Wireless Sensing and Power Harvesting of a Smart Wind Turbine Rotor

Project Outline

a. Goal

The objectives of this project are to:
(1) study the feasibility of quantifying true wind loading with wireless accelerometers,
(2) charge a wireless accelerometer by harvesting the strain energy at the blade root, and
(3) perform passive damage detection of rotor blade.

b. Motivation

Wind energy in the United States is the fastest growing source of clean, renewable and domestic energy. In 2007 5,244 MW were installed at an investment of over $9 billion, which increased the total U.S. wind production by 45% to 16,818 MW. In the last quarter of 2007, 2,930 MW were installed surpassing the total MW installed during all of 2006 (2,454 MW) [1]. Wind energy has near zero carbon and pollutant emissions (most accrued during manufacturing and installation) and benefits the domestic economy.

This significant investment in wind turbines is motivating manufacturers to produce more efficient wind turbines. Efficiency of a turbine can be improved with active rotor blade control to improve wind capture. Active blade pitch [2], microtabs [3], plasma actuators [4] and passive morphing surfaces [5] are just some of the techniques being investigated for active control of the rotor blade. All of these techniques will depend on a measurement of the loading to the blade as the input to the control algorithm, but there is yet to be a clear candidate to provide this measurement. Strain gages, acoustic emission and fiber optics are all being investigated.

Efficiency of a turbine can also be improved with increased size because power available in the wind is proportional to the swept area (square of rotor blade length) and the cube of wind velocity [6-7]. Increased wind velocity can be attained by capturing higher altitude winds with taller towers and longer rotor blades. However, longer blades require higher strength construction and increased mass, which decreases the efficiency of the turbine. As a result, wind engineers are designing less conservative blades.

Sandia National Laboratories is pursuing advances in wind turbine technology to enhance reliability and reduce energy productions costs, specifically by developing a smart rotor blade [8]. The smart rotor blade is envisioned to estimate both loading and deformation caused by wind and then detect induced damage. Purdue University has proposed the use of DC accelerometer technology to capture the mean and dynamic wind loading to wind turbine rotors [9]. DC accelerometers are capable of simultaneously measuring both constant and dynamic acceleration. With these sensors the magnitude of the constant acceleration can be used to determine the rotating forces in the blade and the angle to which the blade is twisted by constant winds. The dynamic loading to the turbine will be identified in terms of the modal operating shapes and amplitudes excited by the wind.

c. Procedure

The general research approach is detailed in Figure 1. Initial modal testing will be performed on a free-free rotor blade to create a validated finite element model. In this testing the average modal frequencies and shapes from the rotor blades will be used as validation for the model. A modal test of the assembled turbine in the laboratory will be performed to properly model the boundary condition of the free-free rotor blades. Measurements will be performed by both wired and wireless sensors for comparison.

In-lab operating loads will be applied to the rotor blades by using the generator as a motor to power the turbine. These loads will be used to verify the estimation of the operating mode shapes from the wireless measurement. On an as-conditions-permit basis, the turbine will be tested outside during steady and unsteady wind conditions. An anemometer in front of the turbine will approximate the wind loading to the rotor blades. Measurement of voltage at a load resistor connected to the generator will be used to approximate the turbine power output. On-site operating mode shapes from true wind loading will be verified with finite element modeling of the same loads. As time permits, a representative or true crack will be produced on one of the rotor blades to investigate possible passive damage detection methods.

Power harvesting of the strain in the root section of the rotor blade will be investigated during the in-lab testing. The ultimate goal, depending on the strain and time available, would be to create a simple circuit to charge the wireless sensor battery. Outdoor testing following successful in laboratory testing, will attempt to identify obstacles to implementing power harvesting on larger scale wind turbines.

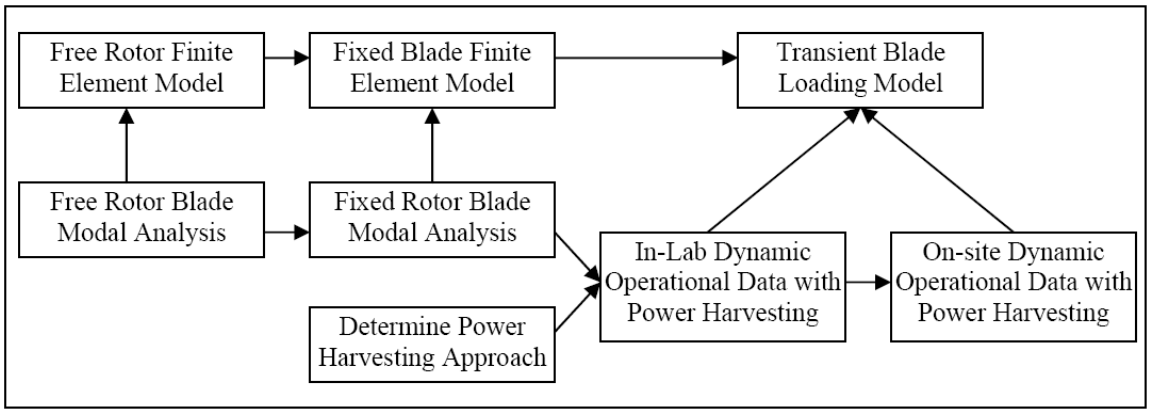

Figure 1, Research Approach for Wireless Rotor Blade

Background Literature

1. [1]
2. [6] p. 68-78, 83-138, 141-194, and 247-317
Or [7] p.11-43, 55-61, 89-124, and 145-159
3. [8]
4. [10, 11]

Project Schedule

Week 1: Safety training and introduction to wind turbine technology [6-7].
Week 2: Modal testing and analysis of free rotor blade. Introduction to power harvesting technology [9].
Week 3: Repeat modal work on other rotor blades. Determine power harvesting approach.
Week 4: Development of validated finite element model of free rotor blade.
Week 5: Modal testing and analysis of rotor blades attached to turbine hub.
Week 6: In-lab testing of operating turbine.
Week 7: On-site testing of operating turbine.
Week 8: Continue on-site testing and compile results.
Week 9: Final report and presentation.

Real Word Design Issues as a Project Consideration

Wind turbine rotor blades with embedded sensors are a potential technology for the substantial improvement in wind turbine efficiency. The work performed in this project is aimed at the concept of wireless sensor integration into utility size (greater than 1.5 MW) turbines with rotor blades longer than 45m. Monitoring of the wind turbine operating mode shapes will accompany similar research on a larger turbine research blade. This technology is directed to the U.S. D.O.E. goal of improving efficiency and reliability of wind turbines.

Facilities and Equipment

1. Whisper 100 (Sandia Labs is pursuing a potential donation from Southwest Windpower.)

Rotor Diameter	7 feet
Weight	47 lbs
Tower	2.5” sched. 40
Start-Up Wind Speed	7.5 mph
Survival Wind Speed	120 mph
Rated Power	900 W at 28 mph
Blades	3-Polypro/carbon glass reinforced

2. Microstrain Wireless (If the range is sufficient, reduced prices may be available.)

Range	± 10 g
Accuracy	10 mg
A/D Converter	12 bit
Frequency Range	0-4 kHz
Real Time Streaming (9 channels)	617 Hz
Dimensions	2.3 x 1.7 x 1 inch
Mass	46 gm

3. Local Wind Site where a 2.5” tower can be raised and lowered day to day.

Software Requirements

1. MATLAB 2006b or newer
2. Abaqus

References

1. American Wind Energy Associtation. "Installed U.S. Wind Power Capacity Surged 45% in 2007: American Wind Energy Association Market Reprt." 2008. http://www.awea.org/newsroom/releases/AWEA_Market_Release_Q4_011708.html (accessed February, 2008)

2. Muljadi, E. and Butterfield, C.. "Pitch-Controlled Variable-Speed Wind Turbine Generation." *IEEE Transactions on Industry Applications* 37, no. 1 (2001): 240-246

3. Yen Nakafuji, D., van Dam, C., Smith, R., and Collins, S.. "Active Load Controls for Airfoils using Microtabs." *Transactions of the ASME* 123, (2001): 282-289

4. Nelson, R., Corke, T., and Othman, H.. "A Smart Wind Turbine Blade Using Distributed Plasma Actuators for Improved Performance." *46th AIAA Aerospace Sciences Meeting and Exhibit*, AIAA 2008-1312 (2008): 1-17

5. de Goeij, W., van Tooren, M., and Beukers, A.. "Implementation of bending-torsion coupling in the design of a wind-turbine rotor-blade." *Applied Energy* 63, (1999): 191-207

6. Manwell, J. F., McGowan, J. G., and Rogers, A. L.. *Wind Energy Explained Theory, Design and Application*, 2002, John Wiley & Sons, LTD., West Sussex, England.

7. Mathew, S.. *Wind Energy Explained Fundamentals, Resource Analysis and Economics*, 2006, Springer Berlin Heidelberg, New York.

8. U.S. Department of Energy. "Wind Energy Multiyear Program Plan For 2007-2012." *Wind and Hydropower Technologies Program* (2008)

9. White, J., Adams, D., Rumsey, M., van Dam, J., and Hughes, S. "Impact Loading and Damage Detection in a Carbon Composite TX-100 Wind Turbine Rotor Blade." *AIAA Aerospace Sciences Meeting and Exhibit Laboratory* (2008)

10. Park, G., Farrar, C., Todd, M., Hodgkiss, W., and Rosing, T. "Energy Harvesting for Structural Health Monitoring Sensor Networks." 2007. www.lanl.gov/projects/ei/pdf_files/LA-14314-MS.pdf (accessed February, 2008)

11. Sodano, H., Inman, D., and Park, G.. "Comparison of Piezoelectric Energy Harvesting Devices for Recharging Batteries." *Journal of Intelligent Material Systems and Structures* 16, (2005): 799-807.