MicroGrid Design, Development and Demonstration

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Partners: NREL, Rocky Research
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Agenda

• Problems & Needs
• Project Objectives
• Technical Approach
  – Local Controls
  – Supervisory Controls
  – Protection
• Project Schedule & Milestones
• Interaction & Collaborations
• Benefits Summary
Problems & Needs

• Generation
  – Predominantly central plant
  – Increasing content of *intermittent renewables*

• Transmission
  – Congestion increasing
  – Capacity margins eroding
  – NIMBY and BANANA constraints

• Distribution
  – Unidirectional power flow across radial systems
  – Incompatible with emerging DG

*SOURCE: GE*
Map created with PowerMap from Platts, a unit of the McGraw-Hill Companies

*SOURCE: ORNL, DOE*
DOE Vision for The Power Grid: Grid 2030

1. National Electric Backbone
   - High-capacity transmission
   - National balance of supply & demand
   - Demand-side management

   Technologies
   - Superconducting cables
   - Advanced materials
   - HVDC, VFT & FACTS
   - Distributed controls
   - Communication

2. Regional Interconnections
   - Regional transmission
   - Multi-state bulk power exchanges

   Technologies
   - HVDC, VFT & FACTS
   - Energy storage to manage supply-demand imbalances

3. Mini-Grids
   - Distributed generation
   - Customized electricity consumption (green, COE, etc)
   - Hydrogen economy

   Technologies
   - Sensors
   - Communications
   - Smart metering
   - Distributed Controls

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MicroGrid Concept and Background

**What is it?**
Coordinated electrical subsystem with
- Multiple Distributed Energy Resources (DER)
- Multiple loads
- Distribution voltage interconnections
- Capable of (macro) grid independent and dispatchable grid interactive operation

**What is driving it?**
- Restructuring of the Electric Power Industry
- Advances in Technology
- New Environmental Regulations  
  - Increasing intermittent renewable penetrations
- Increasing Power Quality Concerns
- Heightened Reliability Awareness
- Potential efficiency benefits of CHP

Requires a systems approach, not merely an interconnection of DER components
Technical Challenges of Current Practices

*Isolated power systems are not new, but…*

- Distribution protection and control practice is largely incompatible with the MicroGrid concept
  - Bi-directional power flows
  - Unit level voltage and VAR support
  - Fault current contribution
  - Island operation
- Non-conventional (inverter based) generation will require new unit control and protection strategies for successful Microgrid operation
  - Intermittency of renewables
  - Low overload, short circuit ratings
  - Power rate (dP/dt) limits
  - Stability of low inertia grids
  - Potential for active load control (e.g., water and hydrogen production)
- Supervisory controls will be needed to achieve the full operating potential
  - Total energy optimization (electrical and thermal)
  - Load management
  - Unit commitment
  - Aggregation and system performance
  - Data acquisition
- Business, regulatory, and tariff structures are presently incompatible with multiparty Microgrids.
MicroGrid Categories

1. Rural Electrification
   (remote off-grid)

2. On-grid MicroGrids
   - Single Facility
   - Multi-Facility
   - Feeder
   - Substation
Project Objectives

Develop and demonstrate advanced controls, energy management and protection technologies that are needed to make microgrids technically and economically viable.
Design Philosophy

- MicroGrids are designed for robust operation using **advanced local control and protection schemes**, even in the absence of supervisory control.
- **Supervisory controls** are used to optimize customer benefits, e.g. performance, operating cost, emissions, etc.
- Energy management platforms will be economical if they incorporate **maximum commonality** among various applications.

Local Controls & Protection
- VAR management / voltage control
- Frequency control
- Energy storage
- Power quality
- Asset protection and fault isolation
- System modeling

Energy Mgmt & Supervisory Control
- Dispatch controls
- Supervisory control optimization
- DMS / real time pricing
- Physical systems for control & communication
Technical Approach

**Supervisory Controls**
- Used to optimize electrical and thermal performance and cost
- Manage feeder connection to bulk grid
- Manage renewable intermittency

**Local Controls**
- Control response based on local measurements.
- Robust response to system disturbances and supervisory level commands.
- Provide inherent stability and load sharing for grid independent and grid interactive connections.
**Advanced Local Control Design**

**Design Philosophy**
- Develop control strategies for non-conventional assets constrained by power ramp rates and current limits (these type of constraints tend to surface when limited generation capacity exists to service loads)
- Utilize non-linear control theory to ensure system stability of non-conventional generation in MicroGrid networks with mixed assets and loads

**Control Objectives**
- Robust response to system disturbances and supervisory level commands
- Provide inherent stability, load sharing, and fault ride-through for low-inertia grid independent, and grid interactive connections

**Status**
- Novel control philosophy for non-conventional generation has been developed and tested in simulation.
- Results indicate robust operation for various system contingencies when applied to constrained non-conventional generation equipment:
  - Fault ride-through and recovery
  - Grid interactive or grid independent operation
  - Low inertia MicroGrids
Local Control Simulation Example

- 12.5kV Main
  - 16 node, including laterals
  - 240v and 600v secondaries with transformers
  - 10 MVA system base
- 8,370 kW Distributed Loads
  - 2450 kW pumps (nameplate)
  - 3100 kW other motors (nameplate), including 750 kW motor start at bus 7
  - 5600 kW impedance loads

- 9,000 kVA Non-conventional DG
  - 115% current limit
  - 0.25 PU/sec + ramp rate limit

Test Case:
0.2s fault followed by disconnect with highly constrained DG

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Supervisory Control Design

**Design Philosophy**
- Achieve multiple control objectives - optimal dispatch control
- Manage voltage and power at the point of interconnect - tieline control
- Provide control set points for local control

**Hierarchical Control Architecture**
- Optimal dispatch control to provide P & Q set point
  - Slow time constant (5-10 mins)
- Tieline control to adjust set point based on tieline limits and commands
  - Faster time constant (10's - 100's of ms)
- Local control to execute on set points and maintain local operation
  - Fastest time constant (μs - ms)
Supervisory Control Design

**Tieline Control**
- Makes the Microgrid a dispatchable entity at the Point of Interconnection (POI)
  - Volt/VAR control
  - Active power flow control and power limits
  - Power ramp rates limits
  - Power-frequency control

**Dispatch Algorithm**
- Determines Unit Commitment (UC) and Economic Dispatch (ED) based on benefit objective function and operation constraints.
  - Incorporates Combined Heat and Power (CHP) and thermal loads.
  - Adds controllable loads as a resource.
  - Accounts for renewable generator intermittency and forecasting.
Tieline Control Simulation Example

Grid Connected
- 13.8kV main
- 4160V feeder
- 480V at asset
- 10MVA base

Main assets:
- 250kW PV
- 350kW Engine Genset
- 200kW Load (initial)

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Test Case 1: VAR command step change
- 0kVar to 100kVar

Test Case 2: Load ramp
- 200kW to 500kW

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Engine Genset Response

Power Limited

Power Ramp Rate Limited

Tieline VAR Step Change Response

VAR Command

Power Limited

Power Ramp Rate Limited
Supervisory Control Platform Testing

Reduce risk before on-site demonstration in Phase II.

- Identify a suitable centralized control hardware platform
- Demonstrate a selected set of supervisory control functions, in a hardware-in-the-loop environment using real time microgrid simulation in GRC lab
- Conduct control hardware and algorithm testing at NREL distributed generation test site.

GE Global Research (GRC)
Laboratory Setup Plan

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Protection Challenges and Solutions

Challenges Created by Microgrids

- Network rather than radial operation in some cases
- Bi-directional current flow from local generation
- Low fault current in islanded mode
- Islanding issues

Protection Solutions

- Protection coordinator at the point of common coupling provides advanced protection functions based on synchronized measurements
- Transfer trip: issuance of a breaker trip command from one decision locus to another, standard tools can be used
- Differential protection, especially of the Microgrid, to provide reliable fault detection and location
- Voltage polarized directional over-current: addresses the issue of back-feeding from generation or other power sources
# Life-Cycle Project Schedule, Major Milestones

## Program Activities

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Program Activities</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
<th>Q9</th>
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| Task 1  | Summarize system specifications and business model.  
Deliverable: Report on microgrid categorization, differentiation, and case study definitions. | | | | | | | | | |
| Task 2  | Control design and system analysis.  
Deliverable: Report on mini-grid control design and simulation results. | | | | | | | | | |
| Task 3  | Evaluation through case studies.  
Deliverable: Report on case study evaluation results including the value story and possible recommendations on refining the existing assets. | | | | | | | | | |
| Task 4  | Validation and verification in lab.  
Milestone: Final Phase 1 review.  
Deliverable: Report summarizing the platform specification, lab setup, test plan, control algorithm, and validation results from laboratory testing. | | | | | | | | | |
| Task 5  | Program management.  
Deliverables:  
- Quarterly progress reports  
- Phase 1 final report | | | | | | | | | |

## Phase 2

| Task 6  | Design engineering equipment for City of Wayne Microgrid.  
Milestone: Final design review.  
Deliverable: Designs, drawings and specifications, single line diagrams, implementation plan, and final design review. | | | | | | | | | |
| Task 7  | Build and procure engineering equipment.  
Deliverable: Report summarizing the list of equipment and bill of materials (BOM). | | | | | | | | | |
| Task 8  | Install and commission engineering equipment. | | | | | | | | | |
| Task 9  | Demonstrate the City of Wayne Microgrid.  
Deliverable: Final demonstration. | | | | | | | | | |
| Task 10 | Program management.  
Deliverables:  
- Quarterly progress reports  
- Phase 2 final report | | | | | | | | | |

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**Major Milestones**

- Task reports, quarterly reports
- Final Design review
- Final Demonstration
- Final Report

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# Life-Cycle Project Budget

## PHASE 1 BUDGET

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## PHASE 2 BUDGET

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Phase II - FY 2007

Demonstrate technology developed in Phase I
Demonstration site to be decided in Q3-2006.

**Microgrid Demonstration Plan:**

- Select a potential microgrid location
- Candidate site includes several 350 kW natural gas engine-generator sets for CHP and 500 KW of solar electric generation.
- Equipment installation will be executed through a separate contract.

**Candidate Functional Requirements:**

- Normally connected to the main grid.
- May be transitioned to islanded mode during grid outage.
- Capability to black start the Microgrid, if necessary.
- Point of interconnection active and reactive power control.
- Unit commitment and economic dispatch control including CHP.
Interactions & Collaborations

National Renewable Energy Laboratory (NREL)

Lab demonstration in Phase I using:
• 200-kW grid simulator: emulate a utility, allow for voltage and frequency control, reproduce disturbances such as sags, swells, and harmonic problems with the utility.
• Load simulator with resistive, inductive, and capacitive elements
• Investigate the supervisory control system response to events such as sudden load changes, phase imbalance condition or loss of phase.

Rocky Research
• Build/provide thermal models for dynamic analysis in Phase I
• Provide Phase II consulting for design of the new CHP system at Phase II (if needed).
Benefits Summary

Development of control algorithms & hardware that promote…

• Energy efficiency and optimal energy utilization
• Reduction in cost of energy and total cost of ownership
• Flexibility to integrate a diverse set of controllable assets
• Demonstration of renewable energy integration
• Aggregation and algorithms to enable dispatchable Microgrids
• Concepts to improve power quality and availability in islanded operation
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