Board 69: Project-based Teaching Approach of a Combined Undergraduate and Graduate Course in Power Electronics

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Abstract

Power electronics, a fast-developing technology within the engineering fields is multidisciplinary and complex subject in its nature. Power electronics design, modeling and analysis include circuit theory, electromagnetics, semiconductor devices, microprocessors, signal processing, control, simulation, heat transfer, electromagnetic compatibility and even artificial intelligence. The classical instruction approach is based on lectures and laboratories assisted by teachers. However, power electronics teaching is not an easy task, due to subject complexity, difficulties and student motivation. A natural and efficient way of teaching power electronics is the problem-oriented and project-based learning (PBL) approach. PBL, as a problem-centered teaching motivates students to learn actively, bringing real professional world and requirements closer to the student, is widely used in engineering education. PBL relies on the paradigm of conceive, design, implement, and test, while the students are encouraged to consider the whole system, in order to obtain hands-on and practical experiences, giving the students the ability to transfer the acquired knowledge into practice. It has the great potential to help students cope with engineering complexities, and those problems that they are facing into their future careers. For such reasons, PBL is considered a suitable method to obtain the desired results and to improve the student learning and interests. The underlying course methodology, task planning, course and laboratory topics, or planned assessment are presented and discussed. The encountered issues and challenges to develop and implement combined (undergraduate and graduate) course power electronics, as part of our new power and energy engineering minor are discussed in detail, together with rationale, ideas and experience of applying PBL on a such power electronics. Course structure and content to implement and develop power electronics concepts, the motivation for the inclusion of projects with renewable energy topics are also discussed.

1. Introduction, Importance of Power Electronics in Electrical Engineering Curriculum

Power electronics, fast developing technologies within the electrical and electronic engineering fields, has a history that is older than many of us practicing and/or teaching the subject. It is an enabling technology for efficient conversion, processing, generation, transmission, distribution and management of the electric energy. Its growth and development have not been what one would call smooth and orderly [1-7]. The *life-changing* moments which have brought the most significant changes and advances into the power electronics have been largely unanticipated. Its modern unprecedented technological evolutions are due to factors, such as: the advances in semiconductor devices, ICs and microprocessors, smart control, or new applications, such as improved power quality requirements, grid integration of renewable energy systems and emerging distributed generation requiring sophisticated power electronic interfaces, smart power converters and control systems, increasing demands for smaller size and lighter power sources, coupled with an expanding market for power electronic circuits and systems in many non-traditional industrial sectors. A large portion of the generated electricity is processed and converted by power electronic converters. Recent increases in market competitiveness and a growing sensitivity to energy conservation and efficiency are placing additional complex and stringent requirements. Moreover, the fast expansion of power electronics into commercial, industrial and residential applications, the pressing needs to develop power systems with lower power distortions, as well as the increased demands for advanced power electronic converters and controllers for renewable energy systems has further intensified the interests in this field. The extensive uses of power electronics in products, equipment and power systems makes the fundamental understanding of power electronics a necessity for students of almost all engineering areas, and in particular for the ones enrolled in the electrical engineering programs. Power electronics engineers need solid scientific knowledge and rich practical experiences when dealing with such fast developing technologies [1-8]. Presently in great demands are the engineers, not only electrical engineers equipped with knowledge of these emerging technologies, which understand the technology environmental impacts, energy conservation or pressing needs for higher efficiencies and have at least basic knowledge of the energy technologies and distributed generation. Such trends have resulted in increased interests in attending power electronics courses at all levels, as well as in offering short courses, workshops and training sessions for professionals. In response to these demands, the universities offering baccalaureate and graduate degrees in electrical and electronics engineering must develop curricula to educate a workforce that is well equipped to meet these challenges.

Teaching power electronics is challenging since the field is broad, requiring knowledge in multiple areas of electrical and computer engineering. The course provider job is often made more difficult because the theoretical analysis of topics, such as magnetic characteristics, thermal analysis or compensator design, is particularly hard to comprehend without experimental observations [1-12]. An effective power electronics course should ideally contain hands-on design and laboratory in addition to the study of theory, analysis, modeling and simulations. The power electronics laboratory course described in this paper attempts to directly address these difficulties by helping students reduce the science to practice. From this perspective, this approach of restructuring the course support laboratory and the inclusion of renewable energy power electronics projects are of critical importance in solidifying the fundamentals of power electronics in the curriculum. This paper is primarily motivated by the current efforts at our department to restructure and upgrade the current undergraduate programs and minors. With generous support of our state government and the Entergy Corporation, we are in process to develop a power and energy engineering minor in our department and college and to upgrade and modernize the existing educational and research experimental facilities and to set and develop new laboratories in the areas of power systems, smart grids, renewable energy and power electronics. The development of a combined undergraduate- and graduate-level course in power electronics is part of this enterprise and a major minor component. It is our hopes that this paper gives the power electronics educational issues and challenges, the deserved exposure and attention. In this paper, the combined course content, teaching plan, methods and approaches are discussed, the proposed assessment method is analyzed and feedback from instructors, educators and professionals are expected. It is the author strongly believes that such discussions and feedback are improving the course content and quality, while in the same time advancing the power electronics education through new topics, new or updated laboratory experiments or applications, as well the development of new course materials, helping the instructors, especially the younger ones interested in education research and teaching in this complex engineering area.

In this paper the description of the new combined power electronics course, including learning objectives, teaching plan, challenges and issues are introduced and discussed. The gained experiences, learning outcomes, proposed course assessment are presented; moreover the adopted PBL method and the expectations are also discussed, while the feedback and suggestions from other instructors and educators are appreciated and welcomed. This paper is organized as follows. Section 2 presents course rationale, teaching methods, the project-based approach, with a discussion of the rationale of the new integrated power engineering laboratory. Section 3 discusses the course content, structure, and projects. Section 4 describes the course evaluation and assessment, and last section gives the conclusions and future work.

2. Pedagogical Approach, Rationale and Methods

Engineering programs within colleges and universities are continuously adapting to the technological advances, industry and overall society needs by introducing new courses, new programs or concentration and concurrently implementing innovative teaching methods to complement the classroom instruction [7-16]. Fundamental engineering theory concepts are still the core materials in all engineering courses, however, the theory and concept application and implementation are becoming more and more specialized. The specialized fields into the engineering disciplines continue to grow to meet such demands. To improve teaching effectiveness it is important in power electronics courses to develop student ability to transfer theoretical knowledge into industrial practice and projects. Power electronics engineers have to be able to cooperate with others as an effective team member, and therefore soft engineering skills, e.g. communication, team-work, presentation and problem-presenting analysis-synthesis are also needed. Advances in power electronics and emerging demands require changes in both the theoretical and practical course aspects [8-27]. However, traditional practical classes into the electrical engineering curricula may obviate this fact because they are seen by students as a mere requirement without any real world interest. Therefore, the main skill involved in electrical engineering (*scientific knowledge transfer to society*) is not enhanced because students do not see the real applications carried out in practical sessions. The traditional approach, through lectures, laboratory experiments, and some limited number of projects may give good knowledge of individual disciplines while mixing disciplines together is difficult as well as the practical skills are not really complete. An alternative approach is to focus on problem-based and project-based learning, either as individual or team projects to extend curriculum to other professional skills. Approach that has been prove quite successfully, during our over 20 years of teaching power electronics and developing power electronics courses for a few institutions, both for electrical engineering and engineering technology programs, at graduate and undergraduate levels. It is a very efficient way to teach power electronics because it gives the students, not only fundamental knowledge but also all the necessary skills the industry and research institutions are looking for.

The combined Power Electronics course is a core component of our new power and energy engineering minor. The minor courses are: 1) Electric Machinery I and II; 2) Introduction to Power Systems; 3) Renewable Energy Systems; 4) Power Distribution; 5) Power Systems Analysis and Operation; 6) Power Generation and Transmission; 7) Energy Management and Industrial Energy Systems; 9) Nuclear Generation; and 10) Power Electronics. Apart of these courses the author also proposed and was approved by the department and college curriculum committees a general engineering course at junior level Introduction to Energy Systems Engineering, a pre-requisites for some of the minor courses and an elective for all engineering programs. All the minor courses are offered at junior and senior level, being also offered for graduate students, enrolled into the Sustainability and Energy Engineering track. The objectives of the power electronics course are to present and cover the fundamental concepts, basics of industrial and power electronic converters over a spectrum of applications and to provide an introduction to the emerging technologies in these fields. Upon completion of this course the students are expected to be familiar with: power computation, concepts, power switching devices, DC-DC, DC-AC, AC-DC and AC-AC power converters, switch-mode power supplies, and drives, as well as with extended utility, renewable energy and power processing applications of power electronics circuits [2-5, 28-32]. The course format makes the students gradually more responsible for the analysis and design of the circuitry, control and components which permits nominal operation of the power converters. The course experience culminates with two mini projects where students analyze, design, simulate and demonstrate power electronics concepts. Each project is carried out by a team of three or four students, often one project is focused on the renewable energy. We believe that this is an efficient and effective approach in teaching power electronics, giving the students the necessary skills and knowledge the modern industries are asking for. Project-based learning has been proven to be an attractive and effective method which can improve engineering education significantly [12-27]. Project-based learning (PBL) is a dynamic approach in which students explore real-world problems and challenges. Students are motived with the PBL scenario compared to the traditional teaching method, in addition the instructors can benefit from it in guiding students to achieve significant learning. Moreover, the PBL method has been widely used in electrical engineering relevant courses, such as electronics, communication, control, instrumentation and power systems, and obtains a promising teaching and learning performance. With this type of active and engaged learning, students are inspired to acquire deeper subject knowledge. Particularly, using PBL approaches to the electrical engineering courses can increase the challenges for students and thereby their motivation and interests [12-27]. Bearing this in mind, the lecturers can give them the form of specific objectives, contextualized within the subject requirements, formulated as competencies which the student must have acquired by the end of a power electronics course, such as:

1. Providing the students with the fundamental power electronics concepts and to prepare them for advanced study in electrical engineering areas.
2. To learn how to search for, classify and analyze technical information about equipment and component datasheets and to be able to identify suitable information sources.
3. To provide hands-on and experimental experience to supplement theory in power converters and switching power supplies and to promote the application of theoretical concepts.
4. To provide students with the ability to find solutions to the problems and to enhance their critical reasoning needed to choose the appropriate solution in accordance with specific criteria.
5. To enhance other competencies within the engineering, such as: the ability to write good technical reports and to make presentations, project management and economics, and team-work.

Having defined the course objectives, goals and outcomes, based on the available educational resources and support, the instructor have to select the most suitable methods to obtain these goals and outcomes. First, the PBL method was chosen because it prompts the students to encounter the core concepts and principles, while managing a specific project, thereby enabling the acquired knowledge application. PBL goes beyond the relationships between knowledge and thinking, helping students to both *know and do*. In fact, it is focuses on *doing something* and *learning on the way* [8, 12-27]. PBL main features from the student learning point of view are:

1. In PBL, a student-centered approach, the focus is on the student competencies to design and to reach the solution, around their concerns and skills, the end product being a reflection of them.

2. In PBL the students solve problems, through self-management, project management, and critical knowledge are enhanced, as they manage the work, offering frequent feedback, self-assessment and consistent opportunities for students to learn from experience.
3. PBL recognizes the student capacity to perform important works, placing them at the core of the learning process, engaging and motivating almost all students.
4. PBL creates positive collaborative relations with instructor or students, creating performing classrooms, forming powerful learning communities focused on achievements and surpassing.
5. PBL stimulates the development of knowledge and competencies, seeking significant learning.

Within the multidisciplinary educational context of the power electronics, PBL approach appears an effective, efficient and interesting instructional strategy. In brief, the PBL strategy aims to engage students in authentic real-world tasks and open-ended projects that can increase the motivation and interests for most of the students. However, there are other additional reasons and rationale for our decision to use the PBL in teaching the power electronics course. First, it is our strong believes *that good teaching, a constant reassessment, updating, and content adjustment, structure and presentation is enhanced by an atmosphere where the research transpires; where the research enhances and energizes the curriculum, course content, and the students which in turn can only have positive impacts on the research that drives them*. In our views, the project must be included, not only in all core upper division courses, but also at sophomore and even freshmen levels, with the project topics selected form the emerging engineering areas (e.g. renewable energy, distributed generation, smart grids, robotics, wireless sensor networks, or mechatronics) have a positive effects on the student motivation, interests and ultimate retention and success. Second reason was the initial lack of adequate educational laboratory infrastructure, insufficient fully operation laboratory workstations, obsolete, incomplete and old equipment making all power engineering, electric machines or power electronics settings, being no exception hard to set, run and perform. However, the things are about to change due to a $2,000,000 generous donation for our college from the Entergy Corporation, with in addition the commitment of our state governor to match the donation [34-36]. About a quarter of this gift is designed to support the power and energy minor laboratory and research infrastructure.

The new electrical engineering laboratories are envisioned as an integrated laboratory, the same laboratory workstation is used for several connected and/or complementary courses. The pilot of this approach is the new Integrated Laboratory for Electric Machines, Power Electronics, Renewable Energy and Power Engineering. This a two-credit, two-semester, and three-hour weekly course laboratory, is replacing the existing four one-credit, one-semester, and three-hour individual laboratories for electric machines, power electronics, renewable energy and power systems. The rationale and motivations for such approach are: the laboratory for each individual course is designed to reinforce basic concepts but have no larger purpose in the curriculum such as logically connecting to the laboratory work completed in earlier or in future courses; the laboratory exercises are completed by the students in different laboratory courses without realizing that the concepts learned are all contributing to the development of truly integrated systems, as the ones used in industry. In the integrated laboratory settings the students are developing deeper understanding of the engineering subjects, the interconnections between various electrical engineering topics or areas, giving them an overall understanding of a system functionalities, features and characteristics. Our development aims to provide an integrative experience to help students better comprehend the conceptual relationship of knowledge learned in different courses and their practical applications in industry. Each laboratory module comprises several hands-on experiments and computer simulations. Based on such practical integrated system students are using the same laboratory module or workstation, but they are studying different system facets, as appropriate for each course, allowing them to appreciate the integrated nature of the modern engineering systems used in industry. This highly integrated approach of the laboratory allows students to examine more open-ended and cross-disciplinary problems, more opportunity for: teamwork and development of communication skills, than in the traditional *compartmentalized* laboratories that focused on a single electrical engineering area.

This integrated multi-course approach of the laboratory has several advantages. First, it gives students a more accurate representation of professional practices, where engineers work shoulder-to-shoulder with people of diverse backgrounds. Second, the integrated settings help the students appreciate ties between electrical engineering sub-disciplines. Third, the students can learn better and appreciate topics that are studied from several viewpoints. Last but not least the informal feedback from industry for such approach was overwhelmingly positive, as well as the similar approaches presented in the literature. In addition, by working with these integrated workstations, integrated and the industry-type software packages, instrumentation and settings helps the students to deeper understand the theory and to acquire the needed skills required by the industry. Further, a working knowledge of analysis, visualization and simulation tools used during the experimental work provides support for creative circuit analysis, evaluation, testing and synthesis. A simulator is a powerful way to test new ideas without difficulties associated with circuit implementation and building. The project experimental work complements and supplements the course lectures, and replaces in part of the adequate laboratory infrastructure. This pilot laboratory, the integrated power and energy education laboratory is in process to be set, design and implement, and it is planned to by fully functional and to be used for the 2019-2020 academic year with the first offering in Fall 2019 semester.

The power electronics section of the integrated power and energy laboratory consist of a sequence of four major experiment groupings, each of which is conducted over the course of two weeks, selected to be complementary with our intention to emphasize the power electronics applications in the power systems and renewable energy, such as: rectifiers, DC-DC power converters, including the maximum power point tracking and power supply experiments, inverters, and AC-AC converters and drives There main objectives in designing the experiments first are emphasizing on the selection and performances of power semiconductor devices in various load and control conditions. Next, a common laboratory hardware station can be used to study: devices, circuits and controls, electric machines and various loads. It provides hands-on experience for students in practical power electronics applications, reinforce and support learning the concepts, expose the students to the measurement techniques, data acquisition and safety issues. Finally it introduces students to the state-of-art simulation tools and software packages, similar to the ones employed in the modern industry. The intention of the experiments is to demonstrate to the students the relationship of device characteristics, device stresses, circuit operation and performances, and control methods used in power electronics. The experiments offer a blend of fundamental device physics, circuit theory, measurement techniques, and in depth familiarization with modern power converters and emerging switching techniques. The implementation of the experiments represents collaboration between the faculty and technical staff in our college with feedback from other institutions.

3. Course Objectives, Goals, Content, Structure and Projects

The Power Electronics course is designed to present the fundamental concepts of power electronics: converter topologies, devices, and control. Converter analysis, design, modeling, and control of switching power converters are presented as relevant to different applications. Analysis, simulation tools and packages, design practice as the ones used in industry are also emphasized. Moodle, used at our university for course management is the instructor-students communication gateway for lecture notes, course materials, announcements, assignments, quizzes, handouts, discussions or grades. The course comprises of the lectures, experiments, and end-of-semester projects. The lectures give an overview of each main course subjects; however, the group work concentrates on making the design of power converters, power sources or power electronics interfaces for renewable energy conversion systems and other industrial applications. At the end of the course, each project team delivers a report describing the analysis and design results, and project oral presentations are arranged as final assessments. In order to provide the knowledge needed to solve the problems in the team's respective projects associated with the corresponding pre-defined specifications, there are the set of lectures and course materials that are prepared and delivered by the instructor. The lectures cover main converter topologies, isolated DC-DC converter topologies, inductor and transformer, input/output filter and close-loop control designs. After the lecture, the students start to do group work to solve the specific problems relevant to their project specifications. By combining lecture teaching and group work can help the students to not only understand the theory, concepts and analysis methods in depth but also promote their capabilities of cooperation with peers and work as a team.

Power electronics is an increasingly important part of modern electric and power systems. The course covers modern power converter topologies for the control and conversion of electrical power with high efficiency with applications in power supplies, renewable energy systems, lighting, electric/hybrid vehicles, and motor drivers. The course is also discussing, power computation, the switching behavior and driver circuits for rectifier diodes, power MOSFETs, IGBTs, and other selected three-terminal devices, as well as the optimal design of magnetic components. Main topical course content consist of the following major power electronics areas:

1. Introduction to Power Electronics: Concepts and Components; History of the Power Electronics; Converter Classification, and Electronic Switches.
2. Power Computation and Magnetic Circuits: Brief Review Magnetic Circuits; Inductors, Transformers; Design Considerations
3. Half-wave Rectifiers: Half-wave Rectifiers with Different Type of Loads; Half-wave Rectifiers with Capacitive Filters; Controlled Half-wave Rectifiers; Commutation
4. Full-wave Rectifier: Single-phase Full-wave Rectifiers; Controlled Full-wave Rectifiers; Three-Phase Rectifiers.
5. AC Voltage Controllers: Single-phase AC Voltage Controllers; Motor Speed Control.
6. DC-DC Converters: Buck, Boost and Buck-Boost Converters; Other types of DC-DC Converters; Continuous and Discontinuous Current Mode Operation
7. DC Power Supplies: Inductors and Transformers; Flyback and Forward Converters; Full- and Half-bridge Converters
8. Inverters: Main Inverter Configurations; Computation and Design Considerations

9. Resonant Converters: Zero-current and Zero-voltage Resonant Switch Converters; Series Resonant Inverters; Series Resonant DC-DC Converters
10. Drive Circuits, Snubbers, Heat Sinks and Thermal Considerations.

Course grading is on an absolute scale, the student is compared against a performance standard, not to other students. Weightings are as follows: Homeworks, other assignments, class participation counts as 15%; Mid-term test as 20%; Final Examination as 25%; Project I as 20%; and Project II as 25%. Notice that these add to 105%, to determine your grade, the lowest score among these four is weighed 5% less, bringing the total to 100%. The final grade is determined by combining test, homework, project and final exam scores according to the weighting scale. Tests are based on problems from homework assignments and textbooks. For graduate students taking the course there are additional topics and course requirements. Additional topics include: Phase-controlled Rectifiers Circuits; Dynamic Modeling and Simulation of DC-DC Converters; Simulating Inverters in MATLAB; Multi-level Converters; and Device Thermal Management [2-5, 28-33]. Grades are based on satisfactory completion of homework assignments, quizzes, exams, and projects. Besides the additional course topics, specifically required for the graduate students, the course work for graduate students also includes: a research paper review and presentation, while each homework and tests include an additional design problem.

Main course objectives, in agreement with the department and college learning objectives include, among others: to learn fundamentals of power electronics components and circuit analysis techniques, and design skills; to acquire basic understanding of various power converter modules used to build power electronics system, to acquire the ability to select and design suitable power converter modules or system in order to meet requirements of industrial applications, and to gain hands-on experience in designing, testing, and debugging power electronic circuits. The student outcomes include among others that the students are able, after completing this course: to analyze, simulate, model and design power electronics converters, their characteristics and performances; as well as power electronics circuits found in residential, industrial and utility applications; to have knowledge and familiarity with the properties of power semiconductor devices as they are used in power electronic circuits; understand, identify, formulate, and solve power electronics related engineering problems; and to be able to analyze and design magnetic inductors and transformers for power electronics circuits, heat sinks and thermal management for power electronics circuits. Additional the course learning objectives include: understand and analyze both known and unknown converter topologies; identify the fundamental control methods (current mode or voltage mode) used in switch mode converters; carefully evaluate the advantages and disadvantages of different converter topologies with respect to a given application; design inductors, transformers, and filters for switch mode converters; perform calculations and/or simulations on the converter feedback circuits and performances; evaluate suitability and applicability of different power electronic components, active as well as passive; and finally perform a basic and most suitable design of a power converter for a specific application. The proposed project-based power electronics are intended to let the students obtain a better deeper understanding of power converter circuits.

Mohan's Power Electronics [28, 29] are selected as the recommended textbooks, while Hart, Introduction to Power Electronics [30], being the course required textbook. These books are doing a particularly good job of examining the principles and concepts of power electronics from an integrated and top-down viewpoint. Additional materials, lecture notes are posted on the course website, while there are also recommended textbooks for graduate students and professionals enrolled in this course [2-4, 30-33], to provide additional insight the course topics. However, the Hart book contains a great deal of design examples, important educational aspect for our PBL approach. Many of the examples and problems provided in these books are an excellent practical support for the course projects. The overhaul effort focused on achieving two primary objectives: 1) updating the course content and materials, designing the most appropriate laboratory experiments and the inclusion of projects, allowing the students to acquire experience and knowledge into the new and interested topics, such as: renewable energy, smart grids or variable speed drives and 2) providing ample opportunities for students to *learn by doing*, i.e. enabling active learning and improving the student soft engineering skills. There were also secondary goals: 1) updating equipment and laboratory experiments, 2) providing enough equipment, licenses and instrumentation to allow the simultaneously conduct and performing of the same or similar testing and design, by several student teams, and 3) improving student technical report writing skills as well the presentation and communication skills.

During the first two lectures, the various project topics and specifications are handed out and thereby chosen by the students depending on their interests and experiences. Based on the common interest, the students can freely form the teams consisting of 3-4 group members, with one graduate student or a professional already working in industry, based on the enrollment level is assigned to each team, usually as a team leader. However, the same project, a power supply design is assigned for all teams. The second projects are selected by each team from a list of projects, targeting renewable energy and distributed generation applications, provided by the instructor(s), which may include: *Power Supply for a Fuel Cell System; Power Conditioning Units for PV Water Pumping; PV Maximum-Power-Point-Tracking Controller; Design a Soft-Starter for a WT Induction Generator; and Control and Power Electronics of a Small Wind Power for Battery Charging*, etc. In our view, power electronics and renewable energy are two important topics for today power and energy engineering students. In many cases, the two topics are inextricably intertwined [31-36]. As the renewable energy sector grows, the needs for engineers qualified to design such systems grows as well. In order to train such engineers, the courses are needed to highlight the unique engineering challenges presented by renewable energy systems. A key element of our course is the use of real-type renewable energy systems. Students design, test, and troubleshoot power electronic circuits (e.g. DC-DC converters or inverters) with tools widely used in industry (e.g. LabVIEW, MATLAB or PSpice). The team builds it initially with the function module and/or by using software packages. Each team demonstrates the finished project to the entire class. A short written report summarizing the project is also required as part of the design project. This process synthesizes all of the basics of the power electronics course and can also be used as starting point of the senior design project. The projects support the following PBL power electronics course specific objectives:

1. To provide the students with opportunity to gain design experience through the completion of the project. The project has five components to it: an analytic design, a computer simulation using LabVIEW or PSpice, circuit implementation, a written report summarizing the work, and an oral presentation. The students gradually build the project experience through experiments with an increasing amount of design responsibility.
2. To reinforce and support the lectures, via exposing the students to similar materials in a practical setting, rather than exposing them to altogether new materials.

3. To introduce the students to state of the art simulation tools, similar to ones, employed extensively into modern industry. Accurate simulation of power electronics circuits is an important element of the development cycle, reducing time and cost.
4. To emphasize the importance of corroborating and comparing simulation results with laboratory measurements. Students must gain a simultaneous appreciation for the power and the limitations of the simulation software packages.
5. To expose students to the safety and measurement techniques which are important in electrical engineering and in particular in power electronics work.
6. To introduce students through projects in the new growing and exciting fields of renewable energy conversion systems.

4. Challenges, Lesson Learned and Student Evaluation

From the author over 20 years of experience in teaching power electronics, drives and industrial electronics courses the major challenges are: quite often power electronics often begins with math, memorization, and lecture are not really engaging students, and there is a significant gap in teaching power electronics controls and thermal aspects in undergraduate courses. Practicum and laboratory experience is instrumental in student professional development, and often the power electronics courses have no laboratory. These are main reasons for us to strongly advocate for the integration of the laboratory in our power and energy minor. Continuity in hardware and software is quite often infrequently preserved between undergraduate, graduate, and research, contradicting the outcome k of the ABET. Power electronics control topics, their good understanding and knowledge must be included into the course content in the context of the proliferation renewable energy systems that require inverter to interface with the local grid and adequate control, variable speed drives, and extensive use of DC-DC power converters and voltage regulation. In our opinion, this approach to addressing some of the challenges include: *teaching concepts from very begging of the course*, while relating each theoretical concept to hands-on experiments, control algorithms, simulation, discussing the industry proven controls, practices, standards, include specific problems where appropriate, circuit simulations, hands-on understanding of simulation, etc. Other challenges and approaches include: *avoid the student first introduction to power electronics, only by equations, some historical briefings are very useful in getting attention*, gives the opportunity to be hands-on in every single class, and try to prepare students for future problems with the tools they will use in their future workplace.

Table 1: Questionnaire for the evaluation of the project-based Power Electronics course

Question	***Score***
Are the course challenging and interesting?	
Have you learn more than expected with the course?	
Is the team project useful to you?	
Was this course intellectually stimulating?	
The course stimulated your interest into this electrical engineering field?	
Are the lectures of high quality and easy to understand?	
What was the level of *hands-on feeling* experienced the laboratory exercises?	
Please provide an overall evaluation of the course	

The evaluation plan will be twofold: a quantifiable measure of completions of the objectives as stated in the proposal; and a measure of student learning and outcome. A multifaceted strategy are planned to be employed, which will include monitoring quantitative measures of student performance (average scores on tests, project reports, assignments, etc.), traditional end-of-term student surveys (run by the college and university), and TAs and faculty interviews. At the end of the course, the instructor(s) are planned to conduct an additional survey to ask students about the PBL methodology introduced in this subject. The main topics in this survey are focusing on the interests and the development of the student competencies that the lecturing team wished to improve via our approach in structuring the course as project-based and combined undergraduate and graduate course, the improvement of the so-called soft engineering skills and a general assessment of the subject. This approach allows, to the electrical engineering undergraduate students get a broad viewing on which improvements that can be brought to electric energy quality, even on a specific matter like power factor correction in power supplies. At the end of the semester, all students will be requested to answer (with a five point scale: 1-very poor, 2-poor, 3-satisactory, 4-good and 5-very good) an anonymous questionnaire as shown in Table 1.

5. Summary, Conclusions and Future Work

This paper presented a project-based learning approach to introduce the students to power electronics concepts, converter topologies, design, analysis and simulation tools and applications. Power Electronics course is part of our new power and energy engineering minor and is offered as combined undergraduate and graduate course, with additional requirements for graduate students. Our instruction approach and the use of PBL methods are designed to reinforce *course power electronics theory and concepts covered* and to discuss *design and analysis methods and tools* used in modern power industry, utility grids, electronics or renewable energy conversion systems. It also provided students with introductory knowledge about converter system design, industry codes, standards and potential specialization in this engineering field. Students learn, verify, and reinforce lecture concepts by performing power converter experiments in the laboratory sessions. In our approach we adopted the principles of the problem-learning methodology. With this approach, students can develop confidence and the abilities needed in project design, as well as in their senior capstone design courses. The design experience develops *the students' lifelong learning skills, self-evaluations, self-discovery, and peer instruction in the design's creation, critique, and justification*. Through the projects, the students learn to use and understand the manufacturer data sheets, application notes, and technical manuals. The experience, which would be difficult to complete individually, gives the students a sense of satisfaction and the accomplishment that is often lacking in many engineering courses, using traditional teaching approaches. Furthermore, the design experience motivates student learning and develops skills required in industry. We emphasize on the depth instead of breadth of course contents through projects, while expanding the scope and range of various topics through sequel courses. Modern simulation, analysis and design tools and software packages are used in this course. A future goal is to develop an e-Learning version of the course and laboratory, allowing the online course delivery. A second goal is design, develop and implement a fully integrate laboratory for the electric machines, drives, power electronics and renewable energy courses, integrated in single system and offered in open-sessions. In this way at the same workstations the students are performing the experiments are required in all the minor courses, while the setting are intended to be similar with the ones found into the industry. In this way, the students are gaining an overall integrated system experience. With the knowledge acquired in this course, our graduates are in a much better position to manage energy conversion and processing applications, and better prepared for future industry career or for graduate studies.

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