ELEC4614 Power electronics

Course Outline – Semester 1, 2016

Never Stand Still | Faculty of Engineering | School of Electrical Engineering and Telecommunications

Course Staff

Course Convener: Prof John Fletcher, Room MSEB701, john.fletcher@unsw.edu.au

Lecturer: Prof John Fletcher
Tutor: Matthew Priestley

Consultations: You are encouraged to ask questions on the course material, during or after the lecture class times in the first instance, rather than via email. Consultation times can be organized by email.

Course Details

Credits

This is a 6 UoC course and the expected workload is 10–12 hours per week throughout the 13 week semester.

Contact Hours

The course consists of 3-4 hours of lectures/tutorial per week.

Contact Hours	Day	Time	Location
Lectures	Tuesday Wednesday	1pm-3pm 5pm-6pm	WebsterA MathewsThA (when required)
Tutorials	Wednesday Friday	11am 12pm	CivEng101 RedC M032
Lab	Assorted		EE 119

Context and Aims

Power electronic circuits are essential for a whole array of consumer and industrial products. At the low power end, these may include switched-mode regulated power supplies for hand-held devices, TVs, light fittings, computers and other entertainment systems. At the high power end, there are diverse industrial applications in high voltage DC transmission, grid connections for wind generators and PV systems; Power supplies for telecommunication equipment, welding, furnaces, and smelting; Power electronic converters for variable-speed drives in automotive and railway traction and accessories, in steel rolling, textile, paper rolling mills, machine tools, robotic, disk and other automation drives, ship propulsion and positioning, aircraft actuators and navigation, to name a few. Electronic processing of electrical power for these applications also provides the means to control these processes to obtain certain desirable goals such as energy efficiency, better product quality and accurate control of the processes

The subject is primarily concerned with the wide range of power electronic converter circuits for AC-DC, DC-DC and DC-AC power conversion. The operating principles, design, characteristics, protection and application of these electronic power converter circuits are treated in detail, with the goal of equipping the students with capability to design, select and maintain such power supplies. The reliable, efficient, cost effective and appropriate converter for a particular application is usually foremost in the mind of a power electronics engineer.

This course also aims to equip the student with a basic understanding of modern power semiconductor devices, their strengths, and their switching and protection techniques. These include power diodes, bipolar and MOSFET power transistors, other gate controlled devices such as thyristors, insulated-gate bipolar transistors (IGBT) and gate turn-off thyristors (GTO). Various important topologies of power converter circuits for specific types of applications are covered and analyzed. These include controlled and uncontrolled rectifiers, DC-DC converters and inverters. The course also equips student with ability to understand and analyze the qualities of waveforms at input and output ends of these converters. The quality of these waveforms is of major concern to users of modern power converter circuits and the utility authorities alike.

The course is intended for students who may want to work in environments where all aspects of the design, application and maintenance of power electronic converter circuits are envisaged. The course will familiarize students with the many diverse power semiconductor devices and their ancillary control circuits at both low and high power levels and prepare them with the requisite design and performance analysis skills for some of these circuits.

Assumed Knowledge

Pre-requisite courses are ELEC2134 (Circuits and System) or equivalent and ELEC2133 (a first course in Electronics) or equivalent. A good understanding of linear circuit theory and electronics is assumed. It will be assumed that the student will have the skills of analyzing RLC circuits with DC and AC inputs; skills of analysis of circuit dynamics with the help of Laplace operator, operation of some basic electronic circuits like diodes, transistors, basic gates and comparators will also be assumed.

Learning outcomes

At the conclusion of the course, the student is expected to:

1. have a basic understanding of modern power semiconductor devices, their strengths, and their switching and protection techniques. These include power diodes, bipolar and MOSFET power transistors, other gate controlled devices such as thyristors, insulated-gate bipolar transistors (IGBT) and gate turn-off thyristors (GTO).
2. understand the operation and develop analysis skills of several important topologies of power converter circuits for specific types of applications. These include controlled and uncontrolled rectifiers, DC-DC converters and inverters.
3. understand and analyze the qualities of waveforms at input and output of these converters. The quality of these waveforms is of major concern to users of modern power converter circuits and the utility authorities alike.

This course is designed to provide the above learning outcomes which arise from targeted graduate capabilities listed in ***Appendix A***. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate attributes (listed in ***Appendix B***). This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in ***Appendix C***.

Syllabus

The subject starts with coverage of the full spectrum of modern power semiconductor devices, their characteristics, both static and switching. Modern power semiconductor devices eg, diodes, thyristors, MOSFETS, and other insulated gate devices such as the IGBT, MCT and the FCT; Static and switching characteristics, gate drive and protection techniques; their drive circuit design and protection techniques including the snubber. Various topologies of power converter circuits are then treated, together with analysis of their operation, control characteristics, efficiency and other operational features. These include major areas of applications in AC-DC, DC-DC, and DC-AC power converter circuits. Analyses of input and output waveforms of these circuits so as to obtain their harmonic performance are also undertaken. A basic understanding of devices, circuit principles and implications in input/output waveform quality is stressed throughout the subject. Application considerations for remote and un-interruptible power supplies, and for computer systems, telecommunications, automobiles, traction and other industrial processes; Utility interaction, harmonic distortion, and power factor will also be included.

Staff Contact Details

Role	**Name**	**Email**	**Location**	**Phone**
Lab in-charge	G. Liyadipitiya	gamini@unsw.edu.au	EE119	NA

Topics Covered:

Section	**Topic**	**Approx. Hours**
1	Introduction; Overview of power semiconductor devices, characteristics.	4
2	Diode (Uncontrolled) rectifiers.	5
3	Controlled AC-DC rectifiers.	4
4	Non-Isolated and isolated DC - DC converters, Control issues.	9
5	DC - AC Converters (Inverters)	5
7	Device losses and thermal design.	3
	Total hours	30

Reading List:

1. N. Mohan, T. M. Undeland & W. P. Robins, “Power Electronics; Converters, Applications and Design”, John Wiley, Second Edition, 1995, New York.

2. J. G. Kassakian, M.F. Schlecht & G.C. Verghese, “Principles of Power Electronics”, Addison Wesley, 1991.

3. R. W. Erickson, "Fundamentals of Power Electronics”, Kluwer Academic Publications, 1997.

4. D. W. Hart, “Introduction to Power Electronics”, Prentice Hall International, 1997.

Teaching Strategies

Delivery Mode

The teaching in this course aims at establishing an understanding of the areas covered using:

- Formal face-to-face lectures, which provide you with a focus on the core analytical material in the course, together with qualitative, alternative explanations to aid your understanding;
- Tutorials, which allow for exercises in problem solving and allow time for you to resolve problems in understanding of lecture material;
- Laboratory work, which supports the formal lecture material and also provides you with skills necessary to perform experimental tasks, report writing and interpretation of experimental results.

Note that there will be a ‘Web Stream’ version of this course that students can opt to take where the face-to-face lecture content is replaced by a selection of key concept videos and an interactive OpenLearning website to guide learning of theoretical concepts. Students opting for this format do not attend lectures but will still need to attend tutorial and lab based components of the course.

Learning in this course

You are expected to attend all lectures (except ‘Web Stream’ enrolled students), tutorials and allocated lab sessions. In addition to the lecture notes, you should read relevant sections of the recommended texts. Reading additional texts will further enhance your learning experience. UNSW *assumes* that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

Tutorial classes

Lectures will be supplemented with problem solving tutorial sessions. Five to six tutorial sheets may be expected. The problem-solving sessions will be on most recently covered topics. Additionally, PSIM or LTSpice sessions may be arranged in room EE214 or equivalent. Students will be expected to participate during these sessions, in the form of questions, suggested solutions and methods. Participation by students and the tutor should be viewed as desirable aspects of these sessions.

You should attempt all of your problem sheet questions in advance of attending any tutorial classes. The importance of adequate preparation prior to each tutorial cannot be overemphasized, as the effectiveness and usefulness of the tutorial depends to a large extent on this preparation. Group learning is encouraged. Solutions will be discussed during the tutorial class and the tutor may cover the more complex questions in the tutorial class. In addition, during the tutorial class, 1-2 new questions that are not in your notes may be provided by the tutor, for you to try in class. These questions and solutions may not be made available on the web, so it is worthwhile for you to attend your tutorial classes to gain maximum benefit from this course.

Assignments:

Students, both under- and postgraduate, may be given hand-in questions and assignments worth 10 marks and organized via the OpenLearning site. Marks scored in these assignments should be indicative of the level of understanding of and proficiency in the topics covered. Assignments will appear on the OpenLearning site about ten days before their due dates.

Laboratory:

Undergraduate and postgraduate students in ELEC4614 will be required to perform five laboratory experiments, each laboratory session being allocated 3 hours. These will be conducted in room 119. Each experiment set will accommodate up to two students. The laboratory schedule will be available on the OpenLearning website on or before the end of week 2. Laboratories will start from **week 3** for students enrolled in Odd weeks and in **week 4** for students enrolled in Even weeks.

Note that laboratory is a compulsory part of ELEC4614 and students must attend the laboratory during their allotted times and commence their experiments well in time. ***Late arrivals in the laboratory will not be allowed to proceed with the experiments.***

Students must complete all five experiments in order to qualify for further assessment.
The list of laboratory experiments for this course is given below.

Laboratory Experiments:

E1 - Buck DC-DC Converter

This experiment introduces the step-down DC-DC PWM converter. Its steady-state characteristic in both continuous and discontinuous modes of operation is studied. The effects between the PWM duty cycle, switching frequency and buck inductor and capacitor values on the input/out characteristics are brought out. The dynamic characteristics of the converter are obtained through frequency response tests. The control loop design for voltage and current control is also studied.

E2 - Boost DC-DC Converter

This experiment introduces the step-down DC-DC PWM converter. Its steady-state characteristic in both continuous and discontinuous modes of operation is studied. The effects between the PWM duty cycle, switching frequency and buck inductor and capacitor values on the input/out characteristics are brought out. The dynamic characteristics of the converter are obtained through frequency response tests. The control loop design for voltage and current control is also studied.

E3 - Single-phase Inverter

Single and three phase pulse-width modulated inverter circuits, Transistor and diode turn-on and -off transients, Modulation schemes, effect of dead times and modulation frequency on output waveform quality.

E4 - Three-phase inverter

This experiment introduces you to the three-phase inverter circuit. Switching schemes for producing three-phase balanced six-step (quasi-square wave) and sine modulated AC output voltages will be studied. Effects of modulation frequency and third-harmonic injection into the modulating waveform will be studied.

E5 – Switching Characteristics: Diodes, MOSFETs and IGBTs

Measure and understand the dynamic characteristics of diodes and semiconductor devices during turn-on and turn-off transients. Be able to determine devices losses using an oscilloscope.

Laboratory sheets must be downloaded from the school Lecture Notes webpage for this course.

All experiments are interfaced with high-speed digital storage oscilloscopes and digital signal processors, when appropriate, with multi-channel data acquisition, waveform generation, control and data analysis, so that complex controls and data analyses are performed quickly and easily.

Laboratory Reports:

At the end of each laboratory session, each student will be required to show their laboratory results to the lab demonstrator for marking. Students are expected to prepare their log books with data, graphs and waveforms generated during their experiments. The lab demonstrator will mark their results and answers to lab sheet questions in their log books and keep a record for forwarding to the lecturer. The log books are expected to include statements about their main observations of performance and characteristics the circuit studied and their conclusions. Answers to questions set in last section of the laboratory sheets for each experiment must also be included.

Note: *All figures/tables must be properly captioned. All graphs/CRO traces must be properly labeled. Axes of all graphs and traces must be properly labeled and scaled. Operating conditions under which data were gathered must also be included.*

Tutorials:

Lectures will be supplemented with problem solving sessions. Five to six tutorial sheets may be expected, each including about ten problems. These problem-solving sessions will be on most recently covered topics. Students will be expected to participate during these sessions, in the form of questions, suggested solutions and methods. Participation by students and the tutor should be viewed as desirable aspects of these sessions.

Tutorial sheets are available on the webpage. Solutions of problems set in tutorial sheets will be posted on the school webpage progressively, soon after problems set in each tutorial sheet are covered in tutorial classes.

Course Assessment:

Students will be assessed according to the following scheme:

Final Examination	60% of total
OpenLearning Assignment	10% of total
Hand-in Assignment(s)	10% of total
Laboratory assessment	20% of total

OpenLearning Assignment worth 10% of the final mark and based on questions that will test the students understanding of initial key concepts. This assignment will be taken online through the OpenLearning website and will be issued Week 3 with completion by Week 5.

Hand-in (via OpenLearning) Assignment worth 10% of the final mark and based on PSIM analysis of one power electronic converter (to be specified) will be due in week 12. This exercise will enable you to present the detailed simulation results for various operating and control conditions that may not be achievable during laboratory.

Laboratory assessment marks will be awarded according to your preparation (completing set preparation exercises and correctness of these or readiness for the lab in terms of pre-reading), how much of the lab you were able to complete, your understanding of the experiments conducted during the lab, the quality of the notes you write during your lab work (according to the guidelines given in lectures/demonstrators), and your understanding of the topic covered by the lab. No formal report is required for each lab, except that the Hand-in-Assignment will include a full report on one of the experiments together with simulation results on the experiment carried out using PSIM. The experiment allocation for the Hand-in-Assignment will be announced in week 9.

The final examination will be worth 60%. Copies of examination papers (without solutions) for the past few years are posted on the webpage.

The final exam in this course is a standard closed-book 2-hour written examination, comprising **five questions of which three must be answered**. The examination tests analytical and critical thinking and general understanding of the course material in a controlled fashion. Questions may be drawn from any aspect of the course (including laboratory), unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses. University approved calculators are allowed. *Please note that you must pass the final exam in order to pass the course.*

Other matters

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment. Students may be asked to sign an attendance list for each lecture and tutorial class. Note again that all lab experiments must be completed in order to be eligible for final assessment.

Relationship of Assessment Methods to Learning Outcomes

	Learning outcomes						
Assessment	**1**	**2**	**3**				
Laboratory practical assessments	✓	✓	✓				
Assignment	✓	✓	✓				
Lab examination							
Final exam	✓	✓	✓				

Academic Honesty and Plagiarism

Plagiarism is the unacknowledged use of other people's work, including the copying of assignment works and laboratory results from other students. Plagiarism is considered a form of academic misconduct, and the University has very strict rules that include some severe penalties. For UNSW policies, penalties and information to help you avoid plagiarism, see http://www.lc.unsw.edu.au/plagiarism. To find out if you understand plagiarism correctly, try this short quiz: https://student.unsw.edu.au/plagiarism-quiz.

Student Responsibilities and Conduct

Students are expected to be familiar with and adhere to all UNSW policies (see https://my.unsw.edu.au/student/atoz/ABC.html), and particular attention is drawn to the following:

Workload

It is expected that you will spend at least **ten to twelve hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both face-to-face classes and *independent, self-directed study*. In periods where you need to need to complete assignments or prepare for examinations, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

General Conduct and Behaviour

Consideration and respect for the needs of your fellow students and teaching staff is an expectation. Conduct which unduly disrupts or interferes with a class is not acceptable and students may be asked to leave the class.

Work Health and Safety

UNSW policy requires each person to work safely and responsibly, in order to avoid personal injury and to protect the safety of others.

Keeping Informed

Announcements may be made during classes, via email (to your student email address) or via online learning and teaching platforms like Moodle. From time to time, UNSW will send important announcements via these media without providing any paper copy. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. You should seek assistance early if you suffer illness or misadventure which affects your course progress. All applications for special consideration must be **lodged online through myUNSW within 3 working days of the assessment**, not to course or school staff. For more detail, consult https://my.unsw.edu.au/student/atoz/SpecialConsideration.html.

Continual Course Improvement

This course is under constant revision in order to improve the learning outcomes for all students. Please forward any feedback (positive or negative) on the course to the course convener or via the Course and Teaching Evaluation and Improvement Process. You can also provide feedback to ELSOC who will raise your concerns at student focus group meetings.

2015 feedback: As a result of previous feedback obtained for this course we replaced an existing laboratory exercise which students had found difficulty understanding (Unity-power factor converter) with one that demonstrates the detailed characteristics of semiconductor devices to enhance understanding of the switching transients of diodes, MOSFETs and IGBTs.

2016 feedback: Lab exercises 1 and 2 have been modified to reduce the number of test results required to be taken. OpenLearning website developed.

Administrative Matters

On issues and procedures regarding such matters as special needs, equity and diversity, occupational health and safety, enrolment, rights, and general expectations of students, please refer to the School and UNSW policies:
http://www.engineering.unsw.edu.au/electrical-engineering/policies-and-procedures
https://my.unsw.edu.au/student/atoz/ABC.html

Appendix A: Targeted Graduate Capabilities

Electrical Engineering and Telecommunications programs are designed to address the following targeted capabilities which were developed by the school in conjunction with the requirements of professional and industry bodies:

- The ability to apply knowledge of basic science and fundamental technologies;
- The skills to communicate effectively, not only with engineers but also with the wider community;
- The capability to undertake challenging analysis and design problems and find optimal solutions;
- Expertise in decomposing a problem into its constituent parts, and in defining the scope of each part;
- A working knowledge of how to locate required information and use information resources to their maximum advantage;
- Proficiency in developing and implementing project plans, investigating alternative solutions, and critically evaluating differing strategies;
- An understanding of the social, cultural and global responsibilities of the professional engineer;
- The ability to work effectively as an individual or in a team;
- An understanding of professional and ethical responsibilities;
- The ability to engage in lifelong independent and reflective learning.

Appendix B: UNSW Graduate Attributes

The course delivery methods and course content addresses a number of core UNSW graduate attributes, as follows:

- Developing scholars who have a deep understanding of their discipline, through lectures and solution of analytical problems in tutorials and assessed by assignments and written examinations.
- Developing rigorous analysis, critique, and reflection, and ability to apply knowledge and skills to solving problems. These will be achieved by the laboratory experiments and interactive checkpoint assessments and lab exams during the labs.
- Developing capable independent and collaborative enquiry, through a series of tutorials spanning the duration of the course.
- Developing digital and information literacy and lifelong learning skills through assignment work.

Appendix C: Engineers Australia (EA) Professional Engineer Competency Standard

	Program Intended Learning Outcomes	
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	✓
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	✓
	PE1.3 In-depth understanding of specialist bodies of knowledge	✓
	PE1.4 Discernment of knowledge development and research directions	
	PE1.5 Knowledge of engineering design practice	✓
	PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice	
PE2: Engineering Application Ability	PE2.1 Application of established engineering methods to complex problem solving	✓
	PE2.2 Fluent application of engineering techniques, tools and resources	✓
	PE2.3 Application of systematic engineering synthesis and design processes	
	PE2.4 Application of systematic approaches to the conduct and management of engineering projects	
PE3: Professional and Personal Attributes	PE3.1 Ethical conduct and professional accountability	
	PE3.2 Effective oral and written communication (professional and lay domains)	✓
	PE3.3 Creative, innovative and pro-active demeanour	✓
	PE3.4 Professional use and management of information	✓
	PE3.5 Orderly management of self, and professional conduct	
	PE3.6 Effective team membership and team leadership	✓