Worldwide Programs in Power Engineering Education

1994 Winter Meeting panel session comparing requirements for graduate and post-graduate studies

During the 1994 IEEE Power Engineering Society Winter Meeting, the PES Power Engineering Education Committee sponsored an international panel session on Power Engineering Education Programs Worldwide. G.T. Heydt chaired the session. The panel of experts and the universities they represented included:

- G.T. Heydt, Purdue University, United States
- C. Arnold, Canterbury University, New Zealand
- T.J. Hammons, Glasgow University, United Kingdom
- H. Mori, Meiji University, Japan
- H. Rudnick, Universidad Catolica, Chile
- A. Vlastos, Chalmers University, Sweden.

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Undergraduate Programs in the United States

G.T. Heydt, Purdue University

Power engineering programs are mostly in electrical engineering (EE) and mechanical engineering (ME), leading to the BSEE and BSME degrees. Some universities have separate departments of power engineering, and most programs are ABET accredited. About 85 such programs nationwide are identifiable in ECE/EE or EPE departments.

Undergraduate BSEE programs (4-year) in the United States and Canada consist of the following:

- **Basic mathematics** (0.5 year)
  Through advanced differential equations
  Exposure to discrete mathematics
  Exposure to matrices and linear algebra
  Basics such as analytic geometry and calculus
  Exposure to transform methods, partial differential equations and vector calculus
- **Basic Sciences** (0.5 year)
  Chemistry, Physics
  Electromagnetic fields
  Thermodynamics
  Includes exposure to other engineering sciences, strength of materials, fluids
- **Humanities** (1 year)
  Communications (public speaking)
  Two or more liberal arts subjects
  Foreign language study
- **Advanced math and sciences** (0.5 year)
- **EE and engineering science** (1.5 years)

The following is a breakdown of a typical BSEE program:

- Basic circuits, 20 percent
- Electives, 17 percent
- Basic communications, 15 percent
- Laboratories, 15 percent
- Computer engineering, 13 percent
- Energy conversion and control, 13 percent
- Solid state, 7 percent.

Typical power electives (three or four courses) include: machines, power system engineering, transmission lines, distribution engineering, project work, power electronics, and high voltage engineering.

The following is the typical spectrum of BSEE power students:

- High percentage of U.S. nationals (85 percent)
- Most end their formal education with the BSEE
- About 15 percent of BSEE students go on to the MSEE
- Most work in the electric utility or manufacturer industries
- A few go into government
- Nearly all are full time day students
- Good (but not excellent) job market.

The main problems facing power engineering education programs are:

- Recruiting students
- Encouraging students to go on to the MSEE
- Updating laboratories.

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Education in Electrical Power Engineering at University of Canterbury, New Zealand

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Power system engineering education has a long history at the University of Canterbury, Christchurch, New Zealand. Electrical power was an essential part of the development of the country from the latter part of the nineteenth century up to the present day. The early introduction of HVDC in the form of the Cook Strait link connecting North and South Islands and its recent upgrade to a hybrid configuration demonstrate New Zealand's innovative abilities in power systems. The importance of power system education was formally recognized in 1975 when Dr. J. Arrillaga was appointed as the first professor of power systems within the department of Electrical and Electronic Engineering.

New Zealand Overview

Tertiary education in New Zealand (population 3,500,000) is catered for by 7 universities and 25 polytechnics, plus a few specialist institutions such as Colleges of Education.

Until recently, only the universities offered degree courses, but this has changed with the government's moves to make the structure of education more flexible. I am led to believe that seven institutions in Auckland alone can now award degrees.

Six universities were credited in 1961 from the seven colleges of the University of New Zealand. Thus, prior to that date there was a unifying structure to the system, and this persists to this day. For example, only Auckland and Otago have medical schools, Auckland and Canterbury have engineering schools, Lincoln was established as an agricultural college and still majors in this area. Massey, Victoria, and Waikato do not have specialist schools, but along with the others, they do have departments with significant strengths.

Recently, Massey has introduced technology courses that are responsive to the needs of the country. Canterbury and Auckland prefer a more traditional approach in trying to give the students a more general engineering education. This rivalry is healthy and good for both the conservatives and liberals and, I hope, for the country.

Lincoln University, the seventh university, was until 1992 an independently funded college of Canterbury, but it now awards its own degrees and actively competes with Canterbury for the local students in areas such as commerce.

Lincoln's agricultural strengths, and its previous ties with Canterbury, give the School a Engineering at Canterbury the strange distinction of having a department (Natural Resource) in another university. The students in this department must attend courses at both universities, at Canterbury first and Lincoln later.

School of Engineering at Canterbury

There are four major departments in the School of Engineering: Chemical and Process, Civil, Electrical and Electronic, Mechanical.

Other departments only offer a limited number of courses and rely on the major departments to supply the remainder of the courses. Of these, the biggest is Natural Resources, which provides a full final year course. The other departments are Environmental Engineering, Engineering Management, Fire Engineering, and Forestry Engineering.

Until recently Civil was the most dominant, reflecting the pioneering phase of New Zealand's history. The major emphasis on creating an infrastructure of roads, railways, bridges, and dams is now over, so their importance has been reduced somewhat. Being a Pacific Rim country, New Zealand is subject to earthquake and volcanic activity, and the Civil Engineering department has a high international profile in this area.

Electrical and Electronic Engineering (EEE) has become the major department and can now be the most selective in its students.

The EEE degree, as with all others, is a 4-year course. There is 1 Intermediate Year, which is common to all the engineering students. This is followed by 3 Professional Years in the relevant department.

EEE Intermediate Year

The Intermediate Year need not be undertaken at Canterbury. The course is dominated by mathematics and physics, with some mechanics, chemistry, and computing courses and can be taken at any other university except Lincoln. This allows students to become familiar with university life while staying relatively close to their homes. Despite this, many students from other areas prefer to stand immediately at Canterbury or Auckland for the Intermediate Year courses. Some students are able to miss out this year if they have good grades from the University Entrance examination, which is the final school qualification, usually obtained at 17-18 years of age.

At the end of the Intermediate Year, successful students select their preferred engineering department, but because of physical limitations of lecture theaters and laboratories, they may not get their first choice. Many students find the prospect of continuing in engineering too daunting, difficult, or (for a large number who do not come up to standard) impossible, and they usually credit their successes toward a science degree.

Entry into the engineering school is also possible for those with other qualifications. An applicant with a suitable BSc degree, or a New Zealand Certificate of Engineering (NZCE) with sufficient work experience can qualify for direct entry into the second Professional Year.

The overall structure of the School of Engineering at Auckland University is similar.

EEE Professional Years

Table 1 provides an overview of the course requirements for the 3 Professional years.

First Professional Year. In this year, the students are offered next to no choice of subjects. The whole year is taken up with departmentally controlled courses, plus one mathematics course. There are several mathematics courses that the students can take, depending on their previous grades. The students must also take a short course in computer programming to ensure they are up to a suitable standard.

Second Professional Year. Students are required to take a core design course and nine elective courses. The electives consist of 13 EEE courses, 3 mathematics courses of which the student can only take one, and any two courses from the remainder of the university, subject to approval by EEE and the relevant department. Surprisingly, few students opt to take courses outside the EEE and mathematics area.

The EEE option courses are all 1 hour per week for the whole academic teaching year of 25 weeks. There is approximately 30-40 percent coursework and 70-60 percent examination weighting in the final mark given for each EEE option.

Third Professional Year. The final year requires the students to undertake a project and three or four options. A

Table 1. Electrical and electronics engineering professional courses, based on first, second, and third Professional Years

First	Second	Third
Design	Computer software	Computer software
Circuits & systems	Computer hardware	Computer hardware
Electronics	Automation & robotics	Systems & control
Electrotechnology	Systems & control	Knowledge engineering
Mechanics	Electromagnetics	Electromagnetics
	Signal processing	Communications
	Communications	Communication electronics
	Communication electronics	Integrated circuits
	Integrated circuits	Economics & management
	Economics & management	Power electronics
	Power electronics	Computer analysis of power systems
	Electrical machines	Electrical machines
	Power systems	

student who wishes to be considered for the award of BE with Honors must take four options. All students are also required to take two extra courses from the Second Professional Year.

As most students take internal courses only, it can be seen that, on completion of their degrees, they have taken 11 of the Second Professional Year options, and so the choice is more cosmetic than real. It is our intention is to remove the Second Year Professional options from the final year but their replacements have not yet been finalized.

The project is required to be done by all final year students and is nominally scheduled for 1.5 days per week for the first two terms (i.e., 20 weeks). The projects are restricted to the scheduled times but with so many students having access to computers, software projects can be easily done at any time, including the vacation periods. At the end of the second term, there is a project inspection where the supervisor and a nominated examiner discuss the work done with the student. In the third term, each student is required to give a formal presentation to the class and staff of not more than 5 minutes duration, with another 5 minutes for questions. The inspection and presentation are worth 25 percent each, and the report accounts for the other 50 percent.

assignments, each worth 40 percent. The advantages and disadvantages of a major assignment have been discussed at a recent conference. The breakdown into four assignments is to prevent some students getting too far behind and to allow some feedback to the students as they progress through what will still be two major assignments. The course attempts to introduce the students to some of the detailed, complex, and interesting aspects of power systems, without necessarily covering everything; many topics are only briefly mentioned, while others are totally ignored.

Power Electronics. This is now very important and the Second Professional Year course introduces all the major topics. There are several labs with a total weighting of 15 percent, there is a 15 percent test, and the remaining 70 percent is obtained from the final 2-hour examination. The Third Professional Year course allows those who wish to study power electronics in more depth to examine several major topics.

New Zealand does not have any heavy electrical manufacturing plant, and so there is little demand for machine designers. Hence, in the Second Professional Year, the basic machines are covered again with an emphasis on applica-

Power Courses

The three courses of major interest to those who intend to enter the power industry are power systems, power electronics, and electrical machines. Of these, the most popular is power electronics at present. In fact, nearly all our courses have some relevance to the power industry, and the old barriers between the electrical disciplines have largely disappeared.

Students have all had an introduction to three-phase systems and the basic electrical machines including transformers in the First Professional Year. Power electronics is also introduced as part of the First Professional Year electronics course.

Table 2 provides an overview of the power systems, power electronics, and electrical machines courses for the Second and Third Professional Years.

Power Systems. In the Second Professional Year, students are introduced to major aspects of power system engineering. No topic is studied in great depth. This allows all students to get an overview of the subject without necessarily covering everything. The students are required to carry two laboratory exercises, and there is a term test. The final examination is worth 70 percent of the total mark.

The Third Professional Year course is at present entitled Computer Analysis of Power Systems, but it is now considered too restrictive and it will revert to its previous name of Power Systems 2 in 1995. The opposite approach to Second Professional Year is used in this course with a great deal of specialization in a limited number of topics.

There is no exam, but there are four assignments and a test, all worth 20 percent each. Last year there were only two

Table 2. Contents of power courses and topics, based on professional years (parenthetical numbers represent the number of lectures)

Second	Third
Power Systems	
Power system layout (2)	Load flow analysis (3)
Per unit system (1)	Transient stability (8)
Power system management (6)	Analysis of unbalanced conditions (4)
High voltage technology (4)	Harmonic analysis (4)
Earthing and grid analysis (2)	System disturbances, fast transients (4)
Faults and protection (3)	Energy market (2)
Load flow (power flow) analysis (2)	Security and optimization (2)
Harmonic penetration analysis (2)	Reliability (1)
Electromagnetic transients	Ferroresonance (1)
	System equivalents (1)
	Incorporation of HVDC into transient stability (3)
	Three-phase load flow (3)
Power Electronics	
Introduction, applications, definitions (1)	Series & parallel operation of devices (2)
Diode circuits with RC, RL, LC, & RLC loads (2)	Snubbers and clamping circuits (3)
Series and parallel resonance (1)	Cooling and heat sink design (2)
Freewheeling diodes & recovery trapped energy (1)	Protection (1)
Single-phase half-wave rectification (1)	AC regulators (3)
Single-phase bridge rectification (1)	Induction motors, ac drives (5)
Multi-stage star rectification (1)	DC-DC switching regulators (8)
Effect of source inductance (1)	DC drives, cycloconverters (4)
Natural commutation process, filters (1)	Forced commutation techniques (4)
Phase-controlled rectification & inversion (4)	Inverter principles (4)
Three-phase semiconverters (1)	HVDC transmission (6)
Dual converters (1)	Harmonic elimination (6)
DC choppers, pulse width modulation	
Power factor and harmonics (1)	
Semiconverters (1)	
Electrical Machines	
Transformers including three-phase (6)	Linear induction motor (18)
Synchronous machines (6)	Permanent magnet machines
Induction machines (5)	Reluctance motors (4)
DC machines (4)	Self-excited induction generator (4)
Reluctance & stepping motors (3)	Unconventional machines (4)
	Unbalanced operation of three-phase motors (6)
	Induction motor harmonics (4)
	Superconductivity (2)

tions and drive systems. The majority of the students will be involved in applying motors to specific load requirements.

There are two laboratory exercises worth 5 percent each and a term test worth 20 percent. The remaining marks can be gained from the final examination.

The Third Professional Year course is a specialist course dealing with more advanced concepts of machines.

In the final year, the intention is to show that this topic is developing as fast as any other, especially as a result of new technologies and new requirements (high-speed transport, missile launchers, new permanent magnetic materials, superconductivity, etc).

Students must understand that it is not all known and that there are areas of controversy such as the N-machine and ball bearing machine. These areas attract intellectual involvement. It is important for the students to realize that there is still debate and that the history of science is unfolding before their eyes.

The assignment requires the students to investigate further into some area of interest using references not greater than 3 years old.

Post-Graduate Studies

The department has a large number of post graduates doing research in electrical engineering. Many students carry on from their undergraduate studies to take a masters degree. The additional qualification is valuable and allows the graduates to be more selective in their choice of employment. The additional financial burden of another year out of the work force is quickly compensated for by the extra salary that can be obtained.

The best students, who are also interested in research, undertake a PhD program, although they normally start by registering for the masters degree.

Master of Engineering. There are three different ways in which a student can obtain an ME degree. The most common method is by examination and report, which runs throughout 1 academic year and must be completed before the next intake of students. For this the student takes six courses over the first two terms. These may be either Third Year Professional courses that they did not take previously, relevant courses outside the department, or the special post-graduate courses given by departmental staff. The course workload is not high, and the students are expected to work on their chosen research topic at the same time. The remainder of the year is devoted purely to research and completion of the report.

The second method of obtaining an ME is by examination and thesis. This method only requires the student to take between four and six courses, but the time to work for the degree is usually between 16 and 18 months. Students who come from other universities (for whom we have no clear indication of their level of capability) and some of our relatively weaker students take this method of getting a second degree.

The third method is an ME by thesis only and is not done frequently. It takes about 2 years to complete and, as the name implies, only involves research. The few part time postgraduates take this option. Occasionally a student is unable to complete a PhD and provided sufficient work has been achieved, and he or she has not already got an ME, this award can be given.

The special masters courses vary from year to year depending on staff research interests and availability. Those being offered in 1994 are:

- Power system harmonic analysis
- HV insulation engineering
- Power semiconductor devices
- Expert systems
- Artificial intelligence
- Theory and practice of image recovery
- Video processing
- Nonlinear signal processing
- Modern data communication networks
- Power system protection
- Industrial power electronics
- Dynamic simulation of ac-dc power systems
- Neural networks
- Adaptive digital signal processing
- Data communications networks and protocols
- Synchronization methods for digital modems
- Data transmission and reception.

Doctor of Philosophy. A PhD degree takes at least 3 years of work and should be completed within 7 years of initial registration.

In order to allow the student and/or supervisor to gracefully withdraw from a bad decision, where possible a student is registered for an ME first. After about 6 months, the situation is reviewed and, if all parties are agreeable, the student is transferred on to the PhD program. This has the added advantage of ensuring the student takes some post-graduate courses.

There are no course requirements for a PhD degree. The quality of the work is judged solely on the thesis. Two examiners are appointed to judge the quality of the work. One is an international expert in the area of the research and, given the size of New Zealand, is always from overseas. The second examiner is from New Zealand. As far as power engineering is concerned, the local examiner is usually from Auckland University, Electricity Corporation of New Zealand (ECNZ, which is the principal generator of electrical energy), or Transpower NZ Ltd (which is the electricity transmission company). A few examiners can also be found in the small but specialized industrial sector. Recently, more examiners have been found in the power distribution companies, as these have grown in size and technical importance due to the merging of many of the smaller companies. Greater expertise is also now to be found in consultant companies which have been created as the government departments have been corporatized or privatized.

Power Related Research. The research carried out by the postgraduates is, of course, closely related to the interests of the staff. Rather than itemize all the different research topics, it is sufficient to note that there are at present 44 ME projects and 41 PhD projects being carried out in the department. Of these, 20 ME and 11 PhD projects are power system related. In the year 1992-93, the department published 42 refereed papers, of which 15 were concerned with power systems. There are at present 18 academic staff members in the department.

Future Directions

There are many topics in electrical power engineering that are not taught or only touched upon. One obvious example is reliability. This is an omission that may well be rectified in the future, given the emphasis the industry is now placing on it. However, the concepts of reliability in general are taught in other courses, and a student will not be unfamiliar with the topic. It must be recognized that the inclusion of a new topic will probably mean the dropping of existing topic.

There are not many academics in the power group, and we prefer to allow the staff to lecture on the topics with which they are most familiar and enthusiastic. Therefore, changes in topics will probably arise naturally with changes in staff and their research interests.

The courses provided by the department have twice been moderated by the Institution of Professional Engineers of New Zealand (IPENZ) in the last 10 years. It is the intention of IPENZ to moderate all the professional engineering courses in New Zealand, and we can expect to repeat the exercise approximately every 8 years. The moderation panel consists of engineers from all the relevant electrical disciplines plus a representative from the IEE (UK). The review, which takes about 1 week of actual time on campus, consists of examining all aspects of the course, including interviewing students and staff. Both moderation exercises have been useful in ensuring that the university and industry recognize each others roles and needs. One positive outcome of the reviews is that the university degree has been shown to have a high international standard, and our graduates can obtain full membership of the IEE and IEEE.

A major criticism of the IPENZ Moderation report has been the department's inability to keep up to date with instrumentation advances. The funding of the department by the university amounts to approximately $US 300,000 p.a., excluding salaries and buildings, which makes the constant re-equipping of laboratories impossible, and we must be very selective. Although IPENZ was able to identify a quite serious deficiency, they were not able to suggest a practical means of rectifying it.

Conclusions

The principal aim of the department is to produce electrical engineers who have a grasp of all the major concepts of the discipline. Further, the students should be capable of in-depth study of any necessary topic to a level sufficient for their employment. Thus, on graduation, the students should be capable of accepting a career in their chosen field with the knowledge that they can quickly reach a level of capability to work effectively. The experience gained at university should also allow them to progress quickly in their chosen employment and/or, if necessary, change their area of expertise.

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Power Engineering Education Programs in the United Kingdom

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Power Engineering Programs in the United Kingdom (UK) differ significantly from university to university. I will comment on the Programs at nine universities that form the core of power engineering education programs in the UK:

- Queen's University of Belfast, Northern Ireland
- University of Manchester Institute of Science and Technology (UMIST) including the Manchester Center for Electrical Energy, England
- University of Glasgow, Scotland
- University of Edinburgh, Scotland
- Imperial College, London University, England
- University of Newcastle upon Tyne, England
- Nottingham Trent University, England
- Robert Gordon University, Aberdeen, Scotland
- University of Strathclyde, Scotland.

Some universities offer general courses with options in Power Engineering, others offer specialized programs. Courses at most universities in the UK have some power engineering content.

Queens' University Belfast

The electrical engineering courses, together with power engineering options offered by this University, are similar to those offered by many universities in the UK.

The Department of Electrical and Electronic Engineering now enrolls about 100 undergraduates each academic year and offers two courses. These are the Bachelor of Engineering (B.Eng) and the Master of Engineering (M.Eng) course in electrical and electronic engineering. Two new B.Eng courses have recently been established: the B.Eng in computer systems engineering and the B.Eng in electronic and software engineering, which is run jointly with the Computer Science Department. All courses are modular, and most subjects constitute a half module. Students choose subjects which can be combined to constitute six modules each year.

The academic year is divided into two semesters, with examinations at the end of each semester. The degree offers career prospects across a wide spectrum: design, research, production, marketing, and sales, and the combination of hardware and software skills is recognized in employment areas embracing avionics, communications, power generation, computing, advanced manufacturing, and robotics.

The M.Eng course in electrical and electronics is a 4-year course that provides a thorough academic education extending beyond the normal honors standard. The B.Eng course in electrical and electronic engineering is an enhanced engineering honors course for suitably qualified students. It normally takes 3 years of full-time study.

All students study a broad range of subjects in the first 2 years. In the final year, many subject options are offered, and each student may choose to take either a broadly based course or to specialize in topics such as communications, control, microelectronics, power systems, or signal processing.

Final year projects cover a wide range of topics, may also cover a broad field, or be highly specialized and related to the research expertise in the department, such as electrical power engineering.

The department has earned an international reputation for excellence in research in communications, control, and power engineering. The Universities Funding Council's recent research assessment awarded the top grade to the department, making it one of only seven such departments in the UK to achieve this standard. Staff publish approximately 100 research papers each year. This has a positive impact on undergraduate courses.

Student project work can be directly associated with current research projects. Postgraduate research in five main areas lead to MS and PhD degrees.

UMIST

The Department of Electrical Engineering and Electronics at UMIST has several undergraduate courses, two of which contain a significant number of power engineering subjects, namely the B.Eng in electrical and electronic engineering, and the B.Eng in electromechanical systems engineering.

I will give a summary of relevant information and data to support and clarify the views I will put forward. This will indicate the scale and breadth of relevant power engineering education at this University. Table 3 summarizes subjects that are currently offered to undergraduates at UMIST in the subject area of Electrical Power Education, the number of students involved this year (as an example), whether it is core material or optional, and in which year it is given.

It should be noted that only those subjects that are clearly *power* have been itemized. However, a power engineer requires detailed knowledge and understanding of a wide range of electrical and electronic topics. Thus the other subjects within the UMIST undergraduate course, although not itemized, are also essential for the education of a power engineer. The UMIST undergraduate course provides a well-

Table 3. Typical modules

Period (weeks)	Title
4	Power system foundation
1	Project management
2	Transmission and distribution plant
2	Power system modeling
2	Power system dynamics and control
2	Insulation coordination
1	Electrical machines for power systems
1	Distribution system planning and design
1	Independent generation
1	Power system protection
1	Reliability assessment of power systems
17	Technical and linguistic orientation
5	Individual specialist study assignments

balanced spectrum of topics which are well suited to satisfy the first degree requirements of a power engineer. It should be noted that although most graduates in the UK are exposed to power education in an undergraduate course only, there are postgraduate courses that specialize in power engineering at a number of universities in the UK. These courses lead to a Masters' degree in electrical power engineering. One such degree is that offered by Manchester Centre for Electrical Engineering at UMIST.

The Manchester Centre for Electrical Energy (MCEE) aims to satisfy the needs of industry in electrical power and energy research, development, and application together with the education and training of electrical power and energy engineers. It combines the activities of UMIST'S Electrical Power Systems and Energy Group, the Power Electronics Group, and the Manchester Machines Research Group. The groups, over a period of more than 30 years, have established UMIST as one of the world's foremost universities involved in electrical power and energy systems.

The Centre has an enviable international reputation for its advanced education, training, research and development in all aspects of power systems engineering, power electronics, high voltage engineering and electrical machines. It offers a full-time or part-time modular MS or diploma degree course in electrical power engineering, together with midcareer training in electrical power engineering based on 1 or 2 week intensive courses.

A MS or PhD degree can be obtained at UMIST and at most universities in the UK by research alone. The department at UMIST is one of the largest in the UK with 60 staff and 800 students. It is organized into a number of strong research groups, including electrical power engineering, each of which has wide interests within its discipline.

University of Glasgow

The second year curriculum at a Scottish University is similar to the first year curriculum at an English, Welsh or Irish University on account of different secondary school education.

The University, founded in 1451, is the second oldest University in Scotland and the fourth oldest in the UK. With over 13,000 students it is the largest in Scotland and the University's School of Engineering is the oldest in Britain. The Regius Chair of Civil Engineering and Mechanics was founded in 1840, and a separate Faculty of Engineering followed in 1923. There are now five departments within the faculty: Aerospace Engineering, Civil Engineering, Electronics and Electrical Engineering, Mechanical Engineering, and Naval Architecture and Ocean Engineering.

The Department of Electronics and Electrical Engineering has some 500 undergraduates taught by nearly 50 staff and offers, some in association with other departments, many B.Eng and B.Sc.(Eng.) degrees. These include:

- Honors Degree in Electronics and Electrical Engineering
- Honors Degree in Electronic Systems and Microcomputer Engineering
- Honors Degree in Electrical Power Engineering
- Honors Degree in Avionics
- Honors Degree in Electronic and Software Engineering
- Master of Engineering Degree in Electronics and Electrical Engineering (European M.Eng.).

The degree in electronics and electrical engineering is a general degree with a power engineering content. Classes taken in the first 3 years are largely compulsory. In the third year, there is one additional subject which is selective. In the fourth year, students select four subjects for a list. An individual project is also undertaken in the fourth year together with a technical essay and delivery of a colloquium essay. Together they make up more than a quarter of the credit hours for the year. In addition, students select one subject from a list of general courses.

Power Engineering Degree. The Power Engineering Degree is aimed at students with an interest in control, generation, and efficient use of electrical energy and combines modern electronics with traditional electrical engineering. The first and second years of the course are the same as that for the general degree in electronics and electrical engineering.

Third year students take the following compulsory whole-year subjects:

- Communications Systems III
- Control III
- Electromagnetic Fields and Waves III
- Electronic Computer Aided Design III
- Electronics III
- Mathematics III
- Power Engineering.

Fourth year compulsory subjects include:

- Power Systems IV
- Electronic Motors and Drive Systems IV
- Power Electronics IV.

In addition, one optional subject is chosen.

The final year project and technical essay must be selected from an approved list of electrical power engineering topics.

European M.Eng. Degree. The European M.Eng. degree offers students the opportunity to gain direct experience of European industry. It incorporates a period working in a European establishment, foreign language tuition, and industrial management studies.

The course is of 5 years duration with the first 3 years following the B.Eng. curriculum. At the end of the third year, students are selected for the fourth and fifth years of integrated language, management and engineering studies. Fourth year subjects may be similar to those for the degree in power engineering. European language studies replace the usual fourth year project. An equivalent project is undertaken during the first half of the fifth year when the student is on placement with a European industrial establishment. This could be in electrical power engineering. During the final 6 months of the fifth year students receive formal tuition in industrial management including law, accountancy, management and economics. Visiting lecturers from industry also feature prominently in the curriculum. The main assignment is the production of a business plan for a real industrial product.

Approximately 90 students are currently enrolled for Power Engineering III, and about 30 students currently take Power Systems IV. There are also of the order of 30 students undertaking Power Engineering and power oriented projects. Most students take up employment in the general area of their final year project.

The department has a high international reputation for excellence in research in electronics and electrical engineering, and staff and students have contributed to numerous publications, etc. in Electrical power engineering and other topics. Staff and students regularly contribute to PES publications. This has had a positive impact on undergraduate teaching.

University of Edinburgh

This university offers a general degree in electrical engineering in which students can take power engineering options.

Second Year. Students normally take three subjects, of which Electrical Engineering II is one subject. Within Electrical Engineering II, they all take the Power & Machines 18-lecture module (1 of 5). This covers introduction to power system planning & operation, power, power factor, three-phase transformers, synchronous machines, and dc machines. In addition, they spend one afternoon in the power laboratory.

Third Year. In Electrical Engineering III (a full-time course), all students take the following power courses. These courses form about 15 percent of the total third year course:

- Power Electronics (9 lectures), which includes power electronic devices, dc choppers, ac voltage regulators, one- and three-phase bridge rectifiers, HVDC links, dc drives
- Power Systems (18 lectures) which includes power system design, load estimation, generation mix, system costs, per unit systems, synchronous machine construction, steady state and transient behavior, power system load flow and fault calculations.

Fourth Year. All students take six modules. All students take the 18-lecture Power Electronics module which covers devices, inverters, PWM, UPS systems, ac drives, SMPS design and control, design of magnetic components.

In addition, about one-third of the class choose the Power Systems and machines 18-lecture module. This is optional. It includes power systems: economics, policy, trading, environment, symmetrical components, fault analysis, protection, induction machines, synchronous machines.

About a quarter of the class take their final year project or dissertation in the power area, and about half of these students will end up with jobs in power engineering.

At Edinburgh, a trend is to include more on power system planning and operation, including economic and environmental considerations, and less on mathematical analysis than in the past. Similarly, in power electronics, more time is spent on looking at applications rather than the detailed analysis of power electronic circuits than covered in the past.

A number of the final year projects are supported by industry. In the final year dissertation, students almost always have substantial contact with industry.

Imperial College, London University

All electrical engineering students in the first year spend 15 hours and in the second year 25 hours doing power experiments. Accompanying lecture courses in the area of power topics total about 27 hours.

There are four elective courses in the third year:

- Introduction to Power Systems
- Advances in Power Systems
- Computer Aided Design in Power Engineering
- Power Electronics.

Each course is of 20 hours. They are taken by 10-20, 10-15, 15-20, and 20-25 students, respectively. There is a third year laboratory where students can fill the first half of the year with power experiments.

There is also a fourth year course on planning but this course attracts very few students.

It is common for about 10 students each session to do "power" projects and enter employment which has a power element.

Under consideration is a general M.Sc course where power topics will be included. It could well be that power specialization would be taken up at the M.Sc level after a first degree in light current topics.

The Electrical Energy Systems Group has a staff of six including a professor and a reader. There is the possibility of a further professor in communication systems for power engineering.

There are in addition 25 research personnel including 16 doctorate students. Areas of particular interest include:

- Power system planning, operation and performance
- Renewable energy, particularly from the wind
- Finite-element analysis and computer-aided design
- Application of artificial intelligence to power system control, etc.

University of Newcastle-upon-Tyne

The degree has a common first year. At second-year level, one module is optional with a choice between mechanical engineering and physical electronics although either is considered a valid choice for power engineering specialization at final year.

Both B.Eng and M.Eng courses exist, B.Eng will suffice to show the range. The final year requires six modules from the following (the first four modules are semester 2 and the others are semester 2), plus 2 modules from the complete list for Electrical/Electronic Engineering:

- Electromagnetic Theory
- Control Systems
- Machines & Drives
- Power Electronics
- Design of Machines and Drives
- Power System Operation & Control
- Electric Drives
- High Voltage Engineering
- Current Developments in Electrical Power.

Typically 5 out of 80 students opt for this final year specialization. At least another 10 students take two or more power options in alterative specializations. The B.Eng/M.Eng split is about 12 M.Eng and 58 B.Eng out of 80.

Years 1 and 2 have one module specifically related to Power, viz. Electromagnetic Devices in year 1, and Electrical Machines and Systems in year 2. Digital and analog electronics, microprocessor control, high level languages. signal processing, semiconductor devices and mechanical engineering are all subjects which are directly relevant to power engineers and are included.

Students on the B.Eng course do project work in all 3 years; most final year projects are industry related.

Students on the M.Eng course do an industrial research project in their fourth year on placements in industry or in research and development establishments. This can include an EU ERASMUS exchange with French or Italian universities on COMETT sponsored placements with European industry. The placements are of 6 months duration. They also do an industry set and assessed group project (4 to 6 students per group) in their third year.

Graduates get employed across a very wide range of industry. It is not easy to be specific.

Curricular trends include:

- Modularization and semesterization (2 semester years)
- Increase in design and project work
- More interest in foreign languages and European placements
- More emphasis on group inter-relations and project skills

- A move towards a 4 year Master degree to allow room for continuous curricular pressure.

Nottingham Trent University

The modularization and semesterization of programs at UK universities has tended to build power engineering as a series of specialist options in years 4 and 5 for the B.Eng and M.Eng degrees, respectively. The base as shown typically for Nottingham Trent University is very broad. An M.Eng student can study twelve power-related options in the final 2 years of the course.

- Power students are more likely to be sponsored than light current students, typically by GEC Alsthom, the Brush Companies, Cegelec, the distribution utilities, and the generating utilities.
- As sponsored students, they will spend their vacations with *their* company. Other students undertake an industrial placement.
- About 25 percent of the total (80) are electrical power students.
- Most return, initially, to their sponsoring company.
- Curriculum trends in recent years involve the introduction of computing and microelectronics as preferential in power courses.

The first 2 years (4 semesters) are common and broadly span electrical and electronic engineering. Semesters 5 through 8 (the M.Eng. Semesters) feature electives to the value of 12 credit points. The *power* electives reflect the power research interests of the department: power electronics and drives. Magnetics and computer aided design of machines and magnetic system, and specialisms such as ASIC design for power electronic systems.

Typically, power electives (worth 10 credit points each) are: control systems, electrical machines, electrical power and utilization, power electronics I and power electronics II, instrumentation, and total quality management.

The project (worth 20 credit points) for power based students is ideally industrially or research based within the power group of lecturers.

Robert Gordon University, Aberdeen

The School of Electronic and Electrical Engineering at the Robert Gordon University offers the following B.Eng (Hons) undergraduate courses:

- B.Eng (Hons), 4 years in electronic and electrical engineering
- B.Eng (Hons), 4 years in electronic and communications engineering
- B.Eng (Hons), 4 years in electronic and computer engineering.

These courses were introduced in October 1993 and have the first 2 years common. The electronic and electrical engineering degree course is essentially the course which contains the power engineering options.

The common second year course introduces the student to the theory and application of ac and dc machines, power electronics and power systems.

Power courses offered in the third year include:

- Electrical Engineering III, including three-phase induction motors, three-phase synchronous machines, drive control systems, other electrical machines, power electronics, power system analysis and protection, and power engineering design.
- Electrical Drives III, which covers drive control requirements, dc drives, ac drives, qualitative treatment of brushless synchronous machine drive and reluctance motor drives, lower power drives, and stepper motors.
- Alternative Energy Systems III, which introduces students to the concepts and principles of alternative energy systems and their application and integration into an interconnected grid system.

In the fourth year, Electrical Engineering IV provides an advanced treatment of aspects of electrical power engineering analysis and relates theoretical studies to practical engineering systems and problems. Topics included are aspects of machine and transformer design, machine analysis, electrical machine condition monitoring, power electronics and drives, and power system analysis and protection.

Electrical Drives IV provides an advanced treatment of aspects of modern industrial drive systems.

Power System Protection IV covers protection and control functions of modern microprocessor-based relays and exposes students to industrially based case studies.

Prior to the creation of these three degree courses there were two B.Eng. (Hons) courses:

- B.Eng. (Hons), 4 years in electronic and electrical engineering
- B.Eng. (Hons), 4 years in electronic and information engineering.

The school has an excellent IEE accreditation record.

Fourth year Hons projects in Power Engineering have an industrial collaborator. The oil industry and service companies provide a focus for power engineering.

An average of twenty students/annum have been opting for power engineering subjects in the third and fourth year. This is a relatively healthy situation and is influenced by the oil industry and the strong research and consultancy profile of Power Engineering within the School of Electronic and Electrical Engineering. The importance of modern power electronics and drives, analysis of systems, and signals applied to machine drives and power systems, etc. is an essential ingredient to attract the interests of students.

Graduates are employed by the oil companies, electricity supply authorities, electrical machine manufacturers, etc.

Regarding curriculum trends, there has been a move away from traditional analysis to power electronics and drives; computer simulation of machines and power systems; input of signal processing to machine drives and power system networks (e.g., online condition monitoring and diagnostics); expert systems in machine drives and power system networks, etc.

With respect to courses which compose the power engineering program, increased options have become available and the new course at the Robert Gordon University suits the needs of the power engineering industries and can be expected to attract the students.

University of Strathclyde

The Department of Electronic and Electrical Engineering is the largest in the university with more than 50 faculty members, over 600 undergraduate students, and over 200 postgraduate students. It offers a B.Eng. course and an M.Eng. course in electronics and electrical engineering run on a two semester/year basis. It also offers two new courses, M.Eng. in electronic and electrical engineering with European studies and M.Eng. in electronic and electrical engineering with business studies.

During each academic year, students study a minimum of 12 credits (one credit is nominally one module). Some modules are compulsory, and others can be selected from lists of optional or elective modules. Progress regulations that govern entry to the new year are summarized on the slide.

Power engineering is introduced in the second year as a compulsory class that carries 1 credit out of 12 credits required to proceed to the third year. Two credits are selected from elective modules. The power engineering module provides the student with an understanding of the construction, operating principles, and applications for electrical power devices and systems.

The seven compulsory modules in the third year are: numerical methods; signals and systems; fields, lines and circuits; measurement and control; electronics CAD; signal processing; and electronics CAD project.

In addition to these compulsory classes, third year students choose five classes from those listed as follows:

- Electrical materials and design
- Semiconductor devices and materials
- Power electronics and machines
- Analogue electronics III
- Power supply and utilization
- Communication II
- Optoelectronics
- Signal processing
- Measurement and control.

One selected class could be power electronics and machines, and another could be power supply and utilization. Power electronics and machines further develops an understanding of electrical machines and introduces the principles, applications and analysis of power semiconductor devices and systems. Power supply and utilization is aimed at understanding and applying the per unit system to the solution of balanced three-phase systems under normal and faulted conditions and to appreciating how electrical power can be applied to the process industry, electro heating and motor drives.

Fourth year information is summarized as follows:

- Analog systems (semester 1), and CAD of electronic systems (semester 2); or power electronics (semester 1), and electrical machines (semester 2)
- Advanced microprocessing (semester 1), and transputers and par. proc. (semester 2)
- Signal processing 1 (semester 1), and signal processing 2 (semester 2); or power system analysis design (semester 1), and power system protection and control (semester 2)
- Automatic control engineering (two-semester, double-credit)
- Data transmission (semester 1), and data networks (semester 2)
- Microwave systems (semester 1), and optical systems (semester 2)
- Communications theory (semester 1), communications systems (semester 2)
- Computer vision (semester 1)
- Power utilization (semester 1), electrical engineering design (semester 2)
- Robotics and simulation (two-semester, double credit)
- Signal processing systems (semester 2)
- Prod and operations management 1 (semester 2); or engineering economics (semester 2).

B.Eng. students select eight classes which carry eight credits from the options indicated on the slide of which six may be power engineering: power electronics, electrical machines, power system analysis and design, power system protection and control, power utilization, and electrical engineering design. All final year students are required to complete an engineering applications project which carries 4 credits.

B.Eng. students can transfer to M.Eng. courses at the end of their third year. M.Eng. EEE/European Studies students spend year four (out of 5 years) in another European country at a collaborating European university. M.Eng. EEE/Business Studies students are required to take management modules in addition to EE subjects.

Over the fourth and fifth year, M.Eng. students take classes amounting to no fewer than 24 credits.

M.Sc in Electrical Power Engineering. The postgraduate electrical power engineering course is one of three M.Sc postgraduate courses which are offered by the department. It is usually undertaken over 1 year. It is intended for those graduates concerned with design, operation and analysis of power supply systems, power plant and industrial electrical equipment. Instruction is equivalent to 2 days/week over the academic year, the prescribed design or research project takes up the remaining time.

The instructional part of the course is composed of the following 12-hour modules: power systems, electrical machines, control and instrumentation, insulation systems, system plant operation, and electrical plant.

The M.Sc course may also be undertaken on a part-time basis over 21 months depending on the qualifications of the candidate.

For undergraduate final year students, the percentage taking power options is 30-40 percent. For M.Sc electrical power engineering, the total number of candidates taking the course each year is 20-30.

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Undergraduate Power Engineering Education Programs in Japan

Hiroyuki Mori, Dept. of Electrical Engineering, Meiji University, Japan (currently visiting associate professor, School of Electrical Engineering, Cornell University)

There are multiple forms of electrical power engineering in Japan:

- Electrical engineering
- Electrical and electronics engineering
- Electronics engineering
- Electronics and communication engineering
- Information and communication engineering
- Control engineering
- Applied electronics engineering
- Communication engineering
- Electronics and information engineering
- Information system engineering.

At the 1993 annual meeting of electrical engineering faculties in Kumamoto, Kyushu, there were 129 university and 222 department members exchanging ideas in education and research programs of electrical engineering departments. There are 72 private universities and 57 national (including city and prefecture) universities. The number of

Table 4. Overview of subjects

Grade I	Grade II	Grade III	Grade IV
Liberal arts	Liberal arts	Liberal arts	EE laws/facilities
English	English	Control theory	High voltage engr
German or French	German or French	Materials	System engr
Math/physics	Math/physics	Math/physics	Systems control
Chemistry	Chemistry	Electric machinery	Power engr
Electromagnetics	Circuit theory	Electronic circuit	Electronic devices
Computer programming	Information processing	Computer engr	Information theory
Drawing	EE drawing	Numerical analysis	Power electronics
Physics experiment	Engr experiment	EE experiment	BS thesis

power programs were 17 at the private universities and 23 at the national universities. (This data is based on research activities at the IEEJ meetings on power systems.)

The following list indicates the ratio of universities with power programs in Japan to those with electrical engineering departments by Region:

- Hokkaido 3/5
- Chubu/Hokuriku 4/19
- Kyushu/Okinawa 3/19
- Tohoku 3/9
- Kansai 7/17
- Tokyo 16/49
- Chugoku 4/8
- **Total 40/129**.

The outline of an electrical engineering department includes electrical engineering, electronics, energy, power systems, computer/information, and control systems. Table 4 shows an overview of subjects for grades I through IV.

Subjects on power engineering include transmission, generation, distribution, power system analysis, high voltage engineering, system engineering, system control, numerical analysis, and computer programming.

Usually, students at Grade IV join the laboratory to spend 1 year for the BS Thesis. At national universities, there are less than 5 students per laboratory, and between 20 and 100 percent of the students go on to work on a master of science degree. At private universities, there are about 12 students per laboratory, and between 0 and 40 percent go on to work on a master of science degree.

The current problems include:

- How to encourage students to take the program
- Lack of research budgets
- Poor facilities
- Deterioration of research and education levels
- Insufficient scholarship systems.

Future problems include:

- Students do not want to get a job in manufacturing companies.
- Student population will drastically decrease, say 50 percent in 10 years
- High school students have no interest in science and engineering school.

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Power Engineering Education in Chile

Hugh Rudnick, Universidad Catolica De Chile

In Chile, which has a population of 13,500,000, about 130,000 students take national university entrance tests each year. Table 5 shows basic educational requirements in Chile. There are 50,000 university openings per year, and the engineering and medical fields receive the top students. The Universidad Catolica offers 2,500 openings each year, and its total enrollment is 12,500.

The school of engineering offers a 6-year engineering program and there are about 2,000 engineering students, an annual entrance of 400 students. About 75 percent of the students go into industrial engineering, which is a hybrid program combining a strong background in systems engineering and management science together with a major in technological field (see Table 6). An alternative program, civil engineering, is offered but it is more technically oriented and not as popular with students. Universidad Catolica de Chile is the only university in the country offering the successful hybrid scheme. The degree requirement is:

- 570 credits in courses
- Two technical internships
- Final thesis or qualification exam.

One credit corresponds to 1-hour of work per week. Technically, a ten-credit course has 3 hours of lectures a week.

In the Electrical Engineering (EE) Department, the EE courses start on the third year. There are about 75 students in school each year, with about 15 being power engineering students.

The power engineering power system graduates are in high demand, the industrial background is welcome, and the employers are the power utilities in Chile and neighboring countries.

Table 5. Years of education required in Chile

Years	Item
2	Pre Basic Education
8	Basic Education (start at 6 years old)
4	Secondary Education
	University Engineering Education
4.5	BSc
6	Professional Degree
1.5	Master (after BSc)
3	PhD (after BSc)

Table 6. Breakdown of typical program in industrial engineering

Credits	Semesters	Item
120	2.5	**Basic Sciences** Mathematics, physics, chemistry
100	2	**Engineering Sciences** Theoretical mechanics, thermodynamics, electricity, computer programming, economics, optimization
100	2	**Systems, Economics, and Management** Statistics, mathematical models, probabilistic models, production, microeconomics, accounting, finances, project evaluation, organization, human behavior, marketing
140	3	**Technological Majors** **Chemical engineering:** reactors and chemical processes, heat and mass transfer, unit operations, control of processes, biotechnology **Computer science:** software engineering, computer systems, programming languages, artificial intelligence, computer theory **Electrical engineering:** power systems, machines, electronics, communications, digital systems, electromagnetic networks, signal analysis, automatic control **Mechanical engineering:** manufacturing, mechanical design, thermal systems **Transportation engineering:** transportation engineering, traffic models, economy
40-60	1	**Humanities and ethics electives**
50-70	1	**In-Depth Electives** **Power engineering electives:** power system planning, economic operation, power system dynamics, distribution systems, power system reliability, power system protection, matrix analysis, electrical traction, machine dynamics
570	6 years	**Total Requirement**

Power Engineering Programs in Sweden

Antonios Vlastos, Professor, School of Electrical and Computer Engineering, Chalmers University of Technology, Sweden

A brief overview of the Chalmers University of Technology faculty board, program areas, and engineering curricula follows.

The faculty board consists of the following:

- Research Committee
- Program Committee
- Undergraduate Studies
- Electrical Engineering.

Program areas include:

- Computer Engineering
- System Engineering
- Microelectronics
- Microwave and Optoelectronics
- Electrical Power Engineering
- Fusion and Radio Astronomy.

There are 13 departments and 80 faculty members and 150 research students.

Table 7 shows the number of graduated electrical and computer engineers, Table 8 provides statistics on students working on their master thesis in electrical power engineering, and Table 9 provides a breakdown of compulsory and elective courses.

Table 7. Number graduated electrical and computer engineers

Year	Electrical Engineers	Computer Engineers
1982/83	157	
1983/84	202	
1984/85	203	
1985/86	139	4
1986/87	187	36
1987/88	148	53
1988/89	192	56
1989/90	138	63
1990/91	156	57
1991/92	139	68

Table 8. Students doing their master thesis in electrical power engineering as a percentage of total students and compared to the total number of students

Year	Percent	Total Students	Power Eng Students
1982/83	14	202	29
1983/84	13	193	24
1984/85	12	194	23
1985/86	13	201	25
1986/87	10	227	22
1987/88	7	217	16
1988/89	10	203	20
1989/90	8	134	11
1990/91	14	187	25
1991/92	14	187	27

The Master of Science program in electrical engineering (admission 200 students per year) or computer science and engineering (admission 100 students per year), requires 4.5 years. The graduate program (1 year) leading to a Master of Science in digital communication systems and technology and requires a previous bachelor in electrical engineering.

Table 9. Compulsory courses

Year	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Compulsory Courses				
1	Calculus A	Calculus B	Calculus C	Calculus D
	English	English	Electrical network theory: part A	Electronic circuits: part I
	Computer programming	Linear algebra	Electrical measurements: part A	
	Intro to study tech & education computers		Intro to switch circuit & logic design	
2	Mechanics: part A	Mechanics: part B	Fourier analysis	Analytical Functions
	Switch circ theory and logic design	Physics: part A	Physics: part B	Numerical analysis
	Probability & statistics		Computer programming advanced courses	
3	Electrical network theory: part B		Electronic circuits: part II	Electronic circuits: part III
	Electromag-netic field theory: part A	electromag-netic field theory: part B	Automatic control	Semiconductor Devices
	Electrical Measurements: part B		Signal processing	Electrical Power Engineering
	Computer Organization			
4	Information retrieval			
5	Masters thesis			
Fourth Year Elective Power Courses				
4	Electrical power systems	Electrical power systems operation and control	Advanced power systems	Large power transmission systems
		Electrical machines	Electrical machines advanced	Magnetic field computation in electrical machines
		Wind & wave generators	Power electronics	Power electronics advanced
				Control of electrical drives
	Electric power engineering electricity	High voltage engineering	Distribution systems rational use of electricity	
			Power system measurement	