POWER ELECTRONICS

OVERALL COURSE OBJECTIVES:

To equip students with comprehensive knowledge and practical skills surrounding lithium-ion cell components, battery management systems, equivalent circuit cell models, State-of-Charge/Health estimation, power estimation, and power electronics, enabling them to effectively design, analyse, simulate and control switched-mode power systems. Use of software tools like MATLAB for data computations and system design is also emphasised.

LEARNING OUTCOMES: On successful completion of the course the students shall be able to:

1. Proficiency in identifying major lithium-ion cell components, understanding battery management systems, and predicting battery pack behaviours.
2. Ability to implement and evaluate various state-of-charge and state-of-health estimation methods using Octave/MATLAB scripts and utilization of these scripts for estimation and data computations.
3. Skills to design battery balancing systems and calculate remaining energy and available power for a battery pack using a comprehensive equivalent-circuit cell model.
4. Understanding of power electronic converter circuit principles along with ability to solve for steady-state voltages, currents, and determine converter efficiency.
5. Capable of designing feedback systems to control a switching converter and performing analysis for the same.
6. Ability to analyze and design magnetic components used in power electronic converters, create EMI filters, and verify their designs with computer-aided tools.

Battery Management System - I	Introduction to battery-management systems
	Equivalent Circuit Cell Model Simulation
Battery Management System - II	Battery State-of-Charge (SOC) Estimation
	Battery State-of-Health (SOH) Estimation
	Battery Pack Balancing and Power Estimation
Power Electronics - I	Introduction to Power Electronics
	Converter Circuits
	Converter Control
Power Electronics - II	Magnetics for Power Electronic Converters
	Input Filter Design
	Techniques of Design-Oriented Analysis
Modeling and Control of Power Electronics	Averaged-Switch Modeling and Simulation
	Modeling and Control of Single-Phase Rectifiers and Inverters
	Current-Mode Control

COURSE CONTENT:

Module 1 :Introduction to battery-management systems [25 Hours]
The course equips students with a solid foundation in lithium-ion cell terminology, battery function, and battery-management-system requirements. The course instills proficiency in identifying major lithium-ion cell components, understanding how battery-management systems measure parameters and control contactors, and specifying minimum protections needed. Students also learn to compute stored energy in a battery pack and grasp the manufacturing procedures of different lithium-ion cell types, along with possible failure modes.

Sub-Topics:

Battery Boot Camp
How lithium-ion cells work
BMS sensing and high-voltage control
BMS design requirements 2-5
How are cells made? How can they fail?

Formative Assessments:
8 Graded Quizzes

Module 2 :Equivalent Circuit Cell Model Simulation [28 Hours]
The course provides detailed instruction on equivalent-circuit models of lithium-ion battery cells. Students will learn about the function of each component, determining parameter values from lab data, and using this information for simulation of cell behaviors. This skill set includes calculating approximate parameter values, determining the coulombic efficiency of a cell, utilizing Octave/MATLAB scripts for data computations, and simulating electric vehicles and battery packs. The course equips students to predict battery pack behaviours in the event of cell-to-cell variation.

Sub-Topics:
Defining an equivalent-circuit model of a Li-ion cell
Identifying parameters of static model
Identifying parameters of dynamic model
Simulating battery packs in different configurations
Co-simulating battery and electric-vehicle load

Formative Assessments:

1 Programming Assignments & 9 Graded Quizzes

Module 3 :Battery State-of-Charge (SOC) Estimation[28 Hours]

The course teaches students to implement various state-of-charge estimation methods and assess their merits. Upon completion, students will be able to execute simple voltage-based and current-based state-of-charge estimators, understand sequential-probabilistic-inference solutions, and operate Octave/MATLAB scripts for linear Kalman filters. Furthermore, they will utilize these scripts for state-of-charge estimation employing extended and sigma-point Kalman filters on lab-test data. A crucial skill students will acquire is the ability to detect and discard erroneous voltage-sensor measurements.

Sub-Topics:

The importance of a good SOC estimator
Introducing the linear Kalman filter as a state estimator
Coming to understand the linear Kalman filter
Cell SOC estimation using an extended Kalman filter
Cell SOC estimation using a sigma-point Kalman filter
Improving computational efficiency using the bar-delta method

Formative Assessments:
2 Programming Assignments & 9 Graded Quizzes

Module 4 :Battery State-of-Health (SOH) Estimation [23 Hours]
The course teaches students to implement various state-of-health estimation methods and evaluate their benefits. Key learning outcomes include identifying primary lithium-ion cell degradation mechanisms, executing Octave/MATLAB scripts for total capacity estimation using different methods, calculating confidence intervals on these estimates and the cell's equivalent series resistance. The course also addresses the tradeoffs between joint and dual estimation of state and parameters, ensuring robust estimates.

Sub-Topics:

A Kalman-filter approach to total capacity estimation
How does lithium-ion cell health degrade?
How to write code for the different total-capacity estimators
Simplified total-least-squares battery-cell capacity estimates
Total-least-squares battery-cell capacity estimation

Formative Assessments:
1 Programming Assignments & 8 Graded Quizzes

Module 5 :Battery Pack Balancing and Power Estimation [23 Hours]
The course offers students insights into designing battery balancing systems and calculating remaining energy and available power for a battery pack. Students will learn to evaluate and articulate the merits of different design choices for cell balancing, design component values for a passive balancing circuit and use Octave/MATLAB tools for related computations. The course equips learners with the ability to compute available power using a comprehensive equivalent-circuit cell model.

Sub-Topics:
Active balancing methods for battery packs
Passive balancing methods for battery packs
How to find available battery power using a simplified cell model
How to find available battery power using a comprehensive cell model
Future Battery-Management-System Algorithms

Formative Assessments:
2 Programming Assignments & 10 Graded Quizzes

Module 6 :Introduction to Power Electronics [12 Hours]
The course offers insights into the primary concepts of switched-mode converter circuits for high-efficiency electrical power control and conversion. This course facilitates understanding of converter circuit principles, steady-state voltages, currents, and power converter efficiency. Hands-on assignments enable simulation, analytic, and modeling skills for different systems and converters. After completing the course, students will understand switched-mode converters, be able to solve for various converter's steady-state voltages and currents, and derive an averaged equivalent circuit model to determine converter efficiency.

Sub-Topics:

Steady-State Converter Analysis
Steady-State Equivalent Circuit Modeling, Losses, and Efficiency

Formative Assessments:
3 Graded Quizzes

Module 7 :Converter Circuits [19 Hours]
The course delves into advanced concepts of switched-mode converter circuits, including power semiconductors realization in inverters or converters with bidirectional power flow. It covers power diodes, power MOSFETs, IGBTs, and refined equivalent circuit models accounting for switching loss effects. The course also explores various converter circuit topologies, such as transformer-isolated forward and flyback converters. Homework includes working on a boost converter, H-bridge inverter, and transformer-isolated converters. Upon completion, students will understand power semiconductor implementation, discontinuous conduction mode, basic dc-dc converter and dc-ac inverter circuits, and transformer isolation implementation in dc-dc converters. The first course, Introduction to Power Electronics, is a prerequisite.

Sub-Topics:

Switch Realization
Power Semiconductor Switches
Discontinuous Conduction Mode
Converter Circuits

Formative Assessments:
4 Graded Quizzes

Module 8 : Converter Control [19 Hours]
This course teaches how to design a feedback system to control a switching converter. The equivalent circuit models derived in the previous courses are extended to model small-signal ac variations. These models are then solved, to find the important transfer functions of the converter and its regulator system. Finally, the feedback loop is modeled, analyzed, and designed to meet requirements such as output regulation, bandwidth and transient response, and rejection of disturbances. Upon completion of this course, you will be able to design and analyze the feedback systems of switching regulators.

This course assumes prior completion of courses Introduction to Power Electronics and Converter Circuits.

Sub-Topics:

AC Equivalent Circuit Modeling
Converter Transfer Functions - Part 1
Converter Transfer Functions - Part 2
Controller Design

Formative Assessments:
5 Graded Quizzes

Module 9 :[Magnetics for Power Electronic Converters] [17 Hours]
The course educates students on the analysis and design of magnetic components, such as inductors and transformers, utilized in power electronic converters. It introduces concepts like inductance, core material saturation, airgap, energy storage in inductors, reluctance, and transformer equivalent circuits. The course helps students understand the fundamentals of magnetic components, modeling of losses in such components, and trade-offs in design. They will also learn to design and optimize inductors and transformers for switched-mode power converters. This course assumes the completion of "Introduction to Power Electronics'' and "Converter Circuits."

Sub-Topics:

Basic Magnetics
Inductor Design
AC Copper Losses
Transformer Design

Formative Assessments:
4 Graded Quizzes

Module 10 :[Input Filter Design] [11 Hours]
The course equips students with an understanding of electromagnetic interference (EMI) and compatibility (EMC), the necessity for input filters, and their effects on converter responses. Students will design damped single and multi-section filters that meet conducted EMI attenuation requirements and maintain the stability of closed-loop controlled power converters. Recommended prerequisites include CU Boulder's Power Electronics specialization and Courses #1 and #2 (Averaged-Switch Modeling and Simulation, Techniques of Design-Oriented Analysis). The course outcomes ensure proficiency in understanding and designing EMI filters and verifying their design with computer-aided tools.

Sub-Topics:

Introduction to Input Filter Design
Multi-Stage Input Filter Design
Single-Stage Input Filter Design

Formative Assessments:
3 Graded Quizzes

Module 11 :Techniques of Design-Oriented Analysis [12 Hours]
The course emphasizes design-oriented analysis techniques, providing insights into switching power converter models, translating these insights into practical designs. The course introduces techniques like the Extra Element Theorem and N-Extra Element Theorem (N-EET), equipping students to simplify circuit analysis, design damping of converters, and derive circuit responses with minimum algebra. The course enhances analytical skills applicable to high-performance closed-loop controlled switching power converter design. Successful completion of CU Boulder's Power Electronics specialization and Course #1 are strongly recommended prerequisites.

Sub-Topics:

Extra Element Theorem
Analysis of SEPIC Frequency Responses Using EET
Design example: SEPIC frequency responses
N Extra Element Theorem (NEET)
NEET Application Example: Two-Section Filter

Formative Assessments:
3 Graded Quizzes

Module 12 :Averaged-Switch Modeling and Simulation [16 Hours]
This course, the first in the Modeling and Control of Power Electronics sequence, focuses on the practical, design-oriented modeling and control of pulse-width modulated switched-mode power converters. It introduces the Middlebrook's feedback theorem and how circuit averaging and averaged-switch modeling techniques can aid the analysis and design of converters. Upon completion, students will be adept at designing high-performance control loops and verifying converter operations using simulations. It's recommended that students complete the CU Boulder Power Electronics specialization before enrolling in this course.

Sub-Topics:

Averaged Switch Modeling and Averaged Circuit Simulations
Modeling, Control and Simulation of Switched-Mode Power Converters
Techniques of Design Oriented Analysis: Feedback Theorem

Formative Assessments:
3 Graded Quizzes

Module 13 :Modeling and Control of Single-Phase Rectifiers and Inverters [14 Hours]

The course focuses on the modeling and control of grid-tied power electronics. Students will learn to understand, analyze, model, and design low-harmonic rectifiers and inverters interfacing with DC power sources and the single-phase AC power grid. Upon completion, students will be proficient in designing low-harmonic rectifiers, inverters, and photovoltaic power systems, and verifying their design using computer-aided tools.

Sub-Topics:

Control of Power Factor Correction Rectifiers
Grid-Tied Power Electronics
Modeling and Control of Single-Phase Inverters

Formative Assessments:
2 Graded Quizzes and 1 peer review assignment

Module 14 :Current-Mode Control [14 Hours]

The course focuses on current-mode control techniques prevalent in switched-mode practical applications. Principles such as slope compensation and high-frequency effects are discussed and students will learn to design high-performance current-mode controllers for dc-dc power converters. Upon completion, students can model and design various current-mode controlled dc-dc converters and verify their designs using computer-aided tools.

Sub-Topics:

Average Current-Mode Control
High-Frequency Effects in Peak Current-Mode Control
Peak Current-Mode Control: More Accurate Model
Peak Current-Mode Control: Simple Model

Formative Assessments:
4 Graded Quizzes.

ASSESSMENT:
For summative assessments, Coursera will provide question banks for which exams can be conducted on the Coursera platform or the faculty will create their own assessments.

Note: If a Course or Specialization becomes unavailable prior to the end of the Term, Coursera may replace such Course or Specialization with a reasonable alternative Course or Specialization.