Examples of information that may be maintained:
  • Administrative contact information
  • Information required for tax purposes
  • Operations contact in case of emergency
  • Affirmation that the new system owner understands and agrees to the OEA, etc.

• May include clause describing penalties for lapsed information
Economic Analysis Methodology

Option (1) Downsized PV System

Option (2) 3.3 MW PV with infrastructure upgrade costs

Option (3) 3.3 MW PV with curtailment to adhere to Operating Envelope

Option (4) 3.3 MW PV using battery and curtailment to adhere to Operating Envelope
# Assumptions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Base Case Value</th>
</tr>
</thead>
</table>
| Solar PV system size         | **Option 1**: 1.32 MW  
**Options 2–4**: 3.3 MW                                                        |
| Storage size                 | **Option 4 only**  
Rated capacity: 0–2.4 MW  
Rated Power: 4x rated capacity (4-hour duration) |
| Solar PV capital costs       | $1/W (DC STC)                                                                  |
| Incremental storage costs    | $1,250/kW (ATB 2021 battery storage CAPEX, 4-hour, advanced)                   |
| Discount rate                | 5%                                                                              |
| PV degradation rate          | 0.5% per year                                                                  |
| Battery degradation rate     | 3% per year                                                                    |
| Battery depth of discharge   | 95%                                                                             |
| Battery roundtrip efficiency | 90%                                                                             |
Upfront Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>CAPEX (million $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.32 MW PV</td>
<td>$1.00</td>
</tr>
<tr>
<td>3.3 MW PV &amp; Upgrade</td>
<td>$2.50</td>
</tr>
<tr>
<td>3.3 MW PV &amp; Curtailment</td>
<td>$1.50</td>
</tr>
<tr>
<td>3.3 MW PV &amp; Storage (0.4 MW)</td>
<td>$2.00</td>
</tr>
<tr>
<td>3.3 MW PV &amp; Storage (2.4 MW)</td>
<td>$3.00</td>
</tr>
</tbody>
</table>
Curtailment of PV Generation by Storage Size

The bar chart shows the curtailment of PV generation percentage for different storage power ratings. The y-axis represents the curtailment of PV generation in percentage, ranging from 0% to 40%. The x-axis represents storage power rating in MW, ranging from 0 to 2.4 MW.

- No storage: 40% curtailment
- 0.4 MW storage: 25% curtailment
- 0.8 MW storage: 15% curtailment
- 1.2 MW storage: 10% curtailment
- 1.6 MW storage: 5% curtailment
- 2 MW storage: 2.5% curtailment
- 2.4 MW storage: 0% curtailment
Breakeven Storage Costs

![Bar chart showing the relationship between storage power rating (MW) and breakeven storage CAPEX ($/kW, 4 hr duration) versus incremental value from storage ($/kW, 4 hr duration). The x-axis represents storage power rating (MW) ranging from 0.4 to 2.4, while the y-axis represents breakeven storage CAPEX ($/kW, 4 hr duration) ranging from $0 to $800. The incremental value from storage is shown on the right y-axis, ranging from $0 to $600. The chart illustrates that as the storage power rating increases, the breakeven storage CAPEX decreases, while the incremental value from storage increases.]
# Revenues Under Sensitivity Cases

<table>
<thead>
<tr>
<th>Option #</th>
<th>Description</th>
<th>CAPEX (million $)</th>
<th>Base Case</th>
<th>Renewable Cost Sensitivity</th>
<th>Storage Cost Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PV cost $1/W 4 hr storage cost $1.250/kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.32-MW PV, downsized to avoid grid violations</td>
<td>0.98</td>
<td>68</td>
<td>55</td>
<td>67</td>
</tr>
<tr>
<td>2</td>
<td>3.3-MW PV + infrastructure upgrade costs of $148,500</td>
<td>2.69</td>
<td>171</td>
<td>139</td>
<td>167</td>
</tr>
<tr>
<td>3</td>
<td>3.3-MW PV + curtailment to avoid violations</td>
<td>1.71</td>
<td>111</td>
<td>90</td>
<td>108</td>
</tr>
<tr>
<td>4a</td>
<td>PV + 0.4-MW / 4-hour battery</td>
<td>1.89</td>
<td>141</td>
<td>123</td>
<td>137</td>
</tr>
<tr>
<td>4b</td>
<td>PV + 2.4-MW / 4-hour battery</td>
<td>2.82</td>
<td>203</td>
<td>190</td>
<td>197</td>
</tr>
</tbody>
</table>
Adopting this Concept

• Could future discussions about your interconnection tariff include these concepts?
• How might an existing interconnection service agreement be modified?
• Specify process for everyone:
  • Developer design
  • System impact study outputs
  • Final operating envelope technical parameters
  • Negotiate terms and conditions
Next Steps

- Are you considering implementing an operating envelope agreement?
- Please let us know!!
- SEIN@NREL.gov

Thank you for attending our webinar

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Clean Energy States Alliance
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*Tuesday, March 29, 3-4:30pm ET*

The Governance of Wholesale Power Markets
*Tuesday, April 12, 2-3pm ET*

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