Power Electronics Circuits

Prof. Daniel Costinett

ECE 482 Lecture 1
January 14, 2016

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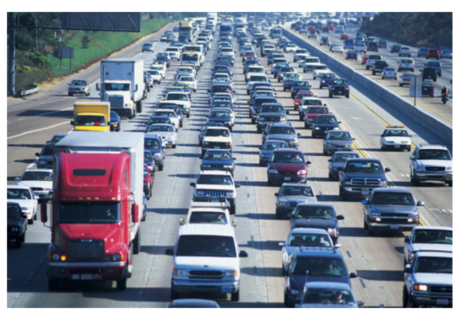
Transportation Electrification

Motivation

- Improve efficiency: reduce energy consumption
- Displace petroleum as primary energy source
- Reduce impact on environment
- Reduce cost

US Energy Information Administration:

- Transportation accounts for 28% of total U.S. energy use
- Transportation accounts for 33% of CO_2 emissions
- Petroleum comprises 90% of US transportation energy use



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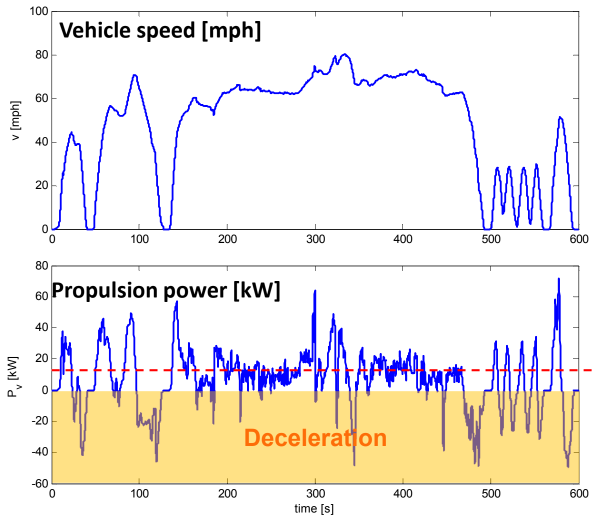
Example: US06 driving cycle



10-min
8 miles

Prius-sized vehicle

Dissipative braking

P_{vavg} = 11.3 kW

235 Wh/mile

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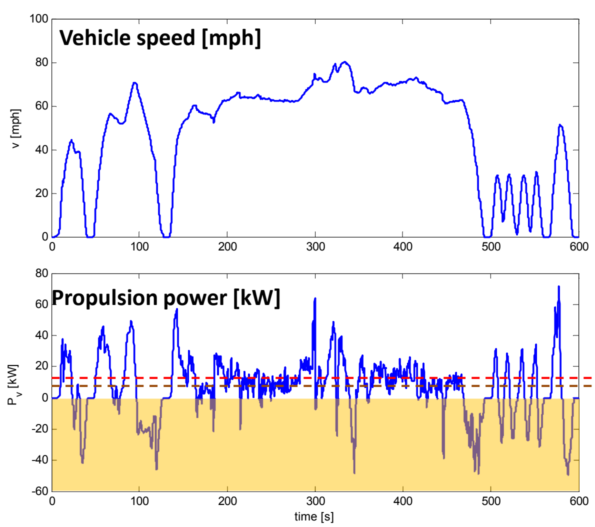
Average power and energy



Prius-sized vehicle

Dissipative braking

P_{vavg} = 11.3 kW

235 Wh/mile

Regenerative braking

P_{vavg} = 7.0 kW

146 Wh/mile

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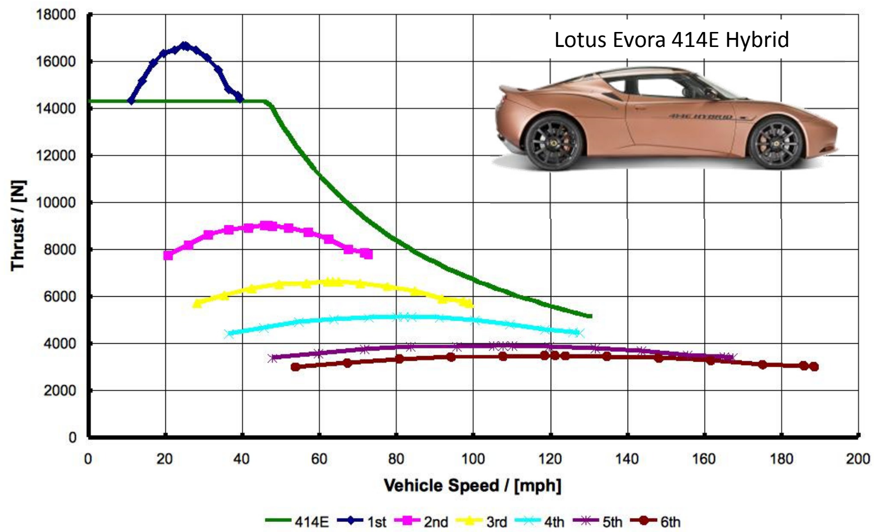
ICE vs ED τ–ω



"Full Acceleration", proactive Magazine, Oct. 2012

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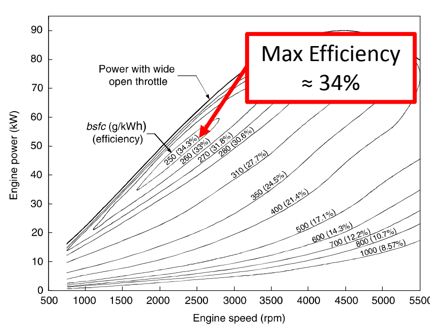
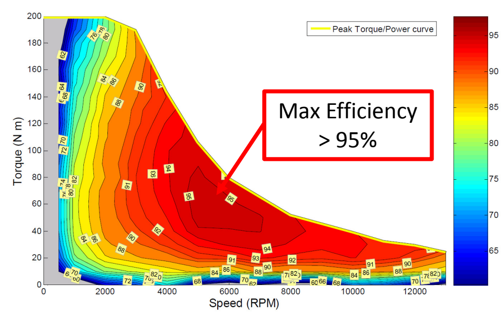
ICE vs. ED η



Internal Combustion Engine (ICE)



Electric Drive (ED)

- $\eta_{ED,pk} \approx 95\%$; $\eta_{ICE,pk} \approx 35\%$
- ED offers full torque at zero speed
  - No need for multi-gear transmission

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Conventional Vs. Electric Vehicle

(Prius-sized vehicle example)

	Tank + Internal Combustion Engine	Electric Vehicle (EV) Battery + Inverter + AC machine
Regenerative braking	NO	YES
Tank-to-wheel efficiency	≈ 20% 1.2 kWh/mile, 28 mpg	≈ 85% 0.17 kWh/mile, 200 mpg equiv.
Energy storage	Gasoline energy content **12.3 kWh/kg**, **36.4 kWh/gallon**	$LiFePO_4$ battery 0.1 kWh/kg, 0.8 kWh/gallon
Refueling	5 gallons/minute **11 MW**, 140 miles/minute	Level I (120Vac): 1.5 kW, <8 miles/hour Level II (240Vac): 6 kW, <32 miles/hour Level III (DC): 100 kW, <9 miles/minute
Cost	12 ¢/mile [$3.50/gallon]	2 ¢/mile [$0.12/kWh]
CO_2 emissions (tailpipe, total)	≈ (300, 350) g CO_2/mile	(0, ≈120) g CO_2/mile [current U.S. electricity mix]

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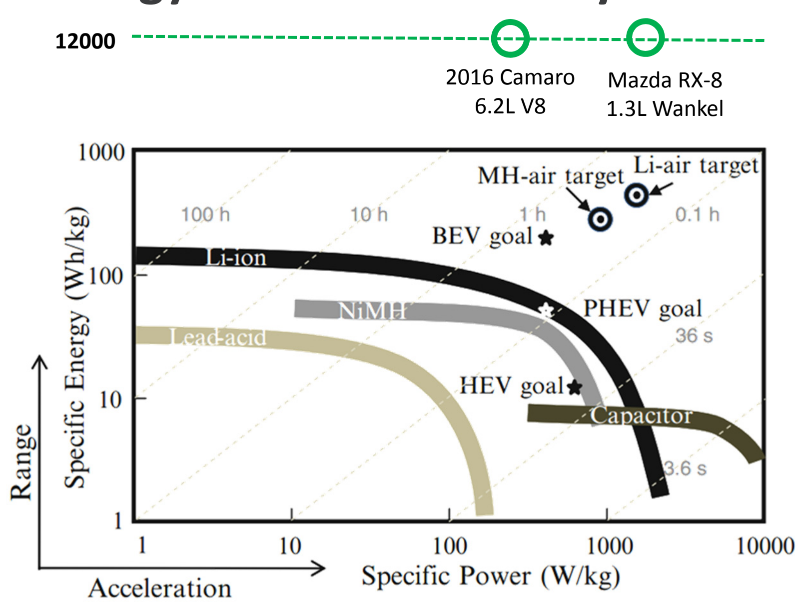
Energy and Power Density of Storage



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Conventional Vs. Electric Vehicle

(Ford Focus comparison)

	Tank + Internal Combustion Engine (Ford Focus ST)	Electric Vehicle (EV) Battery + Inverter + AC machine (Ford Focus Electric)
Purchase Price	$24,495	$39,995
Significant Maintenance	$5,000 (Major Engine Repair)	$0 - 13,500 (Battery Pack Replacement)
Energy Costs (10-year, 15k mi/yr)	$18,000	$3,000
Range	> 350 mi	< 100 mi
Performance	160 hp @ 6500 rpm 0-60 mph : 8.7 sec ¼ mile: (16.4 sec @ 85.4 mph)	123 hp, 2000-12000 rpm 0-60 mph: 9.6 sec ¼ mile: (17.2 sec @ 82.1 mph)
Curb Weight	3,000 lb	3,700 lb

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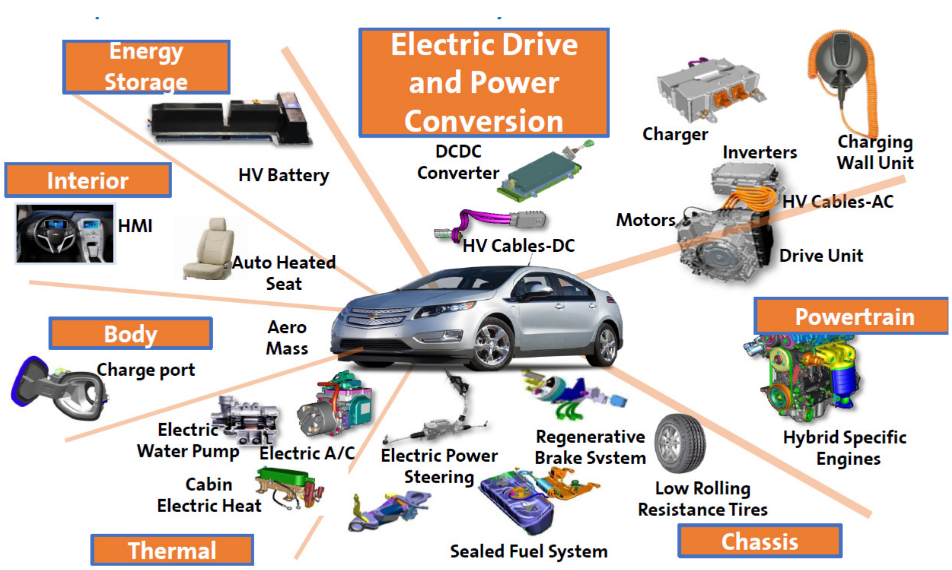
Power Electronics in Electric Vehicles



Peter Savagian, "Barriers to the Electrification of the Automobile," Plenary session, ECCE 2014

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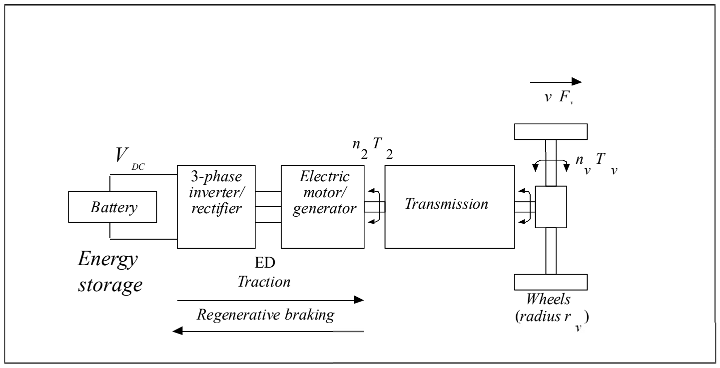
BEV Architecture



Example: Tesla Roadster
- 215 kW electric drive ED1 (sport model)
- 53 kWh Li-ion battery

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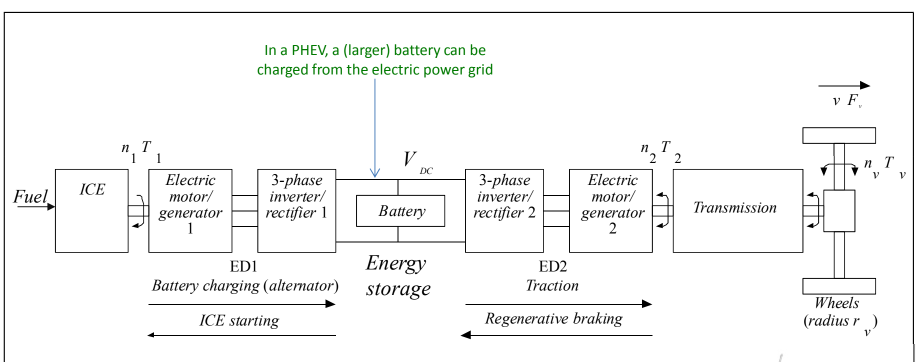
Series HEV Architecture



Example: Chevy Volt, a PHEV with a drive-train based on the series architecture:
- 62 kW (83 hp, 1.4 L) ICE
- 55 kW electric drive ED1
- 111 kW (149 hp) electric drive ED2

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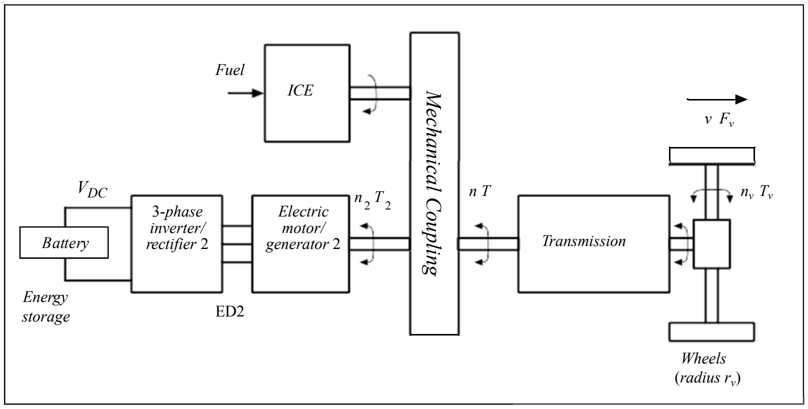
Parallel HEV



Example: 2011 Sonata HEV with a drive-train based on the parallel architecture:

- 121 kW (163 hp, 2.0 L) ICE
- 30 kW electric drive ED1
  - 8.5 kW hybrid starter/generator connected to crankshaft

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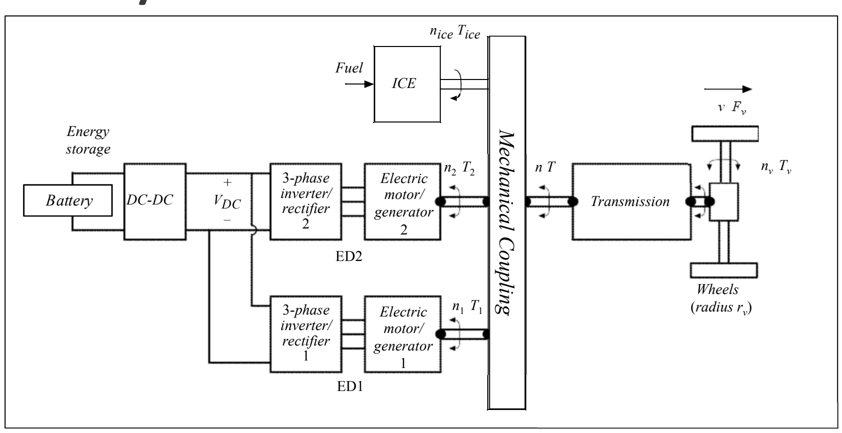
Series/Parallel HEV



Example: 2010 Prius HEV with a drive-train based on the series/parallel architecture :

- 73 kW (98 hp, 1.8 L) ICE
- 60 kW electric drive ED2
  - 100 kW total power
  - 42 kW (149 hp) electric drive ED1

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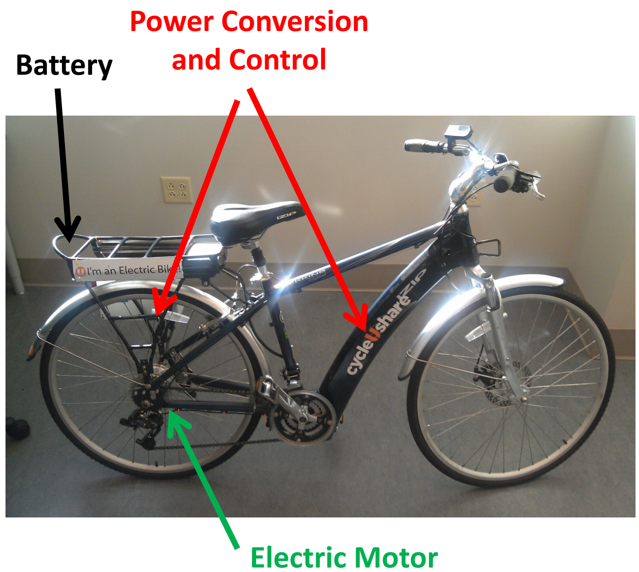
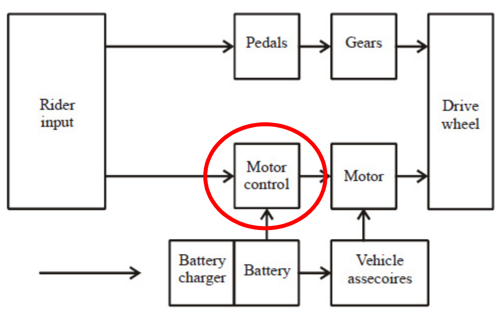
Electric Bicycle Platform



Electric Bicycle System



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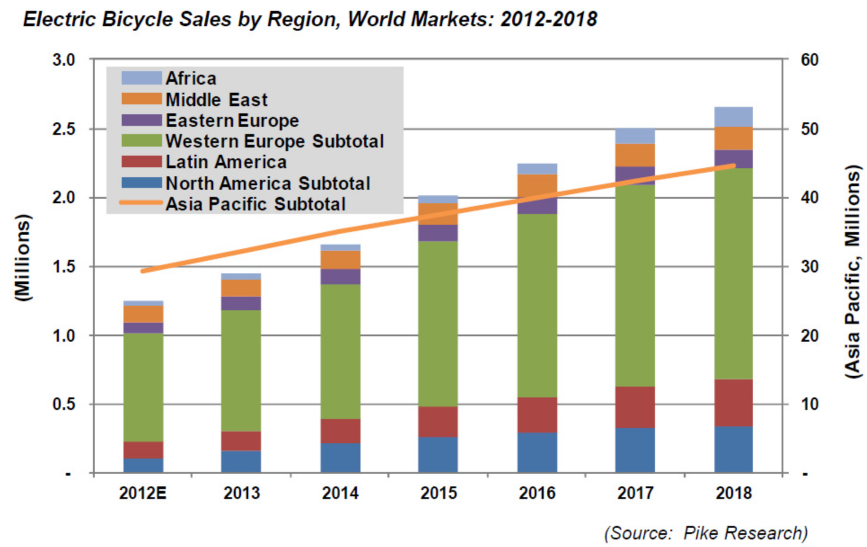
Growing Popularity of E-bikes



Electric Bicycles Worldwide

- E-bikes accounted for $6.9 billion in revenue in 2012
- By utilizing sealed lead-acid (SLA) batteries, the cost of e-bicycles in China averages about $167 (compared to $815 in North America and $1,546 in Western Europe)
- China accounts for 90% of world market
- Western Europe accounts for majority of remaining 10% despite $1,546 average cost
- North America: 89,000 bicycles sold in 2012

Course Details

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Course Introduction

- Hands-on course in design and implementation of power converters
  - Course website: http://web.eecs.utk.edu/~dcostine/ECE482
- Course uses electric bicycle platform as framework for the investigation of practical issues in SMPS construction
- Unlike ECE 481, this is *not* a theory-focused course; expect to spend most of your effort on construction/debugging
- Goal of course is practical experience in designing, building, testing, and debugging power electronics
- System, components, architectures can be modified based on student initiative
- Course is difficult; will require **design** effort and **significant** hands-on time outside of class. Expect to experience circuit failures.
- Prerequisites: undergraduate circuits sequence, Microelectronics, ECE 481 – Power Electronics

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Contact Information

- **Instructor:** Daniel Costinett
  - Office: MK502
  - OH during canceled lectures, in-lab, individually scheduled
  - E-mail: Daniel.Costinett@utk.edu
  - Email questions will be answered within 24 hours (excluding weekends)
  - Please use `[ECE 482]` in the subject line

Course Structure

- Scheduled for one lecture and one 3-hr lab session per week
  - Lectures as needed; many weeks will have two lab sessions
  - Check course website often for schedule
- Theory is presented as necessary for practical design
- Additional theory may be presented in brief sessions during lab time
- Plan to spend 9-12 hours per week on course; mostly lab time

Textbook and materials

- Portions of the Textbook

  R.Erickson, D.Maksimovic, *Fundamentals of Power Electronics*, Springer 2001

  will be used. The textbook is available on-line from campus network
- MATLAB/Simulink, LTSpice, Altium Designer, Xilinx ISE will be used; All installed in MK227 and in the Tesla Lab
- Lecture slides and notes, additional course materials, prelabs, experiments, etc. posted on the course website
- Lab kit is required (purchased from circuits store) in ~1-2 weeks
  - Price: $100-150 per group
  - Additional resistors and capacitors, etc. purchased as needed
  - Need to buy any replacement parts

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Grading

Group

- Lab Completion and Reporting
  - 50% of total grade
  - Turn in one per group

- Labs will be complete in groups of 2-3
  - Choose groups by Tuesday, 1/19
- Late work **will not** be accepted except in cases of documented emergencies
- Due dates posted on website course schedule

Individual

- Pre-Lab Assignments
  - 15% of total grade
  - Turn in one per individual
- In-lab Demonstrations
  - 10% of total grade
  - Questions asked to each group member
- Midterm Exam
  - 15% of total grade
  - Open book/notes, in-class
  - Covers material from experiments
- Peer Evaluation
  - 10% of total grade

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Use of Lab Time

- Attendance is required during all lectures and scheduled lab time
  - Make use of designated time with Instructor present
  - Informal Q&A and end-of-experiment demonstrations
- Work efficiently but do not work independently
  - Understand all aspects of design
- Outside of normal lab hours, key access will be granted (one per group)

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Topics Covered

- **Course Topics**
  - Battery Modeling
  - Modeling and Characterization of AC Machines
  - DC/DC Converter Analysis and Design
  - Loss Modeling of Power Electronics
  - Basic Magnetics and Transformers
  - Feedback Loop Design
  - Layout of Power Electronics Circuits
  - Electric Motor Drivers
  - BLDC and PMSM Control Methods
  - System-Level Control Design

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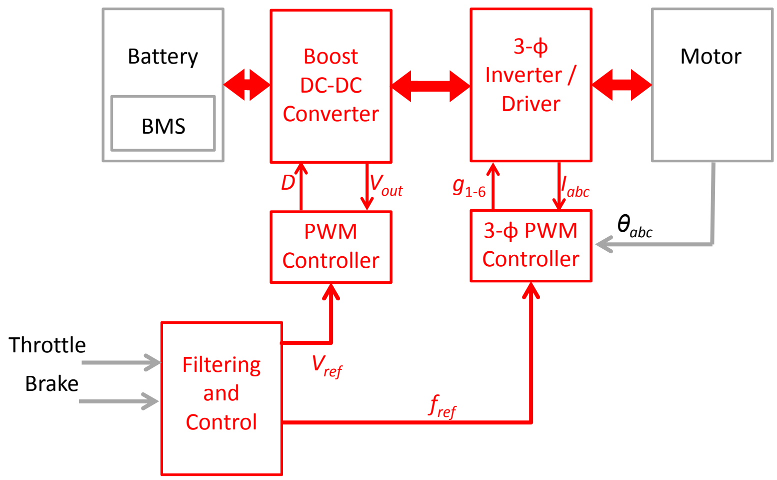
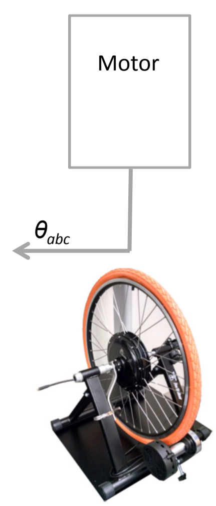
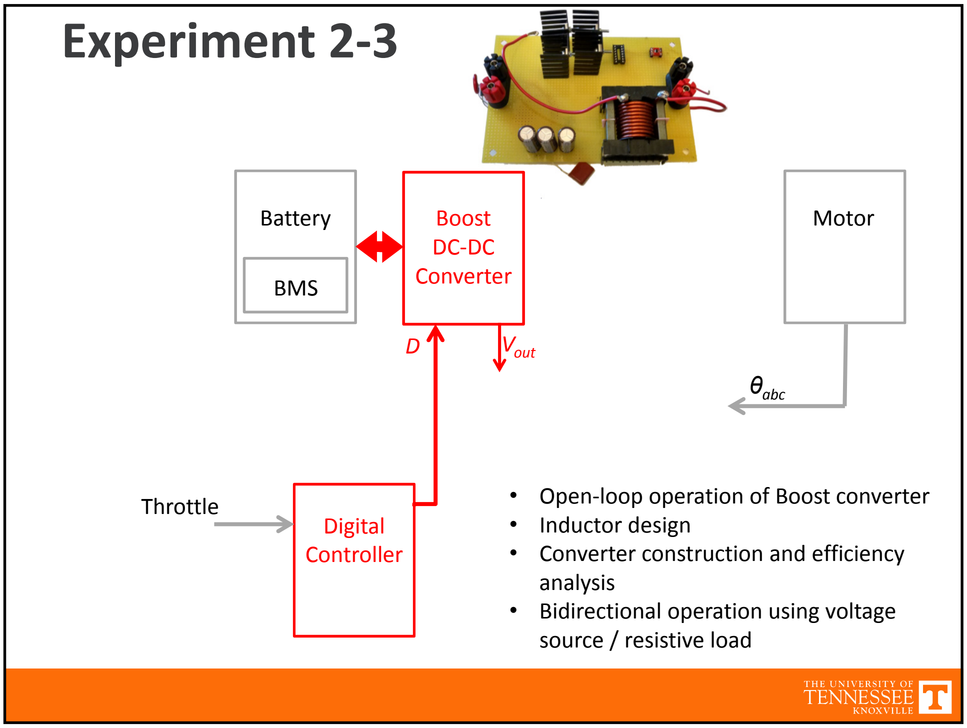
System Structure



Experiment 1



- Identification and characterization of motor
- Modeling of motor using simulink
- Derivation of model parameters from experimental data


Experiment 2-3
Battery
BMS
Boost
DC-DC
Converter
Motor
D
Vout
θabc
Throttle
Digital
Controller
• Open-loop operation of Boost converter
• Inductor design
• Converter construction and efficiency analysis
• Bidirectional operation using voltage source / resistive load
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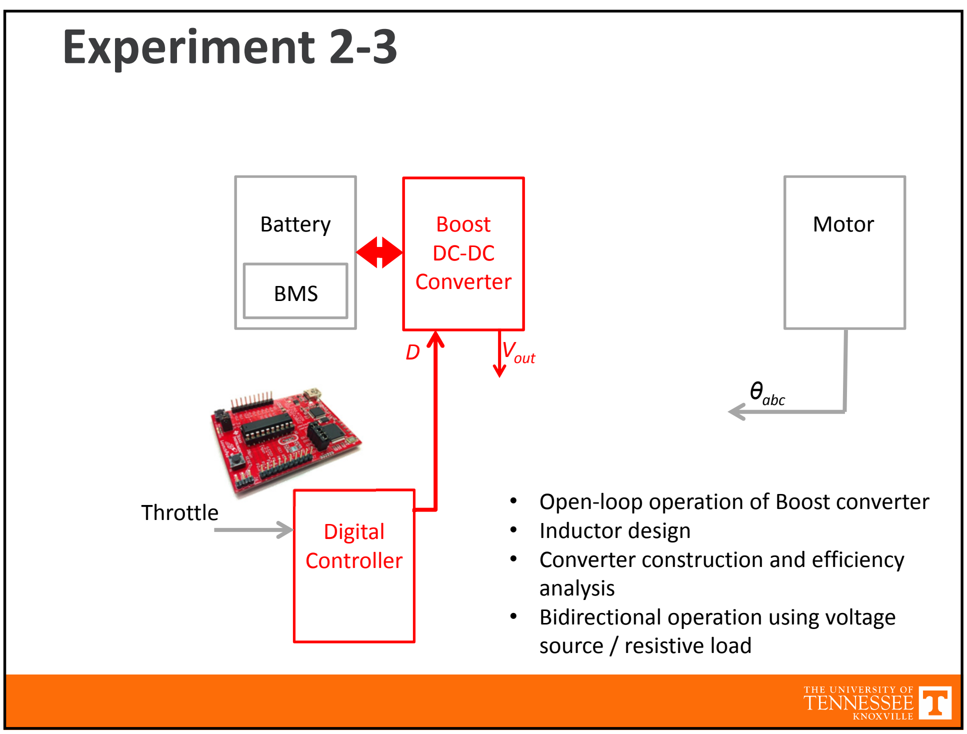
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• Open-loop operation of Boost converter
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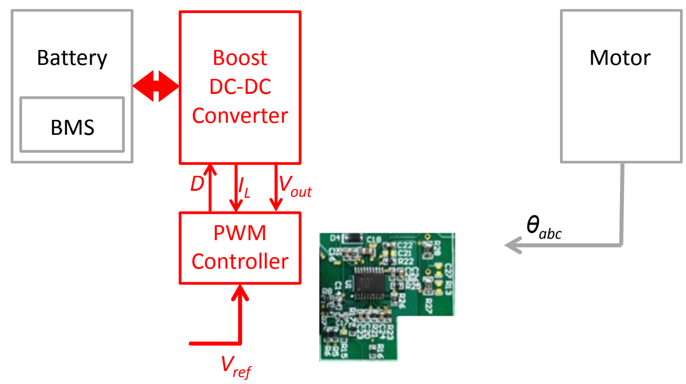
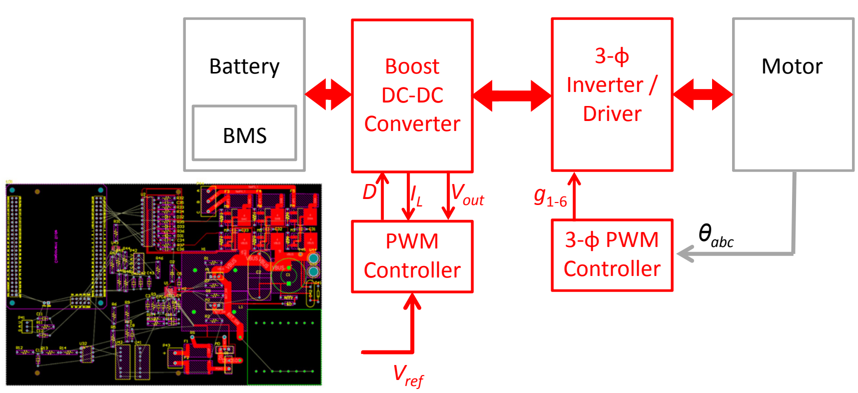
Experiment 4



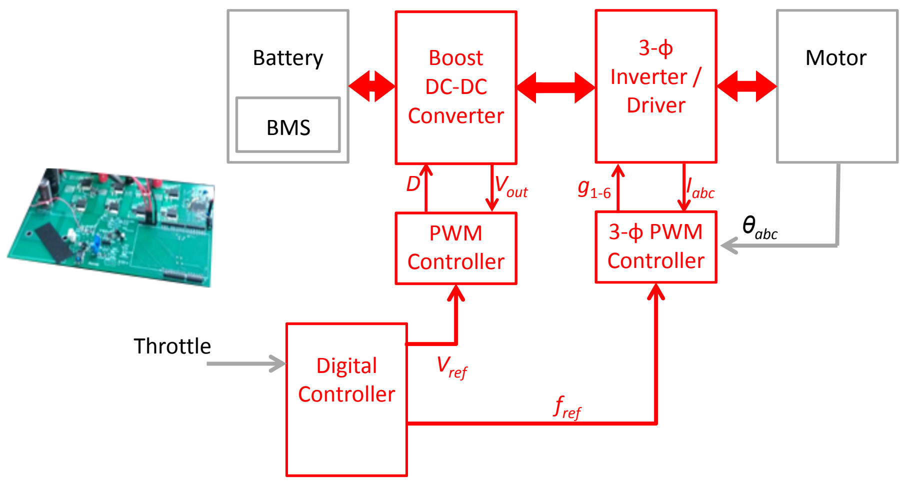
- Closed loop operation of boost converter
- Feedback loop design and stability analysis
- Analog control of PWM converters

Experiment 5



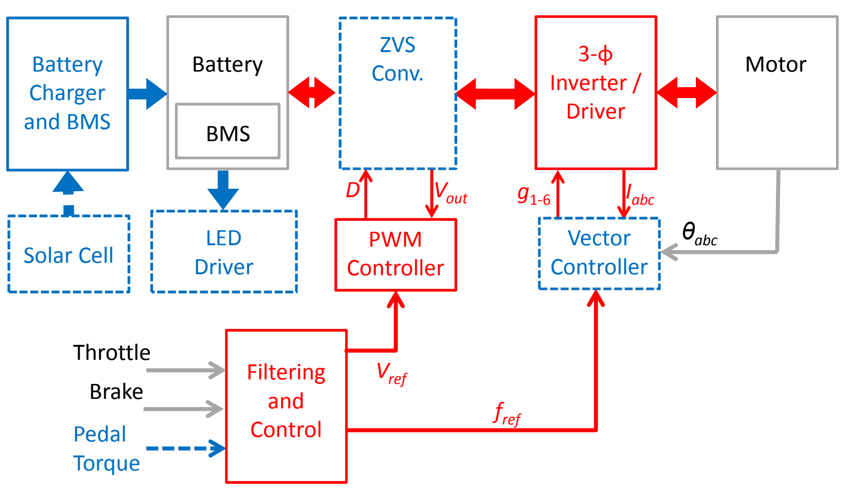
- Circuit layout and PCB design
- Device selection and implementation according to loss analysis
- Basic control of BLDC motors

Experiment 6



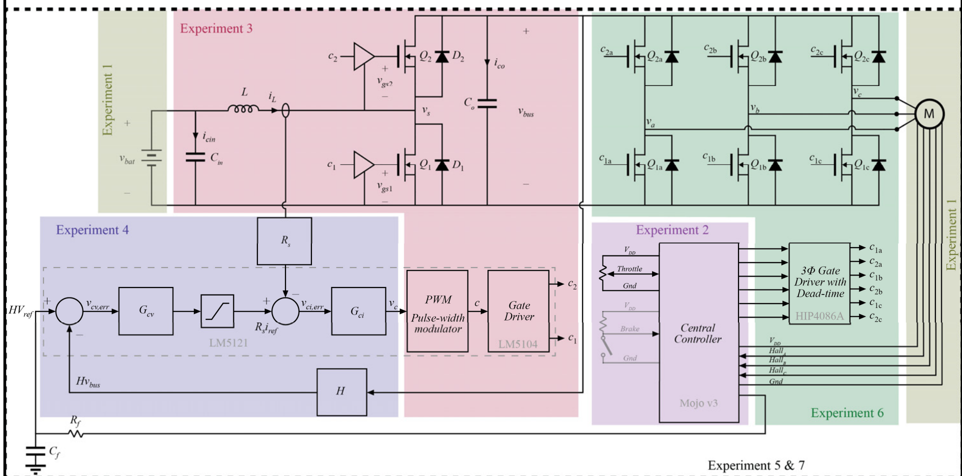
- System-level control techniques

Experiment 7



- System improvements

Example System Implementation



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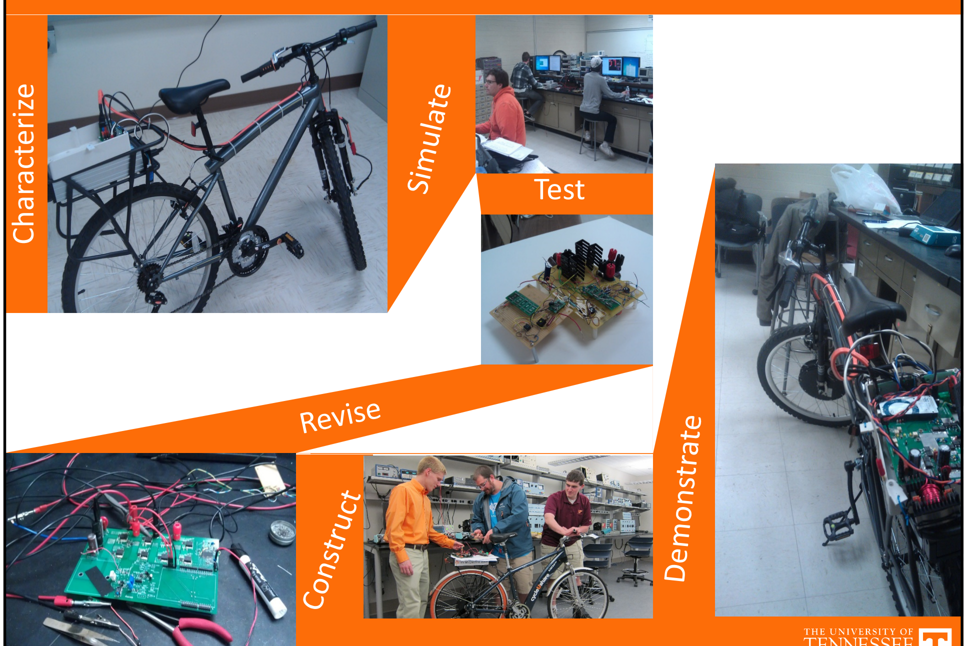

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Design Expo

- No final exam
- Demo operational electric bicycles
- Competition to determine the most efficient and robust system

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Electric Bicycle Safety and Law

- Traffic Law:
  - Electric motor with power output not more than 1000 W
  - Not capable of propelling or assisting at greater than 20 mph
- No helmet laws for riders over age 16; you may request one at any time
- Read Tennessee bicycle safety laws on website

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General Safety

- Lab will work with high voltages (Up to 100 V)
- Will use various machinery with high power moving parts
- High temperatures for soldering
- Use caution at all times
- You may not work with electrical power alone in the lab
- No food or drink allowed in the lab

Safety training Requirements

- Log in to SkillSoft at https://oit2.utk.edu/cbt/login.php
- Once all training is completed print your Skillsoft Learner Records Progress Report and send it to Dr. Costinett
- Must complete with passing scores before Thursday 1/21

Close this window

Learner Records Progress Report:

Login Name JStude32
Learner Name J. Student

COMPLETED

Title	ID	Last Accessed	First Accessed	Completed	Current Score	High Score
Workplace Safety Orientation	esh_sah_a65_sh_enus	Aug 15, 2014	Aug 15, 2014	Aug 15, 2014	100	100
Lockout/Tagout for Authorized Persons	esh_sah_a08_sh_enus	Aug 20, 2014	Aug 15, 2014	Aug 15, 2014	89	89
Hazard Communication: An Employee's Right to Know	esh_sah_b23_sh_enus	Aug 15, 2014	Aug 15, 2014	Aug 15, 2014	100	100
PPE: Eye and Face Protection	esh_sah_a68_sh_enus	Aug 15, 2014	Aug 13, 2014	Aug 15, 2014	100	100
Electrical Safety	esh_sah_b15_sh_enus	Aug 15, 2014	Aug 15, 2014	Aug 15, 2014	100	100
Portable Fire Extinguishers	esh_sah_a42_sh_enus	Aug 14, 2014	Aug 14, 2014	Aug 14, 2014	100	100
Job Hazard Analysis	esh_sah_b29_sh_enus	Aug 13, 2014	Aug 13, 2014	Aug 13, 2014	100	100
NFPA 70E Electrical Safety in the Workplace 2012 Edition	esh_sah_a78_sh_enus	Aug 15, 2014	Aug 13, 2014	Aug 13, 2014	99	100
Course Completions: 8						