IEEE Grad Talks 2010
Energy System Group

ESG Graduate Coordinator: Prof. Olivier Trescases

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Nov.10 / 2010

Faculty in Energy Systems Group

- Z. Tate
  - Advanced metering; situational awareness; high performance computing

- A. Prodic
  - - Digitally controlled SMPS; Power Management; Topologies and ICs

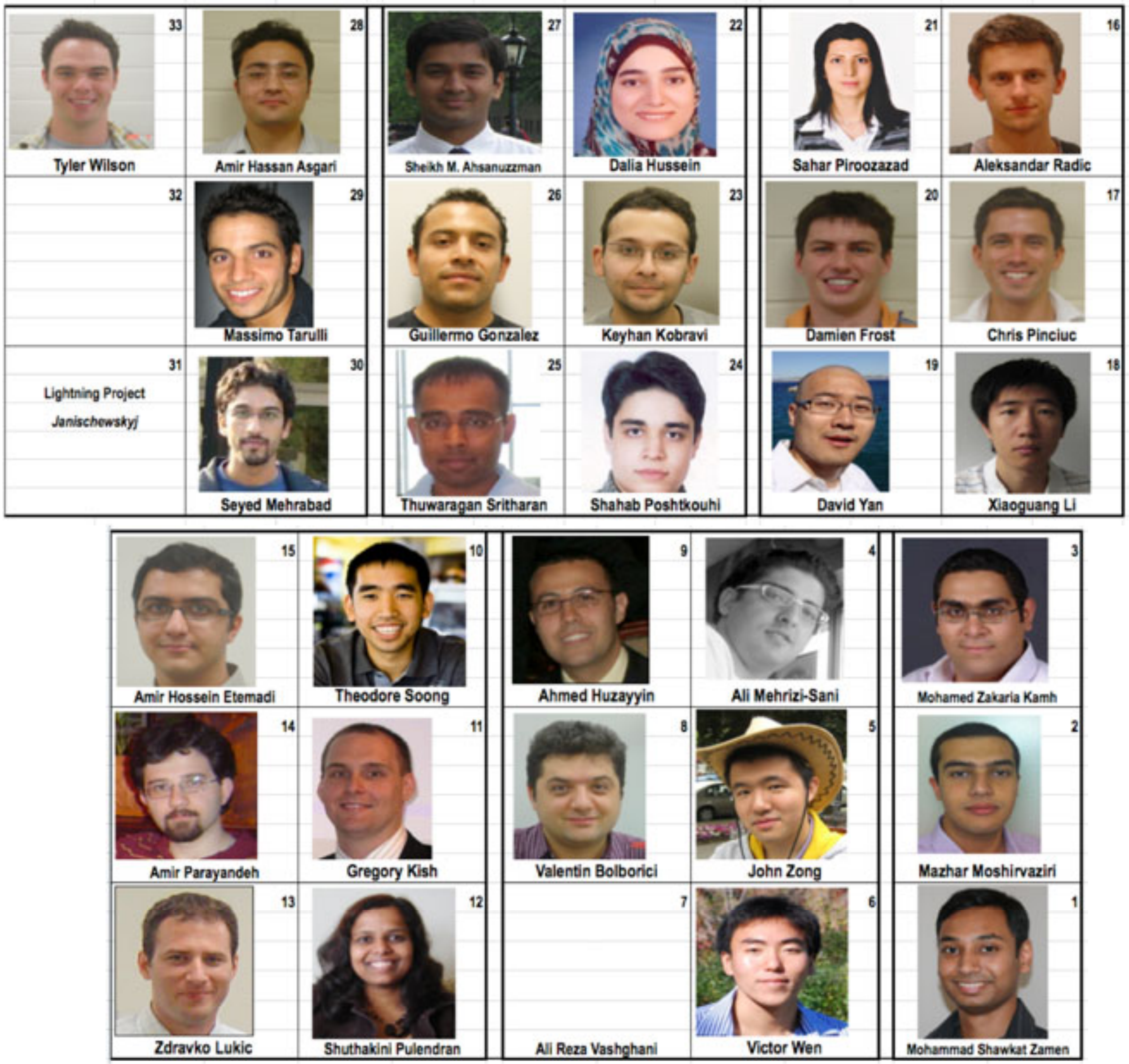
- P Lehn
  - Power systems; integration of distributed resources

- F. P. Dawson
  - Power utilization and system modeling at utilization level

- M.R. Iravani
  - Power systems; integration of distributed resources

- O. Trescases
  - Integrated power management, renewable energy, efficiency optimization

M.A.Sc./Ph.D. Students in ESG



The Energy Lanscape

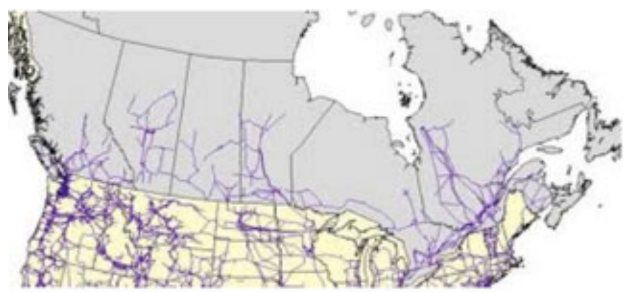
Generation:
MAKE IT

Distribution:
MOVE IT

Consumption:
USE IT









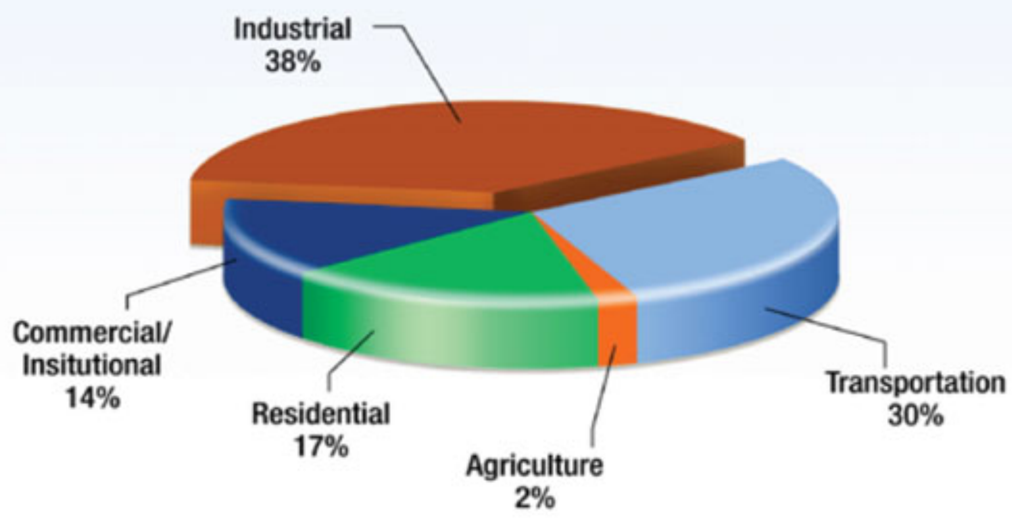
Motivation for Power Electronics

Motivation: Energy Consumption Crisis

! Between 1990 and 2005, energy use in Canada grew by **22 %**

! Population grew by 17 % and GDP grew by 51 %

Energy Consumption by Sector (2005)



Motivation: Energy Consumption Crisis

- Between 1990 and 2005, energy use in Canada grew by **22 %**
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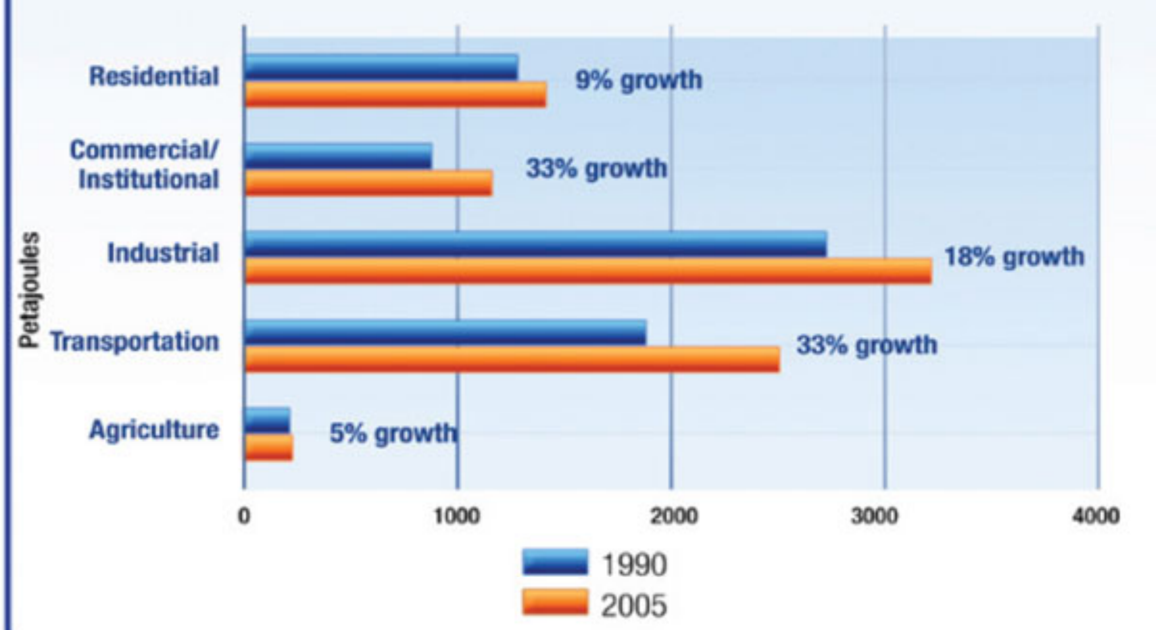
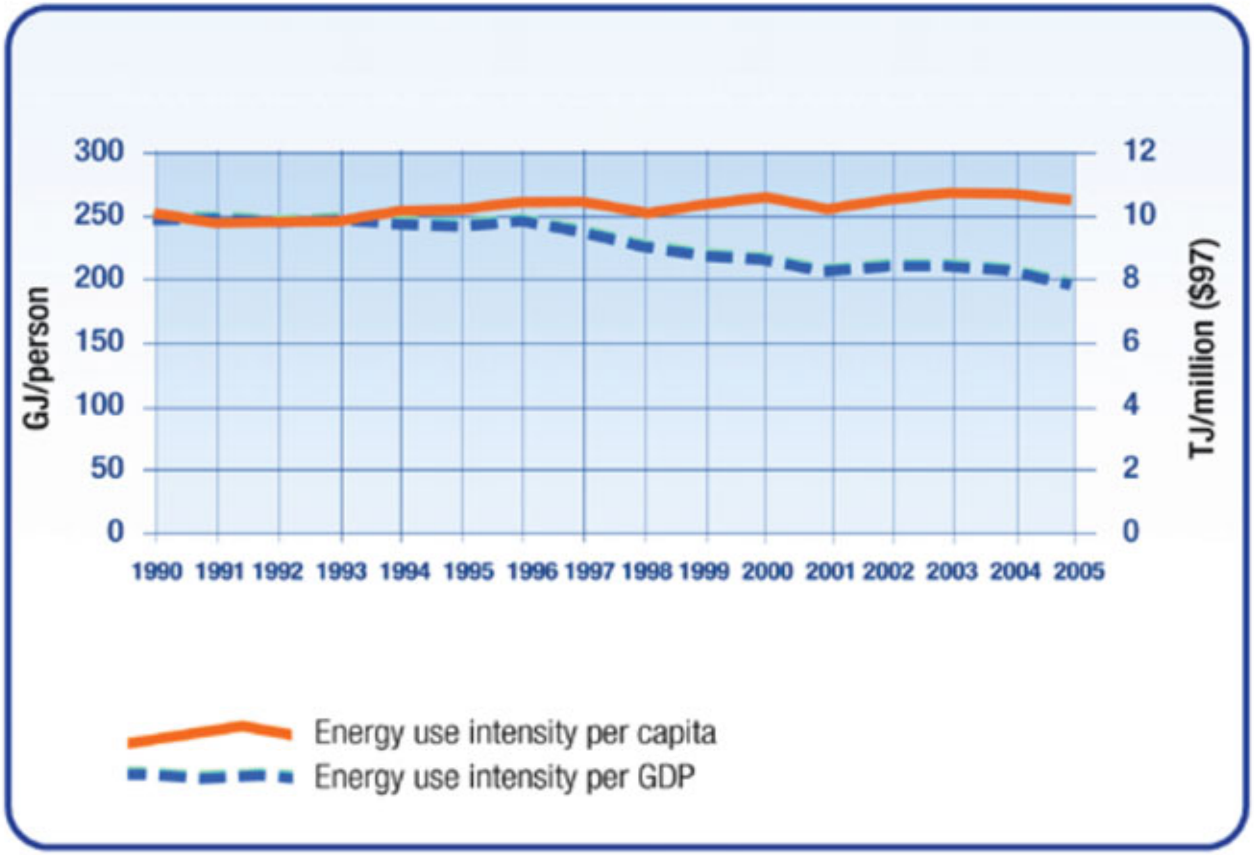
Total GHG Emissions (1990 vs. 2005)



Energy Consumption

! Energy intensity per GDP improved 19 % (1990-2005)

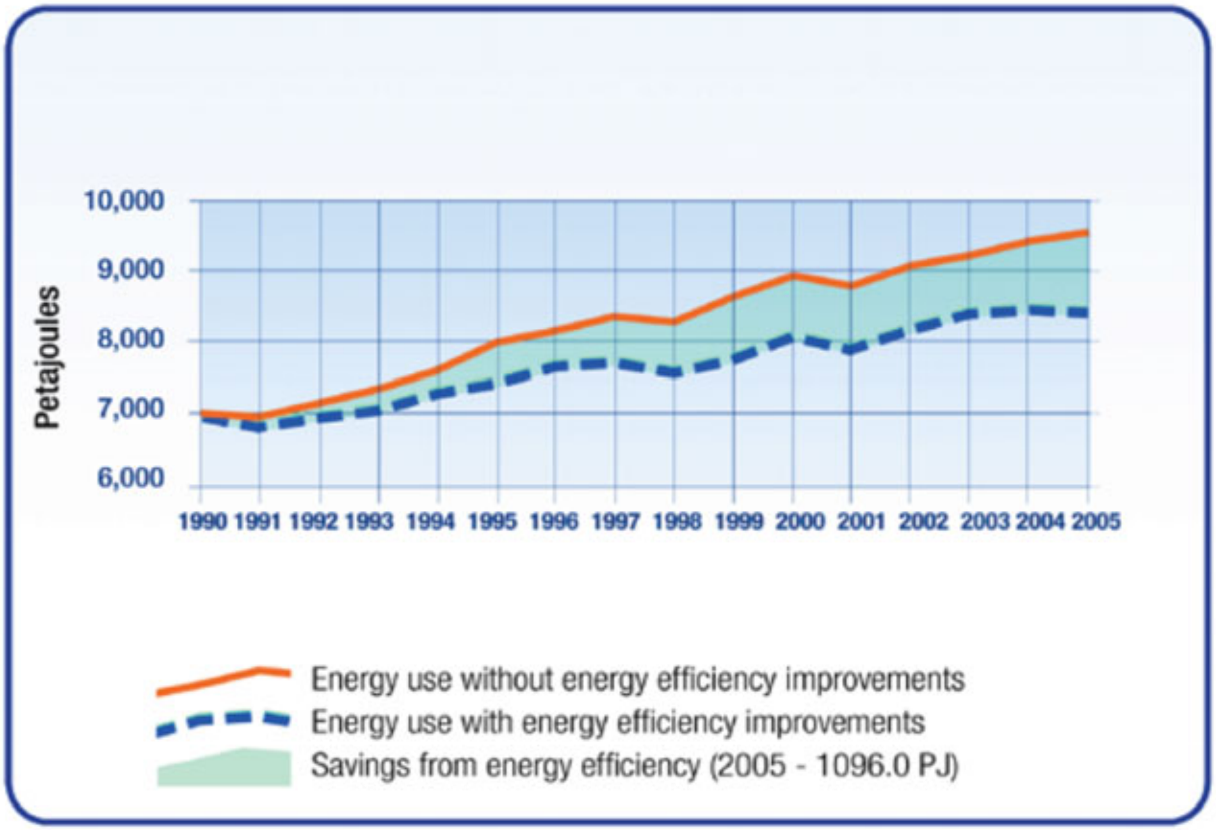
! Energy intensity per capita decreased by 5 %



Energy Efficiency

! Overall efficiency has improved 16 % since 1990, saving 64 Mt of GHG

! Improvements in energy efficiency saved 1096 PJ (1 peta-joule = 10^{15}J)



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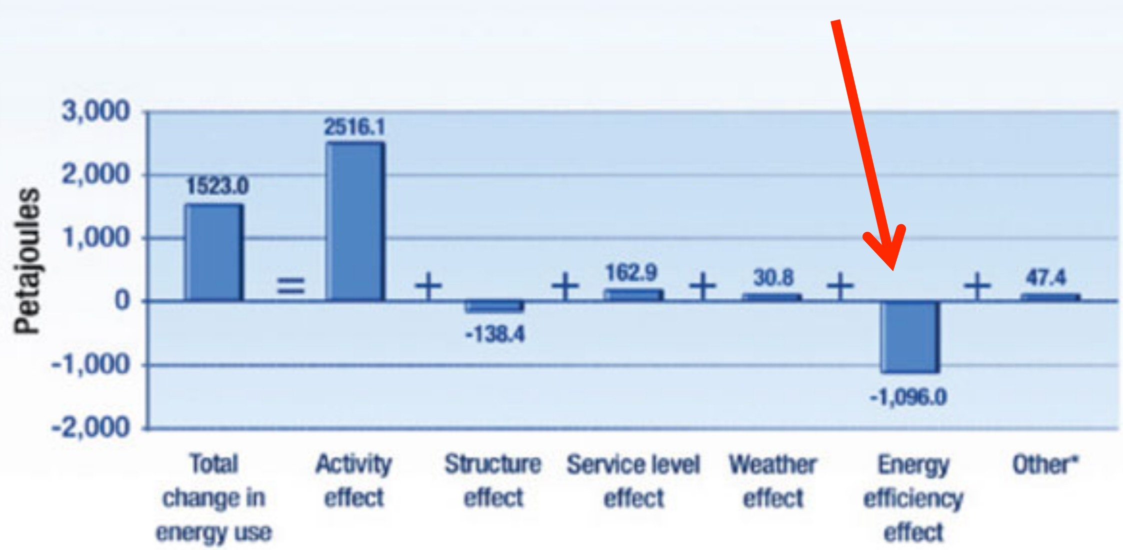


* Other refers to street lighting, non-commercial airline aviation, off-road transportation and agriculture, which are included in the Total change in energy use column above but are excluded from the factorization analysis.

World Energy Usage per Capita

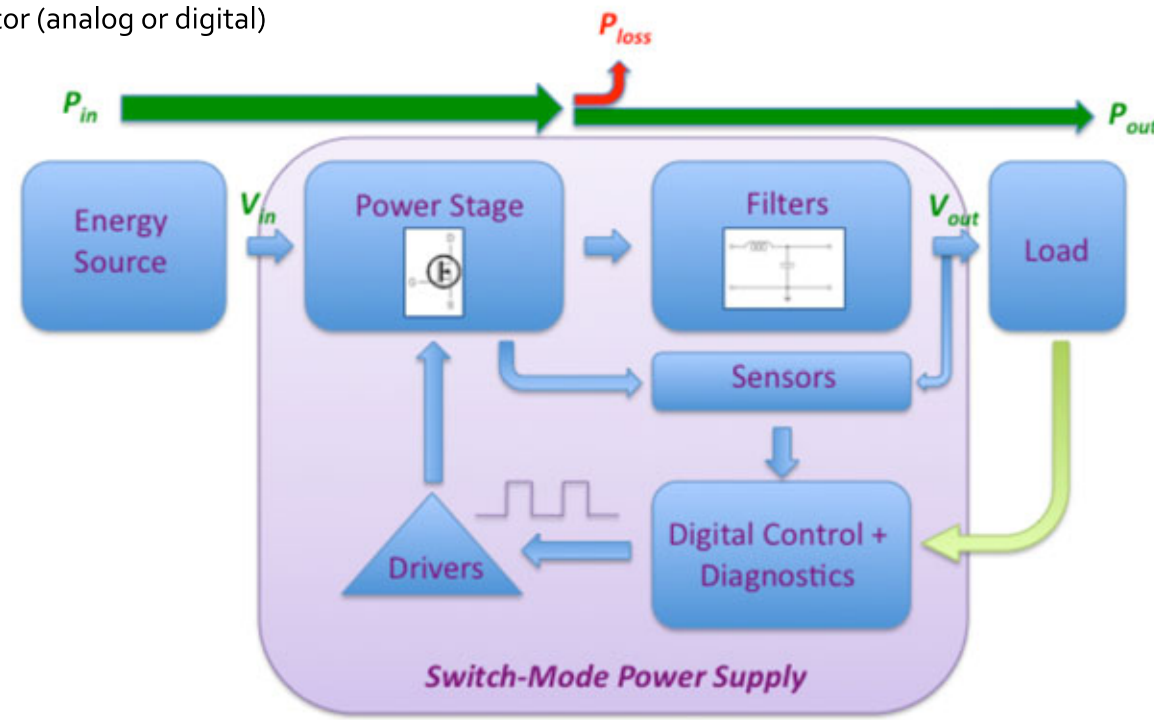
- Canada is far worse then most of the rest of the world in energy usage per capita (slightly better then Kuwait)
- Canada: 427 MBTU
- USA: 334 MBTU
- Europe avg: 146 MBTU
- World avg: 72 MBTU
- There is much work to be done in the future!

Region/Country	1990	2006
Iceland	320.7	568.6
Brunei	277.8	482.1
Singapore	263.4	476.8
Kuwait	208.4	469.8
Canada	395.7	427.2
Luxembourg	378.7	424.1
Norway	404.0	410.8
United States	338.4	334.6
Australia	218.7	276.9
North America	**277.5**	**276.2**
Belgium	219.5	265.1
Saudi Arabia	208.4	255.0
Finland	213.2	252.7
Netherlands	221.8	250.9
Sweden	254.3	245.8
Faroe Islands	16.2	223.9
Bahamas, The	160.0	220.6
Russia	- -	213.9
New Zealand	213.4	211.2
Taiwan	100.8	200.6
Kazakhstan	- -	195.3
Korea, South	89.6	193.4
Austria	149.9	187.2
France	156.8	180.7
Nauru	216.4	178.7
Japan	151.6	178.7
Germany	- -	177.5
Oman	103.5	177.2
Czech Republic	- -	176.6
Estonia	- -	175.2
Turkmenistan	- -	174.1
Ireland	105.3	173.4
Switzerland	172.3	170.7
Saint Pierre and Miquel	558.2	167.9
Hong Kong	89.1	167.7
New Caledonia	147.9	163.0
United Kingdom	161.4	161.7
Denmark	149.8	161.3
Spain	103.0	161.2
Slovenia	- -	160.9

Power Electronics Applications

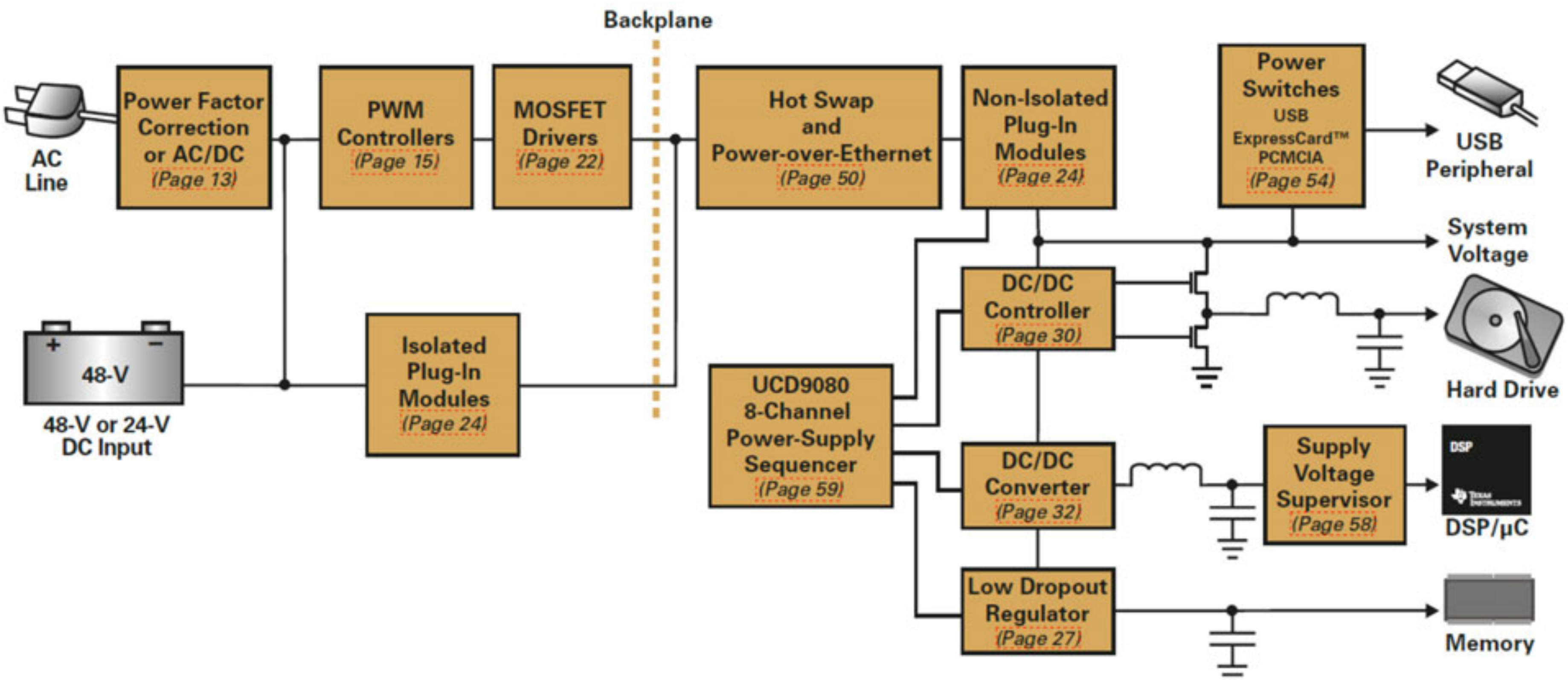
Generic SMPS Topology

- The three basic components of a SMPS:
  - Semiconductor switches (NPN/PNP, DMOS, PMOS, etc.)
  - Passive filters / energy storage elements (magnetics)
  - Compensator (analog or digital)



- Switches are never operated with simultaneous high-current (ID) and high voltage (V_{ds}) :Maximum theoretical efficiency: **100 %**

SMPS Applications: Line Power Solutions



SMPS Applications: Portable Power

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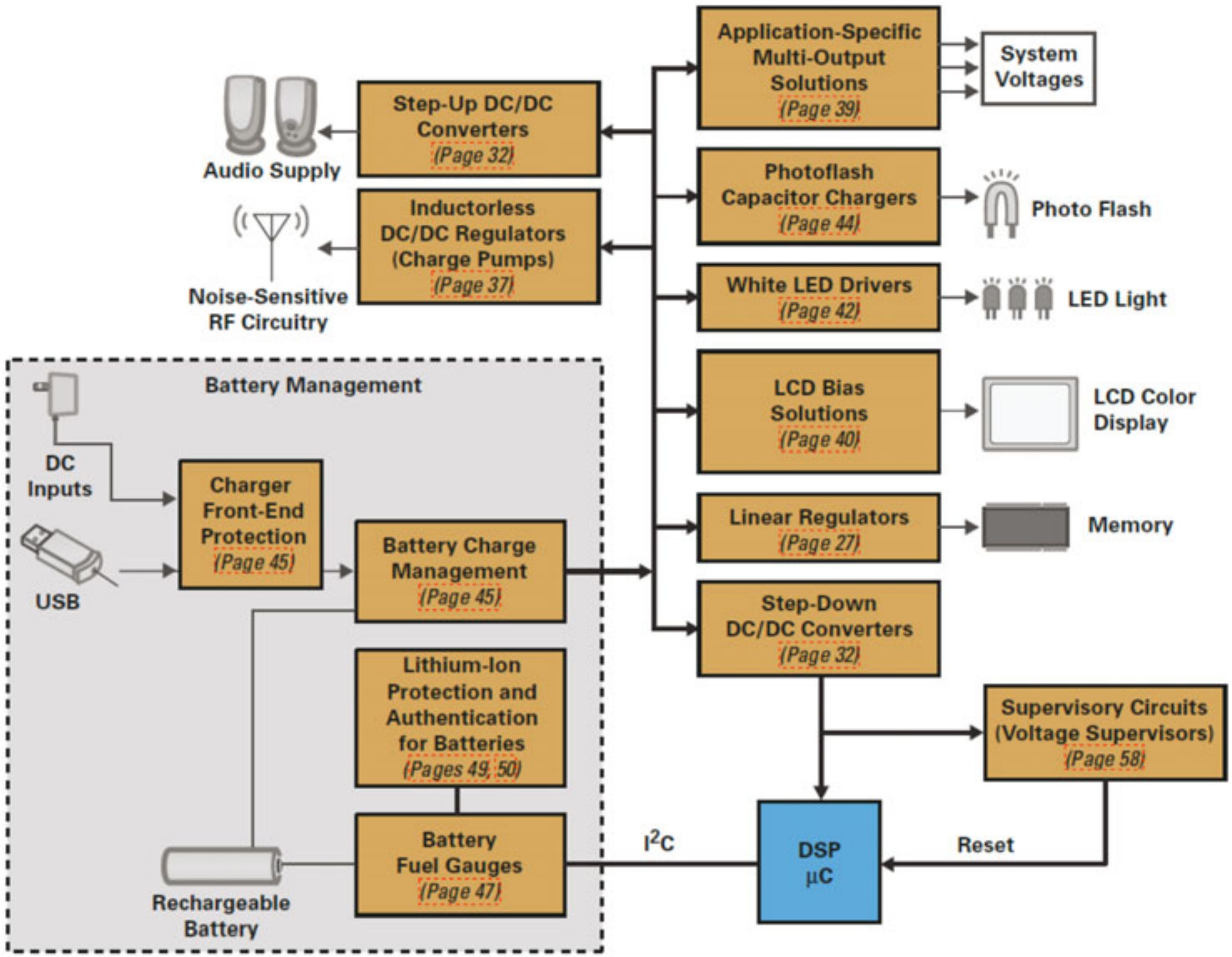
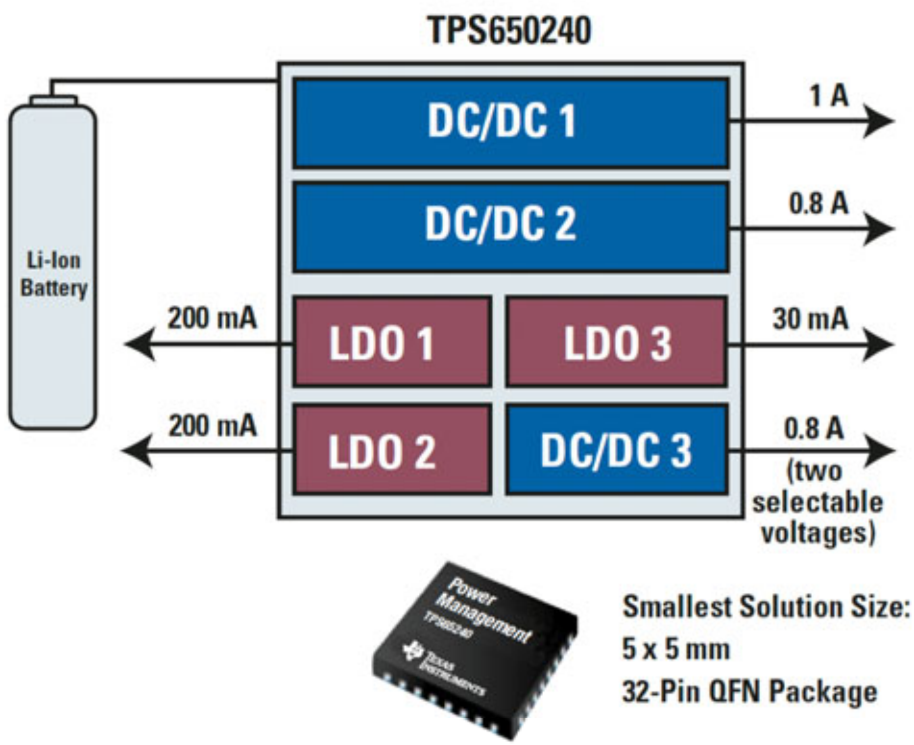
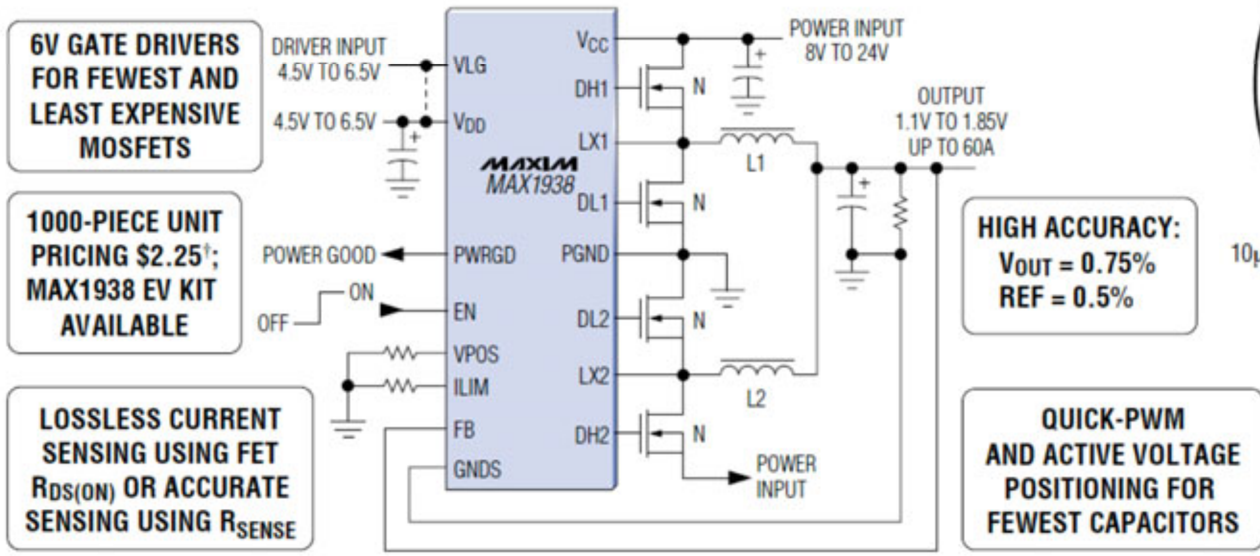


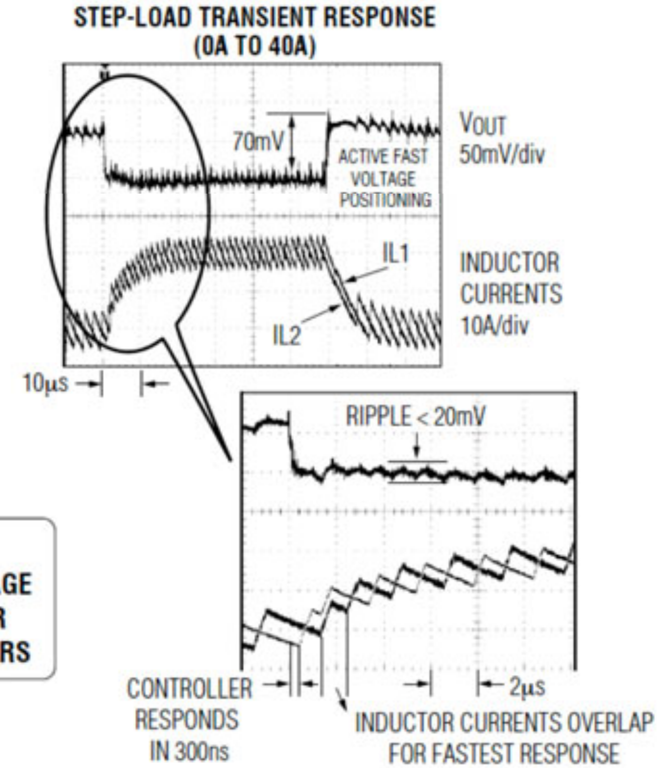
SMPS Applications

- Multi-channel power management units
  - On-chip diagnostics & protection



Power Electronics for CPU Power



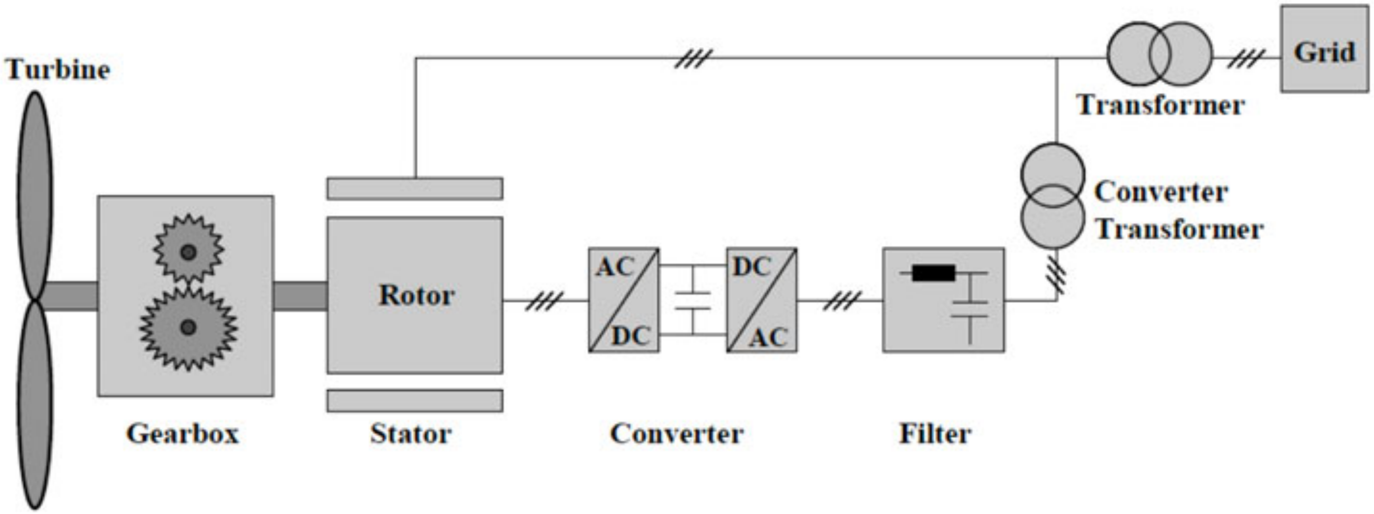


Dell XEON VRM Module

HP VRM Module

Power Electronics for Wind

- High efficiency SMPS are an integral part of wind energy harvesting



Source: Voller et. al. cigre 2009

Power Electronics For Solar

- High efficiency SMPS are an integral part of PV energy harvesting

Micro-inverter for PV

Buck-Boost Converter for PV

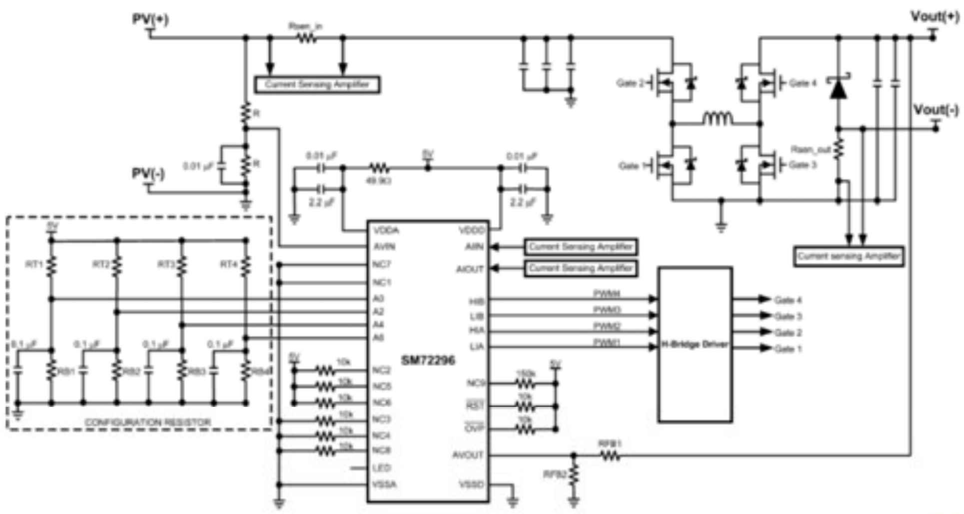
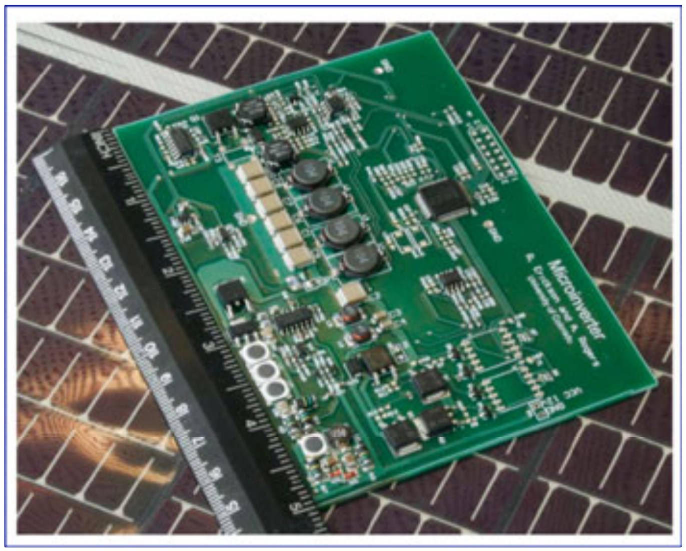


FIGURE 2. Typical Application Circuit

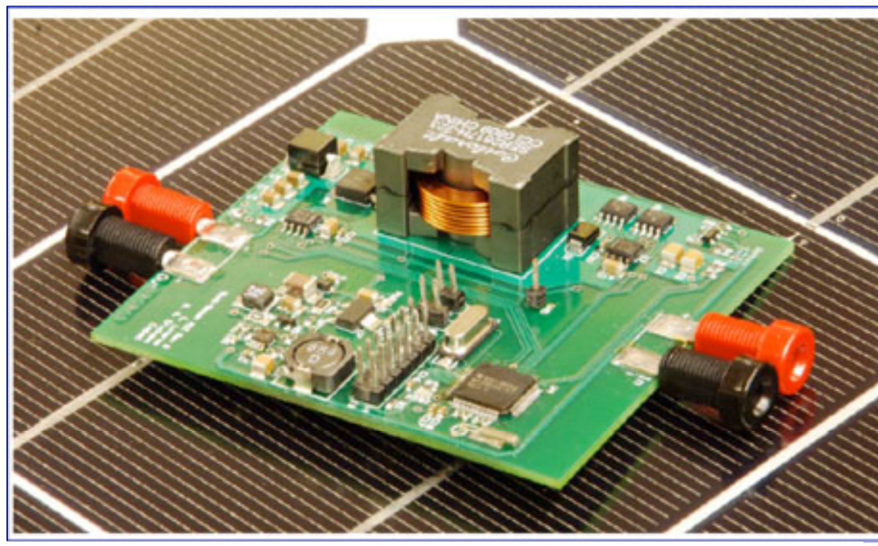
Power Electronics For Solar

- High efficiency SMPS are an integral part of PV energy harvesting

Micro-inverter for PV



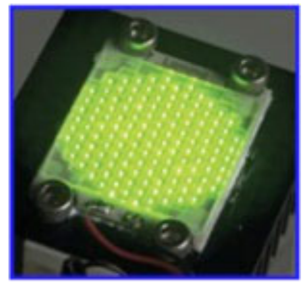
Buck-Boost Converter for PV



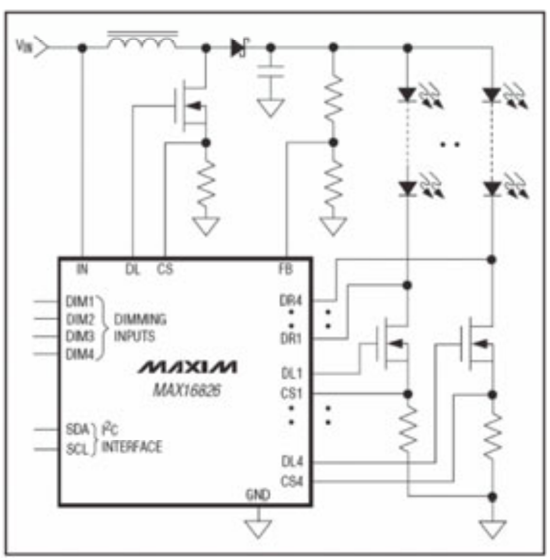
Source: Erickson et. al, APEC'09

Power Electronics for High Efficiency Lighting

- High efficiency SMPS are an integral part of the LED revolution

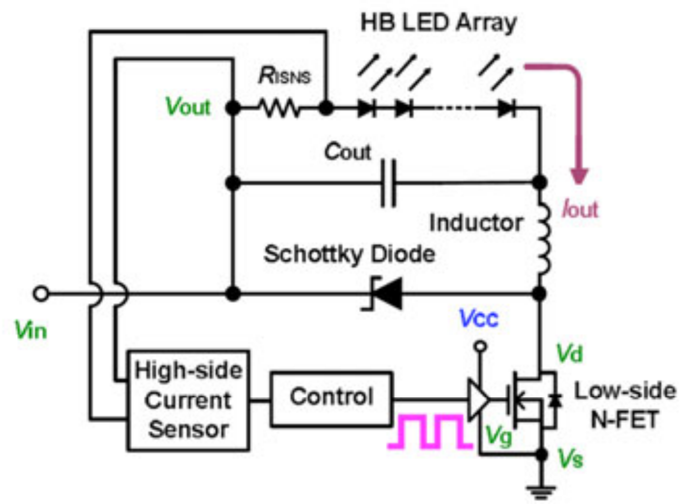


Boost for LED Drive



Source: Maxim

Floating Buck for LED Drive



Source: Fang et. al,APEC'09

Power Electronics for High Efficiency Lighting

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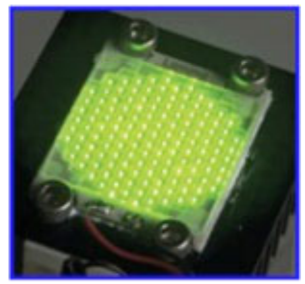
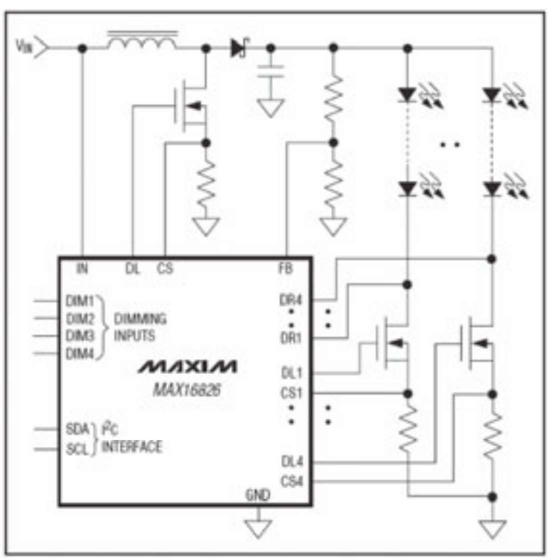
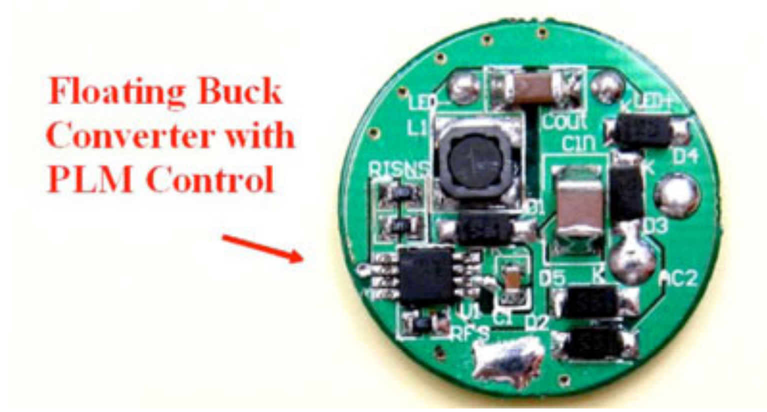


Boost for LED Drive



Source: Maxim

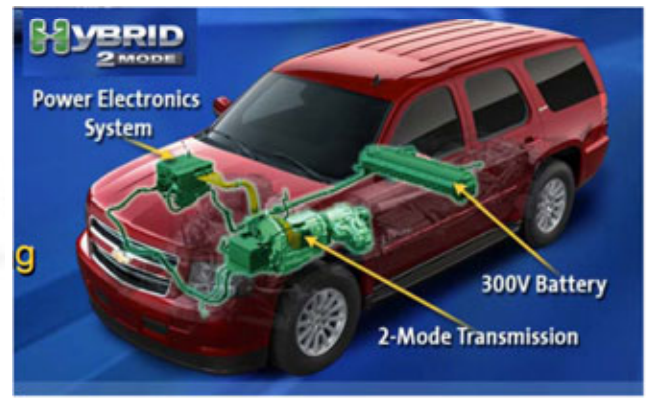
Floating Buck for LED Drive



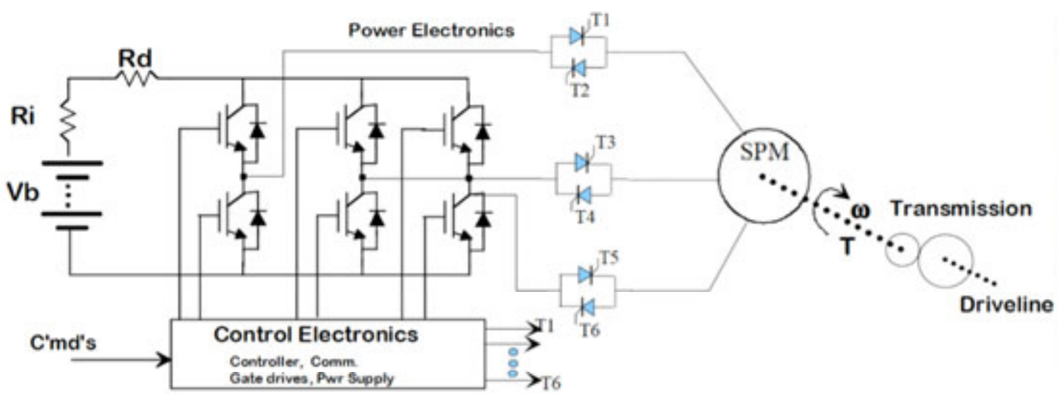
Source: Fang et. al,APEC'09

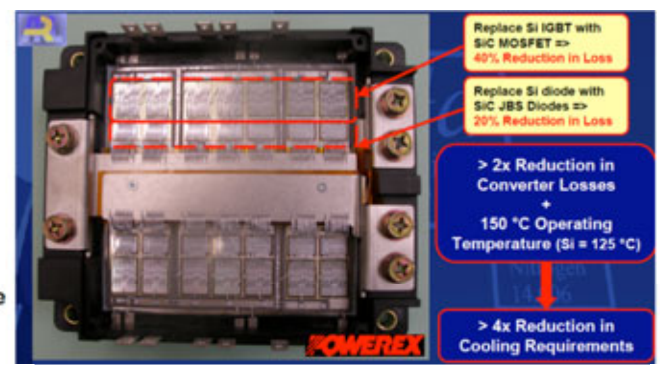
Power Electronics in Automotive/Industrial

! Nearly every car manufacturer is currently mass producing hybrid electric vehicles (HEV)



Source: General Motors, 2008

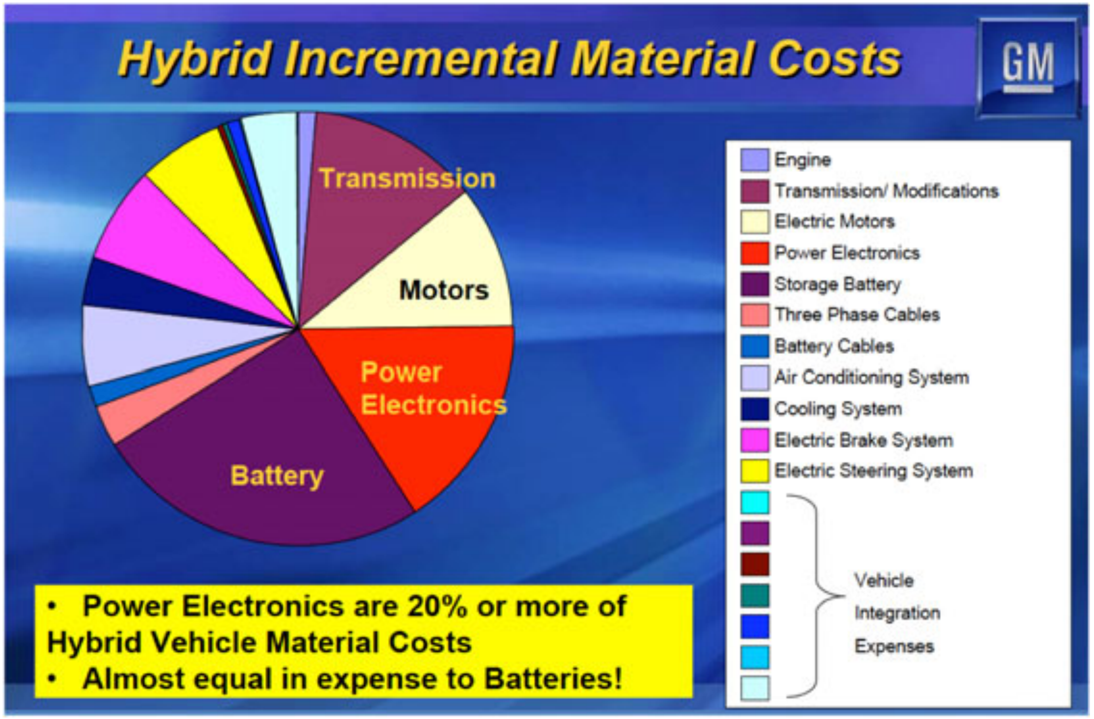




Source: D. Grider, Cree, Inc. 2008

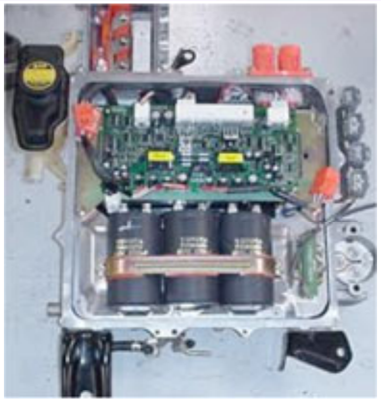
Power Electronics in HEVs and EVs

! 20 % of the HEV incremental costs is for power electronic components



Source: General Motors, 2008

Toyota Inverter + Battery pack:



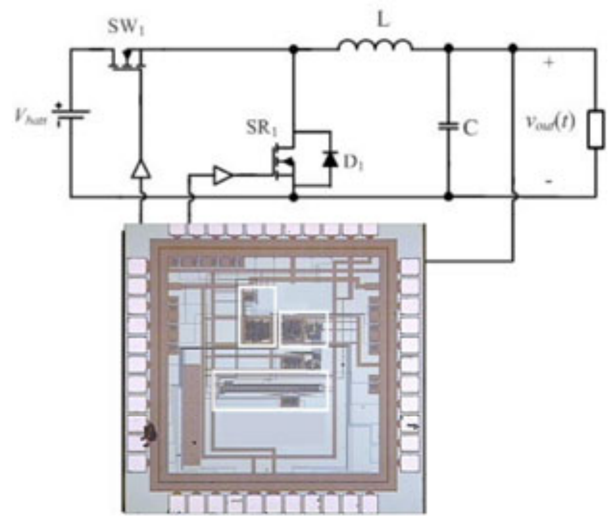
Research Fields in Energy Systems

- Integrating non-conventional energy sources such as wind and solar into the electricity network on a large-scale,
- Integrating energy storage units in the electricity network,
- Using micro-grids to aid storage and generation – employing power electronics, communication and control systems,
- Increasing the degree of automation and utilization of interconnected electricity networks,
- Providing security, continuity, and quality of energy supply against natural and manmade disasters,
- Optimizing hybrid electric vehicles
- On-chip power management
- Power electronics for medical applications
- Improving energy efficiency of industrial processes,
- Improving power density of energy conversion systems,
- Improving robustness of energy conversion systems.

Prof. Prodic's Research Interests

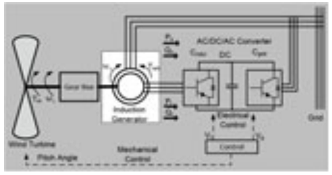
- Digitally controlled SMPS for low-to-medium power applications
  - HF architectures and IC implementation, auto-tuning, optimal response, control-based on-line efficiency optimization and power management, sensor-less parameter extraction
- Novel converter topologies
- Several on-going project examples (industry and government funded)
  - Flexible digitally controlled SMPS
  - On-chip implementation of ultra fast, low-power digital controllers
  - Auxiliary power electronics for automotive applications
  - Power electronics for medical applications (stimulators, implants and surgical devices)
  - Novel PFC topologies

The world's fastest digital controller IC developed in Prof. Prodic's lab.



Prof. Tate's Research Interests

- Leveraging smart meters to improve the reliability & efficiency of the power grid
  - Using smart meter data for real-time system ID and evaluation of possible control schemes
  - Developing new compression techniques to address the massive increases in data collected by smart meters



	23 bits (full prec)	19 bits	16 bits
Unprocessed	2.2131	2.6428	4.3740
SRE	2.2516	3.6901	6.0392
DE	2.5407	3.6097	6.1008

- Using the latest computer processors & architectures for simulation and planning
  - Developing software that utilizes general purpose graphics processing units (GPGPUs) to analyze and optimize wide-
  - area operation & control strategies

- Improving the situational awareness of power grid operators
  - Developing new metrics and visualizations that help operators identify & react
  - to potential problems associated with forecast wind and/or solar plant outputs

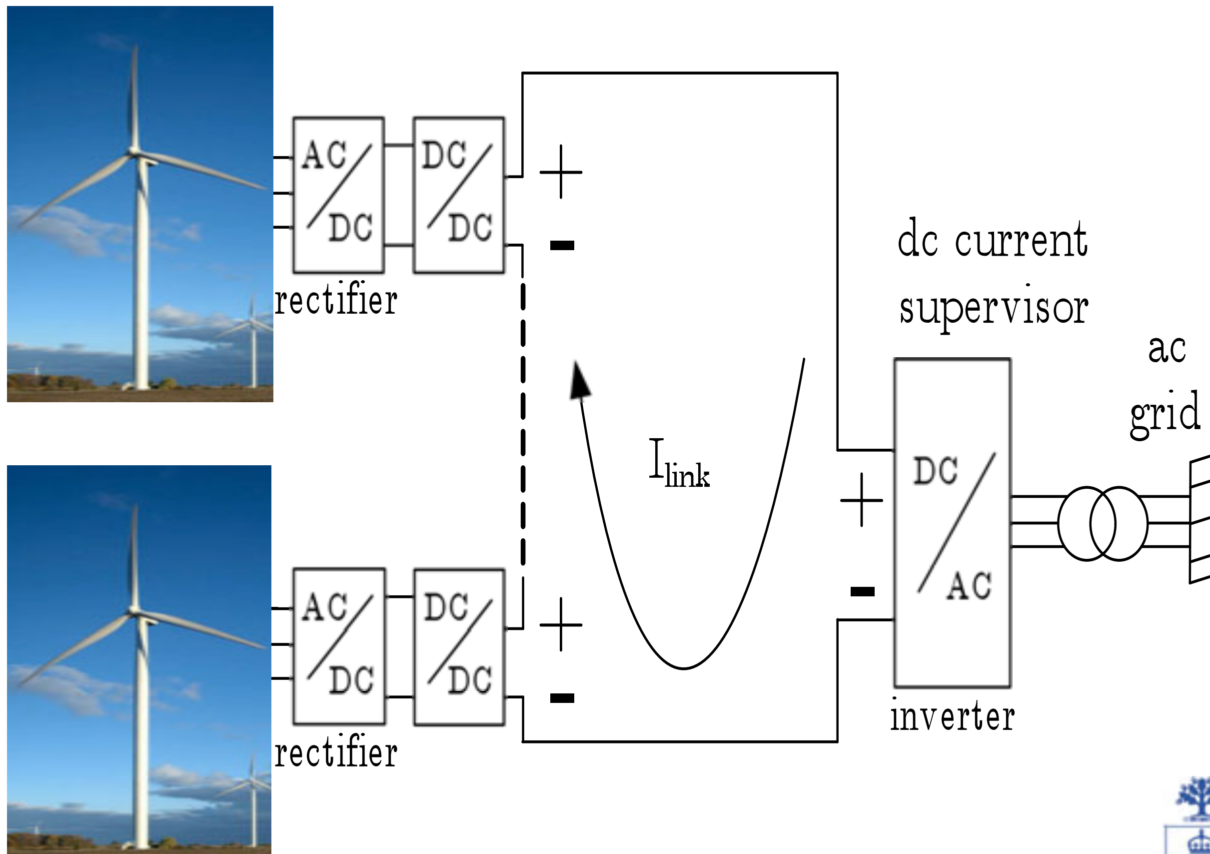
Prof. Lehn's Research Interests

New Power System Architectures and Power Electronics for Integrating Renewable Energy Source into the Grid

!Dc Networks: Enabling energy collection with improved efficiency

!Power Electronics: Enabling very high power conversion

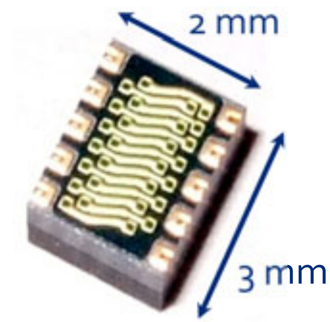
!Power Quality: Mitigating the impact of variable energy sources using energy storage

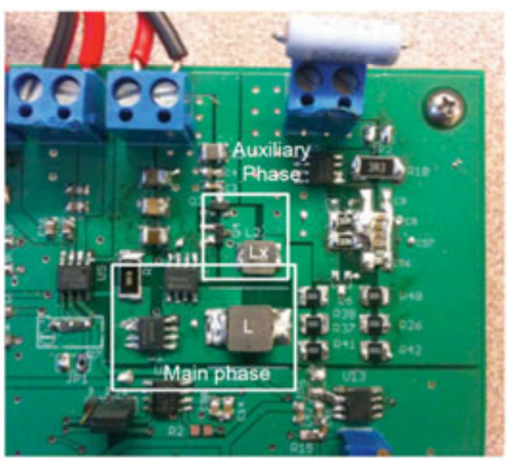


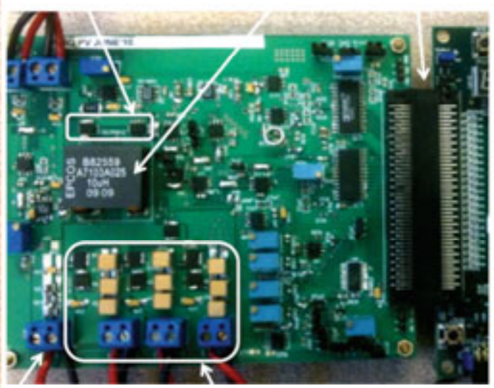
Prof. Trescases: Research Interests

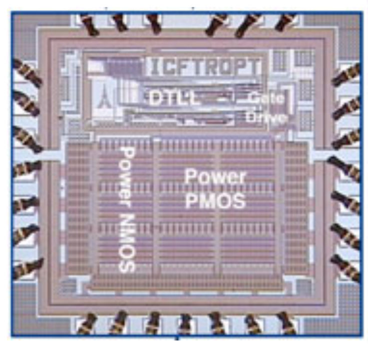
- Power electronics for solar, industrial, automotive, aerospace, and consumer application (mW- kW)
- Topologies, control schemes, efficiency optimization, integrated circuits
- Sample projects:
  - High-frequency, digitally controlled dc-dc converter ICs (efficiency optimization, system-level control schemes, etc.)
  - Power converters in BCD technologies for automotive applications (ECUs)
  - SMPS for driving and optimizing the efficiency of High-Brightness LED (HBLED) modules
  - Battery management for electric vehicles (SOH, SOC estimations, cell balancing, etc.)
  - Distributed power electronics for photovoltaic applications
  - Control of supercapacitors in electric vehicles

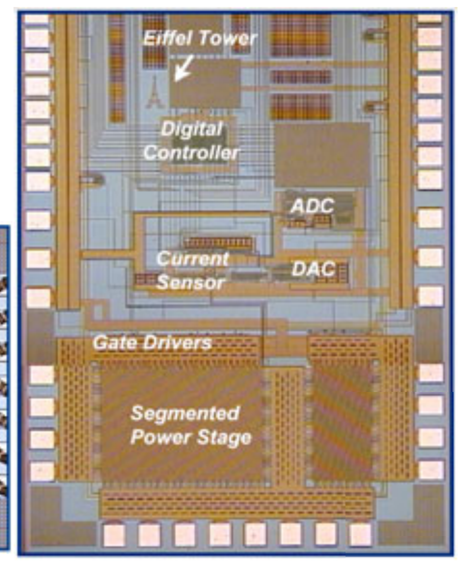
Micro dc-dc
Converter











Prof. Dawson: Research Interests

- Modeling of energy storage devices; supercapacitor, battery
- Modeling of hybrid energy storage systems
- Wastewater treatment using electrochemical decomposition
- Wastewater treatment using ultraviolet light
- Energy harvesting; thermoelectric and piezoelectric generation
- Signal processing in power engineering
- Power electronics and light sources

Prof. Iravani: Research Interests

- Operation, Control, and Protection of Utility Grade Distributed Generation and Energy Storage
- Microgrids and Active Power Distribution Systems
- Wind and Solar PV Based Power Generation Systems
- High-Voltage Direct Current (HVDC) Grids
- Power Electronic Converters for High-Voltage Applications
- Electromagnetic Transients in Power Systems

Active Graduate Courses

- **ECE 533**; Advanced Power Electronics (Trescases)
- **ECE1084**: Advanced High Efficiency SMPS (Trescases)
- **ECE1085**: Power Systems Optimization (Tate)
- **ECE 1065**; Special Topics in Energy Systems: Space Vector Theory & Control (Lehn)
- **ECE 1057**; Static Power Converters 1-Principles of Operation & Application (Iravani)
  - instructor approval
- **ECE 1068**; Introduction to Electromagnetic Compatibility EMC (Dawson)
- **ECE 1066**; Design of High-Frequency SMPS (Prodic)
- **ECE 510**; Introduction to Lighting Systems (Dawson)