DOE/OE Transmission Reliability Program

Loads as a Resource: Frequency Responsive Demand

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June 7-8, 2016
Washington, DC

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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

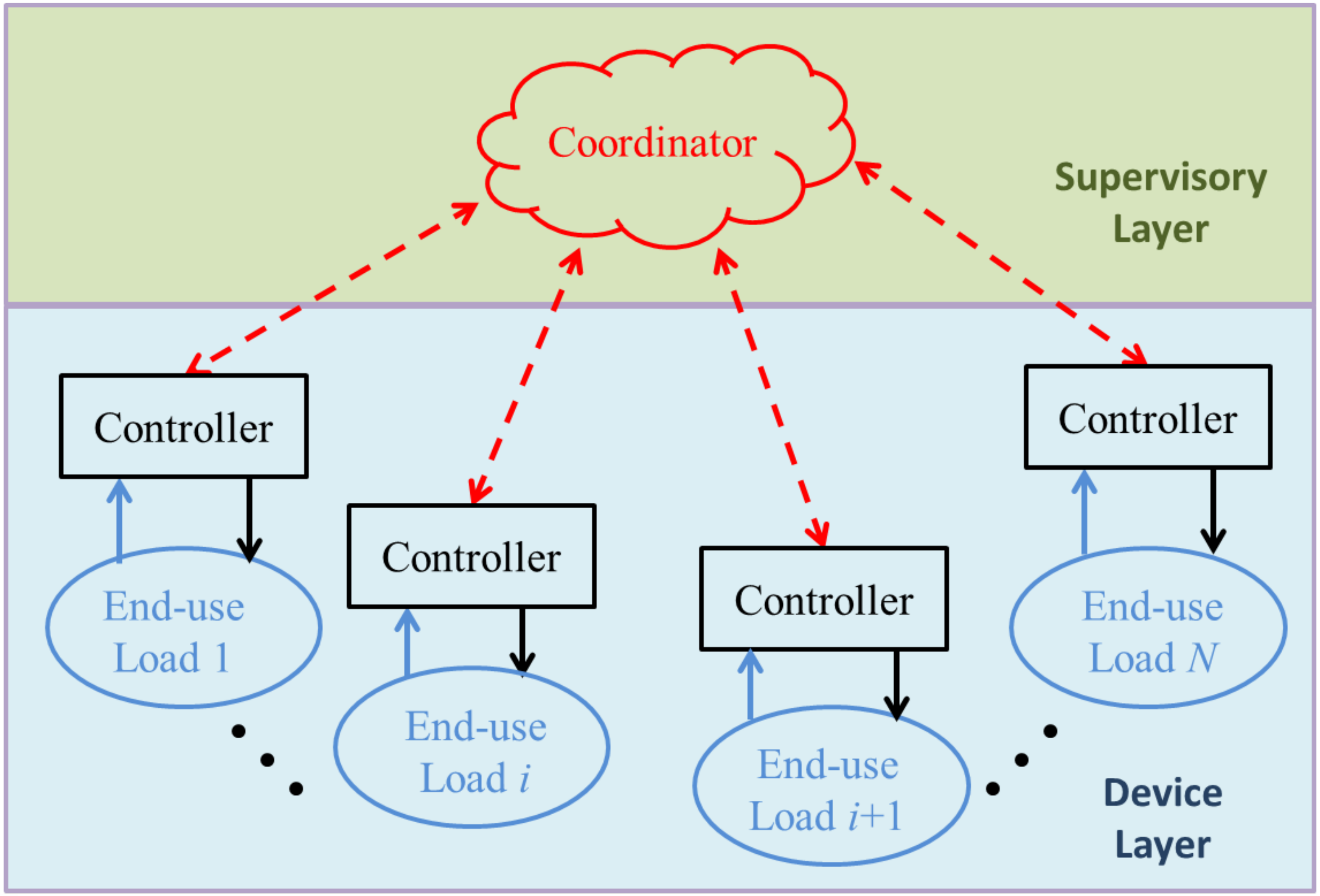
FY15 tasks & deliverables

- 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



Coordinator

Supervisory Layer

Controller

End-use Load 1

Controller

End-use Load i

Controller

End-use Load i+1

Controller

End-use Load N

Device Layer

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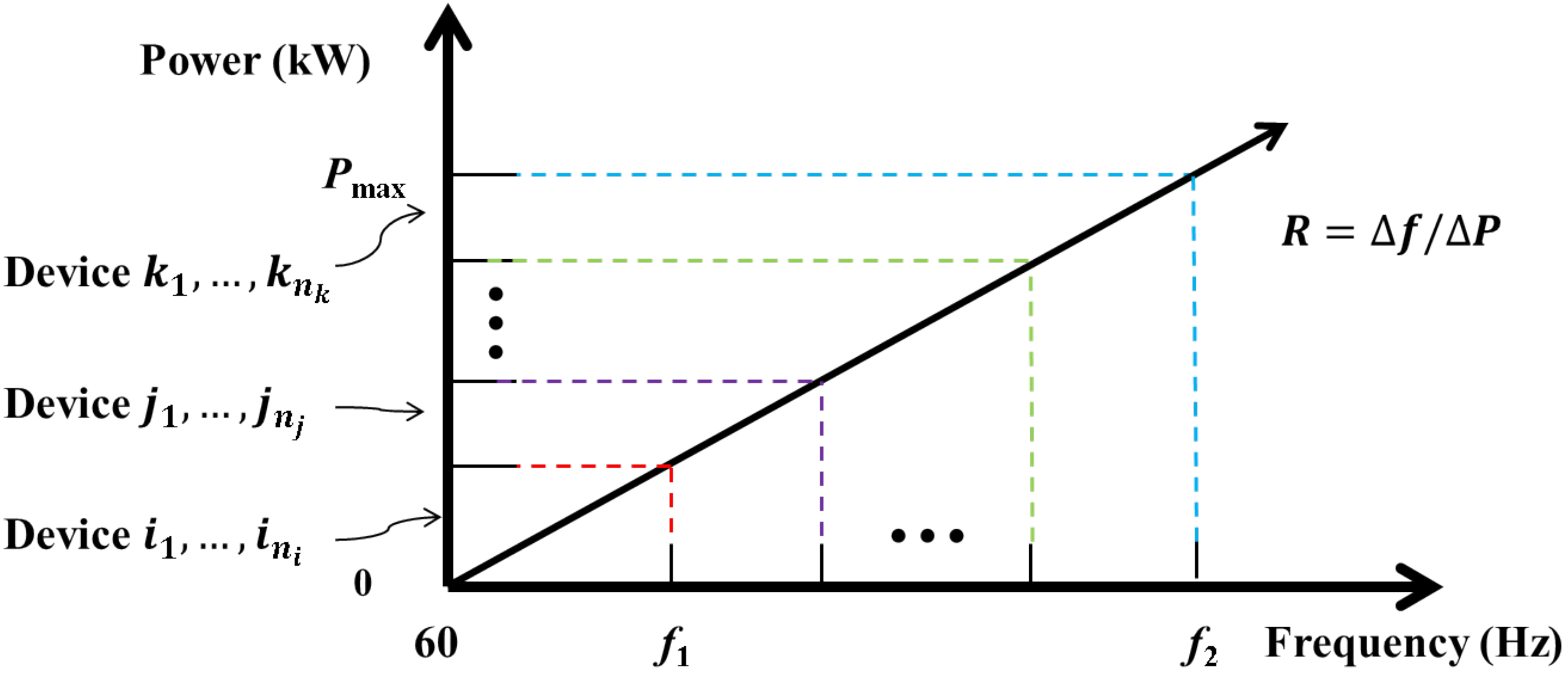
Supervised frequency threshold determination



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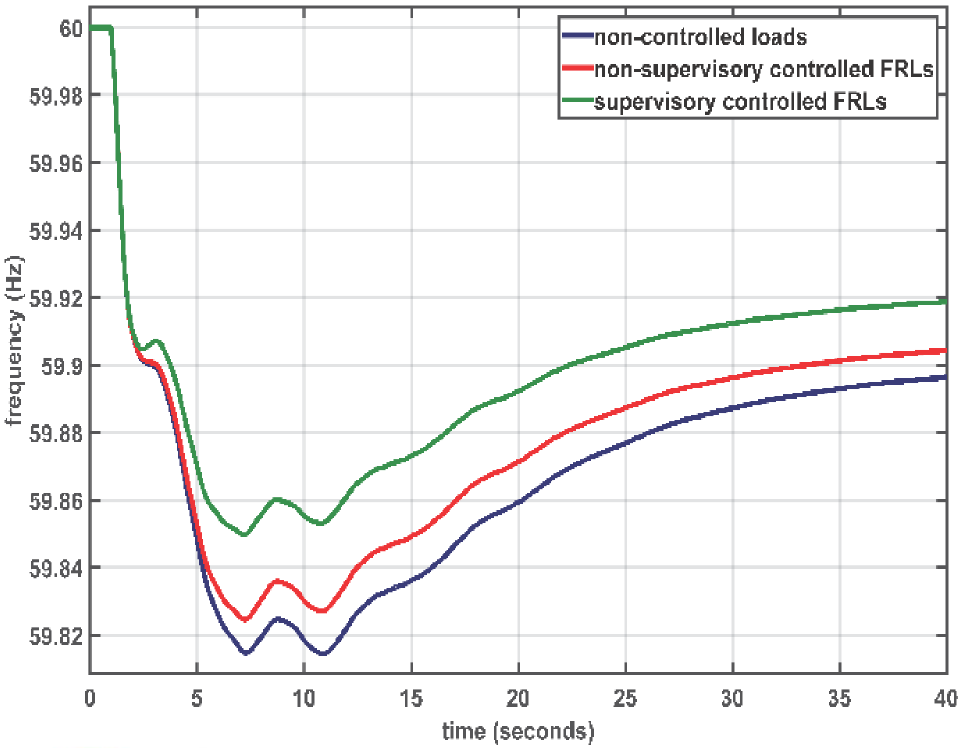
System-wide impacts of GHFC

Test scenarios

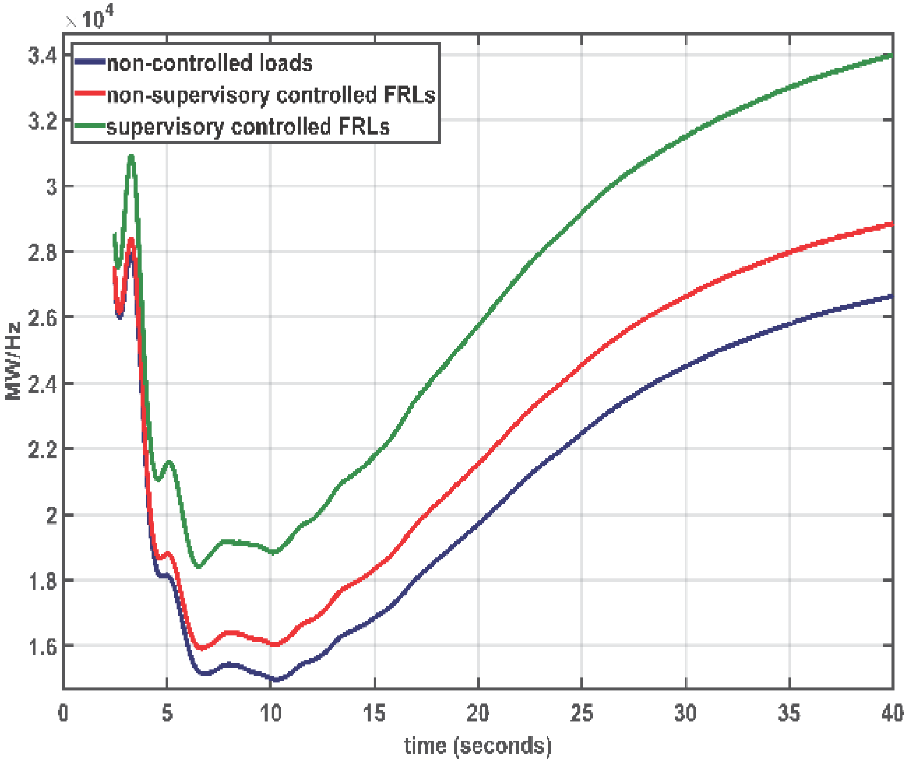
- WECC 2015 heavy-load summer case
- Three main scenarios:
  - (S1) low availability of controllable load, about 900,000 water heaters (about 700MW in ON state)
  - (S2) high availability of controllable load, about 6.2M water heaters (about 4.6GW in ON state)
  - (S3) extreme availability of controllable 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)



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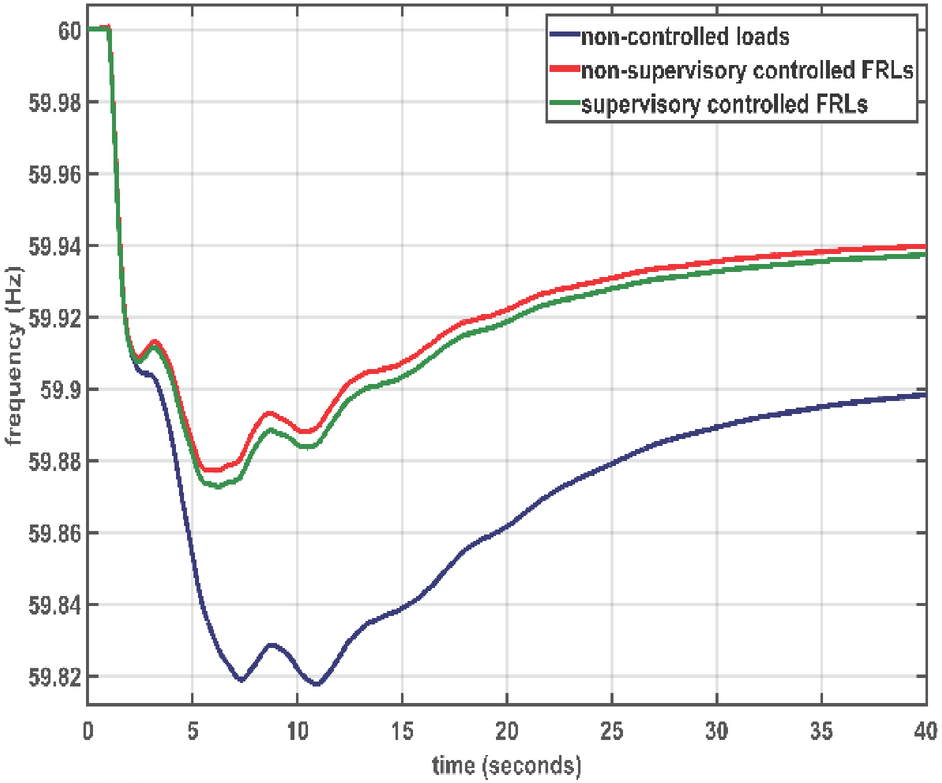
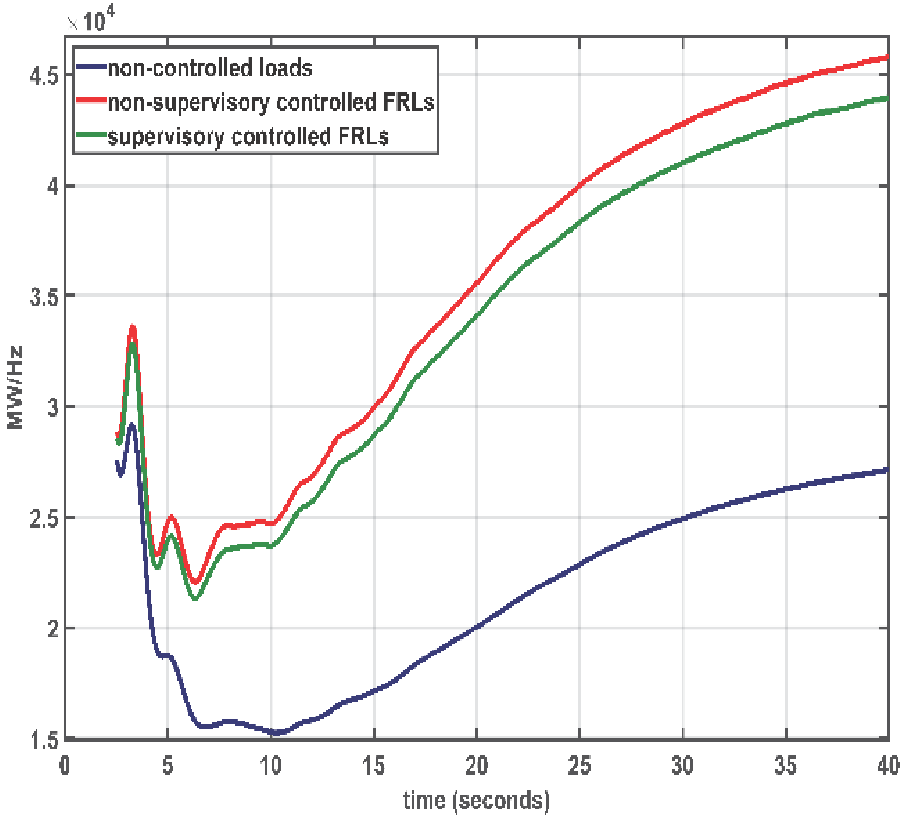
Simulation results –High availability

Frequency Response (Hz)



System Response (MW/Hz)



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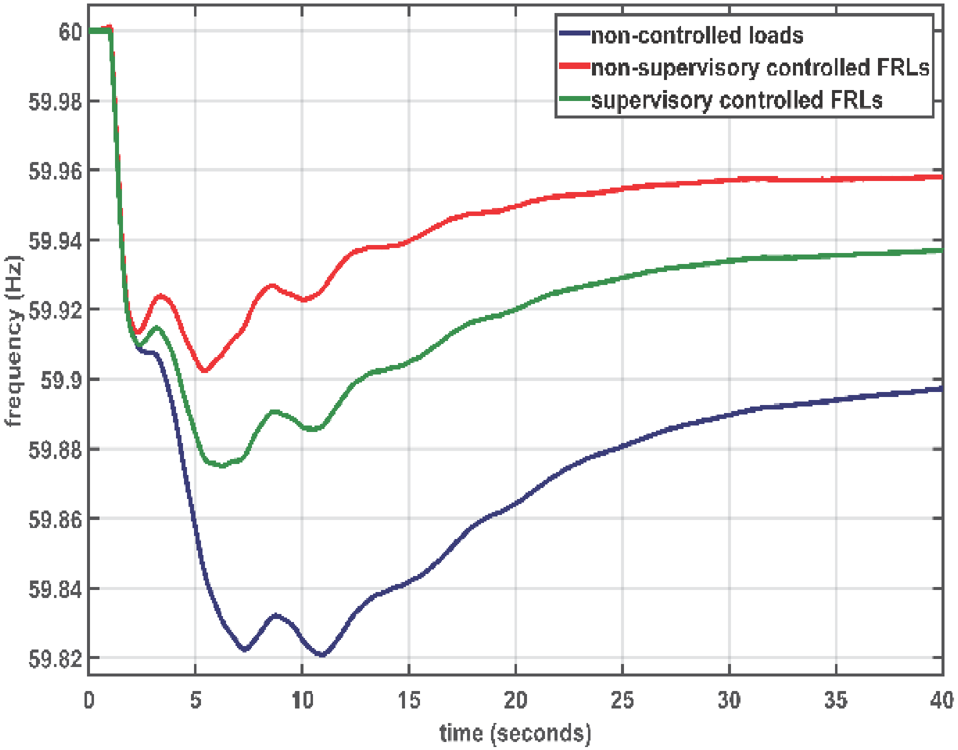
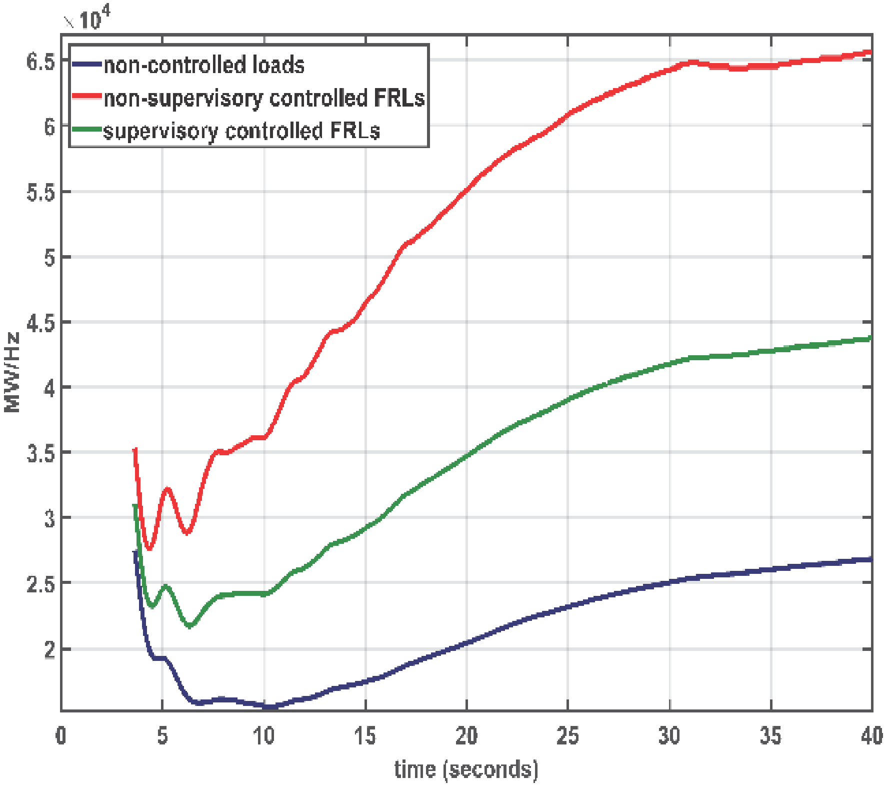
Simulation results –Extreme availability

Frequency Response (Hz)



System Response (MW/Hz)



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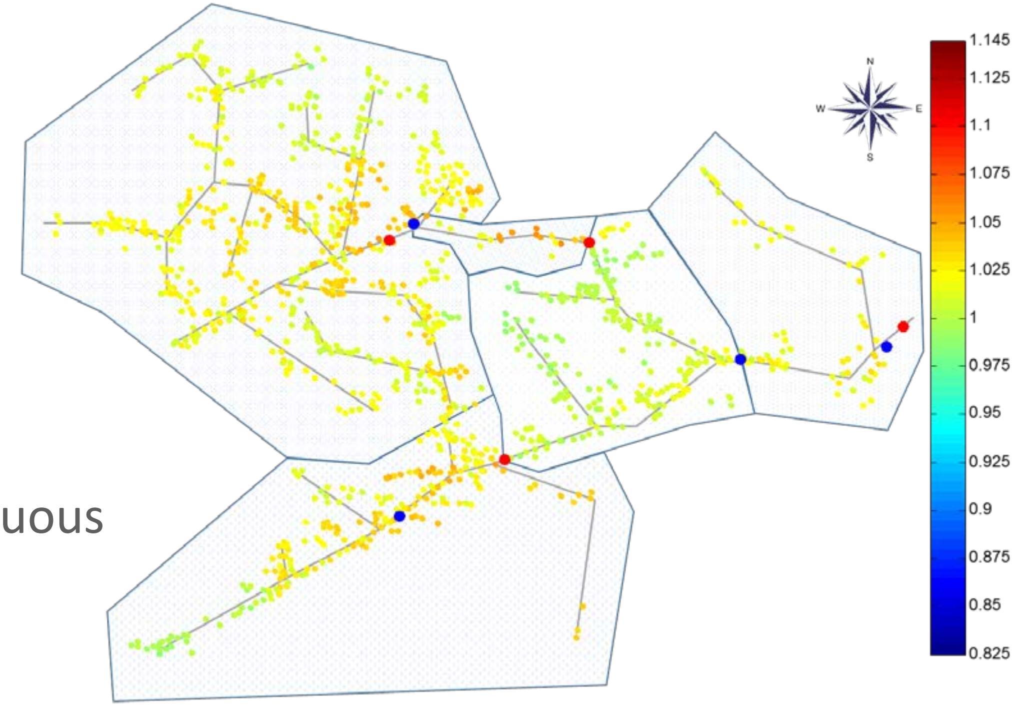
Distribution level impacts of GHFC

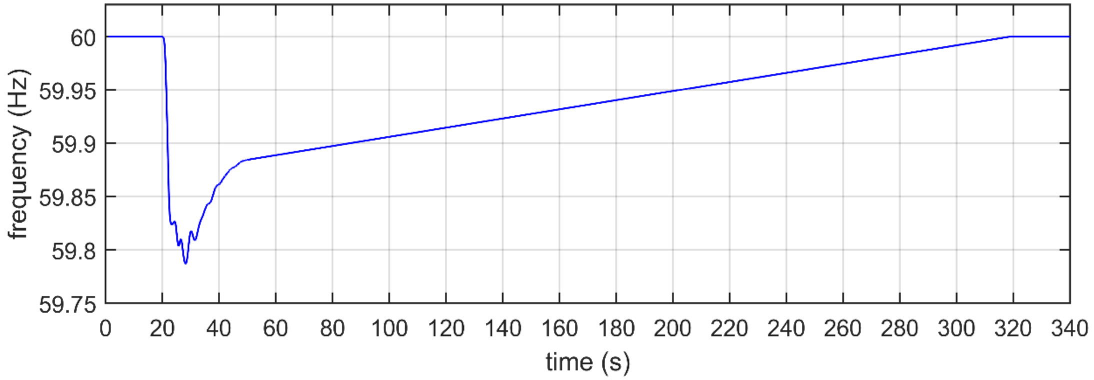
Test system & performance metrics

- 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

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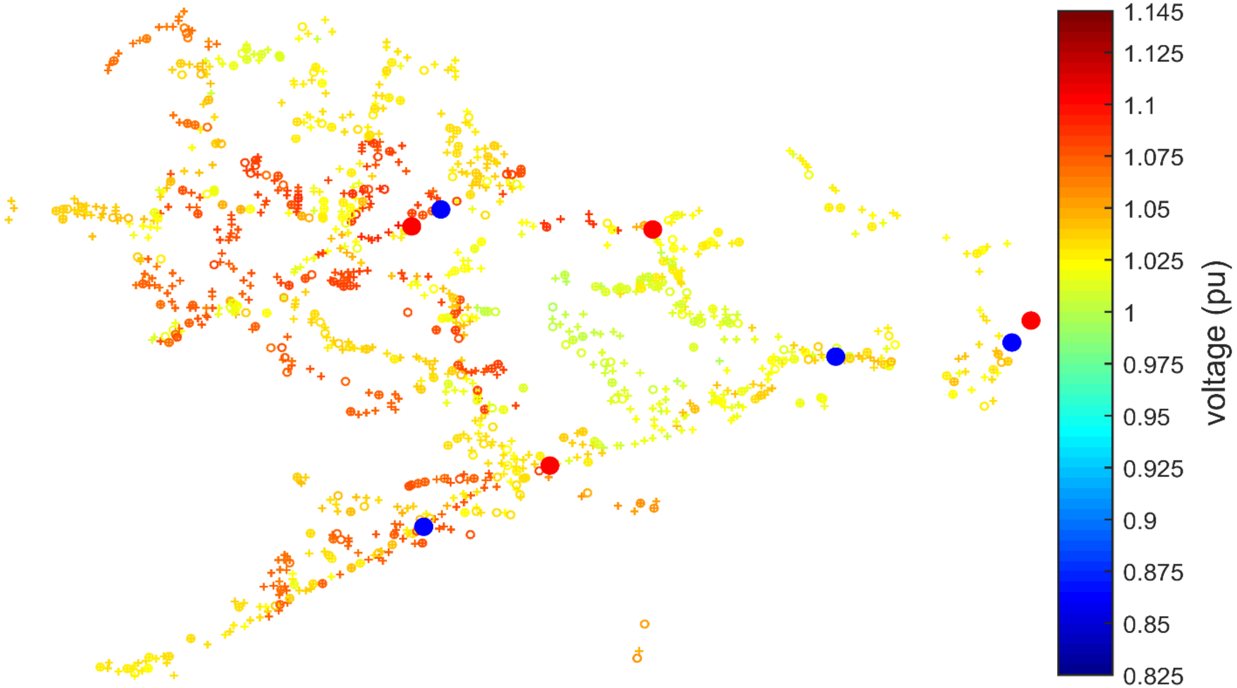
Results –Case 1



	Continuous Voltage Violation (5min)		Instantaneous Voltage Violation (1s)	
Voltage in pu	High Voltage (>1.05)	Low Voltage (<0.95)	High Voltage (>1.10)	Low Voltage (<0.90)
Violation count	117	0	1648	0

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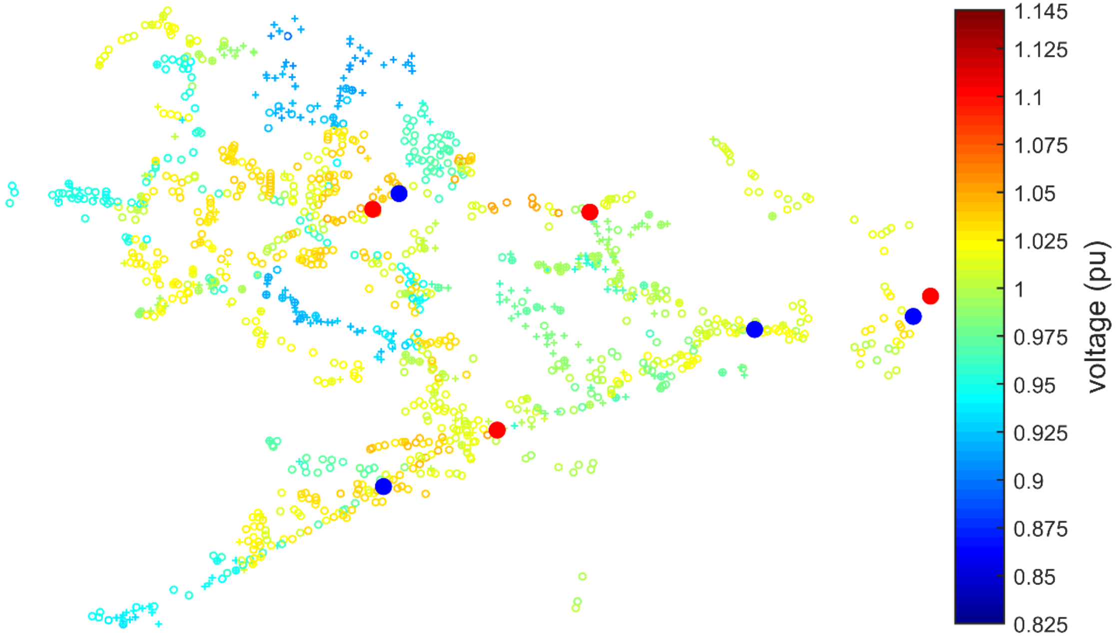
Results –Case 2



	Continuous Voltage Violation (5min)		Instantaneous Voltage Violation (1s)	
Voltage in pu	High Voltage (>1.05)	Low Voltage (<0.95)	High Voltage (>1.10)	Low Voltage (<0.90)
Violation count	478	0	475	39

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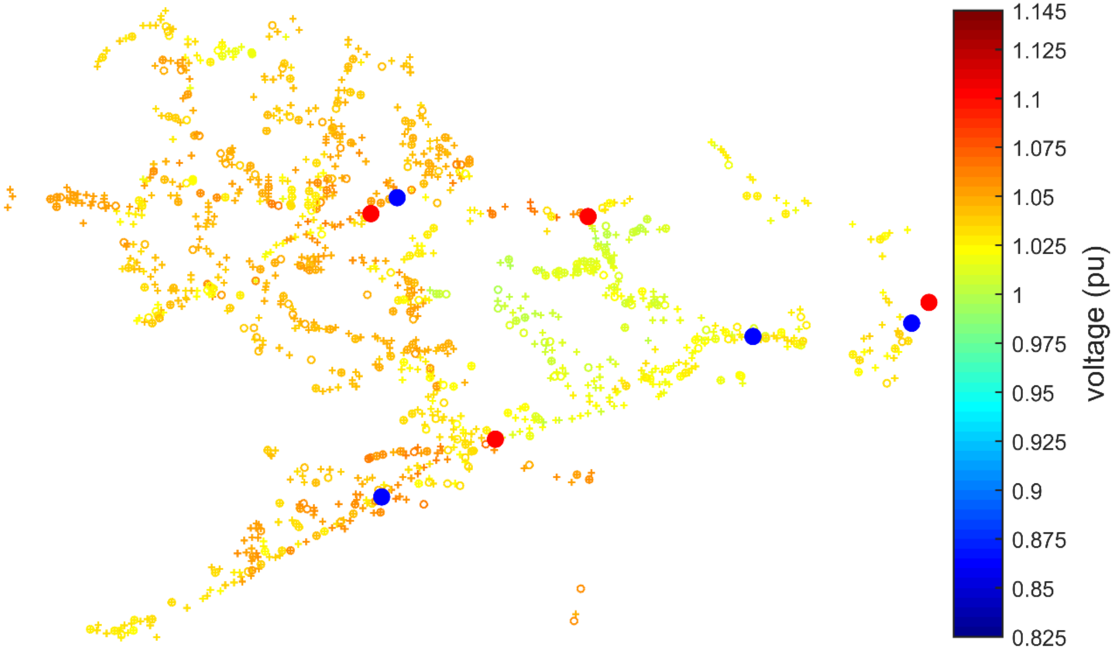
Results –Case 3



	Continuous Voltage Violation (5min)		Instantaneous Voltage Violation (1s)	
Voltage in pu	High Voltage (>1.05)	Low Voltage (<0.95)	High Voltage (>1.10)	Low Voltage (<0.90)
Violation count	49	0	0	0

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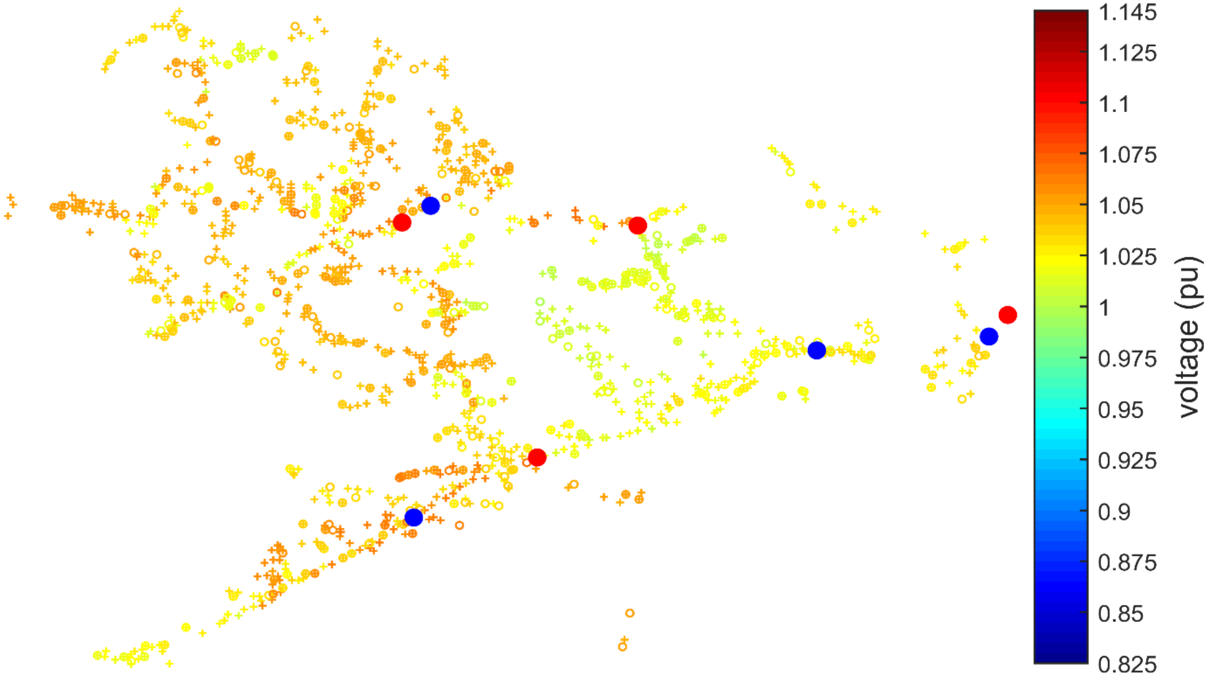
Results –Case 4



	Continuous Voltage Violation (5min)		Instantaneous Voltage Violation (1s)	
Voltage in pu	High Voltage (>1.05)	Low Voltage (<0.95)	High Voltage (>1.10)	Low Voltage (<0.90)
Violation count	29	0	0	0

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FY16 GMLC Category 2 project

HVDC and Load Modulation for Improved Dynamic Response using Phasor Measurements

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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