Final Technical Report

Power System Operation and Planning For Enhanced Wind Generation Penetration - Collaborative Work Force Development

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Principal Investigator
Vijay Vittal
Professor Arizona State University
(480) -965-1879
vijay.vittal@asu.edu

Authors
Gerald T. Heydt – Arizona State University
Raja Ayyanar - Arizona State University
James D. McCalley – Iowa State University
V. Ajjarapu – Iowa State University
Dionysios Aliprantis – Iowa State University

Recipient Organization
Arizona Board of Regents for Arizona State University
PO Box 876011
Arizona State University
Tempe, AZ -85287-6011

Other Project Team Member Organization
Iowa State University

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Executive Summary

This project is a collaborative effort between Arizona State University (ASU) and Iowa State University (ISU) to address the critical issue of work force development specifically dealing with the training of power system engineers to enable power system operation and planning for enhanced wind generation penetration. ASU is the lead school in the Power Systems Engineering Research Center (PSERC – www.pserc.org). ISU is a member university in this center. PSERC is a multi university collaborative research center which includes 13 member universities and 39 industrial member companies which started at a National Science Foundation Industry / University Research Center in 1996. PSERC also includes collaboration with several federal and state entities.

The activities in the proposed project target the following five critical areas:

1. Attracting high school students into an electric energy curriculum stream
2. Attracting electrical engineering students in the sophomore year into an electric energy elective stream
3. Tailoring the electric energy and power systems undergraduate curriculum to include topics related to power system operation and planning including high wind penetration
4. Tailoring the electric energy and power systems graduate curriculum to include topics related to power system operation and planning including high wind penetration
5. Developing continuing education offerings with the industrial partner to foster lifelong learning of engineers in industry including topics related to power system operation and planning including high wind penetration.

The main tasks of the proposed project are:

A. Web based modules to attract high school students
B. Attracting electrical engineering students in the sophomore year into an electric energy elective stream
C. Tailoring the electric energy and power systems undergraduate curriculum to include topics related to power system operation and planning including high wind penetration
D. Incorporating material on renewable energy in existing graduate courses or developing new graduate courses
E. Offering on-line video streamed courses
F. Developing special short courses for utility engineers
G. Work with industry partners to develop other material for utility engineers.

A number of web based modules pertaining to various aspects of wind energy were developed to attract high school students to this exciting disciplinary area. These modules can be accessed at:

http://windenergy.engineering.asu.edu/soholaunch/.

These modules were tested at the Ames and Gilbert High Schools in Iowa. For the convenience of the program staff the modules for the high schools students can be accessed at:

http://home.eng.iastate.edu/~jdm/wind/index.htm.

This educational material has also been provided to teachers at two Iowa high schools: Ames High and Gilbert High. The modular content, labeled Module 0 through 8, is:

0. Introductory material
1. Meteorological basis of wind energy
2. Wind turbine designs
3. Electrical generation
4. AC electrical systems – basics
5. AC electrical systems – additional details
6. The energy content of wind
7. Practical implementation of wind energy systems
8. Electrical transmission and energy storage.

The project also developed courses and enhancements to existing courses to attract electrical engineering students in the sophomore year into the electric energy stream. In this regard two interactive modules were developed. The first module deals with the impact of wind generation on system reliability. An interactive module to explain the concept of capacity outage tables with penetration of wind resources has been developed and demonstrated. An interactive module dealing with DFIG based wind generators has also been developed. In this module a standard DFIG based wind turbine is represented and the user can provide different inputs regarding wind speed and system load and the operation of the machine is simulated via an interactive display and various parameters and variables related to the stator, rotor, and the converter variables are displayed in real time. The graphic user interface (GUI) so obtained is suitable for both graduate and undergraduate education. Two versions of the GUI have been developed a 32-bit version and a 64-bit version. The two versions can be downloaded at:

32-bit:http://dl.dropbox.com/u/68990021/DFIG_GUI_32bit.zip
64-bit:http://dl.dropbox.com/u/68990021/DFIG_GUI_64bit.zip

In addition to these two modules the project also developed new courses pertaining to wind energy at the sophomore level and also enhanced existing course to include specific material related to wind energy. The material for the new course developed can be accessed at:
http://home.eng.iastate.edu/~jdm/engr340/engr340schedule.htm.

Several undergraduate elective courses were modified to incorporate new material related to wind energy. In addition a new course on wind energy was also developed and class tested. The enhancements to existing courses include new material for wind energy applications and extensive discussions on induction and synchronous machines, and covered steady-state analysis of DFIG machines and introduction to dynamic analysis. This material can be accessed at:
http://www.ece.iastate.edu/~dali/Wind_Energy_Conversion.pdf

A number of key graduate courses were also enhanced and a new graduate course on wind energy conversion and grid integration was developed. Significant new material was added to graduate courses related to power system operation and planning, advanced power electronics, and power system stability. The material developed in these courses has been rigorously class tested. A new course dealing with wind energy conversion and grid integration has also been developed and class tested. The material pertaining to this course can be found at:
http://home.engineering.iastate.edu/~jdm/wind/#Grad.

In addition to all the development related to university activities, educational material for engineers in industry was also developed. A short course on wind energy was developed and has been offered twice to industry participants. The recordings from these short courses are available at:

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http://www.windenergy.iastate.edu/wind-energy-seminar.asp

This project has resulted in the development of a comprehensive set of educational material for high school students, sophomore electrical engineering students, elective courses at the undergraduate level, graduate courses, and short courses for practicing engineers. All material is publicly available and has been rigorously class tested and refined. The overall objectives set forth in the proposal have been met.

1.0 Introduction

This project is a joint effort between Arizona State University (ASU) and Iowa State University (ISU) and develops an integrated approach to workforce training related to wind energy integration in the electric grid. The project addresses workforce development in a comprehensive manner and targets activities as depicted in Fig. 1.

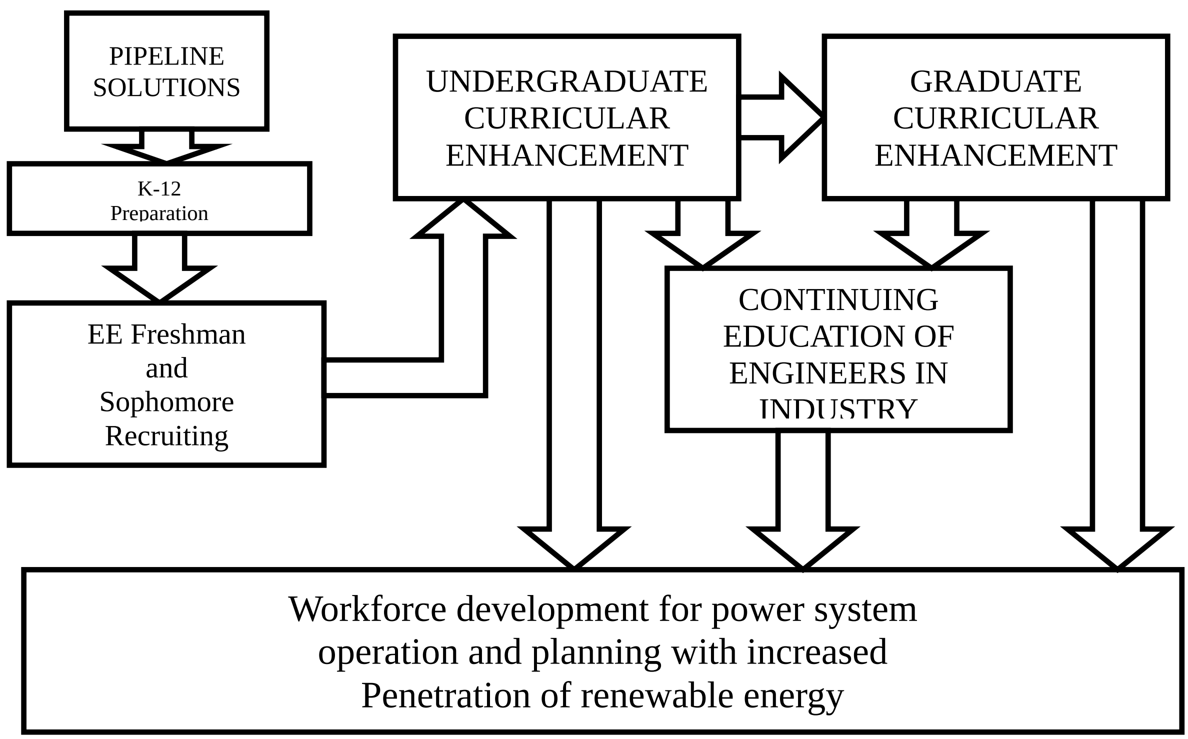

Fig. 1 Comprehensive approach to work force development

Several key aspects of workforce development are addressed in this project starting from pipeline solutions, recruiting of freshman and sophomore students, enhanced undergraduate and graduate curriculum, and contributions to continuing education of practicing engineers in industry. With this objective in focus the activities in the project target five critical areas:

1. Attracting high school students into an electric energy curriculum stream
2. Attracting electrical engineering students in the sophomore/junior years into an electric energy elective stream
3. Tailoring the electric energy and power systems undergraduate curriculum to include topics related to power system operation and planning including high wind penetration
4. Tailoring the electric energy and power systems graduate curriculum to include topics related to power system operation and planning including high wind penetration
5. Developing continuing education offerings with the industrial partner to foster lifelong learning of engineers in industry including topics related to power system operation and planning including high wind penetration.

The workforce development curriculum development conducted in this project includes topics from both power system engineering and power electronics since the grid interface of renewable energy is greatly dependent on both these disciplinary areas. A synthesis of both disciplinary areas has been achieved in the development of the primary components of this project. The main elements of the project workforce development plan include:

1. Development of stand-alone web based modules for high schools students
2. Developing new material and enhancement of existing material in sophomore level gateway courses to attract electrical engineering students into energy related elective courses at the senior level
3. Incorporating material in existing undergraduate courses or developing new undergraduate courses
4. Incorporating material on renewable energy in existing graduate courses or developing new graduate courses
5. Developing special short courses for utility engineers.

Each of the elements identified above has been systematically addressed in the project. The modules developed for high school students cover a wide range of topics ranging from basic principles of wind energy capture to grid integration of wind turbine generators. These modules include a brief quiz at the end of each module. The modules developed have been posted on the Internet for public dissemination. The modules have also been tested and utilized at two high schools in Iowa.

The course material developed both at the undergraduate and graduate levels have been class tested and refined based on the comments received. Significant enhancement of material to existing courses has been achieved in the project. All this material was used in class during a regular offering of the courses during the project. Student feedback was sought and the material developed was appropriately revised.

A short course for electric utility engineers was also developed. Two offerings of the short course for utility engineers have been recorded and posted on the Internet.

This final report provides details of each aspect of the project described above. Appropriate links to publicly posted material developed in the project are also provided. Steps outlining the development of the various components are outlined.

2.0 Project Results

2.1 Web-based modules for high school students

A series of web-based modules were developed for high school students. This task addresses the pipeline issue and develops material to be used in high schools to spark student interest in wind energy and engineering related disciplines. A total of 11 modules have been developed at posted on the Internet for public dissemination. The topics addressed by modules address the following aspects of wind energy:

The first eight modules are available at the following URL:

http://windenergy.engineering.asu.edu/soholaunch/Documents.php

These modules address the following topics:

1. The nature of wind, meteorological explanation, usual and extreme events. Also an introduction to why wind energy is important.
2. Wind turbines, types and designs, commercial availability, history, present deployment. Energy data for the USA – where does electricity come from?
3. Generators, synchronous generators, induction generators, DC generators. How engineers 'model' these devices. What is a 'model'?
4. AC electrical systems, why AC, resistance, reactance, voltage and current, phase angles, measurements, power in AC systems
5. AC systems continued
6. The energy contained in the wind, Betz' law, variation of wind, statistical modeling of wind energy
7. Doubly fed induction generators, design of practical wind generators
8. Electrical transmission systems, energy storage, practical implementation of wind energy resources

The next three modules are available at the following URL:

http://home.eng.iastate.edu/~jdm/wind/index.htm#Highschool

The topics addressed in these modules include:

9. Wind energy basics
10. National wind picture
11. Development process.

These modules have been utilized at two high schools in the State of Iowa; Ames High and Gilbert High. At Ames High, Module 9 was used by instructor Dianna Tibben to introduce students to wind energy in a 9th grade earth science class. Module 10 was presented in an Ames High Physics course by Dr. McCalley in 2010 and has subsequently been used by instructor Elizabeth Brenneman in treating energy principles in her Physics course. Module 11 was used by Ames High Physics instructor Michael Lazere in assisting students in a science club in a project to develop a wind turbine facility on the high school campus. Modules 9 and 10 were used by Gilbert High instructor Dan Knudtson to introduce wind energy within to his Physics class.

2.1 Material to attract freshman and sophomore students into energy related electives

In U.S. universities the undergraduate degree is primarily an electrical engineering degree and specialization is characterized by the electives students choose during their senior year. In order to develop workforce related to wind energy and its integration in the grid it is imperative to develop appropriate gateway courses at the sophomore level to offer students a sampling of the exciting aspects of renewable energy resources and the challenges associated with grid integration of these resources. In order to address this objective both ASU and ISU have targeted specific gateway courses and included enhanced material related to wind energy in these courses.

At ASU EEE 360 - Energy Systems and Power Electronics, is a gateway course which also includes a laboratory component. Significant new material related to wind energy and solar energy has been incorporated in this course. In addition, aspects related to wind energy conversion dealing with induction machines, wound rotor induction machines, and synchronous machines has been introduced. In addition elementary power electronic concepts associated with convertors and inverters are also introduced. The laboratory experience also includes experiments related to the aforementioned topics. Two interactive web-based modules have also been developed for use in this course. The first module addresses the topic of power system reliability and calculates capacity outage tables for a system with increased wind penetration. This module can be accessed at – https://dl.dropbox.com/u/18213836/COT_programs.zip. The second module illustrates the principles of operation a doubly fed induction generator (DFIG) based wind turbine. The user can input appropriate data for a variety of parameters and examine the performance of the DFIG. This module is available in two versions and can be downloaded at the following links:

32-bit: http://dl.dropbox.com/u/68990021/DFIG_GUI_32bit.zip
64-bit: http://dl.dropbox.com/u/68990021/DFIG_GUI_64bit.zip

At ISU, EE 303 – Energy Systems and Power Electronics is the introductory course to electric power systems, and is a required course for all electrical engineering students, offered every semester. The syllabus of this course has been modified with additional material related to the fundamentals of wind energy. This material introduces the basic calculations of energy in the wind stream, then proceeds to describe the most common electromechanical energy conversion topologies used today for converting wind energy to electrical energy, such as squirrel-cage and doubly-fed induction generators, and permanent magnet synchronous generators. The course notes for this course can be accessed at:

http://www.ece.iastate.edu/~dali/Wind_Energy_Conversion.pdf.

In the summers of 2011 and 2012, Drs. McCalley, Aliprantis, and nine other ISU faculty developed and ran a 10 week summer program for undergraduate students in wind energy science, engineering and policy. A two-week short course and once per week seminars were conducted for this program. Undergraduate students were recruited from around the nation. Although this program was funded by the National Science Foundation, some of the materials used were adapted from materials developed under this DOE project. Materials used by faculty and guest speakers for this program can be found at

http://home.engineering.iastate.edu/~jdm/wind/#REU.

This program will be run again during the summer of 2013.

In Fall 2011, Dr. McCalley and 7 other faculty taught an introductory, interdisciplinary undergraduate wind energy course ENGR 340, "Introduction to Wind Energy: System Design & Delivery," with 27 students enrolled, among which were 14 EE students. This course is a required course in an undergraduate minor on wind energy. Significant material was developed in this course, located at

http://home.eng.iastate.edu/~jdm/engr340-2011/engr340schedule.htm.

The course is being taught again in Fall 2012.

2.2 Enhancement of the undergraduate curriculum

At ASU two senior level undergraduate courses namely EEE 473 – Electrical machinery and EEE 472 – Power electronics and power management have been enhanced to include contents related to wind energy conversion. In EEE 473 some of the detailed discussions on dc motors have been de-emphasized in order to dedicate more lectures to induction machines including doubly-fed type and permanent magnet synchronous machines. New lecture material covering the basic principles of operation and models of DFIG have been developed and used in class. EEE 473 covers all ac machine analyses using physically intuitive, space vector based approach which lends itself very well to understand and prepare for the advanced vector control of ac machines including DFIGs in wind generator applications presented in the graduate courses (EEE598 – Renewable electric energy systems at ASU). In addition, EEE 473 also devotes four to five lectures (75 minutes each) on principles and design of voltage source converters used in motor drives and wind generators. Students also gain experience using Simulink and PLECS simulation tools to model machines and power converters.

EEE 472 is the main undergraduate power electronics course at ASU and it is roughly split equally between power management with lower power dc-dc converters and PWM voltage source inverters/rectifiers. New contents on power converter topologies and basic control methods for renewable energy interface mostly solar photovoltaics and wind have been created and introduced in this course. Many of the examples and applications used to illustrate the concepts of voltage source converters have now been derived from the renewable energy interface area. Students routinely use Simulink, PLECS or PSpice simulation tools as part of homework exercises. This course has seen a dramatic increase in student interest and enrollment with more than 90 students enrolled for the upcoming Fall 2012 offering.

At ISU, EE 452 is a senior-level Electrical Machines and Power Electronic Drives technical elective course. This course's structure was completely redesigned, leveraging additional support from the National Science Foundation, Division of Undergraduate Education, under the NSF DUE TUES, “Development of a New Power Electronics Curriculum Relevant to Tomorrow's Power Engineering Challenges” award. The purpose of this course is to introduce students to the fundamentals of power electronic converters as well as provide an understanding of electric machines and machine drives, in the context of modern renewable energy and electric transportation applications. The course is centered around weekly laboratory sessions, where students first learn how to simulate power electronics-based circuits using Matlab/Simulink and the Automated State Model Generator (ASMG) toolbox, and then the applications are implemented in hardware using Texas Instruments microprocessor units and power electronics hardware. The newly developed laboratory material is freely available here:

http://home.engineering.iastate.edu/~dali/EE452_index.html

At ISU, EE 455 is a senior level Introduction to Energy Distribution Systems Course. It covers overhead and underground distribution system descriptions and characteristics, load descriptions and characteristics, overhead line and underground cable models, distribution transformers, three phase power flow and fault analysis, overcurrent protection and power factor correction. In this course a new topic: wind farm collector circuit design is introduced. It covers methods for equivalencing large wind power plant with multiple turbine representation.

A overview module on wind energy was developed and used in an ISU course for selected high-performing undergraduate students called Honors 322. Additional wind and wind-related modules were developed for two other undergraduate courses at ISU, including EE 456 (Power Systems Analysis I) and EE 457 (Power Systems Analysis II). These modules, summarized in the following table, are available at

http://home.engineering.iastate.edu/~jdm/wind/#UG.

Title	**Course**	**Description**
WindOverview	Honors 322	Powerpoint slides providing an overview of wind energy.
Transmission	EE 456	Powerpoint slides summarizing US transmission issues driven by wind energy.
VoltagePowerControlStability	EE 456	Powerpoint slides describing reactive power & voltage aspects of wind energy
TransmissionLineDesignCriteria	EE 456	Word document providing calculation procedures for sag and ampacity, and also describing high temp, low sag transmission
Compact transmission lines	EE 456	Word document describing compact transmission line design considerations.
MW-HzVariability	EE 457	Powerpoint slides summarizing issues related to wind energy variability within power grids.

An ISU course was developed entirely dedicated to wind energy, EE 459/559, titled “Electromechanical wind energy conversion and grid integration.” This course is available to

both undergraduate and graduate students in Electrical Engineering and is further described under Section 2.3 below.
Also at ISU senior design project related to wind energy is proposed. The project consists of a wind turbine coupled to a motor that is controlled by an external power source. The goal of the project is to accurately simulate wind conditions to the turbine in a controlled environment and monitor voltage, current, power, and speed. The end product will resemble a small scale renewable electrical network. The students will simulate wind conditions through the data that is received from wind sensors placed outside (the sensors measure the wind speed and direction). This information will be used to control a three phase induction motor that is coupled to a wind turbine. The motor speed is changed according to the wind speed. The students are expected to develop one working module that demonstrates various concepts related to wind energy.**2.3**

Enhancement of the graduate curriculum

Several courses at the graduate level have been enhanced and a new graduate course specifically dealing with wind energy has been developed. Details regarding these courses are provided below.

At ASU the following courses have been significantly retooled to address key aspects related to wind energy and its integration in the electric grid. EEE 577 is a course offered once a year at Arizona State University. The topic is power system operation and control. Some elements of transmission expansion and generation expansion are included. The course had been based on the textbook by A. Wood and B. Wollenberg, "Power Generation, Operation, and Control," McGraw Hill, 1996. The book is supplemented by notes and Power Point slides on:

- Deregulation
- Wind energy systems
- Solar photovoltaic systems
- Concentrated solar energy systems
- Characterization of uncertainty
- Accommodation of renewable resources in optimization methods (e.g., generation dispatch).

The elements on wind energy occupy about 2.5 weeks of the 15 week semester. Also included is an in depth discussion of the most recent developments in unit commitment including wind energy systems. A complete presentation of the statistics of the level of wind generation in the United States is presented updated to 2011 by data from the U. S. Department of Energy.

Electric Power Quality, EEE 573 was augmented with one week devoted to the impact of inverter based generation resources. This includes: six pulse technology (Graetz bridges), pulse width modulated technologies, the potential value of high pulse order inverters, and the propagation of harmonic signals in both distribution and transmission systems.

EEE 572 Advanced Power Electronics teaches detailed design and advanced control of various types of power electronic converters. Recently a significant amount of material in power converters for photovoltaic and wind generation have been added to the course content, with about 30% of the lecture hours now dedicated to this area. The students are required to complete a fairly complex course project on any power electronic application focusing on the design, control and simulation validation. Solar and wind energy converters have been a popular choice among the EEE 572 students for their course project recently.

EEE598 Renewable electric energy systems has been thoroughly revamped in Spring 2011 and Fall 2012. It includes two major modules – solar photovoltaics and wind energy with each module covering various aspects of the characteristics of the respective resource, modeling, power conversion and control. The wind energy module includes topics on wind energy characteristics,, wind turbine systems and configurations, detailed steady-state and dynamic analysis of doubly fed induction generator and permanent magnet synchronous machine based wind generators, dynamic modeling of wind generators, field oriented control of rotor side and grid side power converters, and control methods for maximum power extraction, active and reactive power control, grid integration issues including low voltage ride through and operation with grid faults and overview of grid support features. Each module has a required course project which involves extensive design and simulation. In Spring 2011 the course project involved modeling a GE 1.5 MW DFIG based wind generator and demonstrating speed control for maximum energy capture and decoupled control of active and reactive power in detailed three-phase simulation using average models of power converters.

EEE 575- Power System Stability is an advanced graduate course dealing with various aspects of power system stability, modeling, and control. Significant new material relating to the modeling of different kinds of wind turbine generators has been included in this course. In addition the impact of increased wind penetration on rotor angle stability, voltage stability and frequency stability is discussed.

As mentioned in Section 2.2, at ISU a new course was developed entirely dedicated to wind energy, EE 459/559, titled “Electromechanical wind energy conversion and grid integration.” This course is available to both undergraduate and graduate students in Electrical Engineering. Modules in the form of Word documents and Powerpoint slides were developed for this course, as summarized in the table below. These modules are available at

http://home.engineering.iastate.edu/~jdm/wind/#Grad

These modules will be further extended and refined each time the course is taught (once per year), with the most recent materials posted to the above website.

Module name	**Description**
GridOpsCoordWind1	Word document covering wind and transient frequency response.
GridOpsCoordWind2	Word document covering wind and frequency regulation.
GridOpsCoordWind3	Word document covering wind and load following.
GridOpsCoordWind4	Word document covering wind and dispatch and scheduling.
GridOpsCoordWind5	Word document covering wind and unit commitment.
GridOpsCoordWind6	Word document covering forecasting and capacity credit.

CapacityCreditWind	Word document addressing capacity credit for wind via effective load carrying
ControlPerfStandards	Word document in paper form addressing control performance standards CPS1, CPS2, BAAL, as affected by increasing penetration levels of wind.
StorageCAESProdCost	Summarizes storage technologies, provides detailed description of CAES, reports on production costing software to evaluate storage technologies.
WindOverview	PPT slides introducing wind energy for EE graduate-level course
WindEnergyTechnology	PPT slides providing overview of wind energy technology
Cost of wind	PPT slides showing how to compute LCOE of wind energy
Transmission	PPT slides covering transmission issues for wind energy
Collection Circuits	PPT slides covering collection circuits analysis and design
Offshore wind	PPT slides covering offshore wind energy technologies.
Inertia	PPT slides covering inertial effects of wind turbines
Inertia with added plots	PPT slides covering inertial effects of wind turbines, with additional plots
PwrProductionVariability	PPT slides covering power production and variability from wind farms
Regulation	PPT slides covering effects on regulation of wind farms
LoadFollowing	PPT slides covering effects on load following of wind farms
Wind&Markets	PPT slides covering integration of wind energy into electricity markets
DFIG-Steady state	PPT slides covering steady-state operation of double-fed induction generators
Transformations	PPT slides covering machine transformations
d-qTransformation	PPT slides covering the d-q transformation for induction machines
VSC	PPT slides covering voltage source converters as used for DFIGs

Additional materials were developed for two other graduate courses, EE 552, Energy systems planning, and EE 553, Steady-state analysis, as summarized in the table below. These modules are available at

http://home.engineering.iastate.edu/~jdm/wind/#GradAdditional

Title	**Course**	**Description**
WindPrimControl	EE 553	Word document addressing primary control needs associated with power systems have high penetrations of wind energy.
PlanningIntro	EE 552	Word document providing introduction to planning with production and investment cost data for all electric generation technologies including wind and solar.
EnergyConversionTechnologies	EE 552	Word document providing description of all electric generation technologies including wind and solar.

These modules will also be further extended and refined each time the course is taught (once every third semester), with the most recent materials posted to the above website.

2.4 Short course development for utility engineers

ISU organized a short course on wind energy in Fall 2009 and Fall 2010. The 2009 short course was called "Wind Generation Technology Short Course." The full course description can be found at

http://powerweb.ece.iastate.edu/Wind_Generation_Brochure_2009.pdf.

It had participants from 13 instructors and 27 attendees over a two-day period. It concluded on day 3 with a tour of a nearby 150 MW wind farm.

The 2010 short course was called "Midwestern Wind Energy: Beyond 20% in 2030." The full course description is at

http://www.ucs.iastate.edu/mnet/_repository/2010/wind/pdf/brochure.pdf

It had participation from 18 instructors and 36 attendees. A complete set of video-audio recordings was made of the 2010 short course and have been made available to undergraduates attending a 10 week summer educational experience at ISU during the summers of 2011 and 2012. These recordings are available at

http://www.windenergy.iastate.edu/wind-energy-seminar.asp

www.eng.iastate.edu/billtest/windenergy/wind-energy-seminar.asp

3.0 Accomplishments

The project has accomplished all objectives set forth in the proposal. New educational material to attract and train workforce at different educational levels and with significantly different analytical detail have been developed and posted on the Internet for dissemination. At the level of increasing the pipeline into the workforce, attractive modules and course work material have been developed for high school students and for electrical engineering students at the sophomore level. The high school material has been tested and utilized at two different high schools. The sophomore level material has been class tested at both participating universities. Both ASU and ISU have seen significant increase in enrolment in the senior elective courses related to electric power and energy systems.

The undergraduate electives at the senior level have been revised and enhanced to incorporate important aspects related to wind energy. These courses have been widely subscribed to at both universities and have evoked significant interest because of the addition of the new material. Evidence of this interest includes:

- A large number of 'hits' to the web sites developed
- A sharp increase in enrollment in undergraduate courses in power
- A concomitant increase in graduate courses in this area, fed by students who took the undergraduate courses developed (e.g., at ASU the enrollment has increased by about 100% over the last year)

The graduate courses have also been enhanced and new courses specifically related to wind energy have been added. Graduate enrolment at both universities is at an all time high and there is record enrolment in the courses that have been enhanced and newly developed. As indicated above, in the graduate area, enrollment has increased by about 100% at ASU.

The short course to industry was extremely successful. The significant participation in terms of numbers of both instructors and attendees was a testament to the high interest in this field by the engineering and regulatory community around the Midwest. Feedback obtained from the attendees indicated a very high level of satisfaction with the various presentations made.