Electrochemical Energy Storage Systems (6 Credits)

Course Description:
This course is designed for engineering students who would like to receive a comprehensive exposure to the field of electrochemical energy storage systems for automotive applications. The course focuses on Lithium ion technology, covering cell materials and fundamental properties, testing procedures for performance characterization, modeling and simulation, pack design, system integration, control, diagnostics and safety.
Background in thermodynamics, heat/mass transfer and system dynamics is necessary for this course, however no prior knowledge of electrochemistry for batteries is expected. All assignments will make use of Matlab/ Simulink, hence proficiency with this software is a must.

Course Objectives:
Upon completion of this course, participants will possess practical knowledge of:

- The operating principles and characteristics of Lithium-ion batteries, including the effects of electrode/electrolyte materials on performance and durability;
- The experimental methods for characterizing performance and life of Li-ion cells, in support of modeling, design and prototype verification;
- Modeling and simulation tools to solve system-level design and optimization problems for battery packs for EVs and HEVs;
- State of the art in battery pack design for automotive applications and methods for system integration and control (Battery Management Systems, charging and balancing strategies, SOC/SOH estimation).

Instructor:

Marcello Canova
Associate Professor, Department of Mechanical and Aerospace Engineering
Associate Director, Center for Automotive Research
The Ohio State University

Visiting Professor, Department of Industrial Engineering
Universita' di Parma

Email: canova.1@osu.edu
Cell: +1 614-607-0629 (SMS, Skype, Messenger, WhatsApp, please – no calls)

Course Web Site:
A course website will be created.

Lectures:
The course program is designed to be developed in 8 weeks, 6 hours per week, starting April 17, 2018.
Tuesday: 16:30 – 18:30
Wednesday: 8:30 – 10:30 and

Texts and References:

- No textbook available covering all subjects of this course;
- Lecture notes will be available online, as well as homework assignments and computer software;
- Reference books, technical papers and other documents will be suggested during each lecture and posted online.

Grading Policy:
4 Homework assignments.

Homework assignments are the only evaluation method for this course. There will be no final exam. Each assignment consists of one or more problems. All assignments will require the use of Matlab™ and Simulink™. For some of the assignment, simulators developed in Matlab/Simulink™ will be provided.

Late submission of HWs is not permitted, except for documented medical or family emergencies.

Guidelines for Homework Preparation:

- Homework will be assigned and submitted via web (no paper or email submissions will be accepted);
- Each assignment requires writing a report that summarizes the analytical work and result. Students will be graded on the format of the report as well;
- Reports will be written electronically (.doc, .pdf); handwritten parts or screenshots (e.g., Simulink block diagrams, Simulink scope windows) will *NOT* be graded. Use the appropriate commands in Matlab to generate high-quality figures.
- The models and functions built for each homework shall be turned in with the report (compress all files into a single folder).

Course Schedule:

Week 1	Apr 17 (Tu)	Lecture 1	Course introduction. Introduction to energy storage systems for automotive applications, notation and common terminology.
	Apr 18 (We)	Lecture 2	Overview of energy storage technologies for automotive applications. Introduction to Lithium ion technology: basic operating principles, properties of electrode materials, state of the art.
		Lecture 3	Overview of Lithium ion battery technology (continued): advanced cathode, electrolyte and anode materials for next-generation batteries.
Week 2	Apr 24 (Tu)	Lecture 4	Elements of applied electrochemistry, thermodynamics of electrochemical cells, open-circuit potential. Chemical kinetics, Arrhenius law, Butler-Volmer equation, Nernst-Planck equation.
	Apr 25 (We)	No Class (Holiday)	
Week 3	May 01 (Tu)	No Class (Holiday)	
	May 02 (We)	Lecture 5	Elements of mass transport: Fick's law and mass transfer in solid and liquid phase; energy balance for electrochemical systems and heat diffusion equation.
		Lecture 6	Methods for materials characterization; potentiostatic and galvanostatic methods, EIS. Overview of imaging methods (SEM, TEM, XRD, NDP).
Week 4	May 08 (Tu)	Lecture 7	Experimental methods and equipment for cell-level and pack-level characterization, USABC protocols for performance and life testing.
	May 09 (We)	Lecture 8	Modeling li-ion cells, classification. Heuristic methods, Equivalent Circuit Model for Li-ion batteries, parameter identification, examples.
		Lecture 9	Physics-based electrochemical models: Porous Electrode Theory (DFN Model), Single Particle Model, Extended Single Particle Model.
Week 5	May 15 (Tu)	Lecture 10	Energy balance, effects of temperature on model parameters. Modeling charge and temperature distribution in large-format cells.
	May 16 (We)	Lecture 11	Approximation methods for fast computation of electrochemical models. Extension of cell models to modules and packs.
		Lecture 12	Introduction to energy storage systems: key components and system integration principles for modules and packs. Examples.
Week 6	May 22 (Tu)	Lecture 13	State of Charge (SOC) estimation in Lithium ion batteries, heuristic methods and their limitations.
	May 23 (We)	Lecture 14	Introduction to state observers, examples.
		Lecture 15	Overview of model-based estimation methods (continued), Kalman Filters, Extended Kalman Filter (EKF). Application to SOC estimation.
Week 7	May 29 (Tu)	Lecture 16	Introduction to battery aging and life prediction, definition of State of Health (SOH). Procedures and test methods for cell aging and residual life assessment.
	May 30 (We)	Lecture 17	Processes at material level leading to cell degradation. Introduction to first-principle models: SEI layer growth theory and application to life estimation.
		Lecture 18	Introduction to charging standards and charging technologies. Principles of safety for high-voltage systems.
Week 8	Jun 5 (Tu)	Lecture 19	Overview of Battery Management Systems (BMS), hardware and software configurations. Methods for pack balancing.
	Jun 6 (We)	Lecture 20	Overview of Thermal Management Systems (TMS), active vs. passive solutions. Introduction to course project.
		Lecture 21	Guest Lecture, course conclusion

Assignments Schedule:

Homework 1 (Basic Definitions; Analysis of Literature and State of the Art)
Assigned during Lecture 2 (April 18)
Due on Lecture 4 (April 24)

Homework 2 (Review of Electrochemistry and Transport Phenomena)
Assigned during Lecture 4 (April 24)
Due on Lecture 8 (May 9)

Homework 3 (Lithium ion Cell Modeling)
Assigned during Lecture 8 (May 9)
Due on Lecture 14 (May 23)

Homework 4 (SOC Estimation, Charging and Balancing)
Assigned during Lecture 14 (May 23)
Due on Lecture 20 (June 6)