Power Electronics Circuits

Prof. Daniel Costinett

ECE 482 Lecture 1
January 23, 2024

THE UNIVERSITY OF
TENNESSEE
KNOXVILLE

Course Introduction

- Hands-on course in design and implementation of power converters
  - 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

Course Structure

- Scheduled for two 3-hr lab sessions per week
- 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

Contact Information

- **Instructor:** Daniel Costinett
  - Office: MK504
  - OH: 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

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; All installed in MK225 and available on remote servers
- 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: $150-200 per group
  - Additional resistors and capacitors, etc. purchased as needed
  - Need to buy any replacement parts

Grading

Group

- Lab Reports
  - 50% of total grade
  - Turn in one per group

Individual

- Pre-Lab Assignments
  - 15% of total grade
  - Turn in one per individual
- In-lab Demo and Participation
  - 20% of total grade
  - Questions asked to each group member
- Midterm Exam
  - 15% of total grade
  - Open book/notes, take-home
  - Covers material from experiments

- Labs will be complete in groups of 2-3
  - Choose groups by *this Thursday*
- Late work will not be accepted except in cases of documented emergencies
- Due dates posted on website course schedule
- All assignments turned in via Canvas

Lab Reports

- Report Guidelines document available with Experiment 1
- Grade dominantly based on functionality and completion
  - Make sure to review procedure
    - Include all requested measurements
    - Respond to any questions or prompts
    - Justify all claims with measurements

Design Expo

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

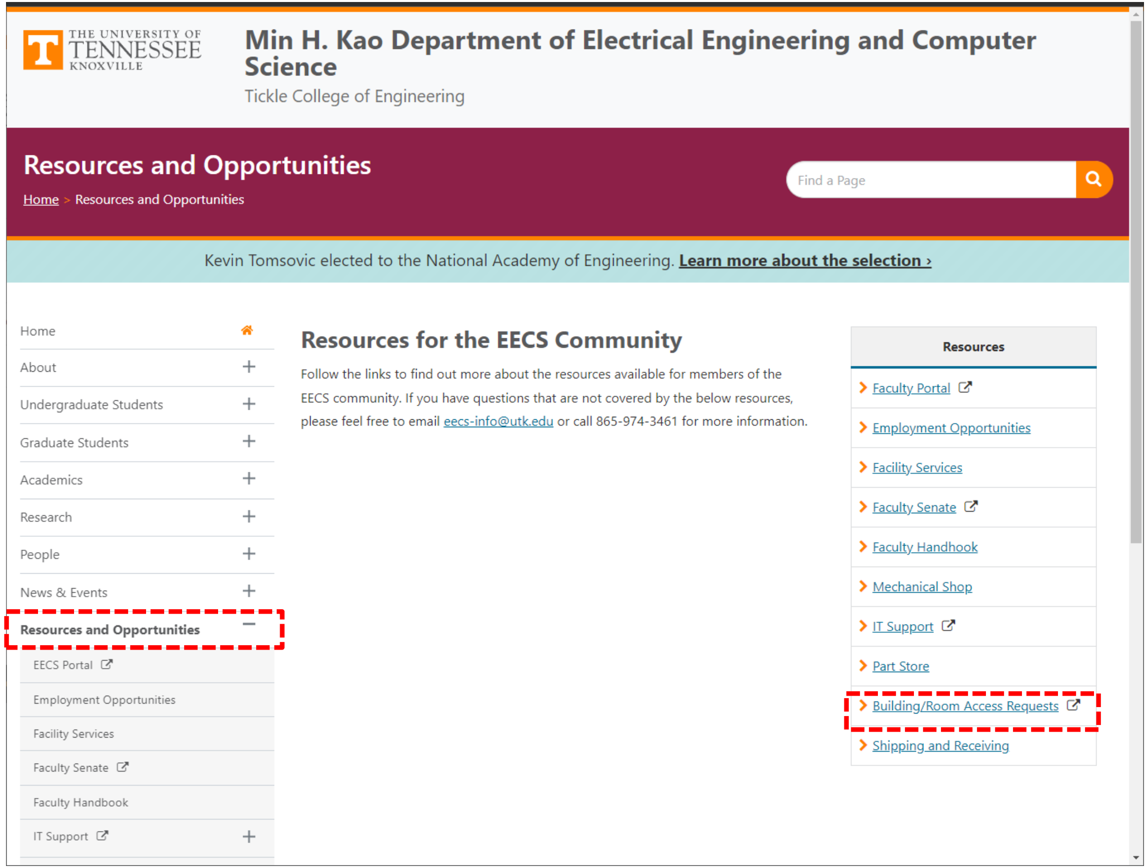
Lectures

- In past, 5-7x 3-hour lectures
- New trial last semester:
  - Using all recorded lectures
  - Watch prior to the associated lab/prelab
  - Discuss during lab sessions
  - Can add additional lectures if needed

Lab Groups

- Self-assign in Canvas prior to next class
  - People → Groups (tab)
  - Groups of 2-3 (5 students)
  - Do not need to stay in same section 482/582
  - Select one person to obtain key for lab access
    - Should be graduate student, is possible

Key Requests



https://www.eecs.utk.edu/resources/

- Fill out as soon as group selected
- Lab doors remain locked

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)

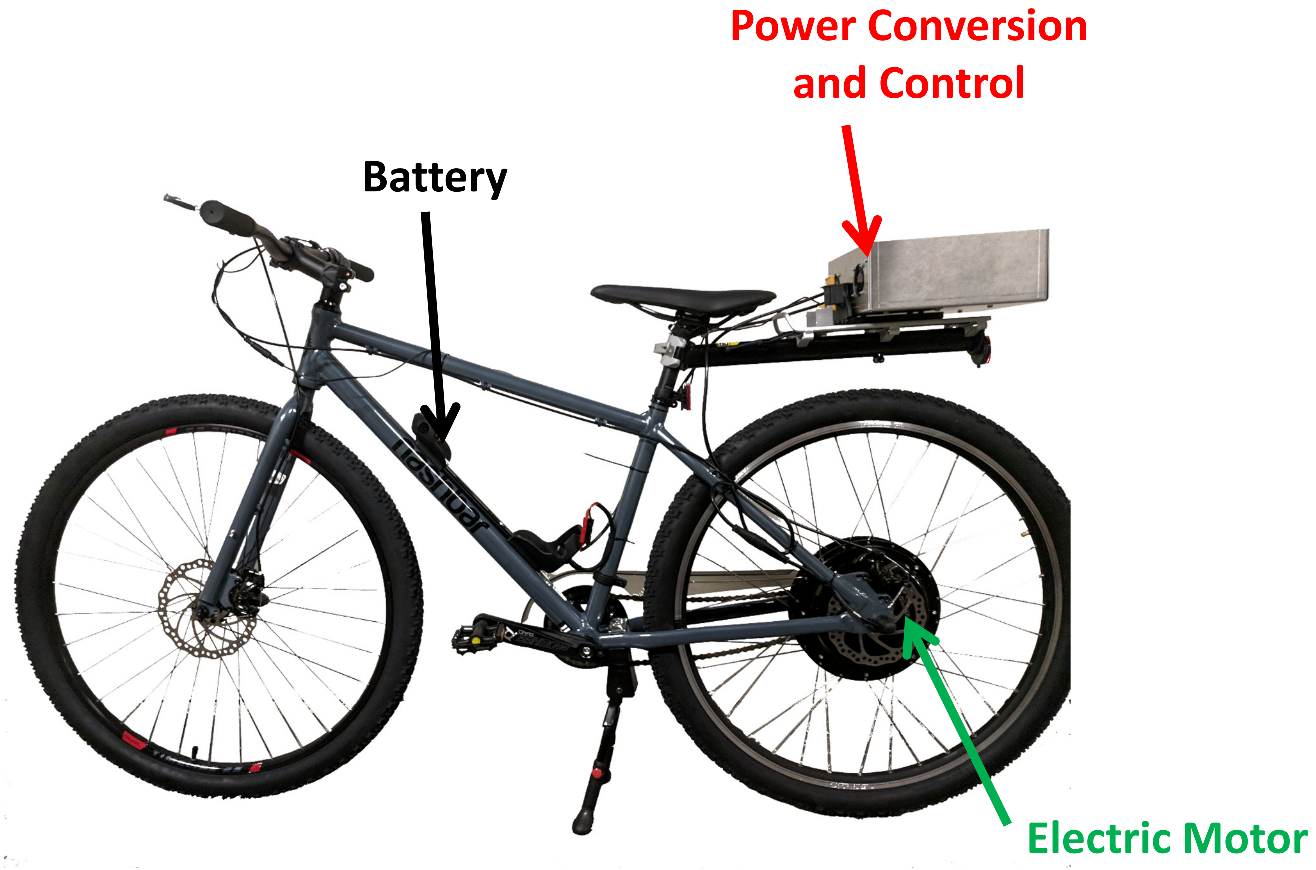
COURSE CONTENT

Topics Covered

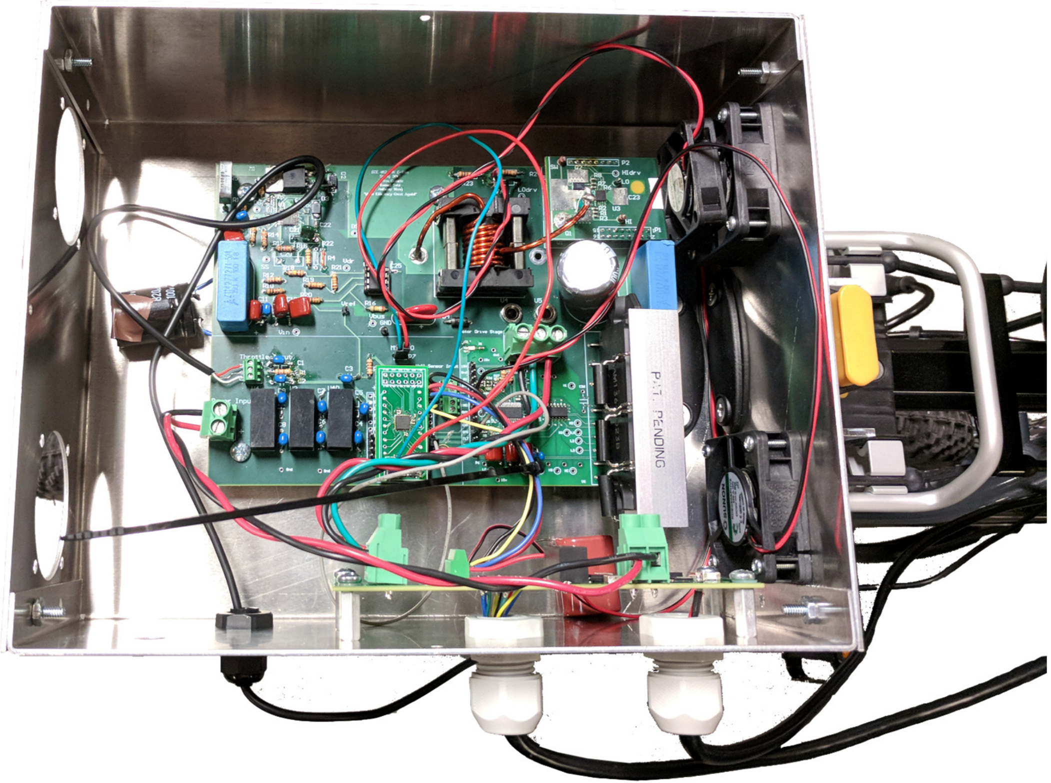
Course Topics

- Battery Modeling
- Modeling and Characterization of AC Machines
- DC/DC Converter Analysis and Design
- Loss Modeling of Power Electronics
- Basic Magnetics and Transformers
- Debugging and prototyping techniques
- Current-mode Control
- Feedback Loop Design
- Layout of Power Electronics Circuits
- BLDC and PMSM Control Methods
- System-Level Control Design

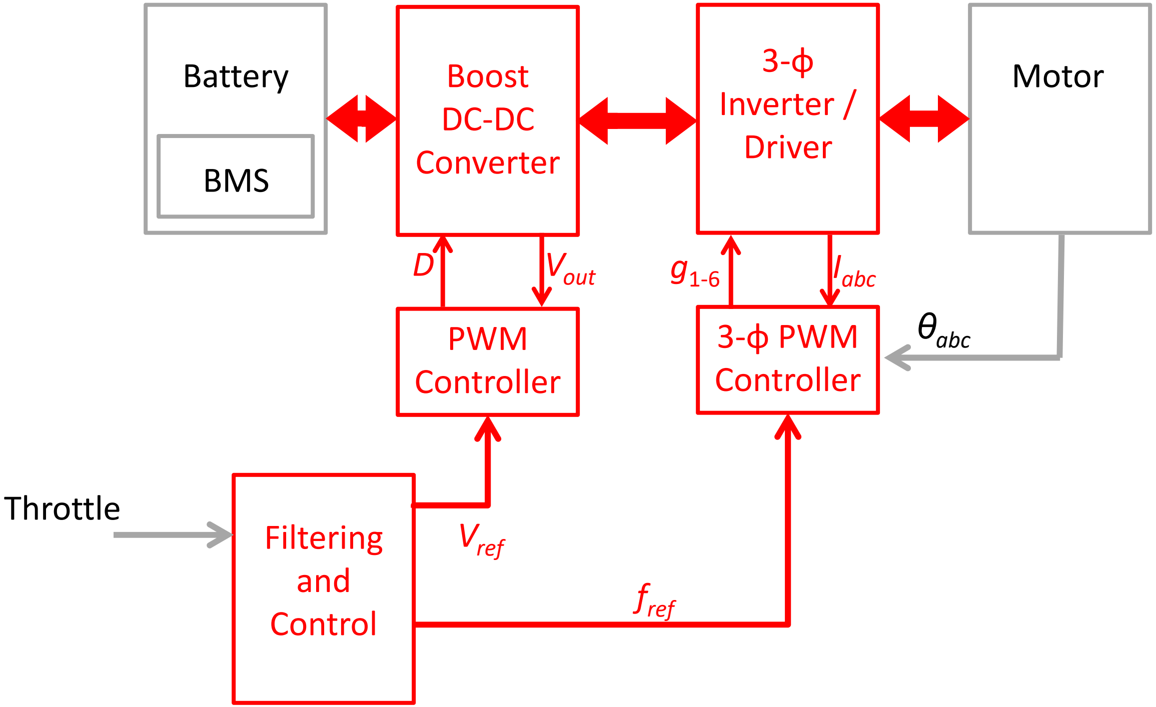
Electric Bicycle Platform



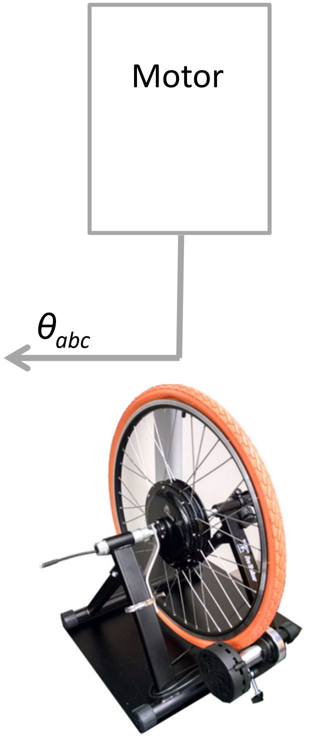
Electrical Build Space



System Structure

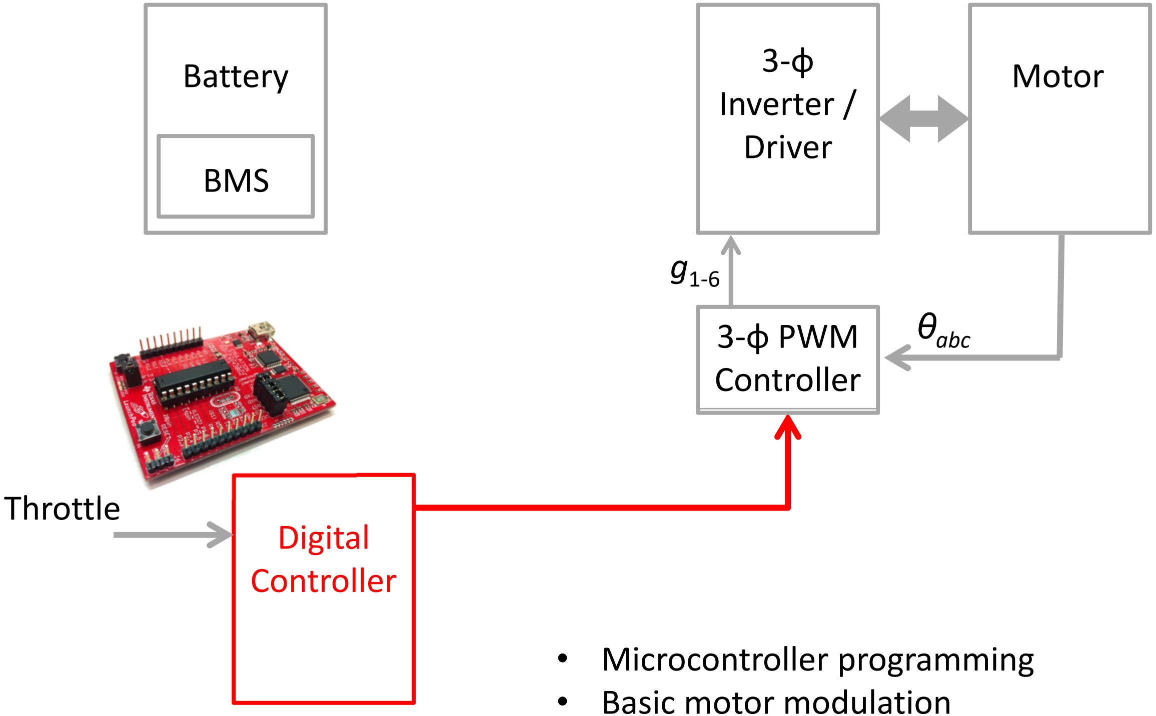


Experiment 1



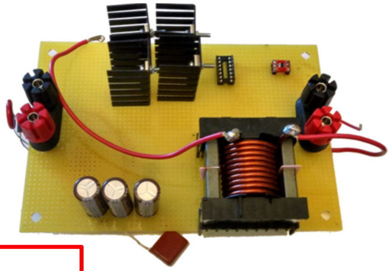
- Identification and characterization of motor
- Modeling of motor using simulink
- Derivation of model parameters from experimental data

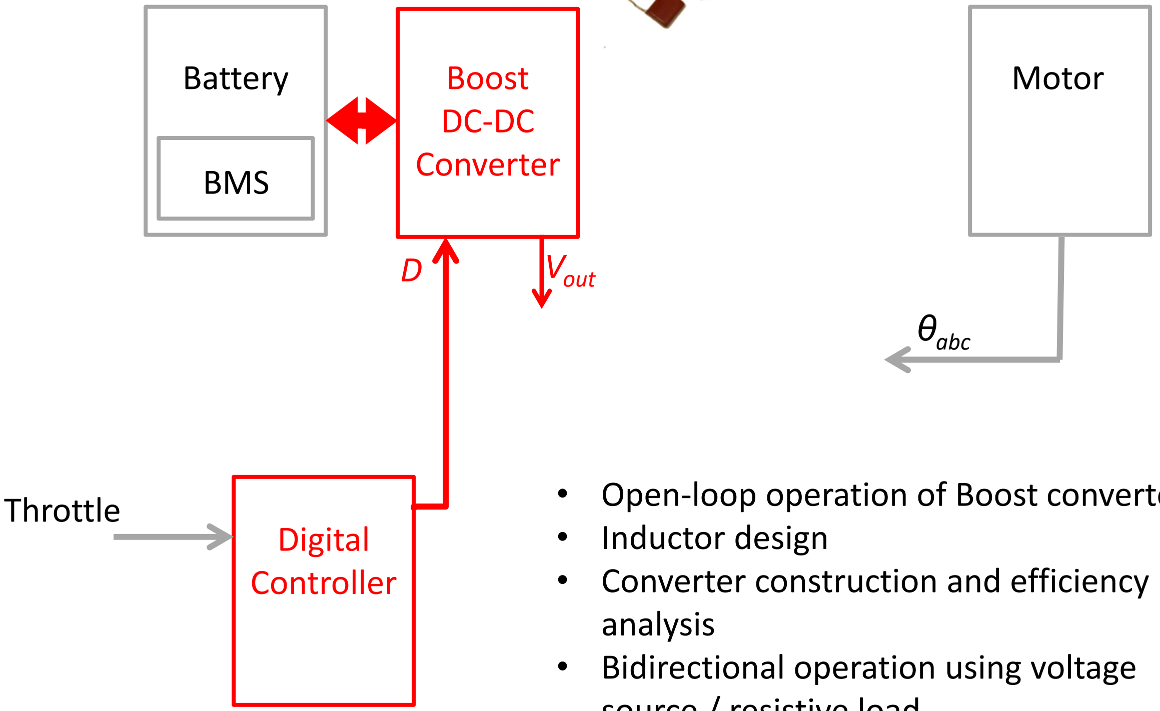
Experiment 2



- Microcontroller programming
- Basic motor modulation

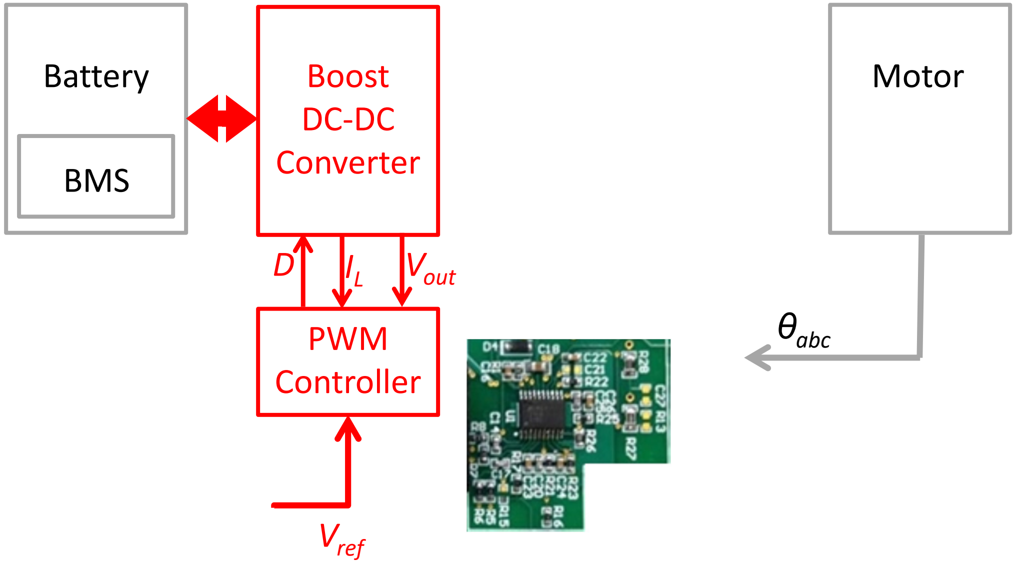
Experiment 3





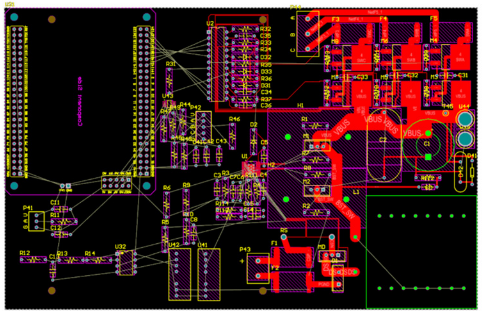
- Open-loop operation of Boost converter
- Inductor design
- Converter construction and efficiency analysis
- Bidirectional operation using voltage source / resistive load

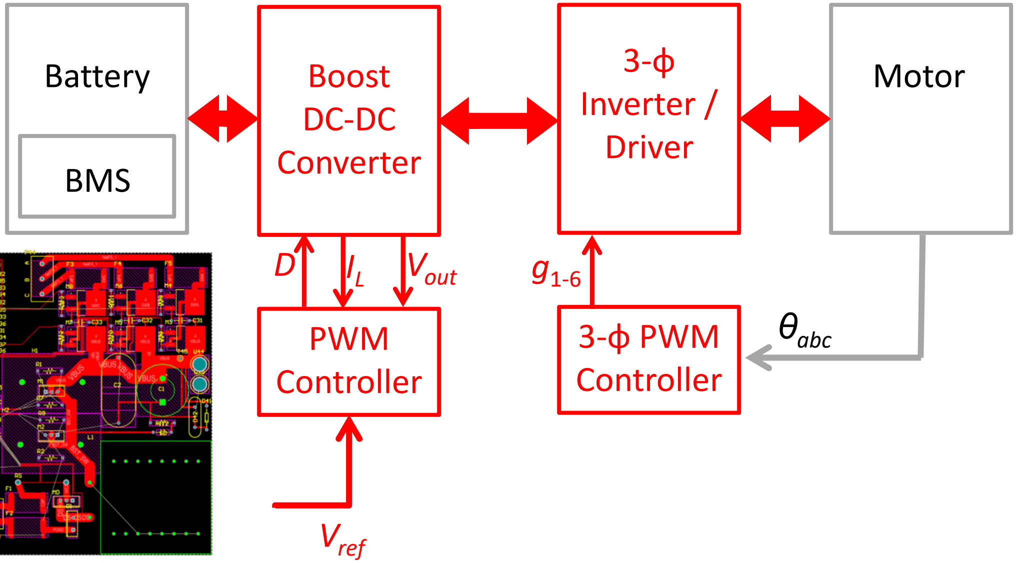
Experiment 4



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

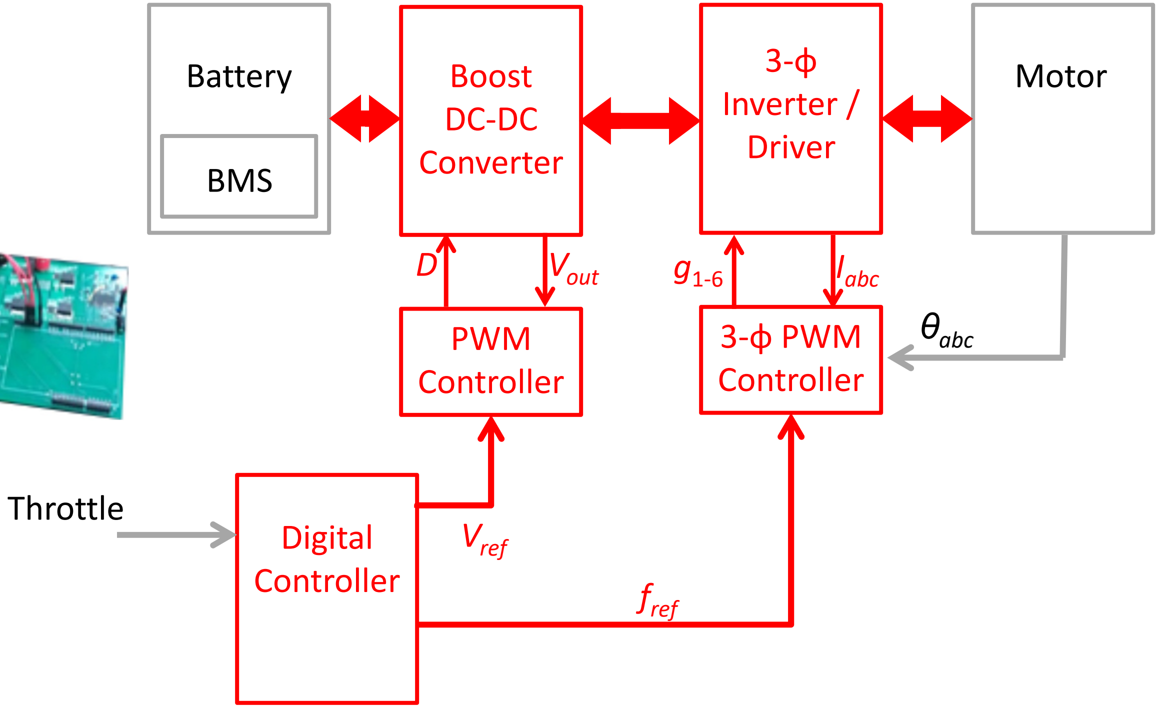
Experiment 5





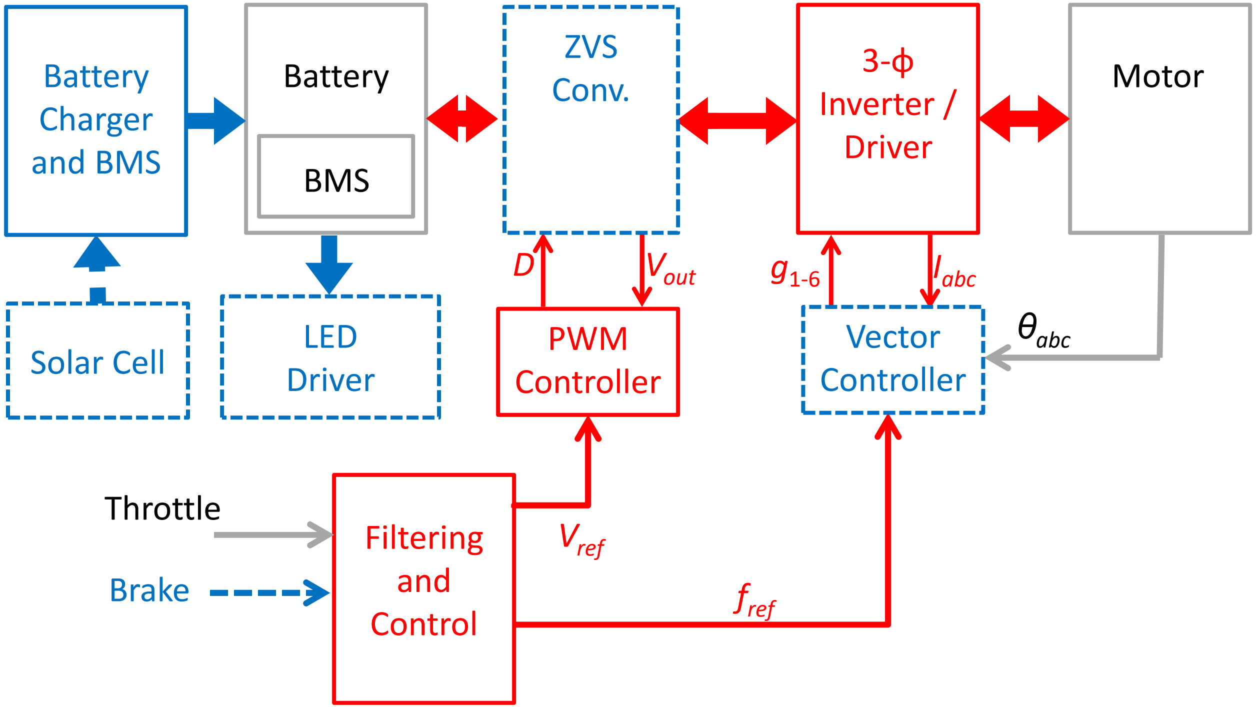
- Circuit layout and PCB design
- Device selection and implementation according to loss analysis
- Basic control of BLDC motors

Experiment 6



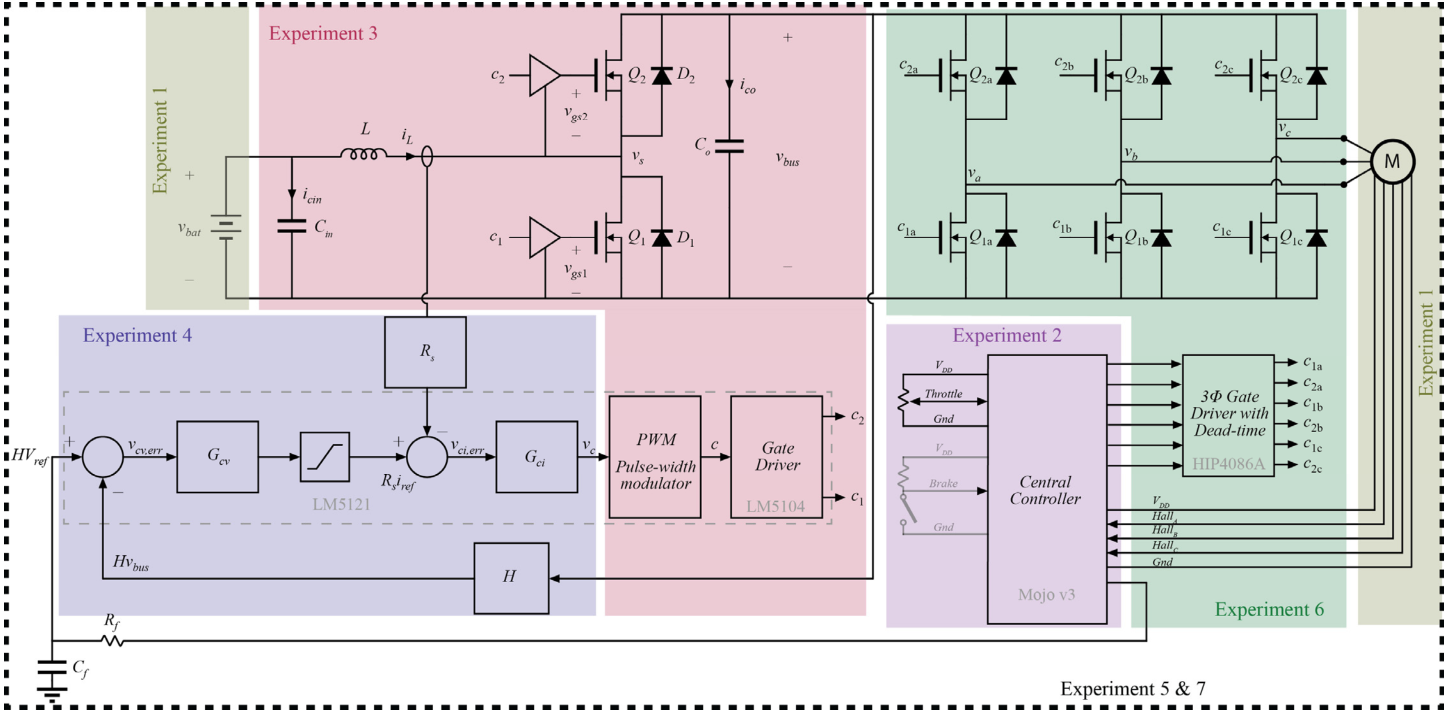
- System-level control techniques

Experiment 7



- System improvements

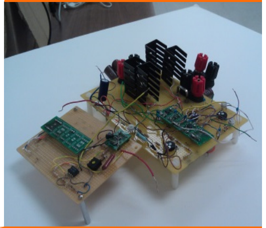
Example System Implementation



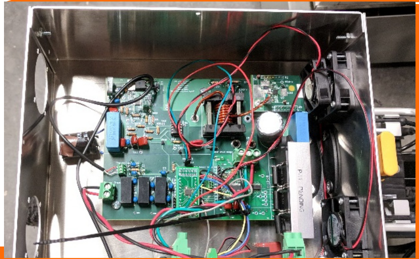
Characterize

Simulate

Test

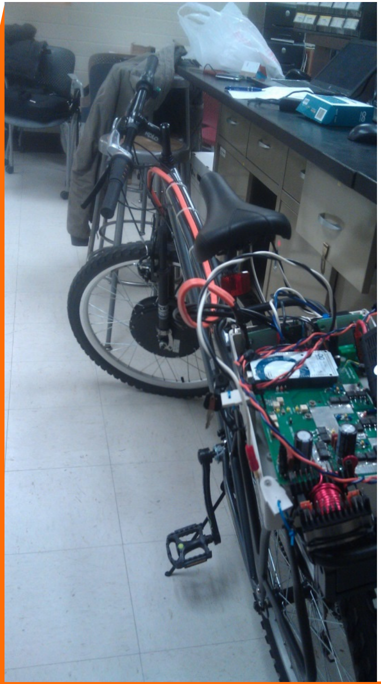


Revise



Construct

Demonstrate



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

General Safety

- Lab will work with high voltages (Up to ~75 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

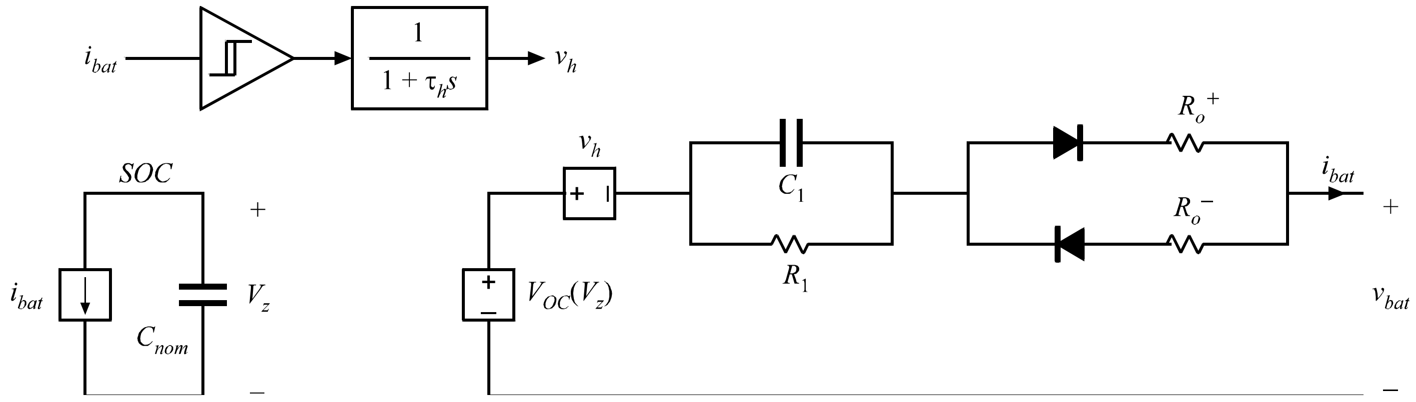
Safety training Requirements

- Login to canvas at https://utk.instructure.com/courses/29416/modules
- Complete training modules
  - General Lab Safety
  - Hazardous Waste
  - Hazard Communication Training and GHS Updates
  - Fire Extinguisher Training
  - Fire Safety in Laboratories
  - Chemical Fume Hood Safety Training
  - Compressed Gas Cylinder Training
  - Laboratory Safety for Undergraduates and Minors (required only if UG or minor)
  - Personal Protective Equipment
  - Electrical Safety, Orientation Level
  - Lead Awareness Training
- Once all training is completed print your "Completed" Transcript and turn it in to Dr. Costinett by e-mail
- Must complete with passing scores before Thursday 1/18

Lab 1

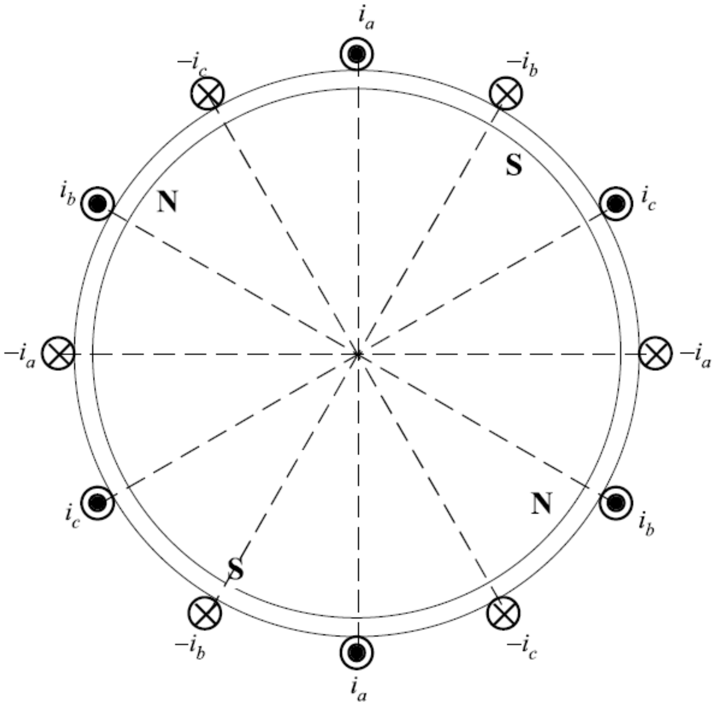
Model D: Diffusion (one-state)

[Plett 2004]



3-Phase, P-Pole PMSM

P = 4 example



Electrical and mechanical angle

$$\theta_r = \frac{P}{2}\theta_{rm}$$

Electrical and mechanical speed

$$\omega_r = \frac{P}{2}\omega_{rm}$$

Max torque per amp

$$T_m \le \lambda_m \frac{P}{2}\frac{3}{2} I$$

Battery Modeling in Experiment 1

- Batteries have Battery Management System (BMS)
  - Limit over-current, over-discharge
  - **Do not** connect directly to battery cell
- Never leave charging or discharging batteries unattended
- Not entirely analytical and solution may not be unique
  - Guess and check is fine, where appropriate
  - Not all parameters need to be included

- Insert batteries into BMS in correct polarity
  - Use voltmeter to be sure
- BMS will cut off with sustained, large current (>~2A)
- After BMS cutoff, connect leads to charger to reset BMS

Motor Modeling in Experiment 1

- Should not apply any voltage to the motor windings or hall outputs
  - Solely measure induced voltage
  - Can power up hall sensors as detailed in lab
- Be careful not to short any wires while spinning the motor

Homework

- Watch experiment 1 recorded lectures
  - With required background ~30 min
- Complete Safety Training
- Select lab groups of 2-3
  - Submit key request (one per group)