Integration of Wind Energy Systems into Power Engineering Education Program at UW-Madison

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Final Report

Executive Summary

This project has developed an integrated curriculum focused on the power engineering aspects of wind energy systems that builds upon a well-established graduate educational program at UW-Madison. Five new courses have been developed and delivered to students. Some of the courses have been offered on multiple occasions. The courses include: Control of electric drives for Wind Power applications, Utility Applications of Power Electronics (Wind Power), Practicum in Small Wind Turbines, Utility Integration of Wind Power, and Wind and Weather for Scientists and Engineers. Utility Applications of Power Electronics (Wind Power) has been provided for distance education as well as on-campus education. Several industrial internships for students have been organized. Numerous campus seminars that provide discussion on emerging issues related to wind power development have been delivered in conjunction with other campus events. Annual student conferences have been initiated, that extend beyond wind power to include sustainable energy topics to draw a large group of stakeholders. Energy policy electives for engineering students have been identified for students to participate through a certificate program. Wind turbines build by students have been installed at a UW-Madison facility, as a test-bed. A Master of Engineering program in Sustainable Systems Engineering has been initiated that incorporates specializations that include in wind energy curricula. The project has enabled UW-Madison to establish leadership at graduate level higher education in the field of wind power integration with the electric grid.

1. Project Objectives

In the emerging energy future, wind power is expected to grow and play a significant role through a major expansion of capacity within the US and elsewhere in the world. In addition to the various technical challenges and solutions, an expansion in the need for skilled personnel is being projected. While the nation's technical college systems are rapidly gearing up to meet the needs of skilled craftsmen and technicians, efforts aimed at the university level education have been sparse. Integration of >20% wind generation into the grid is expected to have a significant impact on the design and operational approaches to manage the variability in wind. Therefore, it is imperative to integrate wind energy technology with curricular programs aimed at advanced students specializing in power engineering education.

This project has developed an integrated curriculum focused on the power engineering aspects of wind energy systems that builds upon a well-established graduate educational program at UW-Madison. Specific objectives have included new course development and adaptation of existing courses on-campus and through distance delivery. Other student activities include industrial internships, professional seminars, and various campus experiences.

2. Project Activities

Project activities have included (i) Course development (ii) Distance delivery (iii) Outreach (iv) UW-Madison wind energy installations (v) Internships and (vi) Policy electives and (vii) Initiation of a graduate degree/Certificate program.

2.1. Course Development

Five courses have been developed under the project. A brief list of weekly topics covered by each of the courses during the semester are listed below:

2.1.1 Control of Electric Drives Wind Power Applications

1. Course introduction and review of wind turbine components and equations
2. Tip Speed Ratio, Maximum Power Point Tracking, Pitch and Yaw Control
3. Wind Generator Types, Fixed vs. Variable Speed
4. Induction Generator Modeling
5. Synchronous Generator Modeling
6. Power Converters for Wind Energy
7. Wind Energy System Configurations
8. Fixed Speed Induction Generator-Based Wind Energy Conversion Systems (WECS)
9. Variable Speed With Squirrel Cage Induction Generator- Based WECS
10. Variable Speed Wind Energy Systems with Synchronous Generators
11. Variable Speed Wind Energy Systems with Synchronous Generators (continued)
12. Doubly-fed Induction Generator-Based (DFIG) WECS
13. DFIG-based WECS (continued)
14. Electric Grid and Reactive Power Control of SG WECS
15. Future Technologies for Wind Power Generation

2.1.2 Utility Applications of Power Electronics (Wind Power)

1. Wind turbines overview, Types of turbines, fixed speed turbines -
2. Reactive power control for Type A using TSC/MSC
3. Reactive power control for Type A using SVC
4. Reactive power control for Type A using STATCOM
5. Reactive power control for Type A using CSC STATCOM
6. Reactive power control for Type A using VeSC STATCOM
7. Variable speed turbines
8. Power electronics for Type C DFIG system
9. Power electronics for Type D Back-back state-of-art

10. Role of storage
11. DC grid architectures
12. Low voltage ride through
13. Multilevel back-back systems
14. Solar/Hybrid and off-grid systems
15. Challenges with high wind penetration (Guest lecture)

2.1.3 Utility Integration of Wind Power Generation

1. Brief History of Electric Utility Industry and Wind Energy in the United States and Canada
2. Regional Wind Integration Studies
3. Wind and load variability and uncertainty
4. Review of Power System Operations
5. Review of OPF Power System Operations
6. Impact of wind on Power System Operations
7. Short term wind forecast and Power System Operations
8. Long term wind forecast and Power System Operations
9. Wind farms and Power System Planning
10. Interconnection studies and Power System Planning
11. Wind Project Development
12. New Challenges in High Penetration Wind Power Generation

13-15. Term projects

2.1.4 Wind and Weather for Scientists and Engineers

1. Course Intro
2. Intro to Atmos Sci.
3. Thermodynamics
4. Radiation
5. Clouds
6. Dynamics
7. General Circulation
8. Boundary Layer
9. Boundary Layer/Weather
10. Weather Systems
11. Climate Dynamics
12. Climate Change

13. Alternative Energy Systems

14 Project presentations

2.1.5 Small Wind Turbine Design

1: Small Wind Turbine System Overview

2: Tower top components

3: Blade Design – Aerodynamics

4: Blade Design – Structural Considerations and Fabrication

5: Tail and Furling System Design

6: Yaw and Tail Bearings

7: Tower and Guys

8: Foundation

9: Alternator Design – Stator

10: Alternator Design – Structure

11: Alternator Design – Rotor

12: Mould Pouring

13: Rectifier Box

14: Tower drop wiring

2.2. Distance Delivery of Courses

Utility Applications of Power Electronics (Wind Power) course has been offered to off-campus students through the outreach program. Distance delivery for other courses will be developed in the future, awaiting development of appropriate program structures. Expansion of distance delivery further will be facilitated by the newly formulated Master of Engineering program in Sustainable Systems Engineering (See Section 2.7 below)

2.3. Outreach

Several seminars have been conducted on campus focused on wind energy, renewable energy by experts from industry, academia and government agencies. Selected topics of seminars are listed below:

- Germany's Energy Future – Greening an Export Nation
- Power to the People: Exploring the Challenges of Energy Poverty
- Prioritizing Innovation: Using the Patent System to Promote the Development of Renewable Energy and Other Socially-Valuable Inventions
- Electricity Market Reform and the Green Agenda
- Envisioning a Fairer Future: Sustainability, Security and Happiness on a Finite Planet
- Green Jobs: Turning Promise into Reality
- Distributed and Centralized Generation

- Primary and Secondary Control for High Penetration Renewables
- New Approaches to Transforming Wind, Rain and Fire into Electricity – Making a Smarter, Cleaner, Efficient Grid
- Renewable Energy Transition and International Climate Cooperation – The German Experience
- From Lasers to Wind Turbines: Frequency-Domain System Identification for Linear Time-Periodic Systems
- Renewable Energy: How Do the Pieces Fit Together?
- Wind Output Forecasts and Scenario Analysis for Stochastic Multiperiod Optimum Power Flow

Annual student conference in 2010 was been conducted in conjunction with the ***UW Energy Hub Conference*** and in 2011 was conducted under the title of ***Greening the Grid*** in November. In 2012, and ongoing years, they are integrated with an annual ***Energy Summit*** organized by the Wisconsin Energy Institute.

2.4. UW-Madison Wind Energy Installations

Installation of small wind turbine has been developed at the UW-Madison Agricultural Research Station. A photograph of the installation is illustrated below:

2.5. Industry Internships

Industry internships have been organized for students at Vestas, American Superconductor, Mortenson Construction, Madison Gas and Electric, GE and ABB for graduate and undergraduate students focused in Wind Energy systems.

2.6. Policy Electives

Several engineering students have enrolled in the Energy Analysis and Policy Program in the past years. A list of policy electives available for students in the program is listed below:

- EnvSt/PubAff 866, Global Environmental Governance. Instructor: Prof. Greg Nemet. Spring semester
- EnvSt 539, Air Resources Science & Policy. Instructor: Prof. Tracey Holloway. Fall semester
- EnvSt/AOS 535, Atmospheric Dispersion & Air Pollution. Instructor: Prof. Tracey Holloway. Spring semester
- AAE/Econ/EnvSt/PubAff 881, Benefit Cost Analysis. Fall semester
- TranPU 725, Public Utilities. Instructor: Prof. Rod Stevenson. Fall and Spring semesters
- Law 837, Regulated Industries: Energy. Instructor: Prof. Peter Carstenson

2.7. Certificate program

In conjunction with priorities and strategic plans at UW-Madison, the proposal for the certificate program was expanded to integrate with the development of a *Master of Engineering degree program in Sustainable Systems Engineering* that has been initiated, to includes Wind energy among topics for specialization. University authorities have approved the program in May 2012, organized for on-line education, and the first cohort of students will be admitted during Fall 2012.

2.8. Publications

The following publications have been prepared and presented by faculty and students who have been funded by the project:

1. D. Ludois, G. Venkataramanan, “An Examination of AC/HVDC Power Circuits for Interconnecting Bulk Wind Generation with the Electric Grid” Energies 2010, 3(6), Special Issue on Wind Energy, 1263-1289.
2. P. Melendez-Vega, J. Reed, D. Ludois, G. Venkataramanan “Low-cost Light-weight Quick-Manufacturable Blades for Human-scale Wind Turbines”, Proceedings of First IEEE Global Humanitarian Technologies Conference, Oct 2011.
3. Daniel Ludois, Jonathan Lee, Patricio Mendoza, Giri Venkataramanan, “Reuse of Post-consumer E-waste for Low Cost Micropower Distribution”, Proceedings of First IEEE Global Humanitarian Technologies Conference, Oct 2011.
4. J. K. Reed, G. Venkataramanan, “Fault Tolerant MVDC-HVAC Power Converter for Wind Farm Applications”, Presented at CIGRE Symposium, March 2012, San Francisco.
5. D.C. Ludois, G. Venkataramanan, P. Melendez, J. Reed, “Practicum in Small Wind Turbine Design”, Poster presented at Power and Energy Conference at Illinois, March 2012.
6. B. Sarlioglu, D. Pan, G. Choi,"A New Course on Control of Wind Power Generation Systems Using Analysis and Simulation," IEEE Symposium on Power Electronics and Machines in Wind Applications (PEMWA), July 16-18, 2012 Denver, Colorado, USA.
7. Bingsen Wang, Giri Venkataramanan, “Dynamics and Stability of Matrix-Converter Based Permanent Magnet Wind Turbine Generator”, To be presented at IECON 2012, Montreal, Canada, Oct 2012.

8. Pedro Melendez-Vega, Giri Venkataramanan, “Aluminum foil coils for human scale wind turbines”, To be presented at IEEE Global Humanitarian Technologies Conference, Oct 2012.

3. Summary

This project has been successfully completed, and has enabled UW-Madison to become established as a leading provider of specialized higher education to meet the needs of a growing wind power industry. The initiative developed during the project has enabled to further initiate programs aimed at sustainability-at-large at UW-Madison.