DOE/OE Transmission Reliability Program

Load as a Resource (LaaR): Frequency Responsive Demand

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June 10-11, 2015
Washington, DC

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Project Objective

- 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

FY14 Recap

Task 1: Improved controller design of hierarchical decentralized control strategy

- Responds to only frequency deviation
- Respect actual response capability of load population
- Allow for simple and scalable implementation

Task 2: Validated hierarchical decentralized control strategy on large-scale systems

- Implement controller on WECC model in PowerWorld

Task 3: Studied system impacts of Grid Friendly™ Appliances for primary frequency control

FY14 Review Comments

- *I am aware of the need for CAISO to be compliant with **NERC Bal 003-1 standard** and wondering how research activity results might help in meeting this requirement. Appears to need additional market designed to take advantage of research.*
- *Implementation ---> **legislated approach vs. market approach**. How to equitably distribute risk and wear and tear on devices/systems? Does technology exist to allow dynamic/continuous re-setting or re-activation of frequency set points? Or a supervisory control system that provides optimal deployment?*
- *would be worthwhile to elaborate on how signal is implemented - connect dots between research & solutions to **real-world implementation**.*

FY15 Deliverables and Risk Factors

Task	Deliverables	Due Date	Risk Factors
1	Complete investigation of hierarchical decentralized controller to meet the NERC reliability standard	5/30/2015	None
2	Complete development of market-based coordination framework for Grid Friendly™ Appliances	6/30/2015	None
3	Complete preliminary hardware testing of developed control strategies for primary frequency control	9/30/2015	Potential issues with experiments such as hardware failure

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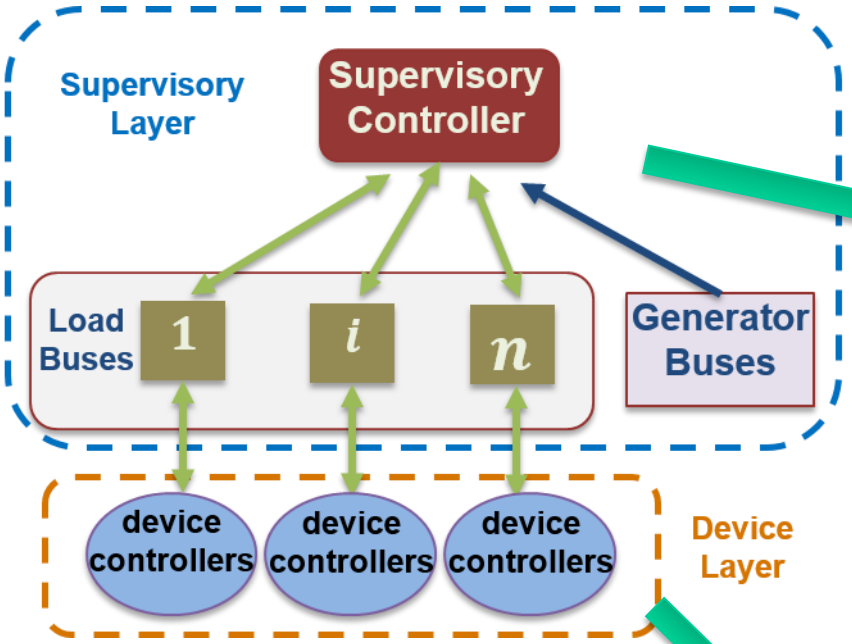
Task 1 (NERC BAL-003-1 Standard)

- "To require sufficient Frequency Response from the Balancing Authority (BA) to maintain Interconnection Frequency within predefined bounds by arresting frequency deviations and supporting frequency until the frequency is restored to its scheduled value."[1]
  - System-wide requirement: Interconnection Frequency Response Obligation (IFRO)
  - Area-wide requirement: Frequency Response Obligation (FRO)
  - IFRO calculated based on contingencies and FRO calculated as a portion of IFRO to be met by areas
- Compliance with FRO and IFRO measured with annual Frequency Response Measure (FRM), which is calculated from system event data

Controller Structure



Every 10 to 15 minutes

- Collect information on current operating condition of each individual device
- Design load control gains used to specify the desired power modulation of the aggregate load response
- Broadcast control gains and system states to individual devices

Real time

- Respond independently in such a way that the aggregate response will meet desired power modulation
- Respect physical device constraints

Hierarchical Gain Coordination

- Desired system-wide load response

$$K_{sys} + IFRO_{sys-GEN} \geq IFRO_{sys}$$

- Desired area-wide load response

$$K_{Ai} + FRO_{Ai-GEN} \geq FRO_{Ai}$$

- Practical implementation

$$K_{sys} = \sum_{Ai=Area\ 1}^{Ai=Area\ k} K_{Ai} \quad \Rightarrow \quad K_{Ai} = K_{sys} \frac{Pcont_{Ai}}{Pcont_{Tot}}$$

$$K_{Ai} = \sum_{Busi=bus\ 1}^{Busi=\ bus\ n} K_{Busi} \quad \Rightarrow \quad K_{Busi} = K_{Ai} \frac{Pcont_{Busi}}{Pcont_{Ai}}$$

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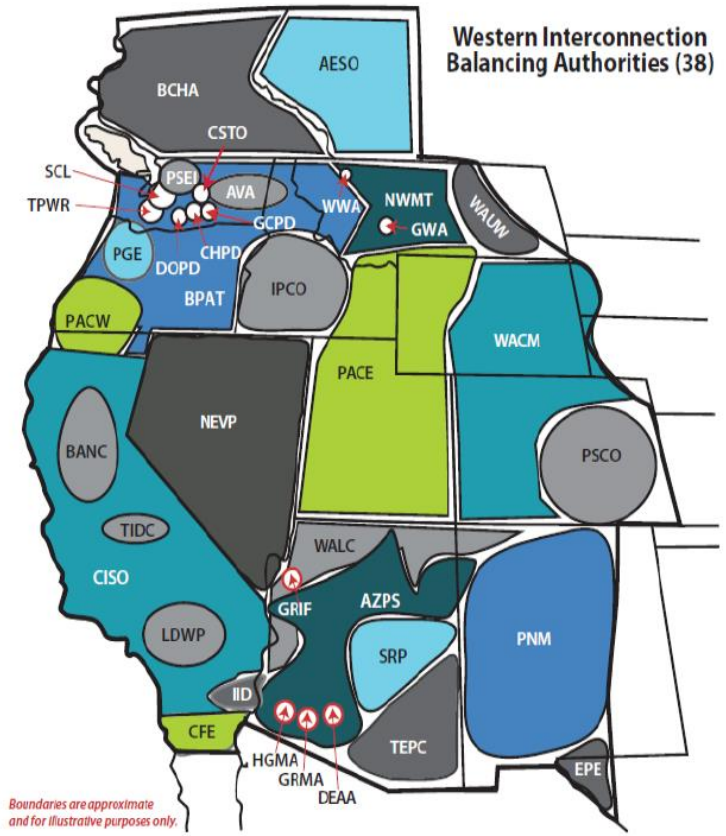
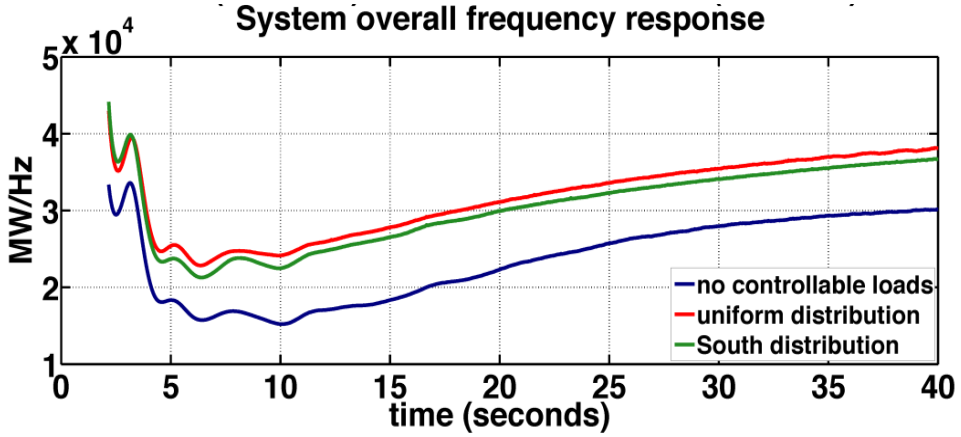
Test System

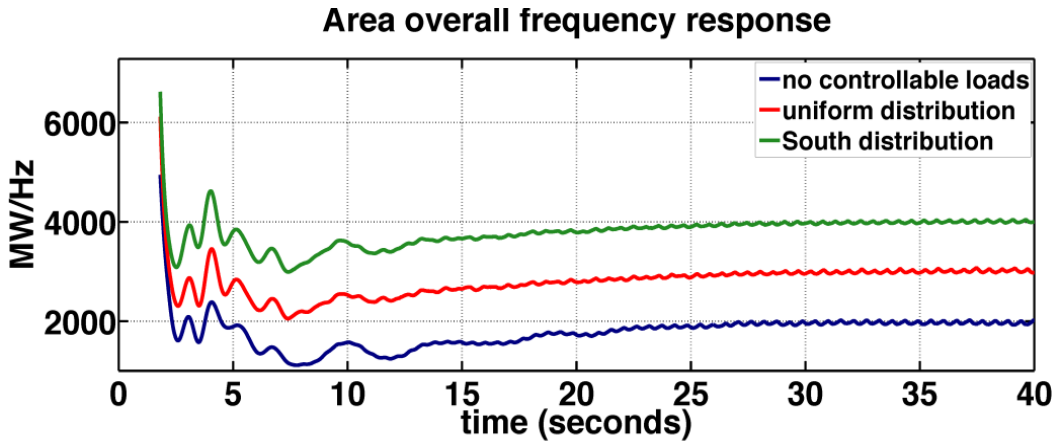
- WECC system simulated in PowerWorld software with User Defined Model for responsive loads
- Simulation cases
  - Case 1: No controllable load
  - Case 2: Controllable load across all areas of the WECC
  - Case 3: Controllable load concentrated in some areas of the Southwest part of the system



Simulation Results

- Controllable load increases system-wide MW/Hz response
- Area gain can be adjusted to meet MW/Hz area requirements



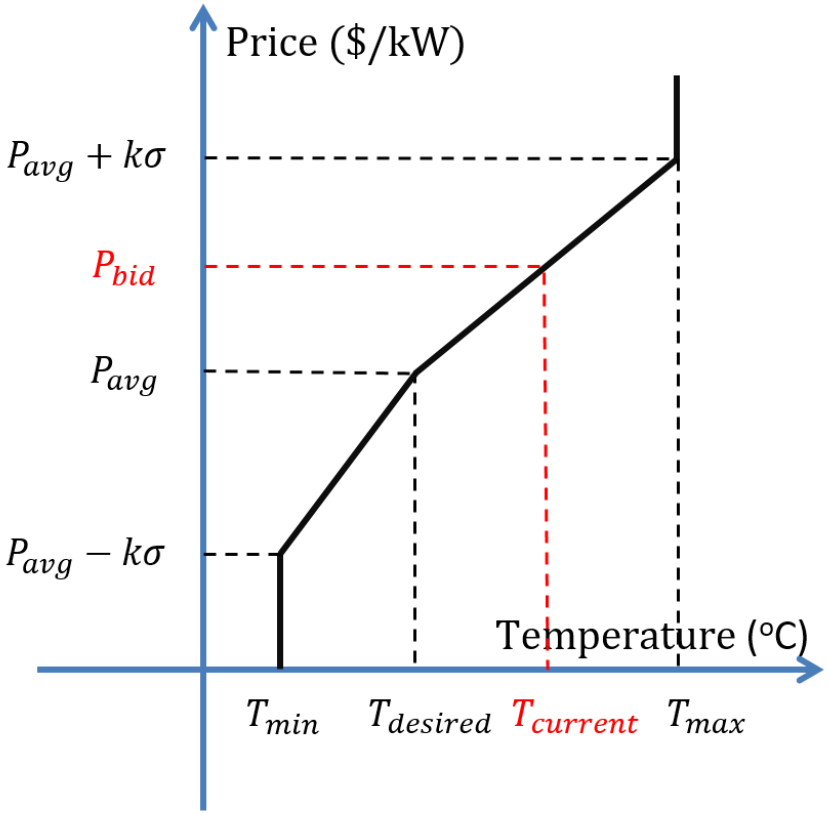


Task 2 (Resource Acquisition)

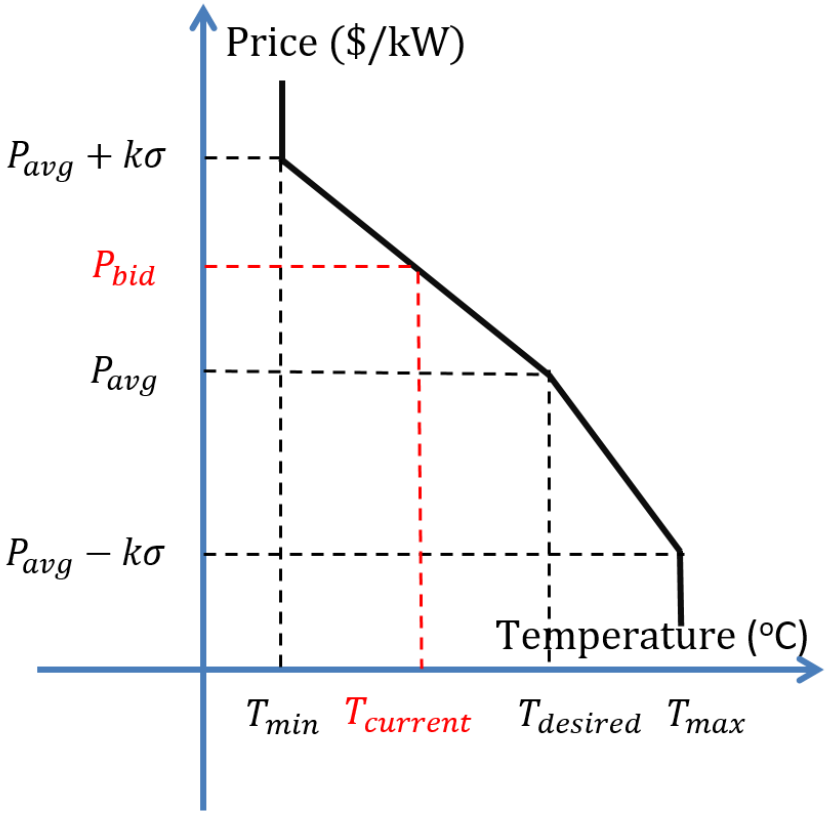
Use transactive market mechanism to acquire the needed amount of resources

- Device bidding mechanism
  - Capability to provide primary frequency control
  - Load power that can be adjusted (kW)
  - Willingness to adjust load power ($/kW)
- Central clearing mechanism
  - Two independent double-auction markets of five minutes (ON-to-OFF and OFF-to-ON)

Device Bidding

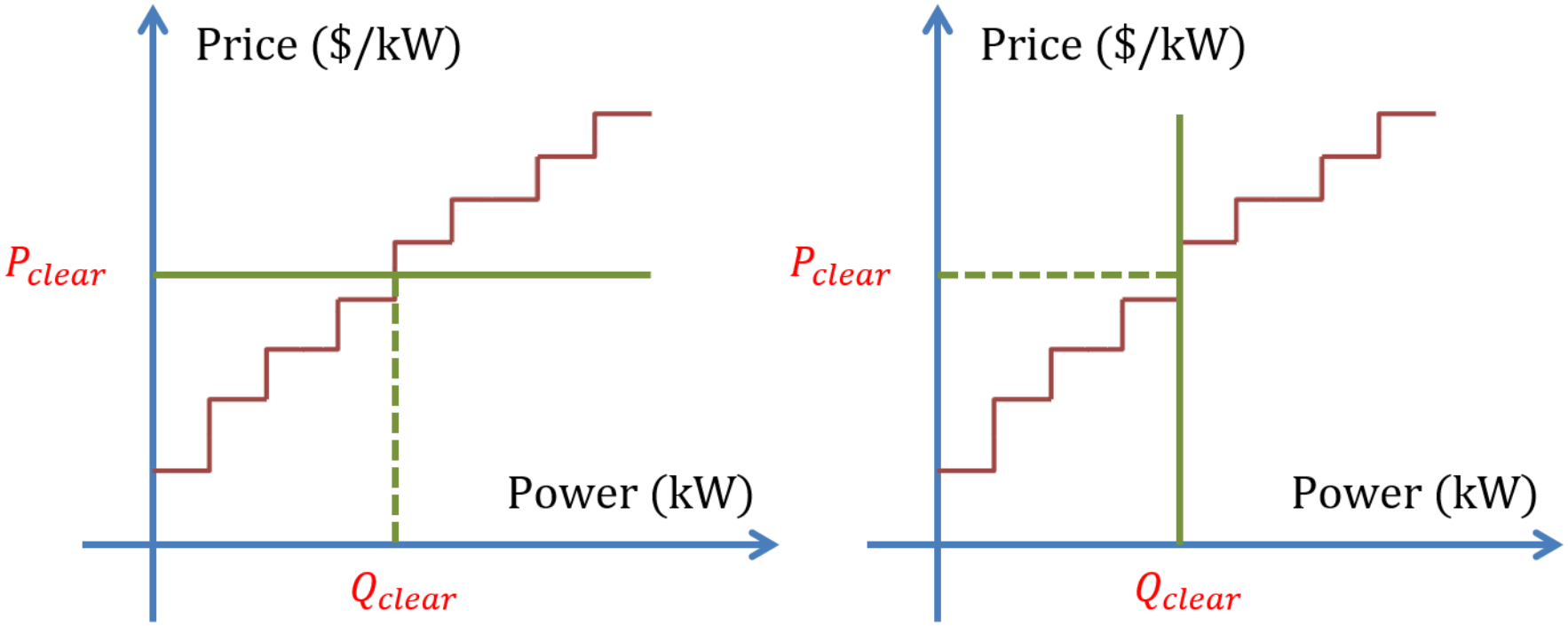


ON Device



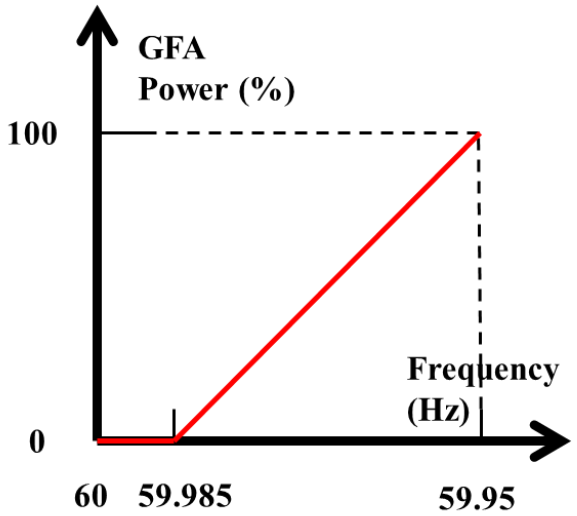
OFF Device

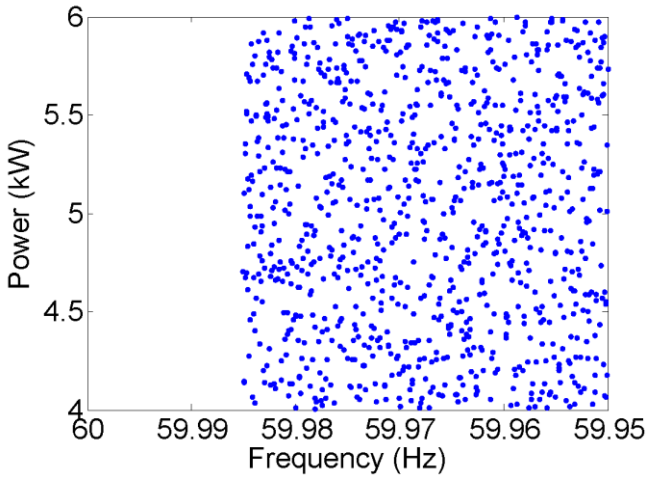
Market Clearing



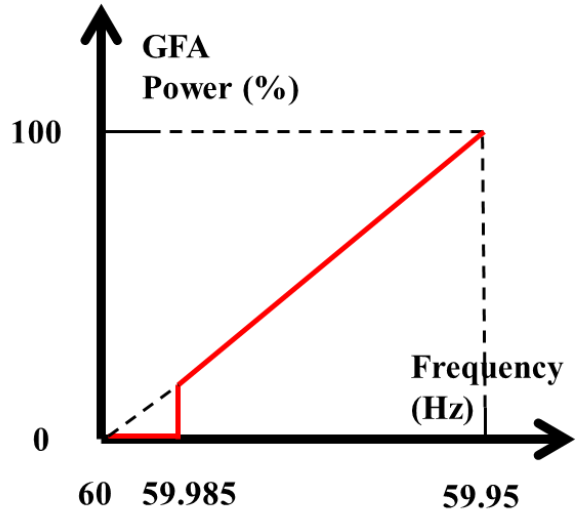
Frequency Threshold Selection Decentralized

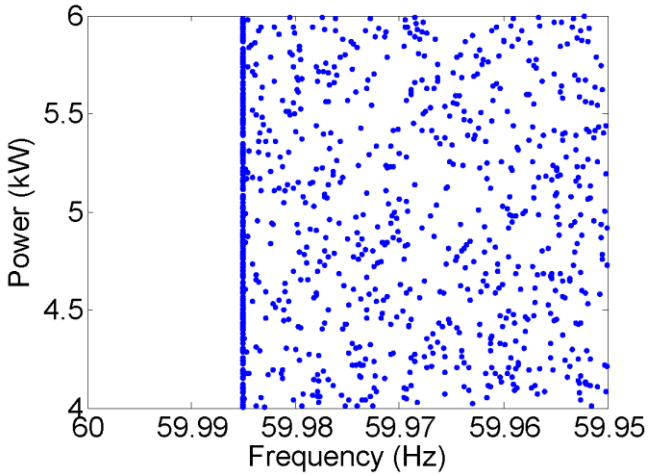
Original



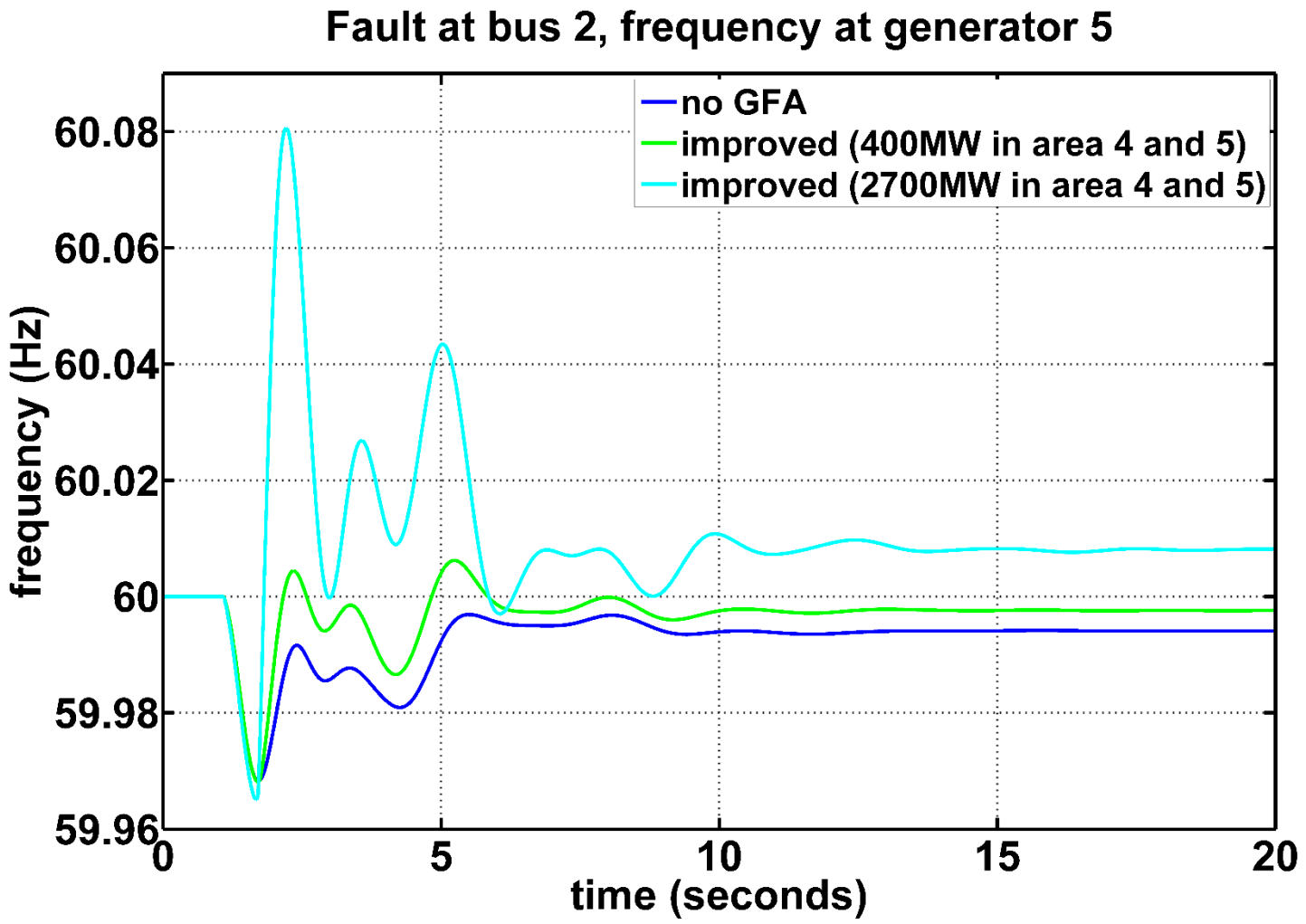


Improved

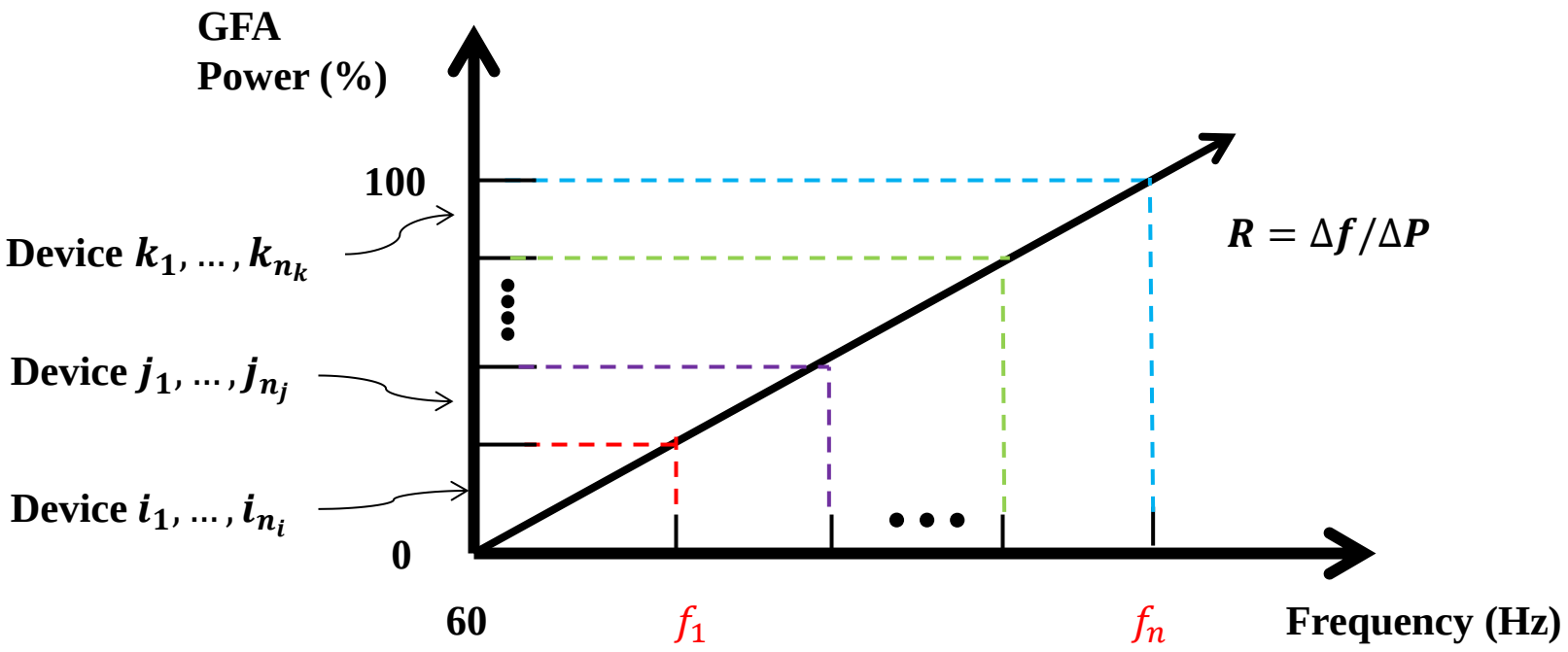




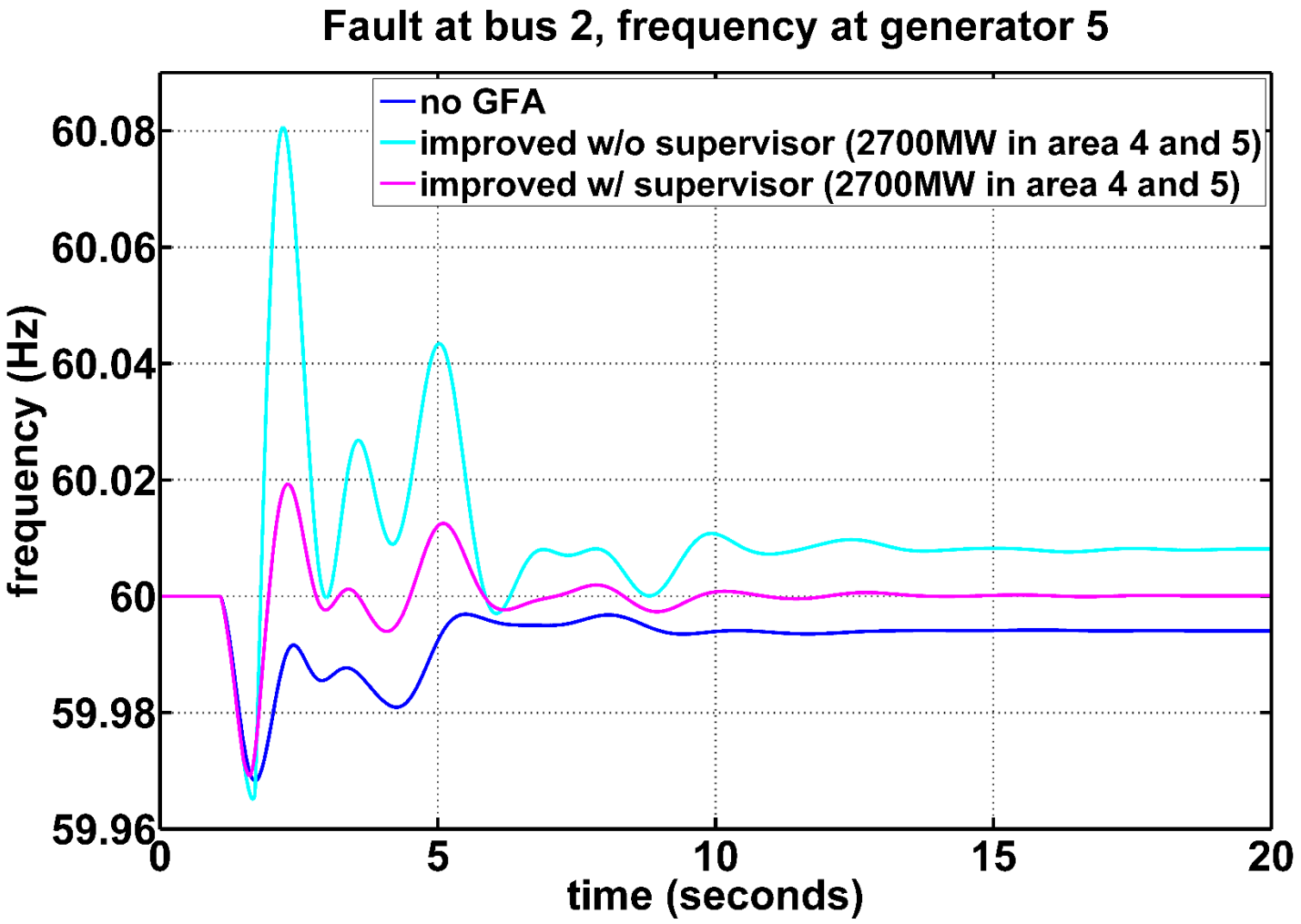
Simulation Results



Frequency Threshold Selection Supervised



Simulation Results



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Task 3 (Hardware Testing)

- Perform hardware testing in a laboratory setting to
  - Improve and calibrate existing load models used for large-scale simulation studies
  - Provide manufacturing recommendations for appliances providing primary frequency control
- Progress to date
  - Re-commissioned and re-inspected hardware
  - Updated data acquisition system to support data collection down to 30ms timescale
  - Installed simple GFA controller on ERWH
  - Built interface control with internal control logic of HPWH to facilitate controller implementation

Next Steps

- Execute experimental studies for hardware testing to collect water heater performance data
- Improve and validate the models of water heaters used in large-scale simulation studies
- Discover the characteristics of load profiles and population statistics of water heaters in the WECC
- Perform studies to analyze the impacts of short cycling on water heaters when providing primary frequency control

FY 16 proposed activities

- Implement improved GFA design in integrated T&D environment (e.g. PowerWorld+GridLAB-D)
  - Implement new GFA design in PowerWorld on the WECC system model
  - Investigate voltage “side effects” on distribution feeders using GridLAB-D
- Investigate integration of proposed transactive market mechanism with existing market products
- Conduct field testing of various end-use loads to provide primary frequency control
- Perform extensive outreach activities

Questions

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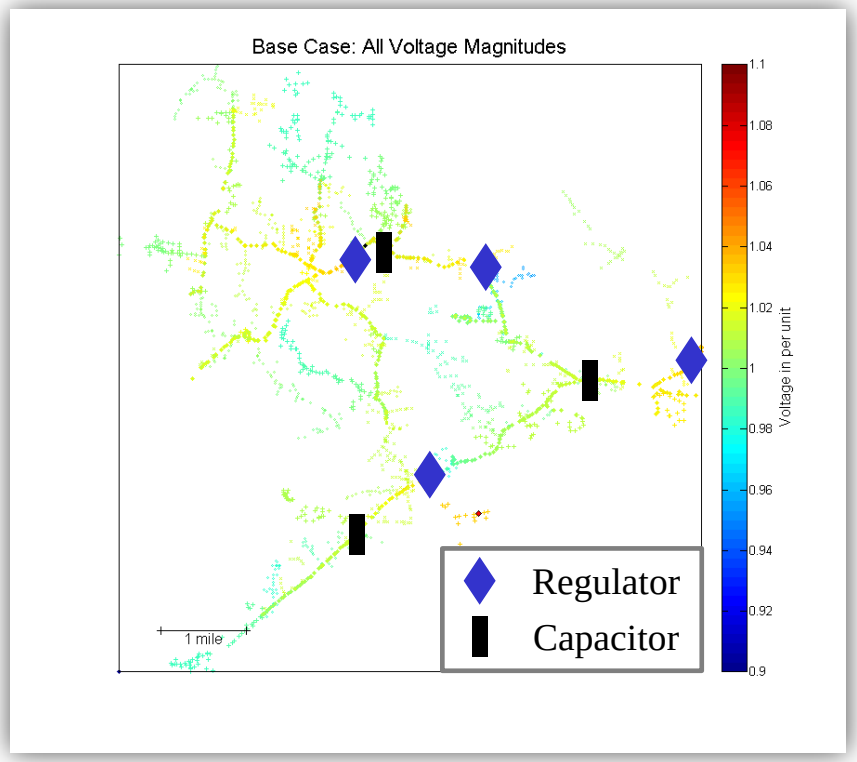
Voltage impacts due to inherent modulation of reactive component of load while load is under primary frequency control

Distribution Test System

- IEEE 8500 Node Test System
  - Large, unbalanced system
  - Real system with multiple voltage control devices
  - Includes service drops
  - Original system had existing voltage control issues
- Modeled in GridLAB-D™
  - Time-series model (1-sec resolution)
  - Added models for 2,440 individual homes + appliances
  - Added 120 PV installations
  - Added *reasonable* voltage controls



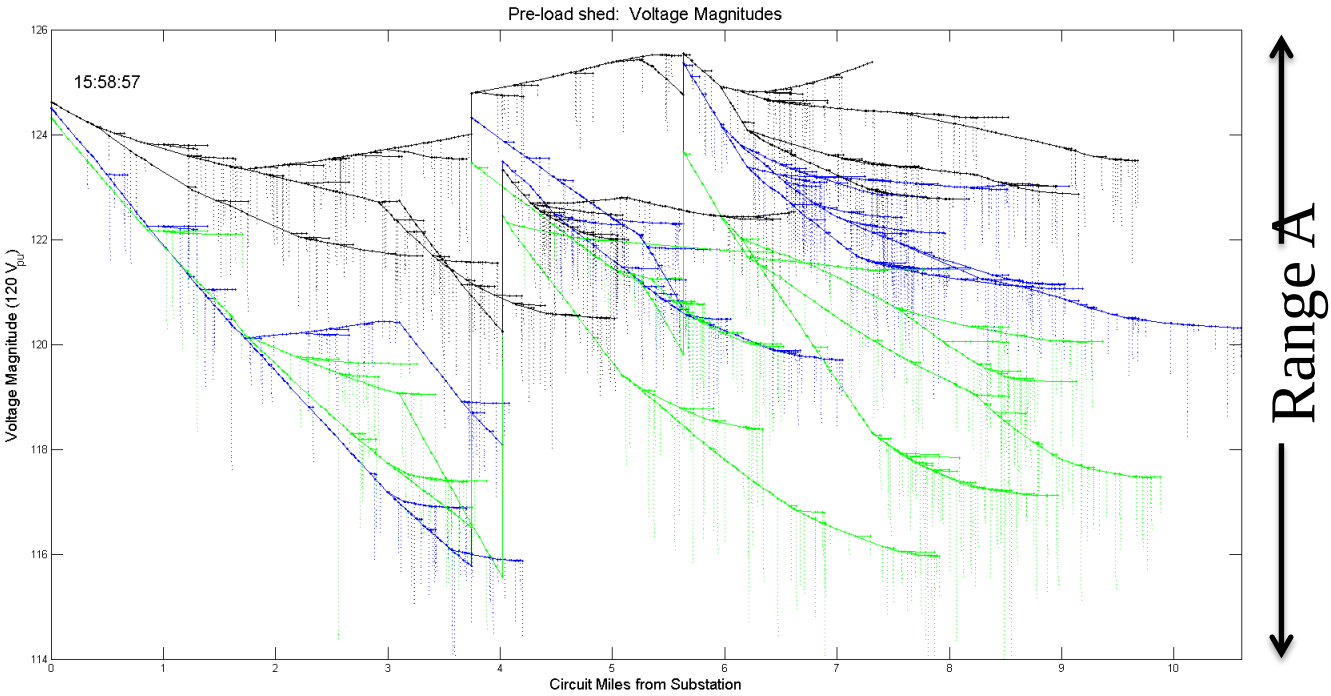
GFA Performance – "Pre-Event"

- Peak load of 9.6 MW on a warm, but mild day (September)
- 2.2 MW of which are water heaters (normal usage patterns are modeled)

- Voltage control is "stressed"
  - Line regulators are "tapped up" to keep voltage at end of system high
  - At end of the system, voltages are extremely low

	No GFA	With GFA
Range A (114-126)		
OV	<1	
UV	168	
Range B (110-126.5)		
OV	0	
UV	0	

Metric = (# meters) * (minutes)



GFA Performance – "Post-Event"

- At 15:59:01 and 16:04:05, an extreme GFA event is modeled
- All ~2.2 MW are reduced to ~0 MW within 4 second period
- Standard regulators respond to voltage changes in secs to mins
- Results in extremely high voltages over 10 min period

	No GFA	With GFA
Range A (114-126)		
OV	<1	1125
UV	168	116
Range B (110-126.5)		
OV	0	575
UV	0	0

Metric = (# meters) * (minutes)