Term 2, 2021

Course Outline

ELEC4613
Electric Drive Systems

Course Staff

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Consultations: You are encouraged to ask questions on the course material, after/during the lecture class times in the first instance, rather than via email. All the online class will be conducted via Microsoft Teams. The chat window and 'raise hand' are great way to interact with the lecturer/tutor during the online class.

You are also encouraged to post your questions at any time in the Channel (of the Microsoft Teams) relating to the topic you wish to ask a question on. The open discussion on MS Teams or questions asked directly during lectures and tutorials is an efficient way, and the whole cohort may benefit from seeing the posted answers.

Any course-related email enquiries should be made from your student email address with ELEC4613 in the subject line; otherwise, they will not be answered.

Keeping Informed: Announcements may be made during classes, via email (to your student email address) and/or via online learning and teaching platforms. In this course, we will use Microsoft Teams for all communications relating to the contents of the course and Moodle (https://moodle.telt.unsw.edu.au/login/index.php) to administer assessments (mid-term exam, quizzes, assignment, final exam).

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 2x2 hour of lectures, a 1-hour tutorial, and a 3-hour laboratory session each week. Enrolled students will be required to complete 4 laboratory experiments during the term. Tutorials and lab sessions will start in week 2 and 4, respectively.

	Day	**Time**	**Location**
Lectures	Monday	11-13	Microsoft Teams Meeting
	Tuesday	14-16	Microsoft Teams Meeting
Tutorials	Friday	13-14	Law 203/Microsoft Teams
	~~Wednesday~~	~~13-14~~	~~Microsoft Teams Meeting~~
Labs	As per Time-Table	As per Time-Table	EE115/Microsoft Teams Meeting

Context and Aims

If you see yourself as the expert driving the 5th industrial revolution that promotes sustainable development and the most sought-after professionals of transport electrification, you have come to the right place. A high level of automation that you see in a self-driving electric car, robotic arms in the industrial process or the wind energy conversion is possible by efficient control of electric motor drives. Electric Drive Systems are an essential part of industrial processes, electric traction systems, wind energy conversion systems, motion control systems, and domestic appliances. Electrically actuated processes and systems deliver high energy efficiency, product quality and highly flexible and high-volume production of items that are in everyday use.

In this course, you will gain knowledge of variable-speed drives and motion control systems used in many industrial processes such as conveyors, machine tools, pumps, compressors, mining drives, electric cars, ship propulsion, all-electric aircraft, servo drives, and automation system. The course stresses the basic understanding of characteristics of machines driven from appropriate power electronic converters and controllers. You will explore the steady state behaviour of drives and the design of high-performance drives. The dynamic issues of drive representation and control system design for the latter will also be covered in this course. You can gain hands-on experience via lab experiments and computer modelling of motor drive systems using simulation platforms such as Matlab-Simulink.

Indicative Lecture Schedule

Weeks	Approximate Lecture Schedule
1	Section 1: Introduction and basic concepts
2	Section 2: Brushed DC Motor Drive Tutorial 1
3	Monday Public Holiday Section 3: Brushless DC Motor Drives Tutorial 1
4	Section 4: Synchronous Motor Drives Tutorial 2 Laboratory E1-E4
5	Section 4: Synchronous Motor Drives Section 5: Induction Motor Drives Tutorial 2 Laboratory E1-E4
6	**No lecture, tutorial and labs**
7	Section 5: Induction Motor Drives Section 6: Dynamic Analysis of DC and AC Machines and Control Tutorial 3 Laboratory E1-E4 Mid-term test - Monday 6:30 pm
8	Section 6: Dynamic Analysis of DC and AC Machines and Control Tutorial 3 and Tutorial 4 Laboratory E1-E4 Assignment release
9	Section 6: Dynamic Analysis of DC and AC Machines and Control

	Section 7: Controller design for electric drive systems Tutorial 4 and Tutorial 5 Laboratory catch-up (if required)
10	Section 7: Controller design for electric drive systems finishes. Tutorial 5 Assignment report due: 5 pm, Friday

Indicative Laboratory Schedule

Period	Summary of Laboratory Program in 2020
Week 1	No lab
Week 2	No lab
Week 3	No lab
Week 4	Lab starts
Week 5	Second week of lab
Week 6	No lab
Week 7	Third week of lab
Week 8	Fourth week of lab
Week 9	Catch-up lab (if required)
Week 10	No lab

Assessment

The final assessment for the course will comprise of:

1.	Laboratory, conduct of 4 experiments (**compulsory**)	20 %
2.	Mid-term Exam in week 7	20 %
3.	Assignment - simulation of one of the experiments performed, together with report on the experiment conducted.	10 %
4.	Final examination (2 hours)	50 %
	Total	**100 %**

COVID19 - Important Health Related Notice

Your health and the health of those in your class is critically important. You must stay at home if you are sick or have been advised to self-isolate by NSW health or government authorities. Current alerts and a list of hotspots can be found here. You will not be penalised for missing a face-to-face activity due to illness or a requirement to self-isolate. We will work with you to ensure continuity of learning during your isolation and have plans in place for you to catch up on any content or learning activities you may miss. Where this might not be possible, an application for fee remission may be discussed.

If you are required to self-isolate and/or need emotional or financial support, please contact the Nucleus: Student Hub. If you are unable to complete an assessment, or attend a class with an attendance or participation requirement, please let your teacher know and apply for special consideration through the Special Consideration portal. To advise the University of a positive COVID-19 test result or if you suspect you have COVID-19 and are being tested, please fill in this form.

UNSW requires all staff and students to follow NSW Health advice. Any failure to act in accordance with that advice may amount to a breach of the Student Code of Conduct. Please refer to the Safe Return to Campus guide for students for more information on safe practices.

Course Details

Credits

This is a 6 UoC course, and the expected workload is 13–16 hours per week throughout the 10-week term.

Relationship to Other Courses

This is a 4th year/postgraduate professional elective course in the School of Electrical Engineering and Telecommunications. It has a compulsory laboratory component for all enrolled students, both undergraduate- and postgraduate.

Pre-requisites and Assumed Knowledge

The pre-requisite for this course is ELEC3105 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.

This course presumes some knowledge of power electronic converter circuits, such as covered in the first course in Power Electronics (ELEC4614 at EET UNSW, for example).

Following Courses

ELEC9711 – Power Electronics for Renewable Energy Systems

Learning outcomes

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

1. explain fundamental elements of drive systems and their interactions,
2. analyse steady-state and dynamic performance characteristics of DC, Synchronous and Induction motor drives supplied from appropriate converters,
3. develop skills in designing important elements (e.g., appropriate motor type, controller, converter) of a drive,
4. design hierarchical torque, speed and position controllers for converter driven motor drive systems and identify related issues.

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

Introduction to Electrical Drive Systems. Elements of drive systems. Requirements for servo and industrial drives. Drive system representation, quadrant operation, dynamic and regenerative braking. Converters for DC motor drives; performance analysis of converter driven DC motors. 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. Controller design Issues.

Course contents

There will be two 2-hours of lecture per week over the 10-week term. Lectures will include some problem solving/tutorial/computer modelling sessions. Lecture notes and slides are available from the course webpage.

Course Content	***Approx Hours***
Analysis of steady-state performance	
Section 1. Introduction to Electrical Drives	**4**
Basic concepts of rotational systems, Load couplings, representation of torque referred to motor and load shafts, Energy relationship. Stability in steady-state, Quadrant operation	
Section 2. Brushed DC motor drives	**4**
Review of DC motors and characteristics	
Switched-mode PWM converters.	
Single- and three-phase thyristor converter circuits.	
Analysis of converter and DC motor circuits.	
Section 3. Brushless DC drives	**2**
BLDC machine fundamentals; Analysis of machine back emf and torque; Ideal back-emf and current waveforms,	
Section 4. Synchronous motor drives	**5**
Review of synchronous motors and characteristics	
Performance under Voltage Source Inverter (VSI) drive	
Performance under Current Source Inverter (CSI) drive	
Section 5. Induction motor drives	**5**
Review of Induction motors and characteristics	
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	
Total	**20**

Analysis of dynamics and control of DC and AC machines

6.	**Dynamics of the separately excited DC motor**	**2**
	AC Machine representation in orthogonal axes	**2**
	Representation of DC machine dynamics;	**3**
	Rotor reference frames	
	Representation of AC machines in 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	**3**
	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.	
7.	**Controller design for electrical drives**	**6**
	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.	
	Torque, current, speed and position controller design for specified bandwidth.	
	Total	**16**

Course total lecture hours: 36

Teaching Strategies

Delivery Modes

The teaching in this course aims at establishing a good fundamental understanding of the areas covered using:

- Lectures will be delivered online this term. These will provide you with a focus on the core analytical material in the course covered according to the Approximate Lecture Schedule (see below), together with qualitative, alternative explanations to aid your understanding. The lecturer will be available on Microsoft Team/via email during each lecture. Students will be able to contact the lecturer during the formal lecture times for consultation by students.
- Tutorials will be delivered in hybrid mode (i.e. the face-face class and the online session will occur simultaneously). Online student will see the face-face students and vice-versa. The hybrid mode is a pilot project from PVC teaching. Tutorial will discuss exercises in problem-solving and allow time for you to resolve problems in understanding of lecture material.
- The laboratory will consist of 3-hour sessions for each of four experiments, E1 – E4. Laboratory demonstrators will familiarise you with the equipment for the scheduled experiment and will help you perform procedures included in the lab sheets for each experiment during each experiment. Each experiment will support the formal lecture material and provide you with the measurement and analytical skills of an electric drive. Students are encouraged to perform simulation studies

on PSIM/Matlab-Simulink platforms, culminating in the analysis of drive systems performance using such platforms.

At the end of each lab session, the lab demonstrator will assess your logbook, which should record all relevant experimental data, graphs, CRO recordings and your findings from the experiment. The demonstrators will also ask each student questions at the end of each lab session in order to ascertain students' in-depth understanding of the experiment performed.

Learning in this course

You are expected to attend all lectures, tutorials, labs in order to maximise learning. You must prepare well for your laboratory classes, and your lab work will be assessed. In addition to the lecture notes/videos, 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 the three modes of course deliveries throughout the course.

Tutorial

You should attempt your problem sheet questions in advance of attending the tutorial classes. The importance of adequate preparation prior to each tutorial cannot be overemphasised, as the effectiveness and usefulness of the tutorial depend largely on this preparation. Group learning is encouraged where possible. The solution to some of the questions set in tutorials will be discussed during the tutorial class. In addition, 1 or 2 new questions, or extensions of existing questions, may be brought in by the tutor for you to try in class. These additional questions and their solutions may not be made available in Moodle, so it is worthwhile for you to attend your tutorial classes to gain maximum benefit.

Laboratory

The laboratory component of this course exposes you to physical motor drives via experiments that 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 hardware experiments, E1 – E4. There are two laboratory sets for each experiment. A maximum of two students can be accommodated for each set in a face-face session. This term, the laboratory will run in hybrid mode in which online students will pair up with the students of the face-face class. The laboratory will start in week 4. Laboratory sheets will be made available on the course page. The 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 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 nature of each experiment and the introduction given for each experiment, you must prepare well in advance for your scheduled experiments.

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

There is no laboratory exemption for this course. Regardless of whether equivalent labs have been completed in previous courses, all students enrolled in this course must complete all four labs. If, for medical reasons (for which a valid medical certificate must be provided) you are unable to attend a lab session, 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 term. Ongoing assessment occurs through the lab marks given by lab demonstrators according to your performance in each lab and the mid-term exam.

Laboratory Assessment

You are required to maintain a lab book (or logbook) for recording your laboratory experimental data and observations. A lab book is an A4 size notebook containing a mix of plain pages and graph sheets. You should purchase your own lab book. Each student 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 to the student's performance in the laboratory. Please read the online Laboratory Guidelines in the course webpage to find more about conducting your experiments.

It is essential that you complete suggested laboratory preparations before attending each lab session. You are required to write the aim of the experiment and draw the circuit diagram, if any, in your laboratory lab book. This will be verified by your demonstrators during each lab session. You will be recording your observations/readings in your lab book.
Laboratory Assessment marks will be awarded according to your preparation, punctuality, involvement, 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 lab sheets), and your understanding of the topic covered by the lab.

Mid-term test

The online mid-session test will be of 2-hour duration. It will give an indication of your general understanding of the analytical components of the course material covered during the first five weeks. Questions may be drawn from any course material up to the end of week 5. It may contain questions requiring some numerical and analytical work and derivations.

The 2-hour mid-term online test will take place in week 7, Monday (12 July) at 6:30 pm; the time for the exam will be advised by the lecturer in due course.

Assignment

Each student will be required to submit a report/assignment topic on one of the experiments performed. The report/assignment will allow some self-directed study leading to some further operational aspects of laboratory experiments that were not considered or observed during lab sessions. These will also 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 Lab report/Assignment must be submitted online (details will be provided closer to the date).

Final Exam

The final exam in this course will consist of a 2-hour written examination online. The examination tests analytical and critical thinking and a 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.*

Relationship of Assessment Methods to Learning Outcomes (1 – 4)

Assessment	1	2	3	4
Laboratory practical assessments	✓	✓	✓	✓
Mid-term exam	✓	✓		
Assignment	✓	✓	✓	✓
Final exam	✓	✓	✓	✓

Course Resources

Text Books and References

1. *Electric Drive Systems* – comprehensive lecture notes from previous lecturer Prof. F. Rahman. PDF file will be made available on the course page.

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* by Ion Boldea and S. A. Nasar, CRC Press, 3rd edition, 2017.

Online resources

All Lecture Notes, Tutorial problem sheets and Laboratory sheets for each experiment are available on the course page in Microsoft Teams.

Other Matters

Dates to note

Important Dates available at: https://student.unsw.edu.au/dates

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 **twelve to 15 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 (on page 6) about Laboratory Safety and the requirement of submission of a 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 can apply for special consideration when illness or other circumstances beyond your control interfere with an assessment performance. If you need to submit an application for special consideration for an exam or assessment, you must submit the application prior to the start of the exam or before the assessment is submitted, except where illness or misadventure prevent you from doing so. Be aware of the **"fit to sit/submit"** rule which means that if you sit an exam or submit an assignment, you are declaring yourself well enough to do so and cannot later apply for Special Consideration. For more information and how to apply, see 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

APPENDICES

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	Course LOs
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	1, 2, 3,4
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	1, 2, 3,4
	PE1.3 In-depth understanding of specialist bodies of knowledge	1, 2, 3,4
	PE1.4 Discernment of knowledge development and research directions	
	PE1.5 knowledge of engineering design practice	3,4
	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	1, 2, 3,4
	PE2.2 Fluent application of engineering techniques, tools and resources	1, 2, 3,4
	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)	1, 2, 3,4
	PE3.3 Creative, innovative and pro-active demeanour	1, 2, 3,4
	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	1, 2, 3,4