Wind Potential and Turbulence Characteristics Assessment for Complex Sites

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To be presented to the
Fachhochschule Techikum Wien
Institut für Erneuerbare Energie
6 October 2017
Presentation Outline

Part 1

- A review of experiences with early wind turbine designs ranging from 10 to 600 kW
- Identifying the turbulence properties and processes that have the greatest impact on wind turbine operations and longevity from detailed field research conducted on 65 and 600 kW turbine designs
- Examples of the response of a 10 kW turbine in complex terrain and a 300 kW of very flexible design at the NWTC

Part 2

- Simulating wind turbine turbulent inflow – TurbSim
- Numerical simulations
- Using TurbSim for small wind turbine design
- Experience with turbine simulations driven by TurbSim-generated inflows
- Some final thoughts
# Early Wind Turbine Examples Discussed

<table>
<thead>
<tr>
<th>Turbine</th>
<th>Rotor Diameter</th>
<th>Rated Power</th>
<th>Rotor</th>
<th>Hub</th>
<th>Power regulation</th>
<th>Yaw control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bergey Excel S</td>
<td>7 m</td>
<td>10 kW</td>
<td>3-bladed, upwind</td>
<td>rigid</td>
<td>furling</td>
<td>passive (tail)</td>
</tr>
<tr>
<td>Jacobs</td>
<td>7.9 m</td>
<td>17.5 kW</td>
<td>3-bladed upwind</td>
<td>rigid</td>
<td>pitch up governor/furling</td>
<td>passive (tail)</td>
</tr>
<tr>
<td>Micon 65/13▲</td>
<td>21 m</td>
<td>65 kW</td>
<td>3-bladed, upwind</td>
<td>rigid</td>
<td>stall</td>
<td>active</td>
</tr>
<tr>
<td>Lynnette Assoc. AWT-26</td>
<td>26.2 m</td>
<td>275 kW</td>
<td>2-bladed, downwind</td>
<td>teetered</td>
<td>stall</td>
<td>passive</td>
</tr>
<tr>
<td>Cannon Wind Eagle CWE300</td>
<td>29 m</td>
<td>300 kW</td>
<td>2-bladed, downwind</td>
<td>teetered</td>
<td>stall</td>
<td>passive (&gt; 50 kW)</td>
</tr>
<tr>
<td>DOE/NASA MOD-0A</td>
<td>38.1 m</td>
<td>200 kW</td>
<td>2-bladed, downwind</td>
<td>rigid</td>
<td>full span, active collective pitch</td>
<td>passive</td>
</tr>
<tr>
<td>Westinghouse WWG600▲</td>
<td>42 m</td>
<td>600 kW</td>
<td>2-bladed, upwind</td>
<td>teetered</td>
<td>full span, active collective pitch</td>
<td>active</td>
</tr>
</tbody>
</table>

▲ turbines primarily discussed and used to develop understanding of turbulent-turbine interaction
Dominant Issues Revealed

- Chronic power underproduction often encountered

- A range of mechanical failures with blades, yaw and pitch drives, generators, and drivetrains

- Failures, while occurring with operation at any hour of the day, were particularly frequent during the nighttime hours often in the hours near and after local sunset
Results of 22 years of Research Into Understanding the Impact of Turbulence on Wind Turbines

- Developed a physical understanding of the role of atmospheric turbulence plays in the dynamic response of wind turbines and its relationship to fatigue damage and risk of mechanical failure.

- Described the atmospheric dynamics responsible creating the inflow turbulent conditions most damaging to wind turbines.

- Developed a stochastic numerical simulation of such conditions that can be used to drive turbine dynamic design codes in order to engineer ameliorating design solutions.
Turbulence-Turbine Interaction – The Basis for the Development of the TurbSim Stochastic Simulator

Available for download from the NREL Publications Web Site
https://www.nrel.gov/docs/fy12osti/52353.pdf
What Did We Learn About How Atmospheric Turbulence Impacts the Operation of Wind Turbines?
Turbulence and Wind Turbines

- Turbulence in the turbine inflow has a significant influence on the power performance efficiency and the lifetime of turbine components.

- The primary source of degraded performance and component reliability are the unsteady aerodynamic effects created by turbulent flow over the turbine rotor blades.

- These unsteady effects create dynamic loads on the rotor blades that in turn excite a range of vibrational frequencies associated with the turbine structure that must be dissipated by the turbine structure.
Turbulence-Induced Dynamic Loads

• The fluctuating structural loads created by turbulent flow across the turbine rotor blades are one of the most important sources of cyclic stresses in the mechanical components of the turbine.

• These cyclic stresses cumulatively induce component fatigue damage that continues to increase until failure.

• We will discuss what we have found in our research that relates turbulent flow properties to fatigue damage accumulation.
Adjacent Micon 65/13 Turbines @ Row 37

- Two identical extensively instrumented turbines except for their rotor blades
- Left turbine used original AeroStar OEM blades & right turbine was equipped with new NREL-designed thin airfoil blades optimized for these wind turbines
- Extensively instrumented meteorological mast upwind and in between the turbines that included atmospheric stability measurements and a 3-D sonic anemometer at near hub height
Using An Upwind Inflow Array and a Westinghouse 600 kW (NWTC ART) Turbine

Details of Inflow Turbulence Dynamics Measured By Planar Array of Five Sonic Anemometers

Nov 1999-April 2000
A Discussion of the Results from Real World Small Turbine Experiences
Strong vertical turbulent momentum flux takes place into rotor under slightly stable conditions as a consequence of the flow being channeled by the upstream terrain.
The Response of the CWE300 Flexible Wind Turbine to Turbulence

An example of how the structure of the inflow turbulence can impact the aeroelastic response of a wind turbine
The Attributes of the TurbSim Stochastic Inflow Turbulence Simulator

- The simulations created by TurbSim are derived from measurements taken as part of early legacy turbulence field programs and from three wind energy sites by NREL and include data from
  - Upwind, downwind, and at Row 37 of a 41 row wind farm in San Gorgonio Pass California
  - An upwind planar array on Row 4 of the National Wind Technology Center
  - A 120-m meteorological mast located on the high plains of Southeast Colorado
Overview

- TurbSim generates time series of 3-component winds on a rectangular 2-D (Y-Z) grid in space
- Intended to be used with AeroDyn, as input for a wind turbine model
- **Statistical** engineering simulation (not physics-based)
Wind Turbine Dynamic Simulation with NREL/NWTC Design Codes

For the latest information see: https://wind.nrel.gov/forum/wind/viewtopic.php?t=341
Thank you for your attention!