Test Results of a Pilot Plant for KERI Microgrid

Korea Electrotechnology Research Institute
New and Renewable Energy System Research Center
Jeon, Jin-Hong
• KERI Microgrid Pilot Plant
• Phase 1 Results
  – HILS Test System
  – Test Results
• Phase 2 Results
  – Test Results
**Phase 1**
- 2007~2008
- System Size: 50kVA
- 3 Sources (1 Renewable, 1 DG, 1 Storage)
- PCC Power Flow Control, Islanding

**Phase 2**
- 2008~2009
- System Size: 100kVA
- 5 Sources (2 Renewables, 2 DGs, 1 Storage)
- PCC Flow Control, Islanding, Resynch.

**Phase 3**
- 2009~2011
- System Size: 200kVA
- 9 Sources (5 Renewables, 2 DGs, 2 Storages)
- PCC Flow Control, Islanding, Resynch., P.Q.
Pilot Plant Phase 1

**Description**

- **Components**
  - 3 Sources, MMS, Loads
  - 1 DG (20kVA D/E)
  - 1 Renewable (20kVA PV/Wind Hybrid)
  - 1 Storage (10kW BESS)

- **Operations**
  - PCC Power Flow Control in Grid-Connected Mode
  - Transition to Islanded Mode
  - Frequency and Voltage Control in Island Mode

- **Purposes**
  - Construction of Pilot Plant
  - Basic Operation Test by Essential Elements
  - Communication and Control Scheme Test
HILS (Hardware In-the-Loop Simulation)

“A technique used in developing and testing of complex real-time embedded systems”

A) Block diagram of embedded system connected to a hardware-in-the-loop simulator

B) Components of a simple hardware-in-the-loop simulator

Autopilot Example

www.embedded.com
Comparison of Different Approaches for MMS Performance Test

“How to test and debug the supervisory control algorithms of MMS”

<table>
<thead>
<tr>
<th></th>
<th>Off-Line Simulation</th>
<th>Real-Time HILS</th>
<th>Field Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>Up to S/W Models</td>
<td>High</td>
<td>Very High</td>
</tr>
<tr>
<td>Parameter Alterations</td>
<td>Fully Possible</td>
<td>Fully Possible</td>
<td>Limited</td>
</tr>
<tr>
<td>Repeatability Reproducibility</td>
<td>Fully Possible</td>
<td>Fully Possible</td>
<td>Limited</td>
</tr>
<tr>
<td>Relative Develop Time</td>
<td>Fast</td>
<td>Medium</td>
<td>Slow</td>
</tr>
<tr>
<td>Speed</td>
<td>Much Longer than Real-Time</td>
<td>Real-Time</td>
<td>Real-Time</td>
</tr>
<tr>
<td>Development Cost</td>
<td>Less than HILS</td>
<td>Less than Field Test</td>
<td>High</td>
</tr>
</tbody>
</table>
Requirements for MMS HILS Test

Needs for Microgrid Simulation
- Easy to Model Power System Components
- Easy to Use User Define Model for RES
- Easy to Simulate Power System
- Hard Real Time Simulator

Uses RTDS

Needs for MMS Interface
- RS232 or RS485 Interface
- Easy to Use User Define Protocols
- Easy to Use Modbus Protocols

Uses RTDS

Need Something for Communication Interface

Communication Emulator
- RTDS Interface
  - Analog and Digital Interface by I/O Card
  - IEC61850 Protocol by GTNET Card
Proposed HILS System
# Real Time Simulation Model

## Major Parameters for Simulation Model

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test System Configuration</strong></td>
<td>• No. of Sources: 3 (Hybrid, Diesel generator, BESS)</td>
</tr>
<tr>
<td></td>
<td>• No. of Loads: 2</td>
</tr>
<tr>
<td></td>
<td>• No. of STS: 1 (Static Switch)</td>
</tr>
<tr>
<td><strong>Generation Capacity of Microsources</strong></td>
<td>• Hybrid 20kW (PV 10kW, Wind 10kW)</td>
</tr>
<tr>
<td></td>
<td>• Diesel generator 20kW</td>
</tr>
<tr>
<td></td>
<td>• BESS system 10kW</td>
</tr>
<tr>
<td><strong>Load1, Load2</strong></td>
<td>• 15kW+j9kVar</td>
</tr>
<tr>
<td></td>
<td>• Constant impedance model (R/X)</td>
</tr>
<tr>
<td><strong>Transformer</strong></td>
<td>• 3-phase 22.9/0.38kV 100kVA</td>
</tr>
<tr>
<td></td>
<td>• Leakage impedance %Z = 6%</td>
</tr>
<tr>
<td><strong>Line impedance</strong></td>
<td>• R = 0.1878Ω/km, X = 0.0968Ω/km</td>
</tr>
</tbody>
</table>

## Schematic Diagram of Simulation Model

![Schematic Diagram](image)
**Specification**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>TMS320VC33-150</td>
</tr>
<tr>
<td>Analog Input</td>
<td>16 Channel, ±10V, 12bit Resolution 500kS/s, 1kHz-40dB bandwidth</td>
</tr>
<tr>
<td>Digital Input</td>
<td>16 Channel, TTL</td>
</tr>
<tr>
<td>Analog Output</td>
<td>12 Channel, ±10V, 12bit Resolution 1kHz-40dB bandwidth</td>
</tr>
<tr>
<td>Digital Output</td>
<td>12 Channel, TTL</td>
</tr>
<tr>
<td>Communication</td>
<td>RS-485 3Ports</td>
</tr>
<tr>
<td>User Interface</td>
<td>Status LED 8EA, Character LCD</td>
</tr>
<tr>
<td>Size</td>
<td>300mm x 210mm x 80mm</td>
</tr>
</tbody>
</table>
HILS Test Results for Phase 1 System

- Grid-Connected Mode
- Island Mode
Test Results of Phase 1 System

Grid-Connected Mode

<table>
<thead>
<tr>
<th>Load increase</th>
<th>Load decrease</th>
<th>Load increase</th>
<th>Load decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>217.641 V</td>
<td>60.000</td>
<td>59.979</td>
<td>59.985</td>
</tr>
<tr>
<td>3.9021 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-2.12314 kW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.47147 kvar</td>
<td>2.54788 kVA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Island Mode

<table>
<thead>
<tr>
<th>Grid connect.</th>
<th>Stand-alone</th>
<th>Voltage</th>
<th>PCC output</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>219.934 V</td>
<td>60.013</td>
<td>60.070</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3437 A</td>
<td>0.09164 kW</td>
<td>0.13954 kvar</td>
<td>0.22658 kVA</td>
<td></td>
</tr>
</tbody>
</table>
Pilot Plant Phase 2

**Description**

- **Components**
  - 5 Sources, MMS, IED/STS, Loads
  - 2 DGs (20kVA D/E, 50kVA D/E)
  - 2 Renewables (20kVA PV/Wind Hybrid, 10kW PV)
  - 1 Storage (20kW BESS)

- **Operations**
  - PCC Power Flow Control in Grid-Connected Mode
  - Transition to Islanded Mode/Resynch.
  - Frequency and Voltage Control in Island Mode
  - Economically Optimized Dispatch
  - Black Start

- **Purposes**
  - More Operation Test with More Components
  - CHP Test with Simulated Thermal Load
  - Performance Test of Microgrid Components

**Phase 2 Pilot Plant Structure**

3 Phase 380V, 100kVA Phase 2 System
Configuration of Phase 2 System

- Total Load: 100kW + j44kVar
- Total Gen: 120kW
  - D/E: 70kW (50kW + 20kW)
  - RES: 30kW
  - BESS: 20kW

Diagram:
- 22.9kV/380V Power Line
- STS/IED
- BESS
- PV (10) - Load
- D/E (50) - Load
- D/E (20) - Load
- PV (10) - WT (10)

RS-485 Link
MMS for Phase 2 System
## Test Cases for Phase 2 System

<table>
<thead>
<tr>
<th>Case</th>
<th>Operation Mode</th>
<th>Control Mode</th>
<th>Control Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-1-1</td>
<td>Inter Mode</td>
<td>μ-source -&gt; P,Q cont. BESS-&gt; P,Q cont.</td>
<td>Active Power Control of PCC</td>
</tr>
<tr>
<td>Case-1-2</td>
<td>Inter -&gt; Islanded</td>
<td>μ-source -&gt; P,Q cont. BESS-&gt; F/V cont.</td>
<td>F/V Control of Microgrid</td>
</tr>
<tr>
<td>Case-2-1</td>
<td>Inter -&gt; Islanded</td>
<td>μ-source -&gt; P,Q cont. BESS-&gt; F/V cont.</td>
<td>F/V Control of Microgrid</td>
</tr>
<tr>
<td>Case-2-2</td>
<td>Resynch</td>
<td>μ-source -&gt; P,Q cont. BESS-&gt; F/V cont.</td>
<td>Resynchronization</td>
</tr>
<tr>
<td>Case-3</td>
<td>Resynch</td>
<td>μ-source -&gt; P,Q cont. BESS-&gt; F/V cont.</td>
<td>Resynchronization</td>
</tr>
</tbody>
</table>
Case 1: Active Power Control of PCC in Inter. mode

Control ON

P_ref : 0kW
P_ref : 10kW
P_ref : -10kW
Test Results of Phase 2 System

Case 2: Frequency/Voltage Control in Islanded mode
Test Results of Phase 2 System

Case 2: Frequency/Voltage Control in Islanded mode
Test Results of Phase 2 System

Case 3: Reconnection with Utility Grid
Pilot Plant Phase 3

Description

- **Components**
  - 9 Sources, MMS, IED/STS, Loads
  - 2 DGs (20kVA D/E, 50kVA D/E)
  - 5 Renewables (20kVA PV/Wind Hybrid, 30kW PV, 10kW Wind, 10kW Thermo-Electric, 1kW Fuel Cell)
  - 2 Storage (50kW BESS, 30kW EDLC)

- **Operations**
  - PCC Power Flow Control in Grid-Connected Mode
  - Transition to Islanded Mode/Resynch.
  - Frequency and Voltage Control in Island Mode
  - Economically Optimized Dispatch
  - Black Start, Power Quality Compensation

- **Purposes**
  - Operation Test with Real-Site Load
  - Demonstrate a Low Voltage Commercial Power Supply System

Phase 3 Pilot Plant Structure

3 Phase 380V, 200kVA Phase 3 System
Thank You!

Jeon, Jin-Hong (jhjeon@keri.re.kr)