Power Electronics Research at the University of Illinois at Urbana-Champaign

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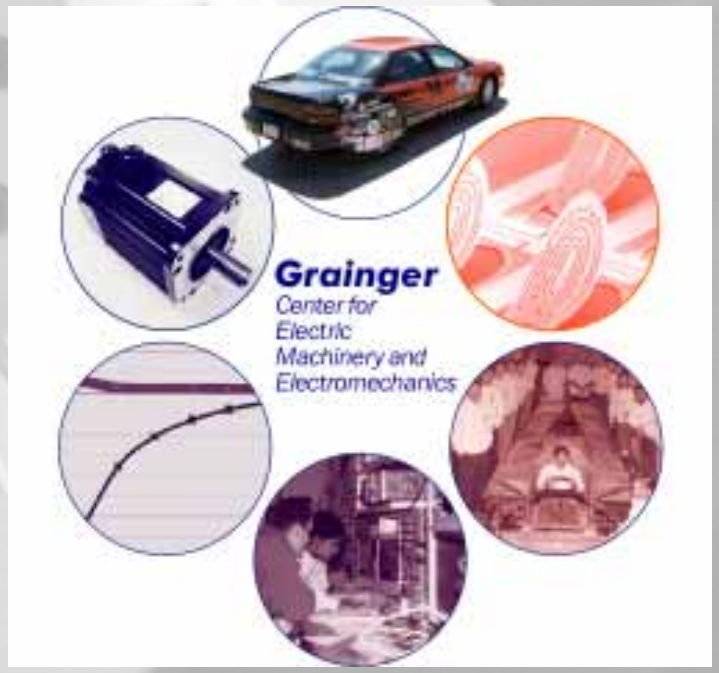


ILLINOIS

Introduction

- The group in power electronics research at Illinois is among the nation's largest – about 25 graduate students and significant undergraduate participation.
- Research leverages the broader program in power and energy systems.
- Emphasis on fundamentals, leveraging developments in control and other fields.
- Power at all levels: milliwatts to kilowatts.

Introduction

- Balance is sought: Each project has theory, simulation, and experimental emphasis.
- Funding is also balanced:
  - Federal support
  - Industry support
  - Endowment support
- Emphasis on long-term viewpoint.
  - Seek trends and innovations on five, ten, twenty-year time frames.
  - Inventions and publications are encouraged.

Themes

- *Best use* of technology and hardware
- *Best performance* for power conversion
- *Best match* between power electronic circuits and controls and the applications

- Nonlinear controls for both analog and digital implementations
- System-level design and performance
- *3rd generation* digital controls

People

- Philip Krein, center director and Professor.
- Patrick Chapman, center associate director and Assistant Professor.
- 3 other faculty in power systems area.
- 2 full-time staff members.
- 25 graduate assistants in power electronics (about 45 total across power).
- Typically 4 paid undergraduate lab assistants.
- About 35 to 40 undergraduates in power electronics courses each year.

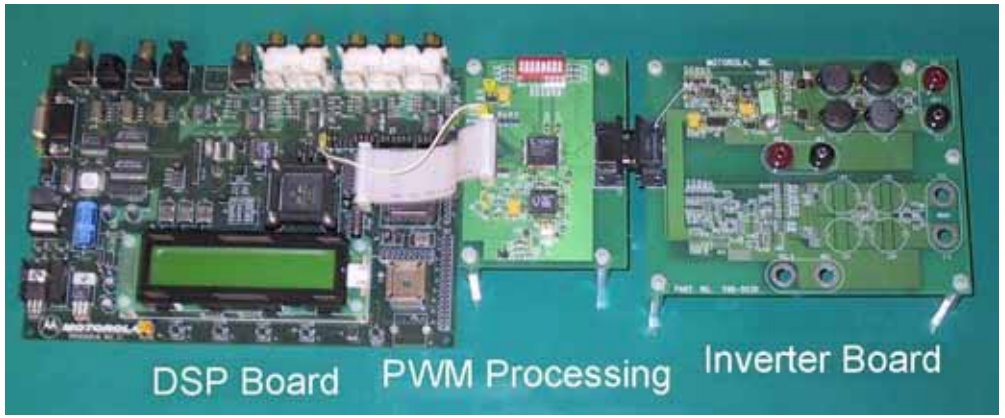
Sample Innovations

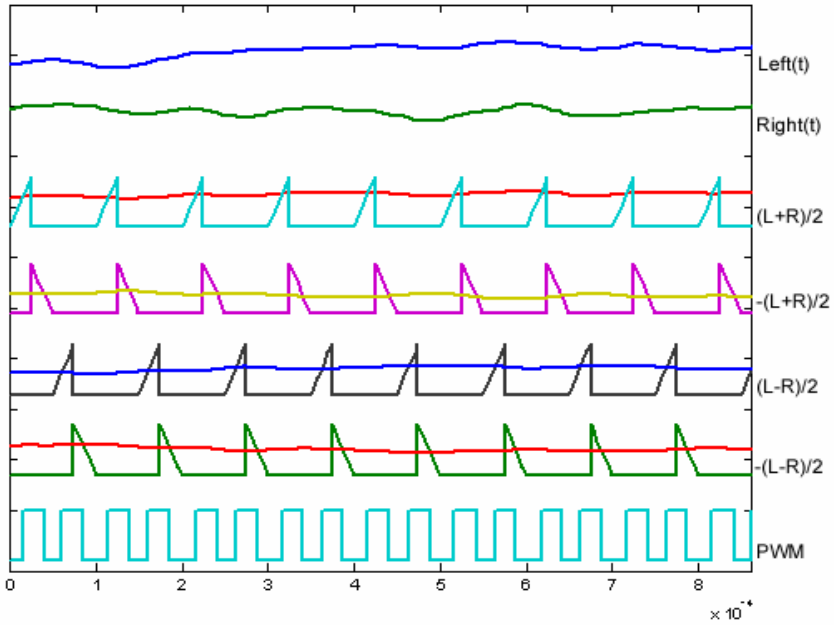
- Sensorless current-mode control
  - Dynamic performance advantages over other current-mode methods.
  - Much improved noise immunity (typically 80 dB or more compared to peak current-mode controls)
- VRM Innovations
  - Early four-phase two-stage VRM, 48 V/2 V, 100 W, current sharing.
  - Series-input parallel-output VRM provides near-ideal dynamic current sharing.

1993 VRM circuit

Sample Innovations

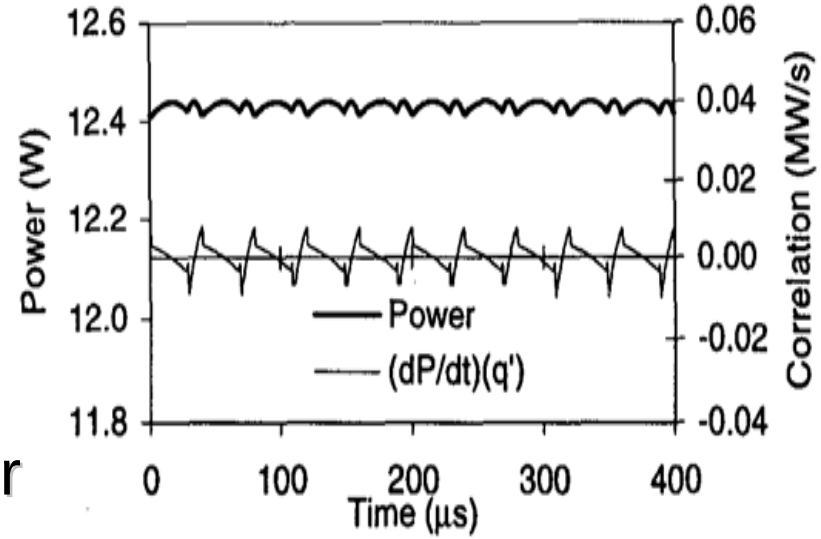
- Precision digital PWM
  - Implemented precise PWM, all-digital process
  - Delivers distortion below -140 dB
  - Suitable for Class D amplifier
- Multi-carrier PWM
  - Example application – high-frequency link inverter with direct PWM output.
  - Example application – multi-channel audio





Sample Innovations

- Ripple correlation control
  - Extracts information from converter ripple signals
  - Use this information to drive toward an optimum (lowest loss, highest power delivery, etc.)
- Fabrication of inductors for monolithic converters
  - Plastic deformation process yields inductors with much higher Q than spiral planar constructions



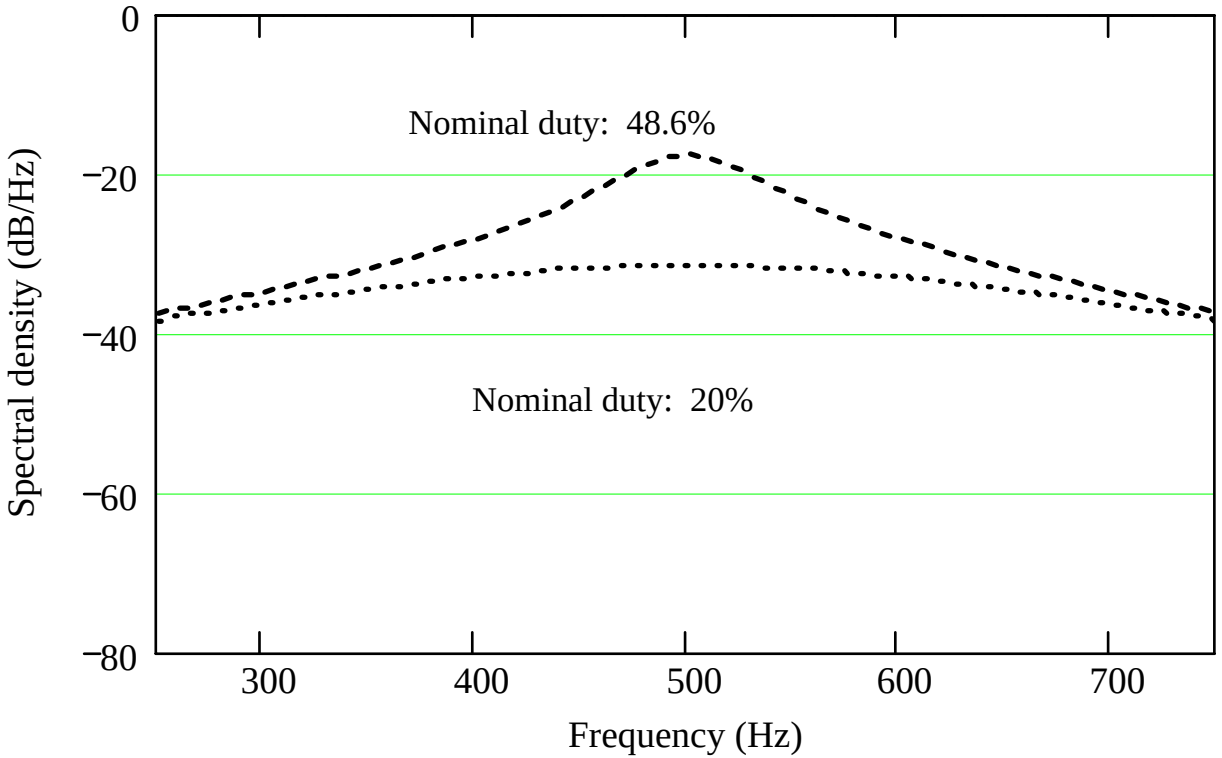
Ripple correlation near MPP for solar application

Fundamental Studies

- Mathematical justification and extension of averaging methods.
- Harmonic elimination approaches
  - Identified a more complete (infinite) range of solutions
  - Implemented in near-real-time algorithms
- Hybrid and electric vehicle systems
- Digital implementations of nonlinear controls

Fundamental Studies

- Noise analysis of dc-dc converters



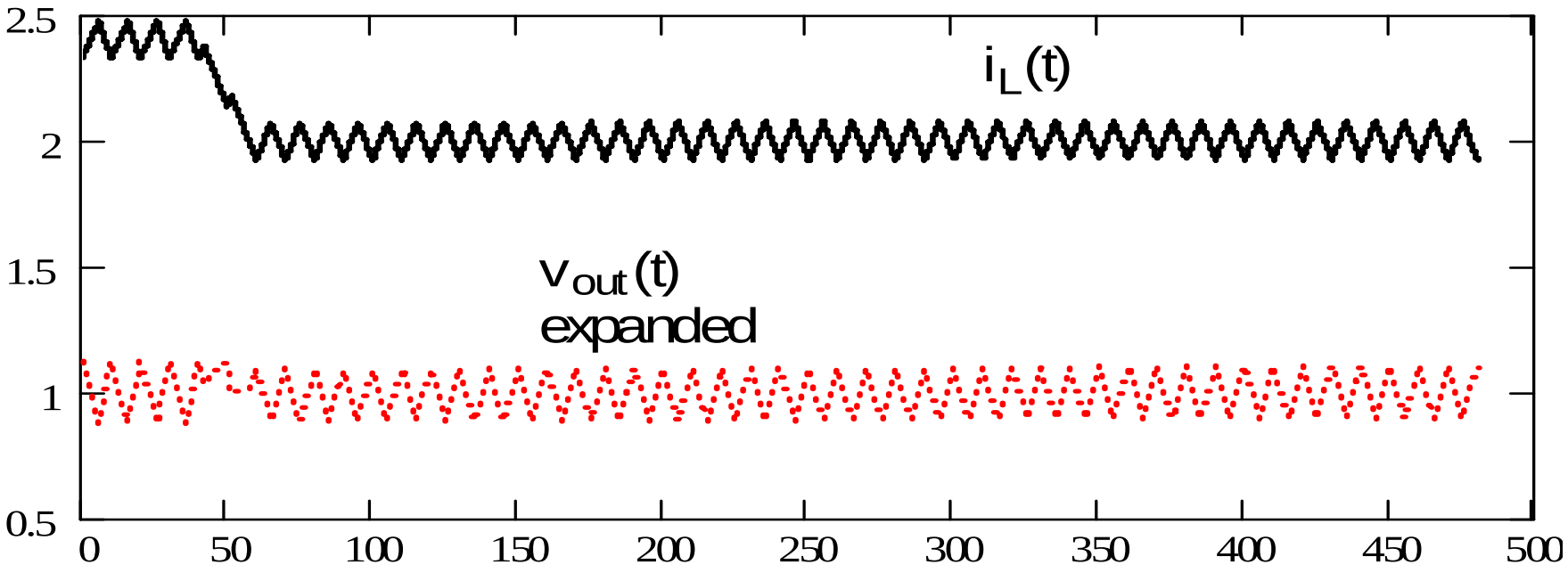
- Microgrid telecom power system architecture

3rd Generation Digital Control

- 1st generation: digital outside the loop (supervision, management, sequencing, etc.)
- 2nd generation: digital inside the loop (z-domain controls, correlation controls, switching frequency management, high-fidelity digital audio)
- 3rd generation: direct real-time control of switches (online optimization, extended bandwidth controls)

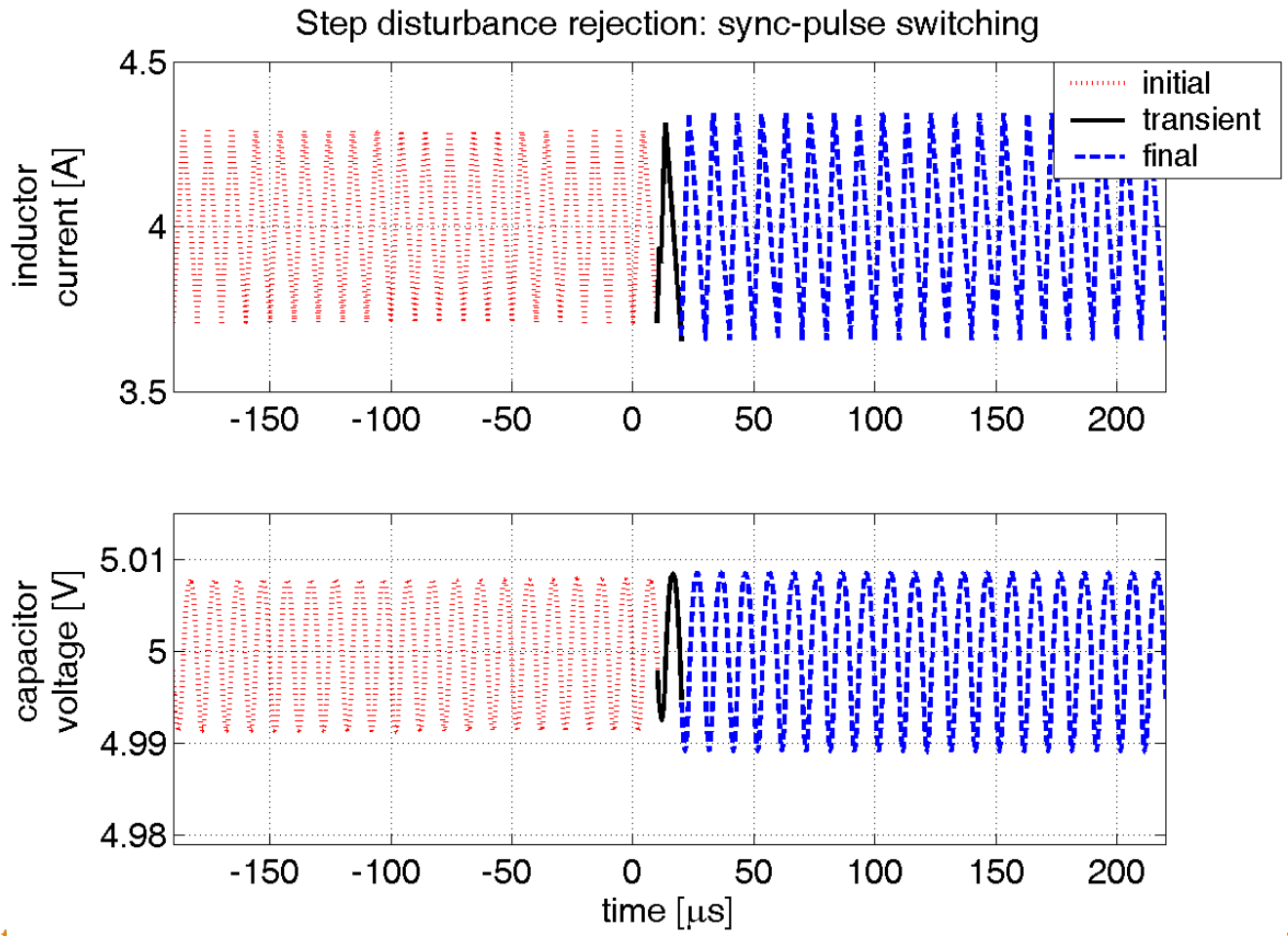
Boost Converter with “Infinite Bandwidth”

- Line step disturbance.
- The digital control eliminates the transient.



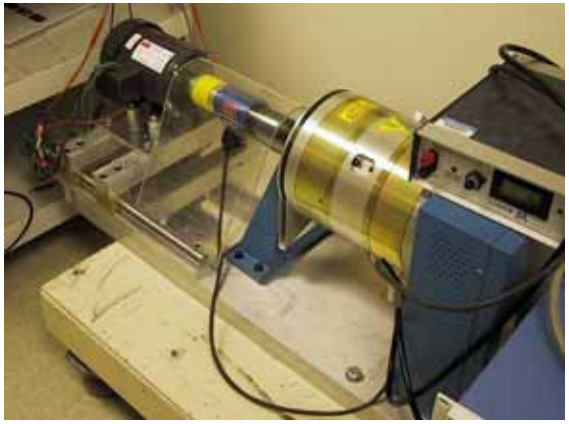
Fundamental Studies

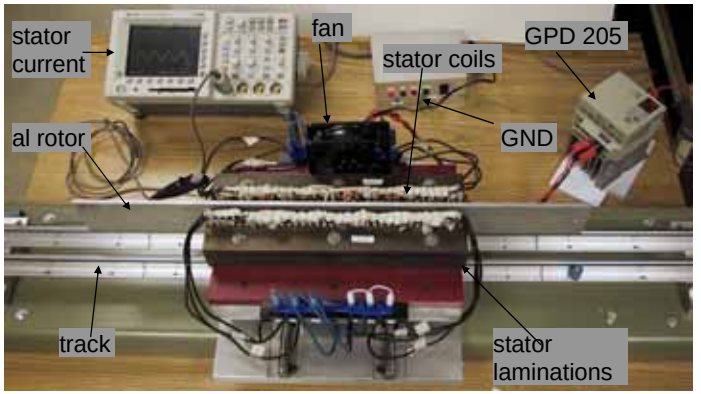
- Cancellation of other large-signal disturbances



Infrastructure

- Rotating and linear machines
- Unique instructional lab

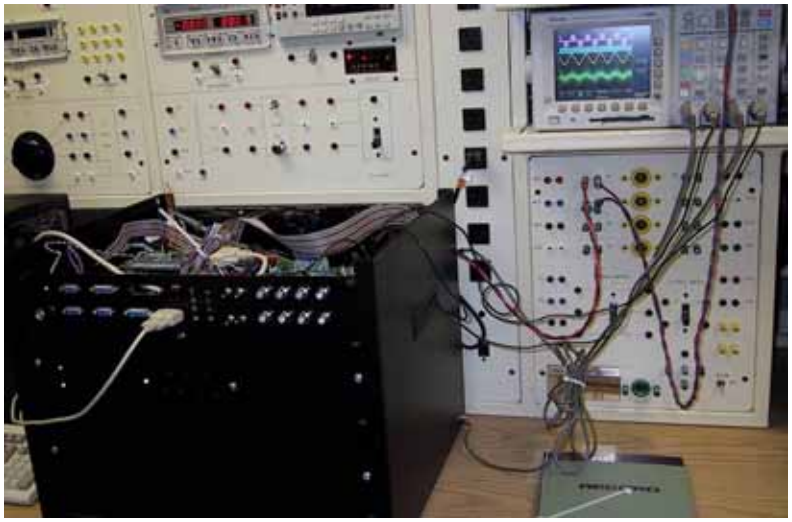




About 40 students per year enroll in power electronics.

Infrastructure

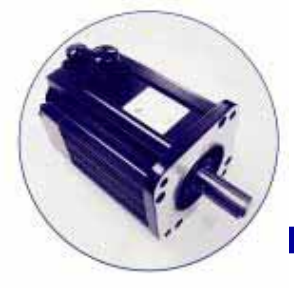
- Power inverters for motor control testing.
- Circuit design tools.



- Design and construction details of our education lab equipment are freely available.

The Grainger CEME

- The Grainger Center for Electric Machine and Electromechanics (CEME) supports a portion of our advanced energy work.
- This University of Illinois program is the largest endowment of its type, and provides significant leveraging for research funds.
- Many projects are highly collaborative. Control, circuit, device, and other work involves faculty in appropriate specialty areas.

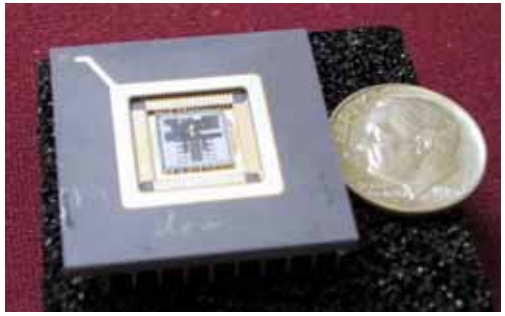


Highlights

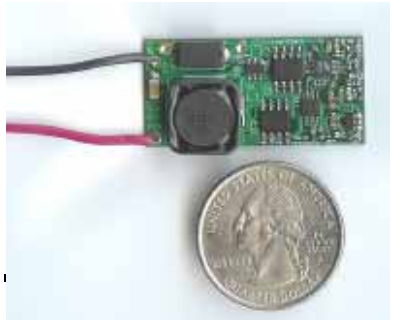
- The CEME sponsored a team for the joint Department of Energy/California Energy Commission Efficiency Challenge. First-place winner in category.
- Active teams in the International Future Energy Challenge competitions.
- Two different graduate students have been awarded with the INTELEC Fellowship for research in telecommunications power.

Sample Projects

- Small-scale converters for micro fuel cells.



- The *power buffer*, a method to use power electronics in loads to mitigate power system dynamics.
- Drives for 42 V automotive applications.
- Local control for distributed ac and dc systems.



- Multi-port energy conversion methods.
- Advanced digital methods for motor control.

Conclusion

- There is a large and active power electronics research team at Illinois
- We leverage practical issues and design concerns with long-term research challenges.
- We also leverage innovations in nonlinear control, signal processing, and other areas.
- A long-term view, five, ten, twenty, or even more years into the future is emphasized.
- Innovations on many scales, and active work at present on digital controls.

Conclusion

- Unique instructional and research labs.
- Strong student interest.
- Growing student population both at graduate and undergraduate levels.
- Vision of power electronics as the key driver for energy innovation.