Statistical modelling for inclusion of wind generation in industrial adequacy studies

Amy Wilson

Durham University

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   - Correlation between demand and wind
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Wind generation and capacity adequacy

Increasing wind generation in energy systems - will the wind be there when we need it?
Wind generation and capacity adequacy

Current capacity adequacy methods assume conventional generation at a given time is independent of the demand at that time. Holds for wind generation?
Wind generation and capacity adequacy

- Model for amount of available wind at a given demand level is required.
- Hindcast? Insufficient data at low wind/high demand times.
- Independence? Doesn’t hold.
Current methodology

Non-sequential approach:
- Does not use a stochastic process to model conventional generation (also often variable generation).
- Instead, distribution of conventional generation estimated at a random point in time (so averaged over all time periods).
- Sufficient for expected value indices.
Non-sequential vs. sequential

Ideal situation - full sequential joint model for demand, conventional generation and variable generation.

- Accounts for correlations through time,
- Model extra aspects of the system such as time to repair,
- Allows for interdependencies that change through time,
- More complete picture of capacity adequacy - probability distribution for size of shortfall.

Problem: this would be a very large project.
Two projects:

  - Non-sequential,
  - Nine years of demand data (rescaled to 2014/15 scenario), 28 years of temperature and wind speed data (wind generation data obtained by combining wind speed data with 2014/15 scenario).

- EPRI project - pilot project for investigating probabilistic methods for including variable generation (VG) when assessing capacity adequacy and highlight further research requirements.
  Three years of data from four regions: BPA, Duke, NVP, WY.
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Correlation - non-sequential

- Demand and wind correlated through time - both have seasonal patterns over year and over day.
- Correlated through temperature?
- Investigated presence of correlation beyond temperature and seasonal patterns.
- Regression model for peak daily demand, conditional on day of week, temperature, days since GMT, \((\text{days since GMT})^2\) (based on model used internally by National Grid).
- Tested whether inclusion of wind speed at time of peak daily demand necessary.
Correlation - non-sequential

- Wind speed term statistically significant (significance likely to be overestimated), but only raised $R^2$ from 91.4% to 91.8%.
- Impact on residuals only seen at high wind speeds - not important for capacity adequacy.
Statistical model for wind

- Peak demand and wind approximately independent at low wind speeds (i.e. times of system stress), conditional on time and temperature.
- So model wind generation conditional on time and temperature (not demand).
- Regression model for wind generation conditional on: temperature (non-linear terms included to allow for differences at high and low temperatures), days since GMT, \((\text{days since GMT})^2\), hour and year.
- Logistic transformation of wind generation to improve fit.
- Random year term added to incorporate weather patterns that change between years \((\text{year} \sim N(0, \sigma^2))\).
Is temperature necessary?

And large improvement in model fit summary statistics.
Risks of independence assumption
Estimating the LOLE

Use model to estimate LOLE:

\[ P(D_t - Y_t > X_t), \]

\( D_t \) = demand (time t), \( Y_t \) = wind (time t), \( X_t \) = conventional generation.
For each \( t \) over period of data

- Take demand and temperature as in historical data (demand rescaled),
- Sample wind generation conditional on this demand and temperature,
- Estimate \( P(D_t - Y_t > X_t) \) from conventional generation distribution.
LOLE results

<table>
<thead>
<tr>
<th>Year</th>
<th>LOLE (hours per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005–06</td>
<td>0.45</td>
</tr>
<tr>
<td>2010–11</td>
<td>3.12</td>
</tr>
<tr>
<td>2013–14</td>
<td>0.13</td>
</tr>
</tbody>
</table>

**Table**: LOLE estimates conditional on one year’s demand/temp profile.

<table>
<thead>
<tr>
<th>Method</th>
<th>LOLE (hours per year)</th>
<th>Lower bound (90% interval)</th>
<th>Upper bound (90% interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Temperature as proxy for demand</em></td>
<td>1.15</td>
<td>0.52</td>
<td>1.95</td>
</tr>
<tr>
<td>Hindcast</td>
<td>0.68</td>
<td>0.31</td>
<td>1.17</td>
</tr>
</tbody>
</table>

**Table**: LOLE estimates over whole dataset.
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Demand/wind correlation - sequential

Sequential model accounting for time and temperature.
Technical challenges

- Sequential model for wind needs improving - not stationary,
- Seasonal effects over day, year. Diurnal effects change through year,
- Link with historical demand, or model demand (difficult),
- Need sequential model for conventional generation.
Wind generation not independent of demand (time, temperature, more?),

- Inadequate data for accurate hindcast estimates,
- Statistical model for wind generation developed - models dependence on time and temperature,
- Sequential approach?
With thanks to:

- Chris Dent,
- Stan Zachary,
- National Grid,
- EPRI and EPRI project partners.