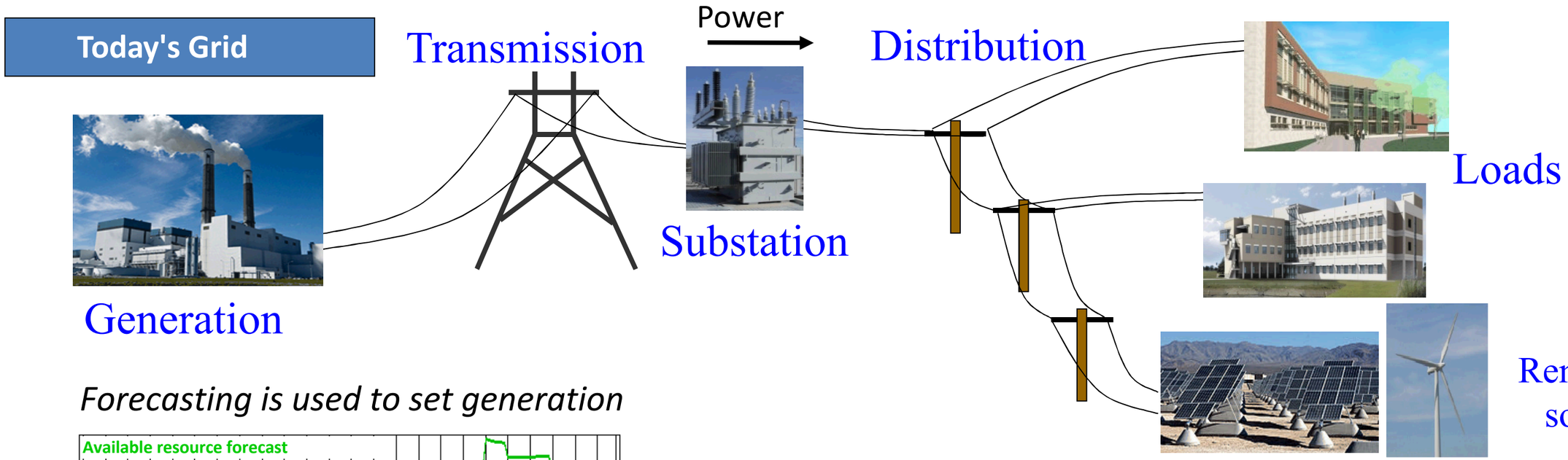
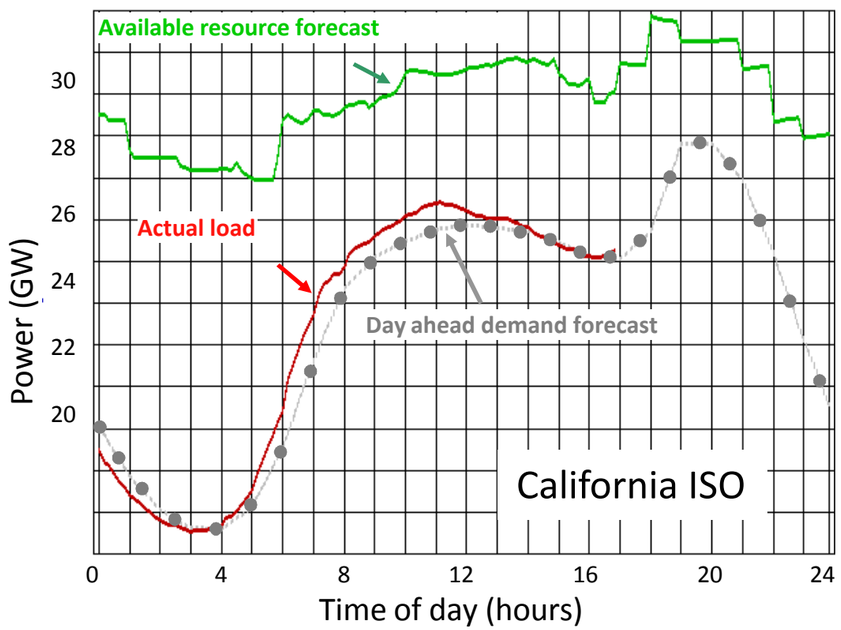
Today's Electrical Grid is Evolving to Accommodate Different Energy Sources and Increase Reliability

SAND2012-8589P



Forecasting is used to set generation



- Centralized generation
- Excess generation & fuel storage
- Fixed infrastructure
- Demand forecasting
- Essentially open loop control with human in the loop
- Limited ability to support renewable sources
- Limited ability to support disruptions
- Smart grid initiatives
- Desire for continued & increased reliability

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It's the end of the grid as we know it

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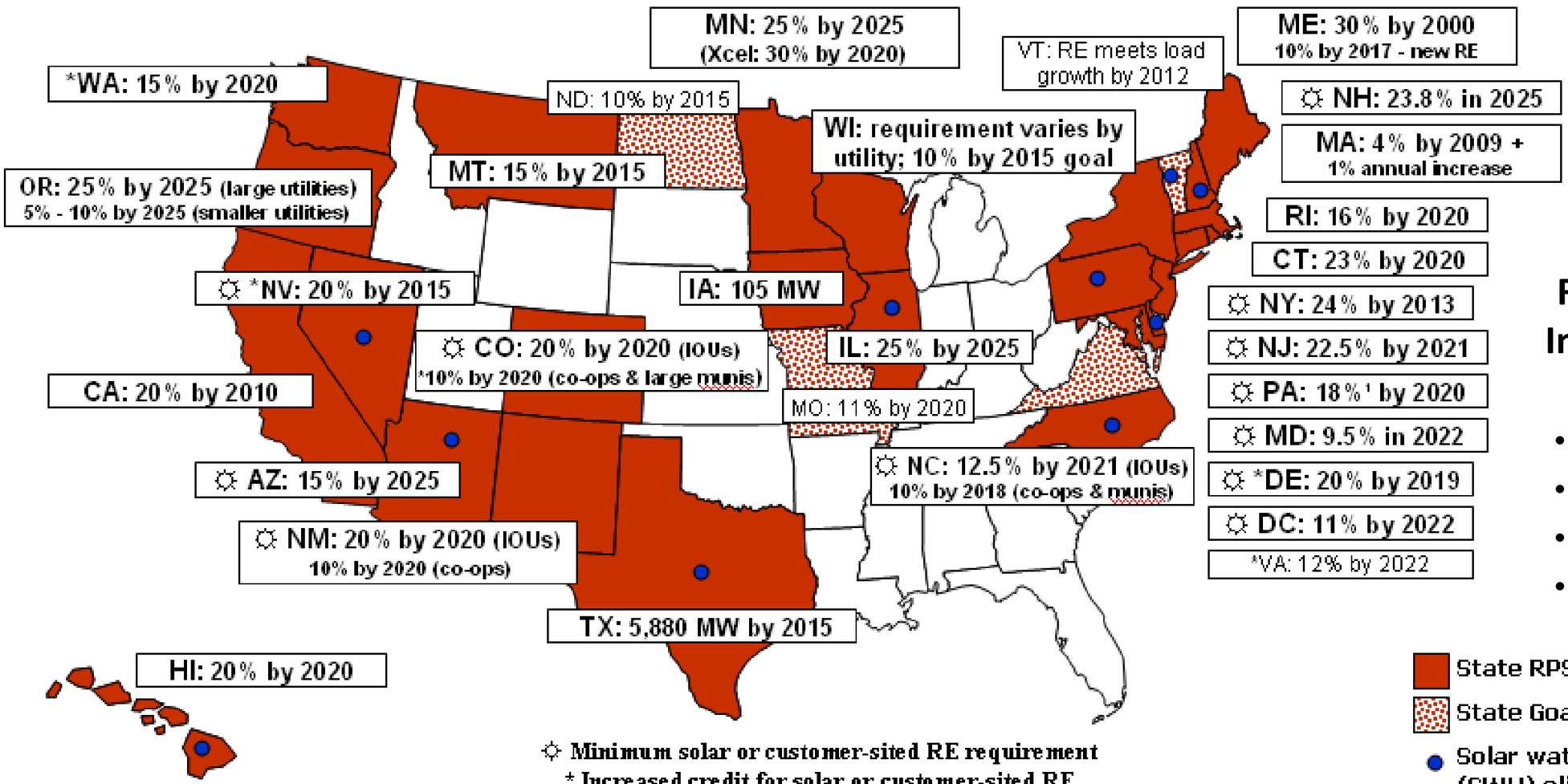
Renewables Are Moving Rapidly Into the Electric Grid

DSIRE: www.dsireusa.org

August 2007

Renewables Portfolio Standards



☼ Minimum solar or customer-sited RE requirement

* Increased credit for solar or customer-sited RE

[1]PA: 8% Tier I / 10% Tier II (includes non-renewables); SWH is a Tier II resource

Steep Growth in U.S. Renewable Energy System Installations is being Driven by:

- Climate change concerns,
- Renewable portfolio standards,
- Incentives,
- Accelerated cost reduction

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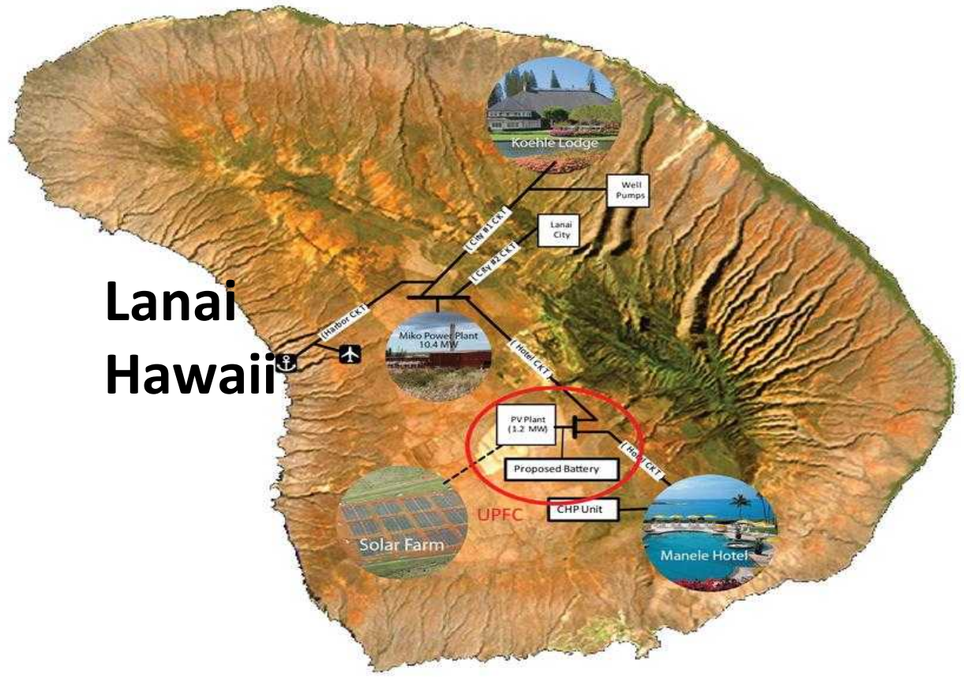
Existing Grid Analysis and Design Methods Have Inherent Limitations

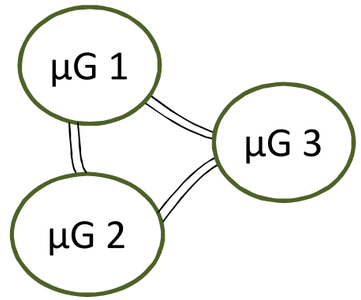
- Dynamics of multi-machine power systems described by current models cannot tolerate variable input sources, significant variations in frequency or voltage (~5%).
- The dynamics of multi-machine power systems are described by differential algebraic equations assuming constant 60Hz sinusoidal network response. The future smart grid may not be constant frequency.
- These approximations are made with integral manifolds. Physics and dynamic behavior is lost in component models. The future smart grid will be highly dynamic.
- The stability of today's grid was designed around centralized fossil fuel generation, not distributed renewable energy sources that vary randomly in time (stochastic).
- Stability limits in today's grid are only known for the current operating model where allowable frequency/voltage fluctuations are small (~5%).

We are developing analysis, design techniques, and technology that address all these issues

Networked, Secure, Scalable Microgrids (SSM ™) for Power Grid Architectures are Being Developed

- Sandia is unlocking microgrid application space through ground breaking nonlinear control theory, agents & informatics.
- Technology is being developed for networked microgrids spanning from conventional to 100% renewable energy sources.
- Future Impact
  - Unlimited use of renewable sources
  - Reduction in fossil fuel based sources
  - Self-adapting, self-healing, architectures
  - Microgrids as building blocks for larger systems





The SSM Test Bed represents a National resource to develop and demonstrate microgrid technology

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Mathematical Approaches Will Enable Complex Tradeoff Design/Analysis

Uniqueness of Hamiltonian formulation

- Thermodynamics based
- Exergy is the unifying metric instead of entropy and provides a missing link in self-organizing systems
- Necessary and sufficient conditions for local and global stability and performance of a class of Hamiltonian systems

Kinetic Energy Potential Energy

$$H = \left[T(\dot{x}) + T_c(\dot{x})\right] + \left[V(x) + V_c(x)\right]$$

$$\dot{H} = \left[\dot{T}(\dot{x}) + \dot{T}_c(\dot{x})\right] + \left[\dot{V}(x) + \dot{V}_c(x)\right]$$

A method for optimizing microgrids through the use of Hamiltonians

- Enables minimization in fuel based sources
- Enables optimization of multiple cost functions

$$c = \int H dt$$

Uniqueness of Fisher Information Equivalency

- Order rather than entropy based approach
- Includes information content and delay

$$I + J = 8\int \left[\left(\overline{T} + \overline{T}_c\right) + \left(\overline{V} + \overline{V}_c\right)\right] dt = 8\int \overline{H} dt$$

- This approach provides an optimization functional to simultaneously minimize information flow and storage

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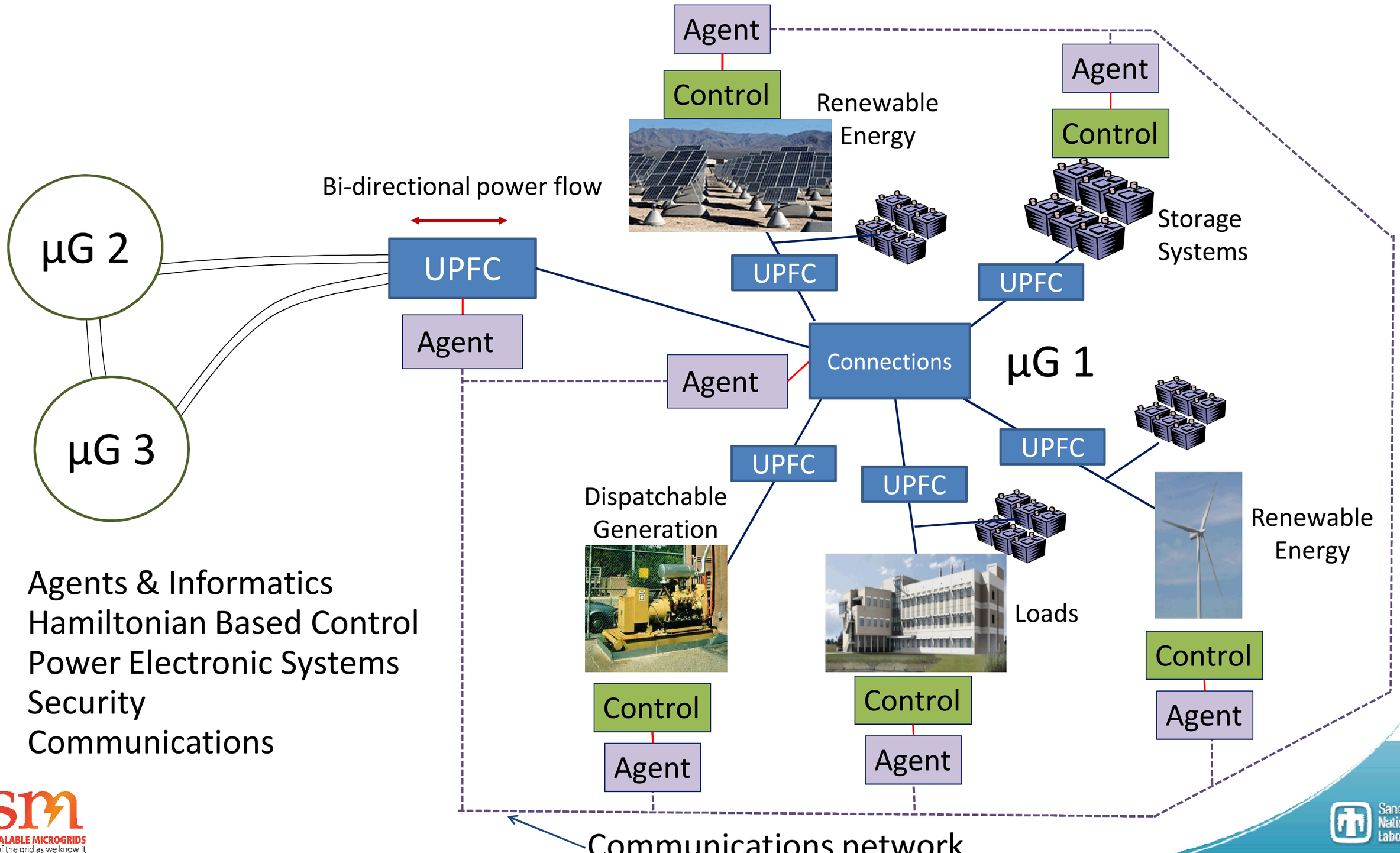
SSM Technology Will Enable A Future Without Constraints



- Agents & Informatics
- Hamiltonian Based Control
- Power Electronic Systems
- Security
- Communications

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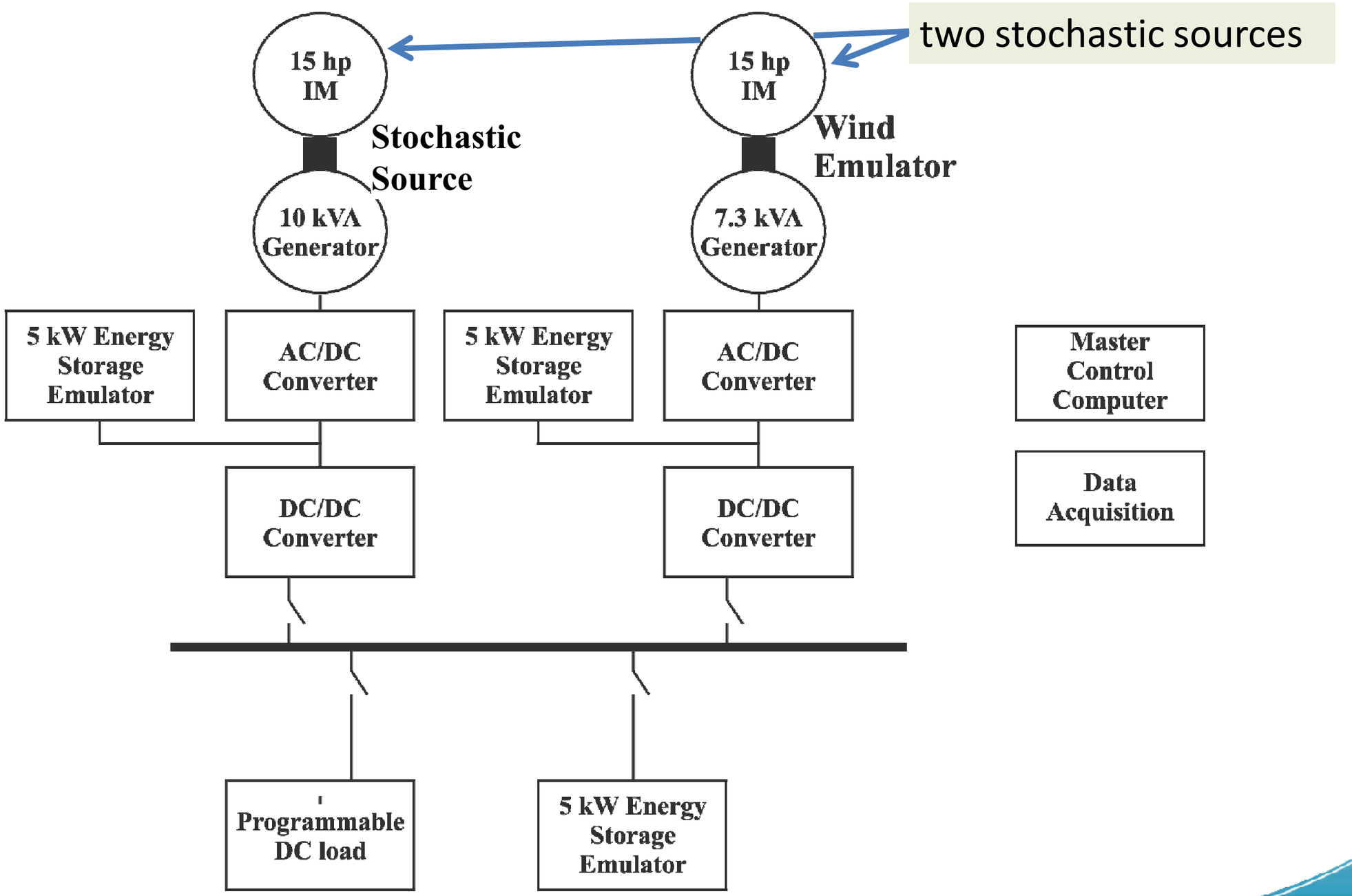
SSM Test Bed Experiment Demonstrates Stable Performance with 100% Random Generation



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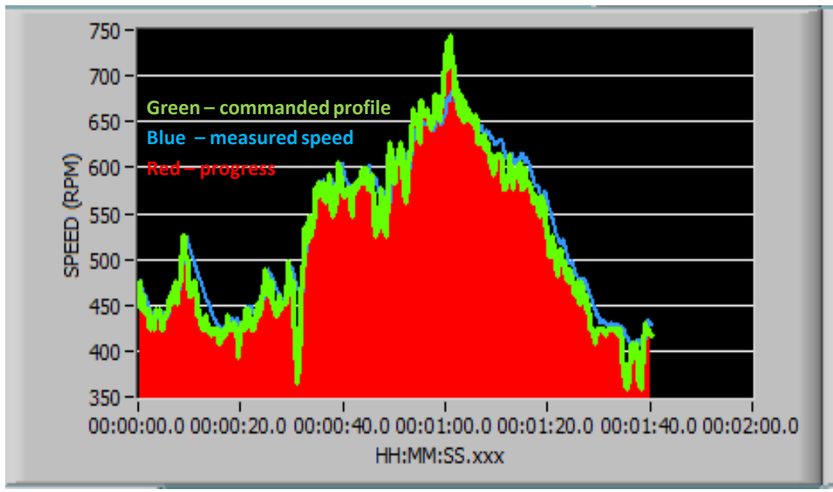
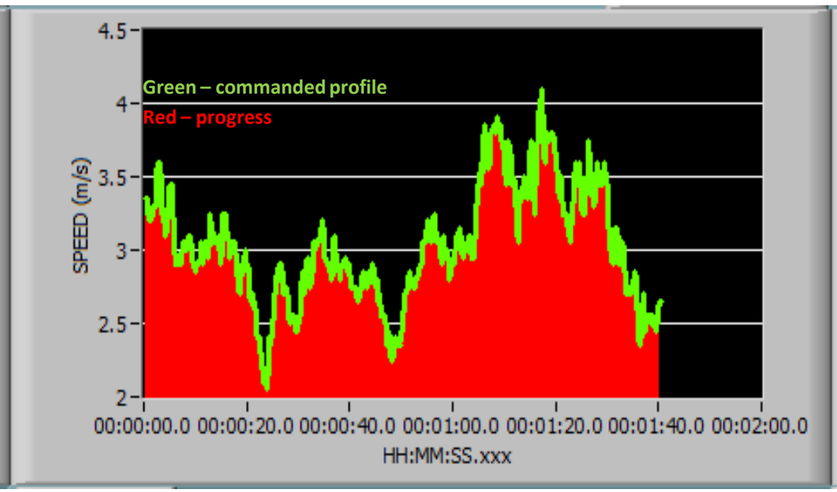
Bus Voltage Regulation Is Maintained With Highly Variable Sources and Loads

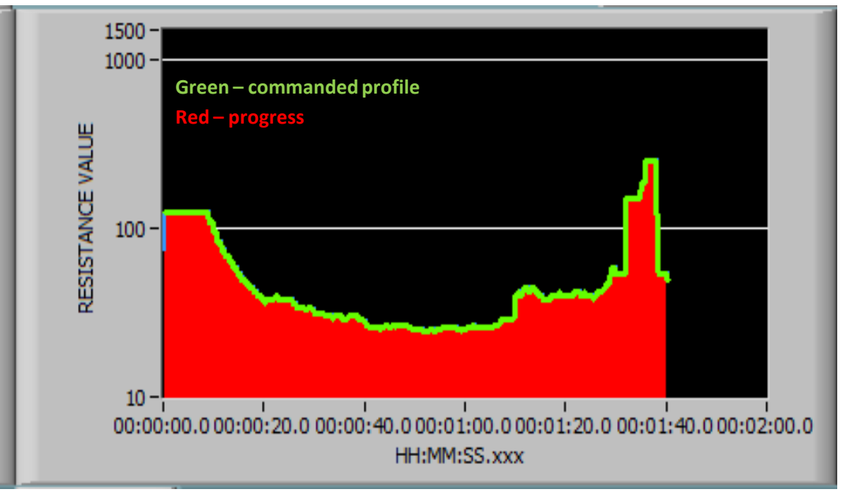
Random Energy Source Verses Time



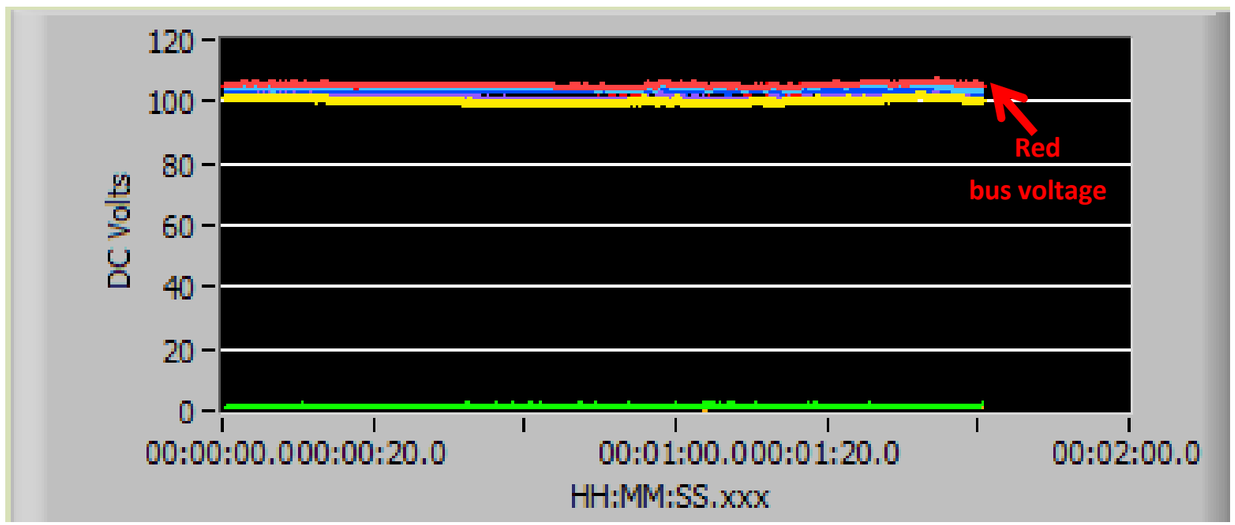
Wind Turbine Speed Versus Time



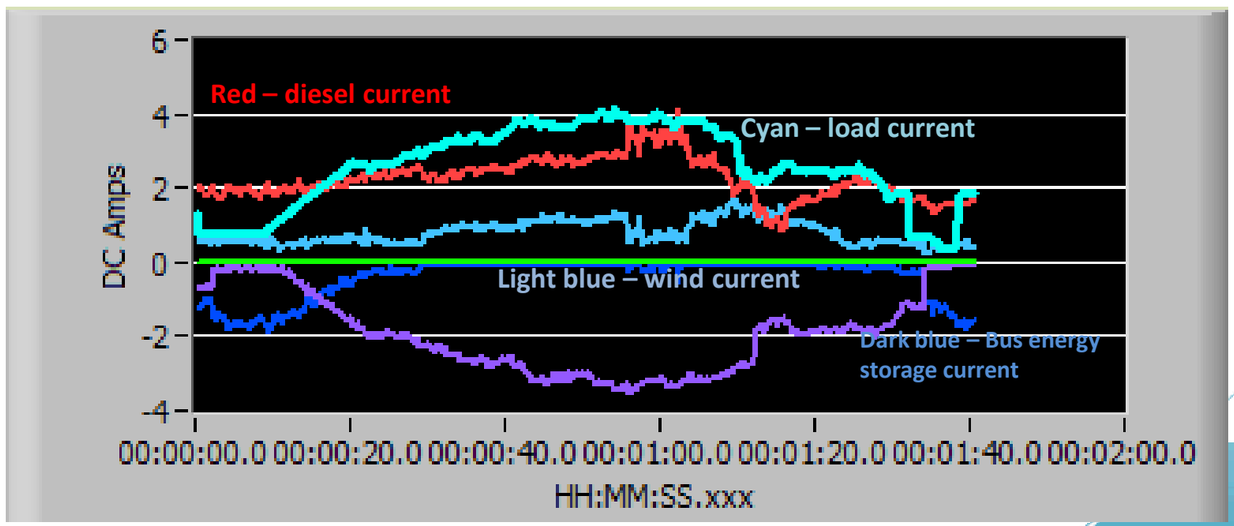
Load Resistance Versus Time



Lack of oscillations indicate that the sources in the system are working in unison.



Source and load currents indicate system energy balances



Sandia Has A Well Established Presence in Microgrid R&D

Conceptual Designs/Assessments (~$200K)	Small Scale Microgrid Demos (~$2M)	Large Scale Microgrid Demos ($5M-$50M)	Operational Prototypes ($5M-$100M)

• Philadelphia Navy Yard - Design completed FY11 DOE OE
• Indian Head NWC – complete FY10, DOE OE
• Ft. Sill – completed FY07, LDRD
• Ft. Bliss – Phase 1 completed FY10, DOE FEMP
• Ft. Carson – Nearing completion, DOE FEMP
• Ft. Devens (99th ANG) – Conceptual design complete, DOE OE/DoD
• Ft. Belvoir – Prelim design complete, DOE OE/FEMP
• Cannon AFB – Design complete FY11
• Vandenberg AFB – Initial site visit complete, DOE FEMP
• Kirtland AFB – Design complete, DOE OE
• Maxwell AFB – Conceptual design complete
	• Maxwell AFB – Integration in progress DOE OE/ Mostly DoD
	• Ft. Sill – SNL serving as advisor
		• SPIDERS JCTD
		  • Camp Smith
		  • Ft Carson
		  • Hickam AFB
			• H.R. 5136 National Defense Authorization Act

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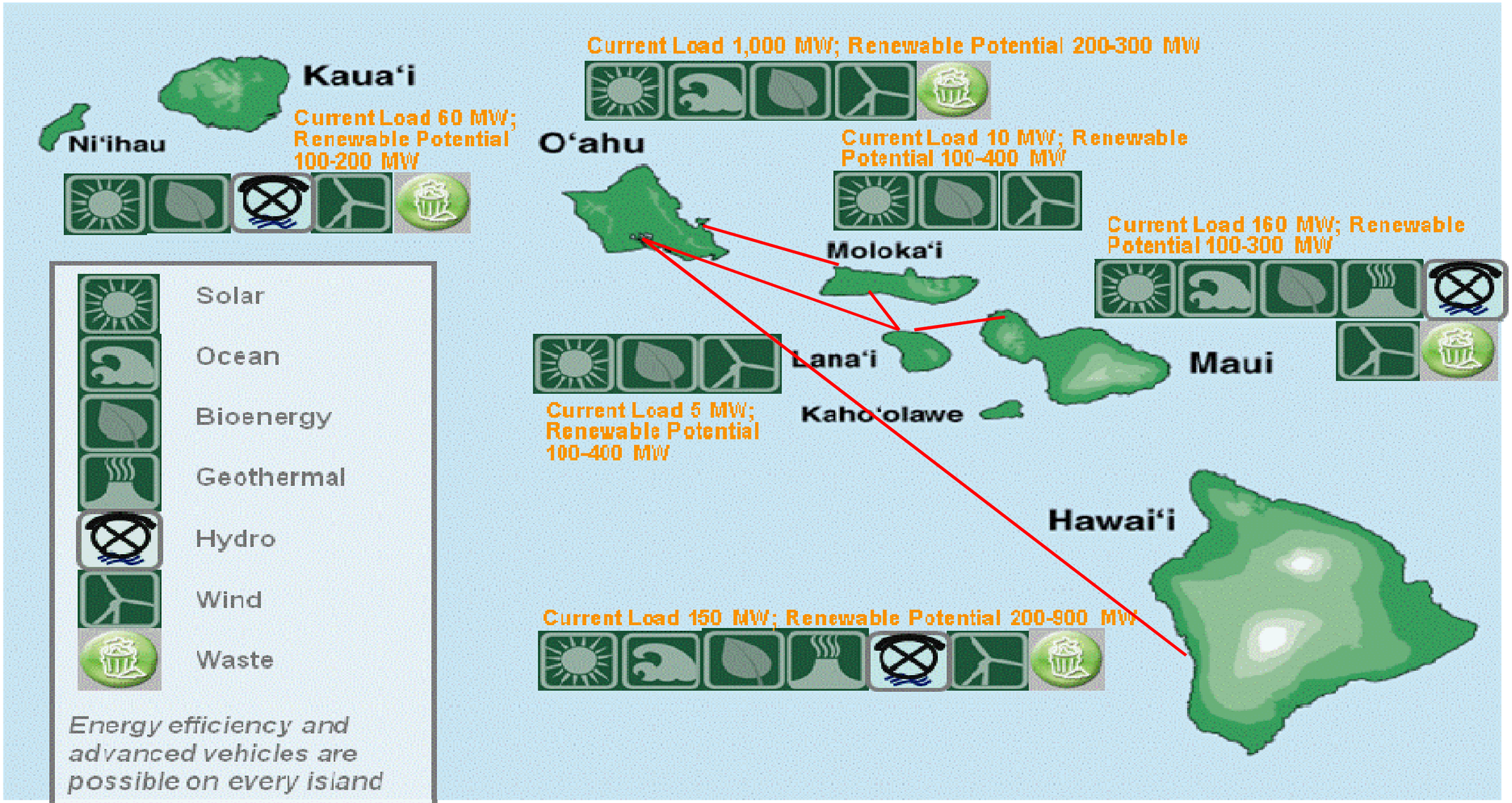
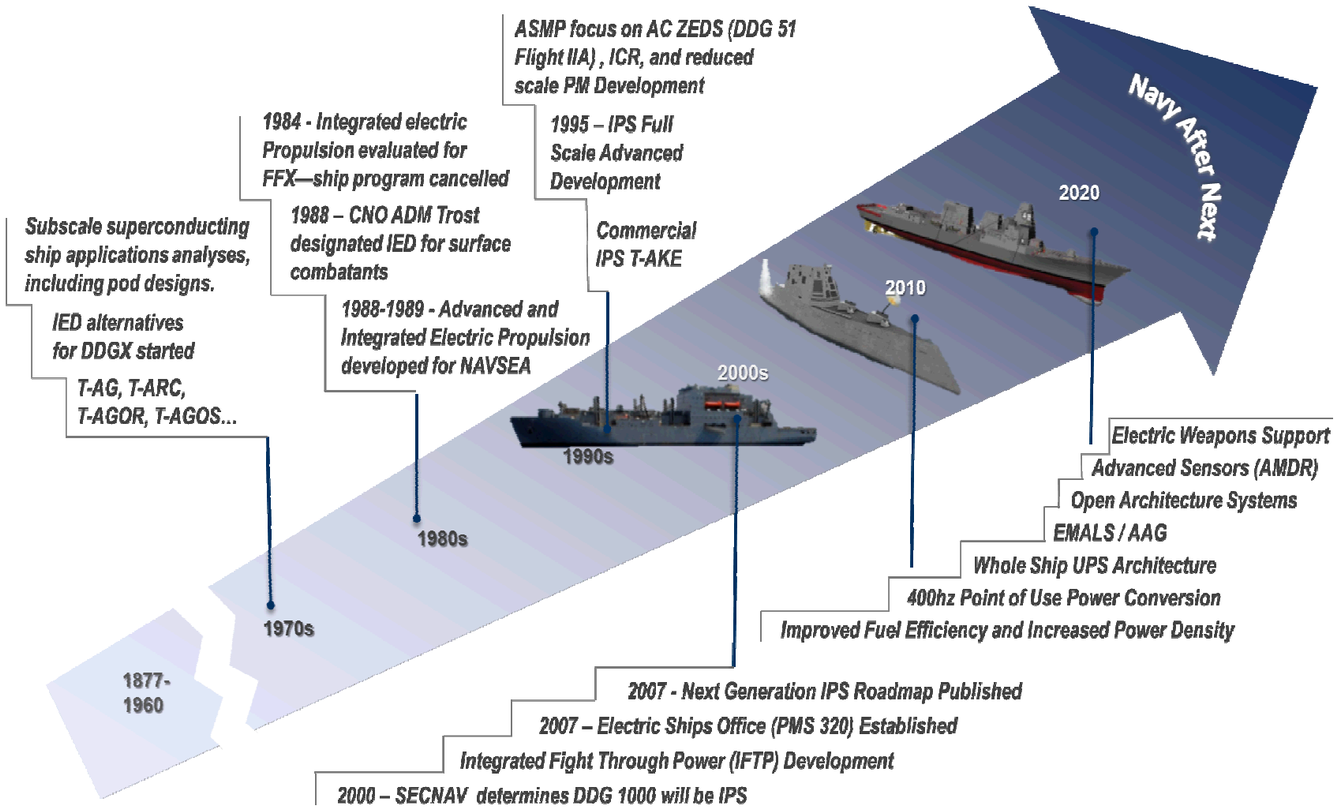
Hawaii Inter-Island Transmission Cables will Integrate Renewable Energy Based Microgrids

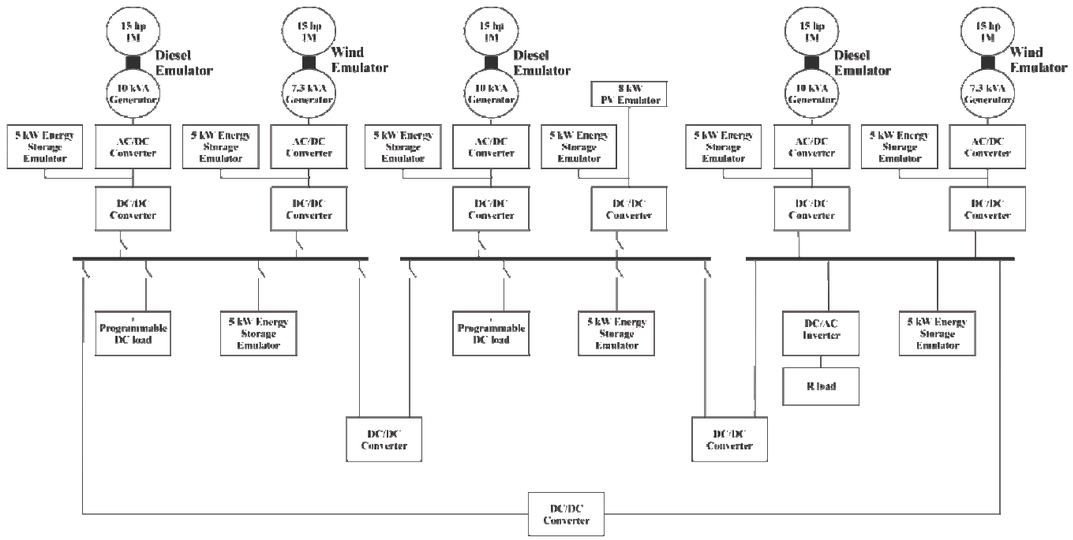


Electric Ships Are An Ideal Application For SSM Technology



A History of Successful Development and Transition

Source: Electric Ships Office, PMS 320 ; Distribution Statement A: Distribution is unlimited.



The 3-Microgrid SSM Test Bed can be configured to simulate complex ship power systems.
(Diagram of the SSM Collective is shown above.)

Ships are the Original Microgrids

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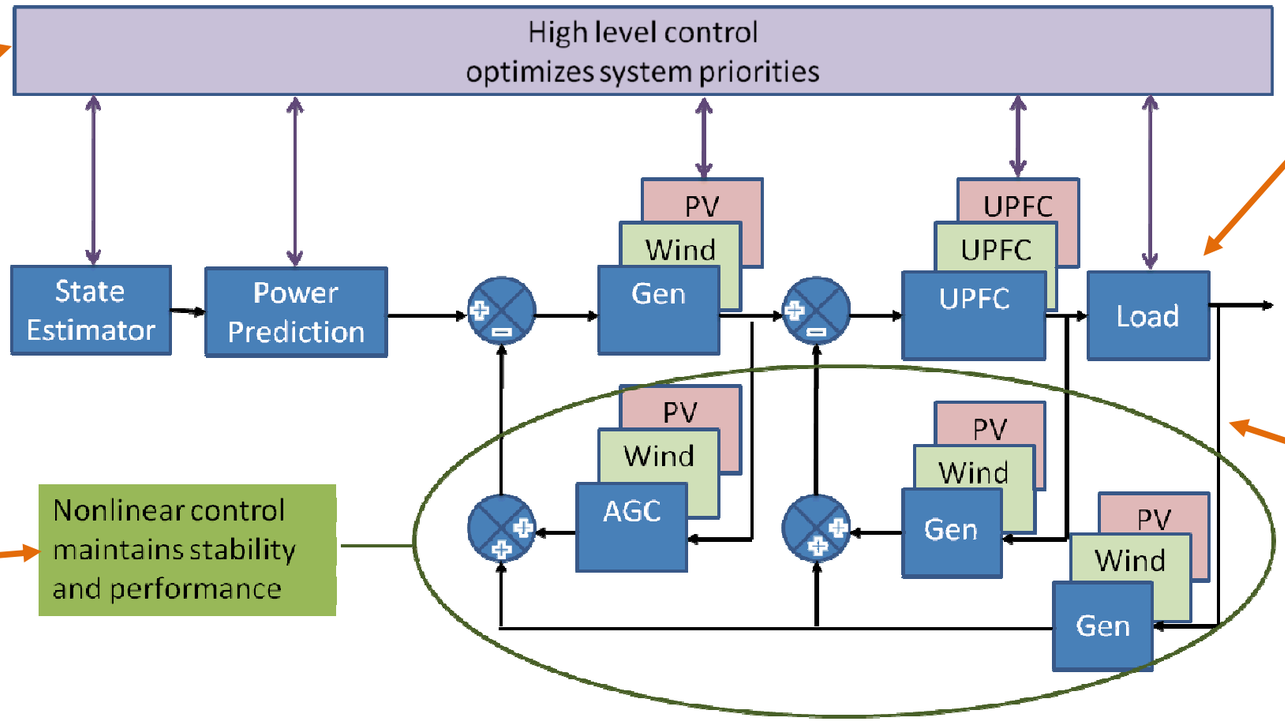
Program Manager

Steve Glover
Project Manager

Marvin Cook
Informatics/Agents

Jason Neely
Power Electronic Systems
and Advanced Controls

David Wilson
Hamiltonian Theory and
Distributed Nonlinear Controls



Tony Lentine
Communications

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