Review on power electronics curriculums in academia and framework development

ISSA, Walid <http://orcid.org/0000-0001-9450-5197>, AL-NAEMI, Faris <http://orcid.org/0000-0002-0588-3514>, AL-GREER, Maher and BASHIR, Imran

Review on Power Electronics Curriculums in Academia and Framework Development

Walid Issa
Faris Al-naemi
Engineering & Maths Department
Sheffield Hallam University
Sheffield, UK
walid.issa@shu.ac.uk

Maher Al-Greer
Imran Bashir
School of Computing, Engineering and Digital Technologies
Teesside University
Middlesbrough, Tees Valley, UK
m.al-greer@tees.ac.uk

***Abstract*— The Department for Business Innovation and Skills (BIS) in the UK has recognized ensuring a good supply of talented Power Electronics engineers as a challenge. Inability to recruit high-quality engineers would drive companies out of the UK. The use of outdated or inappropriate curriculums at universities has been identified as a gap to address this challenge. Some academic institutions have well-recognized power electronics, machines and drives (PEMD) programs where their undergraduate courses are also linked to their research interests. However, other academic institutions do not provide that depth of knowledge required by the PEMD industry, considering it as optional knowledge and do not have suitable training materials. This paper reviews the current state of Power Electronics curriculums and contribute to filling the gaps in skills, talent and training for the PEMD industry by developing a framework for academic curriculum, which is supported by industrial-oriented knowledge and inputs. The developed framework has been designed to fit other disciplines also achieving wider awareness.**

***Index Terms*—Power electronics curriculums, Knowledge and skills, power electronics education**

I. INTRODUCTION

Power electronics is too often a hidden industry that contributes nearly £50bn annually to the UK economy [1] with over 400 identifiable companies and organizations operating in the space [2]. The supply chain supports 82,000 high value jobs in design and manufacture, of which 50,000 are at graduate level. One of the challenges recognized by Department for Business Innovation and Skills (BIS) [1] is to ensure a good supply of talented Power Electronics engineers. Inability to recruit high quality Engineers would make global companies move their design and manufacturing out of the UK. Furthermore, the fact that fewer UK students accepting a place to study EEE would make the problem worse.

The Royal Academy of Engineering reported that project-based learning and employer-informed curriculum interventions, is proper to address equality, diversity and inclusion aspects [3]. However, the contributions towards that still fragmented.

One of the identified gaps in the PEMD industry is the use of outdated or inappropriate teaching materials at universities that enable the industry to obtain skilled and talented graduates [4]. For example, nowadays, wide-bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) have more attention due to their superior performance in automotive and industrial applications compared to Silicon switches [5]–[8]. However, academic curriculums are still behind to make the new graduates aware.

This paper identifies the knowledge and skills gaps by probing the industrial needs through surveys and meetings with industry leaders, i.e. HiT Power, Penso Power and Nexperia. The paper also provides a statistical figures on some areas of knowledge where they require improvements and more contributions from the academics at universities. A curriculum framework has been proposed as a road map for curriculum developers to consider in their development and practice.

II. IDENTIFIED GAPS

A series of discussion sessions have been held with industrial partners to review the current state of the common frameworks in the academia for Power Electronics and to identify the needed skills for an engineer joining this industry. Various gaps and causes have been identified as follows:

- The academic institutes still consider PEMD topics as elective in their courses and very basic knowledge is served to students represented by hands-out without the use of simulation packages or labs.
- Academics usually use outdated references or mainly spending more than 70% of learning material focusing on less-market centered knowledge, i.e. Thyristor-based rectification, driving learners to be less interested. Furthermore, the learning journey contains deeply focused-math complications delivered by improper approaches rather than developing critical analysis and hands-on using simulations and development kits.
- Negligible knowledge on the wide-bandgap devices and recent development at component and system levels.

- No recognized framework for PEMD curriculum is nationally developed to be considered by other institutes at different levels.
- Low attention was brought to other disciplines contributing to this industry like: Mechanical, automotive, aerospace and material courses to embed awareness about their involvement. Their courses contain zero or minimal content about PEMD.
- Fragmented activities to achieve awareness at earlier stages, i.e. school level and STEM clubs.
- Conveying the required industry knowledge and skills into a course curriculum is still lagging behind compared with their intervention and investment in the research.
- The limited number of contact hours allocated by the universities introduces a challenging duty to meet proper PEMD skills.
- No awareness is developed about Freelancing in this industry and building a personal development portfolio after graduation.
- Considering inclusivity is still in its early stages

These gaps have been the benchmark to design a survey and collect information about the content been delivered at academia, used tools, diversity of topics and relevant industrial knowledge and this survey targeted the tutors. Furthermore, another survey version targeted the employers probed the required skills and knowledge of a university graduate and trying to match and build a relation between both. The survey included responses from 38 academic tutors and 18 industry bodies. The survey outcomes are summarized as follows,

- 73.7% of the tutors don't deliver much information about the knowledge and design of the MOSFET/IGBT Gate Drivers, while 88.9% of the industry requires that as essential knowledge for their engineers. The majority of the delivered material focuses on the Thyristors and their operation in AC/DC rectification circuits including single and three-phase rectification.
- 21% of the tutors provide limited or no information about the wide-bandgap semiconductors. However, 55.55% of the industry considers it as required knowledge.
- 65.7% of tutors provide less basic information about magnetics and high frequency wounded components while 50% of the industry requires it and the other 50% recommends it.
- 64.4% deliver in majority a knowledge about diodes and thyristors and their rectification circuits while 44.4% of the industry considers this as not mainly so important and a brief is sufficient for it.
- 42.1% of the tutors deliver a brief about DC/DC converters without deep design knowledge or practical work but 86% of the industry strongly considers it essential.
- 60.5% of tutors deliver no knowledge about EMI and PCB consideration for power electronics circuits and 23.7% deliver a brief. However, 72.2% of the industry considers it a unique knowledge to have.
- Another gap between academics and industry regarding modelling of power converters knowledge as 30.3% of tutors cover that and 55.5% considers it as important.
- 40.8% of tutors deliver nothing about power converters control while 66.7% of the industry requires it.
- Matlab and LTSpice are the main tools used and recommended by industry for graduates to have hands-on and this has a good agreement with what is used in academia.

Authors believe that balanced levels of knowledge should be accomplished. Using simulation tools to validate designs of full converters might meet several points of skills and knowledge.

III. THE PROPOSED CURRICULUM FRAMEWORK

The challenge in setting up a Power Electronics curriculum framework is that it depends on the targeted learners, instructors' backgrounds and the available time scale for delivery. To produce a deliverable curriculum, a modular framework is proposed that enables the instructors to select topic-oriented knowledge that suits the learners and time scale while also meeting their ability to deliver. The outcomes of the survey and the identified gaps have been the benchmark for the developed framework.

Figure 1 shows the proposed curriculum framework that will ultimately build the skills and knowledge required for Power Electronics graduates.

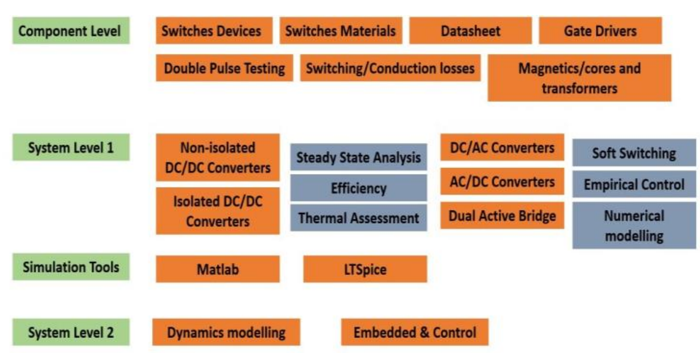

Figure 1. The proposed Power Electronics curriculum framework

The proposed framework is divided into three knowledge levels

- ***<u>Component level</u>***: it covers the basic knowledge about
  - The power switches including diodes, thyristors, MOSFETs and IGBT transistors.
  - The advantage of recent materials used for fabrication on their switching and conduction performance without going to the physical levels
  - Understanding the datasheet and curves
  - Designing MOSFETs/IGBT gate drivers for low and high side switches

- Double pulse testing using LTSpice or PLECS is recommended
- Basics magnetic knowledge about the cores or high-frequency transformers is recommended

- ***System Level 1***: This level is concerned with basic converter topologies understanding and analysis with basic mathematical steady-state models. It includes
  - Non-isolated and isolated DC/DC converters operation and assessment (efficiency, thermal), understanding of their waveforms and steady-state analysis, basic empirical closed-loop control, i.e. hysteresis or PI control.
  - DC/AC converters operation while leading resistive and inductive loads, understanding of their waveforms with and without dead time and empirical closed-loop control, i.e. hysteresis or PI control.
  - AC/DC converters with basic diode and thyristor rectification but more highlights on MOSFETs-based converters and power factor correction.
  - It is not recommended here to include small-signal modelling
  - It is recommended to highlight the difference between hard and soft switching.
  - It is recommended to highlight EMI and PCB consideration
- ***System Level 2***: This level is concerned with the modelling and control of different converter topologies. It is recommended for further studies in power electronics as an advanced module for EEE learners but selective for other engineering disciplines or post-graduates. It includes
  - Small-signal modelling of various converter topologies and applying control theory.
  - Analogue controllers, using, i.e. Type II and III compensators, and their design
  - Digital controllers, i.e. hysteresis, PID, Resonant controller, repetitive control, using Arduino, TI, STM32 or Rapid prototyping tools like dSpace, RT Box or OpalRT.
- ***Simulation tools***: LTSpice and Matlab have been among the most required software kits to be skilled in and used by the industry.

The authors believe that this content can be delivered as one module or two at final year for a EEE student. Less content can be considered for different disciplinary students. The prerequisites should also be considered which are the electronics, circuit analysis and control basics.

IV. A Curriculum Sample

A sample curriculum has been developed at Sheffield Hallam University (SHU) to fit a frame of 48h delivery slot in Power Electronics module. The developed curriculum is available as open access on [9]. The targeted group of students is 24 students including 10 BAME. A various of teaching materials have been delivered via lecturing, Labs, tutorials and industrial workshops. That included also a use of available industrial materials and a delivery of Freelancing in Power Electronics workshop from TikStation Ltd. LTspice was used as the simulation tool to demonstrate the function and operation of some converters. A double pulse testing kit was developed during the project and conducting a test for Si, SiC and GaN power switches. The assessment parts are divided into exam and a coursework.

At the end of the module, the students have shown over 90% engagement in all items of the developed curriculum and coursework. They submitted as a coursework two pieces, (a) Double Pulse Kit testing and results (b) LTSpice simulation of a buck converter. The results are as follows

- An average mark of about 60% for all the assessment work was achieved.
- BAME average mark was 62.5% which is considered as a good representative to the engagement and support they have received. The White students achieved 63.4% average mark.

Regarding the impact, the following was achieved,

- The delivered awareness workshop led to 28 students out of 30 second year students, so 93% of students, to select the Power Electronics module to study in their final year.
- The evaluation questionnaire reveals that 87.5% of students are satisfied with the delivery and outcomes of this module and recommend it to other learners.
- More awareness has been achieved externally by disseminating the developed framework and curriculum sample on [4]
- A very insignificant awarding gap has been achieved of < 1% between underrepresented student groups and white groups.

V. Conclusion

This paper responded to contribute to filling the gaps in skills, talent and training for the power electronics, machines and drives (PEMD) industry by identifying the gaps and developing a curriculum framework. The developed framework and supplied sample of the designed outline helped to bring more awareness about some curriculum components which should be considered by academics in their delivery. Also, it catalysed a stranded frameworks for bespoke designs for different disciplines or targeted learners. The targeted group at Sheffield Hallam University have demonstrated higher level of discussion and knowledge that fits more within the required market skills. The industrial and academic reviewers have shown high agreement with the developed framework.

ACKNOWLEDGMENT

This work is funded by the Innovate UK project 10021552, Sheffield Hallam University (Dr. Walid Issa) and Innovate UK project 10036124, Teesside University (Dr. Maher Al-Greer)

REFERENCES

[1] "Power Electronics: A Strategy for Success," 2011. Accessed: Aug. 18, 2021. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/31795/11-1073-power-electronics-strategy-for-success.pdf

[2] "Driving Innovation In Power Electronics Across The UK Community," 2017. Accessed: Aug. 18, 2021. [Online]. Available: https://www.power-electronics.org.uk/wp-content/uploads/sites/10/2020/04/Powerelectronics-UK-Technology-White-Paper-28-03-2017.pdf

[3] T. Mccrone, R. White, K. Kettlewell, D. Sims, and C. Rush, "Evaluation of University Technical Colleges," 2019. Accessed: Aug. 18, 2021. [Online]. Available: www.nfer.ac.uk

[4] W. Issa, "Guidance Report on Power Electronic Curriculum Development," Apr. 2022, doi: 10.36227/TECHRXIV.19612155.V1.

[5] A. Kar, S. Manna, M. Sengupta, and G. Banerjee, "Design, Fabrication and Testing of gate driver and Double Pulse Test board for SiC MOSFETs," *2021 National Power Electronics Conference, NPEC 2021*, 2021, doi: 10.1109/NPEC52100.2021.9672503.

[6] R. Li, X. Wu, S. Yang, and K. Sheng, "Dynamic on-State Resistance Test and Evaluation of GaN Power Devices Under Hard- and Soft-Switching Conditions by Double and Multiple Pulses," *IEEE Trans Power Electron*, vol. 34, no. 2, pp. 1044–1053, Feb. 2019, doi: 10.1109/TPEL.2018.2844302.

[7] T. Yao and R. Ayyanar, "A Multifunctional Double Pulse Tester for Cascode GaN Devices," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 11, pp. 9023–9031, Nov. 2017, doi: 10.1109/TIE.2017.2694381.

[8] M. I. Masoud, W. Issa, and W. Yates, "A Tutorial on Double Pulse Test of Silicon and Silicon Carbide MOSFETs," *Proceedings - 2023 IEEE Workshop on Electrical Machines Design, Control and Diagnosis, WEMDCD 2023*, 2023, doi: 10.1109/WEMDCD55819.2023.10110895.

[9] "Power Electronics Curriculum – For Power Electronics Learners." https://powerelectronicscurriculum.uk/ (accessed May 03, 2023).