Cal Poly Wind Power Research Center

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Abstract

The Wind Power Research Center is being created at California State Polytechnic University in San Luis Obispo, California. This center brings together faculty, undergraduate and graduate students, and industry partners to conduct applied research and education in support of the wind power industry. Particular emphasis is given to research which serves the needs of manufacturers of smaller wind turbines, and to educating engineers who are well trained to work in all segments of the wind power industry.

1 Introduction

1.1 Background

Although the wind energy industry is expanding rapidly in the United States, academia tends to lag behind the need for directly focused wind energy education and research. The wheels of the academic bureaucracy turn slowly; the mechanisms by which research centers and curricula evolve generally take years to respond to changes in industry. Particularly slow is the change in the academic curriculum, where coursework which directly involves the technology (as opposed to the policy) of wind energy is comparatively uncommon.

In the industry, small turbine manufacturers tend to employ older, less costly, "lower-tech" solutions to the problems of turbine siting, design, and operation. Although this design strategy produces some excellent products, there are gains to be made in cost and energy efficiency by accelerating the pace at which more advanced technology is used with smaller turbines.

1.2 Cal Poly

A group at California State Polytechnic University in San Luis Obispo is working to step up the pace of academic efforts to meet the demands of wind energy for targeted research and well trained graduates. Hosted within the Department of Mechanical Engineering, the Cal Poly Wind Power Research Center brings together faculty, undergraduate and graduate students, and industry partners to solve smaller problems on a more cost effective basis than is usually practicable at institutions with larger research programs. The Cal Poly center is thus designed to work as a complement to the larger programs and fundamental research at research-focused universities.

Cal Poly is ideally situated for small turbine research for several reasons. The first is the location of the institution. On the California coast about halfway between the San Francisco and Los Angeles metropolitan areas, the San Luis Obispo area enjoys year-round temperate weather which seldom interferes with field work. This weather includes a relatively consistent component of wind. During Spring, Summer and Fall, the coastal flow associated with the North Pacific High pressure system is supplemented by thermal gradients between the cool ocean and warm inland regions, and during the Winter months storms regularly bring strong wind to the area.

Cal Poly's location is also beneficial in its relative proximity to the major California wind energy generation centers; all are located within about four hours' driving distance. The area is sufficiently undeveloped that prospective small turbine sites are located within less than ten miles of the university campus. One such site is located on the 2000 acre Escuela Ranch, owned by Cal Poly and used primarily by our College of Agriculture as grazing land. The colleges of engineering and agriculture are currently collaborating on the development of a wind turbine testing facility on this site.

In addition to Cal Poly's location, the academic culture is especially well suited to applied research projects of smaller scale and lower cost than typical projects at many institutions. Cal Poly is characterized by a pedagogical style which emphasizes extensive hands-on participation by students, epitomized by our motto of "Learn by Doing." Our undergraduates are required to complete a Senior project in order to earn their degrees; in some departments such as Mechanical Engineering, the Senior project is conducted as part of a year-long experience in which student teams must design, build, test, and document solutions to a real engineering problems. Most problems are posed by industry partners who act as sponsors.

Cal Poly has extensive facilities which support fabrication and testing activities by students. A 10,000 square foot student machine shop contains traditional and numerically controlled lathes and mills, a welding shop, composite fabrication facilities, and a full wood shop. This facility is dedicated to the support of undergraduate and graduate student projects. Several instructional laboratories in which are taught electronics, composite fabrication, rotordynamics, and control systems are also equipped to support research projects.

Programs for international collaboration exist between Cal Poly Mechanical Engineering and sister departments at several foreign universities such as the Fachhochschule München in Germany and Chalmers University of Technology in Sweden. Because the wind energy industry is more highly developed in several European countries than in the United States, these collaborations – which involve exchanges of students and faculty – offer important opportunities for the transfer of knowledge related to the field.

2 Projects

Several projects are underway at Cal Poly in connection with the wind power center. These include the development of a low-cost wind resource measurement solution, the development of low-cost sensors for use on test turbines, and the development of new technology with which to manufacture affordable, high quality blades for small turbines.

2.1 Blade Design

A principal project currently underway at the Center is the development of a new process for the rapid prototyping of turbine blades, using modern machining and composite manufacturing techniques. Clearly, "rapid prototyping" is outside the realm of standard practice in the utility grade wind turbine manufacturing industry, by virtue of the scale of equipment used. Nevertheless, such a manufacturing process shares much in common with industrial application, and the composite laminate and infusion processes used in the development of the prototype blades is comparable to methods used commercially. The planform development method and structural analysis share commonality with commercial products at all scales.

For the purpose of demonstrating the general method required in setting up rapid prototyping of composite blades, a three-dimensional profile of a simple airfoil with varying chord and twist was carried out. Figure 1 shows the blade profile used, a Clark Y cross-section airfoil with an exaggerated twist and chord distribution. In this particular instance, since blade dimensions were not critical for the purposes of the prototype, they were kept at a practical minimum: a span of approximately three feet and a maximum chord length of six inches. The planform was subsequently manufactured using a computer numerical control (CNC) mill, on ultra-high density foam (see Figure 2).

Ultimately, the goal of this process is to rapidly produce a relatively inexpensive female mold such as

Figure 1: *Model of a twisted, variable chord proof of concept blade.*

Figure 2: *CNC mill used for the manufacturing of rapid prototype composite blade. (Courtesy of Mr. B. Edwards, MS student)*

that shown in Figure 3 from which multiple identical blades may be produced to make at least one full rotor for testing purposes. This proof of concept effort was initiated to evaluate, at minimal expense, how effectively the general manufacturing method may be implemented for manufacturing such prototype test blades in-house. The larger span blades used in the field will be manufactured in a similar manner, using a larger throw CNC router with maximum span of 10 feet and a maximum chord of 2 feet.

Structure

A structural analysis of the manufacturing process required for the composite shell surrounding the shaped core is ongoing, and is based on an evaluation of multiple composite manufacturing alternatives including vacuum bag and resin transfer infusion molding techniques. The internal layout of the composite, foam reinforcement and spars are still undetermined at this point; the proof of concept blade described above is built using a two layers S-glass overlay on a low-density foam core, with resin infusion.

While the overall manufacturing technique is properly representative of the final process being developed, the mechanical properties of this blade are not. Continuing analysis will prescribe the final composite structure and properties of the blades manufactured on campus.

Planform Development

The commercial success of small wind turbine manufacturers demonstrates that aerodynamic efficiency is not a primary priority in that segment of the market. The Bergey XL.1, for example, is a typical example of a small successful machine that uses a very simple non-twisted, constant chord blade. Of course, that philosophy cannot scale to large, utility-grade machines, as the loads produced by an inefficient rotor on that power production scale would be uneconomical to mitigate. It is nevertheless worthwhile to study and apply the same type of philosophy to the design of planforms for small turbines, as the *process* of designing these blades does not depend on size.

Accordingly, the first planform design planned for the Center is one that aims at using a modern Risϕ airfoil profile, and a twist and chord length distribution designed to maximize energy capture at our site at the Escuela Ranch, based on wind speed data collected since January 2008. This is an area of on-

Figure 3: *Completed female mold (Courtesy of Mr. B. Edwards, MS student)*

going research at the Cal Poly Wind Power Center; the newly developed rotor is expected to be complete in the summer of 2009.

2.2 Tower Design

In addition to blade structural design, tower design is critical to the deployment of small wind turbines. Katsanis and Lemieux[1] have developed a novel method of designing towers for small wind turbines, paying particular attention to the analysis of dynamic loads due to vibration and nonlinear effects such as cable slack and buckling. It is anticipated that further refinement of the tower design methodology will be undertaken as part of the field testing at the Cal Poly center.

2.3 Blade Testing

The blade design effort relies on thorough testing to verify the performance and durability of the prototypes. Laboratory testing will be carried out in appropriate facilities, primarily on the Cal Poly campus. Exhaustive field testing will require monitoring the performance, dynamic behavior, and material response (stresses and strains) in the prototypes for long periods of time in operating conditions. In order to meet the need for field testing in an affordable manner, a set of custom low-cost monitoring and measurement devices is being developed at Cal Poly.

The data collection system uses “smart” (microcontroller equipped) data collection nodes which are connected through a wireless mesh data communications system. Data collected at the nodes is stored and processed in situ by the microcontrollers before being periodically transmitted to a receiving station which is located on the Cal Poly campus. The receiving station archives the data and makes it accessible through the Internet.

Wireless mesh networking is a relatively new technology, and affordable commercial solutions which implement this technique with sufficient range for a widely dispersed set of sensors in an outdoor setting are only beginning to become widely available as this project is getting underway. The custom solution which is being developed to meet our data collection needs uses low-power microcontrollers and Digi/MaxStream 900 MHz radio modems. These devices allow sensor nodes to operate unattended from small batteries for periods of months to years depending on the particular sensors being used. The radio modems can transmit data reliably over unobstructed distances from about 1.5 km using simple dipole antennas to over 10 km using high-gain antennas. Most microcontrollers and radios (excepting those in mesh repeaters) are allowed to “sleep” when not actively collecting and transmitting data, resulting in the ability to run for long periods of time from simple batteries and hence not requiring the expense of electrical supply lines or alternative power sources such as solar.

A smart sensor unit which acquires, processes, and transmits blade strain measurements via a point-to-point wireless link has been developed at Cal Poly by Hoffman and Ridgely and tested by Nosti in Summer 2007[2]. Future applications of the sensor technology will include measurements of blade strain, rotor speed and vibrations; additional signals being considered include measured mechanical power capture and electrical power output.

2.4 Resource Measurement

Due to the hilly topography and coastal location in the San Luis Obispo area, the prediction of the average wind resource at a given site quite challenging. Wind resource predictions which are reliable enough to be useful over an area of just a few square miles will require data from many sites. The deployment and maintenance of a sufficiently large number of traditional data logging sensors would be prohibitively expensive. Therefore, the smart wireless system used to measure turbine operating parameters is also being used to create a mesh of wind sensors to cover a large area of the Escuela Ranch facility.

The wind measurement system employs inexpensive AAG One-Wire wind sensors with cup anemometers and simple wind vanes. These components have been chosen for reasonable performance at low cost and power usage. Although the linearity and repeatability of the AAG wind sensors may not be up to the standards of instrumentation-grade products, it is more than sufficient for making site selections for small turbines; and the very low cost and power requirements of these sensors allows them be purchased and deployed at a cost which an operator of small turbines, or a small university, can afford. Rather than the highest measurement accuracy, the Cal Poly project requires reliable data from a large number of sensors.

The radio modems chosen are MaxStream X09-009NSC models upgraded with recent firmware which enables data collection nodes to act as repeaters. This capability is critical, as it allows data to be relayed from sensors which are located out of range or out of the line of sight of the receiving station. Due to the local terrain, having many sensors out of the line of sight of the receiver is inevitable. A prototype wind measurement unit which transmits information from a prospective turbine location on the Escuela Ranch site directly to a receiving station on the Cal Poly campus is shown in Figure 4. A graph of wind speed taken by this station is shown in Figure 5.

Figure 4: *Wind measurement unit with long range (10 km) radio link*

2.5 Collaborations

The Cal Poly Wind Power Research Center is a collaborative effort between the Cal Poly Colleges of Engineering and Agriculture. The test turbines will supply energy for use in agricultural operations at the test site. The most important current need for onsite generated energy at the Escuela Ranch site is for the pumping of water to supply livestock, and it is anticipated that this will be the first practical use. Future uses may include the charging of batteries for vehicles used on the site and in the long term, a supplement to grid power for buildings on site.

Academics

In addition to student research projects, the work of the Cal Poly Wind Power Research Center interacts directly with the undergraduate and graduate curricula at the host institution. In this way, the Center helps to fulfill the need of the wind power industry

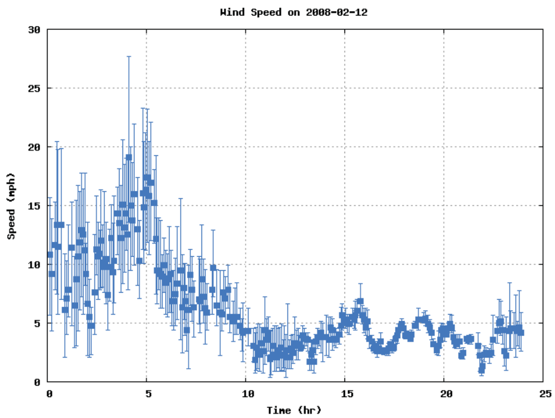

Figure 5: *Typical wind speed data*

for well-trained graduates.

Fluid dynamics being fundamental to turbines, material from wind turbine design is being directly incorporated into the fluid mechanics curriculum at Cal Poly. Lemieux is currently developing new courseware which will directly address the design of wind turbines.

Sensing and automation are important parts of wind power engineering, and the mechatronics curriculum trains students to design and program the computers which carry out this function. The custom hardware and software used for the blade stress and wind sensors is designed to be used not only for data collection but also as an educational tool. The high-level software design follows a modified state machine architecture adapted for embedded systems programming[3]. Programs are coded in C++ and make use of an extensive object library which supports various sensors, actuators, real-time operation, and other features needed in projects similar to the wind resource measurement effort. This software structure is also being used to teach mechatronics courses at Cal Poly. The use of a common programming structure in the research and teaching aspects of this work enhances the effectiveness of undergraduate and graduate students' contributions to the research effort. Because the software is non-proprietary, all components of the project can be shared freely among all interested parties.

The custom circuitry and software are part of an ongoing open source project. Files and documentation can be found by navigating to the web site

`http://me.me.calpoly.edu:1280/research/wiki`

and following the wind turbine project links. It is hoped that the open source materials from this project will become the seeds of a wider collaboration, both in wind energy research and instruction.

References

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[3] Auslander, Ridgely, Ringgenberg, *Control Software for Mechanical Systems: Object Oriented Design in a Real-Time World*, Prentice-Hall, 2002.

[4] Digi/MaxStream product support, `www.maxstream.com`.