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A Project Based Implementation of a Power Systems Course for Electrical and Computer Engineering Technology Students

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Abstract

Western Carolina University (WCU) is the only educational institution that offers engineering and technology degrees in the western part of the state. As the power industry is becoming one of the major recruiters of our graduates in the department of engineering and technology at WCU, developing an emphasis in electric power engineering plays a vital role in educating the next generation of the region's power industry workforce.

To that end, an undergraduate curriculum development effort was planned and is projected to train, prepare for research, and educate the students enrolled in the Department of Engineering and Technology for careers in the power industry. The curriculum includes three fundamental power engineering courses:

1. Power Systems
2. Power Electronics
3. Electrical Machines and Drives

This paper describes in detail the first pilot implementation of the Power Systems course component entitled "Modern Power Systems Analysis" for Electrical and Computer Engineering Technology (ECET) undergraduates and presents its assessment results.

This course includes both lecture and lab sessions which are suitable for junior-level ECET students. During the semester, a campus field trip to explore the electrical infrastructure and major HVAC facilities of the university is organized to introduce students to the practical aspects of power transmission and distribution systems. In addition, a final term project is assigned to challenge the students for the purpose of developing a practical power system infrastructure design proposal to reduce the university's carbon footprint. The design proposal is intended to transport renewable energy generated from a nearby hydroelectric facility to the university.

Finally, a survey is conducted to evaluate the overall course and the faculty performance as well as the sustainability of the established course concept.

I. Introduction

Recognizing our additional need for clean energy in 21st century, electric energy generation through renewable sources (especially wind and solar) and nuclear gained quite a momentum over the recent years. For instance, as of November 2010, U.S. Nuclear Regulatory Commission has received 18 combined license applications for a total of 30 new reactors [1]. In terms of renewables, total non-hydro renewable energy generation in the U.S. increased by 15.9 percent in 2010, following a 14.4-percent increase in 2009. The fastest-growing component was solar (thermal and photovoltaic) power with 36-percent increase. Wind energy generation increased 28.1 percent. Since 1999, generation from non-hydro renewables has almost doubled. In 2010, renewable energy generation made up 10.4 percent of total generation. The largest three contributors were hydro (6.3 percent), wind (2.3 percent), followed by wood and wood-derived fuels (0.9 percent). On the other hand, electrical energy production from fossil fuel sources coal has still the largest share of 44.8% which is followed by natural gas with a share of 23.9% [2].

Growing the demand of electrical energy from sustainable sources requires a skilled workforce that is educated and trained to take the lead on main sub-tasks of generation, transmission & distribution and utilization. In addition, it has been projected that the current power industry will soon be facing a manpower crisis due to attrition within its "soon-to-be-retiring" workforce. In a survey conducted at 20011, The Center for Energy Workforce Development analysis indicates that 36% of skilled utility technician and engineering (excluding positions in nuclear) may need to be replaced due to potential retirement or attrition, with an additional 16% to be replaced by 2020 — almost 110,000 employees in positions identified as the most critical by industry [3]. The North American Electric Reliability Corporation (NERC) in its 2007 report has also identified the aging workforce as a growing challenge to future reliability of the electricity supply and NERC continues to support action and monitor industry progress [4].

The Need for Power Engineering Education and Teaching Methodologies

The demands of the power industry for a skilled workforce in power engineering disciplines combined with a lack of educational programs that support the power industry suggest the immediate need for the development and teaching of courses in power engineering. In order to fill this gap in skilled workforce, Sergeyev and Alaraje recently described an industry-driven power curriculum in an electrical and computer engineering technology program. The primary outcome of their project was to educate a larger number of better qualified engineering technologist graduates with skills and knowledge that are current and relevant [5]. In another recent study, Karayaka *et al.* provided their findings in a first implementation of a course designed within the context of power systems curriculum development efforts to bridge the gaps of regional workforce needs [6]. The paper primarily highlighted the effectiveness of student oriented project based learning. Other papers also discuss the project based teaching along with a problem-oriented approach of power themes which is incorporated in the work described here [9-10]. These studies suggest that the design experience gained through the projects motivates student learning and develops skills required in industry.

Among the collaborative efforts, Mousavinezhad *et al.* described the work of the Electrical and Computer Engineering Department Heads Association with the support of the National Science Foundation in establishing a workshop series on the issues aimed at developing educational and research programs in this critical area of power and energy systems within Electrical and Computer Engineering [7]. Another collaborative effort is the Consortium of Universities for Sustainable Power (CUSP™) which is currently offered by the research group led by Professor Ned Mohan of the University of Minnesota. This consortium includes universities that have come together to utilize, collectively evolve and promote the curriculum developed at the University of Minnesota – Twin Cities with the help of funding from various organizations including NSF, ONR (Office of Naval Research), NASA and EPRI [8].

The following sections describe the new curriculum developed to support the power industry (Section 2), teaching the Power System Analysis course (Section 3), course assessment, results and findings (Section 4), and Conclusions (Section 5).

II. New Curriculum Supporting Power Industry

At WCU, the engineering and engineering technology curricula have been currently developing to support the power industry in the region. Specifically, the electrical engineering curriculum was selected to comprise three common fundamental sustainable power engineering education courses. The courses that have been currently planned to be added to the curriculum are:

1. Power Systems
2. Power Electronics
3. Electrical Machines and Drives

III. The Power Systems Course

The course entitled "Modern Power System Analysis" was designed to support electric power systems basics and it is the first pilot implementation of Power Systems component. This course is a four-credit-hour lecture course that has both lecture and laboratory sessions and is offered to Electrical and Computer Engineering Technology Students.

The detailed course content for the two remaining power engineering courses in the curriculum, entitled "Power Electronics" and "Electric Machines and Drives," are in the process of being developed for their first implementation in the department.

All three courses are required courses to define "power engineering emphasis" in the department, particularly, in Electrical Engineering.

Student Enrollment Figures and Background

The department of engineering and technology with an undergraduate enrollment over 500 students at WCU includes total of four majors of specialty as listed below:

- Bachelor of Science in Electrical Engineering (EE)
- Bachelor of Science in Engineering Technology (ET)
- Bachelor of Science in Electrical and Computer Engineering Technology (ECET)
- Bachelor of Science in Engineering (BSE) with a mechanical engineering specialization

The first three majors are well established and ABET accredited majors serving the region for many years. The BSE program is a new program that was added in fall 2012.

As mentioned earlier, Modern Power Systems Analysis is a junior level course and is currently offered to only ECET majors in the program. Therefore, the course enrollment and assessment data in this paper only includes the ECET major. Consequently, the student demographics data are solely presented for ECET major.

As of fall 2012, the enrollment numbers for all ECET majors at WCU are on the average of sixteen students for each level from freshman to senior. For the “Modern Power System Analysis” course, the total enrollment in the discussed implementation was fifteen. The course was offered in the fall semester of 2012. Each week the class meetings were scheduled for total of five hours of which were equally split between lecture and laboratory sessions. The enrollment statistics of the students in the class are listed in Table 1. As can be seen in the table, total of seven senior, seven junior and one sophomore students who are all male and majoring in Electrical and Computer Engineering Technology participated in this course.

Table 1. Enrollment Figures in “Modern Power System Analysis” Course

	Undergraduate Level	**Gender**	**Major**
Student 1	Junior	Male	ECET
Student 2	Junior	Male	ECET
Student 3	Junior	Male	ECET
Student 4	Senior	Male	ECET
Student 5	Senior	Male	ECET
Student 6	Junior	Male	ECET
Student 7	Senior	Male	ECET
Student 8	Junior	Male	ECET
Student 9	Senior	Male	ECET
Student 10	Junior	Male	ECET
Student 11	Junior	Male	ECET
Student 12	Senior	Male	ECET
Student 13	Senior	Male	ECET
Student 14	Senior	Male	ECET
Student 15	Sophomore	Male	ECET

Teaching the Power Systems Course with a Problem-Oriented Project Based Approach

This course was designed to introduce power system analysis principals with a problem-oriented project based approach. Power transmission and distribution network architecture and composition; load flow studies; symmetrical components; parameters and equivalent circuits in symmetrical components for overhead and underground lines, transformers, generators and loads; substations; voltage and power static control are also covered. MATLAB/Simulink and PowerWorld software are used for power system analysis/design. Prerequisite course included DC Circuit Analysis. AC Circuit Analysis was also required as a corequisite course.

Required textbook:

- Electric Machinery and Power System Fundamentals, Stephen J. Chapman, 2002, McGraw Hill.

Recommended reference books:

- Modern Power System Analysis, Kothari and Nagrath, 2008, McGraw Hill.
- Circuit Analysis Theory and Practice, Robbins & Miller, 4^{th} Edition, 2006, Thomson, Delmar Learning.

Course Objectives/Student Learning Outcomes (or SLO) were designed to enable students with:

- Understand the basics of power system components
- Understand and calculate power transmission and distribution network parameters
- Analyze power systems with load flow studies
- Analyze symmetrical and unsymmetrical faults
- Understand automatic generation and voltage control
- Analyze and understand power system and voltage stability
- Understand compensation in power systems
- Synthesis and design of power systems

Instructional methods and activities for instruction included lectures, group discussions, homework assignments/solutions, use of simulation software and a term project which required both presentation and report components. In addition, laboratory activities were also administered to develop hands-on skills on the basics of electric power technology.

The Grading Policy was determined by students' performance in both individual and team work efforts. Individual effort included homework assignments, midterm exams and participation points, while team work effort included lab experiments/reports and term project. The distribution of points was given in Table 2 as follows:

Table 2. Grade Distribution

1.	Homework Assignments	15%
2.	Lab Experiments/Reports	15%
3.	Two Midterm Exams	30%
4.	Attendance/Participation	10%
5.	Term Project Presentation/Report	30%

Term Project Problem Definition: For the purpose of reducing WCU's carbon footprint as well as supplying clean power to entire campus, a power transmission infrastructure is to be designed to transport electrical power from a nearby hydroelectric generation facility.

Letter grades are assigned according to the following:
A+: 99–100, A: 92–98, A-: 90–91, B+: 88–89, B: 82–87, B-: 80–81,
C+: 78–79, C: 72–77, C-: 70–71; D+: 68–69, D: 62–67, D-: 60–61, and F: 59–0.

Original projected course schedule is given in Table 3.

Table 3. Schedule of Topics for Modern Power System Analysis Course

Topic/Activity	**Week**
AC Circuits Overview	1
AC Power	2
Three-Phase Systems	3
Transformers	4
Inductance and Resistance of Transmission Lines	5
Capacitance of Transmission Lines	6
Representation of Transmission Lines	7
Characteristic and Performance of Transmission Lines	8
Load Flow Studies	9
Automatic Generation and Voltage Control	10
Symmetrical Fault Analysis	11
Symmetrical Components	12
Unsymmetrical Fault Analysis	13
Compensation in Power Systems	14
Powers System and Voltage Stability	15
Final Student Team Presentations	16

The topics addressed and covered in the course in Table 3 are briefly described below.

1. *AC Circuits Overview, AC Power and 3-Phase Systems*: Complex algebra, the concept of phasor in AC circuits, AC power and power factor are reviewed. The nature and dynamics associated with R-L and R-C circuits for AC operation, balanced 3-phase circuits and basics of power system analysis and design are also explained.
2. *Transformers* : Ideal transformer current voltage relationships, turns ratio, reflected impedance, non-ideal transformers, losses, equivalent circuit model, calculation of model parameters, per-unit calculations for single and 3-phase systems, various connection configurations for 3-phase transformers are presented.
3. *Inductance, Resistance and Capacitance of Transmission Lines*: R, L and C calculation methods for various single and 3-phase line configurations including bundled conductors and usage of standard conductor data tables for calculation transmission line parameters are introduced.
4. *Representation, Characteristics and Performance of Transmission Lines*: Transmission line equivalent circuit parameters, voltage, current, active and reactive power variations along the transmission line, π model and its approximations for short, medium and long lines are presented and studied.
5. *Load Flow Studies, Automatic Generation, Voltage Control and Economic Dispatch*: One-line diagrams, bus types, Y_{bus} matrix calculations, power balance equations, iterative solutions such as Gauss and Newton Raphson methods along with examples are introduced. Power system control, indirect transmission line control, DC power flow, calculation of sensitivities, area control error (ACE) concepts are also studied. In addition, generation types and fuels, generator cost curves, formulation of costs and economic dispatch and cost minimization methods are explained.

6. *Symmetrical Fault Analysis, Symmetrical Components and Unsymmetrical Fault Analysis*: Grounding, calculation of grounding resistance, sequence sets, thevenin equivalents for fault analysis, sequence diagrams for transformers, sequence diagrams for fault analysis, single line to ground faults, line to line faults and double line to ground faults are covered.
7. *Compensation in Power Systems, Power System and Voltage Stability*: Reactive power compensation, voltage drops over transmission lines depending on loading and methods for load bus voltage compensation are discussed. Generator mechanical models, power angle and swing equation are also introduced.
8. *Term Project and Student Presentations*: Students were asked to submit an initial summary report of their project framework regarding the choice of reliable, cost efficient transmission infrastructure technologies to be investigated. Recommendations were done based on this initial report. The project parameters are defined as:
    - The hydroelectric generation facility is located at a 55 miles distance.
    - The facility is assumed to operate a 13.8kV/37.5MVA generator.
    - The price of electricity production is assumed to be fixed at 2 cents/kWh
    - The power delivered is supposed to supply the entire electrical energy need of the university which operates on a 12.47kV distribution network.
    - 3-phase transmission system should be designed to optimize cost, efficiency and reliability.
    - An annual 2% campus power demand increase needs to be projected.
    - The transmission system designed needs to have at least 30 years of life span.

    The final report/presentation was required to have:
    - Title Page and Table of Contents
    - Overview/Abstract/Summary
    - Background/History/Introduction
    - Objective/Goals:
        - Building a reliable and efficient transmission system to supply electricity and reduce the carbon foot print of your university
        - A proposal that makes a business case for 30 years at or below 4 cents/kWh
    - Explanation of the engineering, technology proposal that makes business sense for 30 years:
        - The proposal from engineering, technology perspectives (contacting industry experts are recommended):
            - Line Modeling (Y_{bus} matrix calculations based on the choice of transmission lines and transformers)
            - Define your S_{load} (P_{max} and Q_{max} after 30 years) for university.
            - Solve V_{load} (angle and magnitude) for worst case P_{load} and Q_{load} (using iterative methods).
            - Solve $I_{generator}$ and I_{load}, $P_{generator}$, $Q_{generator}$. Check against your line current limits plus the generator limits.
            - Find out max university load proposed transmission system can handle.
        - Business/Economics perspectives (Estimated cost recovery period, initial cost analysis, price per kWh). Include 2% increase in energy use every year. Transmission line right of way is not considered.

- Simulation Studies (PowerWorld™ or Matlab/Simulink™)
- Conclusion/Discussion
- References/works cited

In order to expose students to the real world applications and help facilitate student understanding of the term project, a senior power industry guest speaker from a local utility company was also brought in for a classroom presentation followed by a Q&A session.

There were total of three teams composed of 4 or 5 students. Team proposal highlights can be given as follows:

Team 1 Proposal Highlights (with focus on cost minimization):

Towers	Tubular steel construction with arms in delta configuration; Height: 40 meters, spacing: 200 meters, count: 443
Cables	Starling ACSR; 3 phase AC Total line impedance: 8.479Ω+ 33.762j Ω
Insulators	Glass Insulators, count: 3 per tower, total 1329
Transformers	Both for step-up and step-down, use 40MVA with 115kV in high side, low side is 12.47kV with tap changer
Total cost (including labor)	~ $3.9M (Max cost is $2M for transformers)
Predicted cost recovery period	3 years
Computational Software	MATLAB

Team 2 Proposal Highlights (with focus on reliability assessment and rigorous computational analysis):

Towers	Steel construction lattice towers with delta configuration; Height: 15 meters, spacing: 400 meters, count: 221
Cables	Sparrow ACSR; 3 phase AC Total line impedance: 89.44Ω+ 13.95j Ω
Insulators	Porcelain Insulators, count: 24 insulators per tower, total 5304
Transformers	21.4MVA for step-up: low side 13.8kV, high side 115kV with tap changer; 25 MVA for step-down: high side 115kV, low side is 12.47kV with tap changer
Total cost (including labor)	~ $17.7M (Max cost is $13.58M for towers)
Predicted cost recovery period	10 years
Computational Software	PowerWorld

Team 3 Proposal Highlights (with focus primarily on industry standards and specs as well as computational analysis):

Towers	Tubular steel construction with vertical configuration; Height: 30 meters, spacing: 150 meters, count: 581
Cables	Aluminum XLPE Conductor; 3 phase AC Total line impedance: 66.792Ω+ 1335.84j Ω
Insulators	Not detailed rather combined with tower hardware
Transformers	21.4MVA for both step-up and step down: low side 13.8kV, high side 115kV with tap changer
Total cost (including labor)	~$11.8M (Max cost is labor ~$8M)
Predicted cost recovery period	7 Years
Computational Software	PowerWorld

Assessment statistics for the team performance of these proposals is discussed in the next section.

In terms of course delivery of subject matters, initial topics related to the review of AC circuits and transformers took longer than expected due to the lack of prior student knowledge in AC circuits. As a result, topics 6 and 7 were briefly discussed and only critical items associated with these topics were covered. Final exam day was reserved for team presentations (of 40 minutes each) regarding their term project so that the transmission system proposal for each team was thoroughly synthesized with all aspects, shared and peer evaluated by the other teams as well as instructor and another faculty.

In addition, a total of seven laboratory activities (six hardware labs using LabVolt™ equipment and one software lab using MATLAB™) are conducted to get students familiar with associated power technology and tools. The students worked in teams of three. The lab activities were:

- Safety and the Power Supply
- Phase Sequence
- Real Power and Reactive Power
- Single Phase Transformer
- Usage of MATLAB™ to Calculate and Plot Distance Dependent Transmission Line Voltages and Currents
- Power Flow and Voltage Regulation of a Simple Transmission Line
- Phase Angle and Voltage Drop between Sender and Receiver

In week 8, a campus field trip was also organized to introduce students to the campus electrical infrastructure including campus substation, substation transformers (115kV to 12.47kV), relays, distribution lines, distribution transformers (12.47kV to 440V or 208V) and major HVAC facilities. University energy coordinator and facilities staff were present to interact with students and answer questions. The primary purpose of the trip is to raise awareness of university's load attributes such as energy usage, max power demand and energy conservation methodologies in the overall power system scheme of things.

Course Assessment, Results and Findings

In the final class meeting, the students were asked to complete a survey regarding the course experience and its potential impact in their career. As can be seen in Table 4 where there were 14 respondents for each question, it was determined that 100% of students agreed at some level that the course was useful in improving their overall knowledge and skills in electrical and computer engineering technology applications. When asked if mathematical relationships selected were appropriate and useful 93% of the respondents strongly agreed or somewhat agreed. There was also a strong positive response concerning the use of simulation tools (question 3) and the campus electrical system field trip (question 7). As question 8 on guest speaker reveals with fairly low 57% of agreement, the student expectations and the level of knowledge need to be clearly communicated with the future guest speakers.

Table 4. Student Survey Results

	Strongly Agree	Somewhat Agree	Somewhat Disagree	Disagree	Not Applicable	Agree Percentage
1. Have you found the course useful to improve your knowledge and skills on overall electrical and computer engineering technology applications?	7	7				100%
2. Are Mathematical relationships and calculations selected in this course appropriate?	6	7	1			93%
3. Are the computational simulation tools (Matlab and PowerWorld) selected appropriate?	3	9		2		86%
4. Do you think electrical power systems would be a good tool to promote science and technology majors among college students?	3	7	4			71%
5. Do you think you are interested to work in electrical power systems industry after your graduation?	4	7	1	2		79%
6. Overall quality of instruction was appropriate and useful for this class.	2	7	3	1	1	64%
7. Campus electrical distribution system field trip and associated presentations, discussions were useful and appropriate for this course.	3	10	1			93%
8. Guest speaker from local utility and his presentation were useful and appropriate for this course.	3	5	3	3		57%
9. I am interested in enrolling in future courses of similar subject matters.	3	5	5	1		57%

The instructional areas that will need to be improved upon would be in question 9 with 57%, question 6 with 64% and question 4 for with 71%. The level of difficulty for the first time exposure of this course would most likely be the contributing factor, especially due to the lack of AC circuits' background and learning curve associated with it. The next implementation of this course would certainly require an AC circuits' analysis course as the prerequisite. Another approach to improve in these instructional areas would potentially be the modifications in the course load with more step by step and simplified approach where the student understanding, enthusiasm and interest through various assessment activities is closely monitored.

The return investment for this course was verified when 79% of the students expressed an interest in working in the electrical power industry after graduation.

The average grade on all assignments for all students in the course was C+. The distribution of grades on all assignments followed a fairly normal distribution. The assessment that students in teams excelled was the term project with A- achievement level for both average and median statistics. The term project had three sections of assessment:

1. Initial summary report of the project framework (10%)
2. Final project written report (45%)
3. Final project oral presentation (45%).

The reports were assessed based on the reporting requirements listed in topic 8 in the course topic list above. The oral presentation was peer evaluated by the other teams as well as the instructor and another expert faculty. As a result, there were total of 4 evaluations for each team. The rubric for oral presentation evaluation is given in Table 5.

Table 5. Oral Presentation Evaluation Rubric

Area	Possible Points	Team Score
Presentation Content		
Title slide with team member names	2	
Overview/Summary	5	
Background and history	5	
Problem definition, objective, goals	5	
Engineering and Technology Design Aspects	12	
Cost Studies/Economics	8	
Simulation/Test Studies	8	
Conclusion/Discussion of Results	5	
References Cited	5	
PowerPoint Slide Quality		
Ease of reading including appropriate text, animation and color combinations	5	
Facilitation of Information Flow	5	
Graphs and diagrams numbered and titled	5	
Correct in spelling, grammar and usage	5	
Presentation Delivery		
The team effectively presented without reading directly from personal notes or from the screen	5	

The team speakers faced the audience, maintained eye contact	5	
The team speakers spoke loudly enough and clearly	5	
The team speakers avoided distracting gestures	5	
The team appeared to have adequate preparation for delivery of presentation and showed enthusiasm	5	
Good use of time – ended on time	5	
Overall Presentation Grade (with 5 extra credit)	105	

The lab assignments were the next best in terms of student performance. Overall, it was also observed that the students performed much better in teams in comparison to individual assignments.

Conclusions

In this paper, a problem oriented project based approach to teaching Power Systems at WCU has been presented. This course aims to address the emerging needs of our society at the same time when addressing the needs of students with diverse backgrounds and demographics. The assessment results show that the project-based component of this course enhanced student comprehension and provided student interest in working in the power industry. This course with its project based assessment was also selected in the Department to satisfy ABET performance criteria (b.3.) – (An ability to select and apply a knowledge of engineering to engineering technology problems that require the application of principles and applied procedures or methodologies) and performance criteria (b.4.) – (An ability to select and apply a knowledge of technology to engineering technology problems that require the application of principles and applied procedures or methodologies).

As a next step, the course is projected to be offered with AC Circuit Analysis prerequisite in upcoming years to provide better coverage of the topics listed in Table 3. In addition, it is also planned to develop and incorporate additional lab activities for further understanding and analysis of the subject matter.

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