ELEC4613 - Electric Drive Systems

Course Outline – Semester 2, 2016

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

Course Staff

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Keeping Informed: Announcements may be made during classes, via email (to your student email address) and/or via online learning and teaching platforms – https://subjects.ee.unsw.edu.au/elec4613/. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

Course Summary

Contact Hours

The course consists of 3 hours of lectures/week, a 1-hour tutorial/week, and a 3-hour laboratory session in alternate weeks to complete 4 experiments.

Lectures	**Day**	**Time**	**Location**
	Monday	2 - 4pm	EEG25
	Wednesday	12noon - 1pm	CLB8
Tutorials	Wednesday	1 - 2pm	Ainsworth 202
Laboratory	See lab group in time-table		
Consultation	Thursday	2 – 4pm	MSEB 739

Context and Aims

Course Details

Credits

This is a 6 UoC course and the expected workload is 10–12 hours per week throughout the 13 week session. It comprises of 3 hours of lectures/week, 0.5 hour of tutorial/week and 4 laboratory experiments (of 3 hours duration each) over the duration of the 13-week session.

Relationship to Other Courses

This is a 4th year/postgraduate professional elective course in the School of Electrical Engineering and Telecommunications. It has a laboratory component which is compulsory for both under- and post-graduate students.

Pre-requisites and Assumed Knowledge

The pre-requisite for this course is ELEC3105 -Energy Systems I in EET, UNSW, or an equivalent first course in Energy Systems/Electrical Machines. It is essential that you are familiar with dominant types of electrical machines before this course is attempted. A basic understanding of analogue linear (or classical) closed-loop control principles will be assumed.

Following Courses

NA

Learning outcomes

The aim of this course is to equip students with knowledge of variable-speed drives and motion control systems which are used in many industrial processes such as in conveyors, machine tools, pumps, compressors, mining drives, electric vehicles, ship propulsion, wind energy systems, air-craft actuators, servo drives and automation systems, to name a few. The course stresses the basic understanding of characteristic of machines driven from appropriate power electronic converters and controllers. The steady-state behaviour of such drives will be primarily covered and some dynamic issues of drive representation and control system design will also be introduced.

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Student Learning Outcomes and Graduate attributes

At the conclusion of this course, the students should be able to:

1. understand fundamental elements of drive systems, analyze steady-state characteristics of a few commonly used types of electric drive systemss used in the industry.
2. understand the performance of these drives supplied from appropriate converters.
3. understand the quadrant operation of various types of drives and their control requirements, selection of converters, components, etc.
4. understand how to design the hierarchical control structures for drive systems.
5. select and design important elements of a drive system.
6. apply the theories of electrical machines, power electronic converters and control system design to implement drive systems which are appropriate for specific performances.

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 capabilities (listed in ***Appendix B***). This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in ***Appendix C***.

Syllabus

Elements of electric drive systems; requirements of industrial drives. Drive representation, quadrant operation, dynamic and regenerative braking. DC motors, converters for DC motor drives, performance analysis. Performance analysis of synchronous motor drives with variable voltage or current source and variable frequency supply. Performance analysis of induction motor drives with variable voltage or current source and variable frequency supply. Machine dynamics using orthogonal reference frame representations. Field oriented (or vector) control of synchronous and induction motor drives.

Lecture Content/Schedule

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There will be three hours of lecture per week. The total number of lecture hours over the 12-week session will about 33, the remaining 3 hours will comprise of problem solving/tutorial/computer modelling sessions in lieu of formal lectures. Lecture notes are available from the course Lecture Notes webpage.

Course Content	*Approx Hours*
#	
Analysis of steady-state performance	
#	
Section 1. Introduction to Electrical Drives	**4**
# Rotational Systems, Load couplings, representation of torque referred to motor and load shafts; Energy relationship. Quadrant operation; Steady-state and dynamic operation	# #
Section 2. DC motor drives	**5**
Review of DC motors and characteristics Switched-mode PWM converters. Single- and three-phase thyristor converter circuits. Analysis of converter and DC motor circuits. Effects of discontinuous conduction on drive.	
Section 3. Brushless DC drives (not covered in 2016)	**1.5**
BLDC machine fundamentals; Analysis of machine back emf and torque; Ideal back-emf and current waveforms, Sensor requirements	
Section 4. Synchronous motor drives	**5**
Review of synchronous motors and characteristics Salient and non-salient pole machines; Reluctance motors Performance under Voltage Source Inverter (VSI) drive Performance under Current Source Inverter (CSI) drive Operation with maximum torque, field-weakening and unity power factor.	
Section 5. Induction motor drives	**6**
# Drive characteristics using equivalent circuit representation Performance with variable-voltage and rotor power Static Scherbius drive. Characteristics with VSI-VF inverter and CSI-VF drive Effect of harmonics on drive performance #	
# **Total**	**20**

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Dynamics and control of DC and AC machines

6.	**Dynamics of the separately excited DC motor**	**2**
	AC Machine representation in orthogonal axes	**3**
#	Representation of machine dynamics; Stator, synchronous Rotor reference frames. General orthogonal set; Representation of AC machines in orthogonal reference frames. Representation of synchronous machine dynamics in the stator and rotor reference frames; d- and q-axes currents and fluxes; rotor flux oriented control (RFOC).	
# #	#	
#	Representation of induction machine dynamics in the stator and synchronously rotating reference frames; Condition for alignment of the direct-axis with rotor-flux axis. Indirect rotor-flux oriented control (RFOC) structure; effect of rotor time-constant on RFOC.	**3**
#		
7.	**Controller design for electrical drives**	**5**
	Role of various control loops in drive systems; drive system damping; Sensors for speed, position and current. Hierarchy of control loops for torque/current, speed and position; Role of the inner current loop(s); design considerations for torque, speed and position control loops. Filter design issues; Torque, current, speed and position controller design for specified bandwidth.	
#	# **Total**	**13**
	Total hours:	**33**

Teaching Strategies

Delivery Mode

The teaching in this course aims at establishing a good fundamental 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 sessions, which support the formal lecture material and also provide you with practical construction, measurement and analytical skills;
- Simulation sessions on PSIM / Matlab Simulink platforms culminating in the analysis of drive systems performance using such a platform.

Indicative Lecture Schedule

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Period	Summary of Lecture Program
Week 1	Section 1 (Introduction to Electric Drive Systems, representation of loads, drive quadrants, stability in the steady-state)
Week 2	Section 2 (DC motor drives – steady-state analysis with PWM converters)
Week 3	Section 2 (DC motor drives – steady-state analysis with phase controlled converters)
Week 4	Section 4 (Synchronous motor drives – steady-state analysis with VSI *V/f* drive)
Week 5	Section 4 (Synchronous motor drives – steady-state analysis with CSI *I/f* drive)
Week 6	Section 5 (Induction motor drives – steady-state analysis with VSI *V/f* drive)
Week 7	Section 5 (Induction motor drives – steady-state analysis with VSI *I/f* drive) **Mid-session test**
Week 8	Section 6 (Dynamics of separately excited DC machines; Machine representation in orthogonal reference frames)
Week 9	Section 6 (Dynamic model of synchronous machines; Rotor flux oriented control).
Break	
Week 10	Section 6 (Dynamic model of induction machines; Rotor flux oriented control).
Week 11	Section 7 (Sensors for drive systems; Controller design issues for electric drive systems)
Week 12	Section 7 (Controller design issues for electric drive systems continued. **Assignment due.**

Learning in this course

You are expected to attend all lectures, tutorials, labs, and mid-semester exams in order to maximize learning. You must prepare well for your laboratory classes and your lab work will be assessed. In addition to the lecture notes/video, you should also read relevant sections of the recommended text. Reading additional texts will further enhance your learning experience. Group learning is also encouraged. UNSW *assumes* that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

Consultations

You are encouraged to ask questions on the course material, during and after the lecture class times in the first instance, rather than via email. Specified lecturer consultation times should also be used. You are welcome to email the lecturer/tutor/laboratory demonstrator, who can answer your relevant questions on this course and can also provide you with additional consultation time if required. ALL email enquiries should be made from your student email address with ELEC4613 in the subject-line, otherwise they may not be answered.

Tutorial

You should attempt all of your problem sheet questions in advance of attending the 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. Answers for these questions will be discussed during the tutorial class and the tutor will cover the more complex questions in the tutorial class. In addition, during the tutorial class, 1-2 new questions that may not be 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.

Laboratory

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The laboratory component of this course exposes you to experiments which are designed to give you hands-on experience of electric drive concepts that are covered in lectures. It is a **compulsory** part of the course and must therefore be completed and passed.

The laboratory for this course consists of four experiments, E1 – E4, which will be conducted in room EE119. There are two laboratory sets for each experiment. Maximum of two students can be accommodated for each set. Laboratory will start in week 3 and 4 for students enrolled in odd and even weeks, respectively. Laboratory sheets are available from the course website. A laboratory schedule for each enrolled group will be available via the course web page.

Students are required to read the *School Safety Manual for Laboratory* and *Laboratory Safety Instructions for Laboratory* for this course, and submit the signed *Laboratory Safety Declaration* form to the lab supervisor before they start the first laboratory experiment.

Because of the extensive changes of configuration of each experiment and the introduction given for each experiment, late arrival in the laboratory by **more than 10 minutes will not be acceptable**. You must arrive in lab well in time on the day of your experiment.

Laboratory experiments:

The following four laboratory experiments have been included. Please see the Lab Schedule in the course webpage for your schedule of lab attendance and experiments to perform.

- Experiment E1. Speed control of a DC motor with an inner current loop.
- Experiment E2. Induction motor drive with slip-power recovery.
- Experiment E3. *V/f* and rotor flux oriented (vector controlled) induction motor drive
- Experiment E4. *V/f* and rotor flux oriented (vector controlled) synchronous motor drive

Laboratory Exemption

<u>There is no laboratory exemption for this course</u>. Regardless of whether equivalent labs have been completed in previous courses, all students enrolled in this course must take the labs. If, for medical reasons, (for which a valid medical certificate must be provided) you are unable to attend a lab, you will need to discuss with the laboratory demonstrator/lecturer for a catch-up lab during another lab period.

Assessment

The assessment scheme in this course reflects the intention to assess your learning progress through the semester. Ongoing assessment occurs through the lab marks given by lab demonstrators according to your performance in each lab and the mid-semester exam.

Laboratory Assessment

You are required to maintain a lab book (or log book) for recording your observations. A lab book is an A4 size notebook containing a mix of plain pages and graph sheets. You have to purchase your own lab book from any stores. Each student, in a group of two, must submit the lab book **individually** to the lab demonstrator at the end of each lab session for marking. The lab demonstrator will mark the lab-book according the student's performance in the laboratory. Please read the on-line Laboratory Guidelines in the course webpage.

It is essential that you complete suggested laboratory preparations before coming to the lab. You are required to write the aim of the experiment and draw the circuit diagram, if any, in your laboratory log-book. This will be verified and signed by your demonstrators in the lab. You will be recording your observations/readings in your log-book first and then completing and presenting the results sheet to your lab demonstrator before leaving the lab.

Laboratory Assessment marks will be awarded according to your preparation, punctuality, involvement and presentation of the results obtained, how much of the lab you were able to complete, your understanding of the experiments conducted during the lab, the quality of the records entered during your lab work (according to the guidelines given in the labsheets), and your understanding of the topic covered by the lab.

Laboratory Exam

There are no lab exams for this course.

Mid-Semester Exam/Test

The mid-session examination tests your general understanding of the course material, and is designed to give you feedback on your progress through the analytical components of the course. Questions may be drawn from any course material up to the end of week 6. It may contain questions requiring some numerical and analytical work, and derivations.

Mark scored in this test should be indicative of the level of understanding of and proficiency in the topics covered prior to the assignment. The mid-semester exam will take place in week 7; venue and time for the exam will be advised by the lecturer in due course.

Assignment

The assignment allows self-directed study leading to the solution of partly structured problems**.** One assignment topic will be allocated for each student. This will consist of modelling the steady-state and dynamic responses of one of the laboratory experiments using a simulation platform (PSIM or Matlab/Simulink).

Marks will be allocated according to how completely and correctly the problems have been addressed, and the understanding of the course material demonstrated by the report. The Assignment must be submitted as an email attachment with subject-line – Assignment submission for ELEC4613 - **by 5pm on Friday, 28 October, 2016**. Late submissions will not be accepted.

Final Exam

The final exam in this course is a standard closed-book 3-hour written examination. University approved calculators are allowed. 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). Marks will be assigned according to the correctness of the responses. *Please note that you must pass the final exam in order to pass the course.*

Assessment allocations

The final assessment for the course will will comprise of:

Laboratory, conduct of 4 experiments (**compulsory**)	20 %
Mid-Session Test in week 7	10 %
Assignment (simulation of one of the experiments performed) together with a lab report on the experiment simulated; to be submitted in week 12.	10 %
Final examination (3 hours)	60 %
Total	**100 %**

Relationship of Assessment Methods to Learning Outcomes

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Assessment	1	2	3	4	5	6
Laboratory practical assessments	✓	✓	✓	✓	✓	✓
Mid-semester exam	✓	✓	✓	✓	✓	✓
Assignment	✓	✓	✓	✓	✓	✓
Final exam	✓	✓	✓	✓	✓#	✓#

Course Resources

Text Books and References

1. Electric Drive Systems – comprehensive lecture notes from F. Rahman. Lecture notes in PDF format are available via the School webpage for Lecture Notes. The following books may be consulted for further reading:

Reference books:

2. *Control of Electric Machine Drive Systems* - Seung-Ki Sul, IEEE Press and John Wiley, 2011.
3. Electric Drives, an Integrative Approach, N. Mohan, MINPRE, 2003, ISBN 0-9715292-5-6.

On-line resources

Lecture Notes, tutorial problem sheets and laboratory sheets for each experiment are available from https://subjects.ee.unsw.edu.au/elec4613/

Solutions of tutorial problems will be posted here, soon after the problems are covered in the scheduled tutorial classes.

Mailing list

Announcements concerning course information will be given during lectures and/or via email (which will be sent to your student email address). These will also be placed at the webpage mentioned above.

Other Matters

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 https://student.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://student.unsw.edu.au/guide), 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. Please read the section on Laboratory (in page 6) about on Laboratory Safety and the requirement of submission of signed Laboratory Safety Declaration before you commence your lab (marked in red).

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://student.unsw.edu.au/special-consideration.

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. As a result of previous feedback obtained for this course and in our efforts to provide a rich and meaningful learning experience, we have continued to evaluate and modify our delivery and assessment methods.

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 Capabilities

The course delivery methods and course content directly or indirectly addresses a number of core UNSW graduate capabilities, 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 independent, self-directed professionals who are enterprising, innovative, creative and responsive to change, through challenging design and project tasks.
- Developing citizens who can apply their discipline in other contexts, are culturally aware and environmentally responsible, through interdisciplinary tasks, seminars and group activities.

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	✓