2009 E2S2 Symposium

Designing, Integrating, and Operating a Microgrid
07 May, 2009

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Power Management and Distribution
**Designing, Integrating, and Operating a Microgrid**

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**SPONSOR/MONITOR’S ACRONYM(S):**

**PERFORMING ORGANIZATION REPORT NUMBER:**

**DISTRIBUTION/AVAILABILITY STATEMENT:**
Approved for public release; distribution unlimited

**SUPPLEMENTARY NOTES:**
Presented at the NDIA Environment, Energy Security & Sustainability (E2S2) Symposium & Exhibition held 4-7 May 2009 in Denver, CO. U.S. Government or Federal Rights License

**ABSTRACT:**

**SUBJECT TERMS:**

**SECURITY CLASSIFICATION OF:**
| a. REPORT | b. ABSTRACT | c. THIS PAGE |
| unclassified | unclassified | unclassified |

**LIMITATION OF ABSTRACT:**
Same as Report (SAR)

**NUMBER OF PAGES:**
27

**NAME OF RESPONSIBLE PERSON:**

**Notes:**

Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
Outline

• Microgrid Definition

• Microgrid Benefits

• Testbed Requirements

• Technical Approach

• Results
**What is a Microgrid?**

**General Definition:**

- A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources that can operate in parallel with the grid or in an intentional island mode.

**Key Defining Characteristics:**

- Integrated distributed energy resources (DERs), capable of providing sufficient and continuous energy to mission critical loads
- Independent controls; island and reconnect with minimal disruption
- Flexible configuration and operation of the power delivery system
- Optimized local DERs, large network loads, and broader power system
What a Microgrid is NOT

• One microturbine in a commercial building

• A group of individual generation sources that are not coordinated, but run optimally for a narrowly defined load

• A load or group of loads that cannot be easily separated from the grid or controlled

• A system that can only operate in isolation from the grid

• Does not have to have thermal (whereas CHP by definition has thermal)
Microgrid Overview

Integration Technology
- SYSTEM METERING
- SOURCE CONTROL
- LOAD CONTROL
- SYSTEM PROTECTION
- DISTRIBUTION HARDWARE
- POWER CONDITIONING

Gen Sets
VAC

Renewable Sources
VDC/VAC

Base Camp
VAC

Installation
VAC

CTC
Concurrent Technologies Corporation
Microgrid Potential Benefits

- **IMPROVED RELIABILITY**
  - Critical load support
  - Integration of multiple generation sources (legacy and renewable)

- **RISK MITIGATION**
  - Eliminate dependence upon local utility
  - Integrating available energy sources for backup power

- **ELECTRICAL COST REDUCTION**
  - Intelligent control for peak shaving
  - Renewable Energy Integration
  - Improved asset utilization by integrating distributed sources
Objective – Design, install, and test a scalable microgrid with distributed generation sources and loads

1. Modeling and Simulation – Software tool to confirm design strategies and solutions
2. System Controllers – Combination Distribution Management System and Internet resource
3. Renewable Energy Sources – Combined generation of conventional generation with renewable energy sources.
Microgrid Testbed Requirements

• Improve System Reliability
  – Eliminate single points of failure by using redundant controls
  – Intelligently control sources to meet load requirements
  – Intelligently control loads to avoid system overloads
  – Develop software modeling to predict system limitations and develop appropriate controls
  – Simplify generator synchronization controls by using one controller as opposed to three independent relays (typical scheme)
  – Integrate IEE1547 intertie relay for parallel operation with the utility
  – COTS parts for quick support, replacement
Microgrid Testbed Requirements

• Benefit from System Modeling
  – Develop software models to simulate component and system performance to identify performance limitations and control solutions
  – Use developed models to design and implement future microgrids or improve existing systems

• Improve Asset Utilization
  – Integrate distributed sources and loads into one distribution system to allow for efficient use of generation assets
  – Improving asset utilization reduces fuel consumption and associated logistics requirements
  – Integrate renewable sources as available
Microgrid Approach

- Microgrid Master and Local Controllers
  - Programmable Logic Controllers (PLCs) to coordinate and implement intelligent control of distributed sources and loads.
  - Redundant controllers to avoid single points of failure.
  - LabView based-HMI to provide oversite and configure testing
  - COTS components

- Generator Controls
  - One main controller per generator simplifies synchronization of conventional generation sources compared to configuring and integrating three additional control relays per generator.
  - COTS components
Microgrid Approach

• Software Modeling -
  – Prepare software models of individual sources and loads to predict impact to electrical system.
  – Create a microgrid system model from the individual component models to predict system performance.
  – Validate accuracy and correct simulation models
  – Create test cases and control strategies based upon system performance/limitations predicted and validated by models.

• Control Algorithms –
  – Monitor system health and intelligently control sources and loads
  – Coordinated control between controllers for system stability
Distributed Sources and Loads

• Distributed Sources
  – (1) 35 kW Diesel Generator
  – (1) 35 kW Natural Gas Generator
  – (1) 40 kW Renewable Energy Inverter
  – (1) 400A Utility Service
  – (1) 50 kW Grid Simulator

• Distributed Loads
  – (4) 5 hp three phase motors
  – (1) 20hp dynamometer
  – (1) 225 kW Resistive Load Bank
Test Plan

• Component Model Validation
  – (1) 35 kW Diesel Generator
  – (1) 35 kW Natural Gas Generator
  – (1) 40kW Renewable Energy Inverter
  – (1) 50kW Grid Simulator
  – (4) 5 hp three phase motors
  – (1) 20hp dynamometer
  – (1) 225 kW Resistive Load Bank

– System Model Validation and Analysis

– System Stability Testing and Analysis
# Test Results Summary

**Steady State Accuracy: 90+%**

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Real Power % Accuracy</th>
<th>Reactive Power % Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC1-1</td>
<td>RLB Component Validation Test</td>
<td>&gt;91% (steady state at load bus)</td>
<td>N/A</td>
</tr>
<tr>
<td>TC1-2</td>
<td>MLB Component Validation Test</td>
<td>N/A</td>
<td>&gt;95% (steady state at load bus)</td>
</tr>
<tr>
<td>TC1-3</td>
<td>20 hp Motor w/ Dynamometer Component Validation Test</td>
<td>&gt;95% (steady state at load bus)</td>
<td>&gt;90% (steady state at load bus)</td>
</tr>
<tr>
<td>TC1-4</td>
<td>Inverter Component Validation Test</td>
<td>&gt;99% (steady state at inverter bus)</td>
<td>N/A</td>
</tr>
<tr>
<td>TC1-5</td>
<td>DG Component Validation Test</td>
<td>&gt;92% (steady state at load bus)</td>
<td>&gt;90% (steady state at load bus)</td>
</tr>
<tr>
<td>TC1-6</td>
<td>NGG Component Validation Test</td>
<td>&gt;92% (steady state at load bus)</td>
<td>&gt;90% (steady state at load bus)</td>
</tr>
<tr>
<td>TC2-1</td>
<td>Grid-connected System Validation Test</td>
<td>&gt;97% (steady state at load bus)</td>
<td>&gt;92% (steady state at load bus)</td>
</tr>
</tbody>
</table>
Dyno Component Test One-line
Connected: Utility, 20Hp Dynamometer
Dyno Component Test Results
Model kW vs Actual - 95+% Accurate

TC1-3 Load Bus Total Real Power

- HS kW tot (Testbed) [kW]
- Ptot,load (Model) [kW]
- Real Power accuracy [%]

Real Power [kW]/Percent Accuracy [%]

Time [s]
Dyno Component Test Results
Note: Identify System Stress Points, VAR Requirements

TC1-3 Load Bus Total Reactive Power

- HS kVAR tot (Testbed)
- Qtot,load (Model)

Reactive Power [kVAR]

0.00 0.12k 0.24k 0.36k 0.48k 0.60k 0.72k 0.84k 0.96k 1.08k 1.20k

Time [s]

0 30 60 90 120 150

0.48k 0.60k 0.72k 0.84k 0.96k 1.08k
Inverter Component Test One-Line
Connected: Utility, Inverter
Inverter Component Test Results

Initial Model kW vs Actual -

Note: False Output Ringing Predicted by Model

TC1-4 Inverter Total Real Power

Inverter Output Ringing Predicted
Inverter Component Test Results
Revised Model kW vs Actual

Note: Model Configuration Impacts Simulation Software Results
System Test One-line

Connected: Utility, Gensets, Inverter, RLB, MLB, Dyno
System Test Results

Utility Current THD Measurements

Note: Confirm THD

DG brought online

DG taken offline
System Test Results
Utility Neutral Current Measurements
Note: Confirm Neutral Current Direction
System Test Results

Note: Neutral Current Solutions

• Transformer Isolation
  – Delta-Wye Transformer traps 3\textsuperscript{rd} order harmonics

• Three Phase Harmonic Filter
  – Wye – Delta Transformer to eliminate zero sequence currents

• Neutral Reactor
  – Tuned reactor to block 3\textsuperscript{rd} order currents only

• Neutral Grounding
  – Establish one neutral path to ground
  – Confirm neutral grounding when isolated from utility
Acknowledgements

• ERDC-CERL Contract No.
  – W9132T-07-R-0017

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