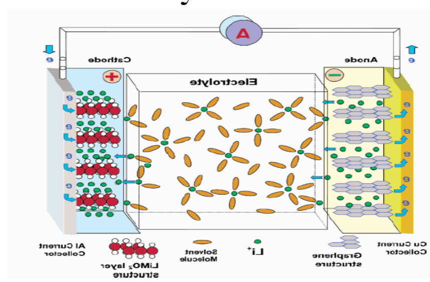
Stanford | SCHOOL OF EARTH, ENERGY & ENVIRONMENTAL SCIENCES

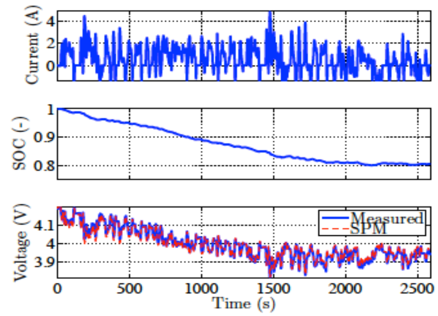
Electrochemical Energy Storage Systems: Modeling and Estimation

Spring 2018 ENERGY 294

Syllabus

Courtesy of ORNL





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Course Description:

Electrochemical energy storage (EES) systems are a critical and emergent need in the growth of sustainable transportation. Improvement in vehicle fuel efficiency and emission controls are possible if transportation migrates from fossil-based energy to other alternatives such as, electrochemical energy storage systems. Enhancing EES systems is paramount to enable the widespread use of electrified vehicles.

The course focuses on modeling and estimation methods as necessary tools to extract the full potential from EES systems used in electrified vehicles, with focus on Lithium-ion batteries. The complex nature of a battery system requires that a physics-based approach, in the form of electrochemical models, be used as a modeling platform to develop system-level control algorithms to allow designer to maximize battery performance and longevity while guaranteeing safety operation.

Course Objectives:

The goals of this course are to provide students with i) modeling and simulation tools to solve system-level design and estimation problems involving Li-ion batteries and ii) competence and methods to approach practical problems related to the monitor, integration and management of batteries covering also experimental methods for testing and characterization.

In particular, in this course we will cover 1) Electrochemical energy storage systems technologies 2) first-principles methods based on electrochemistry to model battery dynamics, 2) electrochemical and control-oriented models, 3) parameter identification problems, 4) estimation algorithms for real-time application. A formal exposure to state space analysis and estimation of dynamical systems will be given.

Tentative Course organization:

Module 1. Introduction

- Energy Storage Applications and Electrified Vehicles
- Battery Technologies
    - Lead-acid Batteries
    - Nickel-Metal Hydride Batteries
    - Lithium Batteries
    - Electrochemical Double Layer Capacitor

Module 2. Background and Practical Cell Measures

- Cell Voltage under load
- Charge and Discharge Rates
- Capacity, Impedance, Energy and Power, Efficiency and Ragone Plot
- Capacity and Pulse Power Testing
- Electrochemical Impedance Spectroscopy Testing

Module 3. Lithium-ion Battery technology and Electrochemistry

- Battery Materials
- Electrochemical Cell and Governing Equations
    - Electrode Kinetics
    - Thermodynamics
    - Solid Phase and Electrolyte Phase
    - Practical cell measurement – Cell Voltage, Capacity Energy and Power
    - Cell Format and Design

Module 4. Lithium-ion Battery Modeling

- Control-oriented models based on Equivalent Circuit methods (ECM)
- Single Particle Models (SPM)
- Sensitivity Study
- Optimization methods for identification

Module 5. State-space system representation and estimation of dynamical systems

- Open Loop versus Closed Loop Observer
- Observer design based on Kalman Filters
- Extended Kalman Filters

Module 6. Lithium-ion Battery Estimation

- Coulomb counting method
- Voltage lookup method
- State-space based estimation using ECM and SPM using Kalman Filters –Extended Kalman Filters

Tentative Schedule and Grading

Approximately five graded homework assignments/projects; Unequal weighting (based on individual requirements) as shown in the table below. 100% total.

Topics	Evaluation/Grading	Est. Weeks
Module 1	HW/10%	1
Module 2	HW/15%	1.5
Module 3	HW/15%	1.5
Module 4	Project/25%	3
Module 5	HW/10%	1
Module 6	Project/25%	2

Prerequisites:

Either knowledge or interest in electrochemistry, modeling, simulation, estimation, and control are expected. Prior working knowledge of Matlab/Simulink™ tools is assumed.

Units: 3

Textbooks:

Course notes are developed specifically for this course and will be distributed throughout the quarter via Canvas along with supplemental material. Nevertheless, the following textbooks are recommended for additional background:

- H. J. Bergveld, W. S. Kruijt, and P. H. Notten, "Battery Management Systems: Design by Modelling," Kluwer Academic Publisher, 2002
- C. Rahn, C.Y. Wang, Battery systems engineering, John Wiley & Sons, 2013
- G. L. Plett Battery Management Systems: Battery Modeling (Vol 1), Artech House ISBN-13: 978-1630810238, 2015

Attendance:

Attendance is your responsibility. Class lectures will cover a significant amount of material. It is to your advantage to take notes, ask questions, and fully participate in the classroom experience.

Honor code:

- Follow the honor code.
- Homework must be completed independently whereas for project assignments you are free and encouraged to discuss with other members of the course. Every assignment you submit (both HW and projects) must be your individual work, even if experimental data are shared.
- Offering and accepting solutions from others is an act of plagiarism and all involved parties will be reported to the Judicial Affairs Office.