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centralized platform project for multiple ECE core courses

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. 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 and modeling, and control of electric drives.

Mr. Nigel Yu, Gannon University

Electrical and Computer Engineering student.

Centralized platform project for multiple ECE core courses

Abstract
This paper presents the authors' teaching practice of utilizing a centralized platform project to link three core major courses (Automatic Control, Power Electronics, and Electric Drives) in ECE curriculum. The centralized platform project emulates the drive system of a golf-cart. It consists of several subsystems such as controller, power processing unit (power electronics converters), interface circuitry, sensors, and electric machines etc. Students enrolled in these three courses will be introduced to the system level block diagram of the integrated golf-cart drive system at the beginning. In each course, students have opportunity to redesign/modify the subsystem relevant to the particular course they are in. After completing these three courses in a sequence, students will have design and testing experience with component, subsystems, and finally an integrated system. Details of the platform project as well as individual course projects will be described in this paper. The assessment method for course evaluation will be presented at the end of the paper along with students' feedbacks and course-exit survey results.

I Introduction

Traditionally major courses in ECE four-year undergraduate curriculum are taught in relative isolation with each course focusing on its own teaching materials and structure. It was found that even the students who have very good GPA struggle during senior capstone design. This is due mainly to the lack of system-level integrating experience. When given a real-life project, students have challenges of linking it with what they have learned from different courses in previous years. "It seems that all the course projects we completed previously in individual course have nothing to do with the senior design" said one student.

One of the student outcomes evaluated by ABET for engineering programs accreditation is "an ability to design a system, component, or process to meet desired needs…"[1]. Among the most-favored pedagogical models to help students attaining this ability are integrated curricula[2], project-based learning (PBL), problem-based learning, and simulation-based learning (SBL). Yadav and Subedi[3] presented their research findings with problem-based learning. Dym and Agogino[4] explored the PBL for teaching engineering design. Their paper lists some of the open research questions that must be answered to identify the best pedagogical practices of improving design learning. It also makes recommendations for research aimed at enhancing design learning. Koh and Tan[5] investigated the effect of SBL on the motivation and performance of engineering students. Their findings suggest that the students perceived their basic psychological needs to be met and that SBL can potentially enhance self-determined motivation as well as improve learning in general. Prince[6] examined the evidence for the effectiveness of active learning. It is found that there is broad but uneven support for the core elements of active, collaborative, cooperative and problem-based learning. Experimental-learning[7] is another approach gaining much attention recently for engineering education. Constans and Kadlowec[8] used a long-term green design project to integrate the mechanical engineering curriculum.

The teaching-learning model adopted by the author and presented by this paper is a combination of several aforementioned engineering pedagogical models, including PBL, SBL, and experimental-learning. There is a major ECE curriculum revision taking place in the author's school. The centralized golf-cart platform project serves as the departmental-level curriculum integration project. It involves the majority of faculty members, four teaching/research laboratories, and more than ten major ECE courses. The scope of this paper is to present author's teaching practice with three courses linked by using the platform project. Table 1 summarizes the teaching sequence of these three courses.

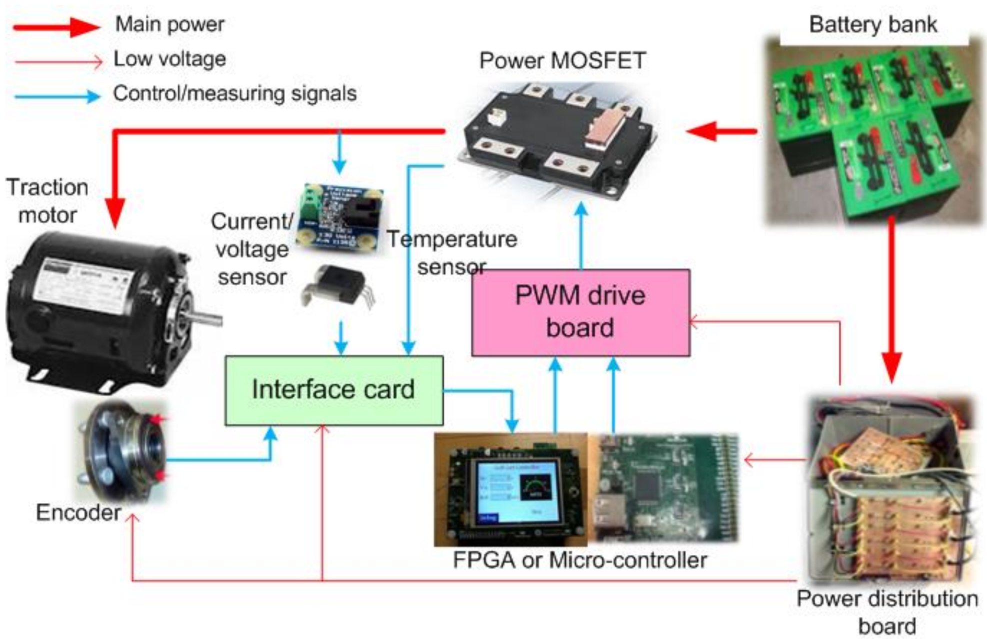
Table 1: Courses location in four-year undergraduate Program

	Junior		Senior
	Winter	Spring	Winter
Automatic Control			
Power Electronics & Lab			
Electric Drives			
Electric Drives Lab			

II The overall project platform

The centralized platform project, with the structure as shown in Figure 1, is based on the drive system of the golf cart. The battery bank (36V) provides the main power for traction motor through power electronics converter to drive the golf cart at different speed. The power distribution board manages different power level requirements (+/- 15V, +/-5V) for variable function blocks. The digital encoder, the analog current/voltage sensors and the temperature sensor monitor the system performance and provide feedback signals to the controller. Microcontroller or FPGA acts as the brain/controller for decision making. One of its functions is to generate PWM (pulse-width-modulation) control signals for speed or torque control based on open-loop or closed-loop control strategies. The PWM drive board amplifies the control signals to trigger the power MOSFET module. The MOSFET module realizes a full-bridge dc/dc converter which provides adjustable dc voltage to the dc traction motor and allows current to follow in both direction. As a result, the DC traction motor can be operated in four-quadrant and under different speed.

(a)



(b)

Figure 1 (a) golf-cart and (b) platform project structure

In order to provide easy and safe access to students, five Opal-RT based workbenches were used to emulate the golf-cart drive system at lower current level as 5A comparing to 65A for the real golf cart. Figure 2 displays the picture of one setup.

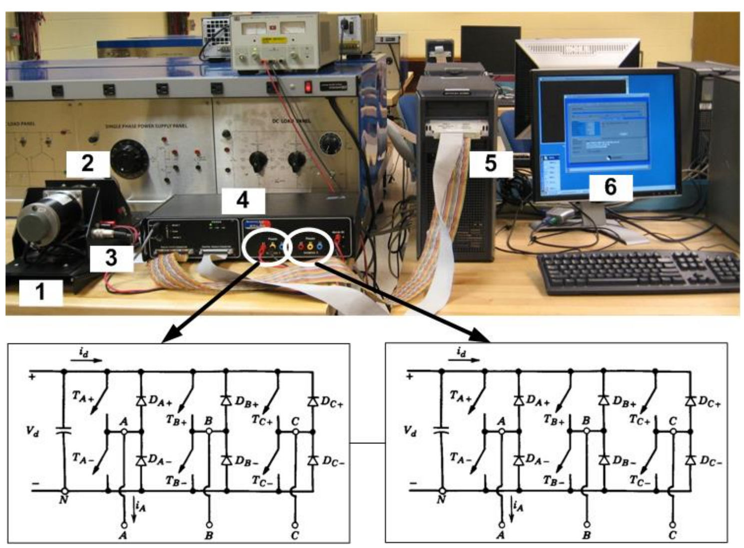


Figure 2. Centralized platform project workbench

- item1-DC motor to be controlled. It emulates the DC traction motor of golf cart.
- item2-DC generator. It emulates load (weight and inertia of golf cart) to DC motor
- item3-encoder to measure the motor speed
- item4-power electronics converter and PWM drive board
- item5-FPGA and I/O ports

- item6-PC with Matlab/Simulink installed for modification and monitoring

As can be seen, this real-life simple system is a good example of an integrated system covering fundamental knowledge from several ECE major courses, such as Power Electronics, Automatic Control, and Electric Drives. Figure 3 shows the color coded block diagram of the golf-cart drive system and the relationship of each block to the aforementioned courses.

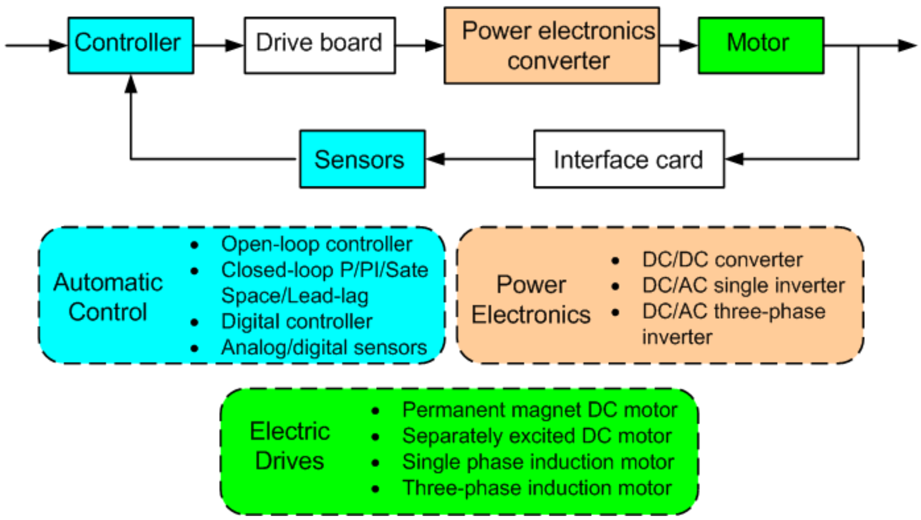


Figure 3 Golf-cart drive system block diagram and the relationship between each block to specific course

The three courses are highlighted with three different colors. The controller and sensor blocks are highlighted in blue which belongs to Automatic Control course. The motor block is highlighted in green which belongs to Electric Drives & Lab course. The power electronics converter block is highlighted in orange which belongs to Power Electronics course. The two white blocks, drive board and interface card, belong to other courses (Electronics and virtual instrument) which are outside the scope of this paper[9]. The dashed line blocks provide the proposed course projects related to the same color course.

If students take the three courses in a sequence, they will have chance to work with the same platform for three times. But each time, the focus is the detailed analysis and design of a different function block. This experience provides students with role-play opportunity as a real engineer in a real industrial environment where a project is always part of a larger system-level project. The subsystems in a larger system are not isolated from each other. Each one of them takes care of special function while interacting with other subsystems through inputs/outputs ports. Each subsystem can also take different design approaches based on the system level requirement.

III Details about the platform project

At the beginning of each course, one lecture is devoted to the introduction of the system block diagram and workbench setup of the golf-cart drive system platform. And then, students in different courses will be assigned to work on different blocks relevant to the particular course. To complete an individual course project, students first carry out the offline simulation as shown in Figure 4 which is also color coded with blue blocks (or subsystems) for automatic control, orange block (or subsystem) for power electronics and the green block (or subsystem) for electric drives. Students in specific course will be asked to design/redesign the subsystems of the relevant color. The rest of the blocks with other colors will be provided to students as known function blocks. After the offline simulation develops satisfying results, students will test their design on the real workbench setup as shown in Figure 2. Table 2 summarizes the known parameters of each workbench. And eventually, students will have chance to test their final design on the real golf cart. It should be pointed out that the high current level golf cart drive system is still under implementation with proposed completion in June 2013. So the projects presented in this paper are all implemented with the lab-size emulated golf-cart drive system as shown in Figure 2.

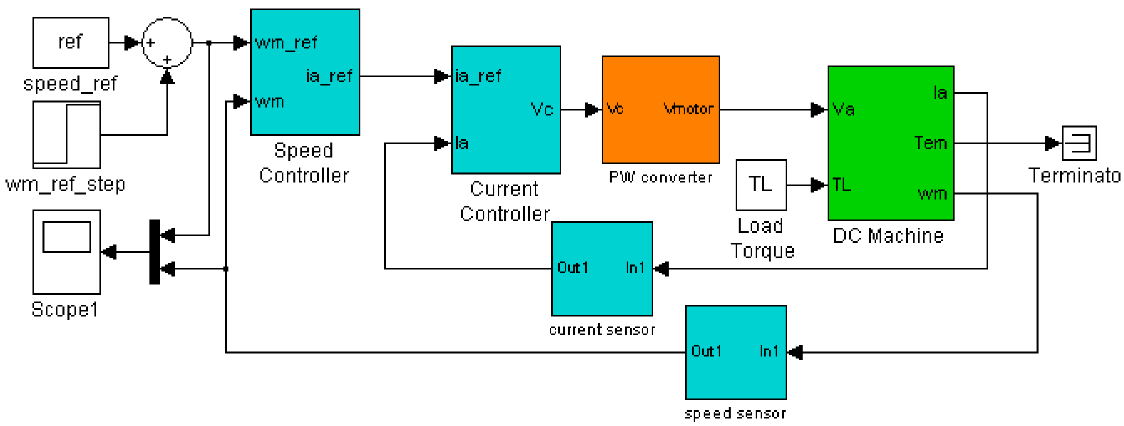


Figure 4 offline simulation model in Simulink

Table 2: System parameters

Motor Parameter	**Value**
Electromotive constant k_E	**0.0772** V/rad/s
Electromagnetic torque constant k_T	**0.067** Nm/A
Armature resistance R_a	**0.7454** Ω
Armature inductance L_a	**4.8** mH
Inertia J_{eq}	**6.87x10^{-5}** Nm/rad/s^2
Friction constant **B**	**0.0003** Nm/(rad/s)
Motor rated speed $w_{m,rated}$	**418**rad/s (or **4000**rpm)
Motor rated armature current i_{rated}	**5A**
Constant friction torque $T_{friction}$	**0. 0756** Nm
Sensor parameters	**Value**
Encoder resolution	**1000** pulses/revolution
Current sensor scale	**0.5**V/A
Voltage sensor scale	**0.1**
Power Electronics converter parameters	**Value**
Switching frequency range	**300~50K** Hz
Dc power supply voltage V_d	**42V**

The rest of the paper will devote to three sample course projects in Automatic Control, Power Electronics, and Electric Drives respectively.

Sample project for Automatic Control

Students in Automatic Control are asked to design a cascaded controller to control the speed of the dc motor that meets the following criteria: maximum overshoot within 20% and steady state error = 0 with self-defined reasonable rise time. Figure 5 gives a possible solution for the workbench test and Figure 6 displays the speed control result.

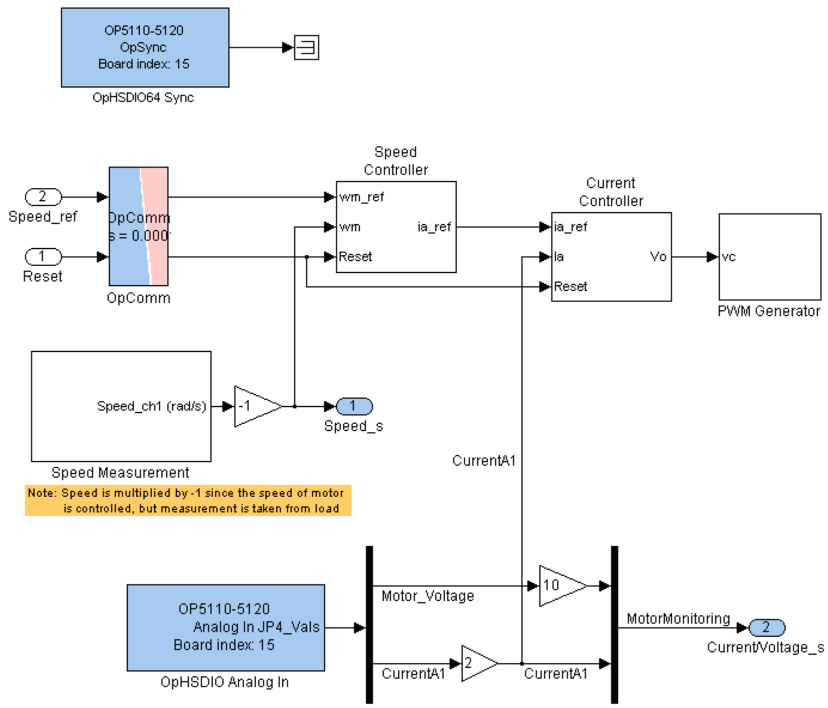
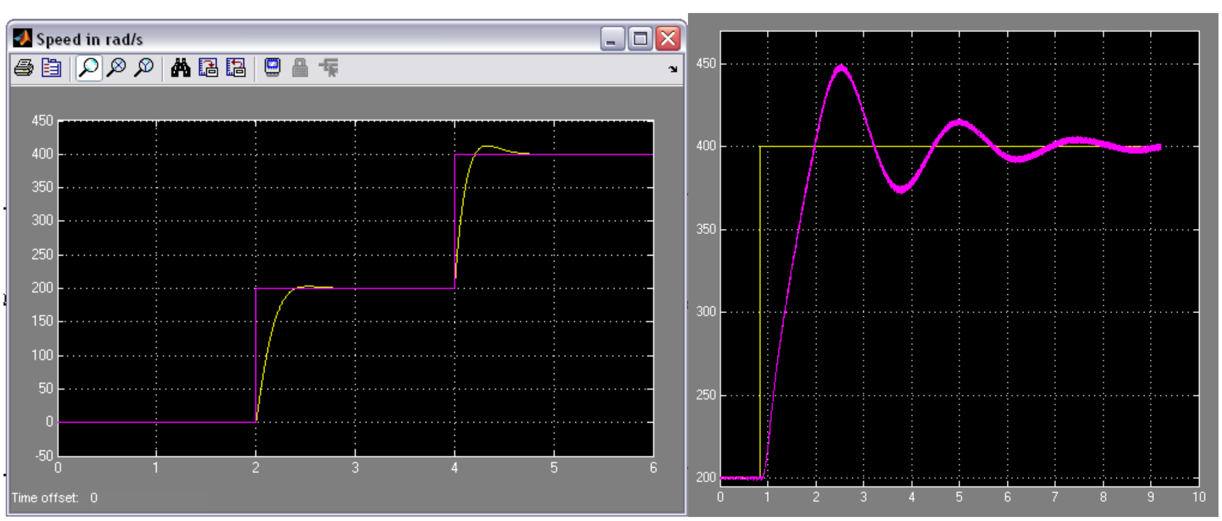


Figure 5 Real-time Hardware-in-the-loop digital control workbench based on Opal-RT system



(a) (b)

Figure 6 speed control results for (a) offline simulation and (b) workbench test

This project focuses on the controllers and the sensors (encoder for speed measurement and current sensor for current measurement). Students will observe the system response with P and PI controllers. They can fine tune the controller gains and observe their effectiveness. This project can be extended to how differently the golf-cart speed respond to open-loop control and closed-loop control. In addition, students can have hands-on experience with over-current fault and can have better understanding of the bandwidth of the physical system.

<u>Sample course project for Power Electronics</u>

One of the projects listed in Power Electronics syllabus is the dc/dc full bridge converter. Students are asked to investigate the difference between the bipolar and unipolar approaches for dc/dc converter. Figure 7 shows the possible solution for unipolar dc/dc full bridge converter on the platform workbench.

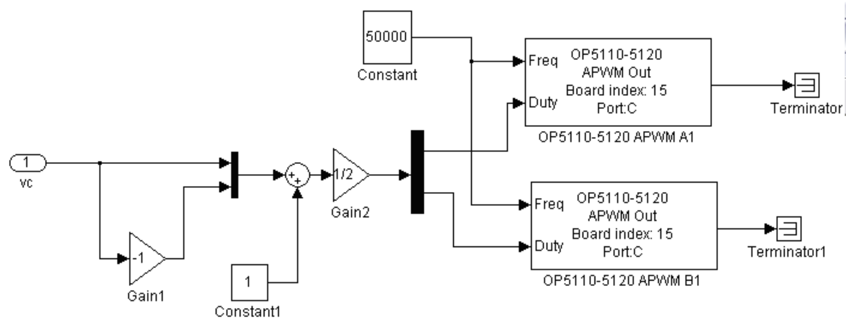
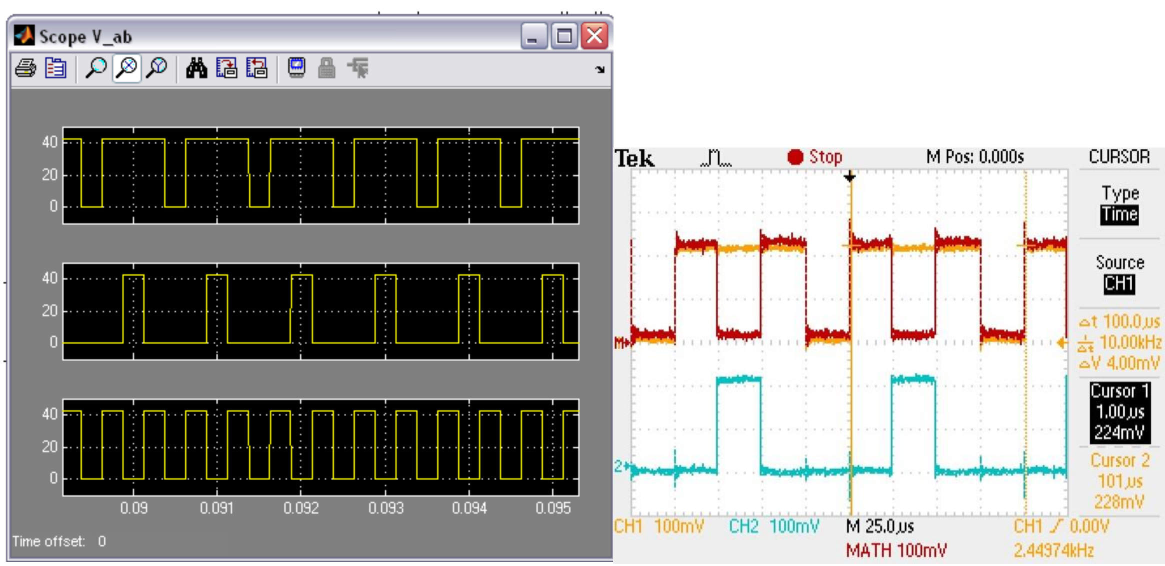


Figure 7 the unipolar dc/dc full bridge converter for real-time digital control workbench

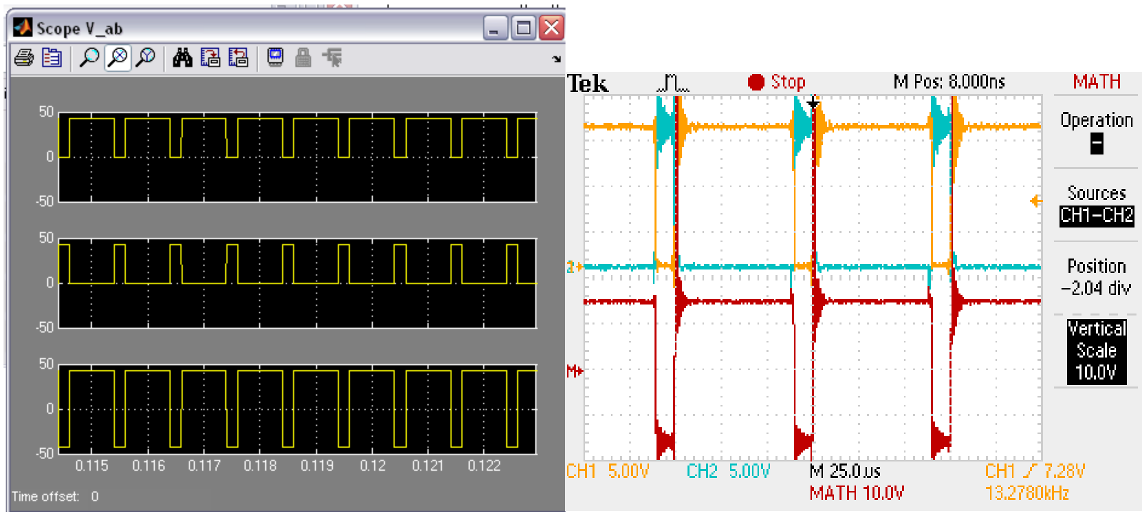
Figure 8 displays the simulated waveforms and oscilloscope display of the real converter output voltage waveforms.



(a) (b)

Figure 8 unipolar dc/dc full bridge converter output voltage waveforms from (a) the offline simulation and (b) the platform workbench

Figure 9 displays the simulated waveforms and oscilloscope display of the real converter output voltage waveforms for bipolar dc/dc full bridge converter. Comparing the waveforms between the unipolar and bipolar, students draw the conclusion that the frequency of unipolar is twice as that of the bipolar and the variation of the output voltage of bipolar is twice as that of the unipolar. In addition, four switching signals are required to realize unipolar compared to two for bipolar.



(a) (b)

Figure 9 bipolar dc/dc full bridge converter output voltage waveforms from (a) the offline simulation and (b) the workbench measurement

It can be clearly seen that this project focuses on the power electronics subsystem. The power electronics converter in the system is to actuate the control signal from the controller and to realize different dc voltage for dc motor speed control. But with the same input signal and the same output average dc voltage, there are multiple options for the converter design.

Sample project for Electric Drives

When students come into Electric Drives class, they have already completed both Automatic Control and Power Electronics. This means they have already conducted aforementioned course projects and can carry out more complex motor control projects. One of the projects in Electric Drives is to realize the four-quadrant operation of dc motor—motor can operate as motor or generator and in two different rotational directions. Figure 10 shows the testing motor’s operation during 40 seconds. The dc machine first operates as a motor in forward running direction, then as a generator in forward running direction. After that, the dc machine operates as a motor in backward running direction, and finally as a generator in backward running direction. It is clear that the real motor speed follows closely with the reference speed which means there is a well-designed speed controller. It also indicates that the power electronic converter functions well to provide required applied voltage to the machine. With this platform project, students in Electric Drives can also experience ac electric drives control for either single phase or three phase. The system level structure will be kept the same while a dc/ac inverter replaces the dc/dc converter and an ac machine replaces the dc machine.

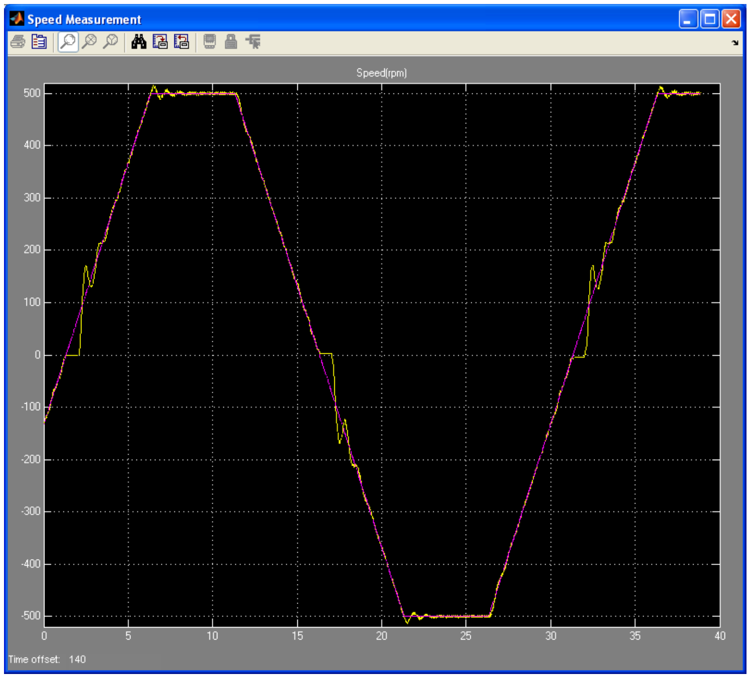


Figure 10 4-Quadrant operation: Speed waveform

IV Assessment and conclusions

Term: Fall 2011

Class: ECE_326_01 Automatic Control
Size: 9

Course Outcomes:

CO 1	Demonstrate the ability of analyzing the stability and response characteristics of dynamic systems
CO 2	Apply classical feedback control methods to improve response characteristics of a dynamic system
CO 3	Demonstrate the ability to analyze a control system with state variable techniques
CO 4	Design classical control for linear dynamic systems using MATLAB

Objective Evidence Folder:

View	Section	Items	Summative Status
◉	1	FCAR	✖
○	2	Course Syllabus	✔
○	3 4	Direct Assessment Results: Key Assignments Status Grade Distribution for Key Assignments	Total: 4 student:20 faculty: 13 Key Assignment 1: Average -- 78.6/100.0; Outcomes Met: Key Assignment 2: Average -- 100.0/100.0; Outcomes Met: Key Assignment 3: Average -- 94.2/100.0; Outcomes Met: Key Assignment 4: Average -- 100.0/100.0; Outcomes Met: CO 3 Key Assignment 5: Average -- 95.3/100.0; Outcomes Met: CO 1 Key Assignment 6: Average -- 91.0/100.0; Outcomes Met: CO 2 Key Assignment 7: Average -- 90.8/100.0; Outcomes Met: CO 4 Key Assignment 8: Average -- 64.3/100.0; Outcomes Met: Key Assignment 9: Average -- 94.0/100.0; Outcomes Met:
○	5	Indirect Assessment Results: Course Outcomes Fulfillment rating factor:5	CO 1: Self -- 5.0; Student -- mean:4.6 sd:0.3 CO 2: Self -- 5.0; Student -- mean:4.6 sd:0.3 CO 3: Self -- 4.0; Student -- mean:4.4 sd:0.3 CO 4: Self -- 5.0; Student -- mean:4.6 sd:0.3 Class Survey Results: Class-- mean:4.7 sd:0.25

Figure 11 summary sheet of course portfolio of Automatic Control in fall 2011

These three courses have been offered using the centralized platform project for five semesters from Fall 2010 to Fall 2012. Each semester, EvalTools@ [10]was used assessment and evaluation by developing the course portfolio for each course, tracking student progress and conducting online course exit survey. Figure 11 shows the summary sheet of Automatic Control in Fall 2011 as an example. It includes Faculty Course Assessment Report (FCAR), course syllabus, direct assessment results with key assignments, and indirect assessment results with class online survey. The direct assessment results show consistent high quality student performance.

The indirect assessment was done in the form of online course exit survey. Figure 12 shows the screen shot of a small portion of the survey. The survey consists of 53 questions in seven categories, including course outcomes, course items, course syllabus, course instruction, faculty items, assessment techniques, overall evaluation, etc. The course exit survey was done for each course for every semester.

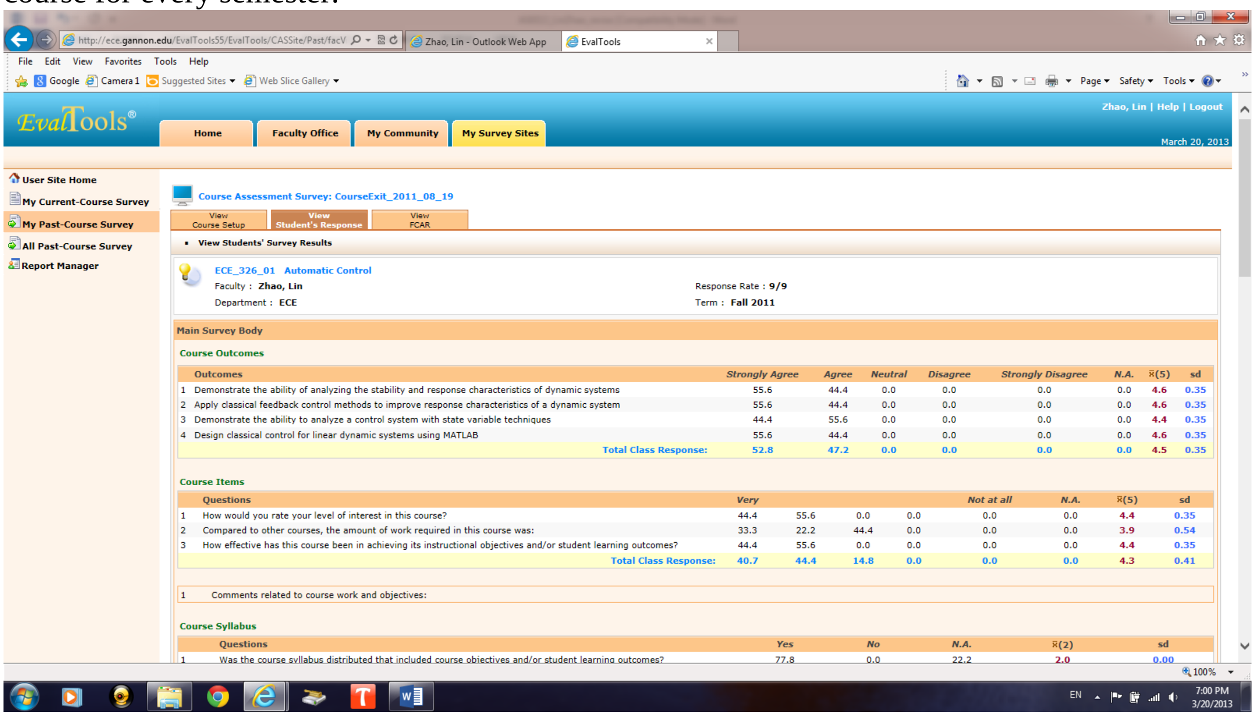


Figure 12 screen shot student course exit survey from EvalTools@

Table 3 summarizes the average course exit survey score (in the scale of 5) for these three courses from Fall 2010 to Fall 2012. It shows an overall evaluation of 905 and above. When answering the survey question of "what did you like best about the course?", some students wrote "I learned more about the components of systems and how they are integrated (vital to electrical engineering)", "learning to analyze actual circuits, which we find in lab and in our professional fields.", "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 with higher voltage equipment".

Table 3: course exit survey data (in a scale of 5)

	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2012
Automatic Control	4.6		4.7		4.8

Power Electronics		4.2		4.4	
Electric Drives Lecture		4.4		4.4	
Electric Drives Lab	4.8		4.6		4.8

This paper presents the author's teaching practice with linking three major ECE courses by employing a centralize golf-cart platform project. The centralized platform consists of several separated yet integrated subsystems with each handling a specific function. Understanding of the relationship among these subsystems provides students with system level concept and thinking. In each course, students have opportunity to redesign/modify the relevant subsystem to meet specific design requirements. By taking these three courses in a sequence, students gain design and testing experience with component, subsystems, and eventually a complex integrated system. Detailed information of the platform project and sample course projects were presented. Both direct and indirect assessment methods are employed to evaluation these three courses for five semesters. The positive feedback from students and high quality performance of students are evidences supporting the conclusion that this centralized platform project based teaching-learning approach is well received.

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