RD3-42: Development of a High-Resolution Virtual Wind Simulator for Optimal Design of Wind Energy Projects

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**Congressional District:** Minnesota 5th
Project Objectives

• Develop, validate and demonstrate the capabilities of an advanced high-performance computing ‘Virtual Wind Simulator’ (VWiS) for predicting atmospheric boundary layer flow and its interactions with wind turbines and wind farms.

  – Improve the design of potential wind energy projects by providing more accurate predictions of local wind turbulence at site and turbine levels.

  – Increase the level of wind energy utilization and reduce the cost of energy production.
Project Tasks

1. Develop the VWiS for high-resolution simulations of wind turbulence and their effect on energy production

2. Validate the VWiS using wind tunnel measurements

3. Test the VWiS using measurements collected at an operational utility-scale wind farm

4. Apply the VWiS to assess wind resources at an undeveloped site with complex terrain
Task 1: Develop the VWiS

Weather Research Forecast Model (WRF)

100km~1000km

Large-eddy simulation

Inflow:
WRF + Synthetic turbulence

Actuator line/disk

Complex terrain

1km~10km

0.1km
Task 2: Validate the VWiS with Wind Tunnel Experiments

Comparison of VWiS predictions (lines) with experiments (circles)
Task 3: Apply VWiS at an operational wind farm (Mower County)

(a) Without inflow turbulence

(b) With inflow turbulence

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<tr>
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<th>T39</th>
<th>T40</th>
<th>T41</th>
<th>T42</th>
<th>T43</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured power (MW)</td>
<td>2.15</td>
<td>2.14</td>
<td>1.86</td>
<td>1.85</td>
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<tr>
<td>Calculated power (MW)</td>
<td>2.38</td>
<td>2.13</td>
<td>2.75</td>
<td>1.51</td>
<td>2.14</td>
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Task 4: Prairie Island wind resource assessment using the VWiS

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<th>T1</th>
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<th>T3</th>
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<th>T5</th>
<th>T6</th>
<th>T7</th>
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</thead>
<tbody>
<tr>
<td>Power (MW)</td>
<td>0.4</td>
<td>0.17</td>
<td>0.45</td>
<td>0.65</td>
<td>0.55</td>
<td>0.55</td>
<td>0.25</td>
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Lessons learned

• Simplifying approximations of the turbine geometry with actuator disks or rotating actuator lines can predict turbine power output at utility-scale wind farms with reasonable accuracy.

• Extensive wind tunnel experiments combined with strategically collected field measurements provide a feasible and effective approach for validating computational models.

• Taking into account atmospheric turbulence effects is extremely important for obtaining accurate wind resource assessment results.

• Neglecting turbulence leads to artificially long turbine wakes and can considerably under-predict the performance of utility-scale wind turbines by as high as 60%.
Lessons learned (cont.)

• Arranging turbines in staggered fashion, as compared to the more traditional aligned arrangement, can lead to significant gains in wind farm performance (as high as 10 percent).

• Site topography and the complex turbulence it induces can have a profound effect on wind farm performance and needs to be taken into account when deciding turbine placement.

• Turbines at Prairie Island need to be installed more than 1km away from the complex terrain and need to be carefully arranged.
Project benefits

• The VWiS provides wind farm developers and operators with a powerful science-based computational tool that can take into account site-specific topography, turbine-atmosphere and turbine-turbine interactions in wind farms. Such effects could not be predicted with existing models.

• Reliable computational model for predicting the power output of and dynamic loading on wind turbines in utility-scale wind farms

• The ViWS can be used to improve the reliability of existing wind farms by allowing operators to assess turbulence loads on turbines in order to:
  1. Identify excessively loaded turbine blades that are likely to fatigue; and
  2. Develop proactive maintenance and health monitoring strategies.
Project benefits (cont.)

- The ViWS can provide a powerful tool for future wind project development:
  - Scientific approach for arranging and spacing wind turbines
  - Optimize wind farm efficiency and enhance reliability by reducing turbulence loads on blades
  - Take into account complex terrain and enable the development of wind projects at challenging sites

- Benefits to the Xcel Energy ratepayers:
  - Reduce the cost of energy for new and existing wind farm installations by increasing power production, reducing maintenance costs, and improving turbine designs.
  - Reduce future energy rates and the need for the federal and state governments to subsidize new wind farm development.
  - Help Minnesota reach its renewable energy goal (25% by 2025) by advancing wind energy as a major renewable electricity resource
Thank you!