



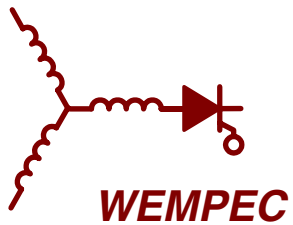
THE UNIVERSITY  
of  
**WISCONSIN**  
MADISON

**UW-Madison**

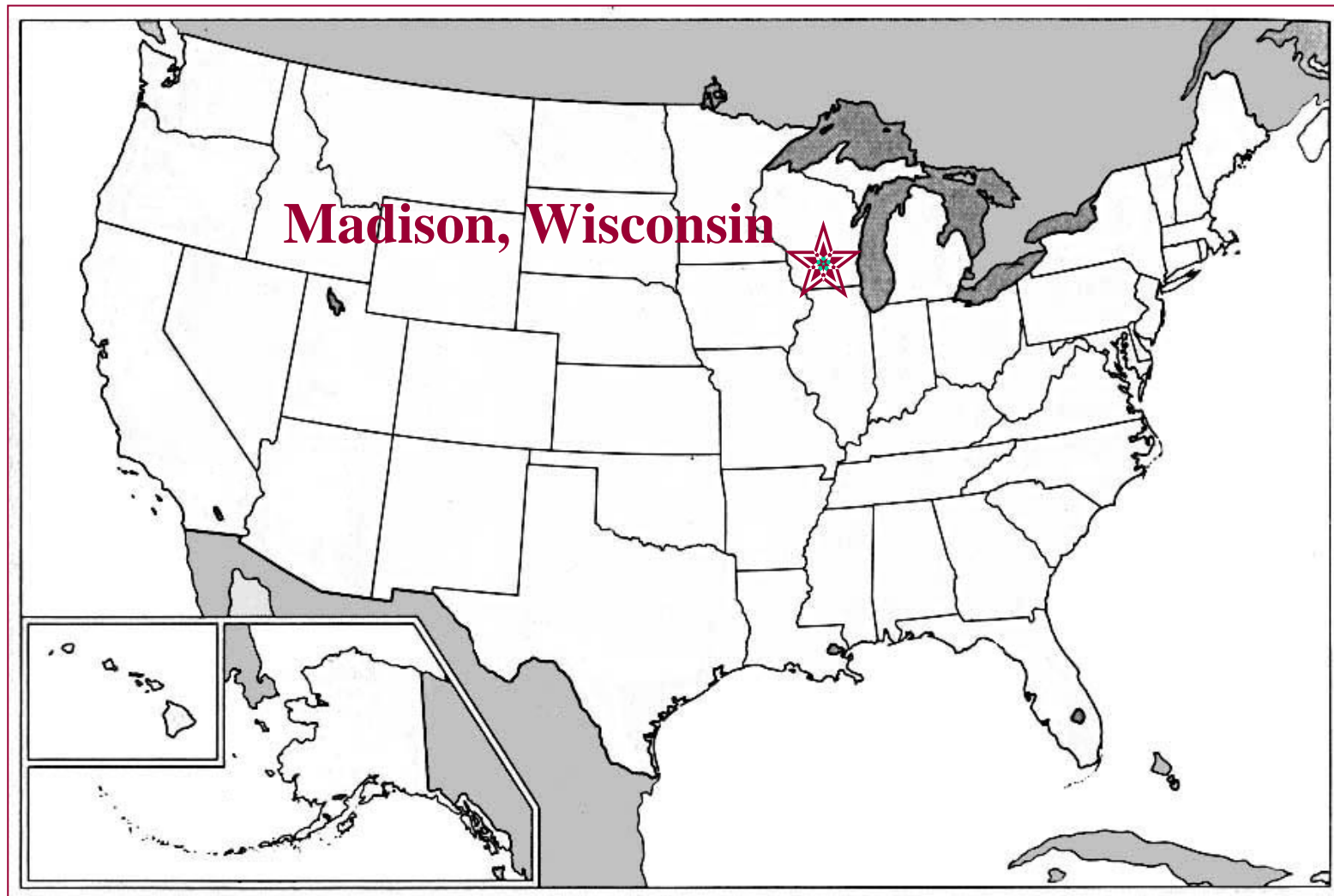
# **Power Electronics, Machines and Drives Research at WEMPEC/WisPERC**

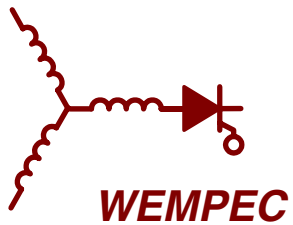
Prof. T. M. Jahns  
[jahns@engr.wisc.edu](mailto:jahns@engr.wisc.edu)

February 25, 2004



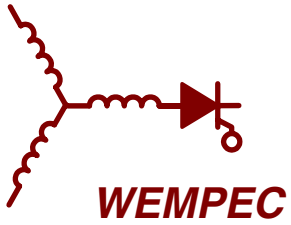
# Where is the University of Wisconsin - Madison?





# University of Wisconsin-Madison





# UW-Madison Statistics

## **Enrollments:**

Total Campus:	>42,000
College of Engineering:	3312
Elec. & Comp. Eng. Dept:	981
<i>Undergraduate:</i>	<i>525</i>
<i>Graduate:</i>	<i>456</i>



*UW University Communications*



*UW University Communications*

## **Electrical & Computer Engineering Department (ECE):**

Faculty: 43

Research Expend. \$16.4M

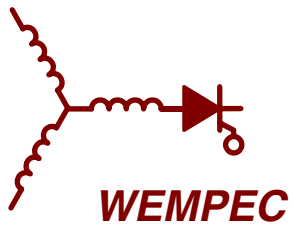
Areas:

*Power Engineering*

*Applied Physics*

*Computer Engineering*

*Systems*



# Who Are We?



Prof. Don Novotny  
(Emeritus)



Prof. Tom Lipo



Prof. Bob Lorenz



Prof. Tom Jahns

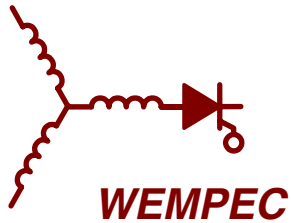


Prof. Bob Lasseter  
(Emeritus)

## Power Electronics and Electrical Machines Faculty

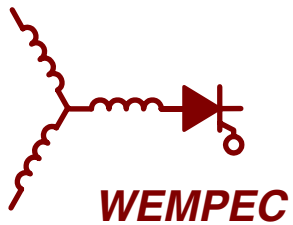


Prof. Giri  
Venkataramanan



# Research Clusters

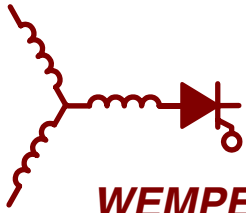
- Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC)
  - *Pre-Competitive Research*
- Wisconsin Power Electronics Research Center (WisPERC)
  - *Sponsored Research*
- Center for Power Electronics Systems (CPES)



# Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC)

- University-Industry Consortium Dedicated to Advancing the State of the Art of Machines and Power Electronics
  - ➔ 40 International Sponsors
  - ➔ > 50 Graduate Students
  - ➔ ~ 10 Visiting Professors / Honorary Scholars

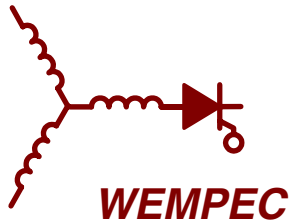




## **WEMPEC**

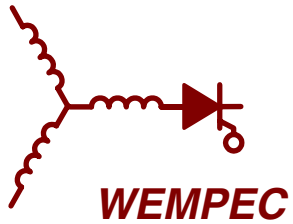
# **WEMPEC Sponsors**

A.O. Smith Corporation  
ABB Inc., Drives and Power Products Div.  
BAE SYSTEMS Controls, Inc.  
Ballard Electric Drives & Power Conversion Div.  
Bombardier Transportation  
Caterpillar, Inc.  
Cutler-Hammer Industrial Controls Division  
Danfoss Drives  
Delphi Energy and Chassis  
DRS Power & Control Technologies, Inc.  
Eaton Corporation, Innovation Center  
Emerson Electric  
Ford Motor Company  
Fuji Electric Corporate R&D, LTD  
GE Global Research Center  
GM Advanced Technology Center  
Grundfos A/S  
Hamilton Sundstrand  
Hoganas AB  
Honeywell International Inc.  
International Rectifier  
Kimberly-Clark Corp.  
Kohler Company  
Miller Electric Manufacturing Co.  
MPC Products Corporation  
Northern Power Systems  
Oak Ridge National Laboratory  
Oshkosh Truck Corporation  
Otis Elevator Company  
Rockwell Automation (Allen-Bradley Division)  
Rockwell Automation/Dodge/Reliance Electric Co.  
S&C Electric Co.  
Schneider Electric (Square D)  
Schneider Toshiba Inverters Europe SAS  
SIEI S.p.A  
SoftSwitching Technologies Corp  
Square D Company  
Toshiba International Corporation  
Unico, Inc.  
Visteon  
Whirlpool Corporation  
Yaskawa Electric America Inc.

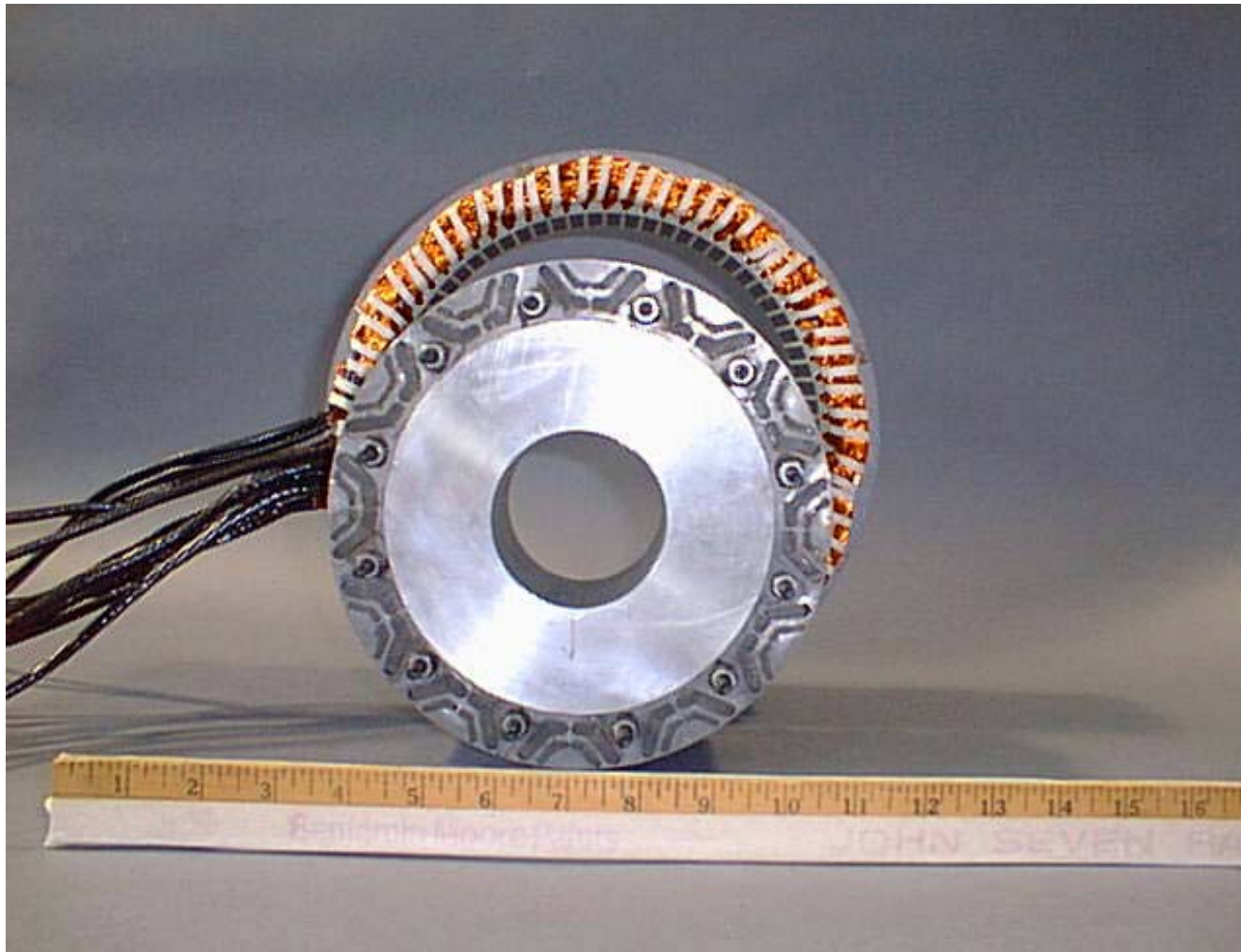


# WEMPEC Research Areas: Electric Machines and Drive Systems

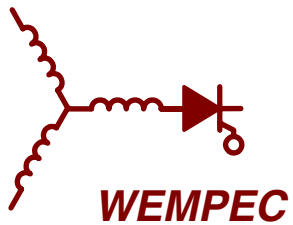
- New types of electrical machines
- Actuators to replace hydraulics
- Aerospace and automobile systems
- Self-sensing machine control
- Observers for actuators and drive systems
- System identification, dealing with parameter uncertainties



# Interior Permanent Magnet (IPM) Synchronous Machines

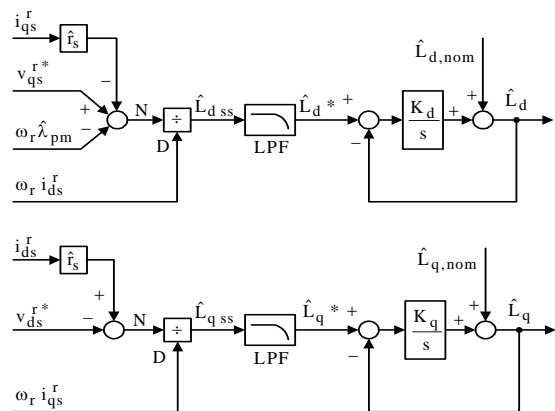


*Automotive Direct-Drive IPM Starter-Alternator (6 kW)*

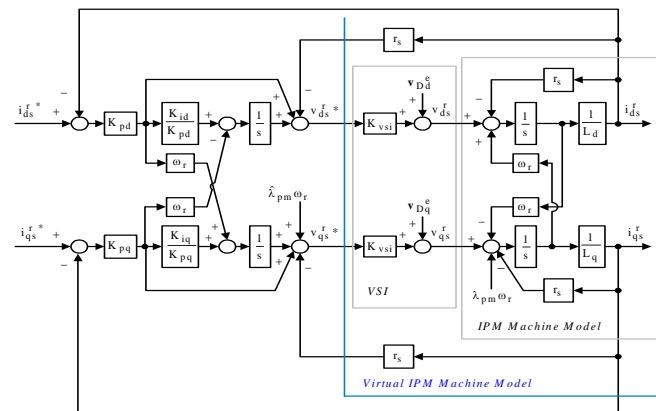


# Improving Interior Permanent Magnet Synchronous Machine Drives

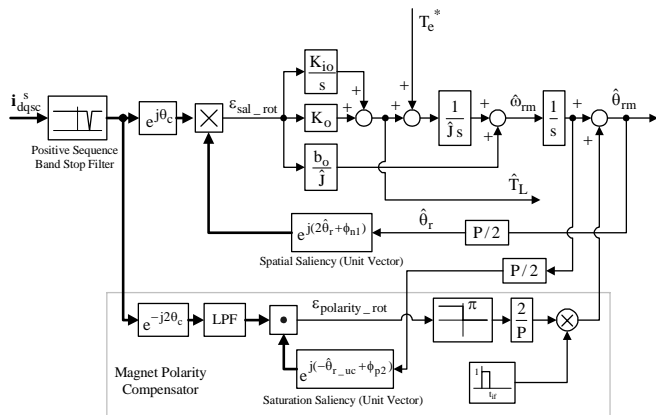
- On-line Adaptive Parameter Estimation



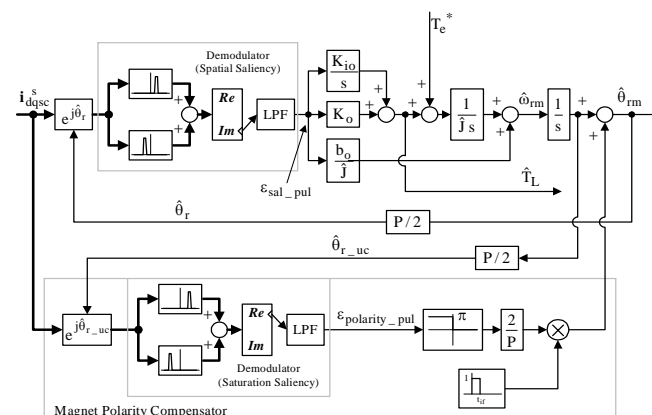
- Synchronous PI Current Regulator in Virtually Translated System

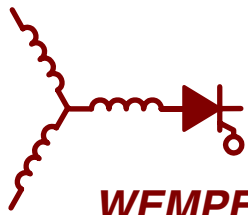


- Self-sensing including Magnet Polarity using Rotating Carrier Signal Injection



- Self-sensing including Magnet Polarity using Pulsating Carrier Signal Injection

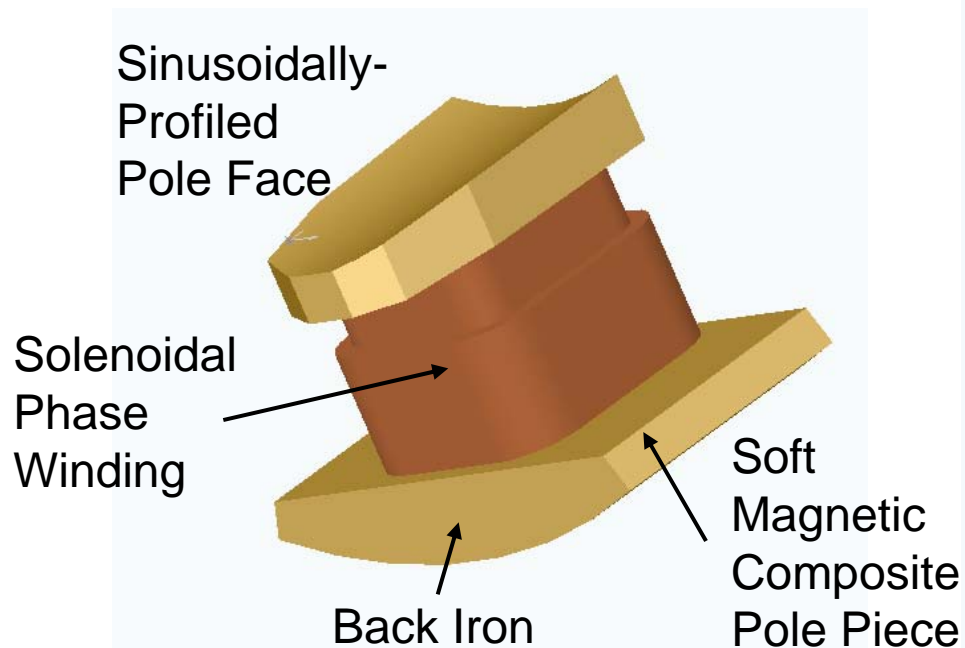




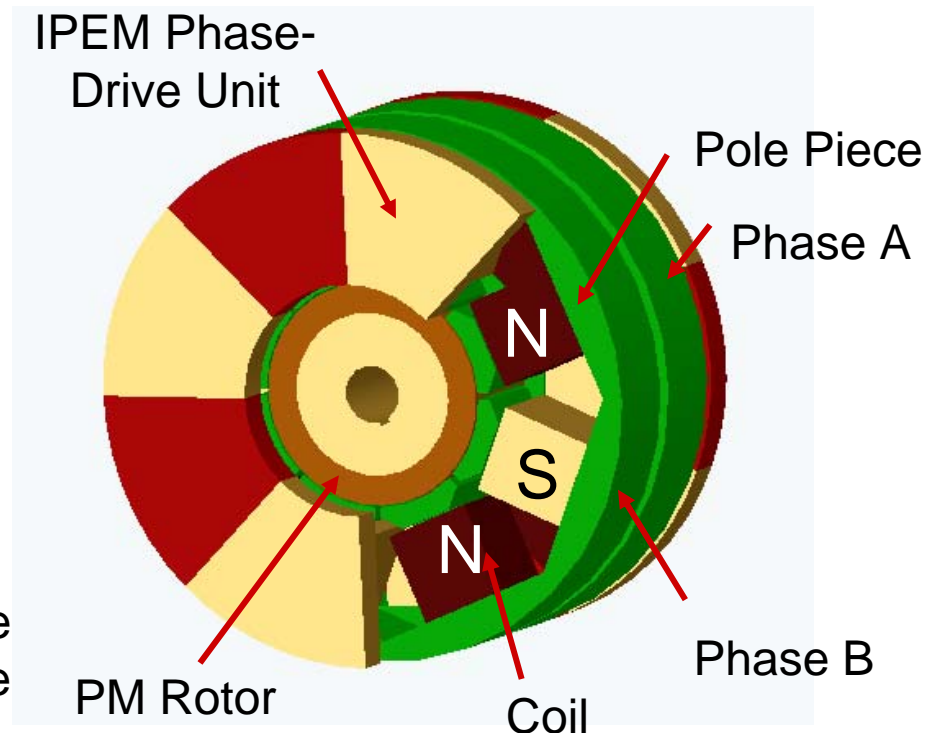
WEMPEC

# Integrated Modular Motor-Converter

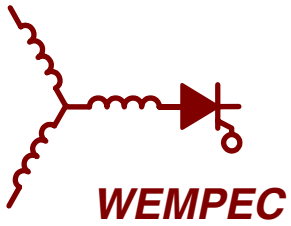
## Individual Pole Unit



## End View

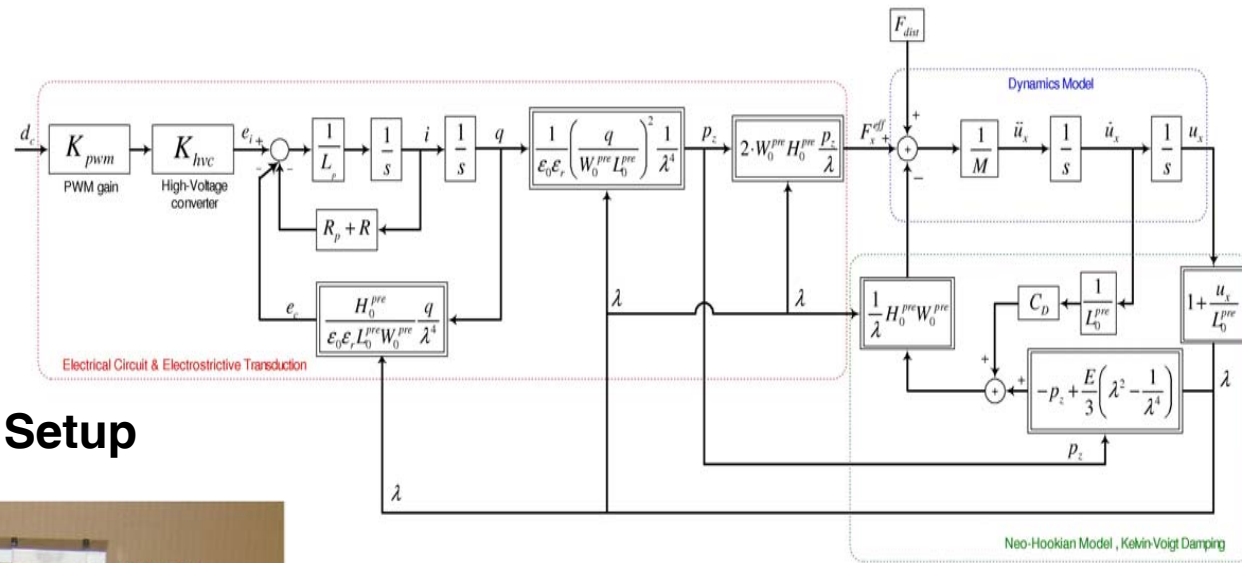


- Objective is to physically integrate motor and converter into same structure:
  - Modular units consisting of individual motor pole and associated drive electronics
- Use SMC material to make 3-dimensional pole unit cores

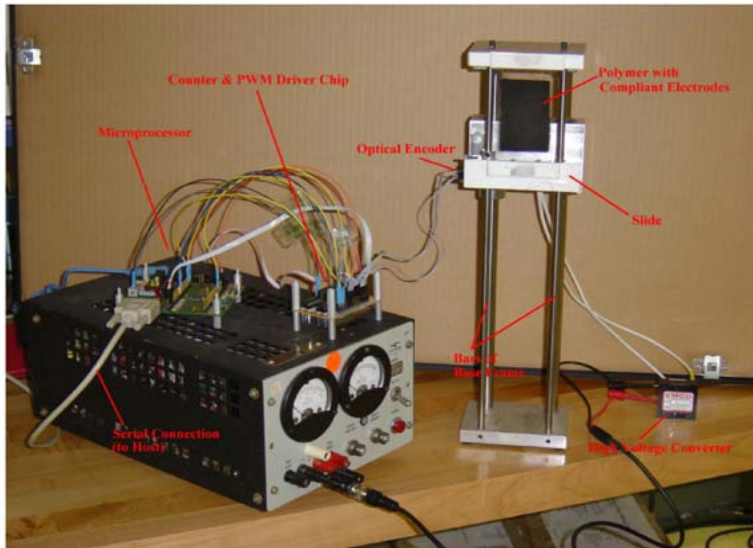


# Electro-Active Polymer Actuators

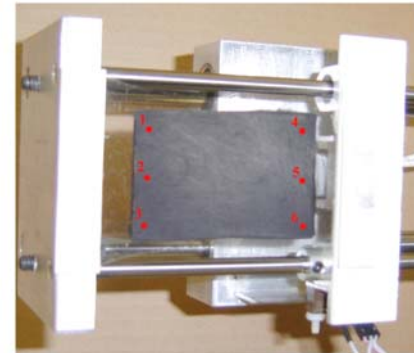
## Electro-Active Polymer Actuator Physical Model

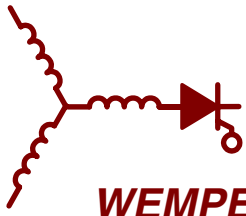


## Overview of Test Setup



## Polymer Actuator Element in Test Stand

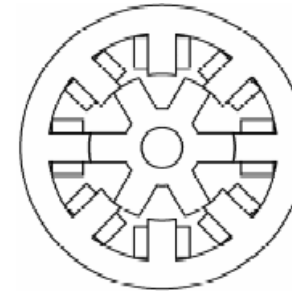
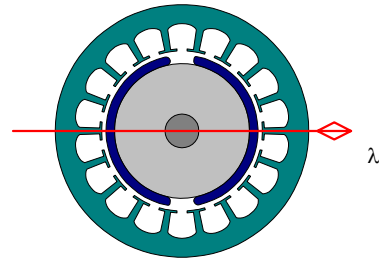
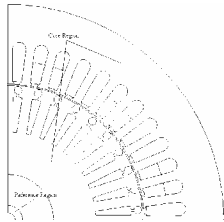




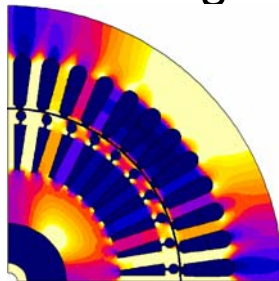
WEMPEC

# Self-Sensing Research

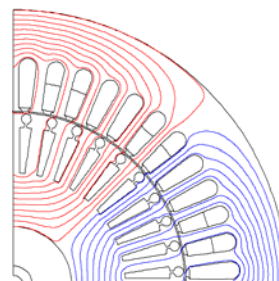
- Machine Types



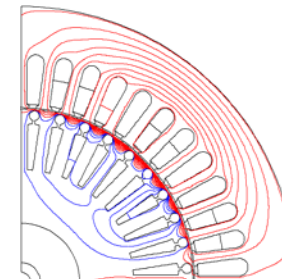
- Machine Design and Saturation Modeling



Relative Permeability

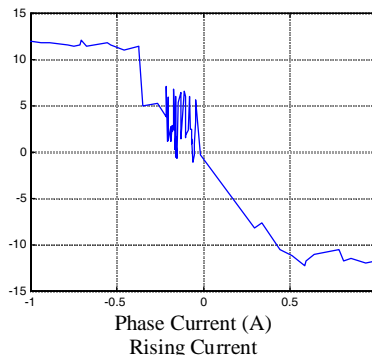


Fundamental Excitation



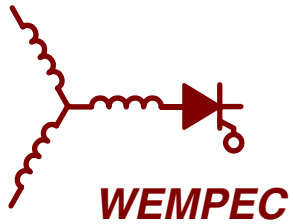
Carrier Excitation

- Inverter Issues



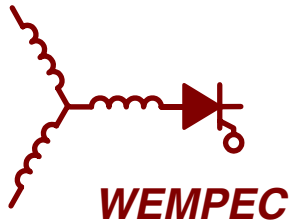
Inverter Voltage Error as a Function of Phase Current Magnitude.

- Inverter voltage error sources:
  - Dead time
  - Device static properties
    - On-state voltage
    - On-state resistance
  - Device dynamic properties
    - Turn-on and turn-off times, variable due to device parasitic capacitance



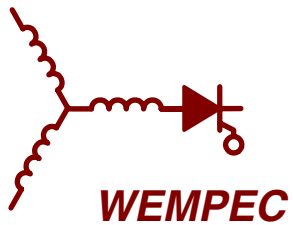
# Current Machine Drive Research Activities – T.A.Lipo

- Pulsating Torque Mitigation Utilizing “Tooth Pairing” Concepts – *Damir Zarko*
- PM Machine with Powdered Iron Poles and Concentrated Windings – *R White*
- True Armature Field Weakening of Axial Flux PM Machines – *Metin Aydin*
- Brushless Synchronous Machine without Rotating Exciter – *Wen Oyang*
- Reduced Cost Wind Turbine Converter – *Pierluigi Tenca*
- Levitated Vehicle Drive Using Rotating Magnet Drum – *Jonathan Bird*
- Single Phase Input – 3 Phase Motor Drive w/ Reduced Switches – *T. Bashaw*
- Common Mode Elimination Using 6 Phase Motor – *Pierluigi Tenca*
- Axial Flux PM Wind Turbine Generator – *Damir Zarko*



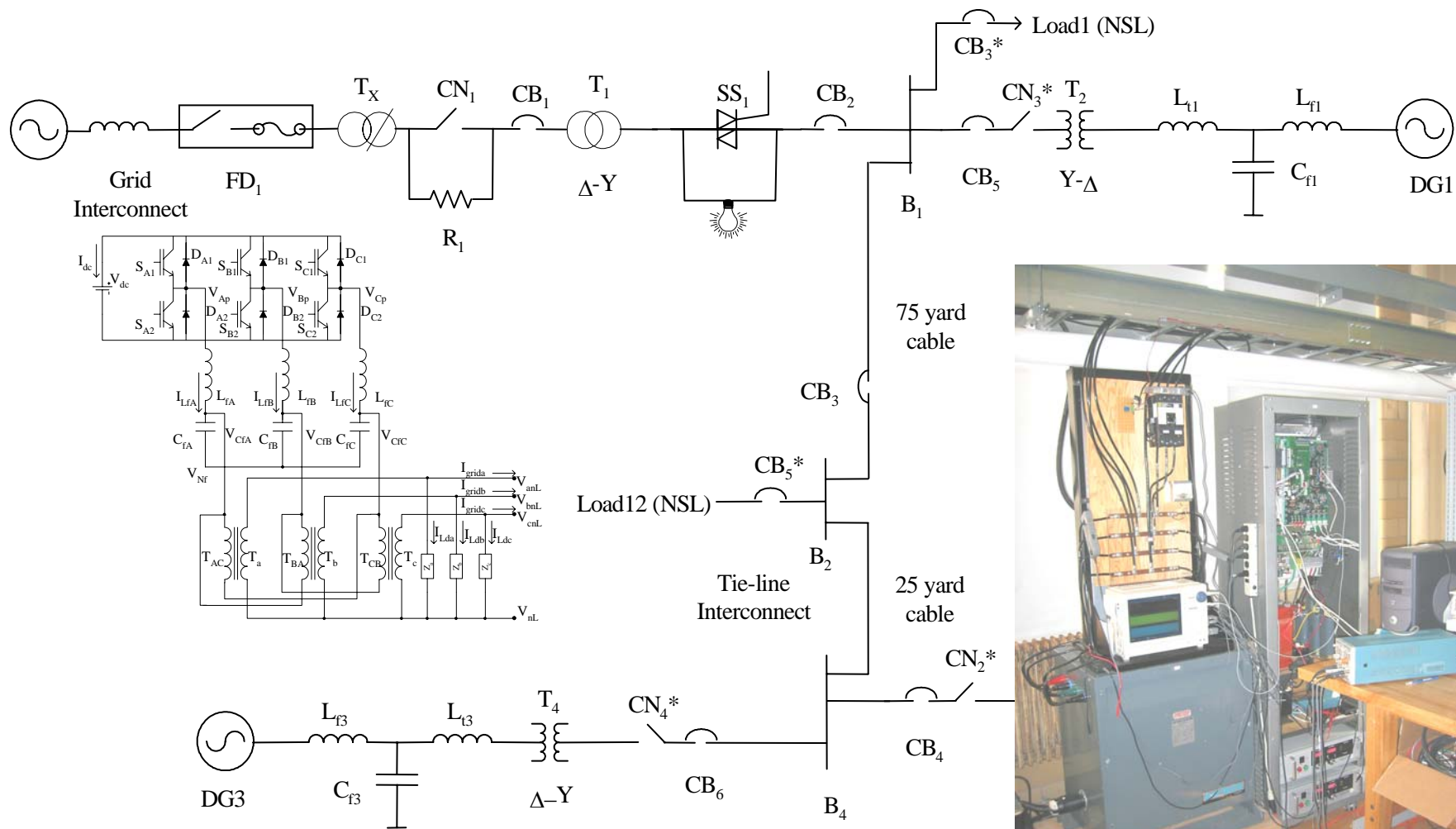
# WEMPEC Research Areas: Power Electronics

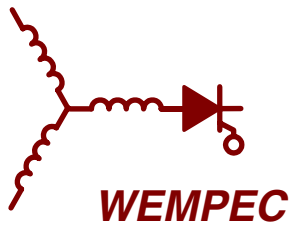
- Power electronic converter topologies
- Control theory applications to power electronics systems – nonlinear dynamics
- Higher levels of functional integration inside power electronics modules
- Integrated current sensors including current regulation and combined thermal control
- Design automation



# Distributed AC Generation

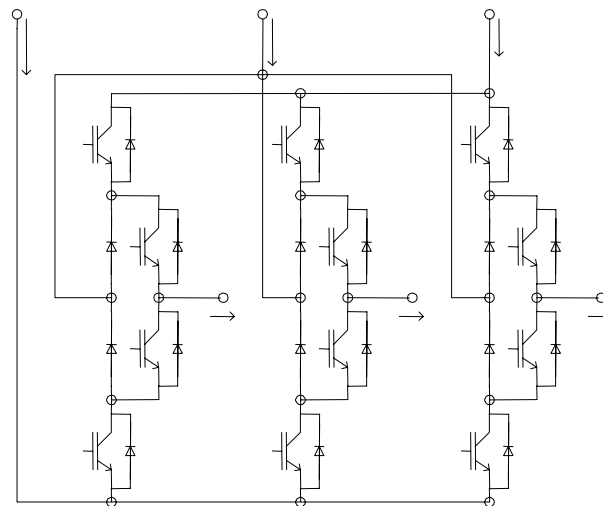
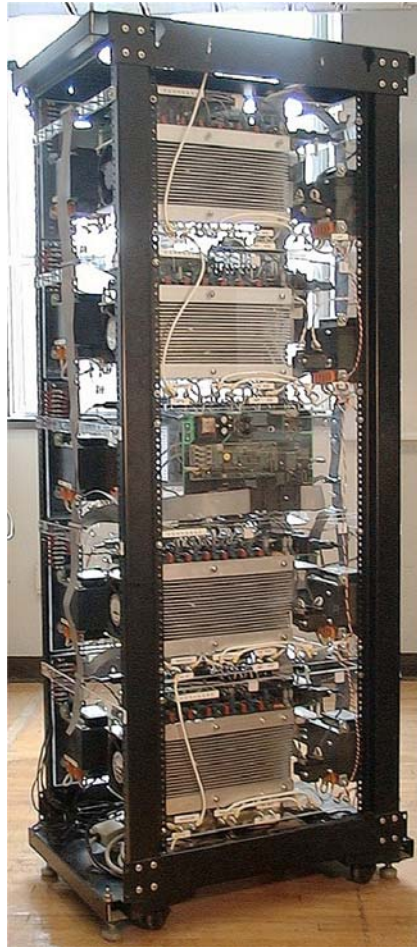
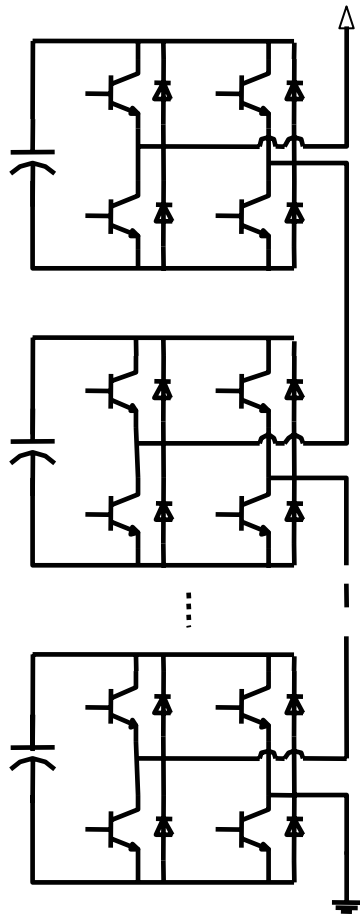
- Operation and control of Microgrids

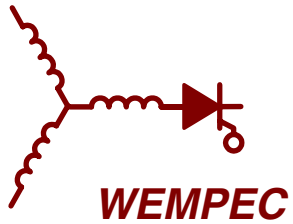




# Multilevel Conversion

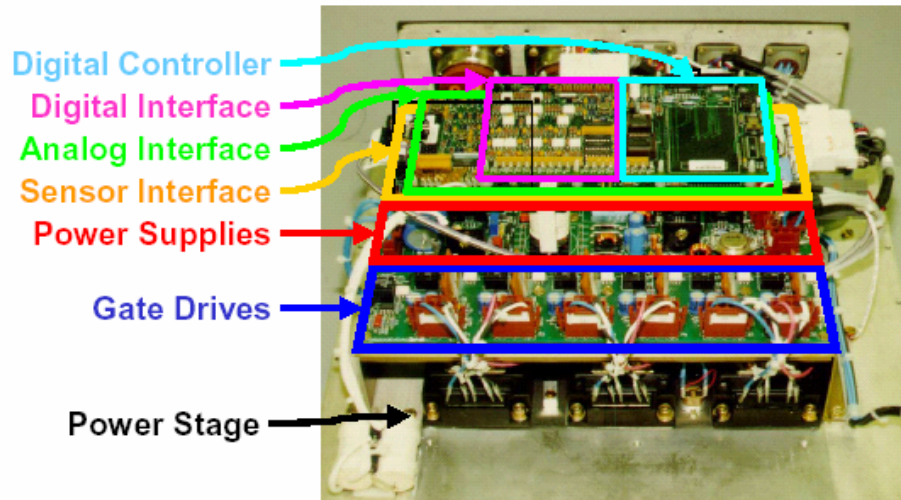
- Modulation, control and reactive minimization





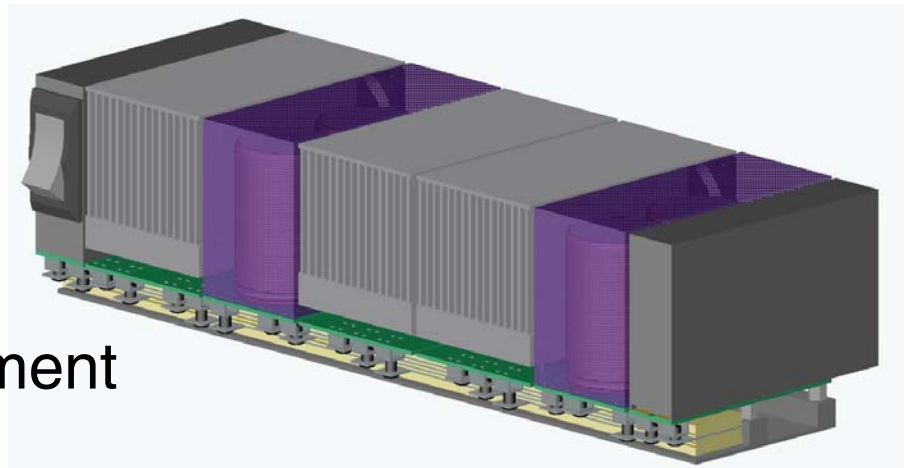
# Power Converter Architectural Design

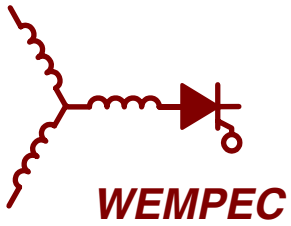
Or Power Electronics Converter Design in the Last Century



*Vision for Future*

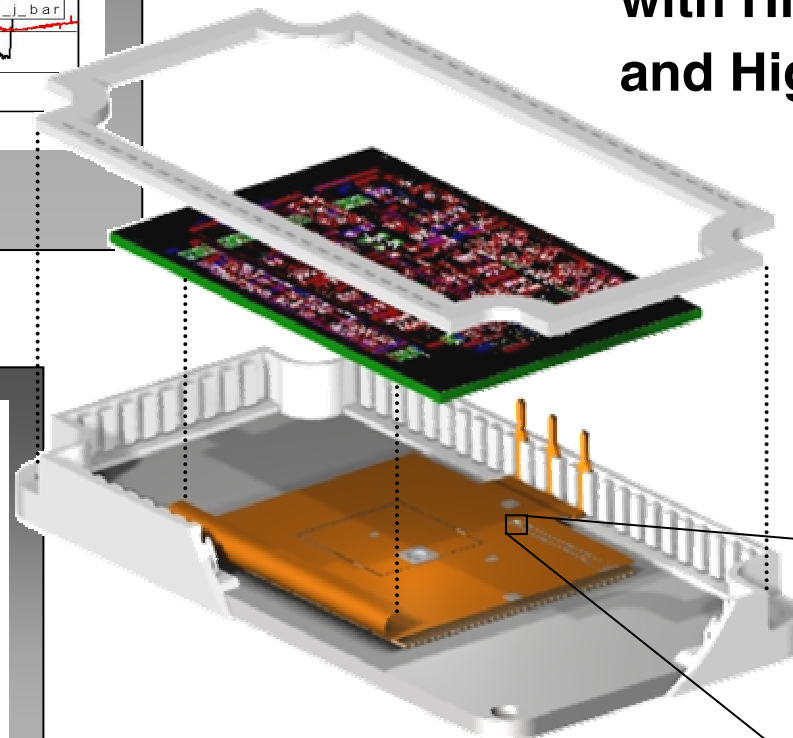
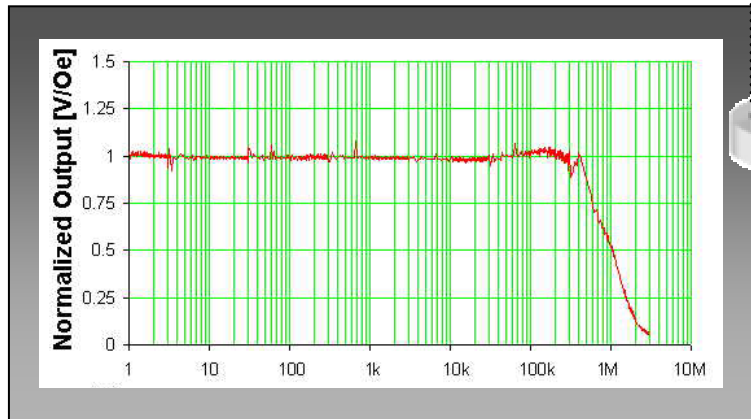
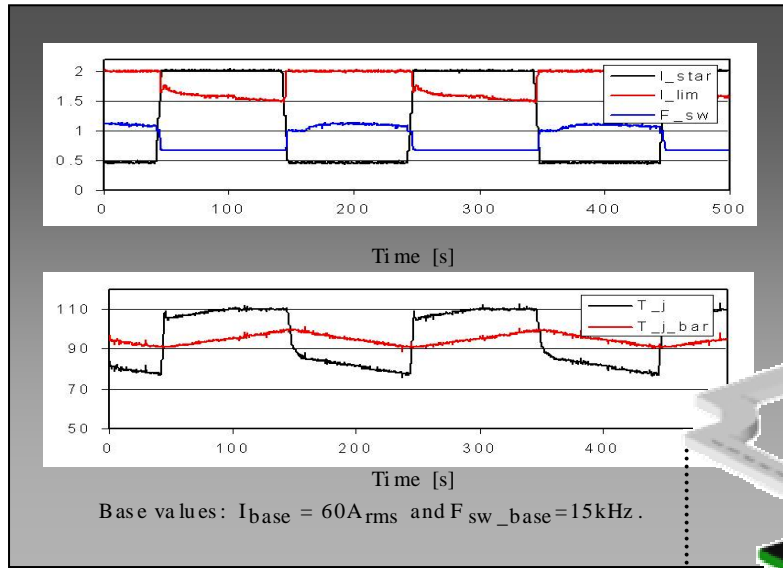
- Modular
- Standardized
- Integrated Thermal Management
- Design for Manufacturing



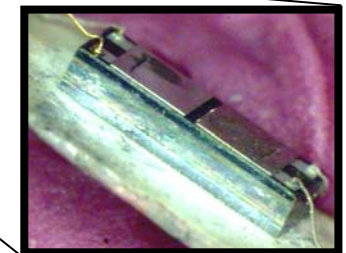


# Integrated Sensing and Active Thermal Control

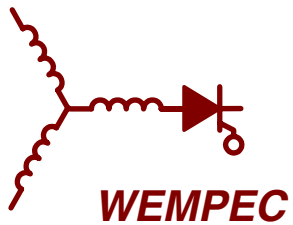
- Active Thermal  $T_j$  and  $\Delta T_j$  Control
- Integrated Current and Temperature Sensor with High Bandwidth and High Accuracy



**GMR Detector**

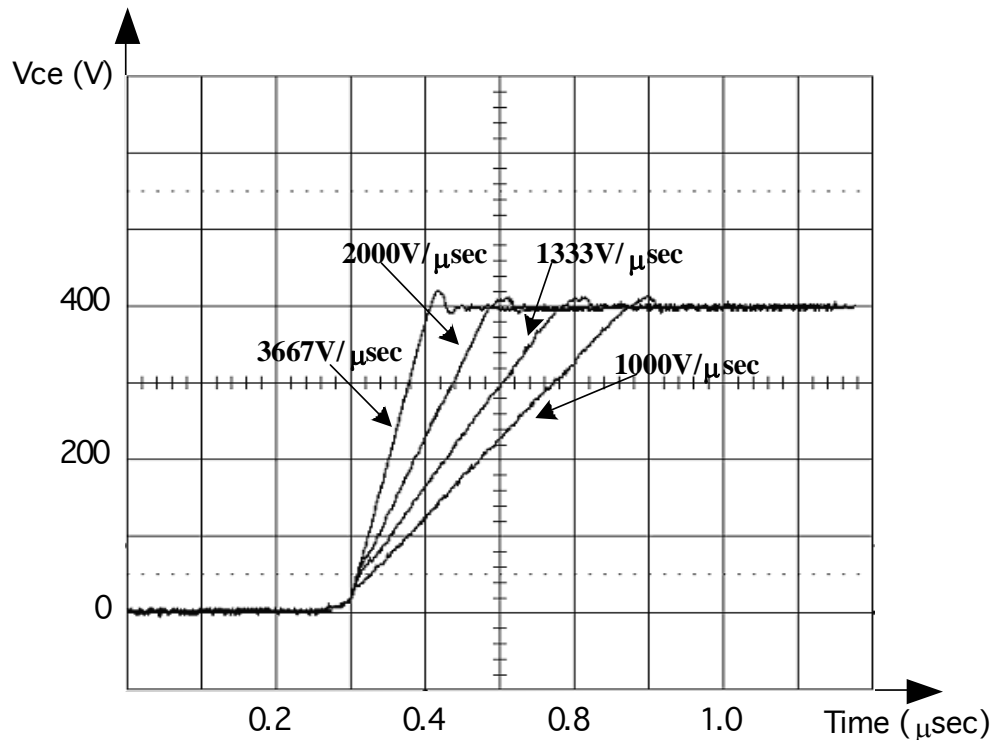


**Integrated Power Electronics Module in Econo3 Package with Flex Layer**

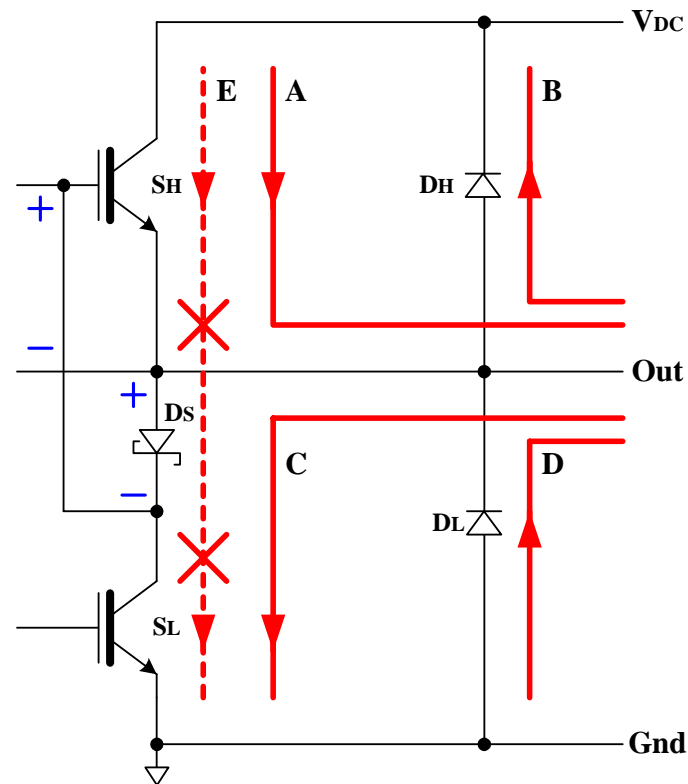


# Advanced Phase-Leg Technology

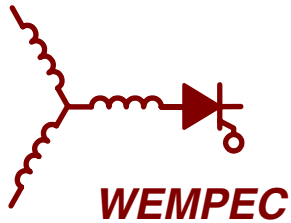
## Adjustable $dv/dt$ Control



## Augmented Phase Leg Configuration



- Electronic control of Miller effect makes it possible to flexibly and dynamically adjust  $dv/dt$
- Addition of series diode eliminates shoot-through fault risk, making control dead time unnecessary



# Current Power Electronics Research Activities – T.A.Lipo

- 3 Phase Current Source Inverter Using Only 3 IGBTs – *Eric Benedict*
- 3 Phase PWM Voltage Source Inverter Using Only 3 IGBTs – *D. Panda*
- Resonant Link Converter with Zero Current and Voltage Switching – *J. Yao*
- Double Bridge Matrix Converter Using Only 6 Switches – *Kee-Ho Shin*
- Reliability Improvement Using a “Four Phase Concept” – *Nick Lemberg*
- Diode Clamped 3 Level Inverter with Unequal Link Voltages – *A. Rockhill*



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**For More Information ....**

**<http://www.wempec.org/>**

**or Contact T.M. Jahns**

**[jahns@engr.wisc.edu](mailto:jahns@engr.wisc.edu)**

**(608) 262-5702**