Loads as a Resource: Frequency Responsive Demand

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Project objectives

• Provide a framework to facilitate large-scale deployment of frequency responsive devices
• Systematically design decentralized frequency-based load control strategies for enhanced stability performance
• Ensure applicability over wide range of operating conditions while accounting for unpredictable end-use behavior and physical device constraints
• Test and validate control strategy using large-scale simulations and field demonstrations
FY15 tasks & deliverables

• Tasks
  – Task 1: Design GFA-based hierarchical frequency control (GHFC) strategy
  – Task 2: Validate system-wide impacts of large-scale deployment of GHFC
  – Task 3: Investigate distribution level impacts of GHFC

• Deliverables
  – Final project report to DOE
  – Submit IEEE PES General Meeting paper
GFA-based hierarchical frequency control (GHFC)
GFA-based hierarchical frequency control design
Supervised frequency threshold determination
System-wide impacts of GHFC
Test scenarios

- WECC 2015 heavy-load summer case
- Three main scenarios:
  - (S1) low availability of controllable load, about 900,000 water heaters (about 700MW in ON state)
  - (S2) high availability of controllable load, about 6.2M water heaters (about 4.6GW in ON state)
  - (S3) extreme availability of controllable load, about 13M water heaters (about 10GW in ON state)
- Three sub-cases for each scenario:
  - (A) No control
  - (B) GHFC without supervisory layer
  - (C) GHFC with supervisory layer
Simulation results – Low availability

Frequency Response (Hz)

System Response (MW/Hz)
Simulation results – High availability

Frequency Response (Hz)

System Response (MW/Hz)
Simulation results – Extreme availability

Frequency Response (Hz)

System Response (MW/Hz)
Distribution level impacts of GHFC
Test system & performance metrics

• IEEE 8500-Node test system
  – Representation of a real system
  – Peak load ~12MW
  – 1977 Homes
  – Calibrated using standard utility guidelines

• Performance metrics
  – Voltage violations, continuous and instantaneous
  – Transformer and line overloads
Test cases

- Under-frequency event, tripping ~2.7GW in the south of the WECC system

- Case 1 – Performance of GHFC
- Case 2 – Performance of GHFC with voltage sorting
- Case 3 – Performance of GHFC with voltage lockout
- Case 4 – Performance of GHFC with voltage lockout and sorting
Results – Case 1

<table>
<thead>
<tr>
<th>Voltage in pu</th>
<th>Continuous Voltage Violation (5min)</th>
<th>Instantaneous Voltage Violation (1s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Voltage (&gt;1.05)</td>
<td>Low Voltage (&lt;0.95)</td>
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<td>Violation count</td>
<td>117</td>
<td>0</td>
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Results - Case 2

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<th>Instantaneous Voltage Violation (1s)</th>
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<td>High Voltage (&gt;1.05)</td>
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<td>475</td>
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<td>Low Voltage (&lt;0.95)</td>
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<td>High Voltage (&gt;1.10)</td>
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Results – Case 3

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<tr>
<td></td>
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## Results – Case 4

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<td>Violation count</td>
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FY16 GMLC Category 2 project

HVDC and Load Modulation for Improved Dynamic Response using Phasor Measurements
Project overview

• Objective
  – Develop a wide-area, PMU-based damping controller using mix of fast acting resources such as HVDC and FACTS assets, loads, and energy storage across a large interconnection

• Team: PNNL (lead), Sandia National Labs, Arizona State University, Penn State University

• Impact
  – Improved damping of electromechanical modes allowing system to operate closer to reserve margins
  – Specify upper bounds of PMU network latencies specified to preserve stable and reliable damping-control operation
  – Stabilization of AC network more flexibly managed than point-to-point DC
FY16 planned activities

1. Design damping-control strategies based on decoupled modulation
   - Design method to decouple signals from multiple PMU locations
   - Develop modulation controller using decoupled signal contents

2. Extend decoupled modulation based damping control to HVDC networks
   - Examine controllability options for the DC network to be used as a damping influence
   - Design controller for modulating HVDC networks

3. Design decentralized control strategies based on robust load modulation

4. Large-scale simulation testing and validation of different damping-control strategies
Task 1 – Design damping-control strategies based on decoupled modulation

• **Quarterly milestones:**
  – Complete initial specifications for the modeling of PDCI modulation control (Q1)
  – Complete investigating the impact of PDCI modulation on various oscillation modes and selection of signals for decoupled modulation (Q2)
  – Complete the design of the decoupled modulation algorithms (Q3)

• **Project Annual SMART Milestone:** Demonstration of the decoupled modulation of PDCI on multiple oscillation modes. Finish writing of corresponding section of the final FY16 project report
Task 2 – Extend decoupled modulation based damping control to HVDC networks

• Quarterly milestones:
  – Letter report to sponsor on literature survey of HVDC lines and network modeling for the time-frame of interest, and survey of existing WECC transmission planning including proposed HVDC lines (Q1)
  – Letter report to sponsor on proposed HVDC networks for WECC based on extending existing transmission plans for HVDC (Q2)
  – Finish setting up DC network in minni-WECC test system and examine controllability options for DC network (Q3)

• Project Annual SMART Milestone: Complete modeling approach and controller design for modulating HVDC networks. Finish writing of corresponding section of the final FY16 project report
Task 3 – Design decentralized control strategies based on robust load modulation

• Quarterly milestones:
  – Complete initial development of aggregated model for residential end-use loads (Q1)
  – Finalize aggregated model development and complete initial control design for residential end-use loads (Q2)
  – Complete damping-control strategies for modulating residential end-use loads (Q3)

• Project Annual SMART Milestone: Finalize design of new damping-control strategies based on robust load modulation. Finish writing of corresponding section of the final FY16 project report
Task 4 – Proof-of-concept testing of different damping-control strategies

• Quarterly milestones:
  – Letter report to sponsor describing available WECC system model and available modeling approaches for HVDC and loads in commercial-grade software (Q2)
  – Complete designing test scenarios and finalize performance metrics to evaluate control effectiveness (Q3)

• Project Annual SMART Milestone: Complete proof-of-concept testing of the proposed control strategies. Finish writing of corresponding section of the final FY16 project report