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Development of lab activities for an ECE undergraduate renewable energy course

Dr. lin zhao, Gannon University

Lin Zhao received the Ph.D. degree in electrical engineering from the University of Western Ontario, London, ON, Canada in 2006. She received the B.Sc. and M.Sc. degrees in electrical engineering from Shandong University, Jinan, China, in 1993 and 1996 respectively. From 1996 to 2002, she was a Faculty Member with the School of Control Science and Engineering and the School of Electrical Engineering, Shandong University. From 2002 to 2007, she was first a Research and Teaching Assistant and then a Postdoctoral Fellow with the Applied Electrostatic Research Center, the University of Western Ontario. Since 2007, she has been with the Department of Electrical and Computer Engineering, Gannon University, Erie, PA, where she is currently an Assistant Professor. Her research interests include electrical machinery design, modelling and analysis of electric drives, and control of electric drives.

Mr. Yuzhe Zhang, Gannon University
Jiawei Zhang, Gannon University

Development of lab activities for an ECE undergraduate renewable energy course

***Abstract*:** This paper presents the development of lab activities for *integration of renewable energy into electrical power systems*. ECE undergraduate students can take this course in their senior year as a technical elective. This course covers variable topics including integrating of different types of renewable energy resources into electrical power systems, the basic concepts of electrical power system, and power electronics application in renewable energy technology. Hands-on experiments have been designed as the integrated part of the course. The lab activities consists of five experiments covering wind, solar, fuel cell, a stand-alone electric power system with solar and wind, and power electronics converter applications. The experiments are designed to be focused on the ECE aspect of the renewable energy and most of the experiments are open-ended.

I Introduction

In the past decade, renewable energy has become one of the hottest topics in engineering education[1]. To catch this trend, Gannon University has been offering the *integration of renewable energy into electrical power systems* course to ECE undergraduate students as a technical elective since Spring2010. Textbooks covering general topics in renewable energy have been published by major higher-education publishers[2-4], yet it is not easy to find a matching textbook that has appropriate knowledge level and tailored scope for junior/senior ECE undergraduate students with the focus especially on ECE aspect of the renewable energy. For this reason, we ended up with combining three different books[5-7]. We faced the similar challenges when trying to add lab activities to the course. After searching for some well-known educational technology companies[8-10], we found ourselves at an awkward situation, on one hand we don't have enough fund to purchase advanced well-developed/equipped lab benches, on the other hand the ones within our budget don't serve the learning objectives of the course well. There are many published papers in the field of renewable energy education[11-16] with some of them addressing the broad scope of renewable energy[11, 12, 14] and the others presenting lab activities for mechanical engineering or non-engineering students[13, 15, 16]. Yet the papers presenting how to develop ECE curriculum concentrated renewable energy lab activities are hard to find. Therefore, we took the approach to develop our own lab activities to match with the lecture content while try to utilize the existing lab equipment as much as we could. The lab activities were developed gradually throughout the years while the course was offering. The students enrolled in this course have been contributing to the design, purchasing and fabricating lab test benches as well.

The lab activities are integrated parts of the course that focuses on "how to integrate different types of renewable energy into electric power system and the impact on the electric power system. The course also stresses the importance of power electronics technology in the process of power conditioning and controlling. The decentralized electric power system concept will be introduced" quoted from the course syllabus. Topics related to doubly-fed-induction-generator for wind energy harvesting are also covered. The prerequisite of the course is circuit II and is offered as a technical elective to undergraduate students. The knowledge linkage between the course and the rest of the ECE curriculum is shown in Figure 1. Besides circuits, senior electrical engineering students at Gannon University have already taken Power Electronics, Automatic Control and Intro to Electric Drives. These courses provide essential background knowledge of electrical generators and motors as well as power electronics technology in electricity conditioning and control. In addition, there are three software packages being used for course projects and labs. They are LabView, PowerWorld, and Matlab/Simulink.

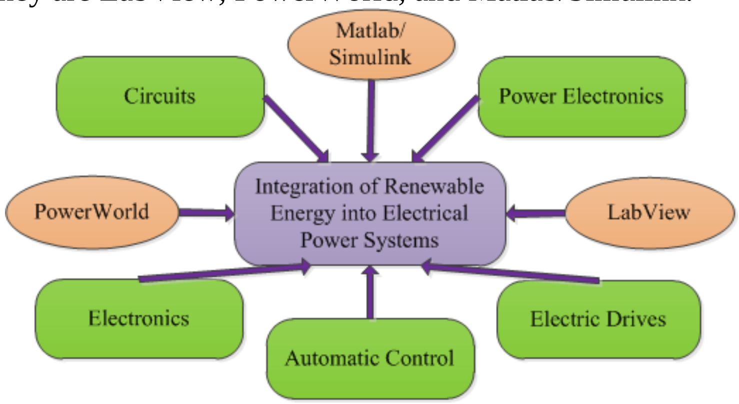


Figure 1 knowledge linkage of the offered renewable energy course

This paper will be focusing on the development of these labs and the knowledge linkage among these labs and to the rest of the courses in ECE curriculum. The feedbacks from students, the assessment and evaluation of the courses with direct/indirect assessment data from both the students and peer faculty members will be presented.

II Lab Activities Development

A. Wind and solar energy lab

The objective of the lab activities has two fold. First, students will have hands-on experience of how energy conversion occurs from wind to electricity and from solar to electricity. Secondly and most importantly, the lab should be designed to emphasize on how electrical engineering contributes to the renewable energy harvesting and how to integrate different types of renewable energy into electrical power systems. Most of the labs are open-ended.

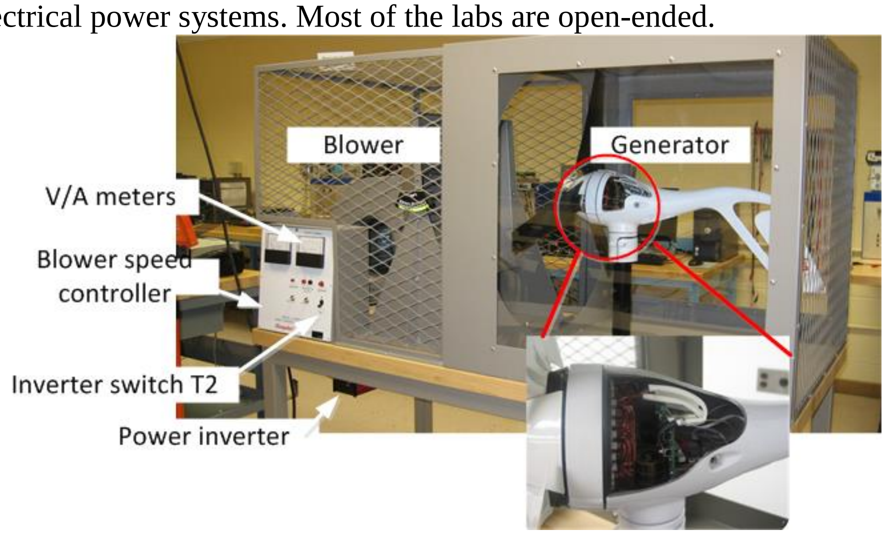


Figure 2 wind energy generator

The wind energy lab was based on the Hampden H-WPG-1B wind power generator as shown in Figure 2. This setup can carry out basic wind energy conversion experiments. The controlled blower can emulate actual wind by changing wind speed and blower angle (wind direction). The wind turbine and the generator unit convert wind energy into electricity. As seen from the figure, the generator output voltage regulating and conditioning circuit is built within the turbine hub. The converted wind energy can be used to charge the battery, to power external DC load and to power external AC load through an inverter. This setup provides students with sufficient activities to work with a lab-sized wind generator system and experience different aspects of the wind turbine generator operation.

The solar energy lab was based on the roof-top 45W solar energy system kit which includes three solar panels and one charge controller as shown in Figure 3. The high power spot lights also seen in the figure were purchased to provide the emulated sun light for the experiment indoor.

Figure 3. solar energy kit and the sunlight emulator

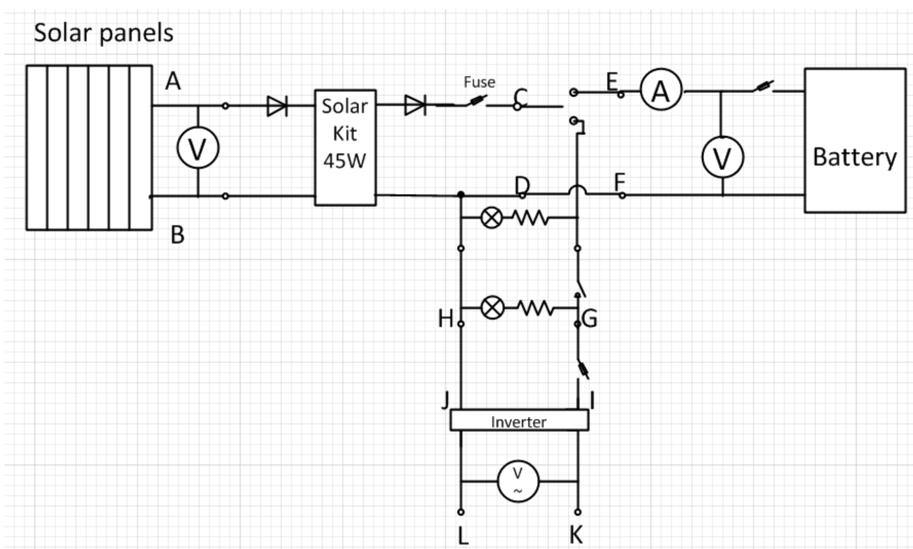


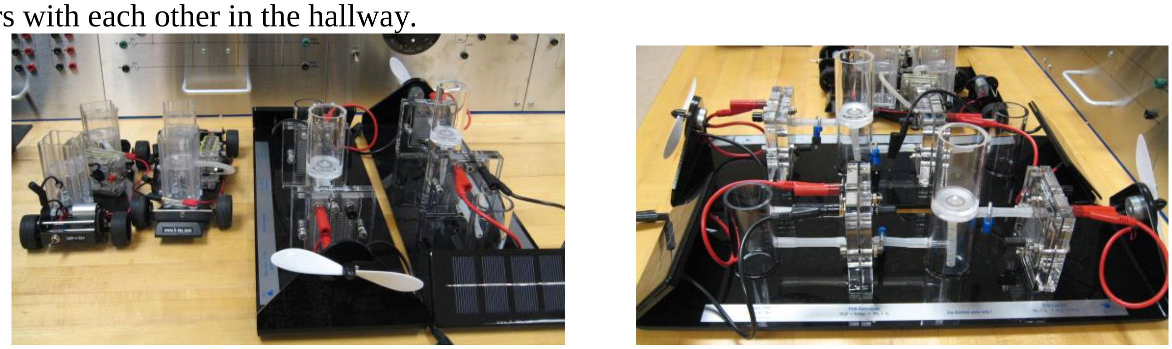
Figure 4. schematic of solar energy system

A control/monitoring panel box was designed and fabricated by students to allow conducting different energy flow projects. The schematic of one of the designs is as shown in Figure 4. The switching box, monitoring meters and the protection devices were designed and built by students as shown in Figure 5. Students were asked to design a stand-alone renewable energy system with solar and wind energy based on the aforementioned devices. The power input to this stand-alone renewable system may vary based on the availability and the power level of the renewable energy resources, such as either in the day or in the night and either in windy day or quiet day. The power output may also vary depending on the electrical load, such as either DC load or AC load and either high current load or low current load, etc. To complete the design and the lab, students will be given the options to combine the solar panel control box (as seen in Figure 5) and the wind energy control box (as seen in Figure 2) to emulate the control logic and strategies based on the power input and output of the renewable system. Students are encouraged to incorporate virtual instrument (LabView) into their lab design to either display the readings in real-time or animate the stored readings.

Figure 5. solar energy control box

B. Fuel cell lab

In the course, the fuel cell was first introduced as an alternative energy resource for electric vehicle. The lab was designed to reflect this idea and to allow students have fun while learning. Hyrunners cars from h-tec as shown in Figure 6 (a) were purchased for this purpose. Each hyrunnder consists of one fuel cell, one oxygen tank, one hydrogen tank and one dc motor gear box set. With electrical power supply, the fuel cell reversely breaks water into hydrogen and oxygen which are restored into different tanks. During the regular operation mode, the fuel cell generates electricity while combining oxygen and hydrogen into water. The dc motor is powered by the electricity generated and drives the car through the gear box. Students had fun racing their cars with each other in the hallway.



(a) (b)

Figure 6 fuel cell lab device (a) hyrunner (b) hybrid system for energy storage

The fuel cell was also introduced as one of the energy storage options. This part of the lab was based on a solar+fuel cell setup as shown in Figure 6 (b). During the day when the solar energy is abundant, generated electricity exceeds the capacity needed. The extra electricity converted from the solar energy can be used to break water into hydrogen and oxygen. The hydrogen can be stored in high pressurized tank as energy storage. During night time, fuel cell can generate electricity consuming the hydrogen stored in the tank.

C. Power electronics lab for renewable energy

Power electronics technology is critical for renewable energy harvesting and usage, especially in the process of power conditioning and controlling. Either it is a stand-alone renewable energy power system or a decentralized power grid with high penetration of renewable energy resources, power electronic converters always play an important role. In this course, there are two power electronics related labs. The first one is basically a review lab to experience DC/DC and DC/AC converters using the workbenches as shown in Figure 7.

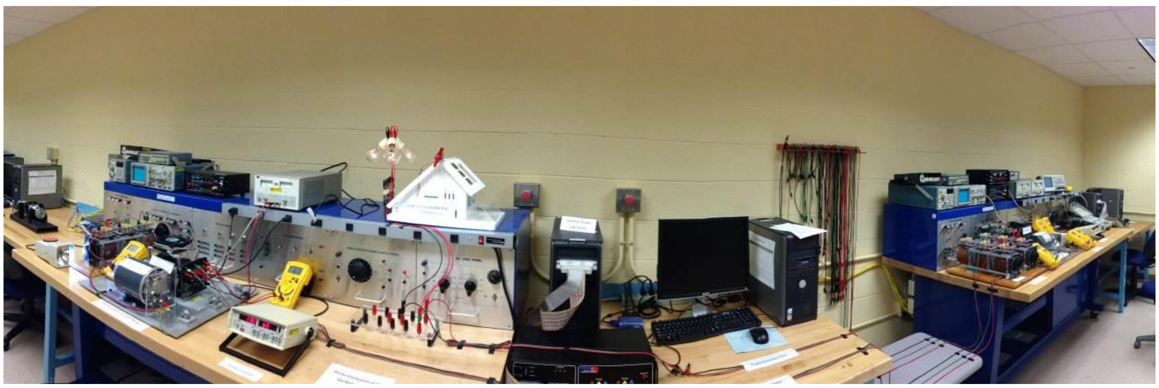


Figure 7. Power electronics testing workbenches

The second one is an open-ended lab about the application of power electronics in wind harvesting with Doubly-Fed-Induction-Generator (DFIG). The DFIG lab has two parts. In the first part, students were provided with a Simulink model of DFIG and asked to add power electronics converters and controller in order to connect this DFIG to power network directly. Most students successfully completed this part and gotten reasonable simulation results.

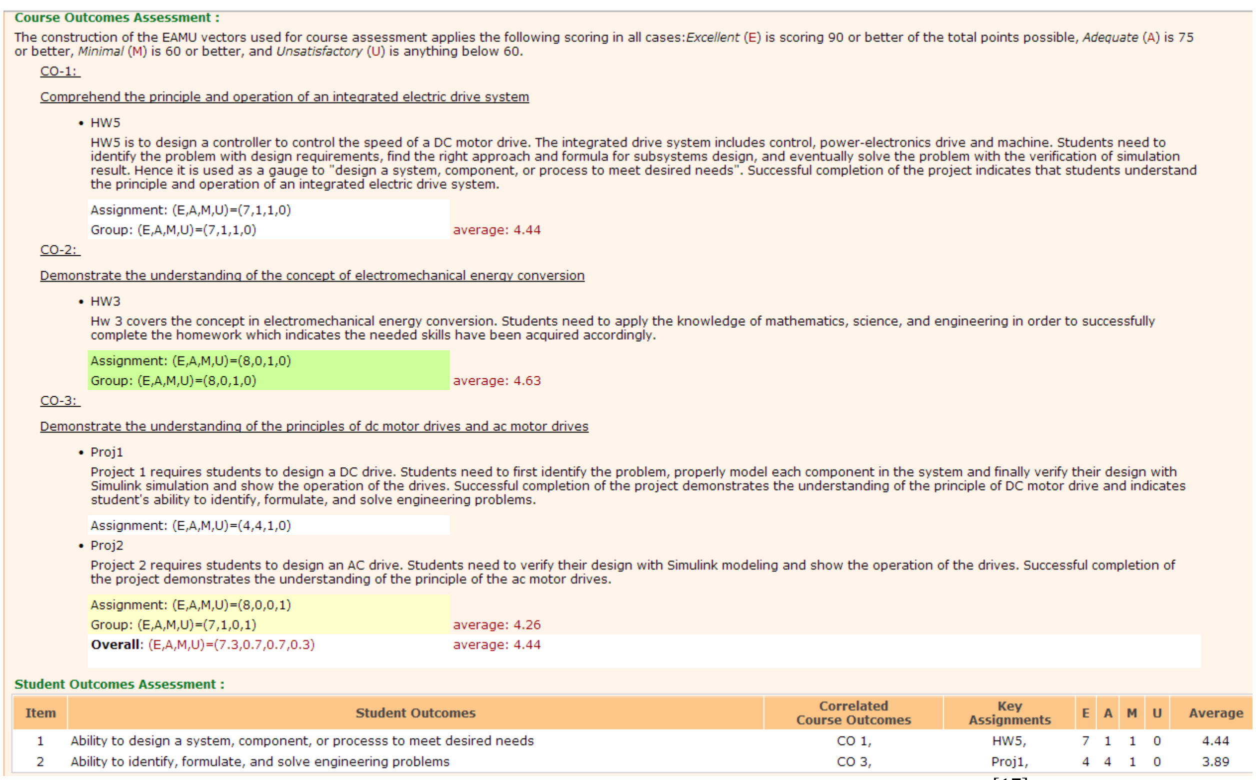
(a) (b)

Figure 8. (a) DFIG from MotorSolver (b) Opal-RT system

The second part is to build a lab-sized wind farm by employing the Hardware-in-the-loop (HiTL) real-time electric drives test workbench. The DFIG, as shown in Figure 8 (a), was purchased from MotorSolver. It was specially designed to match the Opal-RT digital control system as shown in Figure 8 (b). This HiTL electric drives control platform has been used in *Electric Drives Lab* where students conduct eight labs in first semester of their senior year. These labs include DC motor speed control, DC machine four-quadrant operation, V/f control of induction motor, and equivalent parameters measurements of DC motor and three-phase induction motor. Students are challenged to incorporate the DFIG into this platform and to mimic the operation of a wind farm. Unfortunately, this part has not been fully successfully conducted so far. The reason would be not sufficient time allocated to this lab and the complexity of it. Currently one of the graduate students is working on it with the goal to streamline the lab process and make it suitable for undergraduate students.

IV Evaluation and assessment

ECE department of Gannon University has been using EvalTools®[17] for program and course evaluation and assessment for the past decade. The course portfolio including course syllabus, lecture notes, homework assignment/project/lab manuals, grade book, etc is located in the "faculty office" and "student desk" session. Both direct and indirect objective evidences have been collected through EvalTools® for evaluation and assessment.



Course Outcomes Assessment :

The construction of the EAMU vectors used for course assessment applies the following scoring in all cases:*Excellent* (E) is scoring 90 or better of the total points possible, *Adequate* (A) is 75 or better, *Minimal* (M) is 60 or better, and *Unsatisfactory* (U) is anything below 60.

CO-1:

Comprehend the principle and operation of an integrated electric drive system

- HW5

  HW5 is to design a controller to control the speed of a DC motor drive. The integrated drive system includes control, power-electronics drive and machine. Students need to identify the problem with design requirements, find the right approach and formula for subsystems design, and eventually solve the problem with the verification of simulation result. Hence it is used as a gauge to "design a system, component, or process to meet desired needs". Successful completion of the project indicates that students understand the principle and operation of an integrated electric drive system.

  Assignment: (E,A,M,U)=(7,1,1,0)
  Group: (E,A,M,U)=(7,1,1,0) average: 4.44

CO-2:

Demonstrate the understanding of the concept of electromechanical energy conversion

- HW3

  Hw 3 covers the concept in electromechanical energy conversion. Students need to apply the knowledge of mathematics, science, and engineering in order to successfully complete the homework which indicates the needed skills have been acquired accordingly.

  Assignment: (E,A,M,U)=(8,0,1,0)
  Group: (E,A,M,U)=(8,0,1,0) average: 4.63

CO-3:

Demonstrate the understanding of the principles of dc motor drives and ac motor drives

- Proj1

  Project 1 requires students to design a DC drive. Students need to first identify the problem, properly model each component in the system and finally verify their design with Simulink simulation and show the operation of the drives. Successful completion of the project demonstrates the understanding of the principle of DC motor drive and indicates student's ability to identify, formulate, and solve engineering problems.

  Assignment: (E,A,M,U)=(4,4,1,0)

- Proj2

  Project 2 requires students to design an AC drive. Students need to verify their design with Simulink modeling and show the operation of the drives. Successful completion of the project demonstrates the understanding of the principle of the ac motor drives.

  Assignment: (E,A,M,U)=(8,0,0,1)
  Group: (E,A,M,U)=(7,1,0,1) average: 4.26
  Overall: (E,A,M,U)=(7.3,0.7,0.7,0.3) average: 4.44

Student Outcomes Assessment :

Item	Student Outcomes	Correlated Course Outcomes	Key Assignments	E	A	M	U	Average
1	Ability to design a system, component, or processs to meet desired needs	CO 1,	HW5,	7	1	1	0	4.44
2	Ability to identify, formulate, and solve engineering problems	CO 3,	Proj1,	4	4	1	0	3.89

Figure 9. course outcomes assessment summary screen shot[17]

Direct objective evidence—key assignments

Each course outcome has been linked to at least one key assignment which then is mapped to ABET accreditation criteria and/or program educational objectives. The key assignments are graded based on EAMU (Excellent, Adequate, Minimal, and Unsatisfactory) factor. Figure 9 is a sample summary screen shot of the course outcome assessment.

Indirect objective evidence—course exit survey

Course exit survey is treated as an indirect evidence for the course assessment and evaluation. By the end of the semester, students will anonymously answer 52 online questions with a sample screen shot as shown in Figure 11.

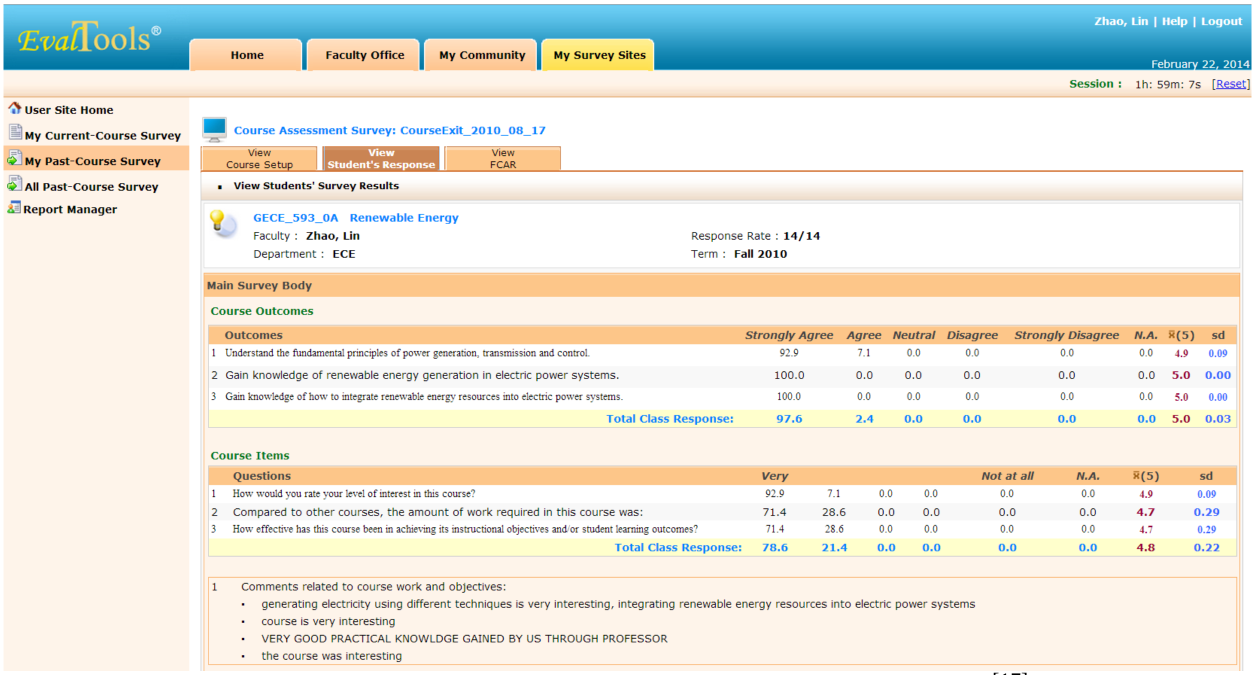


Figure 11. sample screen shot of student course exit survey [17]

Table 1: course exit survey data (in a scale of 5)

Course Number	Course Instruction	Faculty Items	Assessment	Overall
GECE593 1E (Spring2010)	4.6/5.0	4.8/5.0	5.0/5.0	4.8/5.0
GECE593 0A (Spring2010)	4.5/5.0	4.6/5.0	4.8/5.0	4.4/5.0
GECE593 (Fall 2010)	4.8/5.0	4.8/5.0	4.9/5.0	4.9/5.0
GECE593 0A (Spring2012)	4.7/5.0	4.9/5.0	4.9/5.0	4.9/5.0
GECE593 1E (Spring2012)	4.3/5.0	4.6/5.0	4.2/5.0	4.2/5.0
Average	***4.58/5.0***	***4.74/5.0***	***4.76/5.0***	***4.64/5.0***

Table 1 summarizes the course exit survey [17] for the semesters when the renewable energy course and labs were offered. It shows an overall evaluation of above 90% for all the semesters. When answering the survey question of "what did you like best about the course?", some students wrote "introduction into new types of renewable resources and technology to make them grid ready", "generating electricity using different technology is very interesting…and integrating renewable energy resources into electric power system", "I liked that there was a 'real world' application to it. We were able to see how the materials we were learning could be applied to different things", and "I liked the hands on experience…".

The objective folder contains the assessment result surfaced from both direct and indirect objective evidences. A sample screen shot can be seen in Figure 12.

Objective Evidence Folder:

View	Section	Items	Summative Status
◉	1	FCAR	✔
○	2	Course Syllabus	✔
○	3	Direct Assessment Results: Key Assignments Status	Total: 4 student:16 faculty: 13
	4	Grade Distribution for Key Assignments	Key Assignment 1: Average -- 80.6/100.0; Outcomes Met: Key Assignment 2: Average -- 166.6/200.0; Outcomes Met: Key Assignment 3: Average -- 89.4/100.0; Outcomes Met: CO 2 Key Assignment 4: Average -- 79.4/100.0; Outcomes Met: Key Assignment 5: Average -- 95.0/100.0; Outcomes Met: CO 1 Key Assignment 6: Average -- 85.7/100.0; Outcomes Met: CO 3 Key Assignment 7: Average -- 95.9/100.0; Outcomes Met: CO 3 Key Assignment 8: Average -- 82.8/100.0; Outcomes Met: Key Assignment 9: Average -- 80.7/100.0; Outcomes Met: Key Assignment 10: Average -- 77.9/100.0; Outcomes Met: Key Assignment 11: Average -- 95.0/100.0; Outcomes Met:
○	5	Indirect Assessment Results: Course Outcomes Fulfillment rating factor:5	CO 1: Self -- 5.0; Student -- mean:4.4 sd:0.3 CO 2: Self -- 5.0; Student -- mean:4.2 sd:0.3 CO 3: Self -- 5.0; Student -- mean:4.4 sd:0.3 Class Survey Results: Class-- mean:4.4 sd:0.31

Figure 12. objective evidence folder [17]

A faculty committee will review and analyze this folder which acts as a dashboard for the course. Each highlighted link provides detailed info if there is anything needs attention. The committee will suggest necessary action items for further improvement. It will be the faculty member's responsibility to close the action item for next round of teaching. This cycle can be summarized as shown in Figure 13.

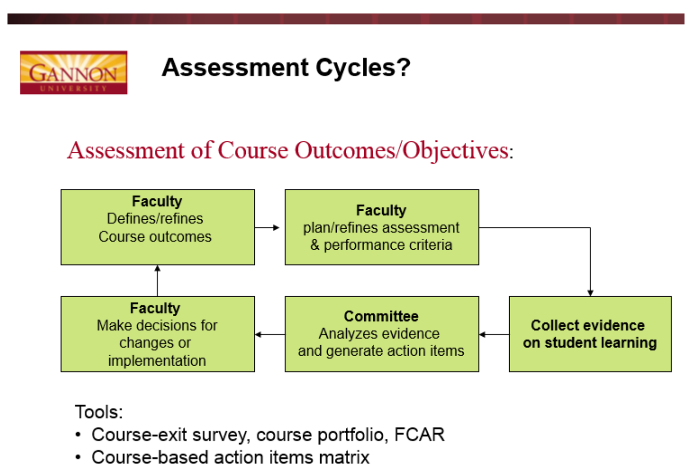


Figure 13. course outcomes assessment faculty committee review cycle[17, 18]

IV Discussion and conclusions

This paper presents authors' experience with the development of lab activities for an undergraduate renewable energy course. The labs were designed not only to provide hands-on experience with different types of renewable energy recourses but also to emphasize on the contribution and challenges of electrical engineering to a decentralized power system with high penetrating of renewable energy resources. The labs presented in this paper have been evolving during the period when the course was offered. Since most labs are open-ended, each group of students contributed to the overall lab development in different ways. From student feedbacks and evaluation throughout the semesters when the course/lab were offered, one can conclude that this teaching-learning approach is well received. These lab activities are still shy from being excellent. The authors hope to stimulate positive and productive discussion by sharing our experience and would like to hear the inputs and feedbacks from reviewers and conference attendees for further improvement.

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