Teaching Power System Engineering – Back to the Basics

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Abstract: Electrical Power Engineering (EPE) is highly conceptual and is built on the foundations of applied mathematics and physics. Often students who lack an affinity with the physical sciences find the learning and teaching process both difficult and tedious. This has been exacerbated over the last decade as many high cost, but learning effective, laboratory exercises have been replaced by computer models. The unit Electrical Power Systems and Machines at the University of Tasmania forms part of the core of the EPE discipline. The unit is also open to students from electrical, mechanical, computer and mechatronic disciplines, which complicates the teaching and learning process further, due to the disparate backgrounds of the students. The paper describes the use of the classical generalised teaching method based on the four teaching components of theoretical foundations, physical models, mathematical/computer models, and laboratory/real-world applications. The outcome was that the fundamental understanding of EPE by the students was enhanced through deep learning. The theoretical foundations were constructed through classical classroom lectures. The physical model part utilised small equipment or machines to demonstrate working principles and develop the underlying theoretical concepts. The mathematical/computer part used self-paced revision problems and assignments to assess understanding of theoretical concepts. The laboratory models were based on a series of hardware and software based experiments to demonstrate application of the theoretical concepts to real-world engineering. The usual student evaluations of teaching and learning (SETL) were utilised to evaluate teaching and learning outcomes. The results were pleasing, returning high SETL scores with students reporting that they found the integrated process assisted them to better understand both the underlying theory and applications for Electrical Power Systems and Machines. The use of the high-cost laboratory exercises have been shown to be warranted and will be retained by the School.

Keywords: Electric Power Education, Theoretical Foundation, Hands-on Model, Mathematical Model, and Experimental Model.

Introduction

Power engineering education is one of the oldest engineering disciplines and designed to graduate students with expertise in electricity generation, transmission and distribution, and operation and control of electrical machines and systems. It is highly mathematical and constructed based on applied physics and its applications, and often units in a course are taught using hypothetical models. Over the last decade, the use of laboratory work in teaching has come under pressure due to the relative high costs involved in maintaining and staffing such large teaching spaces.

In the School of Engineering of the University of Tasmania (UTAS), students take a common first three semesters. This gives a breadth of subjects that enables students to select the area of engineering in which they wish to specialise. Students choose one of six specialisations in Semester 4, including electrical power engineering. A major feature of the electrical power engineering courses is the emphasis placed on laboratory, design and project work. In design classes, students learn how to design power systems, which can operate safely and reliably. In Year 4, each power engineering student may undertake an individual project, which involves an analysis of requirements, feasibility study, and design and development usually resulting in a prototype. Historically laboratory work has been used extensively, however ongoing use requires justification in the face of decreasing resources.

In Year 3, students take Advanced Circuits and Power Electronics, Digital Electronic Systems, Signal and Linear Systems, Engineering Numerical Methods, Electrical Design, Instrumentation and Control, Electrical Machines and Power Systems, and Engineering Project Management and Economics. These lead into the usual Year 4 units such as Power System Operation and Control and Electrical Power Design. The unit *Electrical Machines and Power Systems* was identified by staff as a unit that could be utilised to show students how theory and practice should be seamlessly integrated through the use of laboratory exercises. The content of the unit is typical and covers AC circuits, magnetism and magnetic materials, energy conversion, transformers, DC machines, induction machines, synchronous machines, modelling of transmission lines, control of voltage and reactive power, load flow analysis, three-phase faults and power system protection. The teaching pattern consists of 3 lectures and 1 tutorial/week over the 13 week semester. This is supported by 5×3-hr laboratory sessions and it is this component that has come under threat.

Many techniques have been developed and are already available in literature for teaching power engineering courses effectively. Karady and Holbert (2004) proposed a technique to improve power engineering education through computer assisted interactive learning. Williams and Kline (1994) presented an object oriented graphical approach for teaching electrical machines. Grau (2004) discussed how to teach basic quantum mechanics to electrical and computer engineering students. Bellmunt et al. (2006) introduced a remote laboratory and an automation e-learing-based technique for the course Electrical Workshop of Automation. Chen et al. (2004) reported the experience of teaching the classification-tree method as a black-box testing. Saleh (2005) shared experience and ideas concerning the teaching method at undergraduate engineering course. Cheng et al. (2004) used a web-based method for power electronics and discussed the issues related to assessment of the course. Carrillo et al. 2002 have discussed course curriculum of power engineering education and developed new laboratory practices. The common theme in many of these publications is the need for, and integration of various components such as relevant laboratory exercises and computer simulations, into EPE programs. This paper continues that theme and demonstrates the learning and teaching value of integrating the four basic components of theoretical foundations, physical models, computer models and real world applications.

Model Development

As indicated earlier the "back-to-basics" teaching model was applied to the core unit Electrical Machines and Power Systems (EMPS). Students were presented with the basic fundamentals of machines and systems through a series of lectures, lecture notes and associated material, designed to lead and support their understanding. The supporting material has been designed to assist students to understand the underlying theory and can be accessed on-line. The course material was updated continuously to incorporate technology changes, students' comments, feedback and new ideas. Figure 1 illustrates the overall model used to demonstrate to students how unit content is relevant to their professional life by showing the integrated flow of information. Students are provided with a PowerPoint Presentation that is designed to help them understand the theoretical concept of the machine or system. In EMPS, an induction motor was used to develop the conceptual model; however the process is applicable to any machine or system in power engineering disciplines.

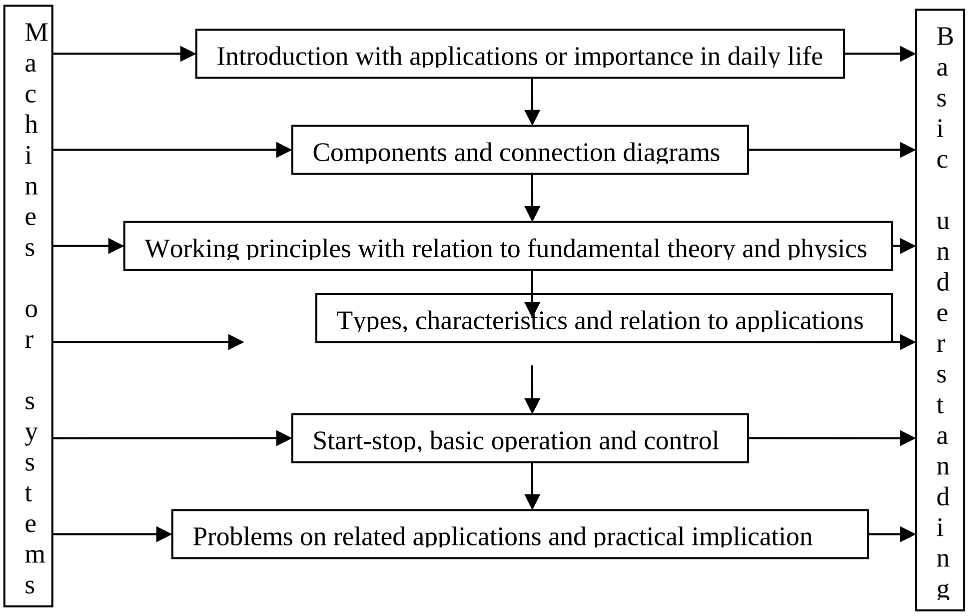

Figure1. Flow-chart of a theoretical foundation model

Physical or Hands-on Models

In EMPS, small electrical machines were taken to the lecture room to demonstrate their construction details and to explain working principles, supporting the theory being presented to the students. This provided them the opportunity to view and appreciate the application of theoretical concepts to the real world, stimulate their interest and to learn within context. A detailed explanation on how the process was applied to a three-phase induction motor follows.

Figure 2 shows a stator of the three-phase two-pole induction motor. Students can easily identify the coils for different phases and view the construction style of windings and coil arrangement. Figure 3 shows a stator of the three-phase four-pole induction motor. Students are shown the difference between two-pole and four-pole machines and their coil arrangements and are able to handle the various components. This leads to an explanation as to how a revolving field is produced when the motor is connected to the power supply. The discussion then follows the following points.

- Why the speed of revolving field for a two-pole machine is twice the speed of the field in a four-pole machine.
- How slots and phase groups are used to distribute flux uniformly in the air-gap. (Figure 4 shows a squirrel-cage rotor of the three-phase induction motor).

- Why the rotor is placed inside the stator and rotates at a speed lower than the synchronous speed.
- Students see how the rotor rotates, how torque is produced, the direction and speed of the rotor and how it is related to the revolving field and the number of poles. Students see the air-gap between the stator and rotor through which energy is transferred from stator to rotor with the same principle as from transformer primary to transformer secondary windings.
- The theory of electromagnetic induction and Lorentz force is then introduced (Figure 5 shows an induction machine that can run as a motor as well as generator).
- Finally the conditions where the machine will run as a motor, a brake and a generator are demonstrated.

Fig.2: A two-pole stator

Fig.3: A four-pole stator

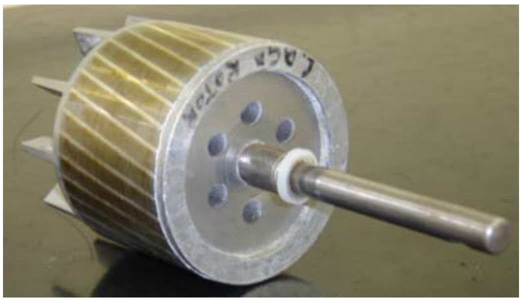

Fig.4: Squirrel-cage rotor

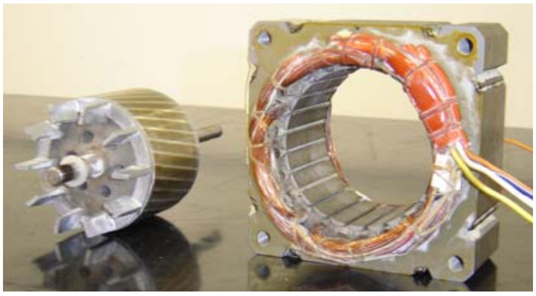

Fig.5: Rotor and stator of induction machine

Mathematical or Computer Models

Mathematical or computer models can play a very important role in teaching EPE and their ongoing use is encouraged, but only if well integrated into the overall learning process. In EMPS, students are provided a series of problems on each theoretical topic and guidance during tutorials. This is reinforced with weekly homework problems that they submit the following week. The problems are designed to lead students to develop their problem solving techniques by gradually increasing the level of difficulty from “easy” to “difficult”. This assists students to succeed and develop to their optimal learning level. The other advantage of this technique is that students are encouraged to reinforce topics soon after a lecture, which helps prepare them for summative assessment such as mid-term tests and final exams.

Assignments to be solved using computer simulations were designed for more advanced level problems on relevant topics. Computer models require writing computer programs and simulations and enhance students’ team building skills as they work in a group environment to discuss the issues, write reports and prepare presentations. They are encouraged to form multi-talented and multicultural teams of local and international students. The intention is that students will have an opportunity to improve communication skills, mix with different cultures, and create a supportive learning environment. In particular, this helps to assimilate the large number of overseas students in the School who join engineering in Year 3, who face problems such as communication, isolation and cultural shock.

Laboratory-Real World Models

Laboratory experiments and computer simulations were integrated to reinforce the theory presented to student during formal classes. Due to cost constraints, laboratory work must be shown to be essential for supporting theoretical content, providing learning outcome and demonstrating real-world applications. Industry placements and field trips were introduced to expose students to real world engineering problems by expanding on their laboratory exercises. Students are usually placed in power distribution utilities of Tasmania for a couple of days – at least one day for in-house training with operation, control and protection of distribution networks, and at least one day for visiting substations, renewable power generation, and equipment of distribution systems. The field trip is integrated into unit content and students are required to submit professional level reports on their activities. This experiential approach provides students with the opportunity to interact with professional engineers in their discipline, and grows their confidence in their knowledge of power engineering. The progress from theory – modelling – laboratories – to industry application, provides students with confidence in their learning. Figures 6 and 7 show the experimental set-up used to study three-phase induction machines. Students are briefed on the theoretical concepts of the experiment to reinforce earlier theory before conducting the experiment.

Fig.6: Experimental set-up view 1

Fig.7: Experimental set-up view 2

Embedded Knowledge and Understanding

As detailed throughout the paper, the teaching and learning process is based on the four key components shown in Figure 8. Embedded knowledge and understanding in EMPS is tested through a series of assessment – homework, lab reports, field-trip reports, mid-term test, assignment and a final examination.

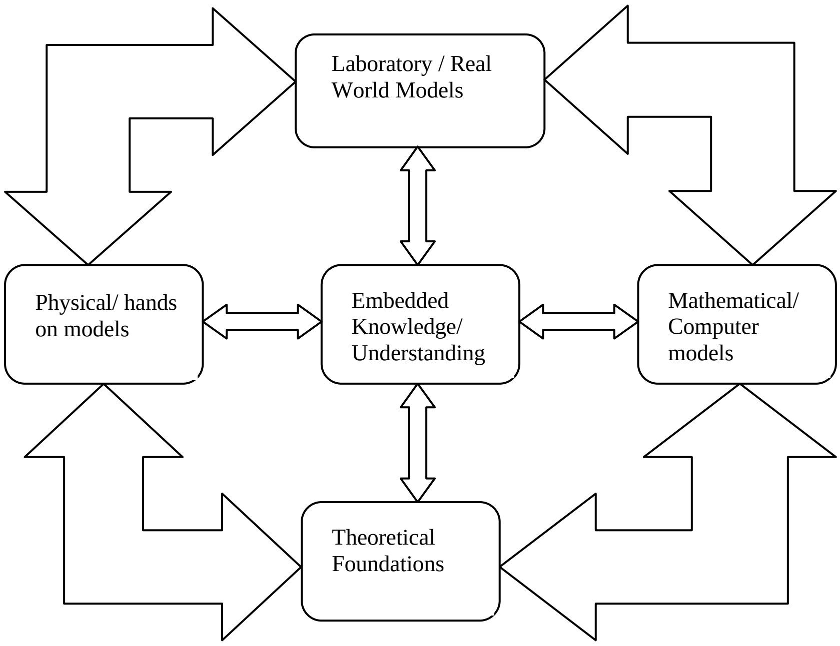

Figure 8: Conceptual Model of the learning-teaching method

Weekly homework is introduced as a part of the students' continuous learning and assessed with the view that weekly feedback would assist students to recognise their strengths and weaknesses and encourage them to contribute more to the self-learning process. The system allows teachers to identify those students at risk and to form strategies for assistance. Laboratory experiments are well integrated, demonstrate real-world applications and the outcomes (reports) designed to test learning outcomes.

A mid-term test is conducted and designed with a similar level of difficulty as in the final examination to provide students with a "wake-up" call and to give them some flavour of the final examination. The mid-term test also provides the teachers with a real picture of the level of embedded knowledge/understanding of the unit by the students. The level of understanding and learning progress of individual students can be determined and poor students identified. A major assignment is set and designed to test overall student understanding. Feedback is provided in a timely and clear manner for all the assessments to allow students to identify and address weaknesses. The final examination is structured to systemically test all the learning outcomes of the unit and provides the teacher with an approximation of their success in helping students to achieve embedded knowledge and understanding of the unit.

Student Evaluations and Discussions

Student Evaluation of Teaching and Learning (SETL) is a standard measure for teaching and learning at the University of Tasmania and the usual Lickert scale of 1 to 5 scale used with '1' for strongly disagree or less desirable and '5' for strongly agree or highly desirable. A SETL was conducted in Semester 2, 2004 for EMPS after implementing the described teaching method. Table 2 shows the outcome for the unit evaluation and Table 3 shows the teaching evaluation of SETL. The results indicate that students were satisfied with both the unit content and the teaching of EMPS. The overall average of the means for unit evaluation was 3.83 and 3.74 for teaching evaluation. All are above the overall School average of around 3.5. The learning and teaching approach described in the paper was also applied to several other units in EPE with SETL results ranging from 3.6 to 3.9.

Table 2: Unit evaluation of KNE342 in Semester 2, Year 2004

Standard SETL used for unit evaluation	Strongly disagree	Disagree	Neutral	Agree	Strong agree	Mean
The unit addressed the learning outcomes stated in the Unit	0.0%	0.0%	14.3%	71.4%	14.3%	4.0
The criteria for each assessment component were clearly identified	0.0%	3.6%	21.4%	53.6%	21.4%	3.9
The workload in this unit was appropriate	3.6%	14.3%	21.4%	50.0%	10.7%	3.5
There was reasonable opportunity for interaction with teaching staff	3.6%	3.6%	17.9%	53.6%	21.4%	3.9
I was given feedback on my assessment work	0.0%	7.1%	25.0%	57.1%	10.7%	3.7
Submitted work was returned to me in a reasonable time frame	0.0%	3.6%	7.1%	57.1%	32.1%	4.2
The unit stimulated my interest in the subject area	0.0%	14.3%	17.9%	42.9%	21.4%	3.7
I gained a good understanding of the subject matter	0.0%	10.7%	14.3%	67.9%	7.1%	3.7
I enhanced my skills in this unit	0.0%	3.6%	21.4%	60.7%	10.7%	3.8
The unit was well taught	3.6%	3.6%	17.9%	46.4%	28.6%	3.9

Table 3: Teaching evaluation of KNE342 in Semester 2, Year 2004

Standard SETL Questions used for teaching evaluation	Strongly disagree	Disagree	Neutral	Agree	Strong agree	Mean
The lecturer was well organised	0.0%	10.3%	10.3%	44.8%	34.5%	4.0
The lecturer made the subject matter interesting	3.4%	17.2%	34.5%	24.1%	17.2%	3.4
The lecturer gave helpful feedback on my progress	0.0%	20.7%	20.7%	44.8%	13.8%	3.5
The lecturer treated students with respect	0.0%	6.9%	10.3%	37.9%	37.9%	4.1
The lecturer knew the subject matter well	0.0%	6.9%	10.3%	44.8%	37.9%	4.1
The lecturer communicated enthusiasm for the subject area	3.4%	3.4%	20.7%	44.8%	27.6%	3.9
The lecturer assisted me in gaining a good understanding of the subject matter	6.9%	3.4%	20.7%	51.7%	17.2%	3.7
The lecturer was good explaining the subject matter	6.9%	10.3%	31.0%	41.4%	10.3%	3.4
I had reasonable opportunity for interaction with the lecturer	0.0%	10.3%	13.8%	51.7%	24.1%	3.9
The lecturer motivated me to learn	6.9%	6.9%	34.5%	37.9%	10.3%	3.4

Some relevant comments made by the students during SETL evaluations were:

- ‘notes are well structured’,
- ‘teaching was clear and tutorial was adequate for understanding’,

- ‘well prepared and always there to assist’,
- ‘the subject is well planned, taught, links together well,
- ‘well structured, good notes, good workload’,
- ‘the entire subject was brilliantly taught,
- ‘responsible and great lecturer! Useful notes and tutorials, reasonable workload,
- ‘good integration of tutorials, lectures and labs’,

Table 4: Average of means of Questions in SETLs for EMPS

Year		Average of means of ‘standard questions’	
		SETL-Unit (out of 5)	SETL-Teaching (out of 5)
Before Implementation of Integrated Method	2002	2.67	2.94
	2003	2.57	2.59
After Implementation of Integrated Method	2004	3.83	3.74

The data in Table 4 is for SETL result from 2002 to 2004 and indicates that the learning-teaching model introduced into the EPE curriculum has been appreciated by students. The generally held view is that the improved SETL results stem from the students’ satisfaction with the integration of all the unit’s components.

Conclusions

The paper describes the use of an integrated learning and teaching approach for electrical power engineering using the unit Electrical Machines and Power Systems as a case study. The method was constituted of the four different components: theoretical foundations, physical/hands-on models, mathematical/computer models, and laboratory experimental/real-world applications. The use of laboratory work was seen to be a key element of the process and should not be replaced with computer simulations. The ongoing use of high cost laboratory infrastructure in the EPE discipline was able to be justified.

Student embedded knowledge and understanding was tested using a range of formative and summative assessment criteria. Student Evaluation of Teaching and Learning (SETL) was used to gauge students’ view of the teaching and learning process. The SETL results, and improvement over previous years, indicated that students were well satisfied with both the unit content and the teaching methodology. It is the authors’ view that the learning and teaching approach described in the paper encourages students to become active participants in their learning process and enhances understanding of principles and applications in Electrical Power Engineering.

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