<u>ME 5xx: Modeling and Control of Batteries</u>

Instructors: Hosam Fathy and Anna Stefanopoulou

Course statement: This course covers battery modeling, control and diagnostic methodologies associated to 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 and then augmented to predict aging and capacity fade. Simulation of the resulting partial differential equations using various popular software tools will be introduced with selected topics on numerical issues. Time- and frequency-domain model order reduction techniques, system identification, parameter estimation, filtering, and control theory will be covered and applied to state of charge, state of health, load governors and rate limiters.

Additionally, electric-circuit battery models, DC/DC converters, and other vehicle implementation issues of power management and balancing will be introduced.

Lectures will be supplemented with laboratory demonstrations and invited presentations conducted by local automotive OEMs, and site visits to battery testing facilities.

Does **not** require extensive background in battery chemistry and materials.
Requires a basic background (undergraduate level) in signals and systems or controls (Laplace and Z-transforms, Stability, time and frequency domain analysis and control design tools).
Mathworks, Dymola, and Comsol simulation software will be used.

Open to graduate or senior students with a basic background in mechanical, chemical, or electrical engineering. Permission from the instructor is required for senior undergraduate students.

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

Email list: The ctools emailing capability will be used to send you announcements. You can always email me with questions. Attach your working m- or mdl- files if needed. Always use ME5xx in the message subject.

Text: A coursepack will be available. Lecture notes and handouts will be distributed in class or through Ctools.

Homework: The lowest homework score will be dropped. You may discuss the homework assignments with each other and with the instructor, but you **<u>must write your own solutions</u>** to the homework which reflect your own understanding of the material.

Grading: TBD (a combination of homework, midterm examinations and a project report)

Office Hours: TBD (in campus) TBD (off-campus)

<u>Course Outline:</u>

Chapter 1: Overview: Battery Electric and Hybrid Vehicles (BEV and BEHV)

Benefits and barriers of a transition to battery electric vehicles
Basic architecture of a battery vehicle (energy, efficiency, and the electrical point of view)

Chapter 2: Battery Technology

Types of batteries & their applications
Chemistry (Principles), Physics (Basic Thermodynamics)
DOE Performance and cost Target, Current technology status

Chapter 2: Lithium Ion Battery

Materials, Structure, Operation
Concentration, Potential, Butler-Volmer Equations
Thermal and Aging Models
Impedance Models and Diagnostics

Chapter 3: Simulation

Partial differential equations (PDE)
Discretization and numerical approximations
Causal (forward) and control-oriented simulations
DOE simulation tools

Chapter 4: Modeling

Preliminaries: state-space, linearization, measures
Model order reduction techniques (from micro to macro)
Minimal Realizations (input/output considerations)
Parameterization, Least squares
Circuit Equivalent models
System Identification (off-line and on-line)

Chapter 5: Estimation and Control

Observer design (pole placement, optimal, nonlinear)
State of Charge estimation
Control Design for charging and Dis-charging (pole placement, optimal, separation principle)
Load governors (over-charging, rate limiters, safeties, saturations)
Model predictive control
State of Health estimation
Parameter adaptation for aging

Chapter 6: Electric, Power electronics, and Vehicle Level

Power management (Voltage regulation, Current Split)
Regenerative braking
Electric Hybrid (supercaps, auxiliary batteries)
Boosting Downsized Internal Combustion Engines
Load-Leveling for Fuel Cell Vehicles
Thermal loads and cooling requirements
Cooling loops, sizing and design issues
Stack cooling