Ultracapacitor Assisted Powertrains

Ardalan Vahidi

Clemson Renewable Energy Systems Lab
Mechanical Engineering
Clemson University

CLEMSON
UNIVERSITY

Overview

- Ultracapacitor-assisted conventional powertrains
- Ultracapacitor-assisted fuel cells
- Future research plan: Ultracapacitor + Batteries

Ultracapacitor-Assisted Conventional Powertrains

The Case for Ultracapacitors in Mild Hybrids

- A simple calculation can show that, for a 2000 kg vehicle, going from 0 to 60 mph in 10 seconds requires over 70kW of power in addition to overcoming drag and road grade.

- An engine rated for steady-state driving conditions may have to work well outside of its efficient operating region to provide this temporary power.

- High power-density ultracapacitors integrated with vehicle powertrains (in a mild parallel hybrid configuration) can boost the power during vehicle acceleration, relax the engine transients and may therefore be an effective mechanism for reducing fuel consumption and emission.

Advantages In Hybrid Vehicles

- High power density
- Low impedance
- Virtually unlimited cycle life
- Rapid charging
- Reliable performance in harsh environments

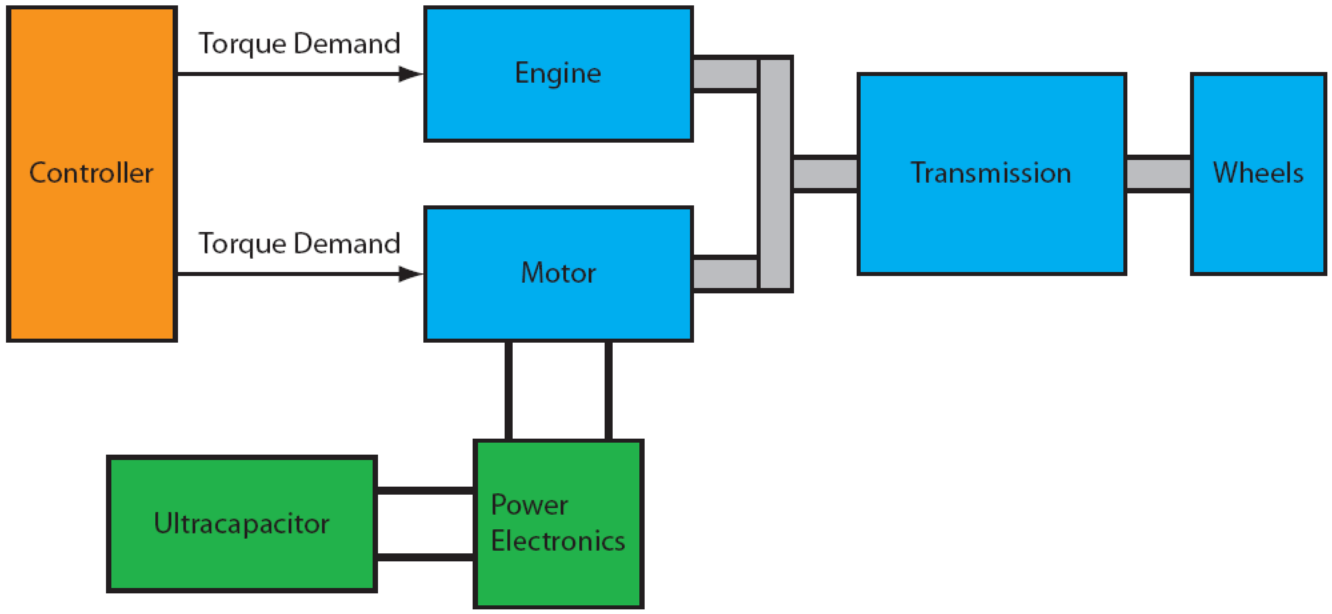
BMOD0140 Maxwell ultracapacitor module:
Capacitance: 140F Voltage: 48 Volts
Mass~13kg
Energy: Only 160 kJ Power: Up to 30~60kW instantaneously

Successful Implementations

"An electric engine has a lot of torque at low revs — that is its main benefit — so it's ideal for fast initial acceleration. At higher revs, once you've begun to accelerate, nothing can beat an internal combustion engine. Our hybrid approach combines the best characteristics of both engines." Prof. Freymann from BMW.
www.utracapacitors.org

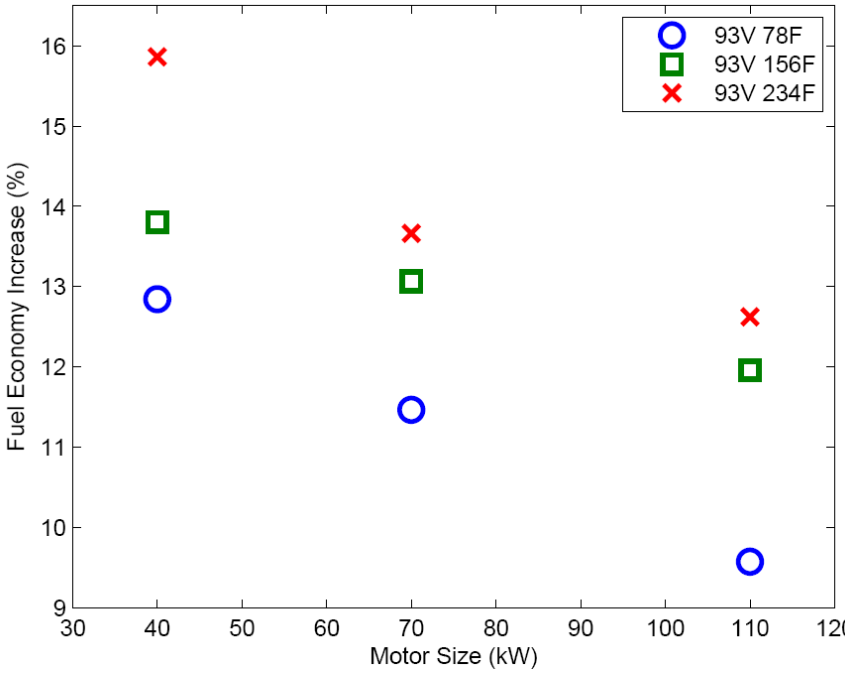
Here, the Siemens generator is driven by a Ford Triton 6.8 liter V-10 engine modified to operate on pure hydrogen. It provides up to 150 kW of electric power in this series hybrid to drive a Siemens ELFA drive system. Excess energy, as well as energy recouped by regenerative braking, is stored in Maxwell ultracapacitors.

Powertrain Configuration

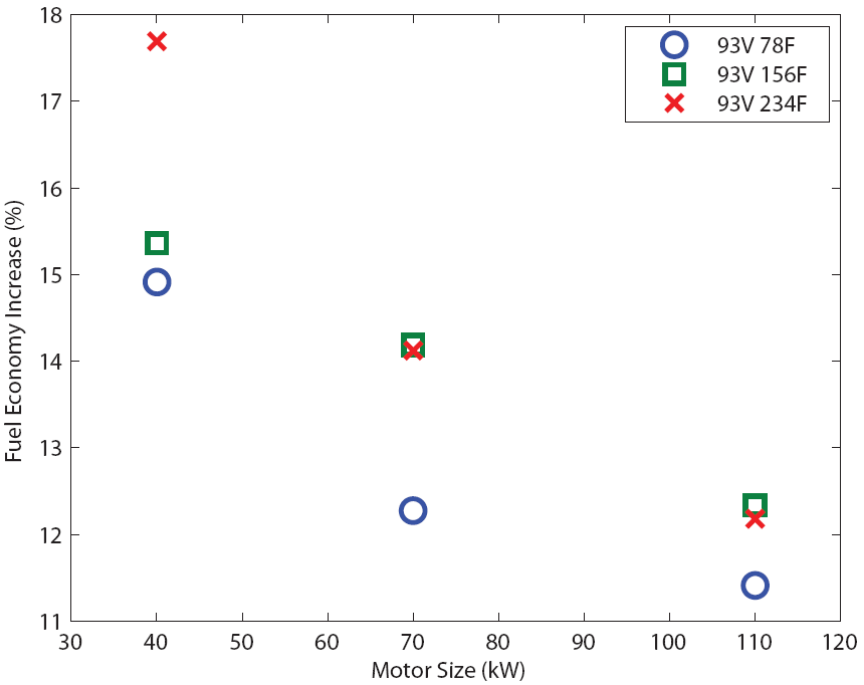


Fuel Economy Improvement

With the original 160kW engine



With a downsized 120kW engine



Demonstrates up to 15% reduction in fuel use for city cycle with 2 ultracapacitor modules and a 40kW induction motor.

D. Rotenberg, A. Vahidi, and I. Kolmanovsky, "Ultracapacitor Assisted Powertrains: Sizing, Modeling and Control, and The Impact on Fuel Economy" *Proceedings of 2008 ACC*.

Ultracapacitor-Assisted Fuel Cells

Ballard Nexa® Fuel Cell Power Module

- PEM Fuel Cell Module
- Rated net power: 1.2 kW
- Rated current: 46 Amps
- DC voltage range: 22 to 50 V
- Integrated control board
  - Regulates hydrogen pressure
  - Compressor speed
  - Controls cell/stack humidity
  - Monitors general system performance

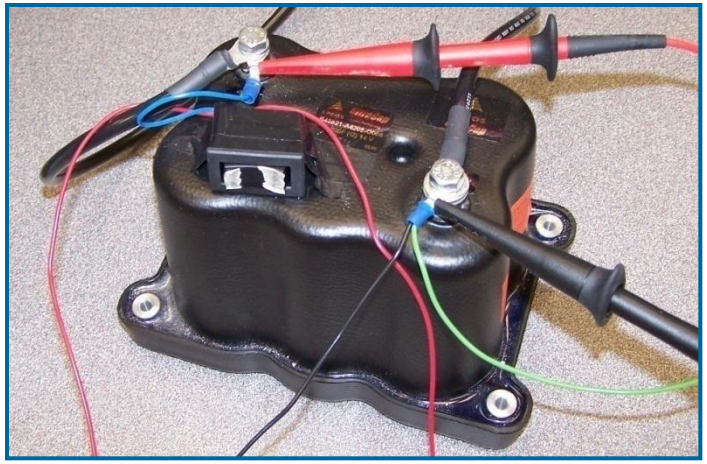
Why a Fuel Cell Hybrid?

- Rapid load transients on fuel cells*,
  - can saturate the air supply system
  - can cause oxygen or hydrogen starvation causing permanent damage to the stack
  - May result in lower efficiencies
- Fuel cells need power assistance during startup and this needs increases in cold temperatures.
- An auxiliary power source is therefore needed to assist during startup and for buffering during transients.
- An ultracapacitor module can provide the required buffer. The fuel cell can be sized for steady-state.

* Schmittinger and Vahidi "A Review of the Main Parameters Influencing Long-Term Performance and Durability of PEM Fuel Cells" *Journal of Power Sources*, 180, 1-14, 2008.

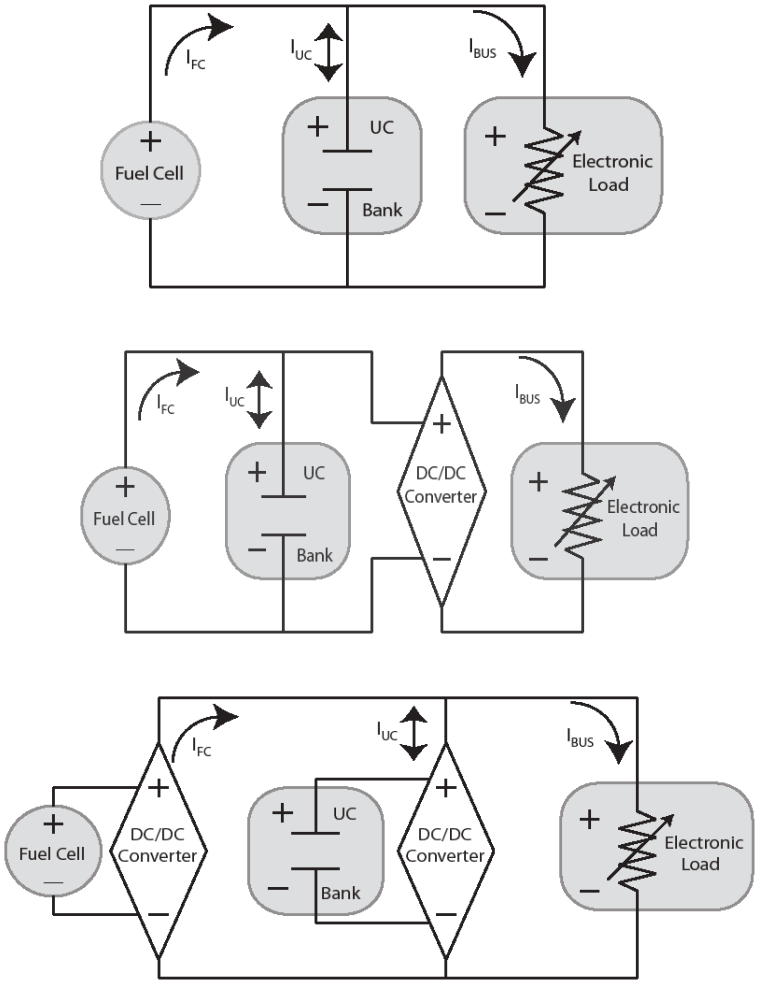
The EPCOS® Ultracapacitor Module

- Rated Voltage – 14 V
- Capacitance – 200 Farads
- Energy storage – 5.44 Wh
- Equivalent series resistance (ESR) of approximately 5.0 mΩ
- Single module can deliver 8 kW for approximately 2.5 seconds

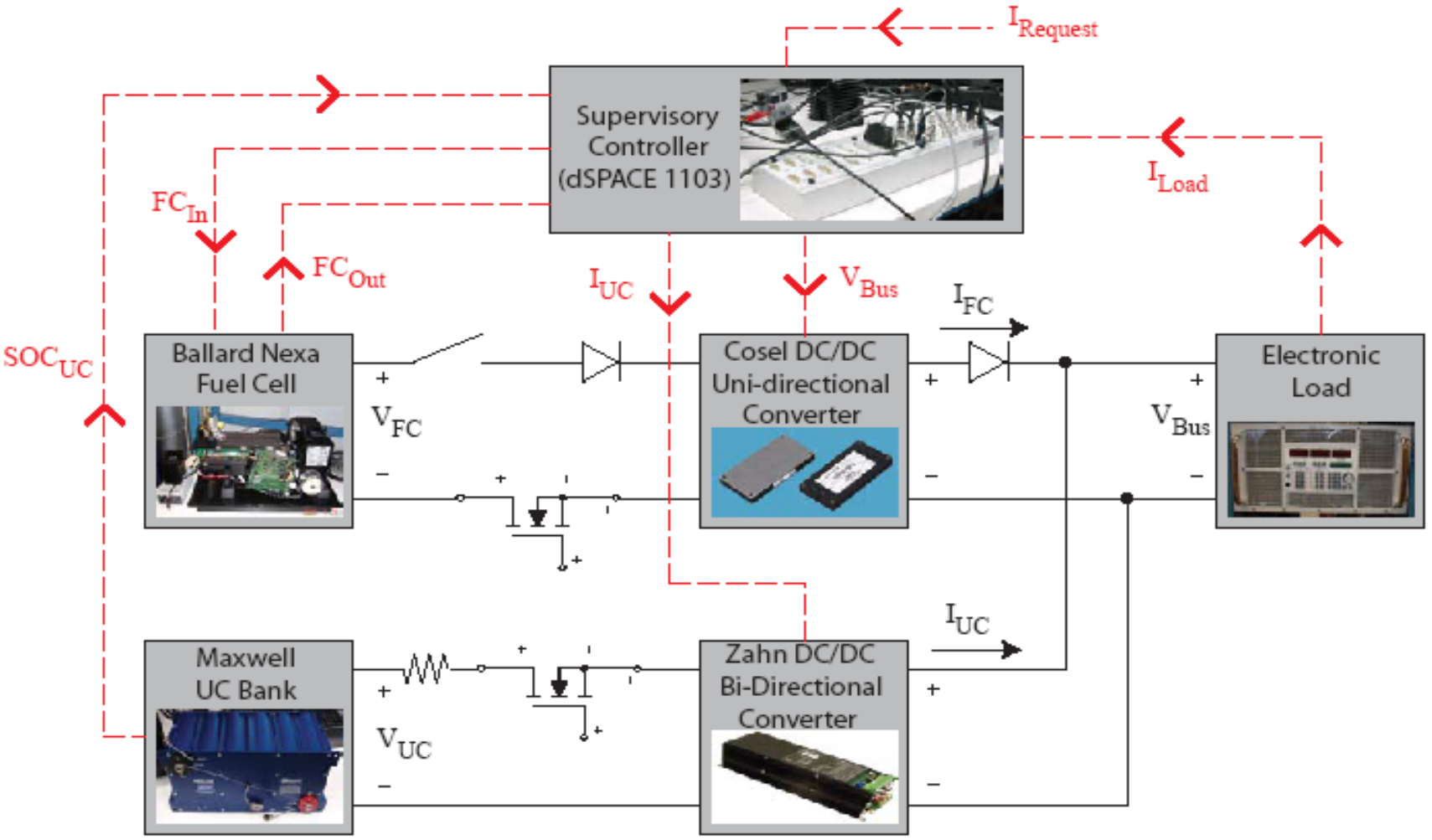


System Integration and Power Electronics

- DC/DC converters act as “actuators” of the system to control output of the unregulated UC bank and fuel cell
- At least one DC/DC converter required for controlling BUS voltage
- Active current control requires addition of second DC/DC converter
- Tradeoff between control of hybrid voltage/current split and additional losses



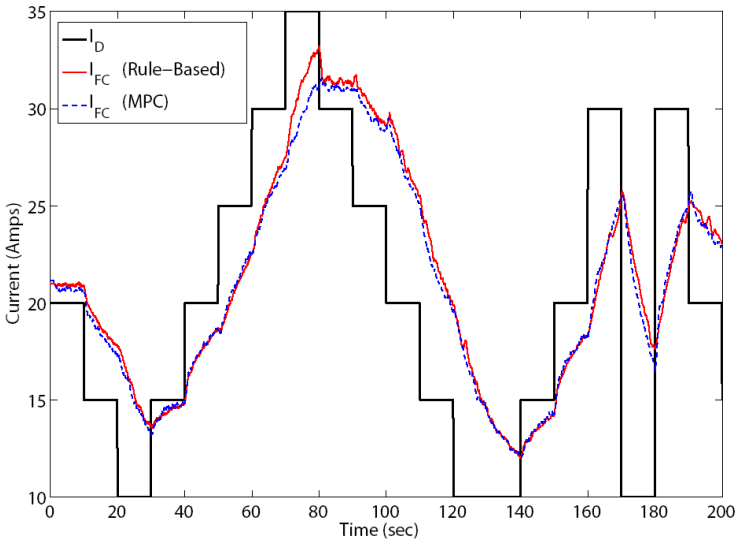
Fuel Cell – Ultracapacitor Laboratory Integration

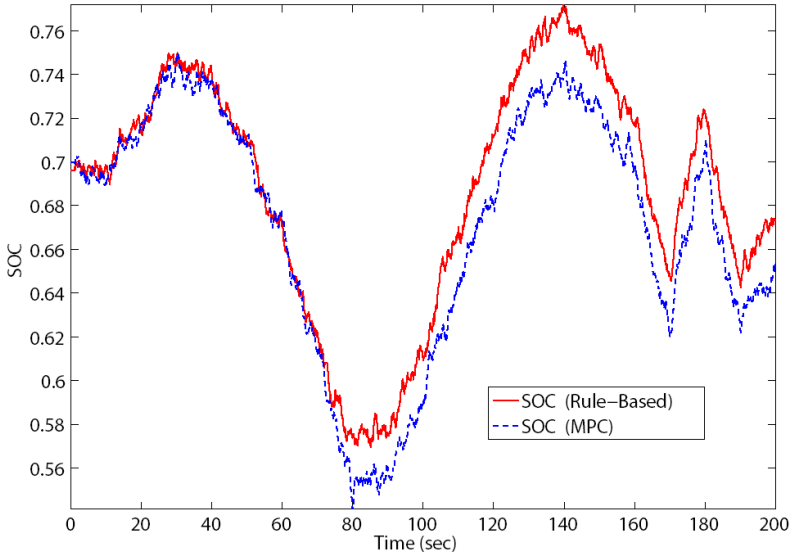


Greenwell, Wesley, and Vahidi, Ardalan, "Experiments in Predictive Coordination of a Fuel Cell/Ultracapacitor Hybrid" *Proceedings of ASME Dynamic Systems and Control Conference*, Ann Arbor, MI, 2008.

Some Experimental Results

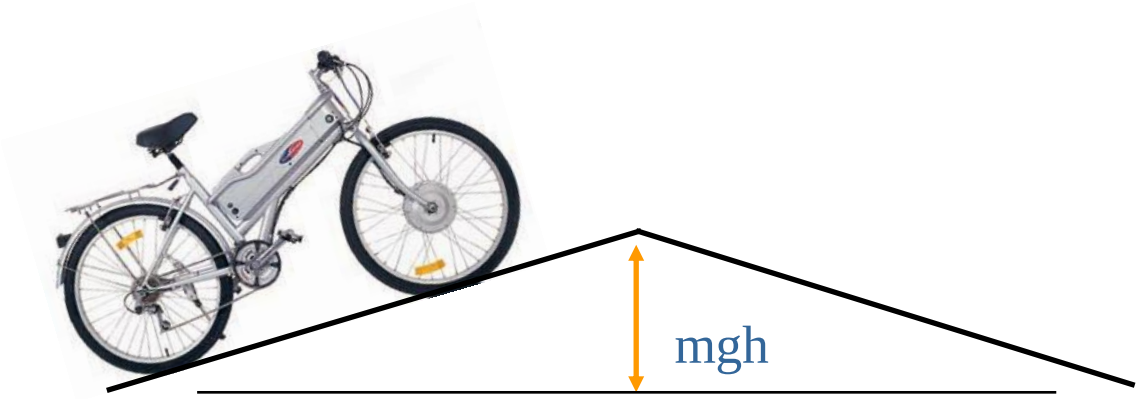
- Two filtering algorithms were used to filter the current demand on the fuel cell.
- During this time the excess power is supplied from (or charged to) the ultracapacitor.

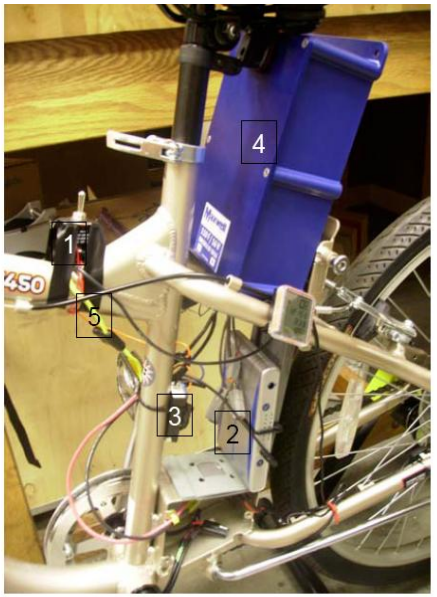


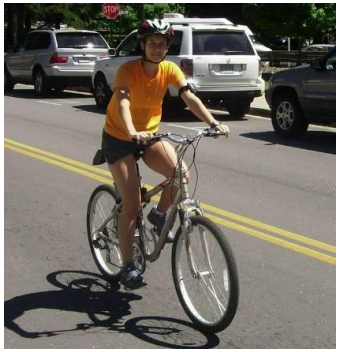


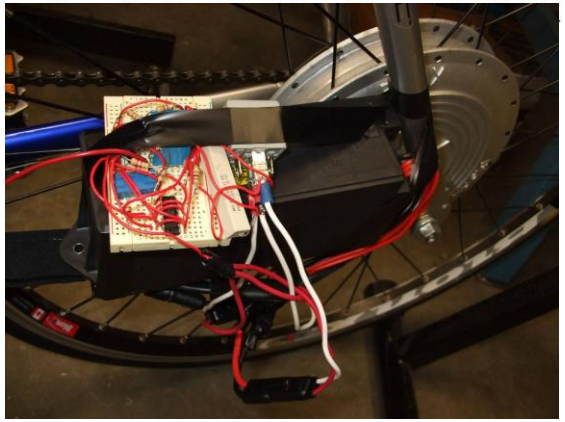
Future Research Plan: Ultracapacitor + Batteries

Ultracapacitor-Battery Hybrid Bicycle









Undergrads: Maria, Carl, and Seneca riding the E-Bike.

Proposed Project: Ultracapacitors + Batteries

Objective: The goal is to determine, via simulation and experiments, potential of ultracapacitors to accommodate electrical payload demands in hybrid vehicles allowing a reduction in battery size and increase in battery life.

Benefits: High power-density ultracapacitors integrated with batteries can boost the power during vehicle acceleration, relax the battery load transients, capture part of regenerated energy and may therefore be a viable method for reducing the battery size without compromising vehicle agility. By covering rapid load transients they will extend life of the expensive battery pack.

Technical Approach:

1. Create detailed simulation models of a typical hybrid vehicle battery pack including a dynamic power response model and a battery aging model.
2. Create integrated battery-ultracapacitor models and a control strategy that coordinates the power split between battery and ultracapacitor under typical driving load demands.
3. Determine via simulation the benefits attainable including impact on battery life and electrical system responsiveness to power demand.
4. Construct an experimental testbed which includes a battery pack, an ultracapacitor, the power electronics, and the control system.
5. Verify simulation results via experiments.

Team: Ardalan Vahidi
+ 1 graduate student

Current Industrial Partners:
Ford Motor Company, ARC-TACOM

Experimental Facility:
200HP Eddy Current Engine Dyno
4kW electronic load,
Ultra-capacitor modules capable of releasing up to 20kW instantaneous power
Multiple dSPACE data acquisition systems
Various power electronics modules