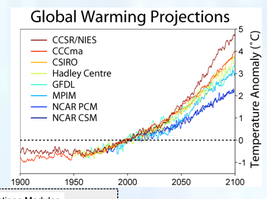
Scalable Micro-grid for a Safe, Secure, Efficient, and Cost-effective Electric Power Infrastructure

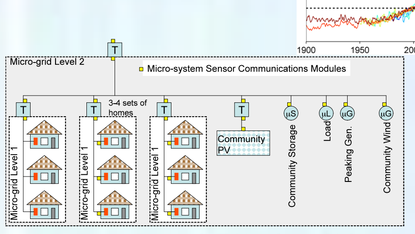
Sandia National Laboratories

Anthony Lentine, Jeff Nelson, Scott Kuszmaul, Sig Gonzales , Steven Goldsmith, Dave Schoenwald , Shannon Spires, Steven Glover, Justin Ford, Greg Nielson, Murat Okandan, Alan Hsu

Problem

"Coal is out (CO_2 regulations)
Natural Gas is risky (future cost),
Nuclear is out (there's no water in NM),
We must use Renewable Energy"
* Paraphrased from PNM





Scalable Micro-grid Concept

Motivation

- **Reduce Reliance on Fossil Fuels**
  - Climate change (Coal electric power plants are the largest contributor)
  - Foreign fuel supplies (oil heating conversion and plug-in hybrid vehicles)
  - Electric demand growing at 1.75%/yr, expect 19% from 2006 to 2016 [1]
    - Shortage likely in both generation (+ 6%) and transmission (+ 7%) in 2016 ➡ brownouts/blackouts!
- **Distributed Energy Resources (DER) ➡ major part of the solution**
  Note: wind turbine power generally centralized and often remote
  - Reduced losses in transmission if generation geographically close to consumption
  - Reduced large capital expenses for plant and transmission lines
  - Increased security by decentralization of lines/plants
- **Today's Grid will not allow high penetration of DER (> 50%)**
  - Stability with high renewable power penetration because of intermittency
  - Distribution network is unidirectional and passive, cannot make full use of DER for capacity or reliability. (safety issues)
  - Distribution network cannot balance generation, storage, and loads.
    - the loads demand power, the generation supplies it or (occasionally) turns off the power
- **Requires Nothing Less than a New Grid Infrastructure!**

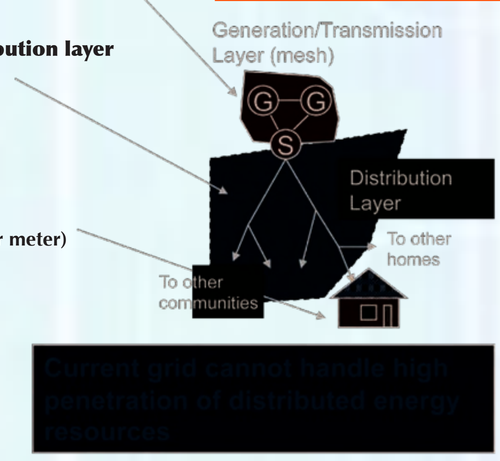
[1] NERC forecast quoted in Executive Intelligence Review, 10/2006

The Existing Grid

Scheduled Generation | Fixed Infrastructure | Random Load

- **Mesh based transmission layer**
  - Sometimes controls and monitoring (SCADA or supervisory control and data acquisition)
    - current, voltage, power factor, etc.
  - Fossil Fuel has 'inherent storage'
- **Unidirectional passive tree-like distribution layer**
  - Little to no monitoring
  - Little to no redundancy
  - Little to no controls
  - Little to no storage
- **The home**
  - Monitoring of usage (e. g., Google power meter)
  - No closed loop control
  - No storage in grid-connected systems

The Current Grid Paradigm
- Predict load a day ahead
- Schedule generation with margin
- Generation ALWAYS supplies load



The Future Grid Paradigm
- Supply no longer predictable
- Must control loads, storage
- Must have smart network

Solutions to accepting a large penetration of distributed energy resources

- Lots of storage, located on-site with renewable energy
  - Un-economical, but potentially makes renewable energy output predictable
  - Still grid-compatibility issues if residences and businesses supply power to the grid in a big way.
- An intelligent green-grid that controls bi-directional power-flow to reduce the need for storage and peaking generation

Storage (peaking) $$$$$

Our goal is to move to the right →

Advanced Power Control Architectures $

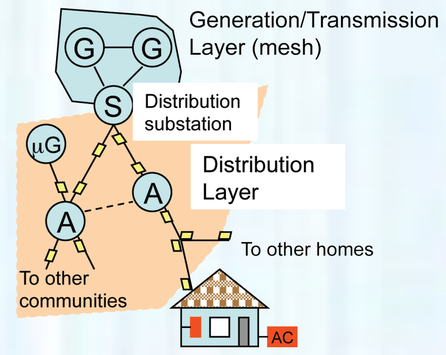
Use INFORMATION and INTELLIGENCE to replace RAW Generating and Storage Capacity

Approach (cont.)

Focus of this LDRD

- **Advanced controls and architecture**
  - High penetration of DER
    - Efficiency
    - Stability
    - Security
    - Safety
    - Reliability
    - Economics
  - Reduction in peaking central generation and storage
    - Control of loads, and storage
- **Microsystems for remote sensing and communications**
  - Change dumb, blind distribution network into microgrids that are:
    - Distributed
    - Smart (have information to make decisions)
    - Active (load control)
- **Representative hardware demonstration/simulation at the Distributed Energy Technology Lab (DETL) at Sandia**

Future intelligent grid



Results

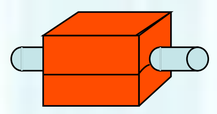
LDRD Control & Power Architecture

- **Why Scalable Microgrids?**
  - Control, generation, use in close geographic area
  - Reliability ➡ pooling of local resources in the event of a grid failure (regulatory issues today)
  - Scalability ➡ few homes to neighborhoods to cities
- **Why Distributed Controls?**
  - Stability ➡ fast time response
  - Resiliency ➡ redundant information
  - Security ➡ no central point of failure
  - Cohesive management of generation, storage, and load.
- **If successful will it be adopted? (It's a big change!)**
  - Depends on the success of the Utility/Industry approaches (USA)
  - 1.4B people without electricity in the world ('Greenfield applications')

First Year Accomplishments
- Models developed, simulations in progress

LDRD Requirements for Sensing for intelligently managing the future grid

Features:
- Scalable at multiple line voltages and multiple points within the network.
- Small, cheap, lightweight
- Long lifetime (40+ years)
- Harsh (outdoor) environment
- Physical Security



Contains …
- Communications … must be secure too (cyber-security)
- Power harvesting (from line)
- Power backup (n – days)
  - Low power, Long lifetime,
- Addressable
  - Physical location information
  - Time information
- Sensing
  - Physical Electrical (Current, Voltage, Frequency, Direction)
  - Environmental (Temperature, Solar irradiance)
  - Strain ?
- Fault Isolation
- Topology discovery

Key Innovation areas:
- Power Harvesting and Backup
- Secure Communications
  - RF, Optical, Power-line?
- Integration for cost and size with High-voltage Power Electronics.

First Year Accomplishments
- In-home sensor/actuator development
  - Preliminary design completed
  - In home actuation is best place to control loads → lowest impact
  - Next year: hardware development
- Distribution layer sensor/actuator
  - Optical sensing: Good properties, and commercially available
  - Investigating lower cost options
  - Biggest cost impact for technology
- Experimental Demonstration (DETL)
  - One line diagram partially complete
  - Test plan under development

Significance

'Smart Grid': It's everywhere!

- **Smart Grid Industrial Focus ⬅ Focus on Operational Efficiency**
  - Advanced Meter Infrastructure (AMI) or 'Smart Meter'
    - A communications gateway between the Home Area Network (HAN) and the Utility
    - A data-logger/collector, giving real-time and archival information on time-dependent Electricity usage.
  - Home Area Network
    - Collection of 'Smart Appliances' respond to Utility signals or user (pre-programmed or real-time) commands
    - Sensing to let users know more information about their electricity usage.
      - Slow (seconds), archival, not necessarily comprehensive (e.g., no PF)
  - Demand Response
    - Dispatch load reduction in response to generation shortage
    - Controlled through Utility or third party (as generation sometimes is)
- **Missing from the Industrial/Utility Focus**
  - Large Percentage of Distributed Renewable Energy (focus on Wind today)
  - Decentralized Distributed Control (focus on Utility control)
  - Sharing of power/storage among DER sources ⬅ regulations prevent it
  - Dynamic Modeling and Simulation (stability) ⬅ (focus on planning, power flow)

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2009-2009-3773P

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