Georgia Institute of Technology

INTELLIGENT POWER INFRASTRUCTURE CONSORTIUM

Power Research at Georgia Tech

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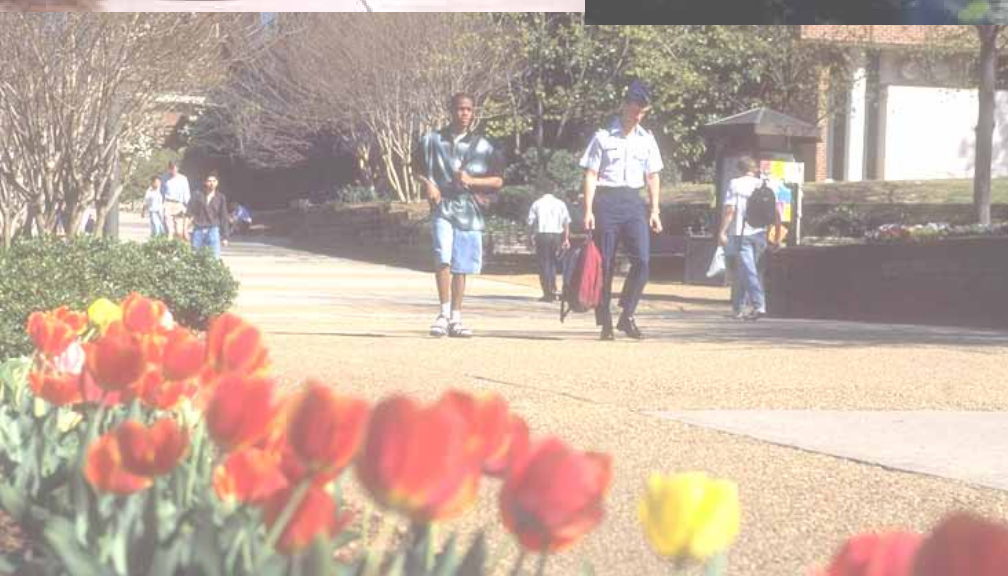
Georgia Institute of Technology



Georgia Institute of Technology

- Premier research university with focus on technology.
- Annual research budget >$349 million
- Georgia Tech – Lorraine, Metz, France gives European presence
- Ranked 5^{th} in 2005 graduate engineering schools (US News & World report)
- 11,000 undergrads, 5,000 graduate students
- College of Engineering – 1275 BS, 896 – MS and 181 – PhD degrees awarded in 2003
- Largest ECE Department in the US - 120 faculty, 1800 undergrad students, 800 grad students
- Strong presence in power, communications, nanotechnology, MEMS and microelectronics, embedded systems, computing, organic electronics, signal & image processing and bio-medical
- Eight faculty working in the power area with competencies in power systems, power electronics, diagnostics, micropower, controls, and high voltage engineering
- Located in Atlanta – fast growing high-tech center.

Electric Power at Georgia Tech

World Renowned Faculty

- M. Begovic
- D. Divan
- T. Habetler
- R. Harley
- A. Meliopolous
- G. Rincon-Mora
- A. Rohatgi
- R. Webb

Areas of Competency

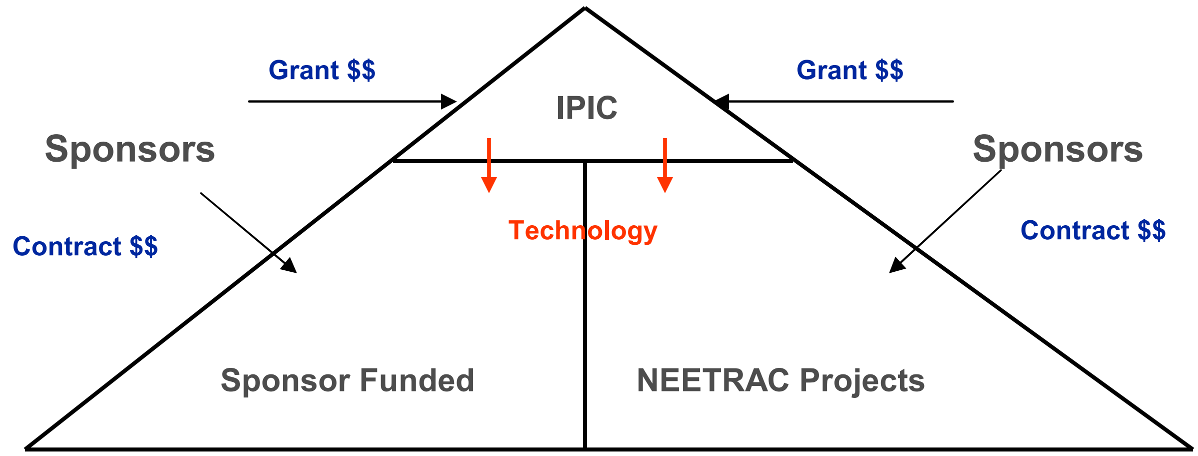
- Power Electronic Circuits & Converters
- Electric Machines, Design & Protection
- High Performance DC/DC Converters
- Neural Networks in Power
- Power Electronics in Power Systems
- Power Systems Analysis & Planning
- High Voltage Engineering
- Photovoltaic Devices & Alternate Energy
- Sensorless Diagnostics Using ANNs
- Power Sensor Networks

- A balanced program covering education, research and tech-transfer
- Eight full time faculty and 39 graduate students
- NEETRAC program provides unique facilities & competencies

Basic Approach

- Strive for a balance between research, teaching and industry outreach
- As basic power electronics technology matures, the types of research conducted in universities v/s industries is shifting
- New research opportunities are emerging at the intersection of power electronics – distributed control – communications – and industrial/consumer/utility applications
- Diagnostics and prognostics, artificial intelligence and neural networks, wide area control, protection and uptime, integration of systems for manufacturability are all key drivers for the future
- Attracting US students into the power program is still a challenge

GT Power Research Program Structure



- IPIC does early-stage high-risk high-impact projects – consortium funded
- The power program at GT receives >$6M/year in funding, including NEETRAC
- IPIC projects have already led to funded projects and to commercialization
- Over 30 utilities, industries and agencies support the work at GT
- DOE Center in Photovoltaics and a Fuel Cell Research Center at GT

Program Accomplishments

Milestones:

- IPIC consortium started in 2005, strong growth
- 14 PhD degrees were awarded to IPIC students (2002-05)
- IPIC faculty and students
  - Published 150 papers in journals and conference proceedings (2004-05)
  - Filed for 14 patents/disclosures in 2004-05
- There are 36 PhD students and 3 MSc students in the IPIC program

Educational Program (includes Distance Learning)

- 10 graduate courses in power
- 6 undergraduate courses in power
- 7 short courses in power

Research Program

- Approximately 35 active projects within IPIC umbrella
- Close working relationship with NEETRAC and PSERC
- Includes three labs on campus, plus access to NEETRAC facilities
- New laboratory facility for power electronics

Intelligent Power Infrastructure Consortium – Research Thrusts

- Power line communications
- Neural nets for system I/D and control

UTILITY APPLNS

- Power line sensornets
- Wide area monitoring
- Distributed power line sensing

- Wide area control
- Wide area protection

- Power system operation and state estimation
- Protective relaying
- Bulk power system reliability

- Congestion management
- System control and stability with FACTS
- Distributed energy sources

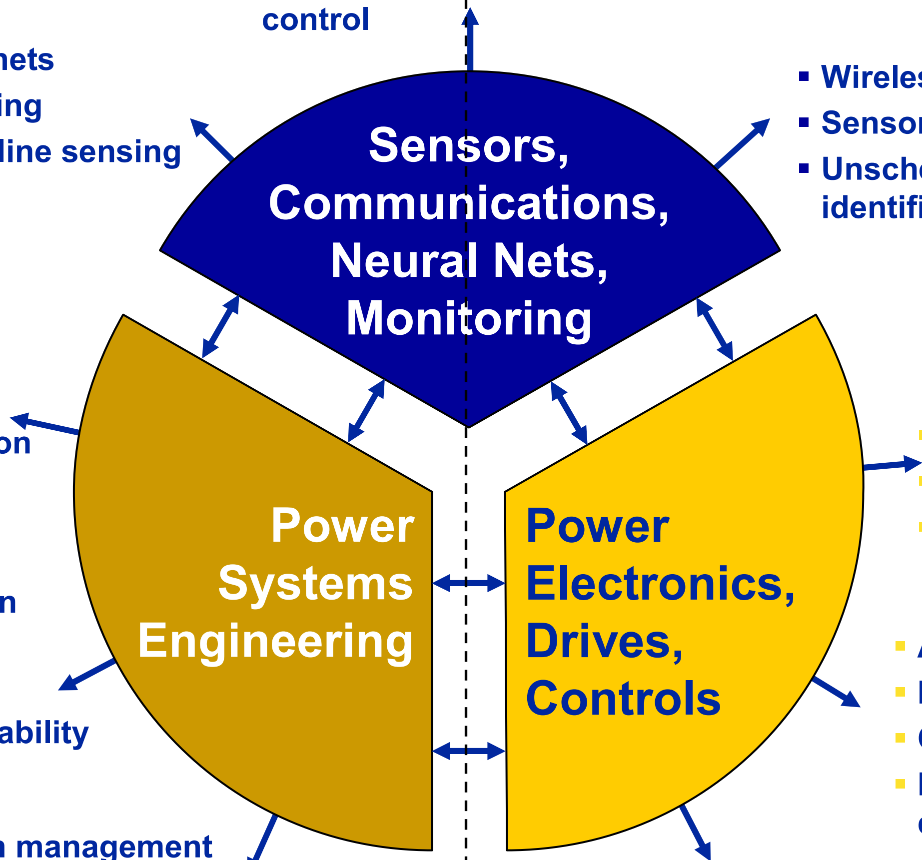
INDUSTRIAL APPLNS

- Wireless sensor networks
- Sensorless motor fault detection
- Unscheduled down-time identification

- Neural network controls for PE
- Component failure prediction
- Power and analog ICs

- Active filters
- Motor Drives
- Current surge limiters
- High power inverters & dc/dc converters

- D-FACTS devices
- Current limiting conductors
- Fault current limiters
- Power quality and reliability



National Electric Energy Testing Research & Applications Center

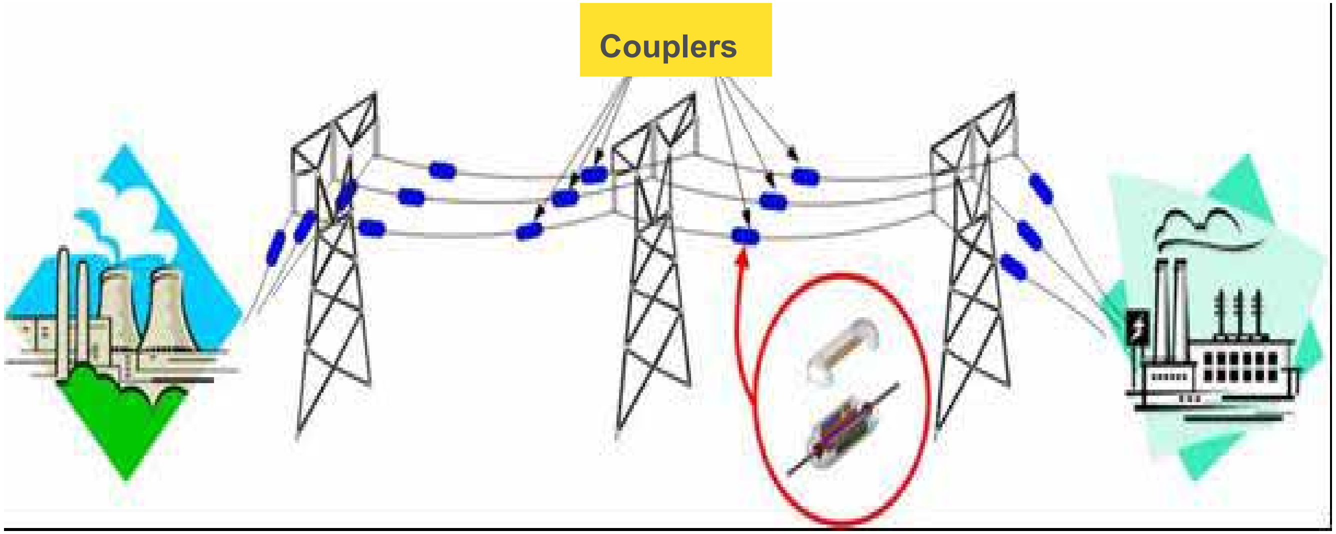
NEETRAC

A Research Center of the Georgia Institute of Technology

Some Ongoing Power Electronics Projects at GT

- Current Limiting Conductors for Preventing Thermal Overload on Power Lines
- Adaptive Critic Design Based Neurocontroller for Static Compensator
- Micro-Engine Based Portable Power Pack
- Optimal Allocation of Static and Dynamic VAR Resources
- Determining Harmonic Contributions from Non-Linear Loads
- Augmentation of Existing MV Transformers with Power Electronics
- High Power DC/DC Converters
- Quasi-Linear DC/DC Converters
- Energy Harvesting System-In-Package for Wireless Micro-Sensors
- An Accurate Integrated Li-Ion Battery Charger
- Dynamically Adaptive Power Supply for Linear RF Power Amplifiers
- Smart Capacitors – Condition Monitoring of Capacitors in PE Applications
- Distributed Sensing Along Power Lines
- Wireless Sensor Networks for Industrial and Utility Applications
- Online Stator Winding Temperature Estimator for Induction Machines
- Fault Detection in Brushless DC Motors
- Offshore Wind Farm Architecture
- Sustainable Single Home Power System for Off-Grid Villages

Distributed Control of Power Line Impedances

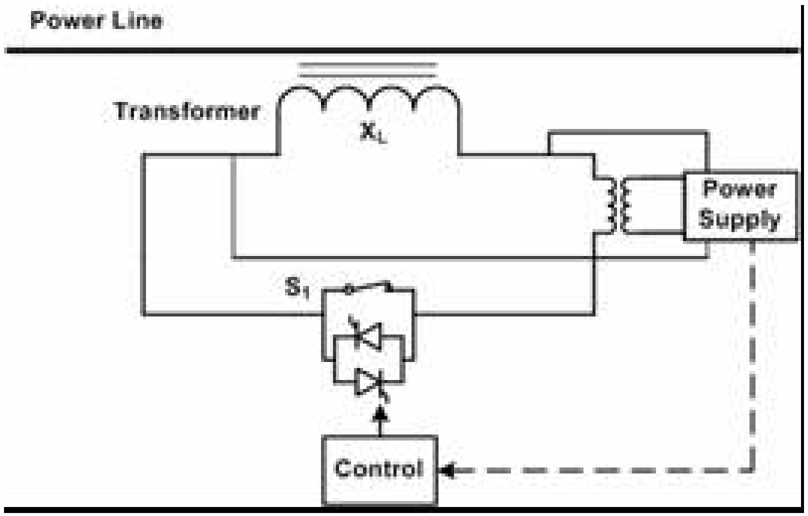


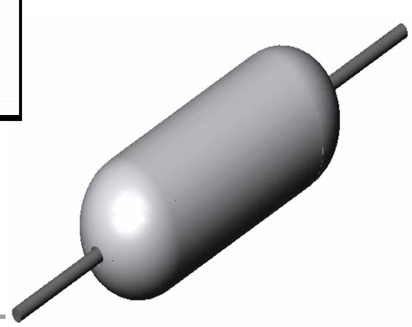
- Control how current flows on the power network, allowing automatic routing of current away from overloaded lines onto lines with available capacity (reliability benefit), and allowing dispatch of more economic generation resources along ‘non-optimal’ transmission corridors (economic benefit).

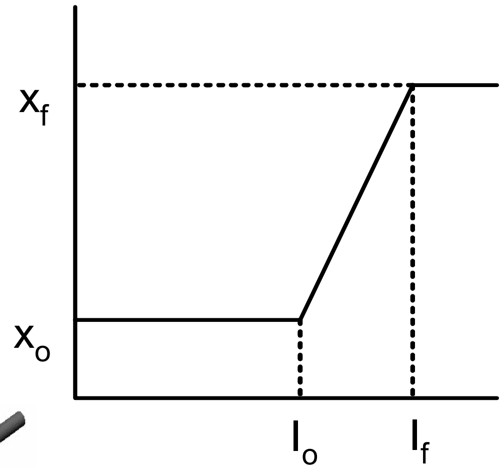
- Accomplished by controlling the impedance of power lines using multiple low-cost devices that clip on to existing power lines. The devices utilize simple commoditized technology and components, allowing rapid deployment with low capital and operating costs. Distributed solution allows mass manufacture and provides high reliability.

Current Limiting Conductors (CLiCs)

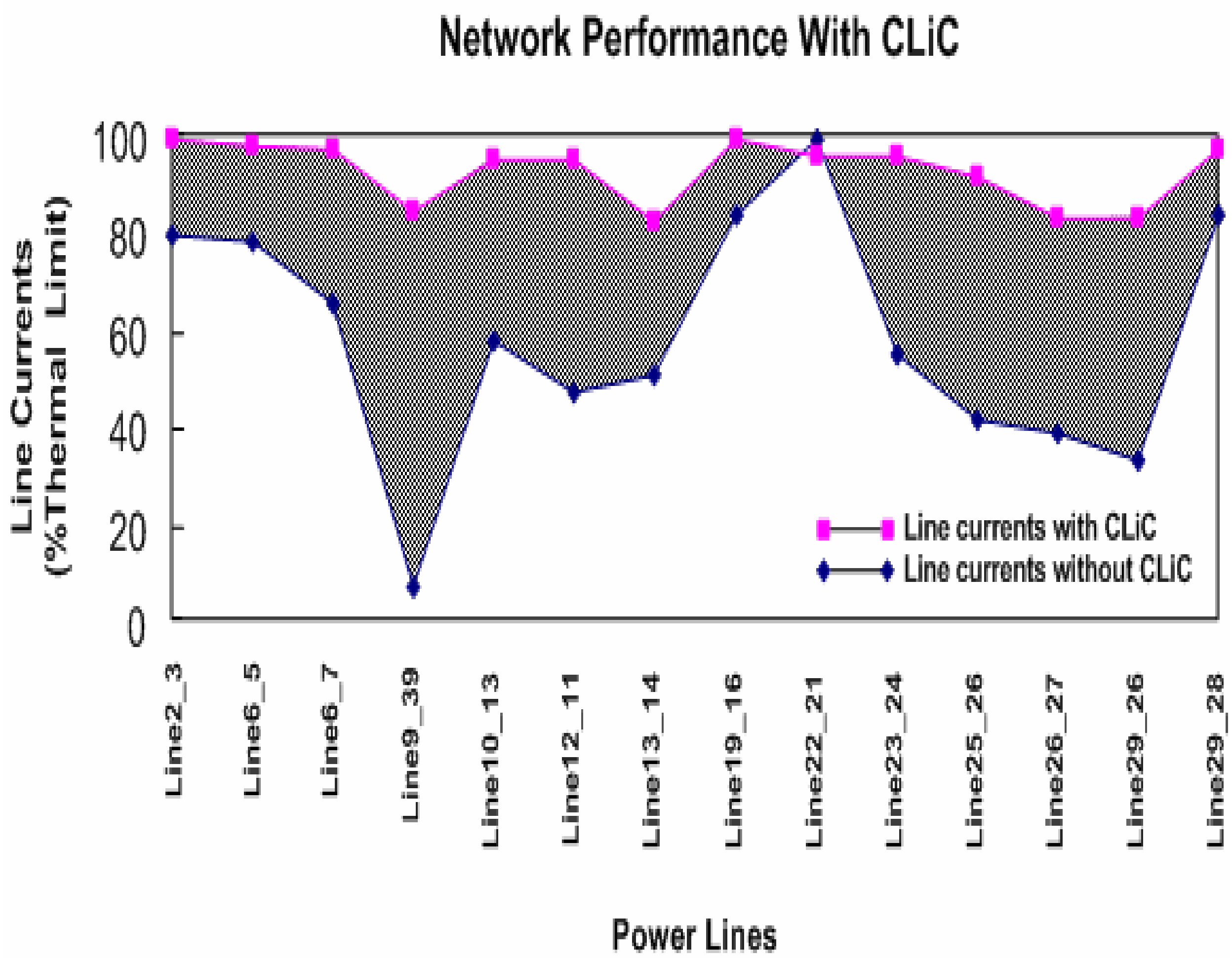
- It has not been possible to control current flows in a ‘meshed’ system, resulting in congestion, even as other lines remain under-utilized
- As current in a power line approaches thermal limit, line inductance needs to increase so that current is diverted automatically to lightly loaded lines
- Distributed Series Reactance modules clip on to the power line
- Does not require communications or change in utility infrastructure





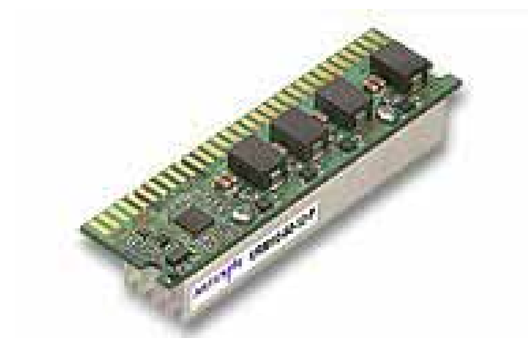


CLiCs – Summary of Results for IEEE 39 Bus System



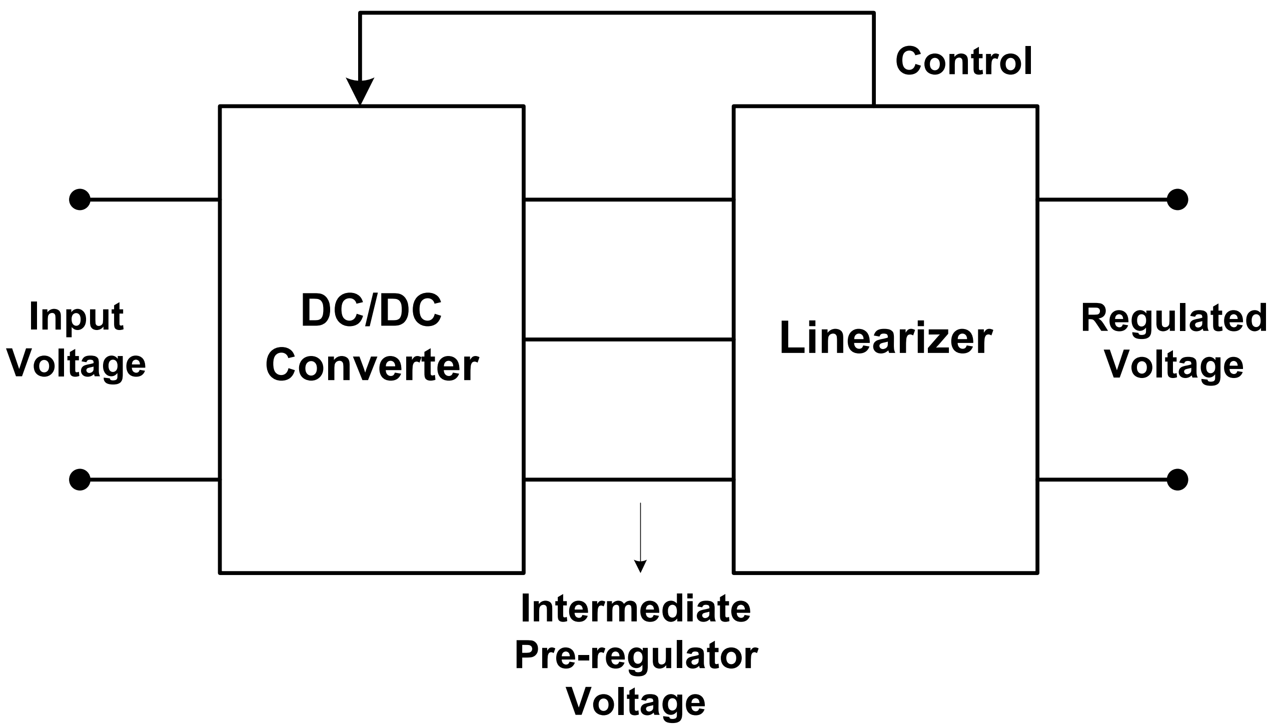
Need for High Performance DC/DC Converters

- Demanding applications, such as medical imaging, fast processors, and pulsed loads are requiring new levels of performance from DC/DC converters
  - Extremely low ripple voltages
  - Sub-cycle response and settling times (new Intel processors consume 100 A with slew rates > 150A/μs and ΔV = 50 mV)
  - High efficiency and small size
- It is generally agreed that power supply technology will be one of the limiting factors for the continued growth of VLSI technologies
- Conventional design approaches are not able to meet these needs easily

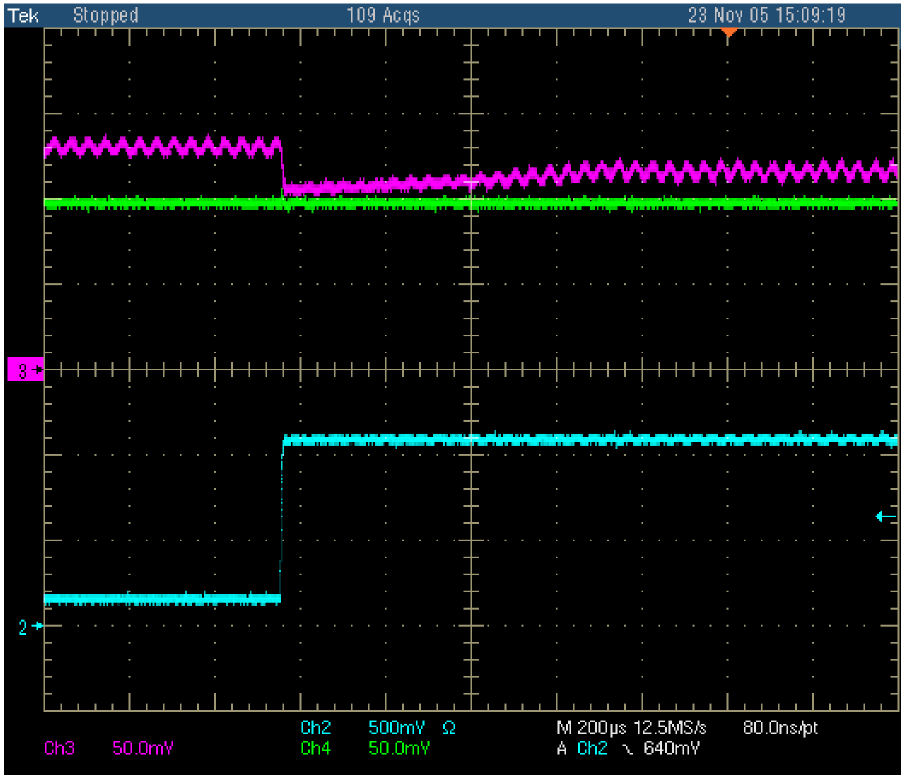


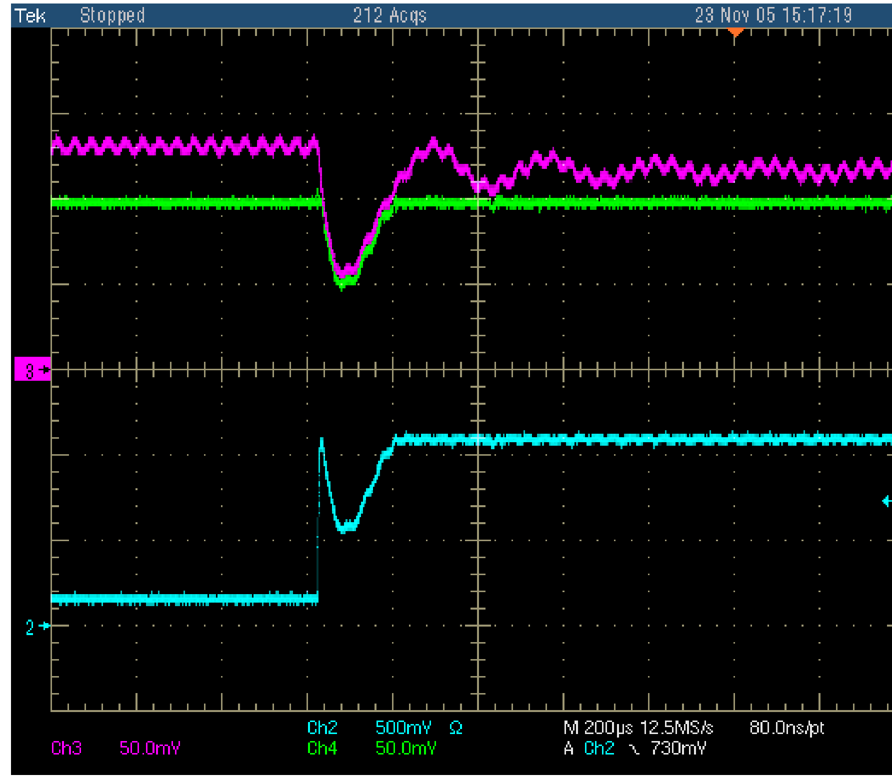
Quasi Linear DC/DC Converters

- A hybrid technique to realize linear power supply performance with switched mode DC/DC converter efficiency and size is proposed



Quasi Linear Buck Converter





With Current Injection and Post-Regulation | **Only Post Regulation, No Current Injection**

Buck regulator (12V → 5V) at 25 KHz switching frequency (2x47uF MLC Bulk Capacitors)

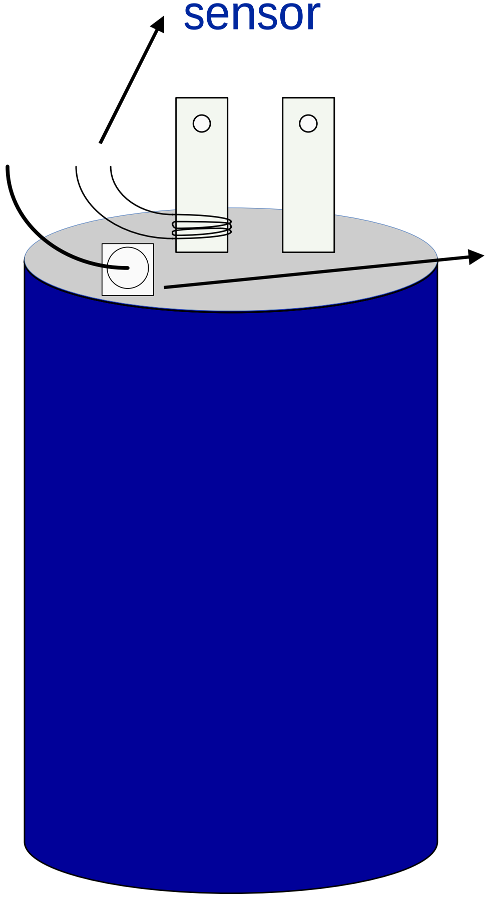
Load switching at 100 Hz

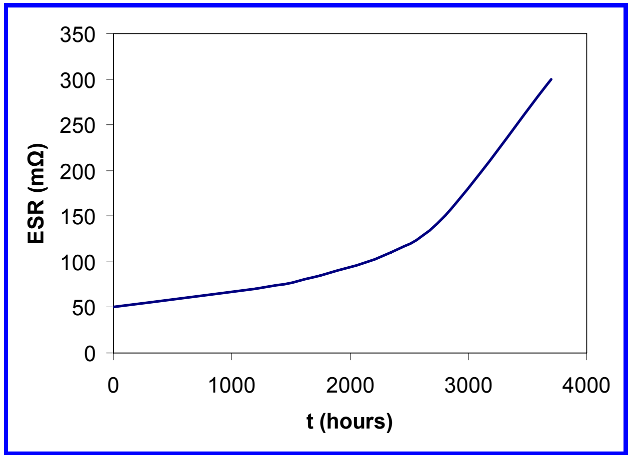
Top trace (Pink): Buck output voltage, 50mV/div -> 2.5V/div

Middle trace (Green): Output load voltage, 50mV/div -> 2.5V/div

Lower trace (Blue): Load current 5A/div

Smart Capacitors: Condition Monitoring of Electrolytic Capacitors





Sense:
- ESR
- Temperature
- Pressure
- Capacitance
- Stress

Estimate:
- ESR, C, Life

Communicate:
- Over existing power bus

Induction Machine Condition Monitoring

- Thermal overload protection

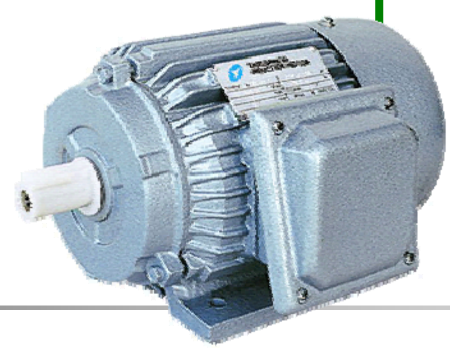
Measure positive sequence in current, resistance, temp.

- Insulation deterioration (35% of failures)
  - Turn-to-turn faults
  - Ground faults

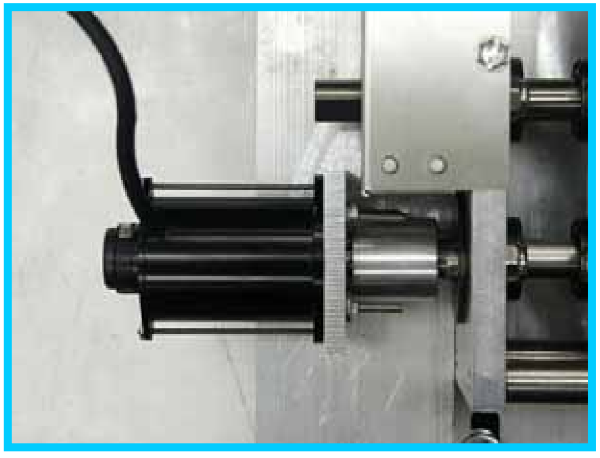
Measure negative sequence in current

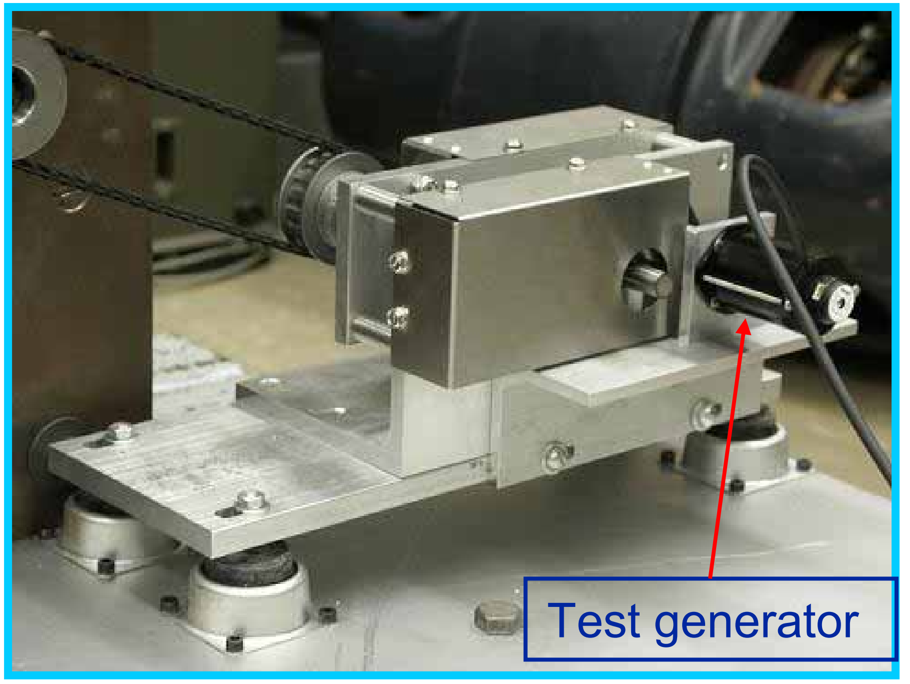
- Broken rotor bars
  - Primarily in medium voltage copper bar rotors.
- Worn bearings (50% of failures)
- Unbalances and misalignment

Measure spectral components in current

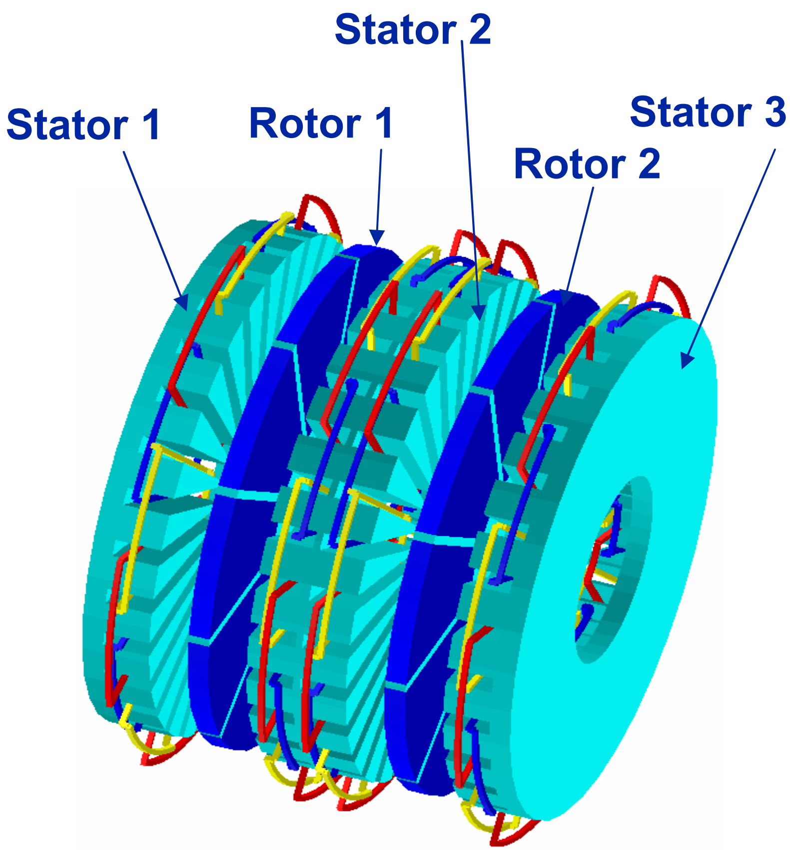


Oscillating PM Generator (30W) Prototype Testing

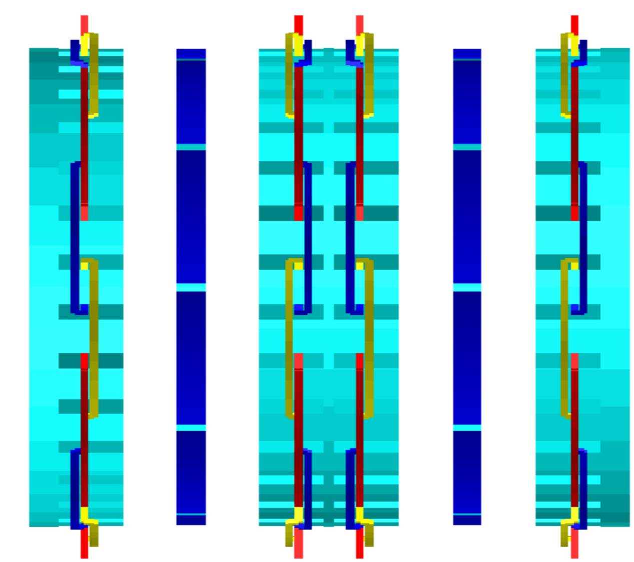




Interior rotor axial flux machine: low inertia



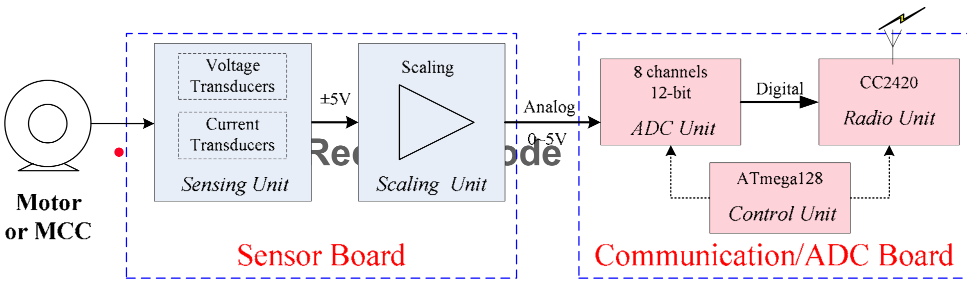
MAXWELL® 3D

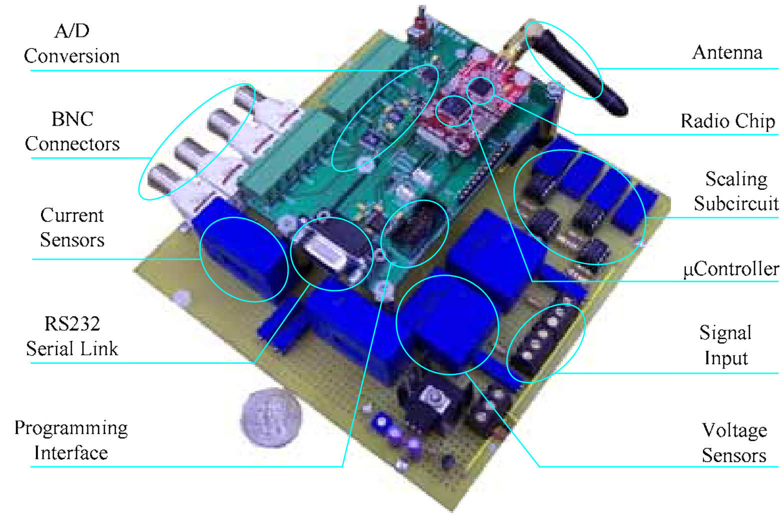


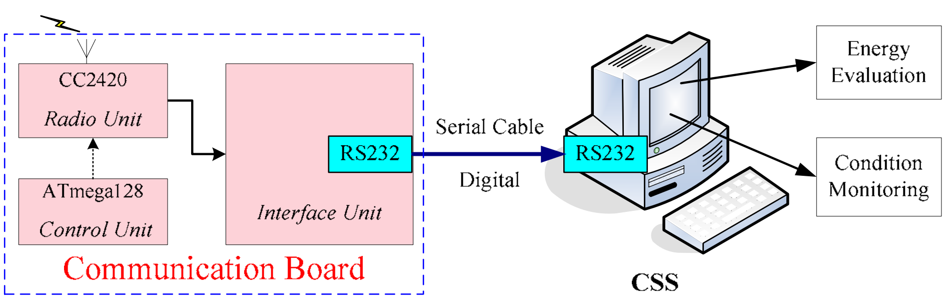
400 W prototype by May

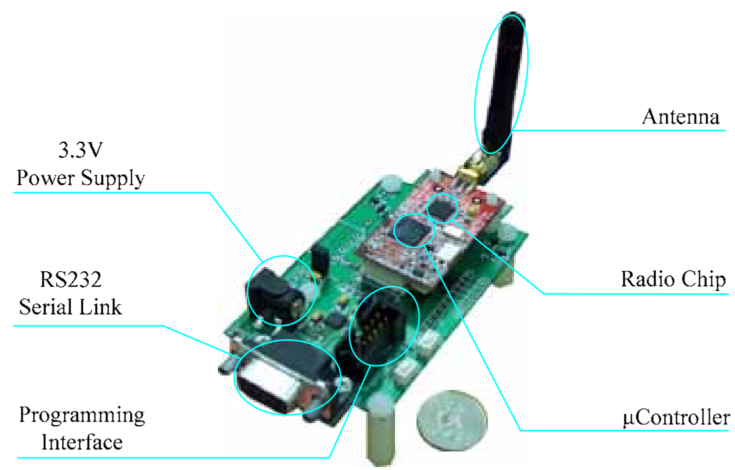
Prototype wireless sensor devices

- Transmitter Node

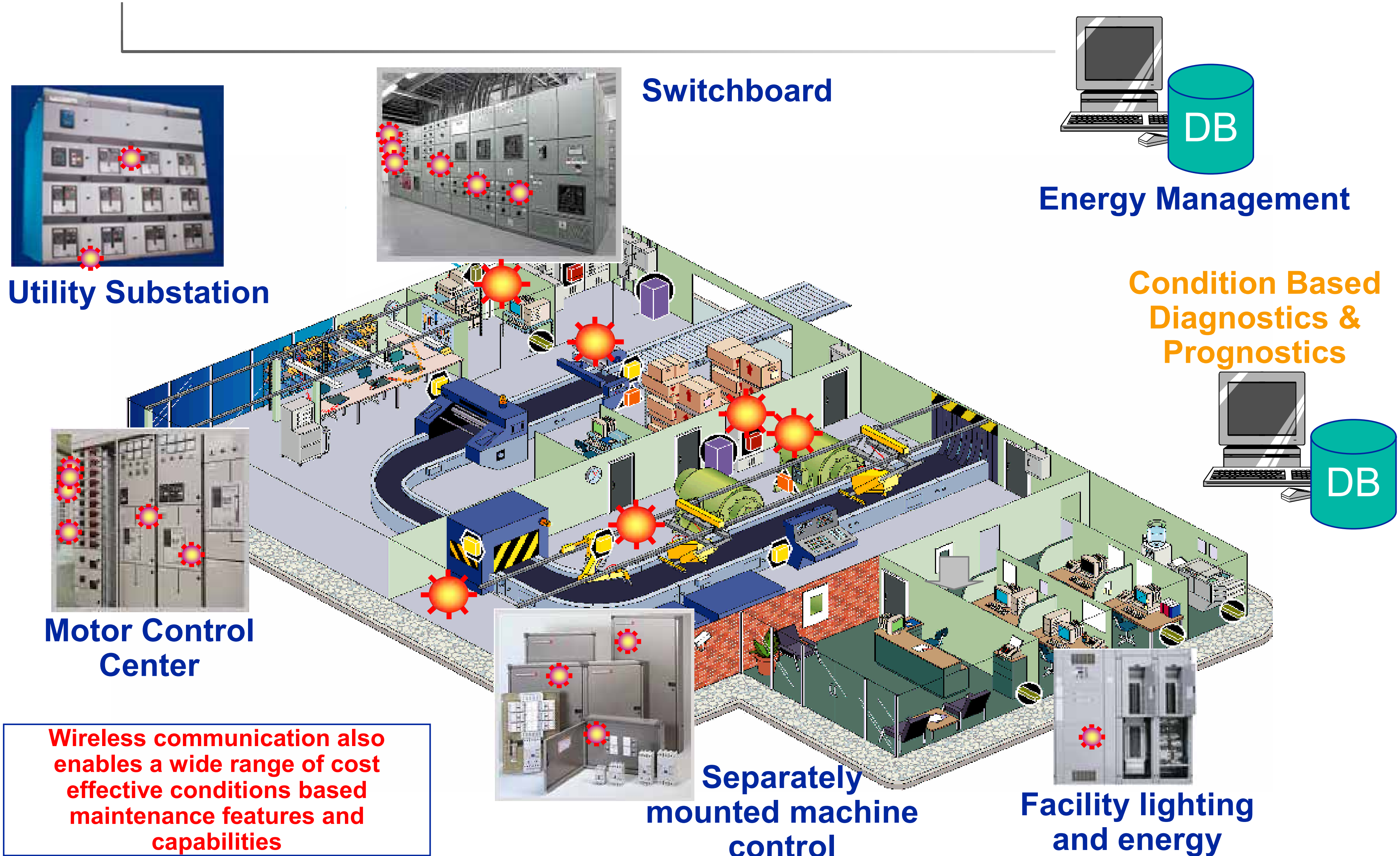








Wireless Sensor Network Architectural Concept

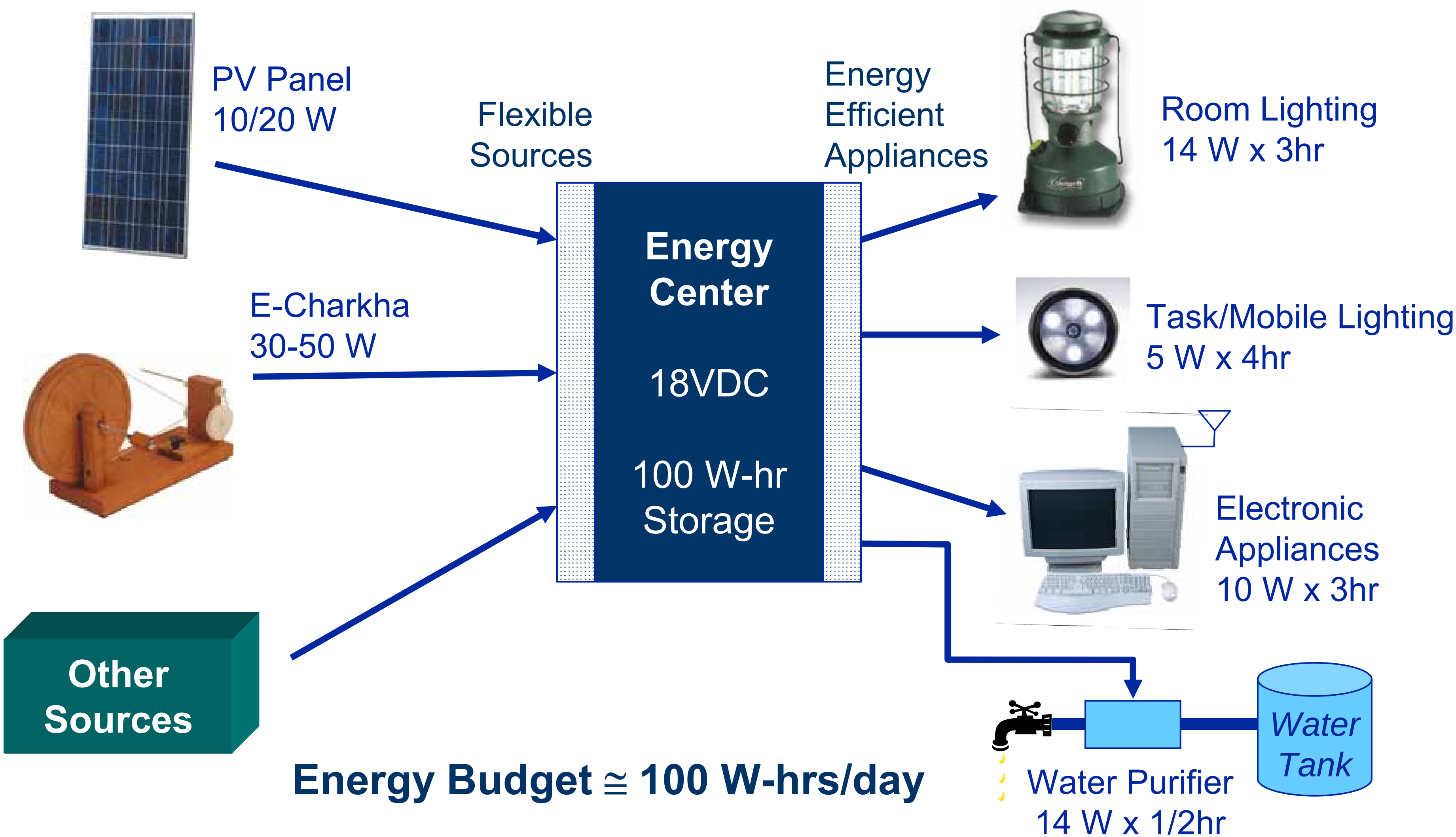


Wireless communication also enables a wide range of cost effective conditions based maintenance features and capabilities

Wireless Communication Enabled

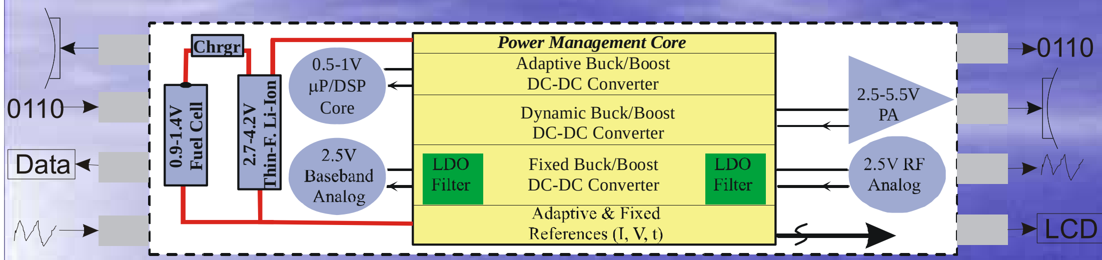
Wireless Sensors

Single Dwelling Energy Center for Off-Grid Villages



Chip Integration of Power Management Circuits

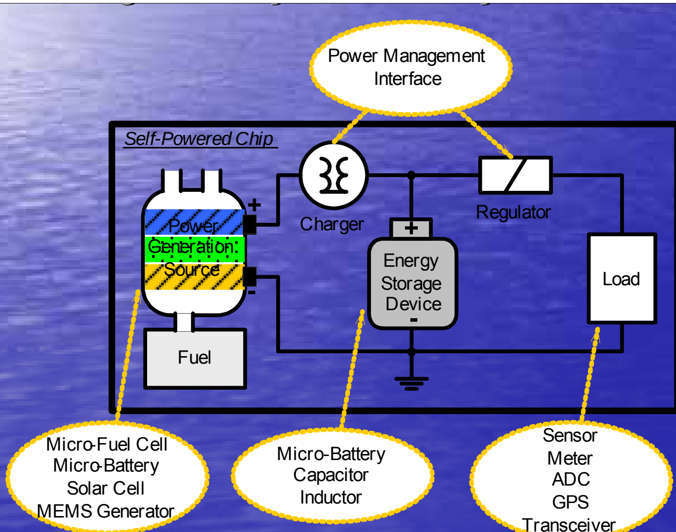
Prof. Gabriel A. Rincón-Mora - Georgia Tech Analog & Power IC Design Lab - http://www.rincon-mora.com



Goals

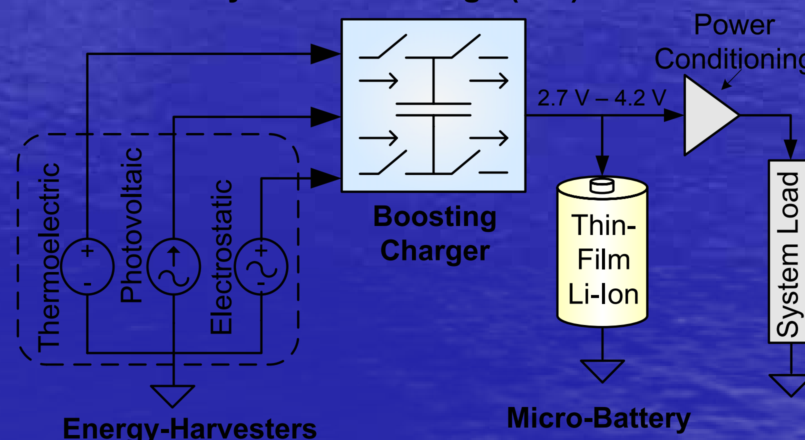
- → *Portable (small & compact)*
- → *Lightweight*
- → *Long-Lasting (long life)*
- → *Self-Powered*
- → *Self-Sustaining*

Extending Battery Life w/ Hybrid Sources



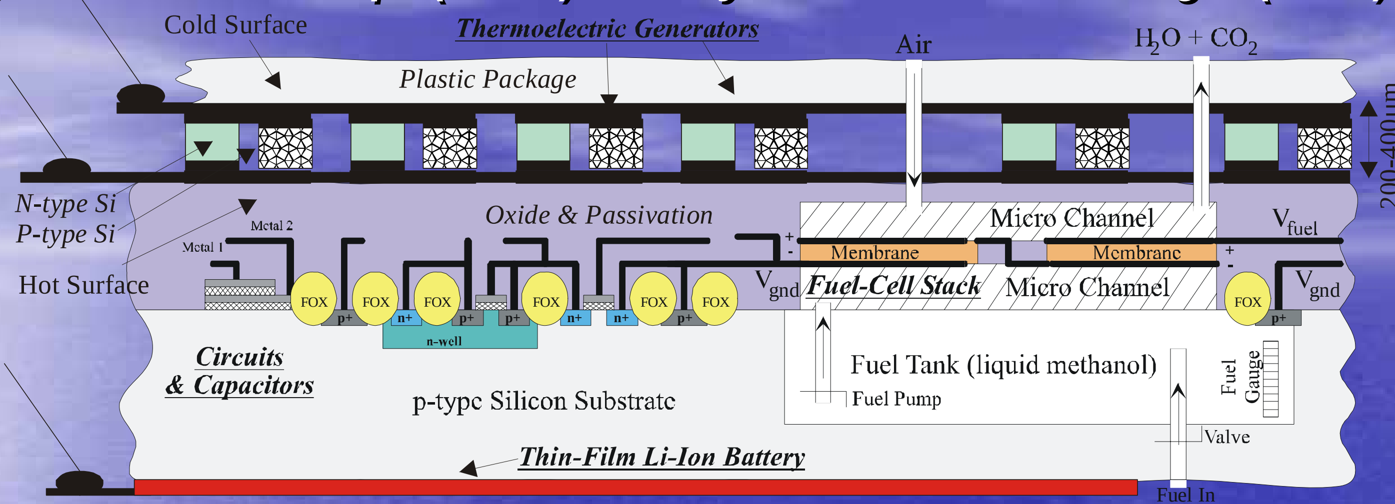
Harvesting Energy

System-in-Package (SiP) Solution

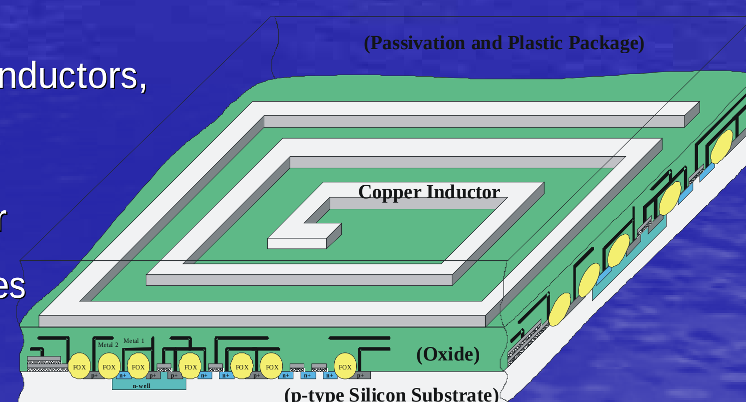


- → *Managing Hybrids*
- → *Intermittent, trickle Charger*
- → *Power Conditioning*
- → *Adaptive DC-DC Converters*
- → *Load Conditioning*
- → *...*

System-on-Chip (SoC) & System-in-Package (SiP)



- **SiP Technologies:** MEMS Devices, CMOS Circuits, & Thin-Film Polymer Li-Ion Batteries
  - **Energy Sources:** MEMS Thermoelectric & Electrostatic Harvesters & Direct-Methanol Micro-Scale Fuel Cells
  - **Energy Storage:** Li-Ion Batteries, Planar Cu Inductors, & Inductor/Capacitor Multipliers
  - **Power Conditioning/Delivery:** CMOS Linear & Switching Regulators & Trim-less References
  - **Load Conditioning/Energy Transfer:** Low Voltage CMOS Chargers



Summary

- Georgia Tech has a strong and vibrant program in power technologies, including power electronics
- In addition to being strong in traditional technology areas, we have strength in emerging areas such as distributed control, neural networks, diagnostics, as well as newer fields such as utility applications
- Contact us ddivan@ece.gatech.edu if you have any questions.