

# ELECTRIC SYSTEMS FOR E-MOBILITY (MECHANICAL)

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## Course Details

Course Code L T P C

SB8006 1 0 2 2

## COURSE DESCRIPTION

The global market for electric vehicles (EVs) is growing continuously at a compounded annualized growth rate (CAGR) of 21.7 per cent. It is expected to grow from 8.1 million units to 39.21 million units by 2030. This exponential growth is being driven by various factors, including concerns for pollution. In this course, students will get exposed to Electric vehicle & mobility and automation. Understand and demonstrate converter circuits. Build firm foundation in lithium-ion cell terminology and function and in battery-management-system. Get exposed and implement motors and motor control units. Learn & demonstrate the purpose of each component in an equivalent-circuit model of a lithium-ion battery cell, how to determine their parameter values from lab-test data, and how to use them to simulate cell behaviors under different load profiles.

## COURSE OBJECTIVE

Students to get exposed to Electric vehicle & mobility dynamics & Battery Management Systems. Understand and build strong foundation on advanced concepts of switched-mode converter circuits. Learn about motors and its control units & Implement the motor and accompanying rotary sensor into a motor control circuit in both hardware and software. Demonstrate equivalent circuit cell model simulation.

## SYLLABUS

## **UNIT I - INTRODUCTION TO ELECTRIC VEHICLES & AUTOMATION (3T+ 6P)**

### **THEORY COMPONENT:**

- Future of Mobility ? [5 Videos, 3 Readings,2 Quizzes]
- Electrification : The Basic Technologies (Part 1) Electric Vehicles, batteries, EVs Made up of? [5 Videos, 2 Reading,2 Quizzes]
- Electrification : The Basic Technologies (Part 2) ?Charging & Charging Infrastructure, EV & the power systems, Industry Perspective on Applications of Electrification [7 Videos, 6 Readings, 2 Quizzes]
- Electrification Impacts ? [7 Videos, 2 Quizzes]
- Vehicle Automation ? The Basic Technologies ? [9 Videos, 1 Reading, 2 Quizzes]
- Automation ? The Impacts ? [6 Videos,1 Quiz]

### **PRACTICAL/LAB COMPONENT: NA**

## **UNIT II - CONVERTER CIRCUITS (3T+ 6P)**

### **THEORY COMPONENT:**

- Single, Two, and Four-Quadrant Switches - [3 Videos,1 Readings ,2 Assignment]
- Basic issues of Power Semiconductors- [11 Videos,1 Readings & 2 Assignment]
- Introduction to DCM and Mode Boundary - [3 Videos, 1 Readings ,2 Assignment]
- Converter Topologies - [6 Videos, 1 Readings,1 Assignment]

### **PRACTICAL/ASSIGNMENT COMPONENT:**

1. Understand why a diode works in some cases, while a transistor is needed in others
2. Understand when single-quadrant, two-quadrant, or four-quadrant switch realizations are needed
3. Complete Assignment to Understand the tradeoff between voltage breakdown, switching time, and forward voltage drop in a power semiconductor device
4. Complete Assignment to Model switching loss using equivalent circuits
5. Complete Assignment to Design gate drivers
6. Work on LTspice File: Synchronous Boost Converter, with associated driver, dead time generator, and PWM models
7. Work on assignment origin of discontinuous conduction modes
8. Will be able to Analyze a converter to find the CCM-DCM mode boundary
9. Will be able to Analyze a converter circuit to find its conversion ratio in DCM
10. Switching Loss Modeling and DCM Analysis
11. Conversion ration analysis of the Cuk Converter in DCM
12. Get exposed to solved study problems on DCM analysis
13. Understand the origins of basic converter topologies
14. Student will be able to Analyze converter circuits containing transformers
15. Apply transformer analysis techniques to the forward converter
16. Apply transformer analysis techniques to the flyback converter

## **UNIT III - MOTOR AND MOTOR CONTROL CIRCUITS (3T+ 6P)**

### **THEORY COMPONENT:**

- AC motor Designs - [8 Videos, 2 Readings, 1 Quiz & 1 Assignment]
- AC motor Control ? [7 Videos ,1 Reading & 1Quiz & 1 Assignment]
- DC motors ? [8 Videos , 1 Readings & 1 Quiz & 1 Assignment ]
- DC motor control and stepper motors - [5 Videos, 1 Readings,1 Quiz, 2 Lab]

### **PRACTICAL/LAB COMPONENT:**

1. Motor Voltage and Current Measurement Lab Assignment
2. Course Project Quiz 1 - Build a DC Motor circuit, and use it to understand about motor Measurements

3. Course Project 2 Quiz - Build a rotary switch circuit, and use it to understand about switch timing

## **UNIT IV - INTRODUCTION TO BATTERY MANAGEMENT SYSTEM (3T+ 6P)**

### **THEORY COMPONENT:**

- Battery Boot Camp - [8 Videos,13 Readings ,7 Quizzes]
- How lithium-ion cells works - [7 Videos,7 Readings & 7 Quizzes]
- BMS sensing and high-voltage control - [9 Videos, 9 Readings ,8 Quizzes]
- BMS design requirements 2-5 - [8 Videos, 8 Readings,8 Quizzes]
- How are cells made? How can they fail?- [5 Videos, 5 Readings,4 Quizzes]

### **PRACTICAL/LAB COMPONENT: NA**

## **UNIT V - EQUIVALENT CIRCUIT CELL MODEL SIMULATION (3T+ 6P)**

### **THEORY COMPONENT:**

- Defining an equivalent-circuit model of a Li-ion cell - [9 Videos, 14 Readings, 9 Quizzes & 1 Overall Quizz]
- Identifying parameters of static model - [6 Videos, 7 Readings, 6 Quizzes & 1 Overall Quiz]
- Identifying parameters of dynamic model- [9 Videos, 9 Readings, 7 Quizzes & 1 Overall Quiz]
- Simulating battery packs in different configurations - [6 Videos, 6 Readings, 6 Quizzes & 1 Overall Quiz]
- Co-simulating battery and electric-vehicle load - [7 Videos, 7 Readings, 5 Quizzes & 1 Overall Quiz]

### **PRACTICAL/LAB COMPONENT:**

1. Octave Code to determine static part of ECM ? Jupyter notebook used in conjunction (20 Mins)
2. Identifying parameters of static model - Jupyter notebook used in conjunction (1 Hour)
3. Octave Code to determine dynamic part of an ECM (20 Mins)
4. Octave Code to simulate an ECM (20 Mins)
5. Octave code to look up model parameter value (20 Mins)
6. Octave code to compute OCV (20 Mins)
7. ECM to simulate constant voltage (30 Mins)
8. ECM to simulate constant power (30 Mins)
9. Octave code to simulate PCM?s (30 Mins)
10. Octave code to simulate SCM?s (30 Mins)
11. Octave code to co-simulate EV and Battery (1 Hour)
12. Tune a Thevenin model using Octave code to match laboratory data set (1 Hour)
13. Tune an Rint model using Octave code to match laboratory data set (1 Hour)
14. Manually tuning an ESC cell model ? (10 Mins)

**TOTAL : 45 PERIODS**

## **COURSE OUTCOMES**

Students will be able to,

- Get exposed to the concepts & need of Electric vehicles , Mobility & Automation
- How to implement the power semiconductor devices in a switching converter
- Understand the origins of the discontinuous conduction mode and be able to solve converters operating in DCM
- Demonstrate the basic dc-dc converter and dc-ac inverter circuits
- How to implement transformer isolation in a dc-dc converter, including the popular forward and flyback converter topologies
- How to specify the proper AC or DC motor for a machine design
- Integrate the motor to a machine, based on analysis of motor equations for voltage, current, torque and speed.
- Implement the motor and accompanying rotary sensor into a motor control circuit in both hardware and software.

- Add a motor and motor control circuit into a microprocessor based development kit.
- Create hardware and firmware to process motor feedback data to a microprocessor for further evaluation.
- List the major functions provided by a battery-management system and state their purpose
- Match battery terminology to a list of definitions - Identify the major components of a lithium-ion cell and their purpose
- Understand how a battery-management system ?measures? current, temperature, and isolation, and how it controls contactors
- Identify electronic components that can provide protection and specify a minimum set of protections needed
- Compute stored energy in a battery pack
- List the manufacturing steps of different types of lithium-ion cells and possible failure modes
- State the purpose for each component in an equivalent-circuit model
- Compute approximate parameter values for a circuit model using data from a simple Lab test
- Determine coulombic efficiency of a cell from lab-test data
- Use provided Octave/MATLAB script to compute open-circuit-voltage relationship for a cell from lab-test data
- Use provided Octave/MATLAB script to compute optimized values for dynamic parameters in model
- Simulate an electric vehicle to yield estimates of range and to specify drivetrain Components
- Simulate battery packs to understand and predict behaviours when there is cell-to-cell variation in parameter values

## **Mandatory Project work**

1. Motor Voltage and Current Measurement Lab
  - ◆ Course Project - Build a DC Motor circuit, and use it to understand about motor Measurements
  - ◆ Course Project - Build a rotary switch circuit, and use it to understand about switch timing
2. Student to modify three sample Octave programs to create functions that can simulate temperature-dependent cells, battery packs built from PCMs, and battery packs built from SCMs

### **Test Project:-**

Design of battery pack for 48V 1000W electric vehicle and determine coulomb efficiency and equivalent circuit parameters using Octave/MATLAB

### **List of Software Students are exposed to**

-Jupyter Notebook

### **Duration of availability of Licensed Software to Students**

-For the entire Semester (Could be extended if required for specific candidates)

## **List of consumables that will be given to per student**

- License for accessing respective Courses
- Orientation on portal access
- Doubt clarification session based on need basis
- Automatic Graded Assessment reports
- Access to discussion forums to relevant courses/streams

## **Student Assessment Plan**

- o Every Sub-units will have a Quiz and every Unit will have an overall Graded Quiz other than Lab exercise and Capstone Projects
- o Few Assignments are also provided for practice in addition to Quiz and Graded assessments
- o All Assessments are online based and self-graded
- o If a students does not score the required minimum of 80% , he will be asked to retake the tutorial and attempt the Quiz again.

## **Unit 1 ? Introduction to Electric Vehicles & Automation**

- Quiz on Mobility Terms
- Quiz on Mobility ? Past, Present & Future
- Quiz on EVs Made of?
- Quiz on Battery Technology
- Quiz on Stakeholders of Electrification
- Overall Graded assessment on all the above topics**
- Quiz on Sustainability & Equity
- Quiz on Impacts of Electrification
- Quiz on Autonomous Vehicles Components
- Quiz on Impacts of Automation

## **Unit 2 ? Converter Circuits**

- Assignment on why a diode works in some cases, while a transistor is needed in others
- Assignment on when single-quadrant, two-quadrant, or four-quadrant switch realizations are needed
- Homework Assignment on Switch Realisation
- Assignment on Simulation to trade off between voltage breakdown, switching time, and forward voltage drop in a power semiconductor device, Model switching loss using equivalent circuits & Design gate drivers
- Homework Assignment on the origin of discontinuous conduction modes
- Analyze a converter to find the CCM-DCM mode boundary
- Analyze a converter circuit to find its conversion ratio in DCM
- Demonstrate the origins of basic converter topologies
- Analyze converter circuits containing transformers
- Apply transformer analysis techniques to the forward converter
- Apply transformer analysis techniques to the flyback converter

## **Unit 3 ? Motor & Motor Control Circuits**

- Quiz on AC Motor Designs
- Quiz on AC Motor Control
- Quiz on DC Motors
- Quiz on DC Motors Control and Stepper Motors
- Motor Voltage and Current Measurement Lab Assignment

**Course Project Quiz 1** - Build a DC Motor circuit, and use it to understand about motor Measurements

**Course Project 2 Quiz** - Build a rotary switch circuit, and use it to understand about switch timing

## **Unit 4 ? Introduction to Battery Management System**

- Pre-requisite Quiz on Battery Boot Camp
- Quiz on battery terminology
- Quiz on parts of electrochemical cell
- Quiz on electro chemical cell storage and release energy
- Quiz on materials to use in electrochemical cell
- Overall assessment on all the above topics**

- Quiz on lithium-ion cells
- Quiz on lithium-ion cells different from electrochemical cells
- Quiz on negative electrodes for lithium-ion cells
- Quiz on positive electrodes for lithium-ion cells
- Quiz on electrolytes and separators for lithium-ion cells
- Quiz on lithium to run out
- Overall assessment on all the above topics**

- Quiz on primary functions of a BMS
- Quiz on Modular design
- Quiz on Cell Voltage in a BMS
- Quiz on sense module temperature in a BMS
- Quiz on sense battery-pack current in a BMS
- Quiz on control contactors with a BMS
- Quiz on electrical isolation in a BMS

### **Overall assessment on all the above topics**

- Quiz on BMS Protect the user and battery pack
- Quiz on BMS interface with other system components
- Quiz on BMS estimate SOC and SOH
- Quiz on Cell SOC and Battery-pack SOC
- Quiz on computing cell available energy and power
- Quiz on computing battery pack available energy and power
- Quiz on kinds of diagnostics must for a BMS report

### **Overall assessment on all the above topics**

- Quiz on lithium-ion cell's electrodes fabricated
- Quiz on lithium-ion cell assembled
- Quiz on lithium-ion cell aging processes
- Quiz on abnormal cell aging processes and failure modes

## **Unit 5 - Equivalent Circuit Cell Model Simulation**

- Quiz on Open-circuit voltage (OCV) and State-of-charge (SOC)
- Quiz on How do we model voltage
- Quiz on Warburg impedance & its implementations
- Quiz on Convert a continuous-time model to discrete-time model
- Quiz on Model parameter values
- Quiz on Hysteresis in a lithium-ion cell and its modelling
- Quiz on equivalent-circuit model of a lithium-ion cell Overall assessment on all the above topics
- Quiz on cell Characterization
- Quiz on open-circuit voltage determination
- Quiz on Cell's coulombic efficiency and total capacity
- Quiz on Cell's temperature dependent OCV
- LAB ? Jupyter notebook - To be used in Conjunction with Octave code to determine static part of ECM
- Quiz on Octave code to determine static part of ECM
- LAB ? Jupyter notebook - To be used in Conjunction with identifying parameters of static model and next steps
- Quiz on Determining dynamic-model parameters
- Quiz on cell data used to find dynamic-model parameter values
- LAB ? Jupyter notebook to run for octave code to determine dynamic part of an ECM
- Quiz on octave code to determine dynamic part of an ECM
- LAB ? Jupyter notebook to run for octave code to simulate an ECM
- Quiz on octave code to simulate an ECM
- LAB ? Jupyter notebook to run for octave code to look up model parameter value
- Quiz on octave code to look up model parameter value
- LAB ? Jupyter notebook to run for octave code to compute OCV
- Quiz on octave code to compute OCV

### **Overall assessment on all the above topics**

- LAB ? Jupyter notebook to run for ECM to simulate constant voltage
- Quiz on how to use ECM to simulate constant voltage
- LAB ? Jupyter notebook to run for ECM to simulate constant power
- Quiz on how to use ECM to simulate constant power
- Quiz on Simulate battery packs
- LAB ? Jupyter notebook to run for Octave code to simulate PCM's

- Quiz on Octave code to simulate PCM?s
- LAB ? Jupyter notebook to run for Octave code to simulate SCM?s
- Quiz on Octave code to simulate SCM?s

### **Overall assessment on all the above topics**

- Quiz on develop a load/battery co-simulator
- Assignment on how to Infer the information needed to develop a load/battery co-simulator based on the example taught.
- Assignment on how to Analyze vehicle/battery co-simulation block diagram to understand the dependencies of simulation variables.
- Quiz on Modelling ideal vehicle dynamics
- Quiz on practical limits to model of vehicle dynamics Quiz on calculating electric-vehicle range
- LAB ? Jupyter notebook to run for Octave code to set up EV simulation
- LAB ? Jupyter notebook to run for Octave code to conduct EV simulation
- Quiz on Octave code to set up EV simulation and conduct EV simulation
- LAB ? Capstone Project to modify three sample Octave programs to create functions that can simulate temperature-dependent cells, battery packs built from PCMs, and battery packs built from SCMs.
- Assignment ? Programming Assignment for manually tuning an ESC cell model

### **Documentary Evidence**

1. <https://www.coursera.org/learn/people-technology-and-the-future-of-mobility>
2. <https://www.coursera.org/learn/converter-circuits>
3. <https://www.coursera.org/learn/motors-circuits-design>
4. <https://www.coursera.org/learn/battery-management-systems>
5. <https://www.coursera.org/learn/equivalent-circuit-cell-model-simulation>