

Design and Validation of Advanced Controls for Networked Power Systems

ONR Controls Workshop
July 28, 2016

Marvin Cook, Jason Neely, David Wilson, Steve Glover
Sandia National Laboratories

Funded By the US Navy and Sandia National Laboratories

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Outline

- **SNL Team Introduction**
- **SSM Test Bed Introduction**
- **Informatics Overview**
- **Recent Experimental Results**
- **Summary**

The technical area leads



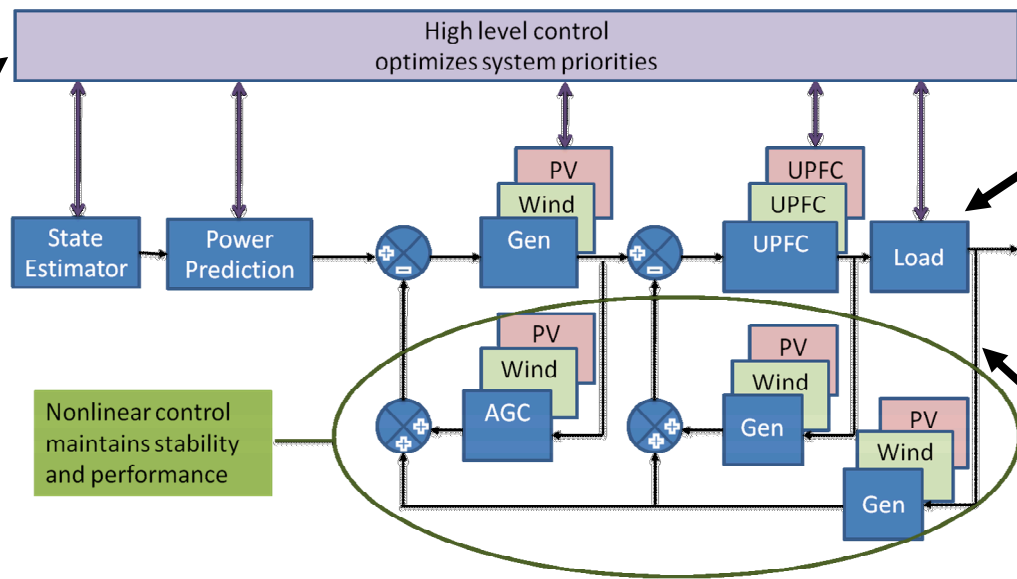
Steve Glover
Project Manager



Jason Neely
Hardware, Modeling,
& Simulation



Marvin Cook
Informatics



Tony Lentine
Communications



David Wilson
Principal Investigator
Nonlinear Controls

Key collaborators

Universities

Purdue University

Michigan Technical University

University of Minnesota

Missouri University of Science and Technology

Texas A&M University

University of New Mexico

Stanford University

Industry & others

Paul C. Krause and Associates

OPAL RT

Perspectives

Clozure Associates

Michael A Ekhaus

Patrick Chapman

Eastern Research Group Inc.

Amplitude Energy Analytics LLC

Leidos

Fiore

Defense Nuclear Facilities Safety Board

EAB

Mike Aimone

James Beckwith

James Boyd

Joe Eto

Daryl Hammond

Erfan Ibrahim

Tim McCoy

William Parks

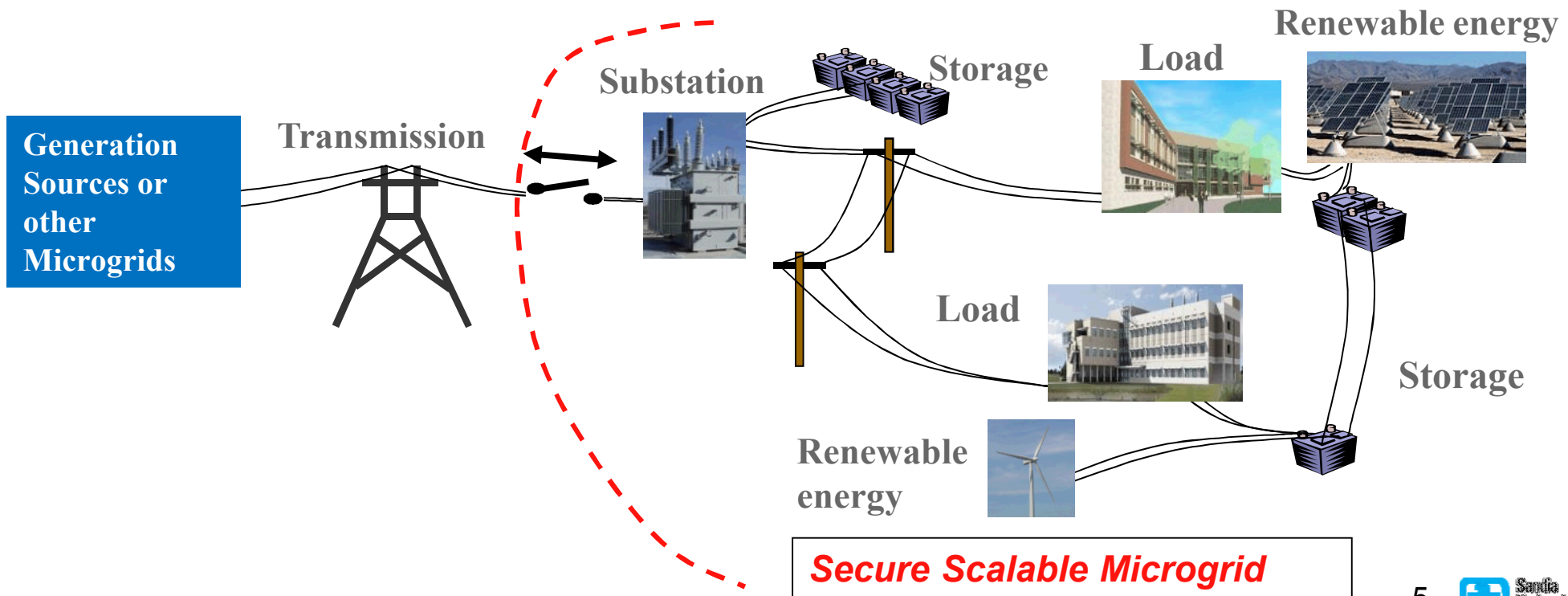
Dan Ton

Ron Sega

David Whitehead

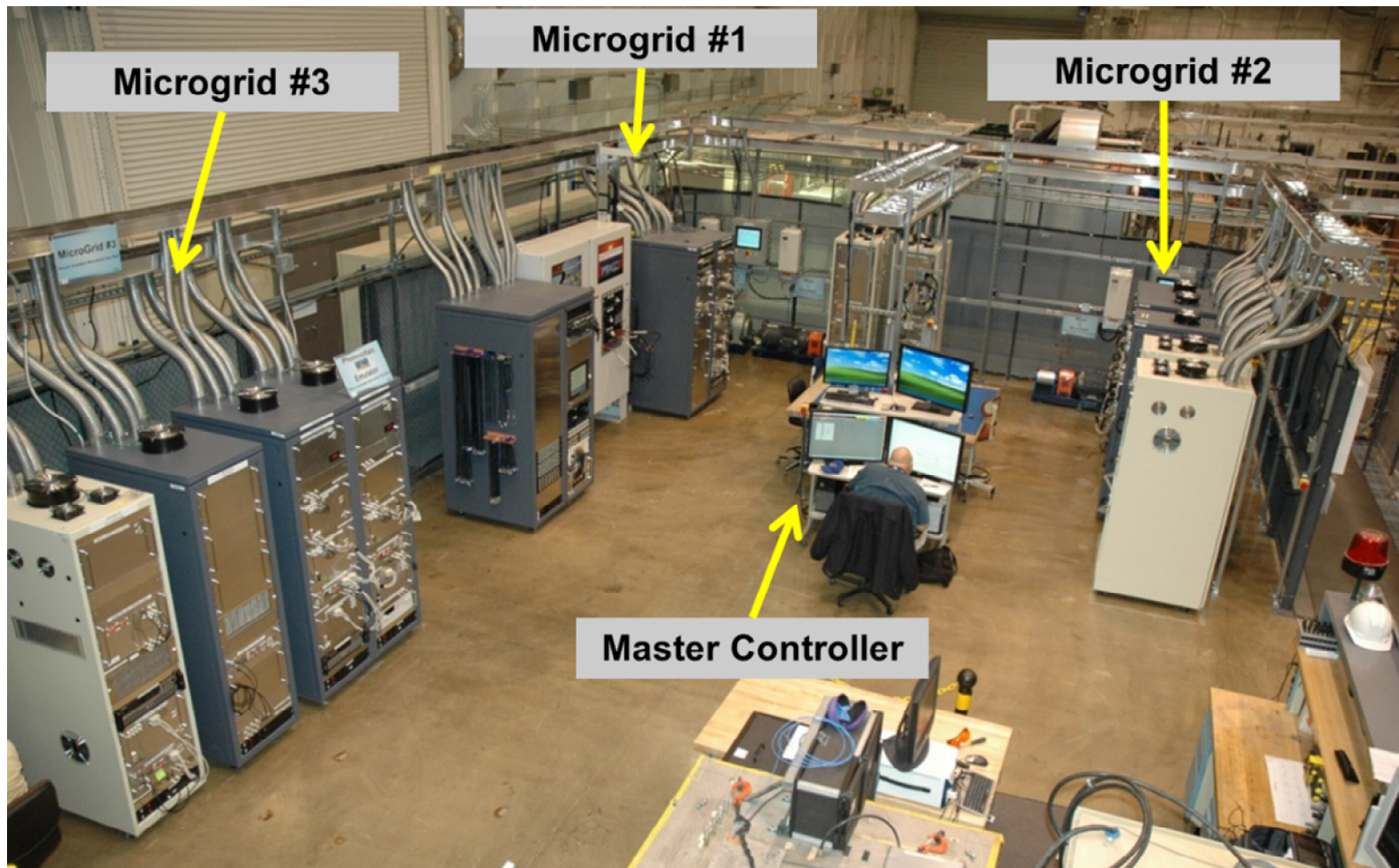
This Research is Enabling a Revolutionary Step Towards Ideal Goals

- Unlimited use of stochastic renewable sources through dynamic power flow control and optimized energy storage.
- Reduction of excess centralized generation capacity reducing our dependence on fossil fuel based generation and associated fuel transportation logistics.
- Self-healing, self-adapting, self-organizing decentralized architectures. This could greatly improve the security of critical infrastructure.



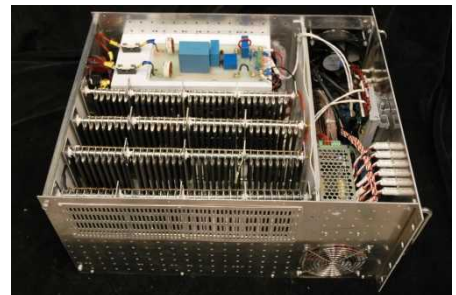
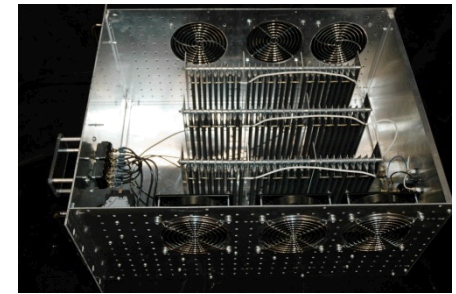
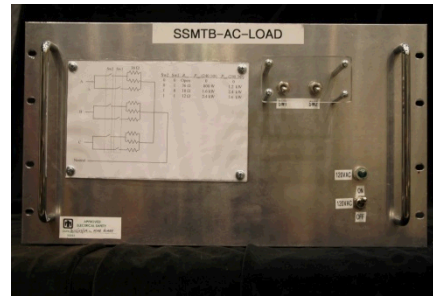
Secure Scalable Microgrid (SSM) Testbed Enables Hardware Testing of Networked Power Systems

- Testbed allows for a high-volume of flexible, repeatable experiments
- Hardware Testbed includes components representing generation, loads, energy storage and transmission/transfer
- Component building blocks enable a variety of system configurations



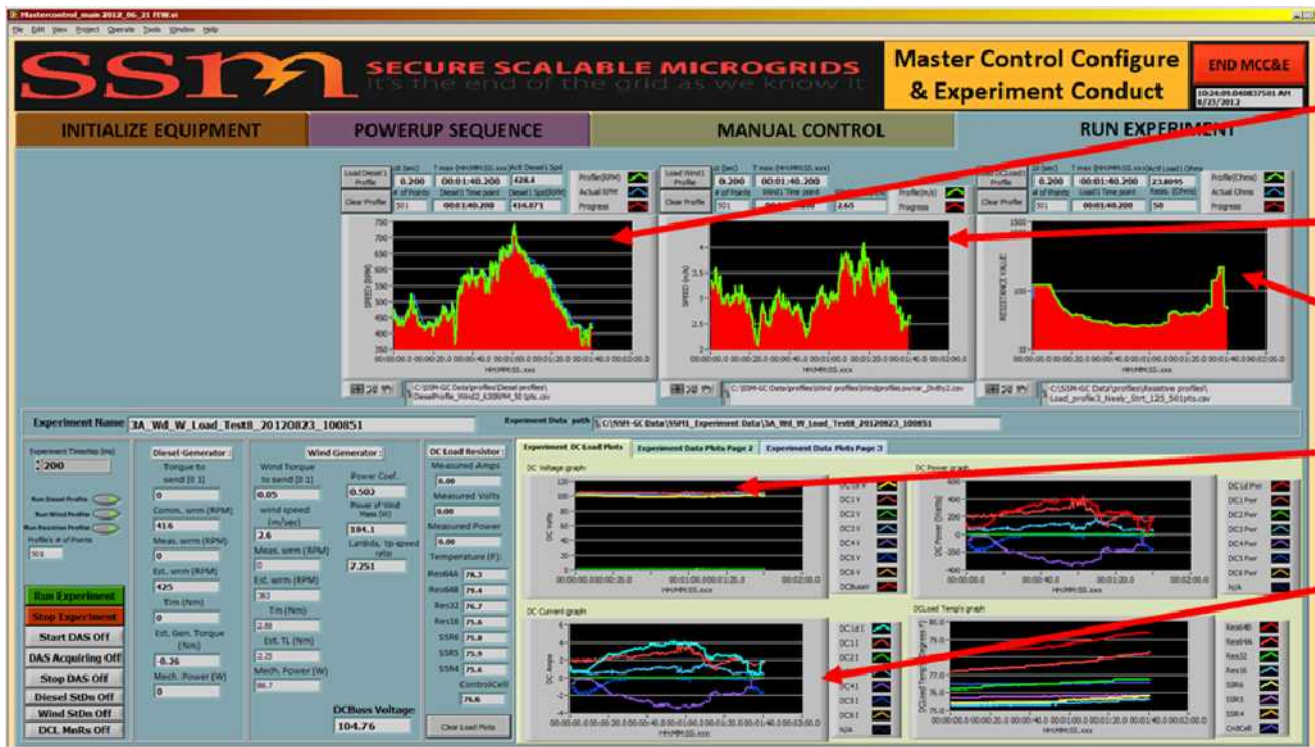
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- Component building blocks enable a variety of system configurations
- Testbed includes
 - Programmable Loads
 - Programmable Generators/Emulators
 - Reconfigurable Bus
 - Power Electronic Converters
 - Energy Storage Emulators
 - Automated Experiment Orchestration
- Master Controller controls load profiles, system settings and the “weather”



Secure Scalable Microgrid (SSM) Testbed Enables Repeated Experimentation of the Same Scenarios

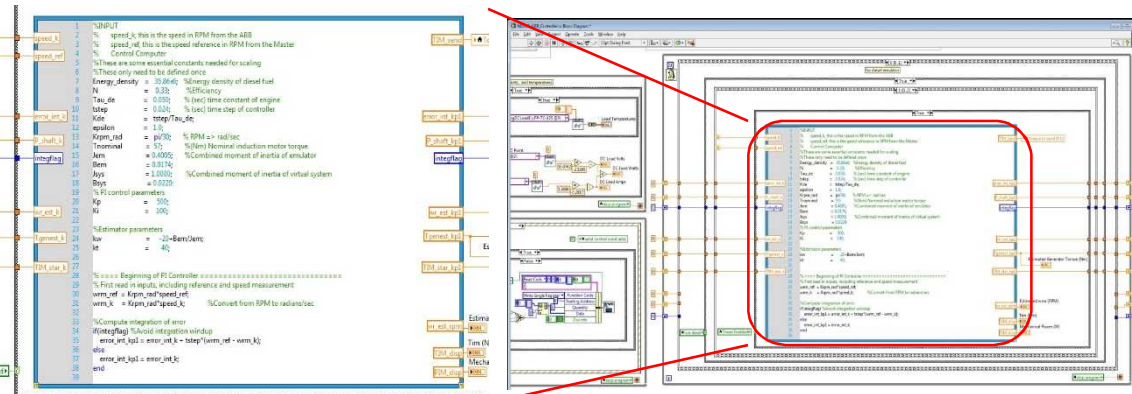
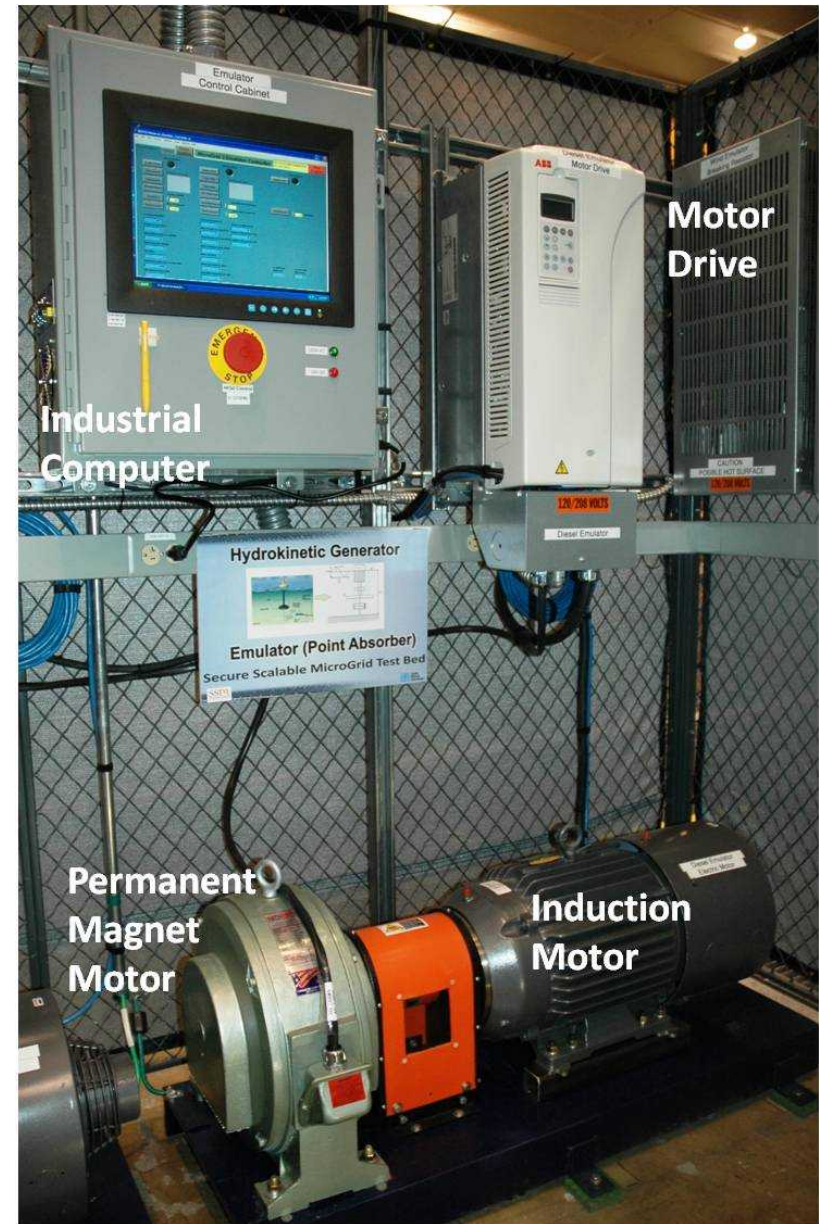
- The Master Controller allows for scripted experiments that include
 - Load profiles
 - Weather Conditions
 - Topological/Architectural constraints
- Identical scenarios with different controls can be tested as a “batch run” of experiments, each leading to different outcomes



- Emulator Profile 1
- Emulator Profile 2 (m/s)
- Digital Resistor (Ω)
- Bus voltage (V)
- Currents into bus (A)

Generator and Renewable Source Dynamics are Modeled and Reproduced in the Laboratory

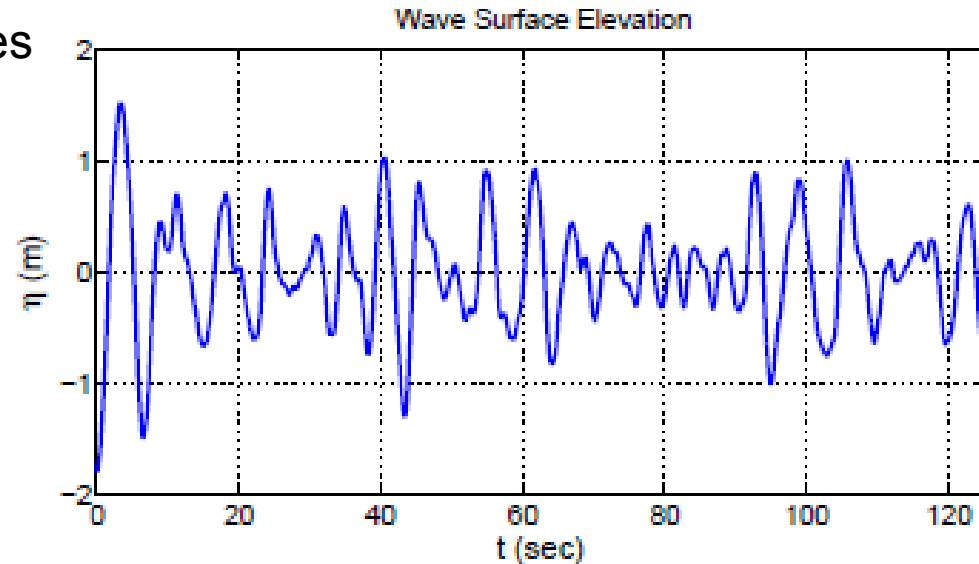
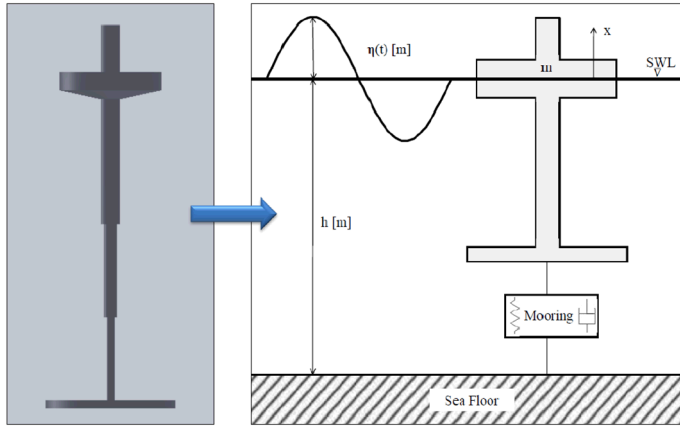
- Baldor 15 HP Induction Motor with speed encoder
- ACS800 30HP ABB drive
 - DTC with 1% error when used with speed encoder
 - 24 msec timestep
 - 5 msec delay after register read
 - Brake Resistor
- 10 kW Georator 36-013-1 Permanent magnet alternator
- Computer runs LabVIEW 2011 with Mathscript RT toolkit



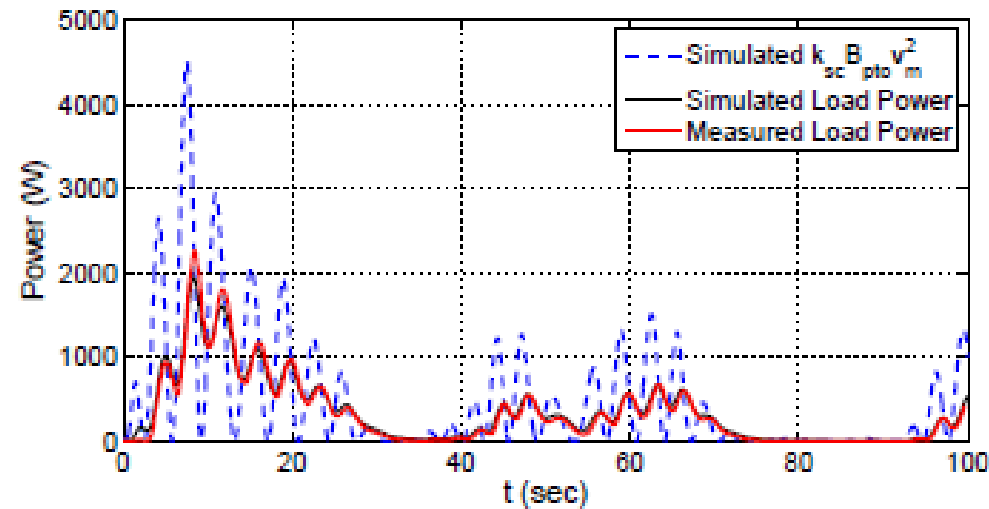
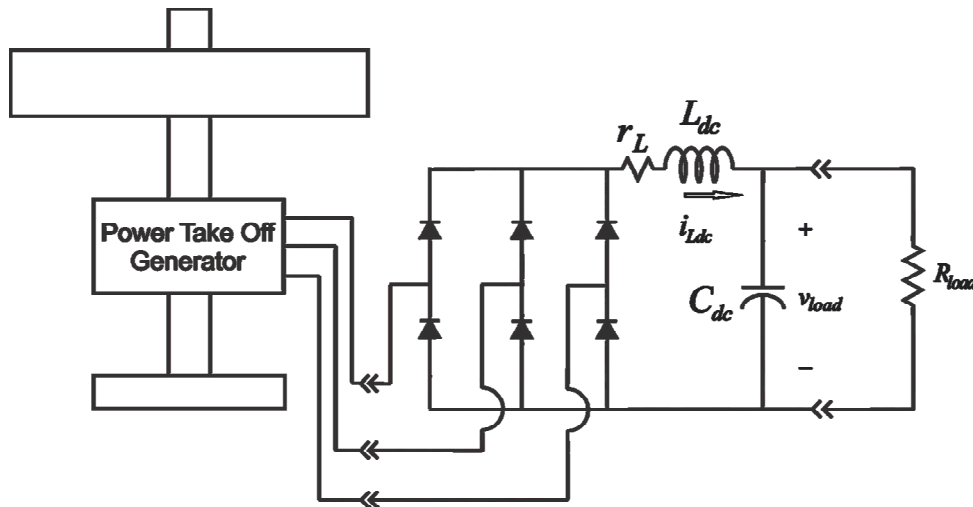
Generator and Renewable Source Dynamics are Modeled and Reproduced in the Laboratory

- This emulator concept has been applied to even the most challenging renewable sources

Wave Energy Converter (WEC)

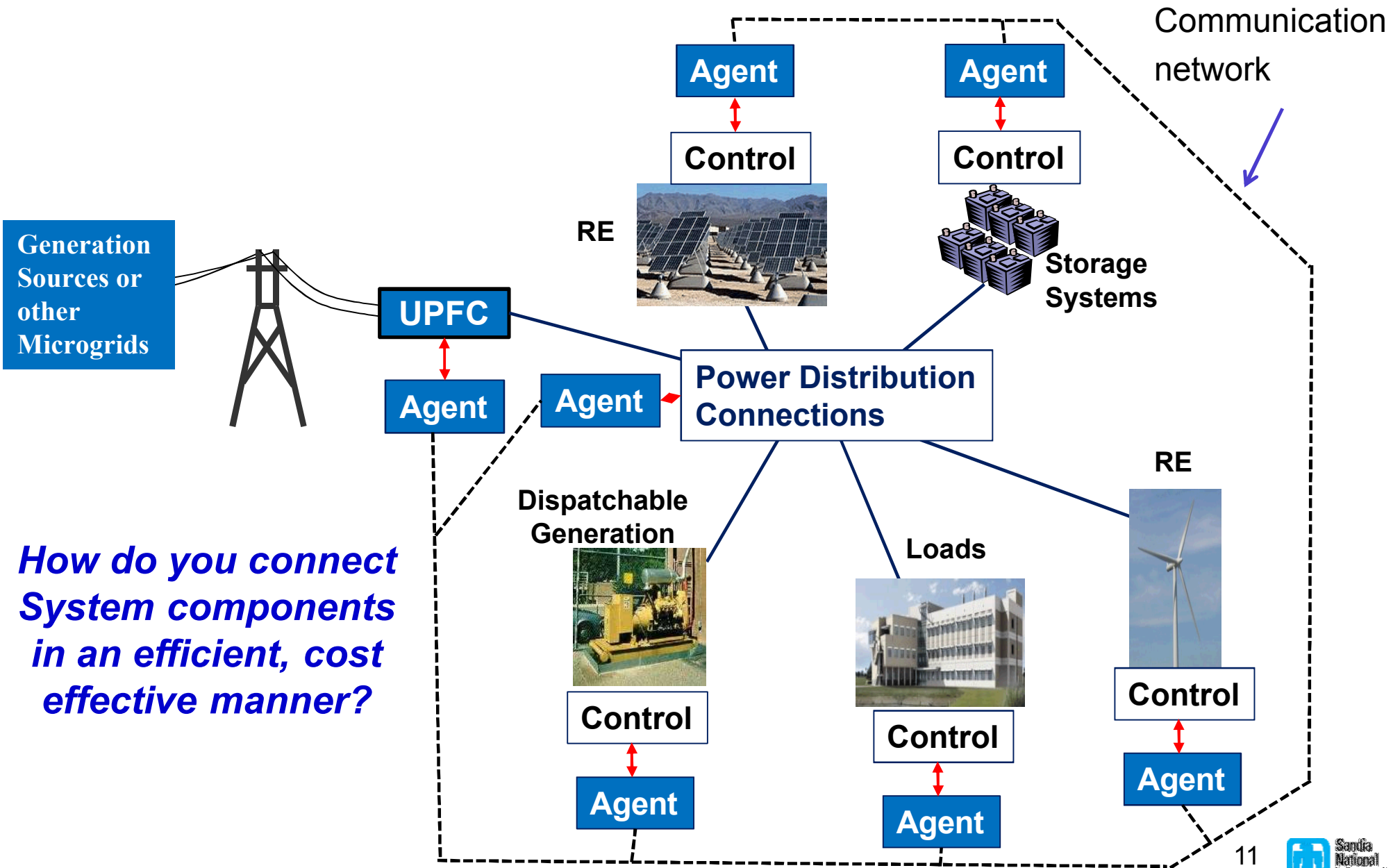


- The emulator was implemented and tested for Wave Energy Converter (WEC) with irregular wave profile¹



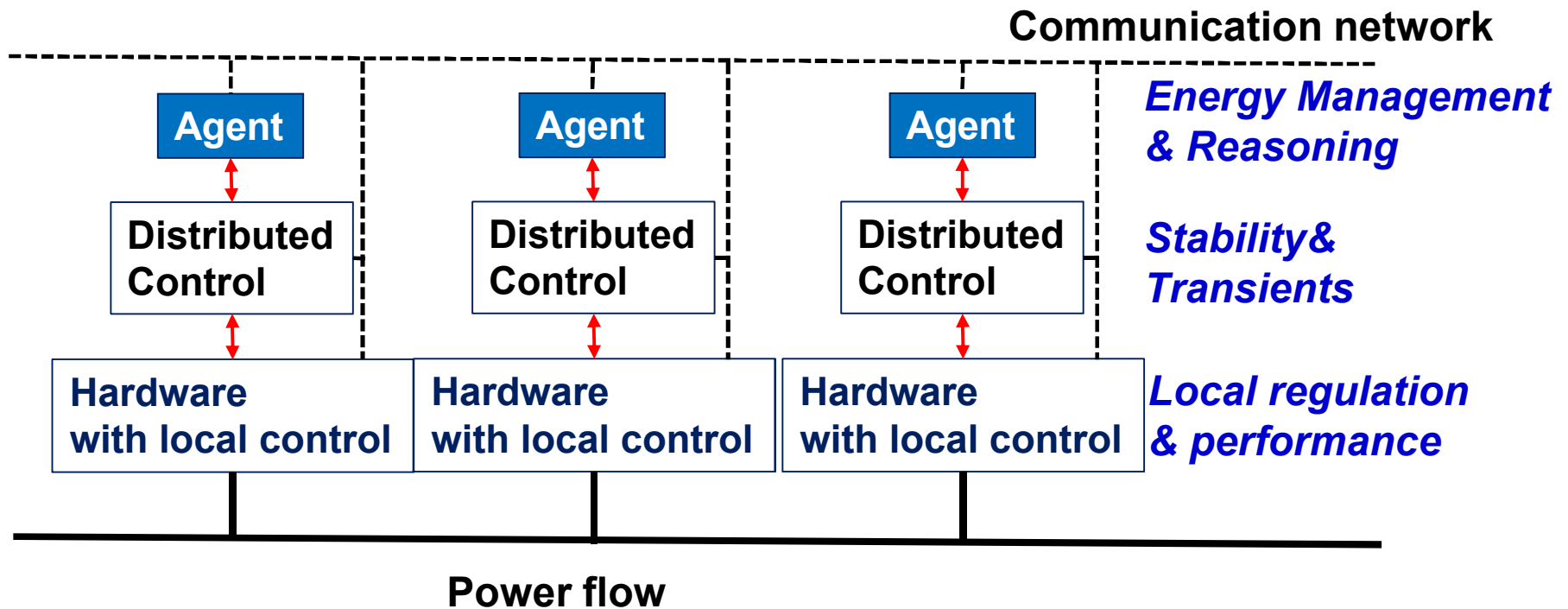
¹Recorded from a data buoy time-series from Umpqua 46229 in June 2008

A Highly Interconnected Microgrid Will Result from these Advancements



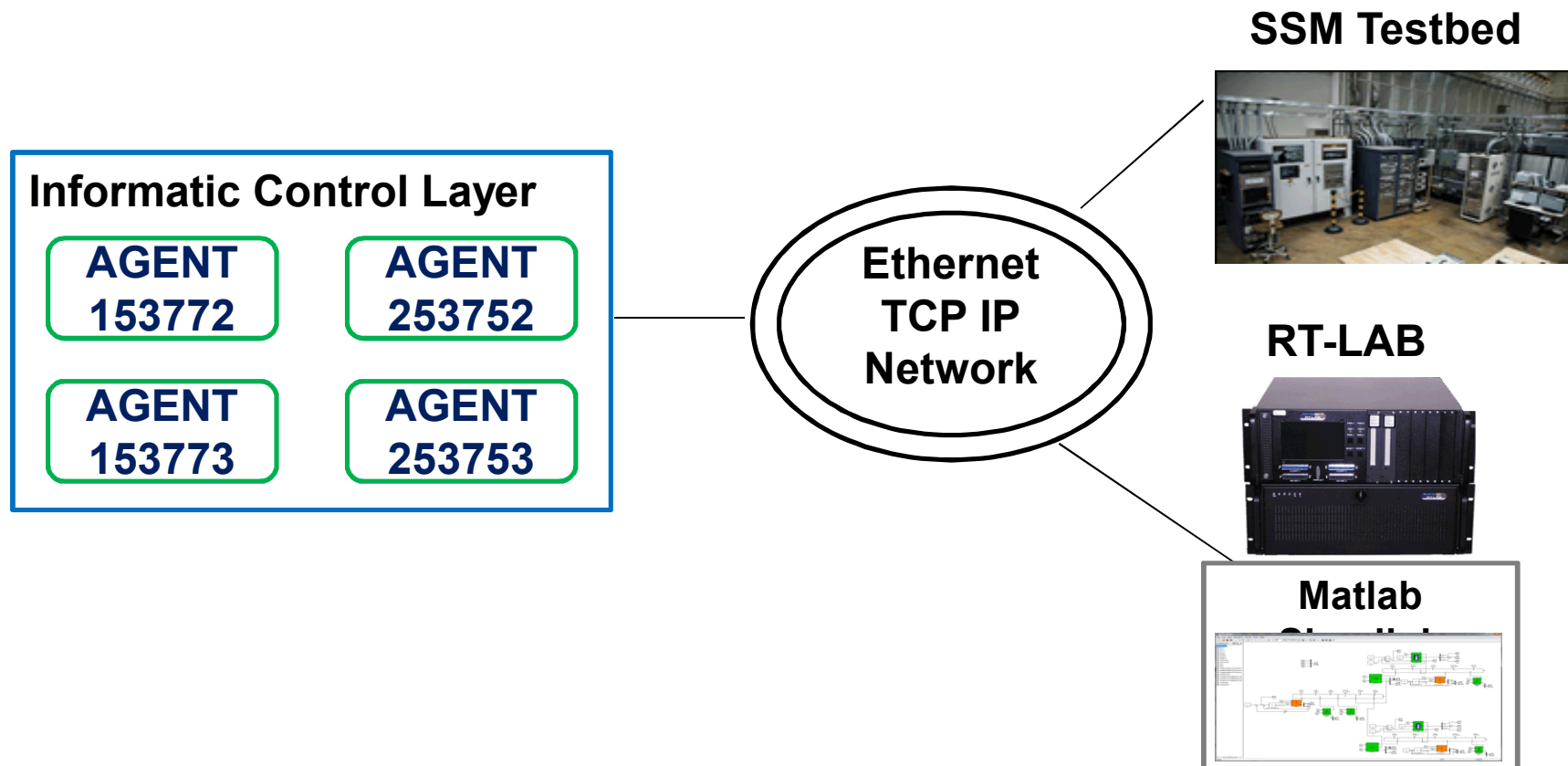
How do you connect System components in an efficient, cost effective manner?

Our Basic Control Structure adds Capability and Supports Flexibility



Energy Management Over Ethernet

- Informatic control layer monitors system state and send control actions via hardwired ethernet
- Low level controllers send periodic measurements via UDP packets at ~800 per second
- Software agents interpret measurement data to form a global model of the energy system state



Informatics Incorporates Optimization

- Optimizer can be a computer resource on the IP network, called remotely, or can be run directly on the agent platform
- Informatic Control Layer sends optimization parameters to an optimizer based on measurements and system objectives
- Optimizer returns reference points that are used by the Informatic Control Layers to drive low level controllers
- Optimizer supports preferences towards particular generation sources within the energy mix

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Energy System Optimizer

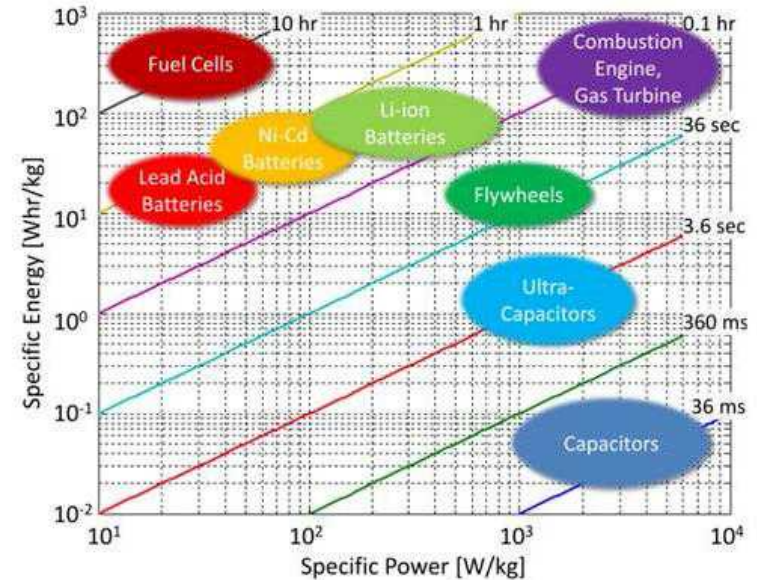
- Electrical system circuit equations
- Variables with bounds
- Allows flexibility in microgrid configurations
- Multi-objective problem specifications
- Optimizes nonlinear constrained problems

Navy Electric Ship Pulse Power App.

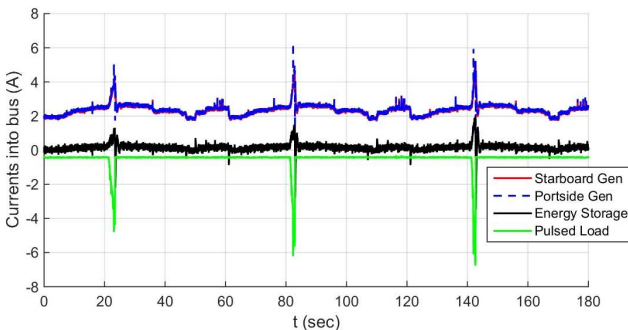
- Pulse load demands drives microgrid performance and energy storage requirements



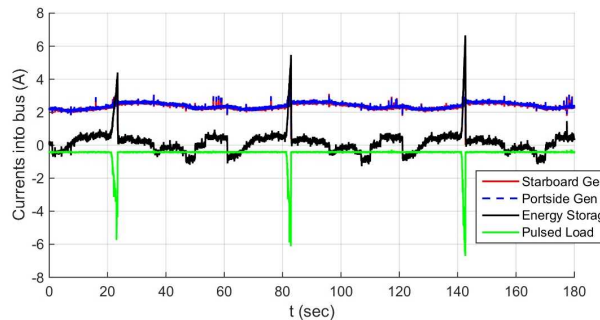
Ragone plot compares various energy storage/ propulsion technologies as function energy density vs power density. Diagonal lines define time constant/charge time. [Maxwell Tech., Inc. white paper, *Ultracapacitor Usage in Wind Turbine Pitch Control Systems*]



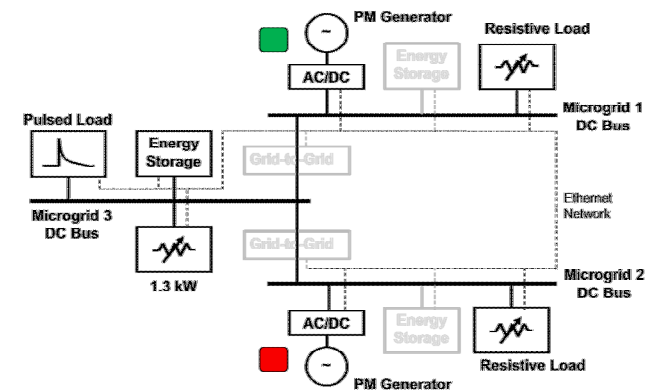
- Multiple pulse load application (EMALS) – DC networked ugrid



Generator Dominated



Energy Storage Dominated



[Ref] J. Neely, L. Rashkin, M. Cook, D. Wilson, S. Glover, *Evaluation of Power Flow Control for an All-Electric Warship Power System with Pulsed Load Applications*, APEX 2016.

Summary

- **SSM Testbed provides a configurable microgrid testing environment for evaluating controls and component performance**
- **SSM Informatics performs closed loop control over an IP network to manage microgrid resources**
- **Recent research result efforts address risks and issues associated with pulse load demands in NAVAL ship applications.**