Mobile Lab Bench to Promote Engineering and Technology Education in Sustainability Topics – Year 1

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Abstract

“Demonstration” and “Discussion” are two important learning tools that effectively promote student retention and comprehension as outlined in the famous learning pyramid of the National Training Labs (Figure 1). In a laboratory setting where resources are limited to accommodate all students, these tools together can be the best alternatives next to “practice by doing.” In order to incorporate 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 were collected to assess the learning experience as well as the effectiveness of the established mobile lab bench concept.

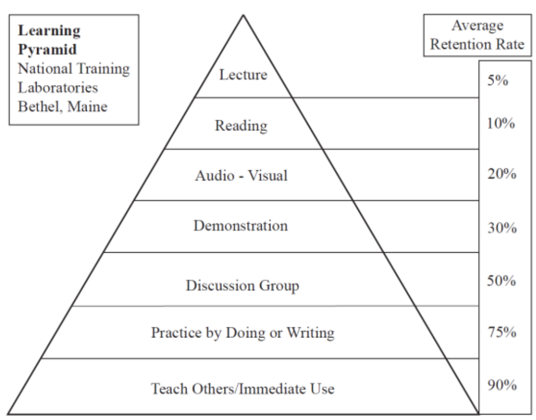

Figure 1. Learning Pyramid[1]

I. Introduction

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[2]. 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[3]. One collaborative effort to fill this gap in skilled workforce is the Consortium of Universities for Sustainable Power[4] (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. Western Carolina University joined this consortium in 2012 to enable the development of a state of the art curriculum in electric power/energy systems.

In the Electrical and Computer Engineering Technology program at Western Carolina University, the course, Modern Power System Analysis, has been developed and implemented for the past three years under the guidance of CUSP™. One common student survey feedback was to have additional lab equipment associated with this course to improve student learning. However, the inclusion of a full-fledged laboratory with new equipment is a difficult task with the currently limited resources for both for the faculty and the department. Therefore, 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.

II. The Mobile Lab Bench Project Objective or Goals

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 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 24 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 2.

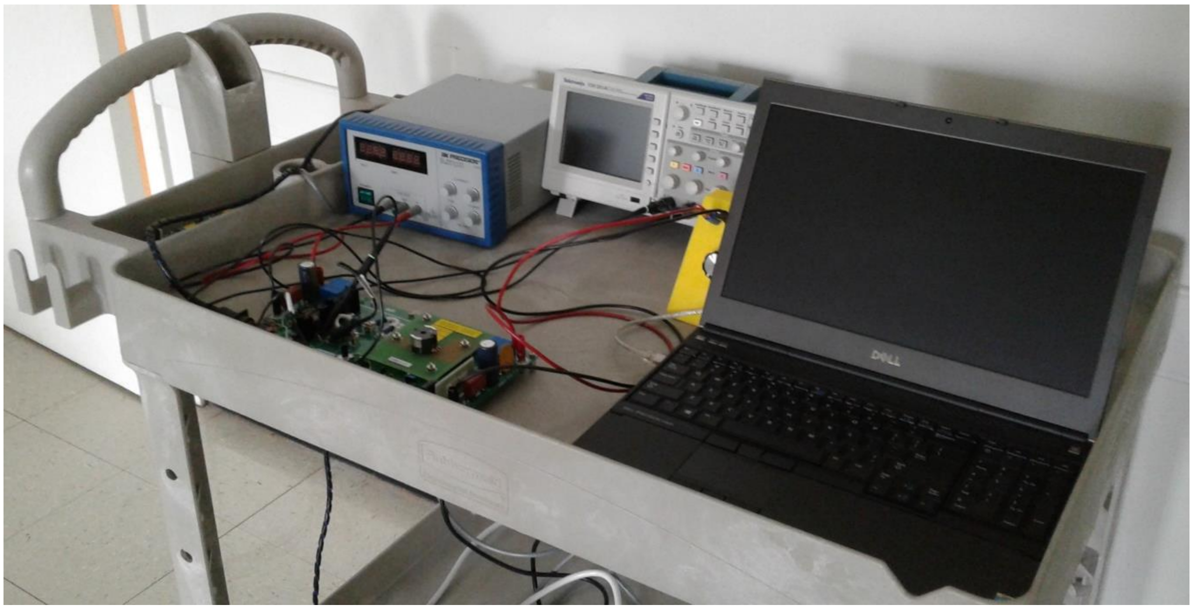

Figure 2. Power electronics mobile lab bench setup

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 paper only includes the ECET major and student demographics are solely presented for the ECET major.

As of spring 2017, the enrollment numbers for all ECET majors at Western Carolina University are on the average of nineteen students for each level from freshman to senior. For the Modern Power System Analysis course, the total enrollment in the discussed implementation was nineteen as well. The enrollment statistics of the students in the class are listed in Table 1. As can be seen in the table, a total of two female and seventeen male students who are all ECET seniors participated in this course.

Table 1. Fall 1016 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

Teaching the Course with Sustainability Focus

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.

Recommended reference books:

- Circuit Analysis Theory and Practice, Robins & Miller, 4th Edition, Thomson, Delmar Learning.
- Introductory Circuit Analysis, 12th 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. In fall 2016 the course grade was determined as a weighted average of assignments using the weights shown in in Table 2.

Table 2. 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.

Letter grades are assigned according to Table 3.

Table 3. Grade Assignments

Numerical Grade		Course Grade	Numerical Grade		Course Grade
≥	<		≥	<	
99	100	**A+**	78	80	**C+**
92	98	**A**	72	78	**C**
90	92	**A-**	70	72	**C-**
88	90	**B+**	68	70	**D+**
82	88	**B**	62	68	**D**
80	82	**B-**	60	62	**D-**
			-	60	**F**

The original projected course schedule is given in Table 4.

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	4-5
AC Transmission Lines	6-7
Power Flow in Power Systems	8-10
Power Transformers	11-12
Distribution System, Loads and Power Quality	13-14
Synchronous Generators	15

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.
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.
9. *Synchronous Generator*: The generator's use in power systems, its architecture, theory of operation, generator's mathematical models and stability, active/reactive power control principles with examples are introduced.

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 9 was briefly discussed and only critical items associated with this topic were covered.

In addition, a total of seven laboratory activities (five hardware labs and two demo labs) are 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. 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 1 – 2
5. Single Phase Transformer
6. Power Flow and Voltage Regulation of a Simple Transmission Line

In addition to the experiments above, the term projectrelated 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.

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. There were 19 respondents for each question, it was determined that 95% 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, 89% 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. There were also a strong positive response with 84% when asked if the lab reports requested were easy to follow.

The area that will need to be improved upon would be in question 2 with 58% agreement 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. One approach to improve in this area would potentially be the modifications in the course load with a more step-by-step and simplified approach so that the student understanding, enthusiasm and interest is closely monitored during demonstration lab activities. The results based on survey question 5 was somewhat low but satisfactory in which 63% of the students 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. Another course management area that can be improved upon would be the time allowed for the demonstration lab for students' satisfactory teaching experience due to the response rate of 74% in question 6. In the next offering of this course, assessment loads can be balanced more efficiently to provide more weight on the demonstration labs.

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	6	1	2	1	79%
2. Do you think the demonstration lab is a good alternative to a standard hands-on lab activity?	7	4	4	3	1	58%
3. Was the demonstration lab procedure presented by the instructor easy to follow?	11	6	0	1	1	89%
4. Do you think power electronics modules and labs would be a good addition to enhance Modern Power System Analysis course?	10	8	1	0	0	95%
5. Do you think you are interested to work in electrical power related industry after your graduation?	8	4	4	2	1	63%
6. Was the time allowed for the demonstration lab satisfactory for your teaching experience?	8	6	2	3	0	74%
7. Was the lab reports requested easy to follow?	8	8	3	0	0	84%
8. Was the rigor level of the questions asked in the report appropriate?	7	12	0	0	0	100%
9. I am interested in enrolling in future courses of similar subject matters.	7	6	3	1	2	68%

In addition to the questions in Table 5, the students were asked if they have any comments. One interesting feedback suggestion was to add a camera to the projector to help students visualize and better follow what is really happening during the demonstration lab.

The return investment for this project implementation is very positive considering that 79% of the students 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 the two demonstration lab reports for all students in the course was B+. The distribution of grades on these assignments followed a fairly normal distribution.

Conclusions

In this paper, 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 for the first two lab activities show that the demonstration lab component of this course enhanced student knowledge and overall course provided student interest in working in the power industry.

As a next step, the course is projected to be offered with a modified assignment load in upcoming years to provide better coverage of the activities mentioned in Section II. In addition, it is planned to incorporate the rest of the four lab activities for further understanding and analysis of the subject matter. A laboratory camera option will also be explored to improve student engagement during the demonstration lab.

Acknowledgements

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Bibliography

1. Learning Pyramid, http://www.fitnyc.edu/files/pdfs/CET_Pyramid.pdf, accessed 05/23/2017.
2. Karayaka, H. B., & Adams, R. D. (2013, June), *A Project Based Implementation of a Power Systems Course for Electrical and Computer Engineering Technology Students*. Paper presented at 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. https://peer.asee.org/19105.
3. Center for Energy Workforce Development, "Gaps in the Energy Workforce Pipeline – 2011 Survey," 2011, available at: http://www.cewd.org/
4. The Consortium of Universities for Sustainable Power, http://cusp.umn.edu, accessed 07/31/2017.

Biographies

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