NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Up to Wind Speed

September Newsletter

Up to Wind Speed is a quarterly newsletter from the U.S. Department of Energy's National Wind Technology Center (NTWC) at the National Renewable Energy Laboratory (NREL).

For more than two decades, research conducted by NREL's Wind Program has helped industry advance wind energy technology, increasing reliability and lowering the cost of energy. As we continue our efforts with the wind industry in 2011, we will keep you up to speed on what's happening in wind energy research and development and provide you with links to NWTC's recent publications.

In this issue:

Studying the Wake of the Wind – TWICS

Prevailing winds sweep eastward off the slopes of the Rocky Mountains and create powerful and turbulent currents flowing past the National Wind Technology Center's (NWTC) research wind turbines. These gentle giants are representative of today's multi-megawatt machines that produce wakes of invisible ripples, which can influence the atmosphere of wind turbines downstream. Understanding their atmospheric effects is important to wind farm dynamics.


Three multi-megawatt wind turbines at the National Wind Technology Center. *PIX 18939*.

A multi-organizational team of scientists and researchers used a scanning LIDAR (Light Detection and Ranging) device to create a detailed picture of the atmosphere in front of, and behind, the large turbines at the NWTC site.

The new study, to be published later this year, is called the Turbine Wake and Inflow Characterization Study, or TWICS, and will provide a better understanding of how turbine wakes behave, and how gusts and rapid changes in wind direction affect wind turbine operations.

To measure wind shifts and wake behavior, researchers monitored a 2.3-megawatt research turbine in April and May. Its tower stretches 80 m (328 ft) high to the central hub and 130 m (426.5 feet) to the top of a blade. The high-resolution scanning Doppler LIDAR developed at the National Oceanic and Atmospheric Administration (NOAA) produces a three-dimensional portrait of atmospheric activity and can capture

a wedge of air up to 3,280 feet from the ground and 4.3 miles long.

In addition, the research team collected meteorological data for validation of turbine wake models in a range of atmospheric stability conditions. The data includes air temperature, wind speed, wind direction, and stream variance profiles. Researchers also used data from a specialized laser called a Windcube LIDAR and a sonic detection and ranging system called a Triton SODAR (Sonic Detection and Ranging) to measure wind and turbulence. Additional instruments, including high-frequency sonic anemometers,have been installed on the NWTC's two new 135 meter (440 foot) tall meteorological towers.

"Even fluctuations in air temperature throughout the day can affect wind turbine wakes," said Professor Julie Lundquist of the University of Colorado at Boulder and NREL's National Wind Technology Center. "The resulting changes in wake behavior can impact the productivity of wind farms with their many rows of turbines, so it's important to observe them in detail and understand how to minimize their impacts." Other TWICS researchers include Robert Banta, Yelena Pichugina, Alan Brewer, Dave Brown, Raul Alvarez and Scott Sandberg of NOAA, Neil Kelley and Andrew Clifton of NREL, and Jeff Mirocha of Lawrence Livermore National Laboratory.

The resulting knowledge from the study can improve turbine design standards and suggest wind farm operational methods to increase the productivity of wind farms, ultimately resulting in reductions to the cost of wind energy.

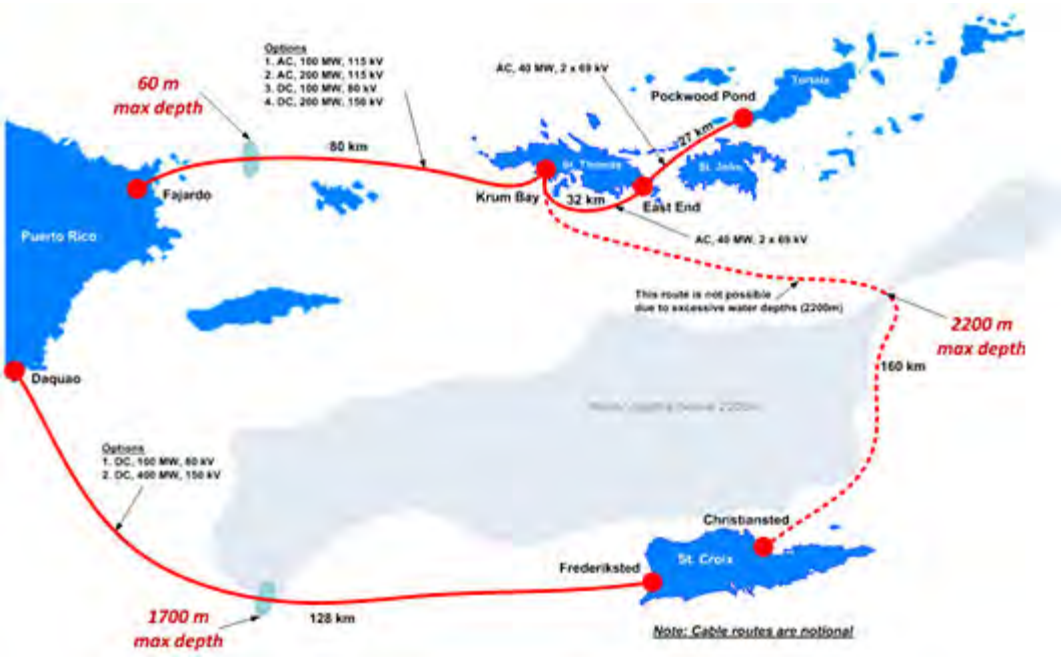
Inter-Island Power Transmission Program

The U.S. Virgin Islands (USVI) face many of the same energy challenges encountered by small island nations around the world, such as dependence on imported fossil fuels and high energy costs. An energy interconnection between St. Thomas and St. Croix islands offers benefits to reduce fossil fuel usage within the local utility, the Water and Power Authority (WAPA) power system. Until recently, such an interconnection was not considered technically feasible due to excessive water depths.

The Energy Development in Island Nations (EDIN) program supports the USVI in their efforts to reduce fossil fuel usage by 60% by 2025. To support the reduction, an inter-island interconnection study is underway. NREL's Transmission and Grid Integration Group (TGIG) has developed several bathymetry maps of the USVI region to assist EDIN in providing technical analysis support to the USVI government and WAPA.

The study focuses on options for a 50-mile interconnection between Puerto Rico and St. Thomas, including a 27-mile interconnection between USVI and the British Virgin Islands (BVI), and an 80-mile interconnection between Puerto Rico and St. Croix (see map below). The objectives of the feasibility study include:

- Determining power capacities, types, and requirements of the three interconnections
- Performing a power system study and identifying necessary infrastructure reinforcements
- Estimating project costs
- Demonstrating potential benefits in terms of generation cost and reliability
- Investigating the impact of interconnection on penetration levels of variable renewable generation (wind and PV) on USVI grid.



Puerto Rico – USVI – BVI interconnection study map.

The NREL maps are based on NOAA bathymetry datasets for the region. These datasets include bathymetry information at 10, 30, and 100-m horizontal resolution. NREL filtered data based on depths and slope angles to create combined depth/slope maps that identify possible submarine cable routes. TGIG offered similar inter-island interconnection analysis for the Oahu Wind Integration and Transmission Study (OWITS). For further information about the USVI analysis, see the Renewable Energy and Inter-Island Power Transmission Presentation.

Comprehensive Gearbox Reliability Collaborative Report Published

NREL recently published the Gearbox Reliability Collaborative Project Report: Findings from Phase 1 and Phase 2 Testing. This document was a collaborative effort by Gearbox Reliability Collaborative (GRC) members and authors and is the first comprehensive description of the GRC project.

The GRC gearbox has a low-speed planetary stage and two parallel stages.

The report describes progress toward meeting the project's goals, which are to:

- Establish a collaborative of wind turbine manufacturers, gearbox designers, bearing experts, universities, consultants, national laboratories, and others to jointly investigate issues related to wind turbine gearbox reliability and to share results and findings
- Design and conduct field and dynamometer tests using two redesigned and heavily instrumented wind turbine gearboxes to build an understanding of how selected loads and events translate into bearing and gear response
- Evaluate and validate current wind turbine, gearbox, gear, and bearing analytical tools/models and develop new tools/models as required (in the report, this activity is referred to as "modeling" to distinguish from data "analysis" activities)
- Establish a database of gearbox failures
- Investigate condition monitoring methods to improve reliability.

Gearbox deficiencies could be the result of many factors and the report discusses the progress that the GRC team has made in its investigations of design, modeling, and testing. The report also highlights 14 findings from the dynamometer and gearbox testing that has been conducted to date. Read the report.

Modeling the Power of Wind Plants

The NREL Transmission and Grid Integration Group (TGIG) collaborates with utilities and grid planners to develop better models of wind plants. TGIG collects data about the power supplied by commercial wind plants and combines it with industry user feedback to validate advanced generator models.

The natural variability of wind power can challenge grid system operators and planners when managing loads, scheduling, line voltage, and determining reserves. Simulation models are used to conduct interconnection studies for proposed and existing wind power plants and assess grid reliability.

Roughly speaking, simulation models fall into one of two categories; planning models and engineering design models. Planning models are implemented in positive-sequence simulation programs, such as General Electric's PSLF/PSDS and Siemens-PTI PSSE programs. They are designed for the study of large-scale interconnected systems. In planning models, simple approximations are desirable to offset computational complexity, and increase simulation speed and data management. The utility industry and other users (consultants, researchers, students, etc.) have grown to expect these models to be nonproprietary, generic, standard, and compatible (or portable) across simulation platforms.

Engineering design models are implemented in three-phase simulation programs such as PSCAD, EMTP, and Matlab/Simulink. These models are generally much more detailed than planning models and are appropriate for conducting a wider range of electrical studies on a proposed or existing project. The studies may include control interaction studies, harmonic/resonance analysis, and equipment/control specification and design.

Using non-proprietary models allows wide distribution of these modeling tools to speed the interconnection process and to better simulate the contribution capabilities of wind turbines to overall power system reliability. NREL works in collaboration with Regional Reliability Organization's (RROs) such as the Western Electricity Coordinating Council (WECC), the California Energy Commission (CEC), and other national laboratories to expand and disseminate the generator modeling information, providing grid operators with a better understanding of the impacts of wind on the utility grid.

NREL Contributes to IEA Wind Research Activities

Since 1977, the United States has been an active participant in IEA Wind—the International Energy Agency research group (Implementing Agreement) on wind energy. Today, NWTC researchers leverage U.S. research dollars by participating in these multi-lateral research activities and by helping plan and manage the work of the groups. NREL represents DOE on every active research task (10 at present). Anyone who is interested can access the information being generated by these groups by contacting the Operating Agent (manager) listed on the IEA Wind website (http://ieawind.org/).

NWTC's Brian Smith served as Chair of the agreement in 2009 and 2010 and NREL manages or co-manages many of these high-profile international activities leading to important technical insights and publications. Highlights of NREL's recent contributions, detailed below, come from the soon-to-be published *IEA Wind 2010 Annual Report,* in the chapter about activities in the United States.

Task 11 Base Technology Information Exchange. Representatives from the United States attend meetings on topics that include radar, radio, and links with wind turbines; sound propagation models and validation; and remote wind speed sensing techniques using SODAR and LIDAR; wind conditions and wind turbine design; high-

reliability solutions and innovative concepts for offshore wind turbines; micrometeorology inside wind farms and wakes between wind farms; and wind farms in complex terrain.

Task 24 Integration of Wind and Hydropower Systems. NREL served as manager of this activity, which has issued a two-volume final technical report. One volume addresses overall issues and one includes case studies from participating countries.

Task 26 Cost of Wind Energy. NREL is managing this activity and has issued the first report described in the June *Up to Wind Speed*. Read the report.

Task 27 Development and Deployment of Consumer Labels for Small Wind Turbines. NWTC's Trudy Forsyth helps the manager of this task (CIEMAT, Spain) and contributed significantly to the U.S. Chapter in 2009 Small Wind Annual Report, the recently approved Recommended Practice for Labeling Small Wind Turbines (see next article), and plans for a Small Wind Association of Testers.

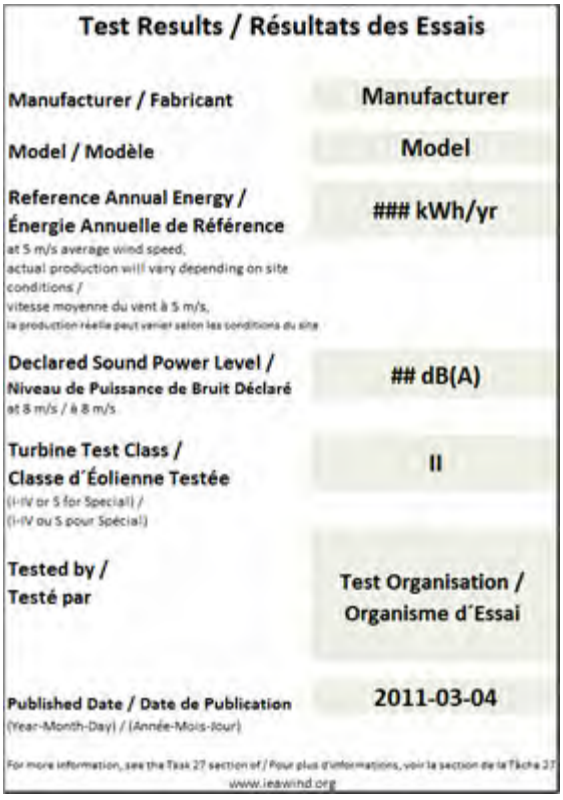
Task 30 Comparison of Dynamic Computer Codes and Models for Offshore Wind Energy (OC4). NREL is co-manager of the task with Fraunhofer IWES, Germany. Assessing jacket structures is managed by Fraunhofer IWES under work package 1. NREL will handle work package 2 that deals with floating semi-submersible structures.

Task 31 Benchmarking of Wind Farm Flow Models. NREL co-manages this work with CENER, Spain. The work further extends the successful work of Task 23 (OC3); subtask 2 managed by NREL's Jason Jonkman and Walt Musial. Read the Final Report for IEA Wind Task 23.

IEA Recently Approved Recommended Practice for Labeling of Small Wind Turbines

Results from the International Energy Agency's (IEA) Wind Task 27, Consumer Labelling [sic] of Small Wind Turbines, include a Recommended Practice, which describes a method for producing the IEA Consumer Label for Small Wind Turbines. NREL's Trudy Forsyth, secretary of IEA Wind Task 27, co-led the label development with 11 participating countries.

The label uses comparable metrics that present test results based on IEC standards in a condensed and comparable form, regardless of where testing is conducted. It provides information that is relevant to the consumer when making purchase decisions, such as the wind turbines estimated energy output, an indicator of durability, and its acoustic parameters. The label gives consumers the ability to easily compare different products available in the small wind turbine market, which is defined as wind turbines with up to a 200m2 swept area. Read more about the label development.



University Students/Researchers Join NWTC for Wind Research

The National Renewable Energy Laboratory (NREL) plays an increasing educational role in the development of renewable energy—a role we could not fulfill without the support of visiting researchers. NREL's National Wind Technology Center (NWTC) interacts with educational institutions, industry, and other research organizations through our

Research Participant Program (RPP).The Research Participant Program (RPP) includes opportunities for Undergraduate and Graduate Internships, Postdoctoral Researchers and Research Associates, and Sabbaticals and Faculty Appointments.

In addition, the NWTC participates in the Science Undergraduate Laboratory Internships (SULI) program. This program is the U.S. Department of Energy's Office of Science undergraduate education and research program. The program is designed to provide undergraduate students with educational training and research experiences to strengthen their knowledge and skills and deepen their commitment to pursue careers in science and technology.

Over the summer, more than 18 university researchers and interns from across the nation and beyond have swelled the ranks at the NWTC, contributing to cutting edge wind research. Some will return to their respective universities in the fall. Others will remain for extended periods.

- **Fiona Dunne**, from the University of Colorado at Boulder, is designing a wind turbine pitch controller that reduces fatigue loads when it has been given a preview measurement of the incoming turbulent wind. Her focus is on feed forward controls in above-rate wind speeds using LIDAR previews. Fiona is funded through a subcontract with the University of Colorado.
- **Bryony DuPont** comes to us from Carnegie Mellon University. She is an RPP student working on her Ph.D. on Wind Plant Optimization, specifically on the optimal layout and turbine design for a given site.
- **Katherine Dykes** is a Ph.D. candidate from the Massachusetts Institute of Technology, Engineering Systems Division. Her work focuses on the deployment of wind energy technology, bringing together models from management and policy areas with more technical models, in particular those for grid integration of wind energy. Katherine assists Maureen Hand on cost modeling efforts for the DOE technology road mapping project. She also is on a team addressing the development of a "systems framework" for wind energy.
- **Lin Fan** hails from Georgia Tech and is an undergraduate SULI student employing high resolution Computational Fluid Dynamics (CFD) to study the impacts of the NWTC's buildings on its wind turbines.
- **Brendan Geels** comes from the Colorado School of Mines. Brendan is a National Science Foundation Fellow and an RPP intern, receiving some of his funding from the Center for Research and Education in Wind (CREW). He will be at the NWTC for 18 months writing his Master's thesis on Drive train Condition Monitoring. Brendan hopes to determine better condition monitoring strategies.
- **Anant Jain** is from Texas Tech University. He will begin the design of a large, two-bladed, high-tip-speed, downwind turbine, with a rigid hub, for use in code comparisons. Anant's design will be the start to his Ph.D. project.
- **Tony Martinez** hails from the University of Puerto Rico. Tony is conducting CFD studies of actuator methods for wind turbine modeling in wind plant (micro-siting) applications.
- **Chris McComb**, from the University of California at Fresno, is working on a summer SULI project for wave energy conversion (WEC) devices that generate electricity from ocean waves. Using a CFD model that has the capability to simulate the performance of WECs, Chris is incorporating power-take-off and mooring line models into the open source CFD code, OpenFOAM. The ability to model high fidelity WECs, with realistic power-take-off systems and mooring lines, will allow more efficient wave devices to be designed.
- **Joshua McDaniel**, is an RPP intern for the Wind Powering America Program from the University of Colorado at Boulder. He processes wind data and equipment for the anemometer loan program. Wind Powering America's Native American anemometer loan program is part of an effort to promote the installation of wind turbines on Native American lands by enabling the measurement of wind resources.
- **Andrew Pace** is from the Colorado School of Mines. His work involves using multiple simultaneous distance measurements from LIDAR, and investigating the use of a disturbance accommodating controller (DAC) to estimate and negate the

affect of extreme wind disturbances. Andrew's research is funded by American Recovery and Reinvestment Act for 18 months.

- **Zach Parsons**, from the Milwaukee School of Engineering (MSOE), is working with the Gearbox Reliability Collaborative. As a SULI student, Zach has spent the last two summers analyzing data on the effects of non-torque loading on a three-point drivetrain suspension to identify design deficiencies contributing to premature gearbox failure.
- **Line Roald** is a Master's-level graduate student from ETH Zürich in Switzerland. Line is working with NREL's offshore modeling team on a thesis project to assess the importance of second-order hydrodynamic effects on offshore floating wind turbines.
- **DeAnna Sewell** comes from the University of Delaware. She is developing a CFD model for transitional, water bottom-mounted offshore wind turbine sub-structures. The model will be used to compute hydrodynamic loads as a comparison to Morison's method, with a particular interest in the joint and horizontal member areas. Current modeling technology relies on Morison's equation, which does not account for several important factors to accurately represent hydrodynamic loads on the structure. DeAnna's work will result in more accurate loads analysis and prediction methods, which will yield more accurate fatigue life estimates.
- **Eric Simley** is from the University of Colorado at Boulder. He is focused on a wind turbine controls project that reduces fatigue loads. Specifically, his research focuses on modeling LIDAR wind speed measurements and studying wind evolution, or the degree to which wind speeds will change between the time they are measured and when they reach a turbine. Eric is funded through a subcontract with the University of Colorado.
- **Søren Stubkier** is a research engineer for AVN Energy A/S and a Ph.D. student at the Institute of Energy Technology at Aalborg University in Denmark. Søren is working with NREL's design tools and controls teams on a thesis project assessing the design and modeling of yaw systems for multi-megawatt wind turbines.
- **Yao Wang** is working on his Master's thesis from North Carolina State University. His work at the NWTC is in CFD modeling of the stable boundary layer and associated turbulence modeling techniques.
- **Na Wang** comes to the NWTC from the Colorado School of Mines and is funded through a Cooperative Research and Development Agreement (CRADA) with Catch the Wind. She is working on a LIDAR-enabled feed forward controller design for turbine load mitigation and power enhancement on the CART3 FAST model. The data originates from the LIDAR simulator embedded in the FAST code.
- **Lindsay Willman,** from the University of Colorado at Boulder, has been working with NWTC staff members on an integrated assessment of MHK power generation for remote areas in Alaska. Lindsay is assessing the technical and economic feasibility of incorporating tidal energy into local energy profiles, including their potential environmental impacts, and regulatory considerations. Her study is expected to provide an integrated assessment procedure for governmental agencies and technology developers.
- **Chris Worley** is a summer wind analysis intern, who recently completed the Mineral and Energy Economics program at the Colorado School of Mines. His dissertation research focused on the role that property rights and market failures play in decisions for locating wind developments. At NREL he is examining how market barriers (like permitting, wildlife, and social nuisance factors) affect the cost of wind development.

Recent NWTC Publications

- 10MW Class Direct Drive HTS Wind Turbine: Cooperative Research and Development Final Report, CRADA Number CRD-08-00312.
- 2010 Wind Technologies Market Report.

- Active Power Control from Wind Power (Presentation). NREL (National Renewable Energy Laboratory).
- Analysis of the Impact of Balancing Area Cooperation on the Operation of the Western Interconnection with Wind and Solar Generation (Presentation). NREL (National Renewable Energy Laboratory).
- Cost-Causation and Integration Cost Analysis for Variable Generation.
- Deployment Barriers to Distributed Wind Energy: Workshop Report — October 28, 2010. (2011).
- Economic Development from Gigawatt-Scale Wind Deployment in Wyoming (Presentation). NREL (National Renewable Energy Laboratory).
- Federal Incentives for Wind Power Deployment (Fact Sheet). Wind and Water Power Program (WWPP).
- Gearbox Reliability Collaborative Project Report: Findings from Phase 1 and Phase 2 Testing.
- How Does Wind Affect Coal? Cycling, Emissions, and Costs (Presentation). NREL (National Renewable Energy Laboratory).
- Impact of High Wind Power Penetration on Hydroelectric Unit Operations in the WWSIS
- Large-Eddy Simulation Study of Wake Propagation and Power Production in an Array of Tidal-Current Turbines: Preprint.
- Large-Eddy Simulation Study of Wake Propagation and Power Production in an Array of Tidal-Current Turbines: Preprint.
- Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning (IVGTF1-2) (Presentation). NREL (National Renewable Energy Laboratory).
- NREL Computer Models Integrate Wind Turbines with Floating Platforms (Fact Sheet). The Spectrum of Clean Energy Innovation, NREL (National Renewable Energy Laboratory). (2011).
- NREL Triples Previous Estimates of U.S. Wind Power Potential (Fact Sheet). The Spectrum of Clean Energy Innovation, NREL (National Renewable Energy Laboratory). (2011).
- Renewable Energy and Inter-Island Power Transmission (Presentation). NREL (National Renewable Energy Laboratory).
- Report on Transmission Cost Allocation for RTOs and Others (Presentation). NREL (National Renewable Energy Laboratory).
- Stakeholder Priorities in Wind Energy (Presentation). NREL (National Renewable Energy Laboratory).
- Testing Active Power Control from Wind Power at the National Wind Technology Center (NWTC) (Presentation). NREL (National Renewable Energy Laboratory).
- Transmission Considerations for Market Operation: U.S. Design (Presentation). NREL (National Renewable Energy Laboratory).
- UWIG Forecasting Workshop — Albany (Presentation). NREL (National Renewable Energy Laboratory).
- UWIG Forecasting Workshop – Albany (Presentation). NREL (National Renewable Energy Laboratory).

- Variable Renewable Generation Impact on Operating Reserves (Presentation). NREL (National Renewable Energy Laboratory).
- Western Renewable Energy Zones (Presentation). NREL (National Renewable Energy Laboratory).
- Wind Energy Benefits, Wind Powering America (WPA) (Fact Sheet). Wind And Water Power Program (WWPP).
- Wind Energy Ordinances (Postcards). Energy Efficiency & Renewable Energy (EERE). (2011).
- Wind Energy Workforce Development: A Roadmap to a Wind Energy Educational Infrastructure (Presentation). NREL (National Renewable Energy Laboratory).
- Wind Integration Study Methods (Presentation). NREL (National Renewable Energy Laboratory).
- Wind Turbine Generator System Power Quality Test Report for the Gaia Wind 11-kW Wind Turbine.
- Wind Resource Maps (Postcard). Wind Powering America (WPA). Energy Efficiency & Renewable Energy (EERE). (2011).
- Wind Turbine Generator System Power Performance Test Report for the Entegrity EW50 Wind Turbine.