Energy Storage Systems for Electric-based Transportations

Course Syllabus and Information

College of Engineering
Department of Electrical and Computer Engineering
Course No. ECE-5995 Selected topics
Winter 2016
M-W: 5:30PM – 7:20PM
0256- MANO Building

Instructor: Professor G. Nazri
Course Objectives

The objective of this course is to learn fundamentals of energy storage systems for electric-based transportation. This course provides basic knowledge in the multidisciplinary field of energy storage devices and their applications in land, space, and marine vehicles.

The focus of the course will be on advanced batteries, supercapacitors, and fuel cells for transpiration applications. Battery sizing and integration on various land-marine-space vehicles will be explored. Hybridization of various energy storage systems such as battery–supercapacitors, Battery–fuel cell, and battery–supercapacitor–fuel cell for different applications also will be discussed in this course.

This course provides the engineering background that is required to work in the field of electric-based transportation. The fundamentals of battery management systems including various methodologies in electrical control and thermal management modes will be discussed. The future prospects of advanced electrification for space and marine vehicles also will be given.

The other objective of this course is to provide project opportunities for students to work in a team and explore technical details of vehicle electrification.
Course Outcomes:

- Learn fundamentals of advanced batteries, supercapacitors and fuel cells for electrification of land-marine, and space vehicles.

- Learn battery sizing and optimization for electrification vehicles.

- Learn hybridization of various energy conversion devices for vehicle electrification.

- Understand battery management systems and state-of-charge estimation.

- Understand fundamentals of active and passive thermal management systems.

- Learn safety aspects of high voltage devices, particularly for hybrid and full electric vehicles.

- Learn various battery testing procedures and verification of battery performances.

- Learn battery packaging from cells to modules and packs.

- Learn codes and standards for electrification of vehicles.

- Learn battery safety, and global market analysis for large format batteries.
Course Syllabus

Introduction of Energy Storage Systems and Vehicle Dynamics

- General background on alternative energy sources and sustainability
- Introduction to electric-based transportation
- Overview of Land-Marine-Space vehicle electrification
- Description of vehicle dynamics and dynamic equations
- Vehicle performance, and fuel economy characteristics
- Basic concept of regenerative braking energy

Electric Vehicles

- Electric vehicles configuration
- Energy and power requirements for various HEVs and EVs
- Vehicle performance and driving cycles

Hybrid Electric Vehicles

- Fundamentals of hybrid electric vehicles
- Series hybrid electric vehicles
- Parallel hybrid electric vehicles
- Start – stop hybrids, Mild hybrids, strong and full hybrids,
- Extended range hybrid vehicles, and full electric vehicles (BEV)
Energy Storage Systems

Batteries

Advanced Lithium Batteries

Li-ion batteries (main focus)
- Principle of operation
- Battery components and design
- Electrode, cell and battery fabrications
- Building block cells, battery modules and packs

Li-polymer batteries and applications
All solid state batteries and future developments
Li-S battery, future battery
Li-Air battery, frontier battery

Beyond lithium batteries

Sodium-battery
Magnesium battery
Aluminum battery
Silicon battery

Nickel Metal Hydride Battery

Advance Ni-MH batteries for transportation
Future prospects of Ni-MH batteries vs. lithium ion batteries
Energy Storage Systems (cont.)

Batteries (cont.)

Lead-acid battery

- Advance lead-acid batteries
- Horizontal plate Pb-Acid batteries for transportation
- Cylindrical Pb-Acid battery vs. flat plate system

High temperature batteries for back-up applications

- Zebra cell
- Li-iron sulfide cells
- Li-S cells

Flow batteries for load leveling and large scale grid application

- Vanadium and iron based batteries
- Semi-fluid flow batteries

Ni-Hydrogen batteries for space and marine applications

- Ni-H₂ cells for space applications
Energy Storage Systems (cont.)

Supercapacitors

Double layer and Supercapacitors for transportation applications
Aqueous and organic based supercapacitors
Pseudo and asymmetric supercapacitors

Battery - Supercapacitor hybridization for large vehicles, locomotives and space
Advance battery-supercap hybrids for auto, space and marine applications

Battery – Fuel Cell hybridization for transportation applications
Lithium battery – PEM fuel cell hybrid

Battery – Solar Cell (Photovoltaic) hybridization
Lithium-ion battery as energy storage back-up for solar energy

Battery – Wind Turbine hybridization
Lithium-ion battery as energy storage back-up for wind energy farms


**Fuel Cells and Hydrogen Storage**

*Advance fuel cells*

- Introduction to fuel cells
- PEM and alkaline fuel cells for transportation
- Solid oxide fuel cells

*Hydrogen storage systems*

- Solid state hydrogen storage tanks
- Gas phase hydrogen storage tanks
- Cryogenic hydrogen storage tanks
- Liquid phase hydrogen storage tanks

*Fuel reformers*

- Advanced fuel reformers

**Battery Recycling Technologies**

- Technology and economic aspects of battery recycling

**Battery Applications for Stationary and Secondary Use**
Battery Chargers and Battery Testing Procedures
- Constant current and constant voltage methods
- Hybrid methods
- Inductive chargers
- Battery power testing for various vehicles
- Battery testing for urban and highway driving cycles

Battery Management Systems (BMS)
- Fundamentals of battery management systems and controls

Battery Thermal Management
- Passive cooling – PCM systems
- Active cooling – Liquids & air systems

Regulations and Safety Aspects of High Voltage Batteries
- Code and Standards
- Safe handling of Lithium Batteries
- Safety of high voltage devices
TERM PROJECTS and REPORTS

- Form a team of 1-2 student members

- Select a system (i.e. vehicle) for electrification
  
  You can select an existing vehicle in the market, or design your own
  You can select any Land, Space or Marine Vehicles
  You can also select a device for electrification including:
    - Power tools
    - Computers
    - Back-up for Solar cells
    - Back-up for wind farm
    - Back-up for emergency (buildings- hospital – industry)
  You can also select battery management systems including;
    - Battery control system
    - Battery thermal management system

- Select battery for your project
  - Lithium battery
  - Ni-MH battery
  - Lead-Acid battery
  - Other batteries
Prepare engineering design and battery sizing for your energy storage

1. Energy storage pack (i.e. battery pack) for your project that may include, construction details (i.e. series – parallel combination of cells), simulation-modeling of battery performance
2. Integration of battery into a vehicle (or device), include power electronics, battery management system, battery thermal management (if required)

The Other Projects to select:

1. Battery Management System, including, Control and power electronics
2. Battery Thermal Management, including, Materials, Simulation & Modeling for passive or active cooling.
3. Battery Economics and Battery Market

Form your project team and select your project by the deadline (Feb 13, 2016)

The project title and project team must be confirmed by the course instructor.
A Collaborative Effort (Homework) Linked to Team Project
This is a Homework in Progress

Your project should include the following:

- Overall objectives of your engineering project.
  
  fuel economy, lowering cost, increasing range, improving performance, etc.

- Estimate requirements of energy storage systems for your project.
  
  discharge power (kW), energy (kWh), weight (kg), and volume (liter)

- Estimate gravimetric and volumetric energy & power density for your application.

- Select promising energy storage system to meet your system (vehicle) requirements.
  (Battery: Lithium battery, nickel metal hydride battery lead-acid battery, or supercapacitor)

- Describe challenges and future opportunities in your proposed project
Collaborative Effort: Team Project
Homework in Progress

- Give performance requirements of your battery pack to meet the requirement of the selected system (i.e., vehicle) in your project
- Provide voltage and current constrains for your battery pack by including constrains of the electric motor and power electronics
- What type of battery chemistry can meet the required energy, power, weight, volume requirements, (try to consider cost and safety as well).
- Design cell, battery module and pack for your application
- Include power electronic and control for your battery pack (brief description)
- Provide engineering drawing of your battery pack design close to actual dimension.
- Provide cost estimate including bill of materials (BoM) for your battery pack
- Provide final project report in IEEE format (15-20 pages) by April 11, 2016.
# Course Grading

<table>
<thead>
<tr>
<th>Grades Factor</th>
<th>Percentage</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Project report</td>
<td>20%</td>
<td>April 11, 2016</td>
</tr>
<tr>
<td>Mid-term exam-1</td>
<td>20%</td>
<td>Feb. 8, 2016</td>
</tr>
<tr>
<td>Mid-term exam 2</td>
<td>20%</td>
<td>March 2, 2016</td>
</tr>
<tr>
<td>Quizzes / Home-works</td>
<td>10%</td>
<td>TBD in class</td>
</tr>
<tr>
<td>Final Exam</td>
<td>30%</td>
<td>April 27, 2016</td>
</tr>
</tbody>
</table>
TEXTBOOK: The course materials will be mostly based on my own lecture notes and Recent review materials that will be provided to our registered students.

The following text is a useful complement for this course

Modern Electric, Hybrid Electric and Fuel Cell Vehicles,
M. Ehsani, Y. Gao, S. Gay, A. Emadi
CRC Press, NY, 2005, not required

USEFUL REFERENCES:

• James Larminie and John Lowry, “Electric Vehicle Technology Explained,”

Energy Storage Systems for Hybrid and Electric Vehicles (4-Credits)  
Winter 2016

- **ASSIGNMENTS:** The student will be responsible for all lecture material and advance reading assignments, term project & term paper, midterm exams, and the final exam.

- **TERM PROJECT and Report:** 1-2 students participate in team project, reporting on electrification of different vehicles and devices (20% of your grade)

- Homework / Quizzes 10%

- **EXAMS:** 2-Mid-term exams each is 20% and Final exam will be 30%.

- **Note:** anyone giving or receiving information during an exam will be given an **immediate failing grade** for the course and other disciplinary action.

No copy-paste from other sources are acceptable for the term project report. Each section of your report will be automatically checked against literatures and reports. Use of figures, drawing and tables are acceptable, condition to giving the proper references next to the figures or table.
Important Dates and Deadlines

• **Term Project:** Form your team and select your term project by. **April 11, 2016**

• **Mid-term Exams:** **February 8, 2016**

• **Term Project Report:** **March 3, 2016**

• **Final Exam:** **University calendar, April 27, 2016**

NO make-up exam.