TEACHING POWER ELECTRONICS AT MONASH UNIVERSITY IN AN AUSTRALIAN CONTEXT

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ABSTRACT - A summary is given of conventional electrical engineering university education and a description of the employment scene for the graduates. The training requirements of graduates for three different industrial employers are given and the steps taken to meet some of these requirements are explained in detail. The steps taken include two training programmes, one an undergraduate final year course and the other a graduate training programme. The final year course teaches to design and construct a real product to specifications, whereas the graduate training programme employs a new graduate or postgraduate student on industrial projects which can be closely supervised for maximum benefit. Both programmes are described in detail and the conclusion developed as to future requirements.

1. INTRODUCTION

For most students, the purpose of an engineering education is to obtain the career they would like, either in order to get a good job or an interesting job. Australia is marked by the existence of many small companies and a few large companies. Few of these companies have much significant research and development capability and few are significant manufacturers. Therefore the job prospects (figure 1) for new graduates are predominantly in technical sales and management. Many positions require engineers who can specify engineering equipment required to be purchased.

The Australian engineering degree is typically for 4 years, the student being awarded an honours or pass level degree depending on their academic performance. It has been traditional for most engineering degrees to aim to teach the student to think and to have the knowledge base of their subject so that when they begin work, they can readily build on this knowledge base and learn vocational specific knowledge. Hence many courses have been oriented to ensuring that the student could, in principle, undertake a research degree.

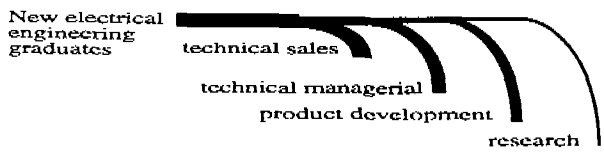

Figure 1. Employment prospects for new electrical engineering graduates

However, research positions are very limited, mostly concentrated in the universities and some specialised government research institutions such as the CSIRO (Commonwealth Scientific and Industrial Research Organisation) or DSTO (Defence Science and Technology Organisation). Due to low levels of research grants from governments, there are very few research positions available at universities and academic positions are limited.

The question arises as to the most appropriate type of university education for the student. Over the last 20 years or so, the university education has changed from being for a small group within society to a large group presently. This has resulted in a change in the range of academic abilities of the students, such that there is often a larger range of abilities, in particular, a greater proportion of less academically able students.

However, in power electronics in Australia, there is a shortage of competent designers, especially in the higher power levels (say above 50kW) [1]. It is one of the few areas of electrical engineering where designs from first principles is still regularly carried out in Australia by small and large companies.

2. MONASH UNIVERSITY POWER ELECTRONICS GROUP

There are 3 lecturers in power electronics at Monash University (listed alphabetically)

Dr Peter Freere
Dr Grahame Holmes
Dr Robin Lisner

Associated with these lecturers are 2 PhD students, 2 M.E. (by research) and 3 full time research assistants and a number of undergraduate students.

In 1995, Monash University Power Electronics Group organised a workshop on "Teaching Power Electronics", with special guest speakers Tom Lipo and Tom Hableter from the USA. Power electronics was defined as requiring a broad knowledge area [2] including;

<u>Power Electronic Converters</u>
switching power supplies
semiconductor devices
industrial converters
utility converters
motor drives
electromagnetic theory
<u>Ancillary Circuits</u>
control theory
electronic circuit design
computer systems

Added to this already large knowledge area is a furiously increasing knowledge base. The pressure from industry is to train undergraduates to be immediately ready for useful work, yet this is at odds with the traditional university teaching system.

3. INDUSTRIAL REQUIREMENTS OF A GRADUATE ENGINEER

At the 1995 "Teaching of Power Electronics" workshop, speakers were invited from industry and academia from around the world. Representatives of three local companies spoke on their requirements for power electronic engineers. The companies represented divergent market operations, Energy Controls being a manufacturer of specialised motor drives, Advanced Energy Systems being designers and researchers of specialised inverters and Siemens which mostly imports products, although it does have some manufacturing capability in power electronics in Australia.

Bernard Schaffler of Energy Controls [1] sees a need for graduates who can work with kiloamps and megawatts - which is not currently fulfilled by the 4 year undergraduate degree. The market is large and in the larger sizes is specialised, hence allowing Australian manufacturers with small production runs to compete. The market includes mines using 1.1kV and the railways moving from 1500-3000V dc to 25kV and 50kV ac traction systems. Mr Schaffler considers that the high power part of the education should be delivered by a Master's degree course, which involves substantial project work. The students should be able to simulate circuits to save time and money in the design stage and the university laboratories should have motors at industry standard voltages of 415V, 1.1kV, 3.3kV and 4.16kV. However, Mr Schaffler recognises that lecturers themselves often do not have this experience, and hence considers that they should spend sabbaticals with power electronic manufacturers.

Mr Schaffler finds that graduates need knowledge of both software (usually C), general electronics, high power electronics and practical engineering. He proposes that it would be more appropriate for engineering departments at universities to offer design services in software writing than offering technical expertise.

Lawrence Borle of Advanced Energy Systems sees the need for graduates as requiring them to know [3]; basic topologies, switching device behaviour, magnetics, thermodynamics, power systems, control theory (including PID, state space techniques, nonlinear). The graduate needs to be able to design the control and supervisory aspects of a converter - hence he needs to know analogue and digital electronics, op amps, comparators, logic devices, signal switches, linear semiconductors, microprocessors, DSP's, FPGAs and ASICs. The graduate should also maintain contact with professional associations to learn the latest techniques etc.

Siemens representative, Andrew McDowell feel that for his company, [4], the skills needed are in the fields shown in table 1.

These three companies have divergent requirements. Whereas the technical requirements for Siemens graduate employment are likely to have been covered in a standard course, the communication aspects and administration skills have only recently begun to be addresses with subjects specifically in targeting this area.

Table 1 Siemens requirements for graduates [4]

product sales	need administration skill, be able to give technical advice
systems application and integration	needs understanding of switch gear, control gear, electromechanical interface, communication, team work skills; commissioning product knowledge
service, diagnosis and repair	needs communication skills with customers, flexible working attitude

The technical requirements for both Energy Controls and Advanced Energy Systems are not at all addressed currently. This stems from a lack of long and short term educational planning with no clear goals or motivation. The power electronics group has made some planning decisions, concentrating on final year subjects and graduate training. Little planning has occurred by the power electronics group for the junior years as these subjects are not controlled by the power electronic group.

5.THE MONASH PRACTICE

Monash power electronic education can be divided into a number of differing levels (figure 2);

1. junior undergraduate
2. final year undergraduate
3. graduate courses
4. graduate training
5. postgraduate studies
6. post doctoral work

Each of these has a differing purpose. Junior undergraduate courses are to introduce the student to the field so that even if the student does not take any more courses, they will have a basic understanding of the terms used and the operation of power electronic devices.

Depending upon which degree course the student is taking, the final year student can take a two semesters course which covers a huge range of material, or if the other degree course is selected, can take two courses from a very different perspective. One course looks at the mathematical basis behind motor drives and modulation strategies and the other course is to teach how to design and build a successful dc-dc converter. In the final year, it is also common for the undergraduate students to have a year long project, which can involve power electronics. This project is usually undertaken at the same time as other subjects.

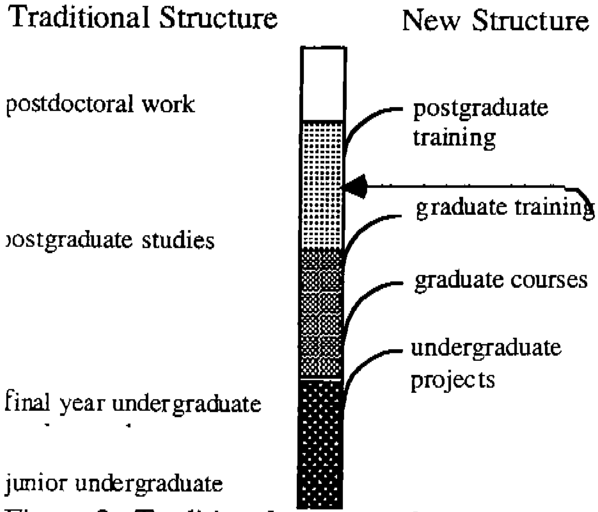

Figure 2. Traditional course and new structure

The graduate course that is offered is a Master's degree course. The students that attend are mostly those who wish to upgrade their qualifications due to limitations in career path. Since the introduction of government fees, there have been no recent enrolments in the power electronics Master's degree course. When it was operating, the students came from a wide range of backgrounds, it was necessary to commence at the final year undergraduate level and then move further on. The course was essentially a mathematical treatment of drive theory (d-q axis modelling) and detailed machine design. For graduates contemplating a post graduate degree, a graduate training programme exists in which graduates work on commercial projects in order to gain experience while being very closely supervised by Dr Holmes or Dr Freere. This allows the graduate to gain useful skills and experience to apply to their postgraduate studies, before they begin their formal study programme.

No formal post doctoral programme has arisen yet, but doctoral students are encouraged to remain working on industrial contracts, but using their specialised knowledge to assist the projects and perform some research.

Whereas many universities have similar undergraduate programmes for the junior years, the final year undergraduate course and the graduate training are concentrated on in this paper as they seem to be unique to Monash University.

6.UNDERGRADUATE FINAL YEAR DC-DC CONVERTER COURSE "POWER ELECTRONICS APPLICATIONS"

This final year course is the only one which particularly attempts to train the students to have a specialised skill. The skill learnt is one of designing and building a dc-dc converter to specifications. The dc-dc converter has been chosen as it is one of the simplest building blocks of modern power electronics and incorporates most of the requirements of larger power electronics such as;

1. magnetic element design (usually a transformer or inductor with high frequency issues)
2. gate drive requirements
3. isolation requirements
4. feedback control loops

In the past, the time table has allocated 1 or 2 lectures a week the semester. This spreads the information required for the subject out over a whole semester and hence the students are unable to effectively tackle their project until near the end of semester. Hence it was decided to offer the course in one intense day in the first week of semester. Since the course has no gaps of days in it, the students are able to absorb more and need less revision. So this process is more efficient time wise and educationally.

The course commences with a full day short course on predominantly dc-dc converter design. This course is designed to get students to work together and to assist each other, hence all meals are usually shared. The day commences at 9 am and finishes at 9 pm.

This version of the course has been running for 3 years and is about to enter its 4th year. The course is project based and the students work in teams of two. The three projects to date have been;

1. 12V to 400V dc-dc converter (figure 3)
2. 240V ac to 12 V dc converter
3. 15-200V ac to 12V dc converter

This years project will be a highly efficient 12V-3V, 500mA dc-dc converter. Each project is designed to give the student direct commercial like design experience, yet at the same time explore new applications with circuit variations. Each team tends to have their own ideas and sometimes these are reasonably original. The literature survey that may precede the design can sometimes uncover a hitherto poorly known circuit and last year this was the case with the finding of a quadratic converter by Cuk et al. This converter is not reported in any of the major power electronic text books, yet can have applications in low power areas where a very large input voltage range is required.

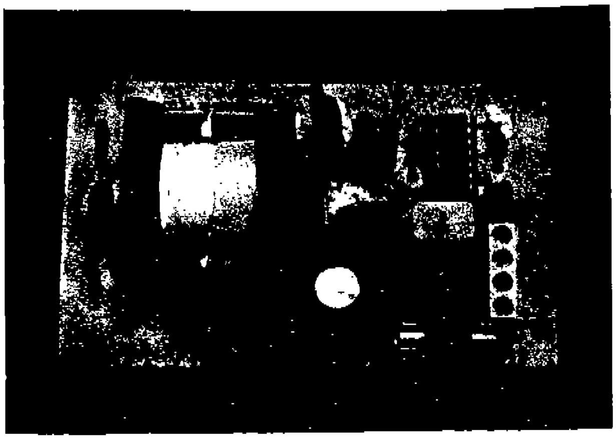

Figure 3 Student project for “Power Electronics Applications”. 340V to 12V DC power switching converter. Note the ground plane and the airgap in the ferrite core.

It has been a deliberate decision not to use simulation tools to test the circuit designs at this juncture, as it was tried in the earlier years of the course and the learning curve to effectively use the simulation packages was too great. It has been felt that better use of the time for the students can be made in design and construction.

The work load is out of all proportion to the credit points allocated to the subject, but it is the one subject that aims to teach practical design and construction and this alone attracts the very keen students. One of the graduates of this course applied for an experienced power electronic designers post and since none applied he was accepted on the basis of the work he did for this subject.

The aim of the subject is to get the students to design to specifications, build it on a printed circuit board and then prove that it performs as expected. As part of the process, the student must learn how to produce printed circuit board (pcb) layouts.

All students are recommended to build the first prototype on a prototype board, so that the basic connections and operation methodology are understood. The characteristics of this circuit are then investigated, in particular looking for non ideal or non expected behaviour. This is investigated to ascertain whether it is due to the circuit or problems with using a prototyping board. When these issues have been satisfactorily dealt with, the pcb is designed and the circuit built on the pcb and retested.

Areas which have not been included in this course relate to EMI and safety standards.

One of the advantages in students taking the power electronic applications course is that if they take their undergraduate thesis afterwards, they have a significant technical advantage over the other students. As an example, figure 4 shows a microhydro test set up which a student has assembled. The student has characterised the turbine performance and is currently completing the design and construction of a self powered voltage regulator suitable for battery charging with input voltages ranging from 15V to 200V and switchable output voltages (12, 24, 48, 96V). It incorporates soft start and inrush current limitation and is also able to recognise a turbine runaway situation and respond accordingly.

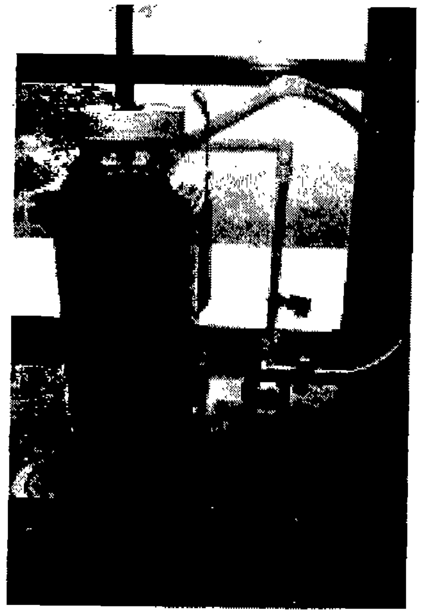

Figure 4. Undergraduate thesis project; micro hydroelectric test system with power electronic voltage and speed regulation.

8.GRADUATE TRAINING

The concept of graduate training was begun and predominantly carried forward by Dr Holmes. It has arisen from three sources;

1. to make graduates more employable
2. to have a supply of competent research assistants and allow them to consider a post graduate degree
3. to train post graduate students so that they may perform their research more competently

As part of this training programme, specific tasks are given to the individual. These tasks are well defined and of a nature such that the supervising member of staff can keep a close eye on the progress and correct errors quickly.

The training has usually been as part of a project where they have worked as a research assistant. This allows them to complete a specific task, which can be closely supervised. Errors on the part of the individual can then be rapidly corrected and significant progress be made.

A number of graduates are very interested on power electronics, but realise their own limitations in knowledge and experience and would like some more experience before they decide on a career path. Such graduates request work and if the industrial consultancy work is available and suitable, and the student is perceived to have sufficient learning capability, they are often employed as a research assistant. By working closely supervised on well defined projects, and with now a team of experienced research assistants around him, then his progress is often rapid. In such cases, many of the research assistants choose to go on to a higher degree programme in power electronics as they become enthused and they realise their limitations in knowledge.

Similarly, postgraduate students are encouraged to embark on this training programme for between 6 months and one year. If they agree, they too will work often mainly on industrial projects, which are closely monitored and in small pieces. This is to provide the student with the ground knowledge base to perform their post graduate work effectively. Quite often, a lack of basic understanding of the field dramatically impedes the students progress in their degree. For example, limited understanding of the finer design points of inverters can require a student to spend many wasted months endeavouring to design and build one, but if he worked on gate drivers, for example, in his training, his progress will be rapid.

The effect of this training is that we now have 3 research assistants working on commercially oriented research, design and development work and paid from this work as well as 4 postgraduate students. As the number of research grants have been reduced and internal funding for universities has also been reduced, this work has become of increasing importance financially and also to provide a knowledge source which is not available within academia.

This process started in 1994 with a large interface for a ship bridge simulator for the navy. The two companies which had been contracted to do the job had completed incompatible equipment and hence the interface equipment was required. Other jobs have included microprocessor controlled battery charger, remote sensing cow detector and identification, car driving simulator test set for medical research, controller for a 250kW inverter, 22kV fault current limiter.

9.CONCLUSION

The final year Power Electronics Applications course and graduate training programme have been designed to meet some of the technical requirements of industry for graduates and to provide effective training for post graduate students. This has been achieved by having a course which aims to teach design and development of a power electronic product and graduate training using appropriate power electronic design projects with close supervision.

Certain technical areas have not been addressed in the graduate training. These include high voltage, current and power devices (above 50kW).

However, the overall result is that the process is effective in producing highly employable graduates and those who do the graduate training have excellent industrial experience. This industrial experience has increased the knowledge levels of the whole group and continues to provide inspiration for research and published papers. The industrial income pays for many pieces of equipment and travel to conferences.

Given that;

1. Australian universities usually have no commercial outlet for their research and development results
2. Australian companies are unable to do much of their own research and development work
3. there are very few research positions available in Australia,
4. government funding of universities is declining

then this process of supporting industry directly by doing research and development, provides;

1. the type of training that can not be found elsewhere
2. it allows an outlet for research and development directly by applying the work to a commercial project.
3. allows the university to directly make a return to the Australian economy
4. a stimulus for finding new research opportunities

It is our hope that we can continue to develop this process such that it becomes the normal way of operating within Australia universities.

The further course developments that would assist with the process of developing students for the workforce are;

1. give experience to students of high power electronics and motors
2. formal Master's degree power electronics programme with specific recognition from potential employers
3. to develop further depth of understanding the students need a one year project with no other conflicting subjects at both undergraduate and Master's degree level. This may require an increase in the 4 year degree to 5 years.

10.REFERENCES

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