School of Electrical Engineering and Telecommunications

Term 2, 2020

Course Outline

ELEC4613

Electric Drive Systems

Course Staff

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Consultations: Lecturer consultation times will be during the formal lecture hours and for an additional hour after each lecture and tutorial. You are welcome to email the tutor or laboratory demonstrator, who can answer your questions on this course and can also provide you with consultation times. **ALL 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 – platforms – in this course, we will use Moodle https://moodle.telt.unsw.edu.au/login/index.php. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

	Day	Time	Location
Lectures	Tuesday	4pm – 6pm	Microsoft Teams Meeting
	Friday	3pm - 5pm	Microsoft Teams Meeting
Tutorials	Friday	1pm – 2pm	Microsoft Teams Meeting
	Wednesday	1pm – 2pm	Microsoft Teams Meeting
Labs	As per Time-Table	As per Time-Table	Microsoft Teams Meeting

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 5 laboratory experiments during the term. Tutorials and lab sessions will start in week 2 and 3 respectively.

Course Details

Credits

This is a 6 UoC course and the expected workload is 13–16 hours per week throughout the 11 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 laboratory component which is compulsory for all enrolled students, both undergraduate- and post-graduate.

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.

Following Courses

ELEC9711 – Power Electronics for Renewable Energy Systems

Context and Aims

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.

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 characteristics of machines driven from appropriate power electronic converters and controllers. The steady-state behaviour of such drives and design of high-performance drives delivering high dynamics will be covered. The dynamic issues of drive representation and control system design for the latter will also be covered in this course.

This course presumes some knowledge of power electronic converter circuits, such as covered in a first course in Power Electronics (ELEC4614 at EET UNSW, for example). The course is complemented with 5 (compulsory) experiments on various types of DC and AC motor drives. It also introduces students to computer modelling of power electronic converters and their control circuits using modern simulation platforms like PSIM or SimPower in Matlab-Simulink.

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 and their interactions,
2. understand how to design the hierarchical control structures for drive systems.
3. understand quadrant operation of various types of drives and their control requirements, selection of converters, components, etc.
4. develop skills in the analyse steady-state performance characteristics of DC, Synchronous and Induction motor drives supplied from appropriate converters.
5. develop skills of selecting and designing important elements of a drive system.
6. understand dynamic representations of DC, Synchronous and Induction motor drives;

7. understand issues, and develop skills, of designing hierarchical torque, speed and position controllers for converter driven motor drive systems.

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.

Lecture Content/Schedule

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 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	**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. Effects of discontinuous conduction on drive.	
Section 3. Brushless DC drives	**2**
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	**5**
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**

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 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).	**3**
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	**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. Filter design issues; 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 on-line this term using video recordings delivered in 2019 and available in Moodle. These will provide you with 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 on-line this term. These will discuss exercises in problem solving and allow time for you to resolve problems in understanding of lecture material. The tutor will be available on Microsoft Team/via email via email for consultations during allocated tutorial hours and for an additional hour after each tutorial.

- Laboratory sessions will consist of 3-hour duration for each of four experiments E1 – E4. These will be held on-line this year. Laboratory demonstrators will be available on Microsoft Team during scheduled laboratory sessions. They will familiarize you with the equipment for the scheduled experiment, and will help you perform step-by-step all procedures included in the lab sheets for each experiment during each experiment. You will receive data for all steps and procedures of the experiment for students to process as indicated in the lab sheets for each experiment, which can be downloaded from Moodle. Each experiment will support the formal lecture material, and provide you with 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, you will submit to you lab demonstrator via Moodle upload your log-book which will include all relevant experimental data, graphs, CRO recordings and your findings from the experiment within 30 minutes from completion of each lab session. 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.

Indicative Lecture Schedule

Weeks	Approximate Lecture Schedule
1	Section 1: Introduction to Electric Drive Systems, representation of loads, drive quadrants, stability in the steady-state)
2	Section 2: DC motor drives – steady-state analysis with PWM converters; steady-state analysis with phase controlled converters
3	Section 3: Brushless DC motor drives; Switched reluctance motor drives
4	Section 4: Synchronous motor drives – steady-state analysis with VSI *V/f* drive; steady-state analysis with CSI *I/f* drive
5	Section 5: Induction motor drives – steady-state analysis with VSI *V/f* drive; steady-state analysis with VSI *I/f* drive
6	**Flexibility week**
7	Section 6: Dynamics of separately excited DC machines; Representation of AC machines in orthogonal reference frames; Dynamic model of synchronous machines; **Mid-term Test: TBA - see course page in Moodle for announcement.**

8	Rotor flux oriented control of synchronous machines; Dynamic model of induction machines;
9	Rotor flux oriented control of induction machines. Section 7: Sensors for drive systems; Controller design for electric drive systems;
10	Section 7: Controller design for electric drive systems continued. Review. **Lab Report + Assignment report due: 5 pm, Friday of Week 10.**

Learning in this course

You are expected to attend all lectures, tutorials, labs, and mid-term tests 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/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 overemphasized, as the effectiveness and usefulness of the tutorial depends largely on this preparation. Group learning is encouraged where possible. Solution of 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 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 hardware experiments, E1 – E4. There are two laboratory sets for each experiment. Maximum of two students can be accommodated for each set. Laboratory will start in week 4. Laboratory sheets are available from Moodle for this course. 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 nature of each experiment and the introduction given for each experiment, you must lab demonstrator in Microsoft Team well in time on 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

Indicative Laboratory Schedule

Period	Summary of Laboratory Program
Week 1	No lab
Week 2	No lab
Week 3	Lab starts - first week of lab
Week 4	Second week of lab
Week 5	Third week of lab
Week 6	
Week 7	Fourth week of lab
Week 8	Fifth week of lab
Week 9	Catch-up lab
Week 10	Lab report due **Friday 5pm**. Late submissions will be penalised @ 10% of the mark allocation for this part for each day of late submission.

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-semester exam.

Laboratory Assessment

You are required to maintain a lab-book (or log book) 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 from stores within UNSW campus. 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 to find more about conducting your experiments.

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 lab-book. This will be verified by your demonstrators during each lab session. You will be recording your observations/readings in your lab-book first and then upload a scanned copy the log book for each experiment to Moodle for the demonstrator to mark. **Upload of late log books by more than 30 minutes will not be acceptable.**

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 on-line 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 test will take place in week 7; the time for the exam will be advised by the lecturer in due course. **Upload of late answer books by more than 30 minutes from the stipulated time will not be acceptable.**

Laboratory Report and 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 of further operational aspects of laboratory experiments that were not considered or observed during lab sessions. These will consist also 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 as email attachment to the course convenor with a cover page clearly stating and your Assignment Topic and Subject for submission and your name and student number on the cover page. **The subject of the email must be "2020 Report/Assignment on E# for ELEC4613"** where # stands for specific experiment allocated for Assignment. **Late submission of Report/Assignment will be penalised 10% of allocated marks/day of late submission.**

Final Exam

The final exam in this course will consist of a 2-hour written examination on-line. 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.* **Upload of late answer books by more than 30 minutes from the stipulated time will not be acceptable.**

Assessment allocations

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 a lab report on the experiment simulated.	10 %
4.	Final examination (2 hours)	50 %
	Total	**100 %**

Relationship of Assessment Methods to Learning Outcomes

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 Prof. F. Rahman. Lecture notes in PDF format are available via Moodle for ELEC4613 - 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* by Ion Boldea and S. A. Nasar, CRC Press, 3rd edition, 2017.

On-line resources

All 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 **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 (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	✓