Secure and Scalable Microgrids
Enabling Technology and Applications

Rensselaer Polytechnic Institute
Workshop on Microgrid Technologies and Applications
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Steve Glover
Electrical Sciences and Experiments Department Manager
Sandia National Laboratories
Albuquerque, NM 87185
Outline

• Overview of the Electrical Science Group
• Microgrids
  – DOE related microgrid activities
  – Secure Scalable Microgrid
Nuclear Weapons Stockpile Responsibilities Drive Deep Expertise in Grid-relevant Science and Engineering

Grid-relevant Science and Engineering at Sandia

- Advanced power systems and AC/DC microgrids
- High voltage breakdown science & experiments
- Pulsed power components and systems development
- Electromagnetics theory/code development
- Electromagnetic experiments
- Systems engineering and integration

Physical Environments
- Weapon storage, transportation, maintenance, storage on delivery platform, launch and in-flight path
- Normal Environments (EMR, ESD, nearby lightning, degaussing)
- Abnormal Environments (lightning, exposure to power sources)
- Hostile Environments (nuclear weapon effects, directed energy weapons, high power microwaves)

System & Components

Other Capabilities include
E-beam supported wind tunnel and high heat flux research
Electrical and Radiation Sciences
Customers, Organization, and Facilities

National security activities for and in collaboration with:

- **Department of Energy** (National Nuclear Security Administration, Office of Science, Office of Electricity)
- **Other federal agencies** (DOD-Army/USAF/NRL, DOT-Federal Aviation Administration, DOL – Mine Safety and Health Admin.)
- **Non-federal entities**
- **Industry** (Goodyear, FMC, Inc., Lockheed Martin Technology Research)
- **Universities**

World class accelerator technology development & high heat flux research

Power systems
All Electric Warship

Sago mine, 2006

Lightning protection

EMP coupling into facilities
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
# Advanced Energy Surety Microgrid (ESM) Projects

## DOE & DoD R&D

To address current shortcomings of power reliability and security, Sandia is investigating advanced microgrid approaches to make distributed energy generation and storage resources more reliable, cost effective, and secure to improve overall critical mission assurance.

Sandia’s microgrid research utilizes smart grid technologies to enable:
- Distributed energy generation and storage to be operated both ‘grid-tied and ‘islanded’,
- Energy demand/response,
- Increased use of renewables
- Secure cyber control,
- Improved reliability and resiliency, and
- Use DoD sites as initial test beds.

## DOE & Utility R&D

Provide higher energy reliability and resiliency to critical community and industrial infrastructure and operations for low probability but high consequence events (natural disasters, intentional events, or large accidents).

Enhance energy safety, security, and reliability for civilian applications with a focus on:
- Providing energy resiliency using distributed generation to maintain critical community functions and operations for extended outages,
- Support demand/response of distributed community generation and storage to support local utility distribution system.

### Table: DOE & DoD R&D

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Community/Utility Coupled Microgrid Efforts Help to Accelerate Commercial Smart Grid Applications

PNM Microgrid Project
- Large-scale PV (500 kW)
- Large-scale Storage
  250 kW 4 hr. energy battery
  500 kW, 40 min power battery
- Smart Grid / SCADA integration

NEDO Microgrid Project
- Energy storage (small)
- Gas Engine (240 kW)
- Fuel Cell (80 kW)
- PV (50 kW)
- Demand response?
  100 kW Dummy load
  Electric Chiller/Thermal storage
Networked, Secure, Scalable Microgrids (SSM™) Enable High-Penetration Renewables and Improved Operations

• Ground breaking nonlinear control theory, informatics, and innovation.
• Tools are being developed for networked microgrids spanning from conventional to 100% stochastic generation.
• Potential impact:
  – Unlimited use of renewable sources
  – Lower-cost provisioning at a given level of renewables
  – Reduction in centralized fossil fuel based sources
  – Self-healing, self-adapting architectures
  – Microgrids as building blocks for larger systems
Tiered Control Structure Enables Prioritization and System Adaptability

High level control optimizes system priorities

Nonlinear control maintains stability and performance

UPFC - Unified power flow controllers
The Basic SSM Test Bed Structure Enables a Flexible Research Platform

New power system components will increase complexity associated with control and performance.
SSM Test Bed Exhibits Dynamics Similar to the Grid

Inter-area oscillations

Energy storage can improve resiliency

Control attributes influence stability
Demonstrated Performance with 100% Stochastic Generation and Load is Enabled Through Controls and Storage

Agents were not part of this experiment.
Hamiltonian Based Control Approach with Full State Control – Reduces Bus Voltage Transients

Source and load profiles

Stochastic source #1

Transients are not evident in the bus voltage

Stochastic source #2

Load

Cyan – load current
Red – diesel current
Light blue – wind current
Purple – load current
Dark blue – Bus energy storage current

Green – commanded profile
Blue – actual profile
Red – indicates progress in time
Understanding and Leveraging Information Flow in a Power System is Necessary for Optimal Performance

- Batch-run experiments enable apples to apples control comparisons
- Example shows the effect of Informatic control update rate on cost

\[ J_i(t_f) = \int_{t_0}^{t_f} (i_{ES}(\tau) - \hat{i}_{ES}(\tau))^2 d\tau \]

\[ J_v(t_f) = \int_{t_0}^{t_f} (v_{load}(\tau) - \hat{v}_{load}(\tau))^2 d\tau \]

Performance vs Update Rate

Cost: \( J = \int (v_{load} - E(v_{load}))^2 dt \) (V^2 sec)
Networked Microgrids can add to Power System Reliability and Resiliency
SSM Testbed Allows Study of Microgrid Collectives

- Centralized data acquisition allows plotting/analysis in Matlab
In Summary

- Sandia Electrical Sciences research is addressing a wide range of power system challenges
  - Controls, stability, protection, and susceptibility

- Sandia’s Energy Surety Microgrid research is addressing reliability and resiliency of DoD and commercial microgrids through near term technologies

- Sandia’s Secure Scalable Microgrid research is integrating:
  - Informatics theory (including cyber security),
  - Hamiltonian based controls,
  - Communication theory,
  - and flexible experimental capabilities

- Scalable approaches to networked microgrids support the building block concept

- DC system control approaches are being migrated to AC systems