Mission: to develop and implement an overall system-driven research, development and education program focused on technology issues in electric power systems, modeling and simulation, advanced controls, advanced component development, and testing, in collaboration with key stakeholders to meet the needs of the navy and other military applications, commercial marine, and the nation’s electric utilities and its suppliers.
Center Highlights

Established at Florida State University in 2000 under a grant from the Office of Naval Research

Focusing on research and education related to application of new technologies to electric power systems

Organized under FSU Vice President for Research

Affiliated with FAMU-FSU College of Engineering

Member of ONR Electric Ship R&D Consortium - ESRDC

~$5 million annual research funding from ONR, NSF, DOE, and Industry

DOD cleared facility at Secret level
# Center Staffing and Facilities

## Staffing
- 11 Tenure track/Non-tenure track faculty
- 19 Staff Researchers and Technical Support
- 4 Post-doctorial Associates
- 25 Students (20 MS/PhD, 5 BS)
- 3 Visiting Scholars
- 7 Administrative Personnel

## Facilities
- 44,000 ft² laboratories and offices, located in Innovation Park, Tallahassee
- Over $35 million specialized power and energy capabilities funded by ONR, DOE, NSF and Industry
CAPS Major Funding Sources

Major Funding Sources

- ESRDC
- Swampworks
- SSPS
- Electric Ships Office
- Sunshine State Solar Grid Initiative (SUNGRIN)
- Next Generation WBG Power Electronics Institute (future)
- Future Renewable Electric Energy Demand Management Systems Center (FREEDM)
- Variety of STTR/SBIR initiatives
- Utility sponsored projects
FSU-CAPS Capabilities

• Integrated 5 MW Hardware-in-the-Loop (HIL) Testbed
  – 5 MW variable voltage/frequency converter
  – 5 MW dynamometers
  – 5 MW MVDC converters (MMC)
  – Real-time Digital Simulators
    RTDS & OPAL-RT using typical time step sizes from 2 μs to 50 μs

• Superconductivity and Cryogenics Labs
  – Superconducting Cable Test Facility
  – Cryo-dielectrics High Voltage Lab
  – Cryo-cooled Systems Lab

• Low Power and Smart Grid Labs

• Extensive non-RT simulation tools and expertise
  – PSCAD, PSS/E, Matlab, PLECS, OpenDSS, etc.
  – COMSOL, Magnet, etc.
Controller Hardware in Loop (CHIL) and Power Hardware in Loop (PHIL)

Controller HIL Simulation
- Controller under test
- Low level transmitting signals (+/-15V, mA)
- A/D and D/A converters are adequate for the interface

Power HIL Simulation
- Power device (load, sink) under test
- High level transmitting signals (kV, kA, MW)
- Power amplifiers required for interface

Diagram:

- Simulator
  - D/A
  - A/D
- Controller under Test
  - A/D
  - D/A
- Power Interface
  - A/D
  - D/A
- Power Device under Test
FSU-CAPS 5 MW Facilities

ONR grants N-00014-10-1-0973 and N-00014-09-1-1097
1. Installed and commissioned a 5 MW gear system extending the dynamometer capabilities to 24,000 rpm
   - Stage 1: 0…1800/3600 rpm
   - Stage 2: 0…12,000/24,000 rpm
   - 1x torque overload for 1 min
   - Containment for device under test
2. Tested a high speed generator using the new gear box
   - Used the VVS as a dynamic load
   - Controlled and protected the experiment via the RTDS case
   - Summary in paper to be presented at ASNE Day 2012

Projects 1 sponsored by

Project 2 sponsored by

Generic test setup for High-Speed generator testing
Hybrid Cyber-Physical Test Bed at FSU-CAPS

RT-Sim of inter DCC Communications

OPNET

DCC cluster A

DCC cluster B

Power HIL amplifier

Physical representation of Sub-Power System

Real-time Simulation of Rest of Power System

120 V
5 kW
Solar PV - Fundamental Challenges on the Grid

• Intermittent resource
  – not always well-correlated with load
    • though, more-so than wind; and,
    • good correlation for commercial & institutional loads
  – difficult to forecast (generally more difficult than wind)
  – Intermittency implications on traditional generation

• Non-dispatchable active power

• Distribution system
  – designed for one-way power flow
  – not designed for hosting generation

• Transmission system
  – Bulk power system designed for dispatchable generation
Simulation-assisted Analysis

• Tools & Approach
  – Load-flow and quasi-static simulation tools
    • Ability to study scenarios like inverter interactions, controller interactions, etc.
  – Real-time simulation
  – Hardware-in-the-Loop (HIL)
    • Integrated dynamic simulation, testing, de-risking, demonstration

• Reduced models
  o Facilitates use of real-time simulation tools (RTDS)
  o Makes modeling and validation process more manageable
    • Fewer input data and parameters reduces risk of wrong/bad data inputs
  o Faster case preparation
  o Faster execution times for validation and study runs
Summary / Considerations

• Hosting capacity (on which allowable % penetration should be based) varies considerably by circuit
  – And, within circuit service area (consider “zoned” limits\(^1\))

• Impacts will be increasingly system-wide

• High-penetration from highly-distributed PV,
  vs. central or distributed large commercial / utility scale
  – Greater geographic smoothing
  – Voltage impact spread-out
  – But … single-phase

• Will need utility-oriented tools

Recommendations

• Shift emphasis from individual project / connection evaluation to system planning:
  – “Integrated Distribution Planning”\(^2\), or “Integrated System Planning”
  – Key to incorporating a “Systematic Impact Assessment”, while still reducing interconnection evaluation and approval time

• Consider “zoned limits”, “local penetration”

• Incorporate more of a risk-based approach at System and Project level (e.g. “severity index”)

• Consider also potential benefits
  – Greater potential impact - greater potential benefit
  – Evaluate PV as an active and integral part of system (rather than merely a potential disturbance)

• Transition research into utility-oriented tools and updated rules and procedures

Thermal Management of Large Scale Complex Systems

Objectives:
• Develop strategies and tools for the design of thermal management systems of large scale complex systems
• Special interest is placed on all-electric ships and aircrafts.

Current topics:
• Ship System-level thermal management
• “Thermal Anticipation” in dedicated cooling systems for large pulsating loads.
• Weight reduction through thermal management strategies
• Waste heat recovery
• Thermal Modeling and Experimental characterization of Power Electronic Building Blocks

Relevant Publications
Early Stage Thermal Management Tools Development

A visualization tool (VisESRDC) has been developed as part of the Electric Ship Research and Development Consortium (ESRDC) funded by the Office of Naval Research (ONR). The tool allows a fast visualization of thermal and electrical loads as well equipment locations within a 3-dimensional physical ship geometry and is integrated with the ESRDC relational database, which houses all the notional data related to the electric ship conceptual development.

A Volume Element thermal management solver is also under development. The tool is used to model each equipment inside the ship taking into account its position and iterations with the vicinity and other equipment.

Combined Cycles for Weight Reduction and Improved Energy Efficiency

We are studying the weight and energy implications of implementing combined cycles in all-electric Navy ships.

Thermal Characterization of Power Electronic Building Blocks
Helium Gas Cooled High Temperature Superconducting Power Cables
• **HTS cables will reduce Mass, Volume, and Losses**
  – HTS cables have potential to meet the power density demands on future AES

• **HTS cables require cryogenic environment**
  – Their efficiency and effectiveness have to be evaluated against the required cryogenic infrastructure
  – The cryogenic infrastructure will be similar to that used for HTS Degaussing

• **HTS cables have zero resistance**
  – The effects of special properties such as Zero Resistance on the AES power system have to be evaluated – Stability, effect of transients, Risk mitigation and controllability of IPS
HTS Cables

• Tunability
  – Power rating depends on the operating temperature
  – Typically, current rating is doubled by lowering the temperature by 10 K

• Fault Current Limiting
  – HTS cables show highly non-linear current-voltage characteristics near their critical current
  – HTS cables can be designed with built-in Fault Current Limiting Characteristics
  – DHS Hydra Cable is designed as FCL capable
HTS Activities at FSU-CAPS

- HTS Cable Development
- Support to Industry
- GHe Cryogenics
- Cryogenic Dielectrics
- Cryogenic Thermal Studies
- HTS Electrical Modeling
- HTS Thermal Modeling

CAPS HTS Activities
### Benefits

- Wide operating temperature (10 K–80 K)
- Enhanced superconducting properties at lower temperatures
- Lower temperatures allow higher power densities when necessary
- Larger temperature gradients can be maintained without a phase change
- Easier to integrate multiple superconducting devices to operate with single helium loop
- Increased flexibility in power system design optimization

### Challenges

- Low heat capacity of helium gas – requires high pressures and flow rates for heat removal
- Helium gas has low dielectric strength – dielectric design has to depend on the solid dielectric medium
- Little experience on helium gas cooled superconducting power devices
- Commercial cryocoolers are inefficient – technological developments necessary

**Helium gas cooled HTS power device technology is attractive for some applications**
Current density of HTS doubles if operating temperature is 10 K lower. Helium gas cooled systems will have higher power densities.
Currently US Navy is the driver of helium gas cooled superconducting applications and helium gas cryogenics technology development

- HTS degaussing systems
- Ship propulsion motors
- Large capacity cryocoolers
- Light weight and efficient heat exchangers
- HTS power cable systems
Cryogenic Helium Circulation Systems

Operating Pressure: up to 250 psi, Expected flow rate: up to 10 g/s

Stirling System
340 W @ 50 K
Cryozone Bohmwind Fan

Cryo Fan

AL 330
Current Phase – Validate cryogenic and thermal issues

- **Monopole**
- **Current rating:** 3 kA and @ 77 K (up to 10 kA @ 40 K)
- **Voltage rating:** 1 kV

Long-term Goal

- **Coaxial dipole with voltage rating ± 5 kV**

Superconducting DC Cable Nominal Specifications

2G HTS - Cryoflex insulation – Ultera Triax Cable Design
Hybrid Termination Design

- LN2 tank 77K
- He Gas at 60 K
- Gas from He refrigerator
- Feedthrough
- Vacuum Jacket
- HTS cable end
- N2 vent
- Gas flow around 30 meter cable

- These terminations are meant to be versatile for testing various cables
- Future terminations for the Navy applications will be much smaller and GHe cooled
Dielectric Characterization of Cable Sections in GHe

Custom in-house designed
High Voltage Bushing

High voltage bushing

Test object (cable with stress cones)

Vacuum jacket

Gaseous pressurized Helium

Heat exchanger 77 K

GHe 2.07 MPa

High voltage source 0...100 kV; 60 Hz

Liquid nitrogen jacket

LHe

LN₂

High Voltage Bushing

As expected, PDIV increases with GHe pressure

At 300 psi, PDIV is 7.4 kV peak for the current dielectric design
Pictures of Cable Installation
A Screenshot During One of The Tests

Current

Voltage – HTS layers

Voltage – Copper layers
DC Withstand Voltage Test

- 30-m long interconnect cable between labs (PD free up to 60 kV\textsubscript{rms})
- Grounded at HV transformer side
- Partial discharge test at AC (up to 3.5 kV\textsubscript{rms} = current limit of transformer)
- DC soak test at 3000 V for 1 hour
- Ungrounded bipolar DC system – 2× voltage during single rail to ground faults
- Second PD test – PD free
FSU-CAPS research portfolio is diverse and includes many aspects of electric power systems

Major focus on All-electric ships

Member of several large consortia and collaborative research teams

Has unique strengths in P-H-I-L and C-H-I-L areas at 5 MW level

Specializes in GHe cooled HTS DC and AC cables

Recently demonstrated a HTS DC power cable up to 5 kA and 3.5 kV

Supports electric power industry and many small R&D businesses