Final Project Report

Mobile Lab Bench to Promote ECET Education in Sustainability Topics

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I. Executive Summary

In order to incorporate the learning tools of demonstration and discussion in a laboratory environment, this project implemented a portable multipurpose lab bench. Improved student engagement and learning enhancement were targeted through the use of this single bench cohesively with classroom presentation of sustainability topics and relevant theory. Lab assessments and end of course surveys for two consecutive years were collected to assess the learning experience as well as the effectiveness of the established mobile lab bench concept. The results of the first-year implementation was recently presented in ASEE Conference for Industry & Education Collaboration[1].

II. Project Objective or Goals

This project for a pilot implementation aims to enhance student learning through the use of a low cost mobile lab bench associated with lab activities that can be used to facilitate both demonstration and discussion mediums as outlined in the famous learning pyramid of the National Training Labs[2]. The main project objective is to promote electrical and computer engineering technology education in sustainability topics. The sources of sustainable power such as wind and solar systems today primarily utilize power electronics as an enabling technology. Therefore, teaching power electronics and associated technology in an engaging manner will eventually serve this objective. The course selected for implementation is Modern Power System Analysis, which has been developed for the past four years under the guidance of Consortium of Universities for Sustainable Power[2] (CUSP™). The proposed teaching methodology includes a portable lab bench, which is capable of performing various lab activities that support the lecture module sequence related to sustainability topics presented in the class. The lab activities are not intended to be exhaustive but simple enough to stimulate student interest in the topic. The activities that are selected from CUSP™ curriculum resources and integrated into the mobile lab bench include:

1. Mobile Lab Bench and Power Pole Circuit Board Familiarization
2. Buck Converters
3. Boost Converters
4. Buck-Boost Converters

In this proposed method of instruction, a short demonstration along with the theory of operation not to exceed 25-30 minutes is presented by the instructor to the students during specific lab hours that cover the aforementioned four lab activities. The goal of these demonstrations is to engage students in the learning process and initiate productive discussions. In order to facilitate this engagement, the instructor displays on the projector screen for student observation, waveforms of key circuit variables and show the effects of changing certain input parameters. After the demonstration, student teams are given the opportunity to examine and review the lab setup to complete the lab evaluation survey. The mobile lab bench includes items for a Power Electronics Lab Station, i.e. an oscilloscope, a power supply, a laptop computer, a power pole circuit board, a rheostat and a utility cart that is projected to serve the entire class of approximately 15-20 students. The power pole circuit board is a low voltage DC-DC converter, which can be configured for buck, buck-boost, and boost functions and is recommended by CUSP™ for laboratory instruction. A sample lab bench setup is shown in in Figure 1. In the second year's implementation, a laboratory camera was also utilized to increase the visibility of lab activities, which are also displayed real-time in the projector screen.

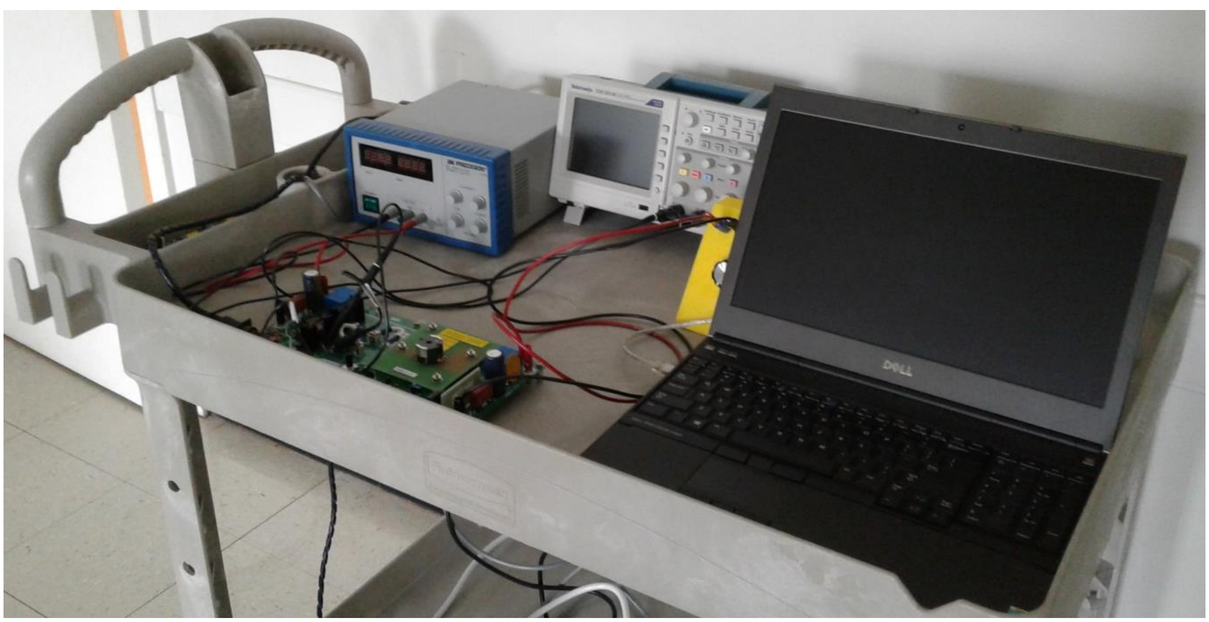

Figure 1. Power electronics mobile lab bench setup

III. Modern Power System Analysis Course

Course Enrollment Figures and Background

The School of Engineering and Technology with an undergraduate enrollment of over 500 students at Western Carolina University includes a 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 mechanical, electric power and manufacturing concentrations

The first three majors are well established, ABET-accredited majors serving the region for many years. The BSE program is a new program that was added in fall 2012 and has three concentration areas; one of which was dedicated to electric power education.

Modern Power Systems Analysis is a senior level course required of all ECET majors. The course was added to the ECET curriculum in fall 2012, primarily due the demand for power engineers and technicians, as vocalized by our industrial advisory board. This is the only course in the ECET major in which students are exposed to electric power systems concepts. The course format was changed in fall 2014 semester to align with CUSP™ objectives. In fall 2016, the mobile lab bench concept was added to this course. The Modern Power Systems Analysis course is currently only offered to ECET majors. Therefore, the course enrollment and project evaluation data in this report only includes the ECET major and student demographics are solely presented for the ECET major.

As of spring 2018, the enrollment numbers for all ECET majors at Western Carolina University are on the average of twenty students for each level from freshman to senior. For the Modern Power System Analysis course, the total enrollment in the discussed implementation was nineteen for the first year and fifteen for the second year. The enrollment statistics of the students in the class are listed in Tables 1 and 2. As can be seen in the tables, a total of three female and thirty-one male students who are all ECET seniors participated in both years.

The Course Structure with Demonstration Laboratory Components

This course is designed to introduce power system analysis principals with a problem-oriented project based approach. Power transmission and distribution network architecture and composition; sustainable power topics; load/power flow studies; power transformers; parameters and equivalent circuits are also covered. MATLAB/Simulink and PowerWorld software are used for power system analysis/design. Prerequisite courses include AC Circuit Analysis and Analog Electronics.

Required textbook:

- Electric Power Systems: A First Course, Ned Mohan, 2012, Wiley.

Table 1. Fall 2016 Enrollment Figures in the Modern Power System Analysis Course

	Undergraduate Level	**Gender**	**Major**
Student 1	Senior	Female	ECET
Student 2	Senior	Female	ECET
Student 3	Senior	Male	ECET
Student 4	Senior	Male	ECET
Student 5	Senior	Male	ECET
Student 6	Senior	Male	ECET
Student 7	Senior	Male	ECET
Student 8	Senior	Male	ECET
Student 9	Senior	Male	ECET
Student 10	Senior	Male	ECET
Student 11	Senior	Male	ECET
Student 12	Senior	Male	ECET
Student 13	Senior	Male	ECET
Student 14	Senior	Male	ECET
Student 15	Senior	Male	ECET
Student 16	Senior	Male	ECET
Student 17	Senior	Male	ECET
Student 18	Senior	Male	ECET
Student 19	Senior	Male	ECET

Table 2. Fall 2017 Enrollment Figures in the Modern Power System Analysis Course

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

Recommended reference books:

- Circuit Analysis Theory and Practice, Robins & Miller, 4^{th} Edition, Thomson, Delmar Learning.
- Introductory Circuit Analysis, 12^{th} Edition, Robert Boylestad, 2010, Prentice Hall.
- Electric Machinery and Power System Fundamentals, Stephen J. Chapman, 2002, McGraw Hill.

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

- Describe and analyze power system components
- Describe the way to calculate power transmission/distribution network parameters
- Model power systems with generators, transmission/distribution network and loads
- Analyze power systems with power flow studies
- Apply the above skills to solve/evaluate real world problems

The Modern Power System Analysis course meets five hours per week. The class time is equally split between lecture and laboratory sessions. Instructional methods and activities for instruction include lectures, group discussions, homework assignments/solutions, in-class quizzes, use of simulation software and a term project, which requires report components. In addition, hands-on and demonstration laboratory activities are also administered to help enforce learning objectives in regards to the basics of electric power and modern power electronics technology.

The course grade is determined by student performance in both individual and team work efforts. Individual effort includes homework assignments, quizzes, midterm and final exams, while team work effort includes lab experiments/reports and the term project. The course grade was determined as a weighted average of assignments using the weights shown in in Table 3.

Table 3. Weight of Course Assignments

1.	Homework Assignments	10%
2.	Lab Experiments/Reports	20%
3.	Midterm and Final Exam	40%
4.	Quizzes	15%
5.	Final Project Report	15%

Term Project Problem Definition: For the purpose of reducing Western Carolina University's carbon footprint as well as supplying clean power to the entire campus, student teams were assigned the task of designing a power transmission infrastructure to transport electrical power from a hydroelectric generation facility at a distance varying for each team.

The original projected course schedule is given in Table 4. The topics addressed and covered in the course in Table 4 are briefly described below.

1. *Introduction to Power* Systems: Electric power, the nature of power systems, power and energy concepts, and the changing landscape of power systems are briefly discussed.

Table 4. Schedule of Topics for Modern Power System Analysis Course

Topic/Activity	**Week**
Introduction to Power Systems	1
Review of AC Fundamentals and Electromagnetics	2
Electric Energy and Environment	3
Sustainable Power Topics	4-6
AC Transmission Lines	7-8
Power Flow in Power Systems	9-11
Power Transformers	12-13
Distribution System, Loads and Power Quality	14-15

2. Review *of AC Fundamentals and Electromagnetics*: Complex algebra, the concept of phasor in AC circuits, AC power and power factor, the nature and dynamics associated with R-L circuits for AC operation, balanced 3-phase circuits and basics of power system analysis and design are reviewed. In addition, basic laws of electromagnetics are introduced and associated applications are discussed.
3. *Electric Energy and Environment*: Energy production and consumption figures in the U.S., choices of electric energy and their consequences, the principles of operation for various power plants including renewables, greenhouse effect and global warming concepts are introduced.
4. *Sustainable Power Topics*: This section is specifically dedicated to switch mode power electronics, which is an enabling technology for today's modern renewable energy and energy efficient systems. Topics of pulse width modulation, switching power pole, DC-DC buck, boost and buck-boost converters are covered.
5. *AC 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 of transmission line parameters are introduced. 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 discussed.
6. *Power Flow in Power Systems*: 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.
7. *Power 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.
8. *Distribution System, Loads and Power Quality*: Basics of distribution system, power system loads, voltage sensitivity of power system loads, power electronics based loads, power quality considerations, linear/nonlinear load characteristics and metrics, IEEE-519 standard for harmonic guidelines and load management topics are explained.

In terms of course delivery of subject matters, sustainable power topics took longer than expected due to the lack of prior student knowledge in switch mode electronics. As a result, topic 8 was briefly discussed and only critical items associated with this topic were covered.

In addition, a total of seven laboratory activities in the first year and eight laboratory activities in the second year were conducted to get students familiar with associated electric power and power electronics technology. Originally, four mobile demonstration labs were planned as discussed in Section II. However, due to the time restrictions associated with the term project progress, only the first and second demo labs were conducted in the first year's implementation. In the second year, all four demo laboratory activities were conducted but the third and the fourth ones were combined in one session. In order to accommodate this update in the second year, the lab order given below was slightly modified. The students worked in teams of three, on average. The lab activities were:

1. Safety and the Power Supply
2. Power Factor Correction
3. Real Power and Reactive Power
4. Sustainable Power Demonstration Labs
5. Single Phase Transformer
6. Power Flow and Voltage Regulation of a Simple Transmission Line

In addition to the experiments above, the term project related activities were concurrently studied starting in Week 3 except during Lab 1, 2 and 4 activities. The sustainable power lab activities were tested and prepared for demonstration during the summer of 2016 with help from a graduate student. In addition, the lab handouts originally provided by CUSP™ were modified to suit the needs of the demonstration labs accordingly. The student teams were required submit meaningful reports for each of these activities.

Project Evaluation, Results and Findings

An evaluation plan was developed and implemented with the purpose of measuring this project's impact in enhancing student learning and retaining students for careers in sustainable power industry. Part of the plan includes a survey of all students who take the Modern Power System Analysis course in the School of Engineering and Technology at Western Carolina University. This plan is an addition to the existing institutional evaluations of our project's performance in retaining students and preparing them for entry into either the workplace or graduate school. At the end of the semester, the students were provided with a survey that assesses the performance of the project through:

1. Student's sense of the learning process associated with the mobile lab bench.
2. Student's interest to work in the industry related to sustainability.
3. Student's desire to enroll in future courses of similar subject matters.
4. Overall student feedback and suggestions.

The survey results for a set of specific survey questions are summarized in Table 5 for both year 1 and 2. In Table 5, the survey results are shown, in each cell, starting with the first year result, followed by the second year. Each cell has the same arrangement. As can be seen in Table 5, there were 19 respondents in the first year and 15 respondents in the second year. Question 9 was not answered (within the five level of agreement) by one student in the second year. It was determined that over 90% of students agreed at some level that power electronics modules and labs would be a good addition to enhance Modern Power System Analysis course. When asked if the demonstration lab procedure presented by the instructor was easy to follow, over 85% of the respondents strongly agreed or somewhat agreed. A perfect agreement was noted on the appropriateness of rigor level of the questions asked in the lab report in the first year. This level of agreement dropped to 80% in the second year primarily due to the increased assessment load associated with demonstration labs. There were also strong positive responses with 84% in the first year and 87% in the second year when asked if the lab reports requested were easy to follow.

Table 5: Student Survey Results.

Survey Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Agree Percentage
1. Have you found the sustainable power (demonstration) labs useful to improve your knowledge and skills on overall electric power systems applications?	9 / 7	6 / 4	1 / 3	2 / 1	1 / -	79 / 73
2. Do you think the demonstration lab is a good alternative to a standard hands-on lab activity?	7 / 2	4 / 5	4 / 5	3 / 3	1 / -	58 / 47
3. Was the demonstration lab procedure presented by the instructor easy to follow?	11 / 5	6 / 8	- / 2	1 / -	1 / -	89 / 87
4. Do you think power electronics modules and labs would be a good addition to enhance Modern Power System Analysis course?	10 / 7	8 / 7	1 / 1	- / -	- / -	95 / 93
5. Do you think you are interested to work in electrical power related industry after your graduation?	8 / 3	4 / 5	4 / 5	2 / 2	1 / -	63 / 53
6. Was the time allowed for the demonstration lab satisfactory for your teaching experience?	8 / 8	6 / 5	2 / 2	3 / -	- / -	74 / 87
7. Was the lab reports requested easy to follow?	8 / 7	8 / 6	3 / 1	- / 1	- / -	84 / 87
8. Was the rigor level of the questions asked in the report appropriate?	7 / 6	12 / 6	- / 3	- / -	- / -	100 / 80
9. I am interested in enrolling in future courses of similar subject matters.	7 / 4	6 / 5	3 / 4	1 / 1	2 / -	68 / 60

The area that will need to be improved upon would be in question 2 with 58% and 47% agreement in year 1 and year 2 respectively when asked if the demonstration lab is a good alternative to a standard hands-on lab activity. It is expected that the student reflection of the demonstration lab is not as good as a hands-on lab, as suggested by the Learning Pyramid. It is also important to note that year 2 implementations included a document camera (Elmo^{TM}) to provide more step-by-step approach so that the student understanding, enthusiasm and interest is closely monitored during demonstration lab activities. However, a lower percentage of agreement was observed in the second year. Increased assessment load for year 2 seems to be the dominant factor in question 2 responses. The results based on survey question 5 was somewhat low but satisfactory in which 63% and 53% of the students in year 1 and 2 respectively expressed an interest in working in the electrical power industry after graduation. It should be emphasized that this is a required course for all ECET majors. Quite similar trend and results as in question 5 can also be observed in question 9, which measures student interest in the power area.

It was concluded that another course management area that can be improved upon after first year's implementation would be the time allowed for the demonstration lab for students' satisfactory teaching experience due to the response rate of 74% in question 6 [1]. Thus, in year 2 offering of this course, assessment loads were balanced more efficiently to provide more weight on the demonstration labs. Evidently, this modification did pay off with an increased 87% agreement.

In addition to the questions in Table 5, the students were asked if they have any comments. One interesting feedback suggestion in year 1 was to add a camera to the projector to help students visualize and better follow what is really happening during the demonstration lab. This was implemented in the second year but it didn't seem to improve the student perception of demonstration labs based on the responses to survey questions 2 and 3.

The return investment for this project implementation is generally positive considering that 79% and 73% of the students in year 1 and year 2 respectively found that the sustainable power (demonstration) labs were useful to improve their knowledge and skills on overall electric power systems applications.

The average grade on all demonstration lab reports for all students in the course was B+ in year 1 and year 2. The distribution of grades on these assignments followed a fairly normal distribution.

Conclusions

In this report, a new laboratory delivery approach to teach the concepts of sustainability at Western Carolina University has been presented. This new approach aims to fill the gap in meeting the learning objectives due to the lack of laboratory resources. The assessment results in year 1 for the first two lab activities showed that the demonstration lab component of this course enhanced student knowledge and overall course provided student interest in working in the power industry. Increased demonstration lab activities with additional lab sessions and assessments did not seem to improve student perception of these labs in comparison to standard hands-on labs. The benefit of document camera used in the second year was also questionable in terms of improving student interest and enthusiasm in demonstration labs.

The course that was offered with a modified assignment load in year 2 to provide better coverage of the lab activities was found to be satisfactory in terms of time allowed for preparation and helped improve student perception of teaching.

It can be concluded that demonstration labs can be a good alternative to hands-on labs as long as student focus and interest over the course of the lab activities can be maintained. However, exhaustive number of demonstration lab activities may cause diminishing returns and ultimately lead to unsatisfactory learning environment as the second-year results suggest.

Acknowledgements

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