Applications of Computer-Based Power Electronics to Electric Vehicle Technology, An Interdisciplinary Senior Course.

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I. Abstract

In this paper, we describe how the design and analysis of power electronics can be made alive to students by focusing all classroom and laboratory experiences on a high-profile, high-tech, production unit such as General Motors' propulsion system for its EV1 electric vehicles. Using this strategy, an interdisciplinary team of faculty at our university successfully designed a senior elective for electrical engineering and electrical engineering technology students in power electronics. Developed under a FIPSE grant, the course covers both the design of state-of-the-art power electronics and the design of associated computer interfacing, all focusing on the propulsion system. Unlike traditional power electronics courses where the design methods are applied to generic scenarios, focusing on such a high-profile modern plant helps motivate students because they see the lessons as real, relevant, and career oriented. The paper includes a comprehensive description of the high-power electronics subsystems and the solid state devices commonly used in power electronics, and it discusses the range of laboratory experiments and projects that students are assigned throughout the semester. The paper also discusses the data acquisition system that was developed using LabView for students to safely monitor high voltages and currents from the propulsion system and the ABC150 battery charger. Finally, results of the assessment of student satisfaction are presented.

II. Background on Electric Vehicles to Understand Our Course Design

In electric vehicles (EV) applications, designers must continue to improve performance and reliability and to ensure an acceptable level of comfort and safety. Batteries must have high energy densities, small size and light weight, and fast recharging capability (low internal resistance), and they must remain safe when damaged or abused and be reliable and affordable. Regenerative braking must be used to extend the operating range of a vehicle, especially in stop/start traffic conditions. During braking, the motor must act as a generator, returning energy to the battery. Discharge paths must be provided to protect the battery and the motor drive circuit from overload, and for air conditioning, dc-dc converters are needed. In addition, drive electronics and battery chargers must be added to the system, including a dc chopper (PWM) that drives the armature winding to provide speed control. Thus, the electric vehicle becomes an excellent focal point for a course in design that can excite and motivate students.

III. What Makes the course exciting?

3.1 Hands-on design

Students find the course exciting because they are involved in hands-on design throughout the course, working with an ABC150 battery charging system, to monitoring its high currents, voltages, control signals, and temperatures at different locations inside the engine, and programming TI microcontrollers to achieve a prescribed acceleration and motor speed. In addition, students use PSpice to simulate a three-phase motor and its high power control circuits. They are doing rather than just listening.

3.2 Industry Projects

Another exciting feature is students engagement in industry type projects that are proposed by our industry partner. Both faculty and research engineers and scientists from our industry partner supervise the teams. Typical projects involve such topics as hybrid vehicle design and the design of software and hardware data acquisition systems for detecting high currents and voltages inside the engine.

3.3 High Technology

The new course was designed to utilize new technologies related to the instrumentation of electric and hybrid electric vehicles. At the high power and solid state device level, the course incorporates Insulated Gate Bipolar Transistor (IGBT) technology with computer interface with smart devices and high speed Silicon Carbide (SiC) devices. In DSP applications, the course utilizes TI microcontrollers to control the three-phase motor of the EV1. The new technology in high speed charging and discharging system is covered in the ABC150 charging system.

3.4 Computer Simulation and Instrumentation

An integral part of the course is the use of PSpice to simulate the propulsion system and LabView for data acquisition to monitor high power voltages and currents at the different phases of the motor and inverter side. Voltages, currents, and temperatures are monitored via sensors mounted inside the engine.

3.5 Industry Guest Lectures

The course includes guest lectures from EV and HEV industries. Exciting topics are usually selected to deliver up-to-date technology in this field. Several examples include hybrid systems used in trucks and buses and important issues in EV/HEV that still need to be worked out by industry.

3.6 Plant Trips

During the last week of classes, students take a plant visitation trip where they get the chance to see different activities in this area and hold discussions with research scientists in areas such as DSP, power electronics, batteries, and power systems, all related to Evs and HEVs.

IV. Topics Covered in the Course

There are five major components covered in this course:

4.1. Motor Applications Involving the General Motors EV1 Power Plant

The EV1 uses a three-phase motor that is controlled by a three-phase inverter. In this design, the given inputs to the inverter are braking and acceleration demands, with the output voltages displaying a PWM waveform, while the motor current displays a sinusoidal waveform.

4.2. Energies, and Battery Charging/Discharging and Regenerating System

An ABC150 battery charging system is used in the course. It is capable of supporting up to 360 A and 600 V through a differential mode operation and can be run in either the auto or the manual mode. In the auto mode, students write a script file to control the power entering the propulsion system.

4.3. Power Electronics and Computer Interface

Power semiconductors used in the chopper circuit are BJT Darlington transistors, power MOSFETs, or IGBTs (insulated gate bipolar transistors). IGBTs are preferred in high voltage applications, and such devices with 600 V ratings are used with battery voltages higher than 150V at operating frequencies from 2 kHz to 18 kHz. In the EV1 propulsion system, 600 V IGBTs are used to drive a 120KW three-phase induction motor. Inverter circuitries operating in the range of 10 kHz to 20 kHz, sinewave modulators, IGBTs are used with recovery diodes. LabView's data acquisition system with 24 channels was used in the development to monitor low and high currents and voltages inside the propulsion system.

4.4. DSP and Fuzzy Logic Control

Students learn to program a TI. microcontroller, writing a simple C program to learn how to use the compiler, linker, and debugger. They write codes to set up a timer to interrupt program execution and set the time base for processor-based speed control systems. An interrupt rate of 10,000 interrupts/second was selected, which is the monitor control update rate used in the exercise. Students use open-loop speed control, and sine tables are used to generate the sine values.

4.5. High Power Solid State Devices

High power solid state devices such as power MOSFETs, IGBTs, and SiCs and their applications in EV/HEVare covered.

In addition to the above topics, this course include topics covered by industry such as hybrid trucks and buses, plant visitation, and a project.

V. Laboratory Components

There are four categories of laboratory components:

5.1. ABC150 battery charging system (one laboratory)

Students learn how to use the manual mode to enter the required power to the propulsion system. The also write a script file to use the auto mode of the system. The file follows a charging curve as prescribed by the battery manual.

5.2. LabView Data Acquisition System (one laboratory and three computer LabView exercises)

Students learn how use the LabView software operating tools to manipulate front panel controls and indicators. They also learn to use the labeling tools and positioning tools in both functions and control palettes. Students learn how to create a virtual instrument and apply it to simple circuits with multiple.

5.3. DSP TI Microcontrollers (four laboratories)

These laboratories are intended to give students practice in the use of a TI mocrocontroller for a required motor speed and acceleration.

5.4. Computer Simulation Using PSpice (four laboratories)

In these laboratories, students use PSpice to design DC-to-DC converters such as Buck, Boost, Buck-Boost, and Kuk Converters. With PSpice, students are able to simulate three-phase induction motors including PWM circuitries with high voltage and current interface circuits. Several algorithms for unipolar and bipolar PWM schemes are selected.

VI. Assessment Data

Student satisfaction was assessed over two offerings of the course. The results have been combined and are presented in the table below, which presents data separated by major. EET students were enrolled only during the second offering of the course. The scale used was 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree.

Assessment of Student Satisfaction

	Item	EE Students (n = 25)	EET Students (n = 4)
1	I enjoyed the team-taught aspects of the course	4.38	4.25
2	The grading system used to evaluate the students in the course was appropriate .	4.23	4.25
3	I enjoyed the presentation by the visiting industry scientists.	4.19	4.00
4	I enjoyed the motors section of the course.	3.88	3.75
5	I enjoyed the battery and energy section.	4.23	4.00
6	I enjoyed the power electronics section.	4.35	4.25
7	I enjoyed using Pspice to simulate power electronics components.	4.16	4.00
8	I enjoyed working in the propulsion laboratory.	4.25	4.25
9	I enjoyed working in groups on our project and in the oral presentation.	4.17	4.00
10	I enjoyed the DSP and fuzzy logic section.	4.07	4.25
11	I enjoyed the field trip to Allison Transmission that helped me see what engineers do in industry.	4.24 (n=24)	4.50 (n=2)
12	I feel that I developed an understanding of electric vehicle components, their operation and simulation.	4.23	4.00
13	The teaching assistants were suitable for the course .	4.02	4.00
14	I learned a lot from my project.	4.71	4.50
15	Including both engineering and technology students in one class is a positive feature of the course.	4.42	4.25
16	Overall, I felt the course has prepared me for a career related to electric and hybrid vehicles.	4.19	4.25
17	Compared with other elective courses in the curriculum, I found this course to be more applied and more industrial oriented.	4.18	4.00
18	I would like to see additional courses related to electric vehicles.	4.30	4.20
19	I would like to take a graduate course following this course if one is offered.	3.95	3.50
20	Compared to other senior level courses in my major, the hands-on nature of this course helped me master the materials to a higher level.	4.34	4.25
21	Compared to other senior level courses in my major, the theory aspects of the course was more difficult.	3.25	3.50
22	Compared to other senior level courses in my major, the homework assignments were more difficult	3.09	3.25
23	Compared to other senior level courses in my major, the laboratory experiments were more challenging.	4.36	4.25
24	Our team of EE and EET students functioned well.	4.20	4.25
25	Students from both majors contributed to the success of the team	4.00	4.00
26	Taking a course with majors from my counterpart's department was a good experience.	4.20	4.50

It is interesting to note the following:

- The responses of the EE and EET students track fairly well. Their responses were comparable on all of the items in the survey.
- The students agreed (4.0 or better) that they enjoyed ten of the eleven items (items 1-11) that

asked how they enjoyed various aspects of the course. The single item that was rated slightly below the "agree" level was item 4 on the section on motors. We will address this item in our planning for the next offering of the course.

- Students said that they understood the working of the basic components and their simulations (item 12) and that they learned a lot from their projects (item 14).
- They agreed that combining EE and EET students in one class is a positive feature (item 15) and that it was a good experience (item 26).
- Neither the EE or EET majors expressed an agreement with wanting to take a graduate course in the subject (item 19), with the EE majors reporting an understandably stronger interest (3.95) than the EET majors (3.50). This latter result is not surprising.
- Items 21 and 22 demonstrates that the EET students found the course a little more challenging than the EE students, but neither found the course more challenging that other senior level courses in their respective majors.
- Items 24 and 25 demonstrate that the teams functioned well that both majors contributed to team success.

VII. Discussions and Conclusion

As shown in the assessment data, students have found the course motivating and exciting, and they feel that the course prepares them for the real world of engineering. The few concerns raised by students on the sequencing of the topics and the pre-requisite topics will be handled in future offerings. The development team was faced with some problems throughout the development [1] of the course and was able to overcome them and offer the course as scheduled by the FIPSE grant.

References

[1] Rizkalla, M.E, Pfile R, Alantably, A, and Yokomoto, C.F, "Development of a Senior Elective for EE and EET Majors in the Design of Electronic Instrumentation for Electric Vehicles, "CD-ROM Proceedings of the 1998 ASEE Annual Conference," Section 2502, 1998.