MECHENG 565
Battery Systems and Control
3 Credits

Instructors: Professor Anna Stefanopoulou (annastef@umich.edu)
Lead Graduate Student Instructor: TBD
Graduate Student Instructor: TBD
Grader: TBD

Course statement: This course covers battery modeling, control and diagnostic methodologies associated with battery electric and battery hybrid electric vehicles. Emphasis is placed upon system-level modeling, model order reduction from micro-scale to macro-scale and surrogate models for load control, estimation, on-board identification and diagnostics for Lithium Ion batteries. The electrochemical, electrical, and transport principles for battery modeling are reviewed. Spatiotemporal models of coupled concentration, potential, and thermal phenomena are introduced. Simulation of the resulting partial differential equations using software tools will be introduced with selected topics on numerical issues. Model order reduction techniques, parameter estimation, filtering, and control theory will be covered and applied to state of charge estimation. Additionally, electric-circuit battery models, DC/DC converters, and other vehicle implementation issues of power management and balancing will be introduced.

The course does **not** require extensive background in battery chemistry and materials, but does require a basic background (undergraduate level) in signals and systems or controls (Laplace transforms, time/frequency analysis and control design tools).

Mathworks Matlab/Simulink will be used in course instruction and projects. We do not have copies to give away, but students who registered can access"virtual site" to use the software. (http://virtualsites.umich.edu). You can also buy the Matlab/Simulink student version.

Home Page: when enrolled use Ctools (https://ctools.umich.edu/portal)
Will contain links to basic course information and lecture material.

Email list: The ctools emailing capability will be used to send you announcements. You must first come to office hours to be able to e-mail us with questions. **Always use MEx99batW11 in your message subject and indicate which office hours you attended and to whom you already talked**. Ideally send your e-mail only to the instructor that taught the relevant material, but you can cc all of them if in doubt.
First describe the problem you are facing in the text of your e-mail. This will help us when we travel and cannot open attachments. You could **attach a pdf with your question including necessary figures, m-file, sml-file, and resulting graphs in one PDF. If we need more info, we will e-mail and ask you to send us your working m or sml file.
***We typically try to respond **within a day**, but our ability to help declines as e-mail volume increases; so please be considerate and concise. Also do NOT wait till the last day. We **will not help outside the office hours during the due-day** of the HW

Textbook: There will be no textbook. Lecture notes and handouts will be distributed in class or through Ctools.

Honor Code: No discussion or collaboration is allowed for the quizzes. You may discuss the homework assignments with each other and with the instructor, but you **must write your own m-files, code, create your own figures, and provide answers** which reflect your own understanding of the material. No copying and pasting of any kind. If in doubt please ask one of the instructors.

Grading: Homework (34%), examA 33%, examB 33%
Graduate students will be typically given extra assignments in homeworks and examinations
Two separate grade curves will be applied for the 499 and the 599 registration.

Homework: Approximately one per week.

Office Hours (on-line students have priority the first 30 min):
Anna, TBD, GSI, TBD, Instructor OH (whoever teaches that day): 30 min after class

MATH and Dynamics notions we will be using a lot in the class:
1. Ordinary Differential equations
2. Linearization
3. Laplace Transforms
4. Transfer functions (poles, zeros, DC gain)
5. Time responses, overshoot, undershoot, settling time, damping ratio, time constant, rise time
6. Stability, characteristic equation, eigenvalues
7. Frequency Domain Representation of systems and signals:
bandwidth, roll-off rate, DCgain, natural, damped frequencies ...
8 States, state-space representation
9. Basics of PID controllers, Root locus ...
Items 1.-6. are a must! You can probably study items 7.-9. and catch up while taking this class.

Syllabus:

Chapter 1: Introduction
Battery Electric and Hybrid Vehicles (BEV and BEHV)
Overview Chemistries and Aging mechanisms

Voltage, Power, and the Electrical point of view
Basic circuit analysis
Sensors, actuators, and experimental test protocols
Background on least-squares
Equivalent Electric Circuit

Chapter 2: Physics-based Models
Butlet-Volmer kinetics
Linear and spherical diffusion of concentrated solutions
Potential
Numerical Approximation
- Forward & backward Euler
- Crank-Nicolson

Model Order Reduction
- Electrode-Averaged Model
- Linearization
- Padé approximations
- Projections

Chapter 3: Battery Controls
State of Charge Estimation
- Coulomb Counting (Input Observer)
- Observability
- Estimation and Voltage Error Convergence
- Kalman Filters and Measurement Noise

State of Health Estimation

Chapter 4: Stack Management
Thermal Dynamics
Thermal Management
Cell Balancing
- Passive Circuits
- Active Balancing

Chapter 5: Vehicle Power Level
Electric Architectures & DC/DC Converters
Fuel Consumption Minimization
Power management (PHEV)