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

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Problem

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 growth of 5.75% (exp. expected 19% from 2006 to 2016 [7])
  - Shortage likely in both generation (+4%) and transmission (+7%) in 2016 (increases Markets!)

Distributed Energy Resources (DER) = major part of the solution
- Note: wind turbine power generally centralized and often remote
  - Reduced lines in transmission if generation geographically close to consumption
  - Reduced large capital expenses for plant and transmission lines
  - Increased security by decentralization of incipient points

- 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 fully use DER for capacity or reliability
  - Distribution network cannot balance generation, storage, and loads
  - The loads demand power, the generation supplies it (occasionally) turns off the power

- Requires Nothing Less than a New Grid Infrastructure!

Scheduled Generation

The Existing Grid

- 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 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
- Use economic, but potentially makes renewable energy output predictable
- Grid compatibility issues if resilience and businesses supply power to the grid in a big way.

Our goal is to move to the right $ Advanced Power Control Architectures

- An intelligent green-grid that controls bi-directional power-flow to reduce the need for storage and peaking generation

Global Warming Projections

Future intelligent grid

- Generation/Transmission Layer (mesh)
- Distribution Substation
- To other consumers
- Distribution Layer
- To other homes
- Micro-system Sensor Communications Modules

Approach (cont.)

Focus of this LDRD

- Advanced controls and architecture
  - High penetration of DER
    - Efficiency
    - Reliability
    - Security
    - Safety
    - Economics
  - Reduction in peaking central generation and storage
  - Control of loads, and storage

- Microsystems for remote sensing and communications
  - Change-detect 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

Results

LDRD Control & Power Architecture

- Why Scalable Microgrid:
  - Control, generation, use in three geographic areas
  - Reliability = quick loss of local resources in the event of a grid failure (regulatory issues left)
  - Scalability = few homes to neighborhoods to cities

- Why Distributed Controls:
  - Reliability = 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 U.S. Industry approaches (IUSA)
    - 1-2B people without electricity in the world (Greenfield application?)

First Year Accomplishments

- Models developed, simulations in progress

LDRD Requirements for Sensing for intelligently managing the future grid

Features:

- Scalable at multiple field sites and multiple points within the network
- Small, cheap (High throughput)
- Long lifetime (30 years)
- Robust (outdoor) environment
- Physical Security

Containers:

- Communications... must be secure too (cybersecurity)
- Power harvesting (from lines)
- Power backup (4 days)
- Low power, Long lifetime
- Adaptable
  - Physical location information
  - New Information
- Sensing
  - Physical Electrical (Current, Voltage, Frequency, Direction)
  - Environmental (Temperature, Solar irradiance)
- Strain
- Fault Isolation
- Signage Discovery

Significance

‘Smart Grid’: It’s everywhere!

- Smart Grid Industrial Focus = Focus on Operational Efficiency
  - Advanced Meter Infrastructure (AMI) or ‘Smart Meter

- Autonomic Control System (ACS) (Amigo or ‘Smart Power"
  - 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 use programmed or real-time commands
  - Sensing to let users know more information about their electricity usage

- Home Area Network
  - Data logger/collector, giving real-time and archival information on time-dependent Electricity usage

- Demand Response
  - Dispatch load in response to generation shortage

- Controlled through Utility or third party (or generation sometimes)

First Year Accomplishments

- In-home automated (USSA development)
  - Power Monitoring and Control
  - Secure Communications
  - RS Optical, Power-law
  - Integration of cost, and new with high value Power Electronics

- Key innovation areas
  - Power Harvesting and Backup
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