NREL Variability Analysis for the Western Interconnect

WECC WebEx

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Composite photo created by NREL
Contents

• Study Data
• Methodology
• Analysis
• Allocation of reserve requirements
Overview

• Investigate the effects of several Energy Imbalance Markets implementations in the Western Interconnect (WI):
  – Operating reserves;
  – Ramping demand;
  – Alternative Scheduling

• Analysis based on aggregation of variability and uncertainty:
  – Uses available load, wind and solar data.

• Calculate the reserve requirements:
  – Estimating within the hour and hourly requirements based on historical data.

• Compared to NREL draft report, this analysis has approximately 1/3 VG.
Study Data
Model Area

- Based on TEPPC PC 0.
- Areas of the WI not already in a market structure (CAISO, Alberta).
- LADWP not included.
- Analysis at BAA granularity.
- Generation only BAAs not considered.
- 28 load and generation BAAs retained – The study ‘Footprint.’
- Regions are:
  – Columbia Grid – Orange;
  – NTTG – Blue;
  – West Connect – White.
Load Data

- 2020 loads provided by WECC;
- Load shape is based on 2006 load;
- 193,700 MW in full Western Interconnect (non-coincident).
- 116,700 MW in analysis footprint (non-coincident);
- One hour load provided, 10-minute synthesized.
Wind Data

- NREL WWSIS wind dataset for 2006;
- 10-minute resolution;
- Sites identified by TEPPC 2020 PC 0;
- 29,085 MW in Western Interconnect;
- Approximately 8% of WI 2020 load;
- 18,272-MW nameplate modeled in analysis – footprint.
Solar Data

- NREL WECC Solar dataset for 2006;
- 10-minute resolution;
- Sites identified by TEPPC 2020 PC 0;
- 14,300 MW in WI;
- Approximately 3% of WI 2020 load;
- 4,568 MW nameplate in analysis footprint.
Reserve Calculations
Reserve Calculations

• Developed for the EWITS study;*
• Statistical approach based on 10-minute time series wind, solar and load;
• Method that can estimate adequate reserves to cover the short term and hour-ahead forecast error based on historical data;
• Predicts requirements based on current hour load and wind, solar production;
• Statistically combine with load regulation requirements;
• Provide 8760 vector of requirements for the production simulations.

*For in-depth discussion see section 5 of the EWITS final report: http://www.nrel.gov/wind/systemsintegration/pdfs/2010/ewits_final_report.pdf
Reserve Definitions

- **Regulation** – Fast changes:
  - Due to variability and short-term forecast errors;
  - Faster than re-dispatch period;
  - AGC resources required.
- **Spinning** – larger, slower, less frequent variations:
  - Due to longer term forecast errors;
  - AGC not required;
  - 10-minute response.
- **Non-spinning/supplemental**:
  - Large, infrequent, slow moving events such as unforecasted ramps;
  - 30-minute response.
Short-Term Forecast Error - Regulation

• Based on persistence forecast;
• Wind data is 10 minute, 10-minute delay for forecast;
• Forecast error is calculated as difference from actual to forecast.
Short-term Calculation

• Measure as standard deviation of the forecast error;
• Forecast error varies with production level;
• Empirical expected error as a function of production is quadratic:
  – Low variability at low and high wind (cut-in and rated);
  – High variability in mid range at steep part of power curve;
  – Solar follows same pattern, more or less.
• Predicts the expected variability for the hour based on the intra-hour statistics, current production;
• Assumes fast dispatch, 10 minutes in this case:
  – Implication is that economic movement happen at 10-minute updates.
Calculation of Short-term Forecast Error

- Calculate and sort error by production level;
- Divide production into deciles;
- Calculate error sigma in each decile;
- Blue line is calculated from data;
- Red line is curve fit;
- Equation of the curve shown below.

$$\sigma_{ST} (\text{Hourly Wind}) = -6.72E-06 \cdot (\text{Hourly Wind})^2 + 0.0437 \cdot (\text{Hourly Wind}) + 26.74$$
Calculating the Regulation Requirement

• Combine load, wind and solar components statistically assuming no correlation in this time frame

\[ \text{Regulation Requirement (With Wind and Solar)} = 3 \cdot \sqrt{\left(\sigma_{Load}\right)^2 + \left(\sigma_{STWind} \text{ (Hourly Wind)}\right)^2 + \left(\sigma_{STSolar} \text{ (Hourly Solar)}\right)^2} \]

• \( \sigma_{Load} \) calculated as fixed % of hourly load based on BA size
• \( \sigma_{STWind} \text{ (Hourly Wind)} \) calculated from previous slide
• \( \sigma_{STSolar} \text{ (Hourly Solar)} \) calculated from solar version
• This is 3 sigma to cover 99.7% of all short term forecast errors
• Assumed equal up and down
• Calculated for each hour of the study year
Hour-ahead Forecast Errors

- Repeat the short term forecast procedure with hour-ahead forecasting;
- Again, same procedure for wind and solar;
- Load following not included.

\[ \sigma_{\text{Hour-ahead}}(\text{Hourly Wind}) = -2.985E - 05 \cdot (\text{Hourly Wind})^2 + 0.1895 \cdot (\text{Hourly Wind}) + 103.2 \]
Spin and Non-spin Calculation

- **One sigma allocated to Spinning category**
  
  \[
  \text{Spinning Requirement (Hour – ahead wind forecast error)} = 1 \cdot \sigma_{\text{hour-ahead}}(\text{Previous Hour Wind})
  \]
  
  - Covers 68%* of all movements less than 1 hour
  - With regulation, covers approximately 98% of 30 minute movements

- **Two sigma allocated to Non-spin category**
  
  \[
  \text{Non-spin Requirement (Hour – ahead wind forecast error)} = 2 \cdot \sigma_{\text{hour-ahead}}(\text{Previous Hour Wind})
  \]
  
  - With spin, covers 99.7%* of all movements less than 1 hour

*assuming movements are normally distributed which is slightly optimistic
Verification of Reserve Coverage

- Shows coverage of VG intra-hour movements;
- Actual ramp data from footprint EIM;
- Red line – Actual average reserve calcs from footprint EIM;
- Probability lines are z% of all ramps at x minutes are less than y MW.
Reserves Provided to E3 for Phase 2 Study

- NREL provided reserve calculations to E3 for phase 2 study;
- Slight variation in calculation of regulation component – load not included in E3 Flex;
- Does not include contingency reserves;
- Areas are slightly different from each other.

<table>
<thead>
<tr>
<th>NREL</th>
<th>E3</th>
<th>Response</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td>Flex</td>
<td>AGC</td>
<td>E3 flex reserve does not contain load</td>
</tr>
<tr>
<td>Spin</td>
<td>Spin</td>
<td>&lt;10 minutes</td>
<td></td>
</tr>
<tr>
<td>Non-spin</td>
<td>Supplemental</td>
<td>&lt;30 minutes</td>
<td>Terminology change</td>
</tr>
</tbody>
</table>
Analysis
Cases

• Complete analysis includes:
  – Footprint EIM
    • All 28 BAAs participating.
  – ‘Regional’ EIM implementations
    • Columbia Grid;
    • Northern Tier Transmission Group;
    • WestConnect.
  – EIM implementations without BPA and/or WAPA participation.
  – Comparison to the Business-As-Usual (BAU) case – No EIM in place;
  – Selected results.
Footprint EIM Regulation

- Detail of the individual regulation components;
- Bars are average values, whiskers are min and max;
- 3 regional results in smaller reductions compared to footprint.

<table>
<thead>
<tr>
<th>Component</th>
<th>MW (BAU)</th>
<th>% Reduction (BAU)</th>
<th>MW (Reg)</th>
<th>% Reduction (Reg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Reg</td>
<td>211</td>
<td>18%</td>
<td>178</td>
<td>16%</td>
</tr>
<tr>
<td>Wind Reg</td>
<td>372</td>
<td>53%</td>
<td>231</td>
<td>33%</td>
</tr>
<tr>
<td>Solar Reg</td>
<td>49</td>
<td>21%</td>
<td>46</td>
<td>19%</td>
</tr>
<tr>
<td>Total Reg</td>
<td>570</td>
<td>36%</td>
<td>419</td>
<td>26%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>BAU (MW)</th>
<th>Regional (MW)</th>
<th>Footprint (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Reg</td>
<td>1142</td>
<td>964</td>
<td>931</td>
</tr>
<tr>
<td>Wind Reg</td>
<td>708</td>
<td>476</td>
<td>336</td>
</tr>
<tr>
<td>Solar Reg</td>
<td>240</td>
<td>193</td>
<td>191</td>
</tr>
<tr>
<td>Total Reg</td>
<td>1594</td>
<td>1175</td>
<td>1024</td>
</tr>
</tbody>
</table>

Regulation detail TEPPC Scenario
Reserve Details for Footprint and Regional EIM

- Up to 42% (2000 MW) reduction in total reserve requirement for footprint EIM;
- 26% for regional EIMs.

<table>
<thead>
<tr>
<th>Reduction over BAU</th>
<th>Footprint</th>
<th>Regional</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>% Reduct.</td>
<td>MW</td>
</tr>
<tr>
<td>Total Reg</td>
<td>570</td>
<td>419</td>
</tr>
<tr>
<td>Spin</td>
<td>481</td>
<td>271</td>
</tr>
<tr>
<td>Non-spin</td>
<td>963</td>
<td>542</td>
</tr>
<tr>
<td>Total</td>
<td>2014</td>
<td>1233</td>
</tr>
</tbody>
</table>

Reserve detail for TEPPC Scenario

- Total Reg: 1594 MW, Spin: 1072 MW, Non-spin: 2144 MW, Total: 4809 MW
- Regional: 1175 MW, Spin: 801 MW, Non-spin: 1601 MW, Total: 3577 MW
- Footprint: 1024 MW, Spin: 590 MW, Non-spin: 1181 MW, Total: 2795 MW
Ramp Demand Reduction – Footprint EIM

- Based on hourly ramps;
- Shows ramp reduction from EIM over BAU;
- Duration plot shows hours per year for reduction level;
- Reduction in net ramp is greater than 1000 MW for 251 hours per year and averages about 260 MW.
Reserve Reduction Duration – Footprint EIM

- Average reductions:
  - 590-MW Regulation;
  - 2092-MW Total Reserves.
Regional EIM – Columbia Grid (CG)

- Average reserves for a CG EIM;
- BPA dominates the wind so saving less than other regions;
- 8070 MW Wind.

<table>
<thead>
<tr>
<th>Reserve Reduction</th>
<th>MW</th>
<th>% Reduc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Reg</td>
<td>37</td>
<td>14%</td>
</tr>
<tr>
<td>Wind Reg</td>
<td>39</td>
<td>15%</td>
</tr>
<tr>
<td>Solar Reg</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Total Reg</td>
<td>85</td>
<td>21%</td>
</tr>
<tr>
<td>Spin</td>
<td>38</td>
<td>12%</td>
</tr>
<tr>
<td>Non-spin</td>
<td>76</td>
<td>12%</td>
</tr>
<tr>
<td>Total</td>
<td>199</td>
<td>15%</td>
</tr>
</tbody>
</table>

Reserve detail for Columbia Grid EIM vs. BAU
Regional EIM – NTTG

- Average reserves;
- Very small solar;
- Wind dominates savings;
- ~4200 MW wind and 20 MW solar.

<table>
<thead>
<tr>
<th>Reserve Reduction</th>
<th>MW</th>
<th>% Reduc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Reg</td>
<td>28</td>
<td>12%</td>
</tr>
<tr>
<td>Wind Reg</td>
<td>87</td>
<td>45%</td>
</tr>
<tr>
<td>Solar Reg</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Total Reg</td>
<td>82</td>
<td>25%</td>
</tr>
<tr>
<td>Spin</td>
<td>79</td>
<td>42%</td>
</tr>
<tr>
<td>Non-spin</td>
<td>158</td>
<td>42%</td>
</tr>
<tr>
<td>Total</td>
<td>319</td>
<td>36%</td>
</tr>
</tbody>
</table>
Regional EIM – WestConnect (WC)

- Average reserves;
- Substantial saving from wind and solar;
- ~5700 MW Wind and 4550 MW solar.

<table>
<thead>
<tr>
<th></th>
<th>Reserve Reduction MW</th>
<th>% Reduc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Reg</td>
<td>113</td>
<td>22%</td>
</tr>
<tr>
<td>Wind Reg</td>
<td>105</td>
<td>41%</td>
</tr>
<tr>
<td>Solar Reg</td>
<td>46</td>
<td>20%</td>
</tr>
<tr>
<td>Total Reg</td>
<td>253</td>
<td>34%</td>
</tr>
<tr>
<td>Spin</td>
<td>154</td>
<td>27%</td>
</tr>
<tr>
<td>Non-spin</td>
<td>307</td>
<td>27%</td>
</tr>
<tr>
<td>Total</td>
<td>714</td>
<td>29%</td>
</tr>
</tbody>
</table>

Reserve detail for WestConnect EIM vs. BAU

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>EIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Reg</td>
<td>519</td>
<td>406</td>
</tr>
<tr>
<td>Wind Reg</td>
<td>258</td>
<td>153</td>
</tr>
<tr>
<td>Solar Reg</td>
<td>236</td>
<td>190</td>
</tr>
<tr>
<td>Total Reg</td>
<td>749</td>
<td>496</td>
</tr>
<tr>
<td>Spin</td>
<td>571</td>
<td>417</td>
</tr>
<tr>
<td>Non-spin</td>
<td>1141</td>
<td>834</td>
</tr>
<tr>
<td>Total</td>
<td>2461</td>
<td>1747</td>
</tr>
</tbody>
</table>
Conclusions

• Method for calculating additional reserve requirements due to wind and solar production;
• EIM results in substantial reduction in reserves requirements and ramping demand;
• Reduced participation reduces benefits for all but reduces the benefits to non-participants the most;
• Full participation leads to maximum benefit across the Western Interconnection, up to 42% of total reserve requirement;
• Regional EIM implementations have smaller but substantial benefits.