Microgrid Testbed

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Microgrid Testbed

**Objective**
Facilitate standardized microgrid testing at system and device level:
- Flexible and reconfigurable
- Standardized interconnections and communication protocols
- Standardized testing procedures with automated operation cases and scenarios

<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>175</td>
<td>200</td>
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</table>

**Technical Scope**
Real Time Digital Simulator-based Hardware-in-the-loop system with high resolution in real-time to test:
- Energy management
- Operation and control
- Communication
- Protection
Challenges & Needs

• **Frequency vs time domain:**
  – Power system simulator: both frequency and time domain
  – Communication system simulator: time domain

• **Continuous vs event-based:**
  – Power system requires continuous time simulation
  – Communication system is based on discrete events

• **Differences in time scales**
  – Power system response in ms
  – Communication and control system response in μs

• **Separate professional simulators available, but no convincing co-simulation results**
Significance and Impact

Flexible platform for testing, verification, and assessment of microgrid components and controllers for system operation, energy management, and protection under different operation scenarios. Allows to:

- Provide standardized and independent testing
- Reduce deployment cost for new devices and solutions
- Perform research
- Investigate safety issues
- Facilitate standards development
Technical Approach – ORNL Microgrid Testbed

• DECC microgrid system modeled in RTDS
  – Complete system model with detailed inverter models
  – Relay-in-the-loop protection test bed
  – Communication-power co-simulation model being built
ORNL Microgrid System Modeling

144 kVA inverters
- Detailed inverter models
- P&Q, F&V, current limiting control loops

Load
- Controllable dynamic P&Q loads
ORNL Microgrid System Modeling

Transformer

- Pi equivalent cable models

Cable
## Microgrid Cable Parameters

<table>
<thead>
<tr>
<th>Cable</th>
<th>From</th>
<th>To</th>
<th>Cable Model</th>
<th>Length (ft)</th>
<th>Ground Length (ft)</th>
<th>Z1 (ohm)</th>
<th>Z0 (ohm)</th>
<th>C (µF)</th>
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<tbody>
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<td>1</td>
<td>PPA1</td>
<td>300 A Contactor</td>
<td>Cobra XFLEX</td>
<td>20</td>
<td>20</td>
<td>0.0013272+0.0006958i</td>
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Detailed Inverter Modeling

Power electronics inverter
Microgrid with detailed inverter models

- Tested in grid-connected mode, islanding mode, and resynchronization.
- Grid-connected mode

Near Bus:
- Inverter 1: \( P_{\text{gen}} = 80 \text{ kW} \rightarrow 40 \text{ kW}, \ Q_{\text{gen}} = 20 \text{ kVar} \)
- Load 1: \( P = 50 \text{ kW}, \ Q = 10 \text{ kVar} \)

Far Bus:
- Inverter 2: \( P_{\text{gen}} = 20 \text{ kW}, \ Q_{\text{gen}} = 0 \)
- Load 2: \( P = 50 \text{ kW}, \ Q = 10 \text{ kVar} \)

Microgrid totals:
- \( P_{\text{gen}} = 100 \text{ kW} \rightarrow 60 \text{ kW}, \ Q_{\text{gen}} = 20 \text{ kVar}, \ P_{\text{load}} = 100 \text{ kW}, \ Q_{\text{load}} = 20 \text{ kVar} \)

Inverter 1 output current

Inverter 2 output current

Microgrid voltage, Grid voltage and current
Microgrid with detailed inverter models

- Transition between grid-connected mode and islanding mode

Near Bus: Inverter 1, from P&Q mode to V&f mode

- Inverter 1 output current
- Microgrid voltage, Grid voltage and current

[Graphs showing transition between grid-connected mode and islanding mode]
IC Engine driven Synchronous Machine

MC parameters and controller structure same as UW GENSET 12.5kW
Voltage is regulated at the machine terminals instead of transformer.
Controller parameters are tuned.

PI of excitation loop changed to \( K_p = 5, \ K_i = 10 \)
All other parameters same
No Cables used.

GENSET 12.5kW

R-Load 1
10.8 \( \Omega \)
R-Load 2
22.2 \( \Omega \)
ZIP-Load
1.933 kW

Controller parameters are tuned.
Load Step Up and Step Down – P&Q

R-Load 2 is initially supplied and ZIP Load OFF.
Step up: R-Load 1 ON and R-Load 2 OFF at 3s
Step down: R-Load 2 ON and R-Load 1 OFF at 7s.

RTDS

Actual load used in simulation is different from the UW specs
Load Step Up and Step Down – Frequency

Synchronous Machine Frequency

GENSET Step load frequency

RTDS

UW specs
Load Step Up and Step Down – V & I
Load Step Up and Step Down – I zoomed

Load increase

Load decrease

Load is well regulated

Current peak depends on the switching instant
Load Step Up and Step Down – V zoomed

Voltage is well regulated
ZIP Load Model

\[ P = P_0 \left[ a_1 \left( \frac{V}{V_0} \right)^2 + a_2 \left( \frac{V}{V_0} \right) + a_3 \right] \]

\[ Q = Q_0 \left[ a_4 \left( \frac{V}{V_0} \right)^2 + a_5 \left( \frac{V}{V_0} \right) + a_6 \right] \]

\( V_0, P_0 \) and \( Q_0 \)

Coefficients \( a_1 - a_6 \) specify the composition of constant impedance, current and power loads

\[ a_1 + a_2 + a_3 = 100\% \quad a_4 + a_5 + a_6 = 100\% \]

RTDS dynamic load model is used
All parameters can be specified in run time
Load Step Up and Step Down – ZIP Load

ZIP-Load is initially supplied and R-Load 2 is OFF. Step Up: R-Load 1 ON and ZIP-Load OFF at 3s. Step Down: ZIP-Load ON and R-Load 1 OFF at 7s.

\[ a_1 = 0.2; \quad a_2 = a_3 = 0.4 \]
\[ a_4 = 1; \quad a_5 = a_6 = 0; \]
\[ P_0 = 1.933 \text{ kW}; \quad Q_0 = 0; \quad V_0 = 208 \text{ V}; \]

\[ a_4 = 1; \quad a_5 = a_6 = 0; \]
\[ P_0 = 1.933 \text{ kW}; \quad Q_0 = 0; \quad V_0 = 208 \text{ V}; \]

Some differences observed during step down.
Relay-in-the-loop protection test

- SEL 351S relays interfaced with RTDS
  - Microgrid system simulated in RTDS
  - CT and VT measurements sent to relays
  - Circuit breaker control outputs from relays interfaced with RTDS
  - Circuit breaker status signals routed through RTAC
Relay-in-the-loop protection test

- Real Time Automation Controller
  - Monitor circuit breakers in RTDS
  - Monitor and coordinate relays
  - Dedicated HMI for physical relays
  - Web interface
  - Remote relay setting changes

SEL RTAC 3530

RTAC Relay HMI

Virtual microgrid system

SEL 351S

RTDS
Differential overcurrent protection

- Microgrid connected to utility
  - Differential protection implemented with overcurrent protecting DERs
  - Inverters injecting P&Q into microgrid
- Using either U5 short time or instantaneous overcurrent characteristics
  - Grid connected faults inside the microgrid are very effectively isolated

Differential protection is very fast and very effective

<table>
<thead>
<tr>
<th>Three-Phase Fault</th>
<th>Protection Operation Delay (Cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Location</td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
</tr>
<tr>
<td>On Grid</td>
<td>External</td>
</tr>
<tr>
<td></td>
<td>Bldg. #3114</td>
</tr>
<tr>
<td></td>
<td>Bldg. #3129</td>
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<tr>
<td></td>
<td>MG Cable</td>
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FY 2014 performance and results, against objectives and outcomes

- FY14: microgrid testbed development for testing and assessment of microgrid operation and control system
  - RTDS-based with HIL capabilities
  - DECC lab system model
  - Standardized testing procedures
- Milestones are met or on track

<table>
<thead>
<tr>
<th>Due Date</th>
<th>Milestone Type</th>
<th>Milestone Description</th>
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<td>12/31/2013</td>
<td>Process Milestone</td>
<td>DECC system model with complete circuit topology and parameters.</td>
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<tr>
<td>03/31/2014</td>
<td>Process Milestone</td>
<td>Basic operation and protection functions with simplified component models.</td>
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<tr>
<td>06/30/2014</td>
<td>Process Milestone</td>
<td>Complete and detailed models of fundamental microgrid components.</td>
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<tr>
<td>09/30/2014</td>
<td>Final Deliverable</td>
<td>Integrated scenario testing with the ORNL microgrid controller. Final annual report.</td>
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</table>
FY 2015 Plan

1. CSEISMIC
   - 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 completion

3. Networked microgrids, collaborate with Chattanooga Electric Power Board

4. DC microgrid & communications

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