The Future of Power Electronics/Power Engineering Education: Challenges and Opportunities

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Abstract—This paper discusses some factors affecting the education sector in the power electronics/power engineering area along with the renewed challenges and opportunities in the light of so many recent R&D developments at system level. It provides an overview of university-based curriculum initiatives and modern methods of instruction encouraging life long learning culture based on problem and project-based learning. The design studio approach currently used at Murdoch University, Perth, Western Australia is outlined. This approach is mapped to the modern attributes of engineering graduates along with Bloom's taxonomic levels of the cognitive domain. It is recognized that the aim should be to achieve learning in the highest possible level of the cognitive domain and the project-based approach is identified as the way forward. Finally, the assessment of students by an industrial panel is also presented as a complementary way to interact with the industry and involve their feedback directly with the educational process.

I. Introduction

Advances in semiconductor technology over the last two decades have made possible the application of high power electronics for utilities and the penetration of such technologies is ever increasing. On the other hand, the wide interest at government/political level for renewable energy systems (Kyoto) along with severe blackouts in many countries have pointed out the lack of investment associated with the power systems, a situation that has existed for decades. The problem of ageing infrastructure and the likelihood of further, perhaps inevitable, blackouts has also resulted in renewed interest in power engineering education.

In the last few years, many universities worldwide have invested in renewing power engineering programs in trying to address these challenges. Market and job opportunities in this field have also increased. However, this does not necessarily mean that such opportunities will automatically translate into increasing numbers of students taking the power electronics/engineering streams needed to maintain the financial viability of these programs and the challenges ahead for educators/researchers are as many as ever.

Power electronics technologies are enabling tools and will continue to make significant contributions to the way energy conversion is realized and ultimately controlled. Undoubtedly, these technologies will keep on moving forward creating unprecedented progress in all areas of industrial and human activities. Education and training remains an important industry by itself and traditionally universities play a leading role. In many countries undergraduate electrical and electronic engineering curricula continue to evolve as new digital technologies mature. Information technology and the use of computers make their contribution to the way teaching and learning is approached.

On the other hand, traditional power engineering areas remained in the undergraduate curriculum as new disciplines such as software and computer engineering, telecommunications, bioengineering and nanotechnologies appeared in the 80s and 90s. However, both industry and students lost interest for the power engineering discipline during the last two decades. These topics were considered by many as "boring" as well. Perception also contributed to that effect as most people thought that there was nothing exciting happening in the power engineering area. Moreover, many people feel that the transformer was invented hundreds of years ago implying that such an area does not offer itself for further research and development. This resulted in many universities closing down power engineering programs due to the lack of funding and student participation. In limited cases, the demand for power engineering degrees remained at acceptable levels only due to foreign students from 2^{nd} and 3^{rd} world nations.

With the availability of high-voltage, high-power semiconductors, power electronics converters and related technologies started to become available in many power engineering areas including: reactive compensation, distributed generation, voltage-source converter (VSC) based HVDC systems, flexible alternating current transmission systems (FACTS), harmonic filters, custom power equipment, variable speed drives and others.

The previously mentioned technological advances renewed the interest and need of power engineering education programs. The proliferation of computer and software technologies to monitor and protect the power systems and the need to address environmental concerns further assisted the case for investment by governments and industry in these areas. This was further supported by many serious problems that appeared with the electrical grid along with the forced deregulation which was made primarily on financial and political reasons ignoring the technical challenges that needed to be addressed. The lack of

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investment into these grids and the problems of establishing the much desired energy market offered a new opportunity for power engineering education and training. Moreover, industry in many countries realized that the lack of power and electrical engineers and the combined retirement of field engineers with high average age profiles would create a gap where skills and expertise would not be available [92], [95], [99], [102]. Several studies were undertaken in many countries and initiatives were put in place to revive the power engineering programs and renew investment in education and training in the area [109]. Such training has been directly linked to power electronics technologies and system technologies and must be addressed in a combined way if these programs are to be viable and self-sustaining into the future.

The objective of the paper is to offer a review of the recent initiatives in education and curriculum development in both power electronics and power engineering in general. Education in the area is strongly linked to the way technology and rapid developments are embraced and used by industry that, at the end, needs the engineers and the thinkers the university produces. The further integration of existing technologies and the likelihood of system level thinking and technologies will affect the way engineers are trained in the future. Therefore, the paper also offers a brief mapping of technology with respect to developments already in the horizon and any future developments. Gaps and needs are identified which must be addressed if education is to address what is needed in the future. Engineering training based on modern approaches of problem-based and project-based learning is discussed as a way forward. The use of Bloom's taxonomic levels of the cognitive domain is introduced as a vehicle to further enhance the curriculum and evaluate existing programs so that the highest learning experiences are provided for students. This method can be used for assessing laboratory programs as well.

The paper is organised in the following way. Technology trends in the areas of power electronics and power engineering are briefly presented first in Section II. The various power electronics and power engineering initiatives in the undergraduate programs are also presented in Section III. These developments started in the mid-70s and continue to evolve as new technologies become available affecting all areas of human activity. The teaching methodologies are described briefly and some future challenges and opportunities are identified in Section IV. In Section V, the approach taken at Murdoch University, Perth, Western Australia is outlined and conclusions are drawn in Section VI.

II. Technology Trends

Power electronics (r)evolution created by the solid-state developments and other technologies has been making its way in numerous fields where traditionally other technologies such as mechanical switches have been employed [1].

The future of power processing and conversion using electronic systems remains extremely interesting and challenging as always [2]. With the maturity of device technology and circuits, the challenge now is to address the need for system integration of electronic power processing technologies [2]. Other matters of importance as summarised in the recent publication [2] include; energy storage, increased penetration of power electronics mainly through distributed generation as sources of variable-speed electronic drives as loads; intelligent control and energy management; thermal and passive component integration. In the same reference [2], it was identified that the educational system (internationally) is not well geared to support the technology trends previously mentioned (i.e., system level integration) as it tends to force specialization into power electronics as a self-sustaining field. This needs to be addressed. Moreover, as power electronics and power engineering further combine through areas such as energy storage, alternative energy, distributed generation, intelligent control and digital signal processing applications, it is considered important to investigate the level of integration between these two close areas in the future in order to address educational needs.

The effects of power electronics technologies are profound in many areas. For instance, power electronics promises to make major impacts on virtually every marine system including propulsion, power distribution, auxiliaries, sonar and radar through the power electronics building blocks and integrated power systems including wide band-gap semiconductors [3]. In other areas, future directions have been discussed in [4] where the power electronics converters will be synthesized from groups of standard building blocks that further comprise of active power switching cells, integrated electromagnetic power passive cells and integrated electromagnetic interference (EMI) filter cells using hybrid integration technology that combines many layers of material including dielectrics. Such specialized types of technology and issues of thermal and mechanical considerations could not easily be part of a core based curriculum. On the high performance computing front, where high current, fast response, high power density are needed and in many other portable applications, magnetics and power device packaging technologies to allow operation in frequencies of 1-10MHz are under development [5]. Vehicular products are also becoming more power electronics driven and the concept of multi-converter systems is under further development [6]. From the power supply point of view, the future is considered to be quite diverse [7]. The wide band-gap semiconductor technologies provide another trajectory in the picture for the future [8]. The concept of the integrated power modules (IPEMs) was further discussed in [9]. The role of power electronics and the new 42V architecture was discussed in detail in [10]. The advancement of power electronics promises to change the marine electrical systems towards more electric power distribution [11]. The all-electric concept is also discussed for aircrafts [12]. The digital era and any associated progress are also affected by power electronics [13]. Home appliances get their own share of the action [14]. When one looks at the power delivery system of the future, changes are also inevitable [15]. The future commercial and military shipboard power systems depend upon pulse-width modulated (PWM) converters and power dense propulsion motors [16]. Undoubtedly, further integration is needed [17]. Interesting information can be found in numerous papers regarding the future of power electronics [18]-[22]. The aerospace industry has already made significant progress to accepting power electronics at many levels [23]-[30]. Miniaturization is one way for many applications [31].

Although this review of the technological trends is not exhaustive, it provides the basis for further discussion when it comes to the educational curriculum and the way it must be approached.

III. Education And Curriculum

A. Power Electronics Curriculum Developments

From the educational point of view on the other hand, undoubtedly, the power electronics curriculum is expanding even in traditional electrical and electronic engineering courses.

The power electronics subject was introduced in the Electrical Engineering program in the 70s [32]-[33]. During the last thirty years many notable initiatives were undertaken to develop it further. For instance, an integrated laboratory program for electric machines, power systems and power electronics was reported in [34]. Computer-based exercises were used to support teaching of utility-related applications of power electronics [35]. Laboratory-based programs kept on evolving [36]-[40]. A workshop held in 1996 at the University of Florida, USA and funded by the National Science Foundation became a serious forum where educational matters were discussed from many points of view including: power electronics education [41], project and problem-based learning [42]. The discussion included survey information [43], issues associated with the ever expanding EE curriculum [44], opportunity in multidisciplinary design curricula [45], integrated curriculum [46]-[47], drives [48]-[49], the role of power electronics in power engineering [50], and simulation [51]-[52].

The power supply design as a subject was included in the undergraduate curriculum evolution [53]. Multimedia and the world-wide-web were also trialed as ways to integrate technology into the teaching of the power electronics [54], [59]. Application-specific power electronics education was also discussed [60], [62]. The building block approach gained momentum [61], [64], [65]. Recently, the topic of power electronics appeared in the mechatronics [63] and the aerospace engineering curriculum [76].

Virtual laboratory development was reported in [66] and a self-learning set-up in [67]. Integration of topics needs careful attention as discussed in [68]. The lack of student interest in many universities the world over for power electronics/power engineering/machines was addressed through an instructional laboratory in [69]. An interesting survey paper dealing with the modern approaches of education in power electronics appears in [70]. Teaching of utility applications of power electronics in a power system sense was reported in [71], [75]. Digital control was also integrated into the relevant courses [72]. The web was used in a clever way to teach thermal design of power electronics [73]. A modular power electronics instructional laboratory was outlined in [74]. An interesting paper addressing the continuing education of power electronics just recently appeared [77].

B. Power Engineering Curriculum Development

There have been many approaches to enhance the power engineering curriculum from many angles. For instance, an educational method for teaching power system harmonics has been reported in [78]. It is based on a computer-based three-phase harmonic generator, a data acquisition system and a computer control system to control the harmonic levels. An interesting approach to the curriculum for power engineering was presented in [79]. Project-oriented curriculum was described in [80], [81]. The bridging of the two disciplines, namely power electronics and power engineering has been considered by many colleagues, and an example was outlined in [82]. Many other topics have been covered as well [83]. Recently, many universities have considered restructuring the curriculum to address the needs of industry and cover the exciting new developments due to power electronics [84]. The interaction with the industry has been used as a vehicle to revitalize the programs [85]. Naturally, the internet made many contributions to the way the curriculum is designed or delivered [86], [91], [93]. The future of the faculty as well as the power engineer has been debated in numerous publication [92], [94], [95], [98], [99]. Other curriculum related topics have been covered in [87], [89], [90], [96]. The future for the teaching of electric power systems is undoubtedly a challenge [97].

C. Future Challenges and Opportunities

The future remains bright as so many new challenges need to be addressed and naturally present as opportunities. Energy storage and management for instance and intelligent systems will play a very important role and must be integrated in the curriculum. As we move from the device and circuit level to the system level we must not forget how new semiconductors based on wide band-gap technology will affect the way power electronics are designed, built and integrated with other systems and be ready to change the curriculum as required. Packaging and electromechanical systems would require new curriculum as the technologies mature. Artificial intelligence and further integration of control, monitoring and diagnostics functions to get self-healing devices and systems would unfoundedly change the way the curriculum is organised. Global expertise and knowledge management systems could be leveraged and networks can be built to assist industry and graduates in the years after graduation for keeping up with developments.

IV. Teaching Methodologies

A. Classic Model

The classic model includes lectures, tutorials and laboratories. In the 90s, the use of the world-wide-web and computer instruction has also been embraced by many to achieve increased learning. There have been many notable initiatives as outlined in the previous Sections.

B. Problem-Based Learning

Problem-based learning (PBL) is not a new concept and has been evolving for almost 30 years now [104], [105], [106]. It started in a few places but it has gained momentum as more universities and faculties embrace the method and try to integrate it within the curriculum [103]. It is not an easy approach especially when most faculty staff are asked to deliver higher research output mainly due to the accountability measures brought about by governments. For instance the research assessment exercise (RAE) already in its third round in the United Kingdom, and similar initiatives in Australia, New Zealand, Hong-Kong, etc. naturally shift the weight away from the teaching activities. It is beyond the scope of this paper to discuss the PBL approach.

C. Project-Based Learning

Project-based learning is an extension of the PBL approach but instead of using a short problem as a tool to deliver information and knowledge, a larger scope project is used. It is well-suited to the engineering disciplines and the way engineers in the industry work and therefore, it is considered as an attractive way to approach teaching and learning in these challenging times. It can be used to embed many of the engineering graduate attributes as outlined in a number of engineering associations such the IEE in the UK and the Engineers Australia [110]. These attributes can be further honed in such teaching mode and deliver skills to students which are demanded by industry and further assist the integration of the engineering graduates into the working environment.

D. Future Challenges and Opportunities

The challenges in this area remain the difficulty that exists to deliver the curriculum through projects and activities as outlined in the project-based learning approach. The first challenge is that there are no textbooks that can be used by students and faculty to operate in such mode. There is a large amount of resources and information but there is a need for manuals where both students and faculty are guided to deliver the highest possible learning through the use of this approach. Projects that are industry-driven are seen to be the way, as they will defeat its purpose if the "reality" component is not maintained in the work that students do to learn the required curriculum by applying their experiences and knowledge to gain higher level of learning as outlined later in the paper by the Bloom's taxonomy of the cognitive domain used in the approach at Murdoch University.

V. Murdoch University's Techland Approach

A. Bloom's Taxonomy

In 1956, Benjamin S. Bloom headed a group of educational psychologists who developed taxonomical levels of intellectual behavior important to learning. This work identified six levels within the cognitive domain. These levels from the lowest to the highest are presented in Fig. 1 and are as follows:

Knowledge: recalling and remembering of information.

The key words are: who, what, when, why, where, which, choose, find, how, define, show, list, name, match, recall, select, relate.

The questions may have the following form: what does it mean…? how much is..?, what is the best..?, which one is…? Why did…? Can you name…? Can you list…? Where is..? What is…? How would you describe..? How would you explain…?

Comprehension: explaining the meaning of information.

The key words are: compare, interpret, explain, extend, illustrate, outline, relate, demonstrate, rephrase, summarize, classify.

The questions may have the following form: what does this mean? Give an example of…., state in your own words…, how would you classify the…? Can you compare…? What is the main idea of…? Can you explain what is happening…? What can you say about..? Which is the best answer …? How would you summarize…? What seems to be…? Which statement supports…? What restrictions would you have…?

Application: use of information, solving of problems using required skills or knowledge

The key words are: apply, build, construct, develop, organize, experiment with, plan, select, solve, utilize, identify, model.

The questions may have the following form: What method or approach would you use to…? What would happen if…? How would you use…? What examples can you find to explain…?

Analysis: Breaking down a whole into components.

The key words are: analyze, categorize, classify, compare, contrast, discover, divide, examine, simplify.

The questions may have the following form: what is the function of…? What is the relationship between…? What is the main idea of…? What conclusions can you draw…? Can you identify the difference between…? Can you make a distinction between…? How would you categorize…? What conclusions can you draw…? What is not applicable to…?

Synthesis: Putting parts together to create a new and integrated whole.

The key words are: build, combine, compose, construct, create, design, develop, estimate, invent, plan, propose, predict, maximize, elaborate, and change.

The questions may have the following form: can you propose an alternative…? What would you do to minimize or maximize…? What way would you use to design…? What would you combine to improve..? How would you change the performance of…? How else would you…? Can you think of a way to change…?

Evaluation: Making judgments about the merits of ideas, verifying value of evidence, recognizing subjectivity.

The key words are: conclude, criticize, decide, defend, determine, evaluate, dispute, judge, justify, compare, rate, recommend, agree, appraise, prioritize, assess, estimate, deduct.

The questions may have the following form: which is more important? Better? More appropriate? Do you agree with the outcomes of..? How would you prove…? Can you assess the performance of…? What are the choices for..? Can you prioritize the …? Why is this approach better than…? What are the consistencies or inconsistencies of…?

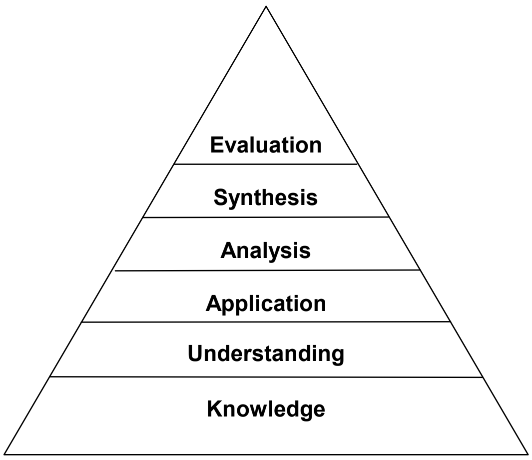

Fig. 1: Bloom's six levels within the cognitive domain.

B. *Engineers Australia Graduate Attributes*

According to the Engineers Australia, the engineering graduates should have the following attributes:

(a) Ability to apply knowledge of basic science and engineering fundamentals

(b) Ability to communicate effectively, not only with engineers but also with the community at large

(c) In depth technical competence in at least one engineering discipline

(d) Ability to undertake problem identification, formulation and solution

(e) Ability to utilize a systems approach to design and operational performance

(f) Ability to function effectively as an individual and in multi disciplinary and multicultural teams with the capacity to be a leader or manager as well as an effective team member

(g) Understanding of the social, cultural, global, environmental and business responsibilities (including an understanding of entrepreneurship and the process of innovation) of the Professional Engineer, and the need for and principles of sustainable development

(h) Understanding of and a commitment to professional and ethical responsibilities

(i) Capacity to undertake lifelong learning.

There are also specific attributes for graduates of every degree. For instance, for the Renewable Energy Bachelor of Engineering Degree the desired attributes are as follows:

(j) Ability to understand and design a wide range of renewable energy systems.

(k) Ability to integrate renewable energy technologies into fully operational systems of all scales, domestic, industrial and district/urban.

(l) Ability to assess and manage the operational characteristics of these systems to ensure best possible levels of energy utilization and economic performance.

C. *Welcome to TECHLAND*

The method of instruction followed at Murdoch University is abbreviated to: Teaching Engineering with Cooperative Holistic Learning and Advanced Noetic Development (TECHLAND).

The class is split into groups and rotating leadership and team building approaches are established. The groups compete with each other and students are encouraged to identify areas where they think they can offer a competitive advantage to their project and how such advantage can be maintained if the other groups come up with similar solutions to the project objectives. The culture of entrepreneurship is cultivated using the latest methods of innovation and critical thinking.

The most important question for educators to ask is whether the various activities and material given to students allows them to achieve learning in the highest level of the cognitive domain. The answers we give can be a guide to improve the education we offer in this are of technology.

D. *Industry Panel Assessment of Students*

Another innovation in the approach used at Murdoch University is the assessment of the final year students by an industrial panel. The support of the industry is vital for the program and thus far the excitement that this idea has created amongst engineers who work in various companies in the area is overwhelming. These assessors feel that this is the ultimate way to influence the way students are trained in order to equip them with what is needed so that they can integrate better and of course faster in an industrial environment. It remains to be seen what happens in the future, but the first time this is trialed this year, the interest is so strong that it becomes a valuable feedback that such a method can be used without hesitation. The students naturally are very worried and excited at the same time as they will be judged by people they have never met and are not their instructor or lecturer. This creates a feeling that they have to work harder as the person assessing them maybe their way to employment. The coordination of this program needs to be done carefully as it is ultimately a public relations exercise and the Engineering Science School at Murdoch University has a full-time industry liaison manager to look after all the details of such initiatives.

VI. CONCLUSION

In this paper the needs for the future of power electronics and power engineering education and training are discussed. Technological trends are reviewed as a basis for the way under which any initiative must be undertaken. Modern approaches to the engineering curriculum based on problem- and project-based learning are presented. It is believed that the future of the sector greatly depends upon the way students are trained to think and ultimately embrace technology trends and changes while they are at the workforce. Programs that assist students to move their learning and experience into the highest level of the cognitive domain as outlined by the well-known Bloom's taxonomy are likely to succeed and better address the needs of both the industry and the graduates universities produce. The way such methods have been integrated into the undergraduate curriculum at Murdoch University, Perth, Western Australia are presented and discussed in detail. Feedback from industry supports the claim that this is the way forward. Student assessment by an industrial panel is also considered as another way stronger links can be nurtured to improve relationships between industry and academia and support the seamless two-ways transfer of technology as well as human resources.

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