ECE 481: Power Electronics

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Department of Electrical Engineering and Computer Science

University of Tennessee Knoxville

Fall 2013

ECE 481: Power Electronics

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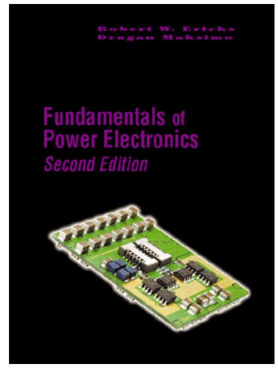
  - Office Hours: MW 3:00-4:00pm

Course Materials

- Textbook:
  - Erickson and Maksimovic, *Fundamentals of Power Electronics*, second edition, Kluwer Academic Publishers, ISBN 0-7923-7270-0
  - Available through campus bookstore, online vendors, or UT libraries
- Course Website
  - http://web.eecs.utk.edu/courses/fall2013/ece481/
  - Includes lectures slides, handouts, supplemental notes, homework assignments, course announcements



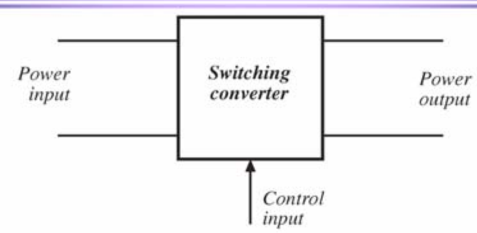
Grading

- Homework
  - Due at beginning of class on date listed on Lecture Schedule web page
  - Homework counts for 40% of grade
  - Collaboration is encouraged on all homework assignments
- Exams
  - 2 Midterms: 25% of grade
  - 1 Final: 35% of grade
  - 1 week, take-home exams
  - Absolutely *no collaboration* allowed on exams

Power Electronics Courses at UTK

Junior	Senior	Graduate	
ECE 325 Electric Energy System Components	ECE 481 Power Electronics	ECE 523 Power Electronics and Drives	ECE 623 Advanced Power Electronics and Drives
	ECE 482 Power Electronic Circuits	ECE 525 Alternative Energy Sources	ECE 625 Utility Applications of Power Electronics
			ECE 626 Solid State Power Semiconductors

1.1 Introduction to Power Processing



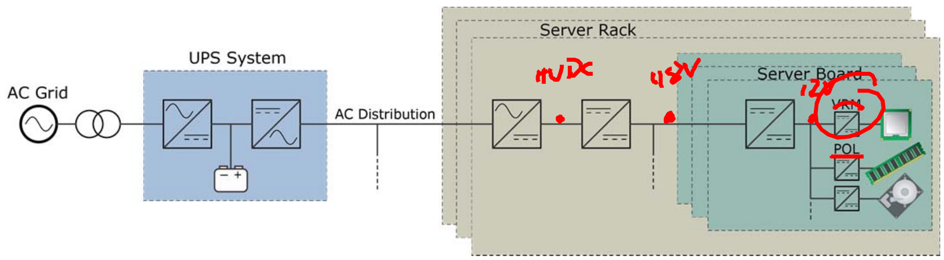
Dc-dc conversion: Change and control voltage magnitude

Ac-dc rectification: Possibly control dc voltage, ac current

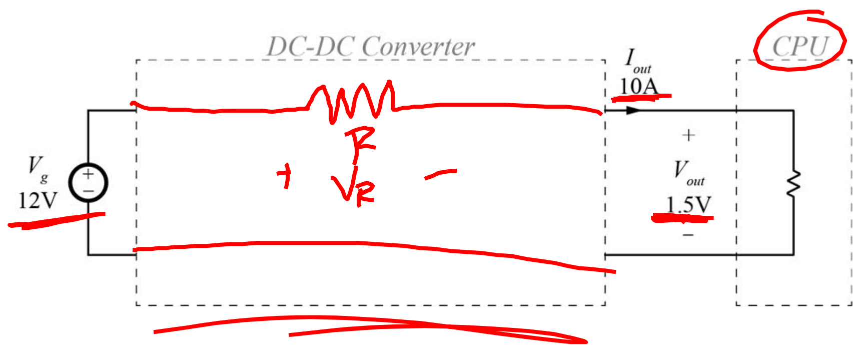
Dc-ac inversion: Produce sinusoid of controllable magnitude and frequency

Ac-ac cycloconversion: Change and control voltage magnitude and frequency

Example Server Power Distribution



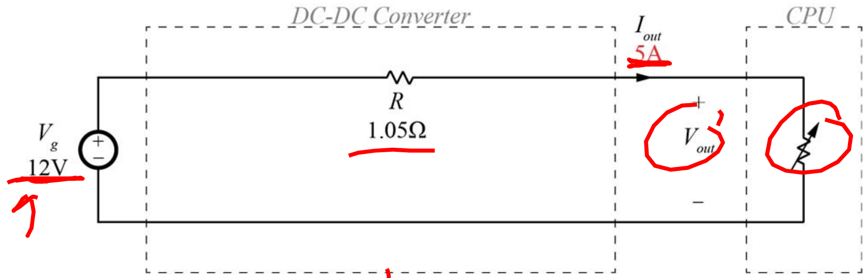
Example VRM Design



$V_R = 12V - 1.5V = 10.5V$

$R = \frac{V_R}{I_{out}} = \frac{10.5V}{10A} = \boxed{1.05\Omega}$

Variations in Load

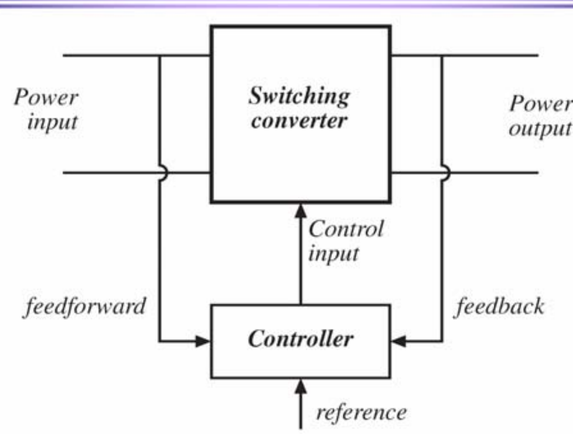


$$\left(V_{out} = V_g - I_{out} R\right) = 6.75V$$

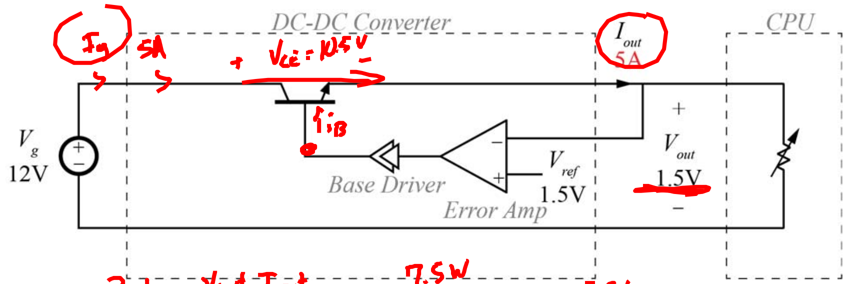
'load regulation' $= \dfrac{\Delta V_{out}}{\Delta i_{out}} = -R$

'line regulation' $= \dfrac{\Delta V_{out}}{\Delta V_g} = \dfrac{\partial (V_g - I_{out} R)}{\partial V_g} = 1$

Control is invariably required



Linear Regulator



$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{out} I_{out}}{V_g I_g} = \frac{7.5W}{60W} = 12.5\%$$

$$\eta = \frac{V_{out}}{V_g} \ (max)$$

High efficiency is essential

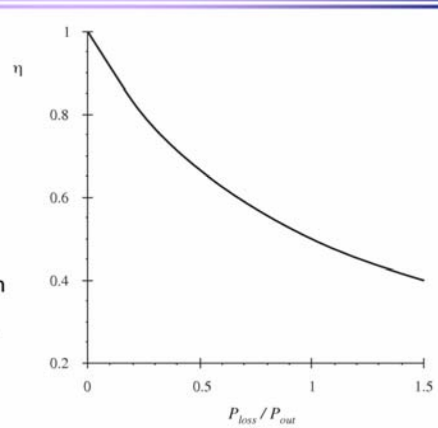
$$\eta = \frac{P_{out}}{P_{in}}$$

$$P_{loss} = P_{in} - P_{out} = P_{out}\left(\frac{1}{\eta} - 1\right)$$

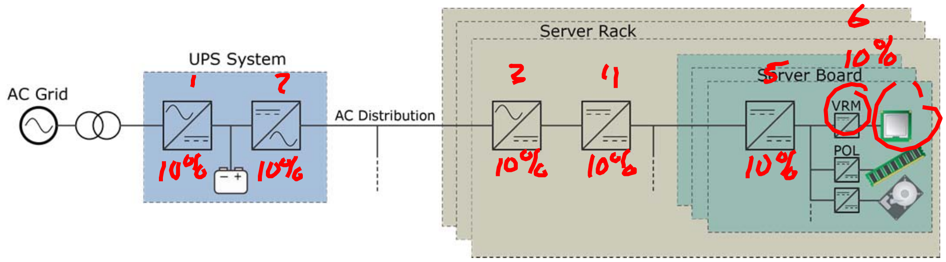
High efficiency leads to low power loss within converter

Small size and reliable operation is then feasible

Efficiency is a good measure of converter performance



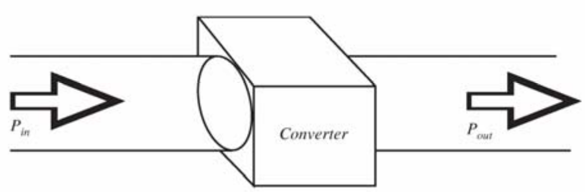
Example Server Power Distribution



System $\eta = (0.1)^6 = 10_{M}\%$

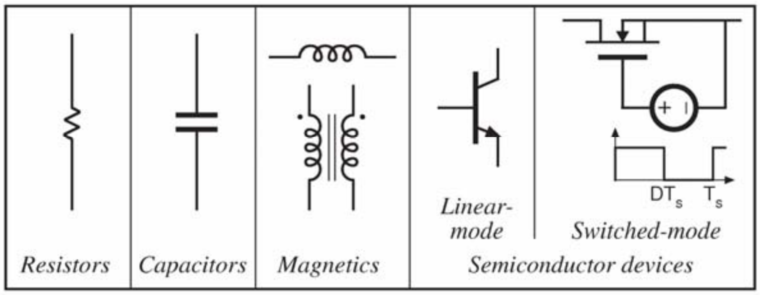
$1W \longrightarrow 1MW$

A high-efficiency converter

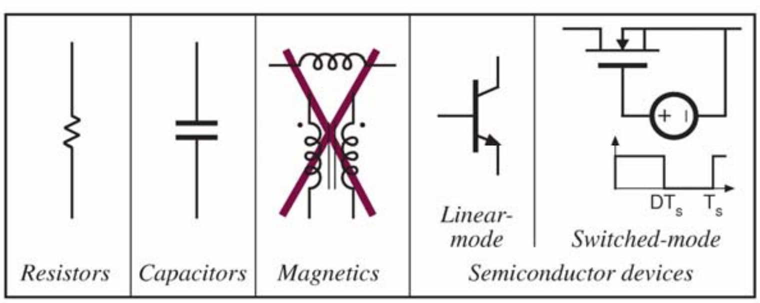


A goal of current converter technology is to construct converters of small size and weight, which process substantial power at high efficiency

Devices available to the circuit designer

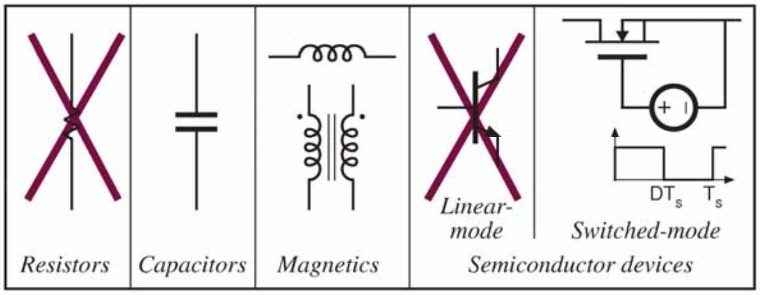


Devices available to the circuit designer



Signal processing: avoid magnetics

Devices available to the circuit designer



Power processing: avoid lossy elements

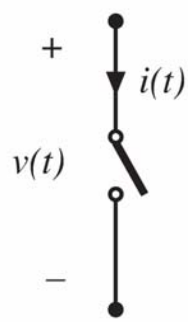
Power loss in an ideal switch

Switch closed: $v(t) = 0$

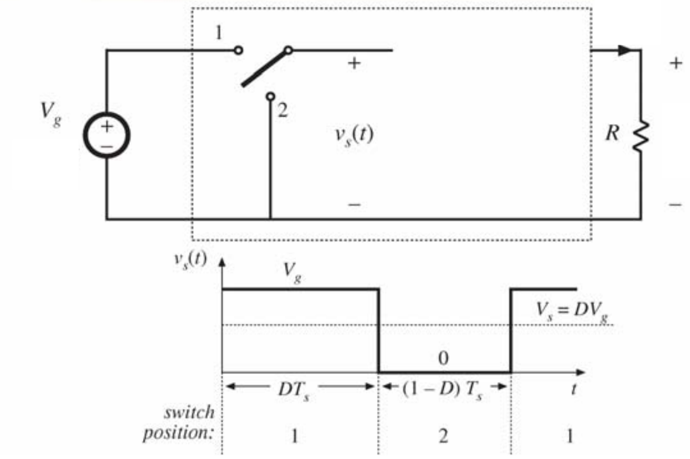
Switch open: $i(t) = 0$

In either event: $p(t) = v(t)\ i(t) = 0$

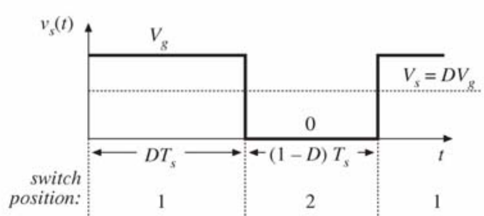
Ideal switch consumes zero power



Use of a SPDT switch



The switch changes the dc voltage level



D = switch duty cycle

$0 \le D \le 1$

T_s = switching period

f_s = switching frequency $= 1 / T_s$

DC component of $v_s(t)$ = average value:

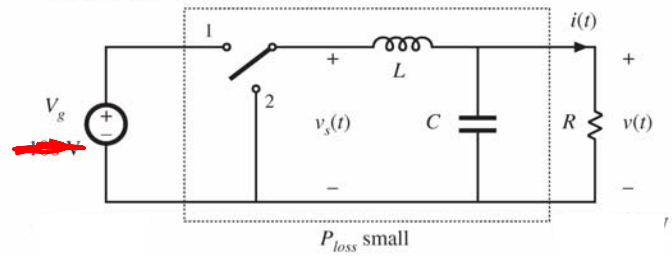
$$V_s = \frac{1}{T_s}\int_0^{T_s} v_s(t)\,dt = DV_g$$

$1.5V = DV_g$

$D = \frac{1.5}{12} = .13$

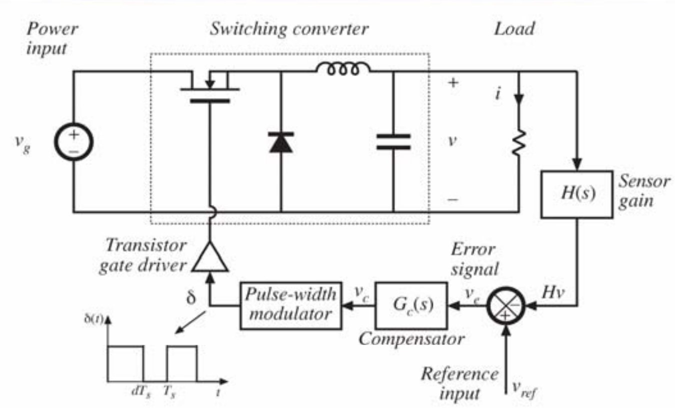
Addition of low pass filter

Addition of (ideally lossless) L-C low-pass filter, for removal of switching harmonics:



- Choose filter cutoff frequency f_0 much smaller than switching frequency f_s
- This circuit is known as the "buck converter"

Addition of control system for regulation of output voltage

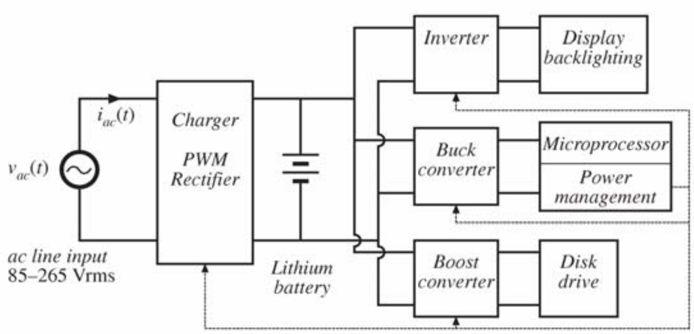


1.2 Several applications of power electronics

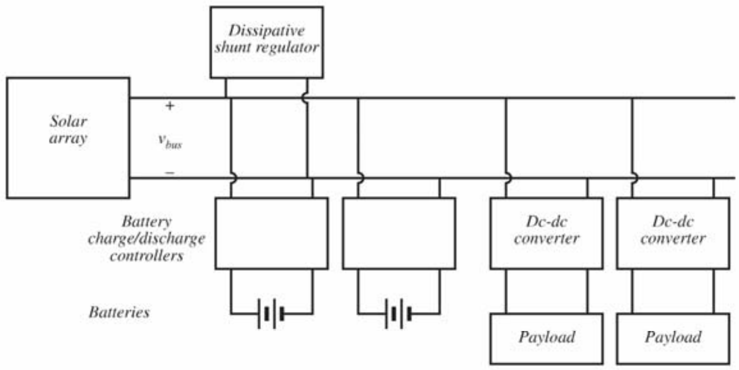
Power levels encountered in high-efficiency converters

- less than 1 W in battery-operated portable equipment
- tens, hundreds, or thousands of watts in power supplies for computers or office equipment
- kW to MW in variable-speed motor drives
- 1000 MW in rectifiers and inverters for utility dc transmission lines

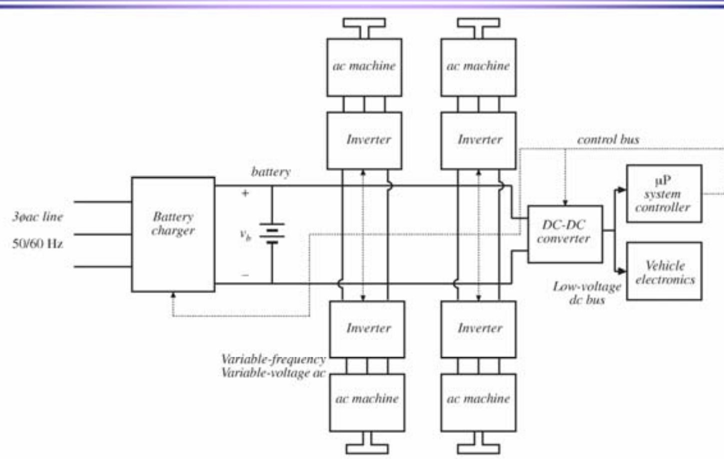
A laptop computer power supply system



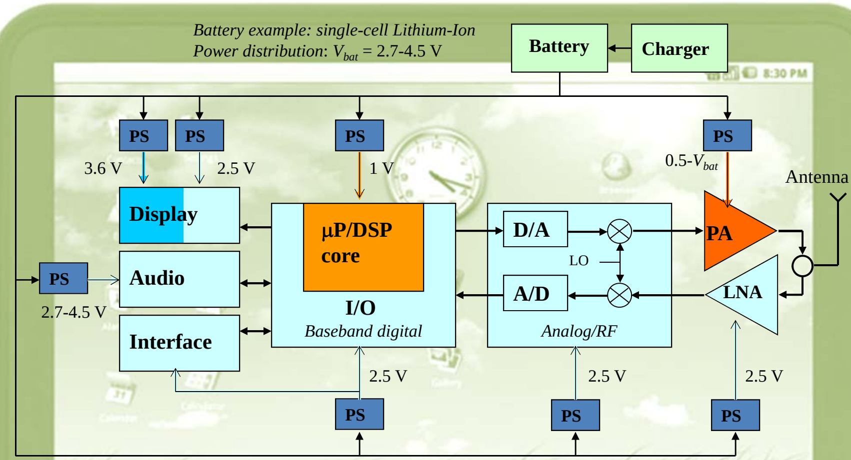
Power system of an earth-orbiting spacecraft



An electric vehicle power and drive system



Power management in mobile electronics



- Major power consumers: baseband digital, display, multiple radio channels
- Power supply demands: small footprint area & integration, high efficiency over wide range of loads, power management interface

Future Applications: Hyperloop

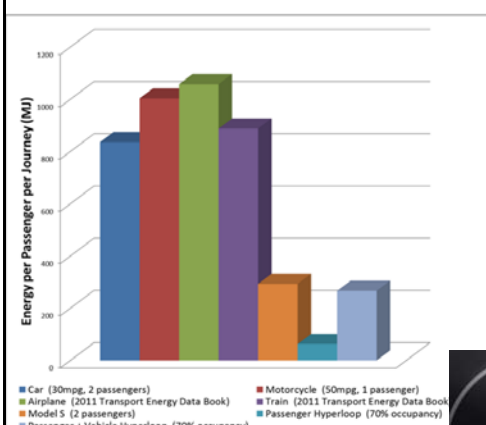
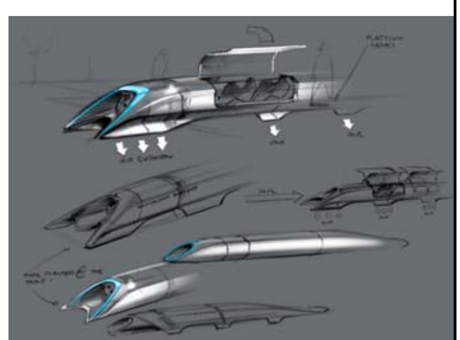
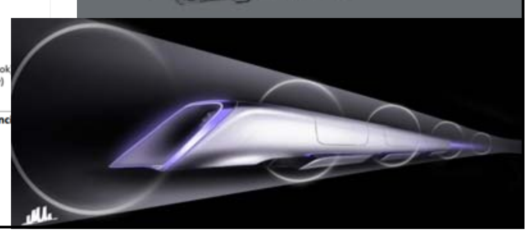


Figure 1. Energy cost per passenger for a journey between Los Angeles and San Franc various modes of transport.





Proposed Power Conversion Architecture

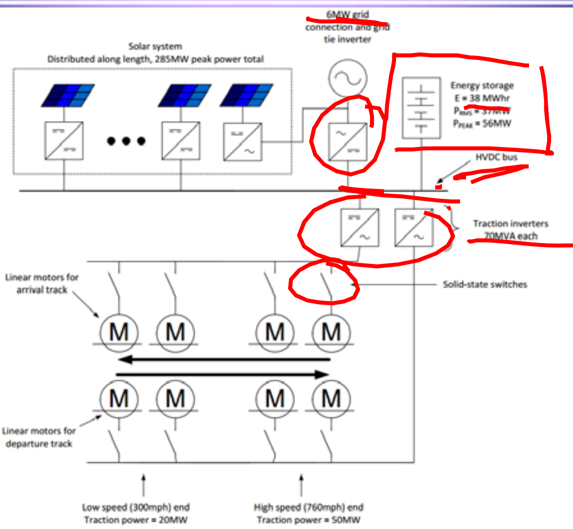


Figure 22. Linear accelerator concept for capsule acceleration and deceleration between 300 and 760 mph (480 and 1,220 kph).

1.3 Elements of power electronics

Power electronics incorporates concepts from the fields of

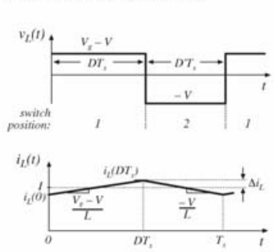
- analog circuits
- electronic devices
- control systems
- power systems
- magnetics
- electric machines
- numerical simulation

Part I. Converters in equilibrium

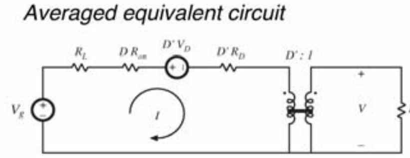
2. Principles of steady state converter analysis
3. Steady-state equivalent circuit modeling, losses, and efficiency
4. Switch realization
5. The discontinuous conduction mode
6. Converter circuits

Part I. Converters in equilibrium

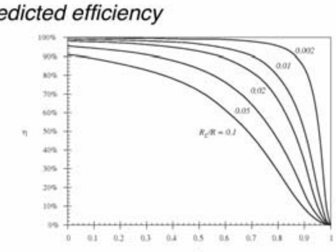
Inductor waveforms



Averaged equivalent circuit



Predicted efficiency

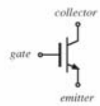


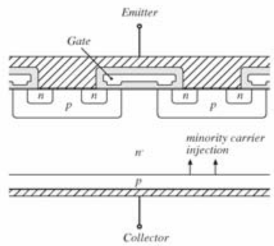
Discontinuous conduction mode

Transformer isolation

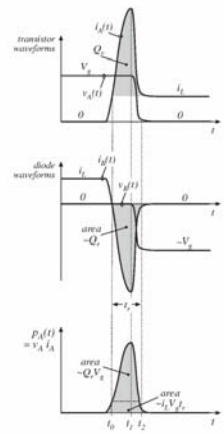
Switch realization: semiconductor devices

The IGBT





Switching loss

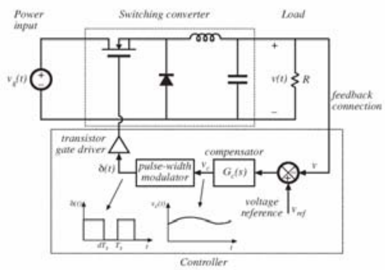


Part II. Converter dynamics and control

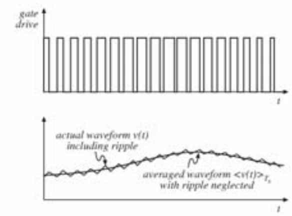
7. Ac modeling
8. Converter transfer functions
9. Controller design
10. Input filter design
11. Ac and dc equivalent circuit modeling of the discontinuous conduction mode
12. Current-programmed control

Part II. Converter dynamics and control

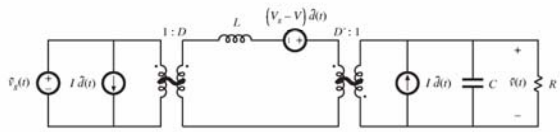
Closed-loop converter system



Averaging the waveforms



Small-signal averaged equivalent circuit

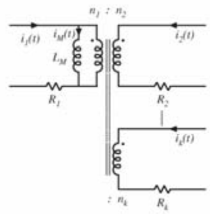


Part III. Magnetics

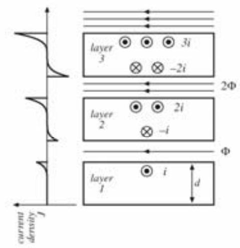
13. Basic magnetics theory
14. Inductor design
15. Transformer design

Part III. Magnetics

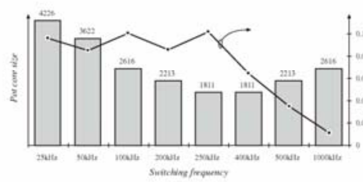
transformer design



the proximity effect



transformer size vs. switching frequency



EcoCAR2
PLUGGING IN TO THE FUTURE

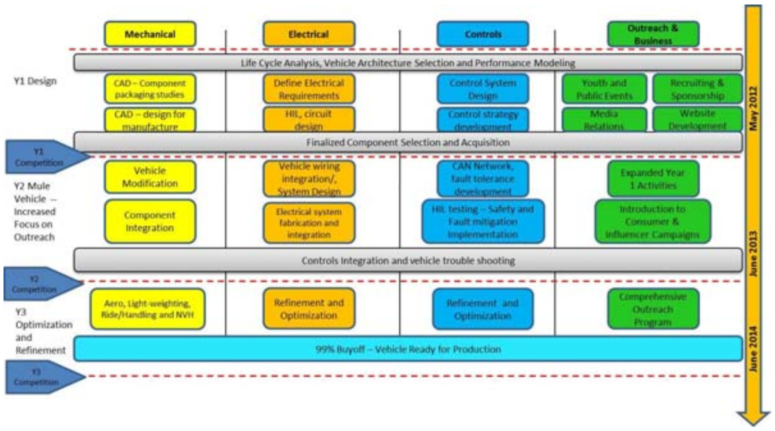
What is EcoCAR2?

- A three year collegiate automotive engineering competition
- The latest competition series in 23-year history of Advanced Vehicle Technology Competitions (AVTCs)
  - Since 1987, DOE has sponsored AVTCs in partnership with the domestic auto industry to:
    - Simulate the development of advanced propulsion and alternative fuel technologies
    - Provide the training ground for the next generation of automotive engineers
  - Provide real-world, systems-level engineering challenges for students using industry-leading engineering tools, components and hardware and mimic the auto industry's vehicle development process

Competition Organization

- Year 1
  - Math-based modeling using tools to simulate and select vehicle architectures
  - Hardware-in-the-loop to allow for controls strategy testing before any work on vehicle is started = reduces vehicle development time and increases safety and security
  - Teams design ESS systems and powertrain hardware
- Year 2
  - Teams integrate their new subsystem components into the vehicle and develop a "Mule Vehicle"
- Year 3
  - Teams refine their vehicle to "Near Showroom" quality and performance

Vehicle Development Process



EE/CS Opportunities

- Electric Powertrain Integration
- High Voltage Distribution
- Controller Area Network Integration
- Controls
- Infotainment Hardware/Software Development

Academic Integration

- Supporting Courses
  - ECE400 Senior Design
  - ME480/588 Introduction to Hybrid Vehicles
  - ME494 Vehicle Modeling and Simulation
  - ME599 Hybrid Vehicle Simulation and Controls Development
- Networking/Recruiting Opportunities for Students

Fall 2013 or Spring 2014

Possible Elective Fall 2013

UTK AVTC History

- Served as Capstone design experience for students in ME and ECE
- Over 500 of our students have participated in unique design experiences
- UTK has participated for twenty years of these competitions

CHRYSLER

EcoCAR2 Universities

California State University Los Angeles	Colorado State University	Embry-Riddle Aeronautical University	Mississippi State University
North Carolina State University	The Ohio State University	Pennsylvania State University	Purdue University
Rose-Hulman Institute of Technology	University of Tennessee, Knoxville	University of Victoria	University of Washington
University of Waterloo	Virginia Tech	Wayne State University	

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