2014 Smart Grid R&D Program
Peer Review Meeting

Complete System-Level Efficient and Interoperable Solution for Microgrid Integrated Controls (CSEISMIC)

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Objective
Microgrids: future distribution system. Develop a microgrid with the complete functions:
- Grid-connected and islanded modes
- Islanding transition
- Resynchronization and reconnection
- Energy management
- Protection

Life-cycle Funding Summary ($K)

<table>
<thead>
<tr>
<th>Prior to FY 14</th>
<th>FY14, authorized</th>
<th>FY15, requested</th>
<th>Out-year(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>560</td>
<td>475</td>
<td>500</td>
<td>500</td>
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</tbody>
</table>

Technical Scope
- Central controller: microSCADA and microEMS
- Component control: primary source, microgrid switch
- Microgrid communication
- Relay protection
Challenges & Needs

• Challenges: distribution system is evolving from a passive radial topology to a complex and active system.
  – Increasing requirements for higher liability, stability, and efficiency
  – Diversified components and their coordination
  – Voltage fluctuation
  – Current DMS or single-node energy management cannot address all issues
  – Uncertainty: both loads and generation
  – Safety concerns rise because of Ineffectiveness of conventional protection

• Need a microgrid controller with the functions:
  – Grid-connected and islanded operation
  – Islanding transition and resynchronization
  – Energy management and DER coordination
  – Participate in energy market and utility operation
  – Effective relay protection
**CSEISMIC**

**Significance and Impact**

**Significance:** CSEISMIC microgrid controller is the complete and integrated solution for microgrid control, operation, energy management and protection.

- Systematic approach to enable real-time control and operation: grid-connected and islanded operation, islanding transition and resynchronization
- Energy management to realize networked real and reactive power optimization
- Coordinate high penetration of DER, energy storage, electric vehicle, and demand response
- Provide ancillary services to main grid and participation in energy market
- Accommodate legacy components and architecture

**Impact:**

- Improve system reliability by enabling islanding operation
- Improve system stability using advanced monitoring and control
- Improve system efficiency by optimizing the power flow
- Reduce total energy cost by energy management
• Microgrid controller consists of microgrid SCADA and energy management (EMS)
• SCADA performs supervisory control for sources, loads, microgrid switch, protection relays, etc.
• Volt/freq control and transition control are performed at device level with control modes and setting points dispatched by microgrid controller.
• EMS dispatches operational optimization commands.
• Single-point interface between microgrid and system operator/energy market to participate in utility operation and energy market activities.
Operational at the ORNL DECC lab
Now 3 buses, 4 sources, 3 loads
Will expend to 4 buses, loop/radial reconfigurable

Leveraged projects:
- Power flow controller
- Community energy storage
- Building technology
- Advanced metering infrastructure
- GridEye
Technical Approach - Communications

- Ethernet routing communication network, cable, fiber optic, wireless
- Point-to-point communication, Ethernet, between primary source and MS
- Point-to-point communication Serial
- Point-to-point communication, Ethernet
Unintentional Islanding

- Blue: local measurement
- Red: SCADA data acquisition

- MS switch is manually opened.
- SCADA data update speed is 3 seconds, and no transients are seen by SCADA.
 INV1 controls its output to adjust PCC voltage magnitude and frequency.

- Thresholds: $\Delta V \leq 2 \text{ V}$, $\Delta f \leq 0.1 \text{ Hz}$, $\Delta \alpha \leq 1^\circ$

- $f$ is controlled slightly higher (60.05 Hz) than grid frequency during resynchronization, maximum $T_{\text{resyn}} \approx 20 \text{ sec}$.

- Phase angle control or larger frequency difference is needed for faster resynchronization.
Microgrid Protection - Challenges

• Common distribution protection practice
  – Un-directional overcurrent protection
  – Electromechanical relays
    • Proven track record
    • Simplicity

• Challenges of DERs and microgrids
  – Bidirectional power flow
    • More complex coordination
    • Faults more difficult to isolate
  – Severely reduced fault current when disconnecting from utility
    • Fault current from TVA: 7.4 kA on 480 V circuit
    • Fault current from DECC lab inverters: 0.33 kA on 480 V circuit
    • Need to protect system for both cases without tripping on load current!
RTDS-Based Microgrid Protection HIL Test Bed

- Real Time Digital Simulator
- Hardware-in-the-loop microgrid test bed
- Real Time Automation Controller (RTAC)
  - Protection control control
- SEL 351S relays
  - Both physical and virtual
# Microgrid Protection Scheme Development and Testing

<table>
<thead>
<tr>
<th>Protection Schemes</th>
<th>Microgrid Status</th>
<th>Fault Locations</th>
<th>Effective Protection?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Internal</td>
<td>No</td>
<td>Relay unable to detect fault current from downstream DERs.</td>
</tr>
<tr>
<td></td>
<td>Islanded</td>
<td>Internal</td>
<td>No</td>
<td>Unable to isolate the faults. Microgrid is shutdown.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal</td>
<td>Yes</td>
<td>No need to change settings.</td>
</tr>
<tr>
<td></td>
<td>Islanded</td>
<td>Internal</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Differential OC</td>
<td>On-grid</td>
<td>External</td>
<td>Yes</td>
<td>Faults cleared in 3-6 cycles.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Internal</td>
<td>Yes</td>
<td>No need to change settings.</td>
</tr>
<tr>
<td></td>
<td>Islanded</td>
<td>Internal</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Directional control</td>
<td></td>
<td>No</td>
<td></td>
<td>Problems with voltage polarization during faults.</td>
</tr>
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</table>
Technical Approach – Microgrid EMS

- Coordinated three-stage scheduling: day-ahead bidding, hour-ahead dispatch and real-time optimal power flow (OPF).
- Unbalanced three-phase distribution system.
- Co-optimization of real and reactive power.
- Capability of handling uncertainties.
- Using renewable energy and load forecast tools.
- Grid-connected and islanded modes.

Using renewable and load forecast tools

Bidding strategy (long term, daily)

Short-term dispatch (5-10 mins)

Real-time OPF (1 min)

Voltage management

Responsive demand management

Grid-connected mode

Islanded mode
Prior Year Progress and Results – Microgrid EMS

- Development of DER economic models
- Integration of forecast results of Wind, PV and market prices.
  - Scenario generation and reduction.
- Microgrid optimal bidding strategy in the day-ahead market
  - Included intermittent DERs, storage and responsive loads.
  - Considered uncertainties of DERs, day-ahead and real-time market prices.
  - Proposed a hybrid stochastic/robust optimization model.
  - A journal paper is ready for submission.
FY 2014 performance and results, against objectives and outcomes

- FY13: individual component controller development
- FY14: microgrid system integration and communication
  - Functional microgrid with real-time control capabilities
  - EMS development will be completed by FY14.
  - 3 papers submitted.
- Milestones are met or on track.

<table>
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<tr>
<th>Due Date</th>
<th>Milestone Type</th>
<th>Milestone Description</th>
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<tbody>
<tr>
<td>12/31/2013</td>
<td>Process Milestone</td>
<td>Implementation and testing of communication network.</td>
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<tr>
<td>03/31/2014</td>
<td>Process Milestone</td>
<td>Implementation and testing of grid-connected and islanded modes, islanding transition and reconnection in the DECC microgrid.</td>
</tr>
<tr>
<td>06/30/2014</td>
<td>Process Milestone</td>
<td>Implementation and testing of microgrid protection.</td>
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<tr>
<td>09/30/2014</td>
<td>Final Deliverable</td>
<td>Development of microgrid EMS. Final annual report.</td>
</tr>
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FY 2015 Plan

1. CSEISMIC, collaborate with NIST, IREQ, and NI
   • Complete development of the microgrid controller – EMS implementation, communication standardization, microgrid controller development for field demonstration.
   • Participation on Technical Advisory Committee.
   • Standards – collaborate with NIST on microgrid standardized test bed, microgrid controller standard development.

2. Hardware-in-the-loop microgrid test bed, collaborate with RTDS

3. Networked microgrids, collaborate with Chattanooga Electric Power Board

4. Integrated communications, controls and connected devices for DC microgrids (I3CDC). Partners: LBNL, Virginia Tech, and Emerge Alliance

5. De-coupled microgrid control, collaborate with OSIsoft
Collaborations

- **NIST**: Microgrid standardized test bed, microgrid controller standard
- **Hydro-Quebec IREQ**: microgrid protection
- **Chattanooga EPB**: networked microgrids
- **National Instruments**: microgrid control for field implementation
- **OSIsoft**: de-coupled microgrid control
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Q & A