MECHENG 739
Management and Control of Electric Vehicle Batteries
Fall 2015-2016 Course Outline
Department of Mechanical Engineering
McMaster University

COURSE OBJECTIVE

The purpose of this course is to provide a basic knowledge of the key aspects of managing battery systems in Hybrid Electric Vehicles (HEVs) and Battery Electric Vehicles (BEVs). This course provides a fundamental understanding of battery modeling, analysis, state of charge, and state of health estimation. Concepts such as parameters estimation, system identification, optimization, filtering, and control theory will be applied to battery systems.

INSTRUCTOR AND CONTACT INFORMATION

Time: Sat 1:00 pm – 4:00 pm
Class Room: ETB-533

Instructor: Dr. Ryan Ahmed
ryan.ahmed@mcmaster.ca

Office: McMaster Automotive Resource Center (MARC)
Center for Mechatronics and Hybrid Technologies (CMHT)
Office Hours: Sat 12:00 - 1:00 pm

COURSE ELEMENTS

<table>
<thead>
<tr>
<th>Avenue:</th>
<th>Innovation:</th>
<th>Numeracy:</th>
<th>Participation:</th>
<th>Guest speaker(s):</th>
<th>Final Exam:</th>
<th>Experiments:</th>
<th>Written skills:</th>
<th>Group Project:</th>
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</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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COURSE DESCRIPTION

This course covers the principals of Battery Management Systems (BMS) for monitoring, diagnosis, and control of batteries in Hybrid Electric Vehicles (HEVs) and Battery Electric Vehicles (BEVs). The course is targeted towards systems engineers, research scientists, and academics who want to gain a fundamental understanding of battery modeling, analysis, state of charge, and state of health estimation. Topics include introduction to battery systems, battery equivalent circuit-based modeling, battery electrochemical modeling, reduced-order modeling, cell balancing, thermal management, state of charge, and state of health estimation. Concepts such as parameters estimation, system identification, optimization, filtering, and control theory will be applied to battery systems. The techniques covered in this course are mostly related to Li-ion cells and packs as used in automotive applications. These can however also be applied to other battery chemistries.

http://mech.mcmaster.ca/courses_graduate.html
# Learning Outcomes

Upon completion of this course, students will be able to complete the following key tasks:

- Understand the basic principles of batteries and battery management systems for electric vehicle applications
- Develop a basic understanding of battery testing techniques and procedures used in the automotive industry
- Apply their programming skills to develop advanced code scripts related to battery modeling, optimization, state of charge and state of health estimation
- Develop an understanding of battery aging and degradation mechanisms
- Understand the basics of electrochemical battery modeling (physics-based modeling)

# Course Prerequisites

1. MATLAB/Simulink/SimScape
2. Basic chemistry and materials background
3. Control theory background
   - State Space representation
   - Transfer functions
   - PID controllers
   - Root Locus techniques
   - Optimization
   - Stability analysis
   - Z-domain, S-Domain analysis
   - State estimation techniques

# Required Course Materials and Readings

**Books:**


**Research Papers:**

**Battery Modeling, SOC, and SOH Literature Review**


http://mech.mcmaster.ca/courses_graduate.html
Electrochemical Modeling


- Carmelo Speltino, Domenico Di Domenico, Giovanni Fiengo, and Anna G. Stefanopoulou. Comparison of reduced order lithium-ion battery models for control applications. In Joint 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference, October 2009.


Behavioural-based Modeling


State of charge Estimation


http://mech.mcmaster.ca/courses_graduate.html


**Battery Parameters Identification**


**Estimation Strategies**


**Genetic Algorithm Optimization**


**Thermal Management**


**Battery Testing**


  http://mech.mcmaster.ca/courses_graduate.html
• "www.epa.gov/nvfel/testing/dynamometer.htm," EPA United States Environmental Protection Agency.

Additional readings and handouts to be assigned/provided by instructor

**EVALUATION**

All work will be evaluated on an individual basis except in certain cases where group work is expected. In these cases, group members will share the same grade adjusted by peer evaluation. Your final grade will be calculated as follows:

**Components and Weights**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Project</td>
<td>40%</td>
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<tr>
<td>Assignments</td>
<td>35%</td>
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<tr>
<td>Midterm Exam</td>
<td>25%</td>
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</tbody>
</table>

**Conversion**

At the end of the course your overall percentage grade will be converted to your letter grade in accordance with the following conversion scheme.

<table>
<thead>
<tr>
<th>LETTER GRADE</th>
<th>PERCENT</th>
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<tbody>
<tr>
<td>A+</td>
<td>90 - 100</td>
</tr>
<tr>
<td>A</td>
<td>85 - 89</td>
</tr>
<tr>
<td>A-</td>
<td>80 - 84</td>
</tr>
<tr>
<td>B+</td>
<td>75 - 79</td>
</tr>
<tr>
<td>B</td>
<td>70 - 74</td>
</tr>
<tr>
<td>B-</td>
<td>60 – 69</td>
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<tr>
<td>F</td>
<td>00 - 59</td>
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</table>

**Communication and Feedback**

Students who wish to correspond with the instructor directly via email must send messages that originate from their official McMaster University email account. This protects the confidentiality and sensitivity of information as well as confirms the identity of the student.

Instructors are encouraged to conduct an informal course review with students by Week #4 to allow time for modifications in curriculum delivery. Instructors should provide evaluation feedback for at least 10% of the final grade to students prior to Week #8 in the term.

http://mech.mcmaster.ca/courses_graduate.html
• **Final Project Team Assignment (40%)**

**Final Report/Paper (25%)**
For your group project, you are required to select one of the topics/strategies discussed in class and further develop or compare strategies. Ultimately, students are required to summarize the results attained in a form of a conference paper. This assignment will be conducted in groups of 4 to 5 students. As a guide, the assignment should be approximately **10 typed pages, spaced at 1.5, excluding exhibits and appendices.** Most of your research will likely to involve reading journal papers related to the topic.

**Presentation (15%)**
All teams have to present their team work to the class. All team members are expected to be part of the presentation. The students will have 20 minutes plus question and answer period. All team members will receive the same grade for their presentation.

• **Written Assignments (35%)**

Students will be given five assignments to work on during the entire course. Assignments will include extensive programming using MATLAB/Simulink. The assignments will include hands-on experience of techniques currently implemented in battery management systems. Students will be given 2 weeks to solve each assignment.

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**ACADEMIC DISHONESTY**

It is the student’s responsibility to understand what constitutes academic dishonesty. Please refer to the University Senate Academic Integrity Policy at the following URL:


This policy describes the responsibilities, procedures, and guidelines for students and faculty should a case of academic dishonesty arise. Academic dishonesty is defined as to knowingly act or fail to act in a way that results or could result in unearned academic credit or advantage. Please refer to the policy for a list of examples. The policy also provides faculty with procedures to follow in cases of academic dishonesty as well as general guidelines for penalties. For further information related to the policy, please refer to the Office of Academic Integrity at:

[http://www.mcmaster.ca/academicintegrity](http://www.mcmaster.ca/academicintegrity)

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**STUDENT ACCESSIBILITY SERVICES**

Student Accessibility Services (SAS) offers various support services for students with disabilities. Students are required to inform SAS of accommodation needs for examinations on or before the last date for withdrawal from a course without failure (please refer to official university sessional dates). Students must forward a copy of such SAS accommodation to the instructor immediately upon receipt. If a student with a disability chooses NOT to take advantage of an SAS accommodation and chooses to sit for a regular exam, a petition for relief may not be filed after the examination is complete. The SAS website is:

[http://mech.mcmaster.ca/courses_graduate.html](http://mech.mcmaster.ca/courses_graduate.html)
The instructor and university reserve the right to modify elements of the course during the term. The university may change the dates and deadlines for any or all courses in extreme circumstances. If either type of modification becomes necessary, reasonable notice and communication with the students will be given with explanation and the opportunity to comment on changes. It is the responsibility of the student to check their McMaster email and course websites weekly during the term and to note any changes.
# COURSE SCHEDULE

**MECHENG739**  
Management and Control of Electric Vehicle Batteries  
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<table>
<thead>
<tr>
<th>WEEK</th>
<th>TOPIC</th>
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| 1    | • Introduction to Batteries  
     | • Basic Definitions  
     | • Battery Characteristics  
     | • Kirchhoff’s circuit Laws (Review)  
     | • Battery Pack Design  
     | • Battery Construction  
     | • Battery Operation  
     | • Battery Electrochemistry |
| 2    | • Introduction to Battery Management Systems  
     | • Coulomb Counting  
     | • Battery Modeling Overview  
     | • Lumped-Parameters (Behavioral) Models  
     | • Equivalent Circuit-based models  
     | • SOC-OCV Relationship Derivation – MATLAB Example  
     | • OCV-R Battery Model – MATLAB/Simulink Example  
     | • Battery Models simulation – MATLAB Example |
| 3    | • GA Optimization  
     | • Model parameters identification: MATLAB EXAMPLE |
| 4    | • Introduction to Discrete-Time Domain  
     | • OCV-RRC Battery Model  
     | • Online Parameters Estimation – RLS  
     | • RLS Parameters Estimation: MATLAB Example  
     | • Battery Testing |
| 5    | • Control theory overview: transfer functions, stability, root locus, Observability and controllability  
     | • State Space Representation  
     | • Transformation from State Space to Transfer Function  
     | • Kalman Filtering  
     | • State of Charge Estimation |

http://mech.mcmaster.ca/courses_graduate.html
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<tr>
<th>6</th>
<th>MIDTERM EXAM</th>
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| 7 | • Introduction to Battery Degradation  
• Current Profile from Velocity Profile  
• Electric Vehicle Model  
• Driving Cycles – Battery Cycler  
• Battery Aging Tests |
| 8 | • Constant Current Constant Voltage (CCCV) Mode  
• Full-Order Electrochemical Battery Model  
• Reduced-Order Models  
• MATLAB Example |
| 9 | • Full-Order Electrochemical Battery Model – Continued  
• Reduced-Order Models – Continued  
• MATLAB Example – Continued |
| 10 | • Battery Pack design  
• Cell Balancing  
• Active and Passive Balancing – MATLAB/Example |
| 11 | • Thermal management  
• Pack observability  
• Core temperature estimation  
• MATLAB Example |
| 12 | TEAM PRESENTATIONS – GROUP PROJECT |