Continuing Education in Power Electronics

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***Abstract*—Continuing education has become an increasingly important part of the mission of higher education in the United States and around the world. The objective of engineering continuing education is to help practicing engineers stay current with technological advances relevant to their current or future job assignments. This paper presents the strategies and guidelines for continuing education in power electronics. Critical issues pertaining to engineering education, such as how to identify learning needs, define learning outcomes, design course contents, select instructional methods, assess student performance, and conduct course evaluation, are discussed in detail.**

***Index Terms*—Continuing education, electrical engineering education, electronics engineering education, engineering continuing education, engineering education, power electronics, power engineering education, road vehicle electric propulsion, road vehicle electronics, road vehicle power systems.**

I. Introduction

The GENERAL task of power electronics is to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for user loads, as shown in Fig. 1 [1]. Power electronics is recognized as the enabling technology propelling many national critical technology areas, such as telecommunications, computers, automation and process control, robotics, transportation, and all forms of environment-friendly energy conversion [1], [2].

In particular, power electronics is quickly proliferating in automotive systems, including powertrain, chassis, safety, and body subsystems, as summarized in Table I. Automotive power electronics has become one of the fastest growing areas for power electronics applications. The paradigm shift of the automotive industry from traditional internal combustion engines to electric or hybrid drivetrains will create a tremendous demand for power-electronics-proficient engineers nationwide.

However, power electronics instruction is often not a core component of electrical engineering curricula nationwide [3]–[6]. The majority of practicing electrical engineers has little or no exposure to the subject. Even among those who are directly involved with power electronics design and development, the percentage of engineers being self-taught on the subject is estimated as high as 90%. There are also many nonelectrical automotive engineers who are interested in learning the basics of power electronics and related automotive applications. Furthermore, there is a lack of learning materials on power electronics focusing on automotive applications.

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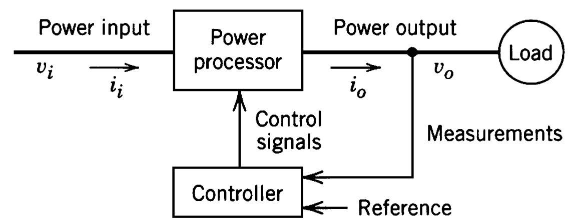

Fig. 1. Block diagram of a power electronic system [1]. (*This figure is used with permission from John Wiley & Sons, Inc.*)

The University of Michigan—Dearborn (UMD) is located at the heartland of the automotive industry. The “Big Three” U.S. auto makers (GM, Ford, and DaimlerChrysler) and many automotive suppliers are located within a 50-mile radius from the UMD campus, a region representing the largest manufacturing concentration in America. One of the primary missions of the College of Engineering and Computer Science at UMD is to provide unique educational opportunities for engineers to remain competitive in a fast-paced, global environment that is constantly demanding new knowledge and enhanced skills. The Engineering Professional Development (EPD) at UMD offers an extensive range of professional developmental programs, which demonstrate a commitment to career growth and expansion. As an entrepreneurial link between academia and industry, EPD offers flexible, innovative, and dynamic programs that contribute to the technical vitality of the engineering profession as a whole.

In response to the emerging needs of power electronics education, a short course entitled Automotive Power Electronics: Devices, Circuits and Systems was developed at the University of Michigan—Dearborn in 2000. The targeted audience was practicing engineers employed by automotive original equipment manufacturers (OEMs) and suppliers who have not received any formal training but are interested in the subject.

II. Learning Outcomes

The objective of this engineering continuing education course is to introduce the basic concepts of power electronic devices, circuits, and systems with a special emphasis on their automotive applications. Therefore, by the end of the course, participants are expected to be able to perform the following:

1) develop a strong functional literacy in automotive power electronics;
2) learn the basic concept of power semiconductor devices;
3) learn the basic operation of typical power converter circuits;

TABLE I
POWER ELECTRONICS APPLICATIONS IN AUTOMOTIVE SYSTEMS

Automotive Subsystems	Power Electronics Applications	Circuits and Devices
Powertrain	Electrical and hybrid drivetrains, fuel injector solenoid driver, ignition coil driver, transmission control solenoid driver, electric cooling fan control, electronic throttle control actuator driver, alternator rectifier, voltage regulator, integrated starter generator drive.	High- and low-side switch circuits, H-bridge and three-phase inverter/converter circuits, low-voltage (30-100V) power MOSFET, high-voltage (400-600V) IGBT, diode.
Chassis and Safety	Electrical power steering, motor drive, ABS solenoid driver, traction control solenoid driver, active suspension actuator driver, airbag ignition driver.	High- and low-side switch circuits, H-bridge and three-phase inverter/converter circuits, low-voltage power MOSFET, diode.
Body	Lighting control, high intensity discharge (HID) lamp driver, power seat/power door/power window actuator driver, windshield wiper motor drive, defrosting/defogging control, climate control, instrumentation panel.	High- and low-side switch circuits, H-bridge and three-phase inverter/converter circuits, DC/DC converters, low and high voltage power MOSFET
Electrical/Ele tronic Architectures	Electrical distribution and active power management, multiplex wiring, 42V PowerNet.	High- and low-side switch circuits,. DC/DC converters, low voltage power MOSFET

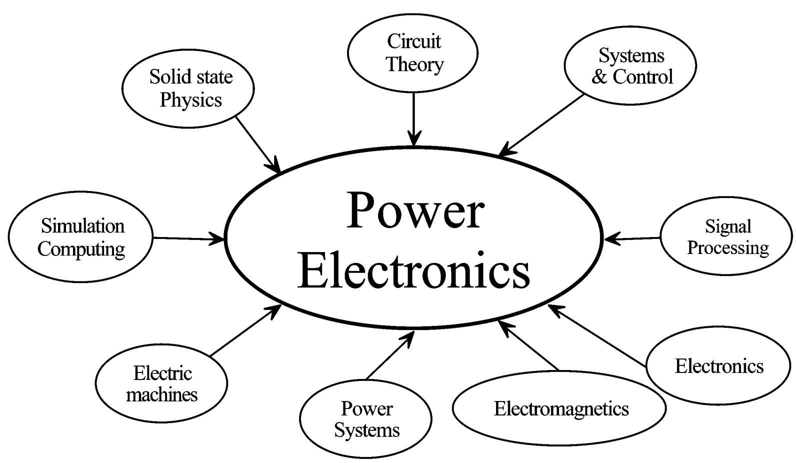

Fig. 2. Interdisciplinary nature of power electronics [1]. (*This figure is used with permission from John Wiley and Sons, Inc.*)

4) understand typical automotive applications of power electronics, including actuator drivers and motor drives;
5) develop an appreciation for practical design issues, including selection of power devices, thermal management, reliability, and electromagnetic compatibility (EMC).

III. Course Design

Power electronics possesses a strong interdisciplinary nature [1]. It encompasses many different fields within electrical engineering, such as power systems, circuit theory, power semiconductor devices, electrical machines, control theory, analog/digital electronics and signal processing, electromagnetics, and thermal design as shown in Fig. 2. In addition, automotive power electronics must address issues specially related to automotive applications, such as automotive sensors and actuators, under-hood operating environments, EMC, safety, and reliability requirement.

Combining the knowledge of these diverse fields makes the study of power electronics extremely difficult and challenging. Traditionally, most electrical engineering curricula divide the content of power electronics into two full three-credit-hour regular courses both at the undergraduate and the graduate level [1], [2]. These two courses amount to approximately 80 hours of lecture time and 160 hours of self-study time in the traditional curricula. However, like most short courses for engineering continuing education, Automotive Power Electronics was developed in the format of two or three days (16 or 24 hours in total) to fit into the busy schedule of the participants. Consequently, an immense challenge was presented for designing the short course. The traditional course content and structures had to be considerably redesigned in an innovative way to cover the same subject

TABLE II
OUTLINES OF THE AUTOMOTIVE POWER ELECTRONICS SHORT COURSE

TOPICS	TIME (HOUR)	DIFFICULTY LEVEL	LEARNING OUTCOMES
Overview of Power Electronics: ▪ What is power electronics? ▪ General applications and automotive applications ▪ Classification of power processors and converters ▪ Interdisciplinary nature of power electronics ▪ Switching versus linear circuits	1	Basic	a
Power Semiconductor Devices: ▪ Ideal power switches and semiconductor physics ▪ Diodes, MOSFET, and IGBT ▪ Power ICs and emerging device technologies ▪ Power losses and thermal management ▪ Reliability of power semiconductor devices	3	Basic to advanced	a, b, d, e
Electric Loads and Passive Components: ▪ Capacitors, inductors, and transformers ▪ Lamps, Solenoids, coils, and relays ▪ Motors (DC, induction, BLDC, switched reluctance)	1	Basic	a, d
Power Electronic Converters: ▪ Steady state analysis ▪ Pulse Width Modulation (PWM) concept ▪ AC/DC rectifiers, DC/DC converters, DC/AC inverters ▪ Controls of power electronics	4	Basic to advanced	a, c, d, e
Automotive Power Electronics Case Studies: ▪ Fuel injector solenoid driver circuits ▪ IGBT ignition coil driver circuits ▪ Alternator rectifier & voltage regulator circuits ▪ PM DC motor drive circuits ▪ HID lamp driver circuits ▪ Electric power steering systems ▪ 42V PowerNet ▪ Traction motor drives (induction, BLDC, SR)	4	Advanced	a, b, c, d, e
Modeling and Simulation: ▪ MOSFET switching circuit and power losses ▪ PWM converters (DC/DC and DC/AC) ▪ Automotive ignition circuits	3	Advanced	a, b, c, d, e

in a much-shortened time period without sacrificing the quality and depth of the course. This difficulty seems to exist in most subject areas across engineering disciplines and is not particularly limited to the power electronics continuing education.

Table II outlines the course structure and topics of the Automotive Power Electronics short course. The specific learning outcomes listed in Section II are also linked to these topics. The short course is divided into two major sessions: fundamentals of power electronics and case studies of power electronics applications in automotive systems. The fundamental session includes power electronics overview, power semiconductor devices, electrical loads and passive components, and basic power electronic converters. The case study session discusses the specific applications of power electronics in automotive systems. Examples include a fuel-injector solenoid driver, an insulated-gate bipolar transistor (IGBT) ignition coil driver, an alternator rectifier and voltage regulator, a power window control circuit, high-intensity-discharge (HID) lamp driver circuits, electric power-steering systems, 42-V electrical systems (42-V *PowerNet*), and electric/hybrid drivetrains (including field-oriented control of induction, brushless dc, switched reluctance motors). Fig. 3 shows the diagram of a fast-recovery fuel injector driver circuit discussed as an example in the case study session [7]. These topics, usually not offered in regular undergraduate or graduate power electronics courses, comprise a very important part of the short course and provide the necessary relevance to the participating engineer's job functions. They also provide an ideal forum for classroom discussion since most participating engineers have some degree of familiarity with these applications. Some learners may even have extensive experience with a certain type of circuits. Finally, a session on simulation and laboratory demonstration is designed to provide the students with an opportunity to enhance what they have learned in the fundamental and case-study sessions.

Because of the limited time and scope of this short course, several topics were excluded from the short course. Those topics, although an integral part of classical power electronics course content, are not widely applied in automotive systems. These topics include phase-controlled rectifiers, ac/ac converters, and resonant converters.

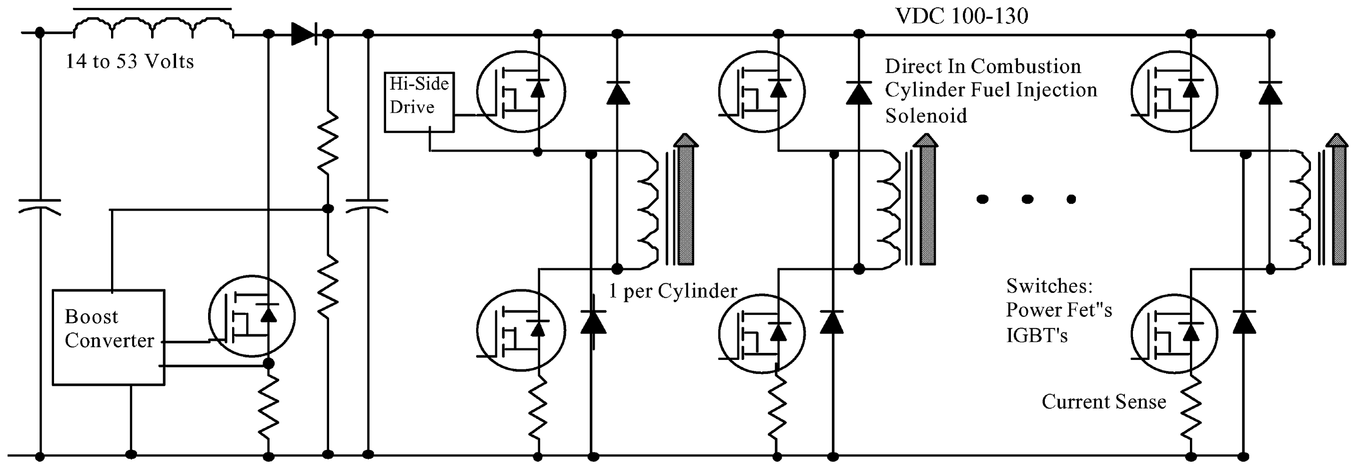

Fig. 3. Fast-recovery fuel-injector driver circuit.

IV. Instructional Methods

The lecture starts with an overview on power electronics, followed by a detailed discussion on individual technical topics. The overview covers the basic functions, general and automotive-specific applications of power electronics, the classification of power processors and converters, and the interdisciplinary nature of power electronics.

Multiple computer simulation and laboratory minisessions were integrated into the short course. After each major topic session, the learners are given 30–45 minutes to use PSPICE software to construct the power electronic circuits covered by the preceding lecture and observe the circuit and device behaviors and the impact of various circuit parameters. For example, a simple low-side metal–oxide–semiconductor field-effect transistor (MOSFET) switching circuit was used to help the learners understand the operation and the switching loss calculation of semiconductor power devices. The learners were also required to construct a dc/dc converter, an H-bridge dc/ac circuit, and the control signal-generating circuits to better understand the pulsewidth modulation (PWM) concept. For automotive-specific applications, an inductive-discharge ignition circuit is simulated to help the learners understand this important application and the related design issues.

V. Course Assessment

Because of the nature of continuing education, a written exam may not be a suitable method for assessment. Several assessment methods, outlined hereafter, were adopted to assess the students learning outcomes.

1) Oral quizzes were used at the conclusion of each lecture session. Sample questions include the following:
   — What are the four basic classes of power converters?
   — Why are IGBTs preferred over power MOSFETs for electric drivetrain applications?
   — What is the basic idea of pulsewidth modulation?
2) Sample problem solutions were combined with classroom exercises. After an sample problem was solved, the learners were provided with a similar problem to solve on their own. For example, the learners were asked to derive the relationship between the output and input voltages of a step-up ("boost") dc/dc converter as a function of duty cycle after a step-down ("buck") converter was fully discussed by the instructor.
3) Computer simulation and modeling sessions were used to assess learning outcomes. The learners were required to design power electronic circuits and observe how the circuits behave on circuit simulators, immediately after these circuits were covered in the preceding lecture sessions.

VI. Course Evaluation

The effectiveness of the automotive power electronics short course was evaluated by all participants of the course. Table III summarizes the survey result of the short course from approximately 45 participants in 2001–2003. Overall, the short course was rated positively by the participants (64% rated "excellent" and 36% rated "good"). While the survey clearly showed that the learning outcomes and prerequisites were well defined, and the course materials were up-to-date, there was still room for improvement in making the course more relevant to the participant's job performance and more challenging and interesting.

VII. Critical Issues Pertaining to Engineering Continuing Education

Continuing education has become an increasingly important part of the mission of higher education in the United States and around the world [8], [9]. Particularly in engineering disciplines, many universities and colleges are actively engaged in providing advanced, meaningful educational programs to the professional engineering community [10]–[12]. The objective of engineering continuing education is to help practicing engineers stay current with technological advances relevant to their current or future job assignments. The rate of change in critical technologies, such as information technology, microelectronics, telecommunications, material science, chemical engineering, and bioengineering, approaches 25% per year. The estimation is that a practicing engineer should participate in 100 to 300 hours of continuing education each year to stay current in his or her professional area [11]. Besides technical conferences and symposia,

TABLE III
ANALYSIS OF THE SHORT COURSE EVALUATION SURVEY

Survey Questions	Response		
1. Considering your career goals, does this course fulfill your needs?	Completely 64%	Satisfactorily 36%	Inadequately 0%
2. Was this course job-related?	Yes 100%	No 0%	
3. If this course is job-related, to what extent will you be able to use the information you received in the performance of your job?	Great extent 57%	Some extent 36%	Not at all 7%
4. Were the learning outcomes of the course clearly defined?	Completely 100%	Satisfactorily 0%	Inadequately 0%
5. Were the prerequisites adequate?	Completely 86%	Satisfactorily 14%	Inadequately 0%
6. Was the course challenging and interesting?	Always 79%	Sometimes 21%	Never 0%
7. Was the course material up-to-date?	Up-to-date 93%	A little outdated 7%	Mostly outdated 0%
8. What is your opinion of the course materials?	Excellent 57%	Good 36%	Fair 7%
9. Was there undue repetition of materials already covered in other courses?	Never 43%	Rarely 50%	Sometimes 7%
10. Would an advanced version of this course be of interest to you?	Yes 64%	No 36%	
11. Would you recommend this course to other?	Yes 100%	No 0%	
12. Overall, how would you rate this course?	Excellent 64%	Good 36%	Fair 0%

university courses (regular or short courses) provide a very important resource for practicing engineers to fulfill their training needs. Many engineering faculty are actively involved in developing and teaching courses for industrial audiences. However, it should be pointed out that engineering continuing education is considerably different from traditional full-time undergraduate/graduate education because the participants have diverse educational backgrounds, learning needs, time usage patterns, and learning styles. Engineering educators must take these factors into consideration while developing and teaching continuing education courses [13].

Critical issues pertaining to all engineering continuing education are how to identify learning needs, define learning outcomes, design course contents, select instructional methods, assess student performance, and conduct course evaluation.

A. Identify Learning Needs

Continuing education courses need to be planned in response to identified needs of the target learner group. The purpose of identifying learning needs is to identify the difference between an existing condition and a desired condition. Needs represent a shortage/deficit condition or required enhancement in contrast to interest. Multiple information sources can be used to identify needs. Needs may be identified within a society, a profession, a community, an organization, or an individual. Needs may arise from a variety of reasons, such as new legislation or regulations, new performance expectations or deficiencies, changes in information, skills, attitudes, processes, systems, organizations, occupations, and professions. The process should identify who is affected by the need, that is, who the potential learner should be. The rationale and planning for each course should be the result of needs that have been identified and documented by some assessment methods. These methods for assessment include focus groups, questionnaires and surveys, participants' comments and suggestions, records, reports, tests or self-assessments, print media, observations, and work samples. Once needs have been identified, they must be analyzed to determine if an educational or training solution is appropriate. Engineering faculty, who are usually experts in their technical fields, should work closely with the continuing education staff in their organizations to identify such needs and opportunities.

B. Defining Learning Outcomes

Clear and concise written statements of intended learning outcomes must be provided based on identified needs for each continuing education course. Learning outcomes, which provide a framework for the proposed course, are the basis for selection of content and instructional strategies. They also describe to learners exactly what knowledge, skills, and/or attitudes they are expected to accomplish/demonstrate as a result of the course and form the basis for providing periodic feedback, measuring progress, and final assessment of learning. The learning outcomes must be clear, concise, measurable, and developed directly from identified needs. Learners should be informed of these intended learning outcomes prior to and during the course.

C. Course Design

Most short courses for engineering continuing education are developed in the format of two or three days (16 or 24 hours in total) to fit into the busy schedule of the participants.

This format, consequently, presents an immense challenge for designing the short course. The traditional course content and structures, which are usually presented throughout one or two semesters with a total of 40 or more conduct hours, must be considerably redesigned in an innovative way to cover the same subject in a much shorter time period without sacrificing the quality and depth of the course. This difficulty seems to exist in most subject areas across engineering disciplines and is not particularly limited to a particular continuing education course.

Such difficulty can be overcome because the short-course audience is quite different from the traditional undergraduate or even graduate students. First, most short-course participants are practicing engineers with a reasonably good understanding of the fundamental principles and basic concepts of electrical engineering and many years of experience in the design and development of electronic products. They are more likely to have a clear sense of what they already know and what they need to learn for professional development. They tend to be more capable of grasping new engineering concepts quickly and readily than most traditional students, who are still in the early development stage of their engineering background. Second, only the key topics pertaining to the fundamental understanding of the subject and important examples directly related to the participant's current or future job assignments need to be covered in great detail. Other topics should only be briefly discussed, and the option of further study on these topics should be left to those who are particularly interested. Third, detailed mathematical derivations, while important to help a traditional student gain fundamental understanding on subjects in science and engineering, are often unnecessary or even counterproductive in short courses designed to serve the needs of engineering professionals. Short-course instructors often can more productively describe the physical picture of a concept with only a moderate amount of mathematical derivations.

D. Instructional Methods

Instructional methods should be consistent with the learning outcomes and accommodate the diverse learning styles of the engineering audience. The methods used should provide opportunities for learners to be actively involved, interact with the instructor and materials as well as other students, process what they have learned, and receive feedback that reinforces learning. The methods described in the subsections hereafter seem to be very effective in teaching an engineering continuing education course.

1) Top-Down Approach: Practicing engineers prefer to learn new technical materials in a top-down fashion, namely, they like to grasp the "big picture" first, such as the basic function, general application, development history, and marketing information of the technology, and then get down to technical details. This concept is referred to as a "top-down" learning approach. They need to first decide where and how the new materials will fit into their existing knowledge base. Traditional college students who are limited in their knowledge and experience tend to learn technical details first, then gradually build the "big picture" toward the end (i.e., a "bottom-up" learning approach). While the bottom-up approach is often used by university faculty in teaching undergraduate courses in math, sciences, and engineering, it is generally not suitable for engineering continuing education. The lecture starts with an overview on the subject and is then followed by a detailed discussion on individual technical topics. The overview provides the audience with a brief description on the content and scope of the short course and a road map for the more detailed discussion later.

2) Classroom Interaction: Learners need to become actively involved, interacting with the instructor and other students in any kind of teaching, especially in continuing education courses. Participating engineers in a short course often have very diverse backgrounds, experiences, and learning objectives. The method of course material delivery needs to be adjusted accordingly to maximize the learning experience of each audience group. A good practice is to encourage the participants to introduce themselves in the beginning of the course. The introduction should include their names, affiliations, job functions, and, most important, why they are interested in taking the short course. The instructor should use this information to enhance the classroom interaction by addressing issues of common interest to the group, designing questions to which individual participants can easily feel connected, and using examples that may be related to the work experience of the audience.

Some attendees may have extensive experience and knowledge on the subject being discussed and can be valuable assets to the instructor and the class as a whole. The instructor should take advantage of their presence and leverage their expertise to bring the classroom discussion to the next level. The input from these attendees as well as others is often useful in revising the course materials for future classes. However, caution needs to be taken to involve the whole class in the discussion, including those who are less knowledgeable on the subject. On the other hand, some participants may come to the class with a preexisting incomplete or incorrect understanding of the subject. The instructor should identify these misunderstandings or misconceptions during the classroom discussion and make clarifications promptly. Discussion among the participants is an effective way of learning and should be highly encouraged and carefully guided.

3) Learn by Doing: Most engineers prefer to learn by doing. While it is difficult to arrange formal laboratory or problem-solving sessions for a two- or three-day short course, the instructor should provide as much hands-on learning experience as practically possible. To this end, multiple computer simulation and/or laboratory demo sessions may be integrated into the short course.

E. Assessment of Student Performance

Assessment of learning outcomes refers to specific processes through which learners demonstrate the attainment of learning outcomes. In a short course, the instructor has the obligation to require learners to demonstrate that they have attained the learning outcomes. How learners will demonstrate their attainment of the outcomes should be an integral part of the short course. The assessment procedure should be carefully planned when the short course is developed. Learner demonstrations serve many purposes for learners and instructors. Assessments actively involve the learners and provide them with a basis for refining their knowledge and skills. Learner demonstrations help keep learners actively involved, reinforce learning, monitor learner progress, and provide feedback to both the learners and instructor on their progress. Assessments may be made at the conclusion of each session or the whole short course, or after some elapsed time following the learning experience. Learning outcomes dictate the nature of learner demonstrations. Assessments may take diverse forms, such as performance demonstrations under real or simulated conditions, written or oral examinations and written reports, or completion of a project, self-assessment, or locally or externally developed standardized examinations. Because the assessment method depends on the intended learning outcomes, they must be measurable or observable, clearly stated, and focused on the performance of the learner. Assessment of learning outcomes must be a part of the short course, and methods of the assessment procedure must be made known to the learners. Learners should be advised in advance what will be required of them. Whether or not scores are provided for each learner depends on the intent of the short course. In a short course where individual proficiency is a goal, demonstrations by each individual should be required. The assignment of individual scores would be appropriate. A pass/fail designation would also be appropriate. In a short course where individual proficiency is not a specific goal, group demonstrations, such as group discussion, which would provide a means of determining whether participants have achieved learning outcomes, may be appropriate.

Traditional written examinations are often not suitable or practical for the assessment of continuing education short courses because of the time constraint and the extremely fast pace of these courses. Instead, assessments should be effectively integrated into the short courses throughout the lectures, classroom interaction, and other activities. The following assessment methods may be adopted for engineering continuing education courses.

- *Giving oral quizzes at the conclusion of each lecture session*—The questions should summarize the basics of the covered course materials and be directed toward each learner on a rational basis.
- *Combining sample problem solutions with classroom exercises*—After a sample problem is solved, the learners should be provided with a similar problem and asked to solve it on their own.
- *Using computer simulation and/or laboratory sessions to assess learning outcomes*—This technique has proven to be an excellent method to monitor learner progress, to reinforce learning, and to provide feedback to both the learners and the instructor.

F. Course Evaluation

Short courses in continuing education should be carefully evaluated to measure the quality and determine the worth of the course offerings. Evaluation is a coordinated process that examines all aspects of a short course, such as the need assessment, course content, delivery process, and the extent to which learning outcomes are achieved. It consists of gathering data about the short course based on established criteria and observable evidence. Evaluation includes an analysis of the results of learning assessments or measurements of learners' attainment of the learning outcomes but is much more encompassing. A common practice is to use learner reaction surveys, such as end-of-course evaluations, which are based on the learning outcomes. In order to yield the data needed for an adequate evaluation of learning experiences, the surveys should be designed to capture specific information that will allow providers to make continuous improvement in their offerings. Summative evaluations should be prepared and analyzed based on the following minimum components:

1) Did the learning experience and the instructional methods result in individual performance change (i.e., the learning outcomes)?
2) Did the learners indicate that the learning outcomes were appropriate for the stated short course and for the learners involved?
3) Was the short-course execution effective and efficient?

VIII. Conclusion

This paper has presented the authors' experience in continuing education in the power electronics field. Critical issues pertaining to engineering continuing education, such as how to identify learning needs, define learning outcomes, design course contents, select instructional methods, assess student performance, and conduct course evaluation, were discussed in detail.

While the Automotive Power Electronics continuing education course has been successful, the authors feel that there is still room for improvement. Technology changes at a fast pace, which will challenge not only the practice engineers, but also the educators themselves. The curriculum should be updated each time the course is offered to reflect the newest technology available and to reflect the needs of the audience. For example, fuel-cell-related material will be included in the next planned class, and the software package Simplorer [14] will be introduced for the laboratory simulations.

Effective communication with perspective employers for their support of continuing education is also a necessity because many employers do not realize that a short course in continuing education is the best way to keep their engineers competent in doing their assigned projects.

A survey of participants should be done two to three weeks before the class begins to help the instructor to tailor the course material if necessary. Following up with participants and their employers also helps the instructor measure the success of the course.

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