

Fundamentals of Electric Drive Systems

EEL 4930 Section 0009

Class Periods: Tuesday Period 4 (10:40 AM – 11:30 AM)

Thursday Period 4-5 (10:40 AM-12:35 PM)

Location: BLK 0415

Academic Term: Spring 2023

Instructor:

Name: Prof. Baoyun Ge (he/him/his)

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Office Phone Number: (352)294-3926

Office Hours: Office Hour 1: Online, See Canvas for the Link Monday, 4 pm to 5 pm

Office Hour 2: Larson Hall 221 Tuesday, 4 pm to 5 pm

Teaching Assistant/Peer Mentor/Supervised Teaching Student:

NA

Course Description

Electric drive systems (EDS) are used extensively in a wide range of applications, including electric vehicles, drones, electric aircraft, robots, wind generators, satellites, spacecraft, etc. This course will introduce the fundamentals of electric drive systems, with a special focus on the steady-state analysis of permanent magnet AC drives, which are used extensively in these applications. Three speakers respectively from Tesla, C-Motive Technologies, and Ford are invited to give students some taste of forefront development on these topics.

Course Pre-Requisites / Co-Requisites

1. EEL 3211C – Basic Electric Energy Engineering
2. EEL 3135 – Introduction to Signals and Systems

Course Objectives

The main objective of this course is to expose students to the three pillars of electric drive systems:

1. Electric machines (EM): we will start with reviewing the operating principles of DC machines and then switch to permanent magnet AC machines with the introduction of AC windings, traveling waves, and brushless concepts. Steady-state analysis, magnetic circuit analysis, and finite element analysis will be covered.
2. Power electronics (PE): we will base our discussion on the classic two-level three-phase voltage source inverter. The concepts of pulse width modulation (PWM) and modulation depth will be taught to understand its steady-state characteristics. In addition, limitations due to parasitic and thermal will be introduced.
3. Feedback control (FC): we will model electric machines and inverters on the dq -axis and build high-performance feedback control for them. A physics-based approach will be used to show how to build torque and speed regulators step by step. The concept of the estimator/observer will be introduced as well.

Three speakers, Drs Y. Li, P. Killeen, and Y. Xu, respectively from Tesla, C-Motive Technologies, and Ford Motor are invited to give students some taste of forefront development on these topics.

It is expected that students will gain knowledge on how to perform steady-state analysis on electric drive systems and get familiar with CAD tools like Matlab/Simulink, COMSOL, LTSpice, and PLECS to virtual prototype sub-components of electric drive systems and evaluate their performance.

Materials and Supply Fees

NA

Relation to Program Outcomes (ABET):

The table below is an example. Please consult with your department's ABET coordinator when filling this out.

| Outcome | Coverage* |
|---------|-----------|
|---------|-----------|

| | |
|---|------|
| 1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics | High |
| 2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors | |
| 3. An ability to communicate effectively with a range of audiences | |
| 4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts | |
| 5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives | |
| 6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions | High |
| 7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies | |

*Coverage is given as high, medium, or low. An empty box indicates that this outcome is not covered or assessed in the course.

Required Textbooks and Software

No required textbook.

Software: see Canvas

Recommended Materials

If students would like to explore advanced topics on electric drive systems, we refer to:

- Introduction to Electric Machines and Drives, 1st Edition ([Amazon Link](#))
Authors: D. W. Novotny, T. A. Lipo, T. M. Jahns
Publisher: University of Wisconsin
- Electric Machinery, 6th Edition ([Amazon Link](#))
Authors: A. E. Fitzgerald, Charles Kingsley, Jr., Stephen D. Umans
Publisher: McGraw-Hill Science/Engineering
- Vector Control and Dynamics of AC Drives, 1st Edition ([Amazon Link](#))
Authors: D. W. Novotny, T. A. Lipo
Publisher: Clarendon Press

Course Schedule

| Week | Date | Lecturer | Area | Topic | Demo | HW/Exam |
|------|--------------|----------|------|--|-------------------------|---------|
| 01 | 1/10 1/12 | Ge | EM | Pre-Requisites, EDS Intro, Applications, Three Speakers, Team Project, Software, Electromagnetic Energy Conversion | Homopolar Machine | Quiz 1 |
| 02 | 1/17 1/19 | Ge | EM | Copper, Iron, PMs, DC Machines, Inside Out, Traveling Wave | Tesla's Egg of Columbus | HW 1 |
| 03 | 1/24 1/26 | Ge | EM | PM Machines, AC Windings, Steady-State Equivalent Circuit Analysis, <i>abc</i> -Axis Modeling | PLECS | Quiz 2 |

| | | | | | | |
|--------------------------|--------------|----------------|----|---|------------|------------|
| 04 | 1/31 2/2 | Ge | EM | Field Analysis, Finite Element Analysis of PM Machines, Torque and Shear Stress | COMSOL | HW 2 |
| 05 | 2/7 2/9 | Ge, Li | EM | Seminar, Summary, and Exam 1 | | Exam 1 |
| 06 | 2/14 2/16 | Ge | PE | Switch Mode Power Supply, DC-DC Converter, DC-AC Converter | LTSpice | Quiz 3 |
| 07 | 2/21 2/23 | Ge | PE | 2-Level Three Phase Inverter, Pulse Width Modulation, Sinusoidal Pulse Width Modulation | PLECS | HW 3 |
| 08 | 2/28 3/2 | Ge | FC | $\alpha\beta$ -Axis Modeling: Why and How, Space Vector Pulse Width Modulation | PLECS | Quiz 4 |
| 09 | 3/7 3/9 | Ge | PE | Modulation Depth, Power Electronics Circuit Parasitic, Thermal Limitation | LTSpice | HW 4 |
| Spring Break, No Lecture | | | | | | |
| 10 | 3/21 3/23 | Ge, Killeen | PE | Seminar, Summary, Exam 2 | | Exam 2 |
| 11 | 3/28 3/30 | Ge | FC | Control of DC Machines, Control of AC Machines, dq -Axis Theory, Clarke and Park Transformation | PLECS | Quiz 5 |
| 12 | 4/4 4/6 | Ge | FC | dq -Axis Theory, Torque and Flux, Dynamic Equivalent Circuit and Control Block Diagram | PLECS | HW 5 |
| 13 | 4/11 4/13 | Ge | FC | Torque/Current, Speed Regulators | PLECS | Quiz 6 |
| 14 | 4/18 4/20 | Ge, Xu | FC | Position Sensor, Estimator/Observer Techniques, Seminar | PLECS, HIL | HW 6 |
| 15 | 4/25 | Ge | FC | Summary of Feedback Control and the Course | | |
| 16 | 5/4 | Ge | | | | Final Exam |

Attendance Policy, Class Expectations, and Make-Up Policy

Requirements for class attendance and make-up exams, assignments, and other work in this course are consistent with university policies. Click here to read the university attendance policies:

<https://catalog.ufl.edu/UGRD/academic-regulations/attendance-policies/>

Evaluation of Grades

| Assignment | Total Points | Percentage of Final Grade |
|-------------------|---------------------|----------------------------------|
| Homework Sets (6) | 100 each | 30% |
| Quizzes (6) | 100 each | 10% |
| Midterm Exam (2) | 100 each | 40% |
| Final Exam | 100 | 20% |
| | | 100% |

Homework and exam problems are designed to test students' ability to apply equivalent circuit and magnetic circuit models, conduct dq -axis analysis, and formulate closed-loop motion control. There are homework problems involving the usage of CAD tools to virtually prototype electric drive systems, evaluate performance, and determine the effectiveness of the design.

This course is co-listed with the undergraduate course EEL 5934, for which these assignments will be graded differently.

The graduate section also includes a team project assignment. The graduate and undergraduate sections will be graded separately. The graduate section will have different weights for the exams.

Grading Policy

The following is given as an example only.

| Percent | Grade | Grade Points |
|----------------|--------------|---------------------|
| 93.4 - 100 | A | 4.00 |
| 90.0 - 93.3 | A- | 3.67 |
| 86.7 - 89.9 | B+ | 3.33 |
| 83.4 - 86.6 | B | 3.00 |
| 80.0 - 83.3 | B- | 2.67 |
| 76.7 - 79.9 | C+ | 2.33 |
| 73.4 - 76.6 | C | 2.00 |
| 70.0 - 73.3 | C- | 1.67 |
| 66.7 - 69.9 | D+ | 1.33 |
| 63.4 - 66.6 | D | 1.00 |
| 60.0 - 63.3 | D- | 0.67 |
| 0 - 59.9 | E | 0.00 |

More information on UF grading policy may be found at:

<https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx>

Students Requiring Accommodations

Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting <https://disability.ufl.edu/students/get-started/>. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

Course Evaluation

Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at <https://gatorevals.ua.ufl.edu/students/>. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via <https://ufl.bluera.com/ufl/>. Summaries of course evaluation results are available to students at <https://gatorevals.ua.ufl.edu/public-results/>.

In-Class Recording

Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A “class lecture” is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To “publish” means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform,

including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

University Honesty Policy

UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (<https://sccr.dso.ufl.edu/process/student-conduct-code/>) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment

The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:

- Your academic advisor or Graduate Program Coordinator
- Jennifer Nappo, Director of Human Resources, 352-392-0904, jpennacc@ufl.edu
- Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
- Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use

All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Student Privacy

There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: <https://registrar.ufl.edu/ferpa.html>

Campus Resources:

Health and Wellness

U Matter, We Care:

Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

Counseling and Wellness Center: <https://counseling.ufl.edu>, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Sexual Discrimination, Harassment, Assault, or Violence

If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

Sexual Assault Recovery Services (SARS)

Student Health Care Center, 392-1161.

University Police Department at 392-1111 (or 9-1-1 for emergencies), or <http://www.police.ufl.edu/>.

Academic Resources

E-learning technical support, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu.
<https://lss.at.ufl.edu/help.shtml>.

Career Connections Center, Reitz Union, 392-1601. Career assistance and counseling; <https://career.ufl.edu>.

Library Support, <http://cms.uflib.ufl.edu/ask>. Various ways to receive assistance with respect to using the libraries or finding resources.

Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring.
<https://teachingcenter.ufl.edu/>.

Writing Studio, 302 Tigert Hall, 846-1138. Help brainstorming, formatting, and writing papers.
<https://writing.ufl.edu/writing-studio/>.

Student Complaints Campus: <https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/>; <https://care.dso.ufl.edu>.

On-Line Students Complaints: <https://distance.ufl.edu/state-authorization-status/#student-complaint>.