GATE Center of Excellence in Innovative Drivetrains in Electric Automotive Technology Education (IDEATE)

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10 June 2015
Project ID: TI021

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Overview

Timeline
- Start: 10/1/2011
- Finish: 9/30/2016
- 75% complete

Barriers
- Lack of advanced technology curricula
- Lack of trained engineers and scientists

Budget
- Project funding:
  - DOE share: $954.2 K
  - Cost share: $253.4 K
- Government funding received in:
  - FY14: $161.0 K
  - FY15: $162.0 K
- $497.1 K spent (52%) (as of 3/31/2015)

Partners
- University of Colorado Colorado Springs (project lead)
- University of Colorado Boulder
- Utah State University
Relevance/Objectives of IDEATE

- Establish a Graduate Certificate in Electric Drivetrain Technology
- Establish an MSEE option in Battery Controls and an MSEE emphasis area in Vehicle Power Electronics to educate a future workforce
- Develop courses and materials that support fundamental research, which will enable development of new technology in IDEATE topics
- Remove barriers to study by making IDEATE coursework nationally accessible via on-line means, and offering GATE Fellowships

Graduate Education in **Battery Controls**

- University of Colorado Colorado Springs

Graduate Education in **Vehicle Power Electronics**

- University of Colorado Boulder
- Utah State University

### Graduate courses supporting PhD in EE emphasis area in **Battery Controls**
- Feedback Control
- Digital Control
- Multivariable Ctrl.
- Systems I, II, III

### MSEE option in **Battery Controls**
- Optimization
- System Identification
- Kalman Filtering
- Model Pred. Ctrl.

### Graduate Certificate in **Electric Drivetrain Technology**
- Modeling Battery Dynamics
- Battery Management & Ctrl.
- Power Electronics for Electric Drive Vehicles
- Adjustable Speed AC Drives

### MSEE emphasis area in **Vehicle Power Electronics**
- Intro. to Pwr. Elect.
- Res., Soft Switch
- Model/ctrl Pwr. Elect.
- Pwr. Elect Lab

### Graduate courses supporting PhD in EE emphasis area **Vehicle Pwr. Elect.**
- Analog IC Design
- Mix. Signal IC Des.
- Renewable Energy
- Ctrl. Sys. Analysis
- Digital Control Sys.

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10 June 2015  
*DOE Merit Review: VSS-150 (IDEATE)*
Relevance of IDEATE Objectives

Addresses barrier 1: Lack of advanced technology curricula
- Creation of five new specialty courses:
  - Modeling, Simulation and Identification of Battery Dynamics
  - Battery Management and Control
  - Optimization Methods for Systems and Control
  - Power Electronics for Electric Drive Vehicles
  - Adjustable Speed AC Drives

Addresses barrier 2: Lack of trained engineers and scientists
- Graduate certificate in Electric Drivetrain Technology retrains engineers
- MSEE option/emphasis areas educate a future workforce
- Supports fundamental MSEE/PhD research in IDEATE topics to continuously advance knowledge in the field
- Removes barriers to study by making IDEATE coursework nationally accessible via on-line means, and through offering GATE Fellowships
Key IDEATE Milestones During FY15

- Key objectives for the past year included:
  - Offering certificate and specialized MSEE courses
  - Revising, updating content of courses
  - Packaging several UCCS courses to enable on-line delivery
  - Progress in implementation of hardware battery-pack simulator

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*Anticipated completion 8/2015
Approach: Uniqueness of IDEATE

- The University of Colorado Boulder (CU-Boulder) is widely regarded as having one of the top U.S. graduate programs in **power electronics**
- The University of Colorado Colorado Springs (UCCS) has unrivaled expertise in algorithms for **automotive battery control**
- By collaborating, IDEATE builds on our team’s proven strengths to **develop innovative curricula** and to **initiate courses and programs** that will provide students with a **unique opportunity for holistic and specialty education in electric drivetrain technology**
- Graduates from these programs will provide benefit not only to major automotive manufacturers, but also to new electric drivetrain focused small businesses and suppliers
Approach: Principal Overall IDEATE Tasks

**Administrative (✓ = complete)**
- ✓ Undergo university processes to have Graduate Certificate and MSEE option approved
- ✓ Create processes for admissions, graduation
- ✓ Create processes for review of GATE Fellowship applications and funds disbursal
  - Advertise availability of programs (ongoing)
  - Process applications and GATE Fellowship requests (ongoing)
  - Generate newsletters for IAB, soliciting feedback (ongoing)

**Curricular**
- ✓ Create curriculum and teaching materials for five new courses
- ✓ Implement new laboratory
  - Refine curriculum/teaching materials based on own observations, IAB input (ongoing)
  - Offer certificate and related MSEE courses (ongoing)
  - Package MSEE-BC courses for on-line delivery (started)
  - Develop hardware battery simulator for laboratory (started)
## Approach: Principal IDEATE Tasks, FY15

### Administrative
- Advertise availability of programs
- Process applications and GATE Fellowship requests
- Generate newsletter for Industry Advisory Board, soliciting feedback

### Curricular
- Refine curriculum/teaching materials for courses
- Offer certificate courses: ECE5710, ECE5720, ECEN5017, ECEN5737
- Offer MSEE-BC courses, ECE5510, ECE5550, ECE5560, ECE5570
- Continue packaging MSEE-BC courses for on-line delivery

### Future tasks
- Continue packaging MSEE-BC courses for on-line delivery
- Software development for hardware battery simulator platform
- Refresh courses based on IAB feedback and experience
New Tech. Accomplishment: Enrollments

- 193 unique students have taken at least one IDEATE course
- 10 certificate graduates; 23 MSEE grads

Number of students having taken at least “N” IDEATE courses by end of indicated fiscal year

Number of students having completed program by end of indicated fiscal year

10 June 2015
New Tech. Accomplishment: Packaging

- Continued packaging MSEE-BC courses for polished online delivery
- Completed ECE5710/20: Battery Modeling, Control
- Completed ECE5550/60: Kalman Filtering, System Identification

10 June 2015

DOE Merit Review: VSS-150 (IDEATE)
New Tech. Accomplishment: Packaging

- Example screen-capture of video from ECE5710 shown
- Fully typeset lecture notes, which are narrated and marked up during the lecture segment
- 84 segments, each about 20–30 min long, comprise course content
New Accomplishment: MSEE-BC Thesis

- Example MSEE-BC thesis topic from FY15: Reduced-Order Models of Lithium-Ion Cells Having Blended Electrodes, Albert Rodriguez Marco, Spring 2015
  - Motivation: Cells having blended active materials are notoriously difficult targets for controls (e.g., SOC estimation) algorithms
  - Thesis: Developing physics-based reduced-order models of cells having blended electrode materials
This project was not reviewed last year.
IDEATE Collaborations and Coordination

- Team collaboration: org-chart shown
- Industry advisory board:¹
  - Equipment manufacturer, vehicle companies, national laboratory, venture capital company, battery cell design/manufacturer, battery pack design companies, automotive semiconductor companies,
- This industry advisory board has expressed interest in:
  - Providing paid internship opportunities to IDEATE students
  - Hiring graduates from the program,
  - Providing guest lecturers as well as PhD qualified personnel to sit on thesis and dissertation committees.

IDEATE Remaining Challenges and Barriers

- **Impact**: We desire to maximize the availability and impact of this program
  - This requires that we continue to develop our advertising strategy, and
  - Make *ECEN 5737: Adjustable Speed AC Drives* available to Utah State University students

- **Hands-on**: We desire to add a lab component to *ECE5710: Modeling, Simulation and Identification of Battery Dynamics* for enhanced learning
  - This requires we continue to develop our hardware battery-pack simulator to enable safe remote access to synthetic data processes

- **Relevance**: We desire to be increasingly relevant to the needs of industry
  - This requires that we keep in close contact with our Industry Advisory Board, and that we consider modifications to curricula to meet their suggestions
IDEATE Proposed Future Work

Plans for remainder of FY15
- Refresh course curricula and content/teaching materials based on self assessment and input from Industry Advisory Board
- Continue to polish and package courses for enhanced on-line delivery, including related courses in controls and power-electronics curriculum (see next slide for schedule of packaging MSEE-BC courses)

Plans for FY16
- Offer courses to next cohort of students
- Complete development of hardware battery simulator for use with algorithm verification
- Refine advertising strategy based on results of present efforts
- Continue to polish and package courses; advise MSEE students
**IDEATE Proposed Future Work**

- Continue to package all MSEE-BC courses at UCCS for on-line delivery capability to expand program reach.
- Schedule determined by timetable of normal university course offerings.
- Completion expected by Summer of 2016.

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**Core (required) courses for M.S.E.E. option in Battery Controls**

**Elective courses for M.S.E.E. option in Battery Controls**
Summary

- IDEATE addresses a technology workforce shortfall with programs emphasizing two key technologies necessary to propel U.S. automotive industry to the next level, the electrified drivetrain:
  - Battery Modeling and Controls
  - Vehicle Power Electronics
- New Graduate Certificate in Electric Drivetrain Technology and new MSEE options will retrain traditional automotive engineers and educate new entrants to the workforce
- All administrative procedures are defined; curriculum is designed; course materials have been developed
- Ongoing work in polishing courses; packaging for on-line delivery
GATE Center of Excellence in
Innovative Drivetrains in Electric Automotive Technology Education (IDEATE)

Technical Back-Up Slides
Ongoing Tech. Accomplishment: Curricular

- Refined curriculum and teaching materials for *ECE5710: Modeling, Simulation, Identification of Battery Dynamics*. Offered Fall 2012/13/14
  - Brief consideration of equivalent-circuit models and their limitations
  - Substantial attention given to deriving particle-scale homogeneous-phase physics-based models of internal cell dynamics
  - Volume-averaging techniques used to create continuum models
  - Cutting edge methods for automatically converting continuum models to reduced-order controls models investigated in detail
Ongoing Tech. Accomplishment: Curricular

- Refined curriculum and teaching materials for *ECE5720: Battery Management and Control*. Offered Spring 2013/14/15
  - Overview of the major functions of a battery management system
  - In-depth consideration of several methods for battery state estimation
  - Some standard and improved methods for battery health estimation
  - Motivation and methodology for cell balancing
  - Voltage-based power limit estimation
  - Optimized controls for power estimation

![Diagram of battery management system](image-url)
Ongoing Tech. Accomplishment: Curricular

- Refined curriculum and teaching materials for *ECEN5017: Power Electronics for Electric Drive Vehicles*. Offered Fall 2012/13/14
  - Electric drive vehicle system architecture
  - Electric system control and dynamic modeling in Simulink
  - Power converters for motor drives
  - Power converters for energy storage, battery management electronics
  - Power converters for battery chargers and utility interface

Electric Drive Vehicles
- System Architecture: EV, HEV, PHEV, ..., xEV; Series, parallel, complex
- Electric system control and dynamics; Simulink modeling and simulation

Power Converters for Motor Drives
- Bi-directional DC-AC
- High power density, high current, high temperature
- Sensing and digital control

Power Converters for Energy Storage
- Energy storage cells, battery management system electronics
- Bi-directional DC-DC
- Sensing and digital controls

Power Converters for Battery Chargers
- Level I, II, III; charger requirements
- Bi-directional AC-DC, DC-DC
- Control and coordination with BMS
Ongoing Tech. Accomplishment: Curricular

- Refined existing course ECEN 5737: Adjustable Speed AC Drives curriculum and teaching materials to be direct companion to the Power Electronics for Electric Drive Vehicles course. Offered Spring 2013/14/15
  - Introduction to electric machines for electric vehicles
  - Principles for analysis of electric machines, reference frame theory
  - Operation and control of symmetrical induction machines
  - Operation and control of permanent-magnet synchronous machines