Wind Turbine Technology Research at Sandia National Labs

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University of Massachusetts Lowell
Sandia National Laboratories

“Exceptional Service in the National Interest”

- National Security Laboratory
- Broad mission in developing science and technology applications to meet our rapidly changing, complex national security challenges
**Energy and Climate Program Areas at Sandia**

**Mission:** The **Energy Program Area** home to research programs in
- renewable energy systems
- nuclear energy systems
- energy for transportation
- energy efficiency.

Address the challenges of:
- reducing our dependence on foreign oil
- advancing energy storage technologies

**Mission:** The **Climate Program Area** is home to research programs for
- sensing and monitoring
- carbon capture, sequestration
- water systems.

These programs will tackle the important challenges of:
- providing the foundation to a global climate treaty
- closing the carbon cycle through credible carbon management strategies
- assuring water safety, security, and sustainability

**Director, Margie Tatro**

**Director, Rob Leland**

[Image of Sandia National Laboratories logo]
Innovative Blade Developments

Recent History

BMI 2000-02  ERS-100

Carbon-Hybrid Blade Developments
2003-05  CX-100, TX-100

WindPACT (2001-05)  BSDS

CX-100 with Flap for Active Control (2011-12)

STAR 27m Swept Blade  (2005-09)

Sensor Blade I/II  (2008-10)
**Blade Reliability Collaborative**

- **Goal:** Develop a collaborative framework to determine the causes of premature blade failure, the best inspection methods, and the adequacy of modeling tools and testing protocols.

- **Methodology:**
  - **Blade Defect and Damage Database** – Aggregate data from blade manufacturers, service companies, and operators to determine largest sources of blade unreliability.
  - **Inspection Validation** – Evaluate the ability of inspection techniques to accurately characterize blade defects and damage in manufacturing plants and in the field.
  - **Effects of Defects**
  - **Analysis Validation**
  - **Certification Testing**
  - **Standards and Partnerships** – Identify pathways to implementing improved design, manufacture, and inspection with international standards committees and industrial partners.

- **Partners:** SNL AANC, Montana State, NREL, EPRI, U-Mass. Lowell, GE, Vestas, Gamesa, TPI Composites, Rope Partners, EDPR, Dantec Dynamics.

SNL Contact: Joshua Paquette
Materials Research

- **Goal:** Advance the state of composite materials for use in large-scale wind turbine blades.

- **Methodology:**
  - Determine composite fatigue & strength properties
    - New materials & forms
    - Ply drops, adhesives, core, alternate materials
  - Engineer materials to reduce weight & increase reliability of blades
  - Build up SNL/MSU Fatigue Database
    - Material properties (10000+ tests for 175 materials)
    - Develop design improvements
      - Structurally more efficient airfoils
      - Composite hybrids

- **Partners:** Montana State and multiple industry members; PPG, Owens-Corning, Reichold, Arkema, GE, Clipper, many others

SNL Contact: Josh Paquette
**Aerodynamics & Aero-acoustics**

- **Goal:** Enable innovation in blade design through the use of advanced models for predicting blade loads and noise.

- **Recent Projects**
  - Computational Fluid Dynamics (CFD) analysis of MW-scale blades with innovative inboard design features (with UC-Davis)
  - Development of the TANDEM code for prediction of wind turbine blade trailing edge noise (with Penn State University)
  - Unsteady blade loading models for active aerodynamic load control devices (trailing edge flaps).

SNL Contact: Matt Barone
Structural and Mechanical Adaptive Rotor Technology (SMART Rotor)

**Goal:** Investigate the blade fatigue load control potential of small, light-weight control devices and control systems with simulations and validate the simulation results with wind-tunnel and flight tests.

**Program Focus:**
- **Field test** – 9-m active aerodynamic load control (SMART) blade set on Micon test turbine at Bushland, TX
- **Devices** – investigate conventional flaps, micro tabs, morphing trailing edges and micro flaps
- **Sensors** – investigate suitability/reliability for measurement of structural and aerodynamic states
- **Controls** – develop appropriate control algorithms
- **Wind tunnel** – test gust response of model with integrated devices and actuators
- **Simulation tools** – improve resolution and fidelity, validate

**Industry Impact & Opportunities:**
- Improved blade fatigue load control, leading to rotor weight reductions or increased rotor area, and lower cost of energy

SNL Contact: Dale Berg
CREW: Continuous Reliability Enhancement database for Wind

Create a *national reliability database* of wind plant operating data to enable reliability analysis

- Track operating performance at a system-to-component level
- Characterize issues and identify technology improvement opportunities
- Enable O&M cost reduction
- Benchmark reliability performance
- Protect proprietary information
- Increase confidence: financial sector and policy makers

SNL Contact: Alistair Ogilvie
Fault Summary

- Fault Rate & Fault Downtime, ordered by unavailability impact
  - Average Annual Fault Rate = expected # faults per year per turbine
  - Mean Downtime per Fault = average duration of a single fault

Event Data Source: ORAP for Wind®
# Renewable Systems Integration

## Project Objectives

- Develop power system simulation models for wind power plants that regional transmission operators can utilize

- Improve on the first generation of wind power plant models to include emerging wind power plant functionality

- Validate models against field data to ensure proper behavior of model during system events

Contact: Ben Karlson - Benjamin.Karlson@sandia.gov
Generic Wind Power Plant Modeling

Actual Wind Power Plant Layout

- POI or connection to the grid
- Interconnection Transmission Line
- Collector System Station
- Individual WTGs
- Feeders and Laterals (overhead and/or underground)

Equivalent Wind Power Plant Representation for Simulation

- Interconnection Transmission Line
- Station Transformer(s)
- Collector System Equivalent
- Pad-mounted Transformer Equivalent
- Wind Turbine Generator Equivalent
- PF Correction Shunt Capacitors
- POI or Connection to the Transmission System
- Plant-level Reactive Compensation

...or in special cases (e.g., heterogeneous feeders or WTGs of different types)...

Type 4 WTG
Type 1 WTG

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Wind Turbine Generators & Models

**Type 1 WTG**
Cage Rotor Induction Generator

**Type 2 WTG**
Wound Rotor Induction Generator with variable rotor resistance

**WECC WT1**
Generic Model
Volt/frequency protection modeled separately

**WECC WT2**
Generic Model
Volt/frequency protection modeled separately

**Type 3 WTG**
Doubly Fed Asynchronous Generator (DFAG)

**Type 4 WTG**
Full Converter (FC)

**WECC WT3**
Generic Model
Volt/frequency protection modeled separately

**WECC WT4**
Generic Model
Volt/frequency protection modeled separately
<table>
<thead>
<tr>
<th>Industry Effort</th>
<th>SNL’s Role</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WECC – Renewable Energy Modeling Task Force</strong></td>
<td><strong>Task Force Chair</strong></td>
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<tr>
<td>● Improve/expand model structure to cover a wider range of WTG controls and capabilities</td>
<td></td>
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<tr>
<td>● Validation practices (including plant level, field data)</td>
<td></td>
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<tr>
<td>● Improve availability of default model data for generic models</td>
<td></td>
</tr>
<tr>
<td><strong>IEEE – Dynamic Performance of Wind Power Generation Working Group</strong></td>
<td><strong>Former Chair – Participating Member</strong></td>
</tr>
<tr>
<td>● Technical coordination</td>
<td></td>
</tr>
<tr>
<td><strong>IEC TC88 WG27 – Electrical Simulation Models for Wind Power Generation</strong></td>
<td><strong>Lead Delegate for the U.S.</strong></td>
</tr>
<tr>
<td>● Standard generic model specifications</td>
<td></td>
</tr>
<tr>
<td><strong>EnerNex/UWIG Project</strong></td>
<td><strong>Project Member</strong></td>
</tr>
<tr>
<td>● Generic model refinement and documentation</td>
<td></td>
</tr>
<tr>
<td><strong>EPRI/NREL/SNL Validation Project</strong></td>
<td><strong>Project Member</strong></td>
</tr>
<tr>
<td>● Generic model validation and refinement</td>
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**Goal:** Enable the creation and widespread use of more advanced, more accurate numerical models for simulation and evaluation of new wind energy technology.

**Program Focus:**
- Full aeroelastic system dynamics
- Fluid/structure interactions
- Blade structural modeling
- Leverage Sandia’s high performance computing

**Industry Impact & Opportunities:**
- Enable the shift from small system build/break/redesign to effective advanced simulations for large systems of the future
- Reduce risk and cost in new design evaluation and development

SNL Contacts: Brian Resor
Blade Design with NuMAD

NuMAD:
Numerical Manufacturing And Design Tool

Blade Geometry

Materials & Layups

Stack Placement

ANSYS FE Model

ANSYS Analysis

Modal

Buckling

Stress & Strain

Beam Properties
Wind turbine blades include:

- Variable section shapes with twist,
- Multiple materials and composite layups (glass, carbon, balsa, foam, epoxy, adhesives)
- One or more shear webs

Beam Model: Up to 6 DOF per node (Colors represent composite stacks)
System Analysis with Wind Turbine
Aeroelastic Simulation

Aerodynamic Performance

Turbulent Wind Input

Structure and Materials

Aeroelastic System Dynamics Model
Includes Controls Implementation

System Response

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Wind Radar Program

Mitigation Strategy

**Goal:** Develop mitigation options to reduce the reflectivity of wind turbine rotors.

- Test COTS technologies to determine which are most effective at reducing impact of turbines on radars.
- Design a producible wind turbine blade with a significantly reduced radar cross section.

**Approach:**

- Identify potential material combinations
- Demonstrate that these combinations can be produced in small sections (18”x18”)
- Test the RCS of these blade sections
- Produce a 9 or 13 meter blade with the new material combinations and test RCS in field

SNL Contact: Dave Minster
First Test of COTS Technologies to Mitigate Effects of Wind Turbines on Radars
Offshore Wind

- Technical challenges, higher costs
- Close to load centers
- Limited shallow depths in U.S.
- Proposals in U.S.
  - Cape Cod (Cape Wind)
  - Long Island (LIPA)
  - Texas gulf coast
- 1500 MW installed in Europe

<table>
<thead>
<tr>
<th>Country</th>
<th>Capacity (MW)</th>
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<tbody>
<tr>
<td>Belgium</td>
<td>30</td>
</tr>
<tr>
<td>Denmark</td>
<td>397.9</td>
</tr>
<tr>
<td>Ireland</td>
<td>25</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>246.8</td>
</tr>
<tr>
<td>Sweden</td>
<td>133.3</td>
</tr>
<tr>
<td>UK</td>
<td>588</td>
</tr>
<tr>
<td><strong>Total capacity - World</strong></td>
<td><strong>1,421</strong></td>
</tr>
</tbody>
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**Source:** BTM Consult ApS - March 2009

SNL Contact: Todd Griffith
Current Offshore Wind Research Activities

- **Offshore Structural Health and Prognostics Management***
  - Develop optimization functions that balance the performance, rate of growth of damage and the associated cost of repair / replacement

- **Offshore Innovative Concepts and Approaches**
  - Concept studies on the co-location of offshore wind and MHK energy devices
  - Evaluate feasibility for VAWT technology and leverage longstanding history and knowledgebase

- **Large Off-Shore Rotor Development**
  - Design studies for very large rotors to identify and assess enabling technologies
  - Phase II reference model inclusive of rotor innovations

- **Sediment Transport, Scour and Foundation Impact Analysis****
  - Predict flow and scour around foundations, anchors, and moorings of offshore wind power devices, arrays of devices, and their inner-array cable installations
  - Develop specifications for required flow measurements, measuring flow fields, and collecting representative erosion rate data as a function of shear stress to estimate scour

- **Interaction of Wind and Wave Loading Simulations**

* Leverage existing landbased program
** Leverage existing water power program
Large Blade Innovations

100-m Sandia Blade Design

**Goal:** Provide technology research to produce innovations and advanced design concepts to develop very large utility-grade blade and rotor designs for offshore and onshore (where possible).

- **Methodology:**
  - Develop and apply scaling laws to scale-up of 5 MW turbine system.
  - Create 13.2 MW Sandia Baseline (100 m long blade) with detailed composite laminates
  - Apply innovative concepts to baseline to reduce weight, and improve performance & cost effectiveness

- **Partners:** European UpWind Program

**FY10 Offshore Accomplishments:**

- Completion of baseline 100-meter blade for offshore applications
- Visualization Study for 1/3 scale floating wind turbine platform for the DeepCWind Consortium
Thank You