Energy Technologies Area Lawrence Berkeley National Laboratory

LBNL's Frequency Response Study for FERC

Prepared for
Office of Electricity Reliability
Federal Energy Regulatory Commission

Prepared by
Joseph H. Eto, Principal Investigator
Lawrence Berkeley National Laboratory

Project Team
John Undrill, John Undrill, LLC
Ciaran Roberts, Lawrence Berkeley National Laboratory
Peter Mackin, Utility Systems Efficiencies, Inc.

July 10, 2018

Overview of Today's Presentation

- Project objectives/motivation for this study
- Key findings/study recommendation - *headlines*
- Power system frequency control concepts
- Project study methods
- Findings and recommendations
- Final cross-cutting recommendations
- List of technical reports prepared for this project

Project Objectives and Motivation

To build upon a previous FERC report prepared by LBNL to address frequency response issues holistically considering how all aspects of the US generation fleet (and loads) might change in the future on an interconnection-specific basis

The LBNL 2010 study developed new metrics, but used them to study only the impacts of one new form of generation (i.e., electronically coupled, variable renewable generation) on frequency response

LBNL-4142E

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation

Joseph H. Eto, Principal Investigator
Lawrence Berkeley National Laboratory

John Undrill
John Undrill, LLC

Peter Mackin, Ron Daschmans, Ben Williams, Brian Haney, Randall Hunt, Jeff Ellis
Utility Systems Efficiencies, Inc.

Howard Illian
EnergyMark, Inc.

Carlos Martinez
Electric Power Group, LLC

Mark O'Malley
University College Dublin

Katie Coughlin, Kristina Hamachi LaCommare
Lawrence Berkeley National Laboratory

December 2010

The work described in this report was funded by the Federal Energy Regulatory Commission, Office of Electric Reliability. The Lawrence Berkeley National Laboratory is operated by the University of California for the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Key Study Findings

Rapidly deployed and then sustained primary control action in response to the sudden loss of generation is a fundamental reliability requirement.

This requirement is met by the action of turbine governors and, in some cases, by fast demand response.

Generation interconnection policies determine:

- The extent to which the fleet is equipped to provide primary frequency response

Generation dispatch policies determine:

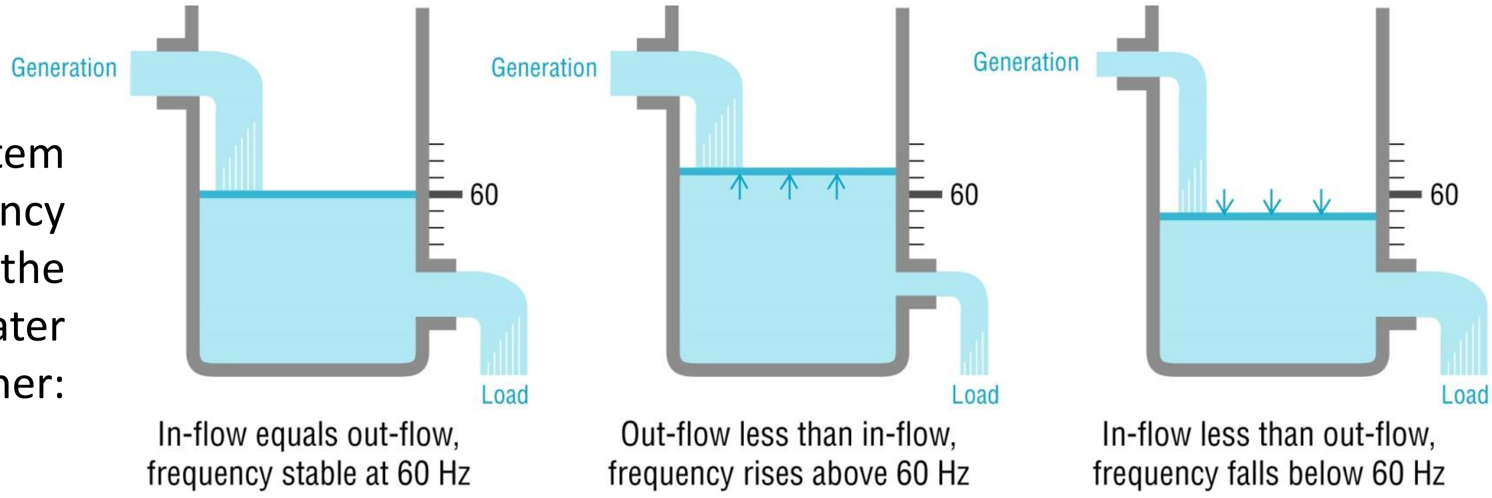
- The amount of primary frequency response that can be delivered
  …which depends on the size of the generation loss event the interconnection is designed to withstand
- The speed with which primary frequency response will deploy
  …which depends on the types of units dispatched and the headroom assigned to individual units

Study Recommendations

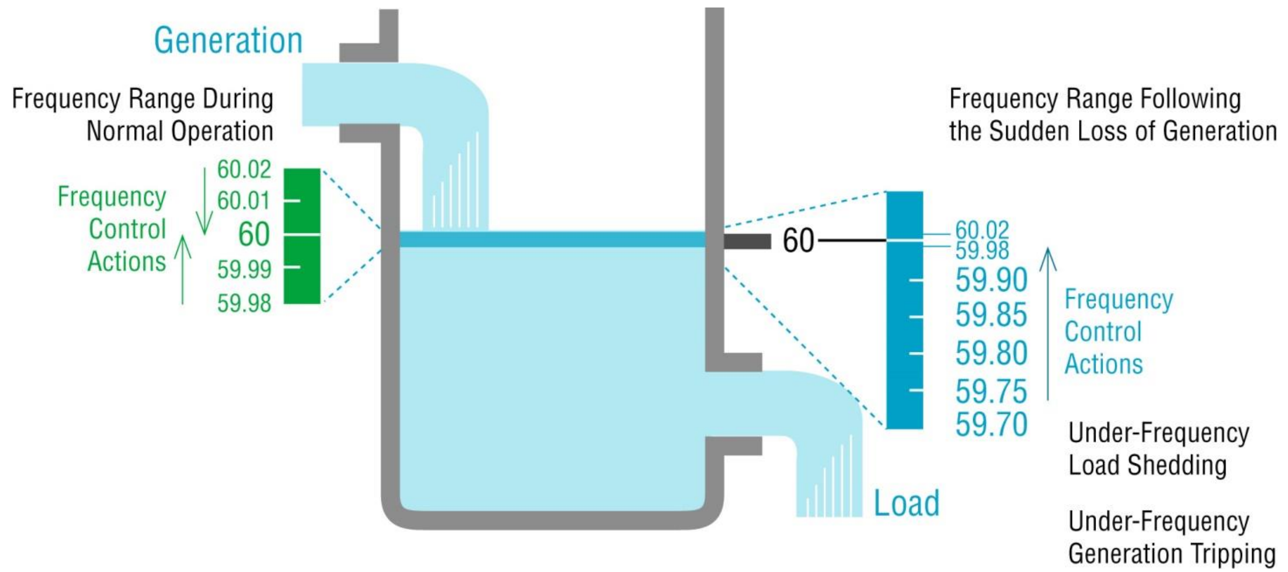
- Focused attention needed on the collection, maintenance, and validation of operating data and study models
- International practices should be reviewed as options for U.S. grid operators to consider for adoption/adaptation
- All generators should have the capability to provide sustained primary frequency response
- Barriers to adding a frequency bias to plant load controllers should be evaluated and addressed
- The contributions of non-traditional resources for primary frequency control should be studied and incorporated, as appropriate, into future operations
- The changing composition of loads should be studied and addressed

Power System Frequency Concepts

Power system frequency explained using the analogy of water level in a container:

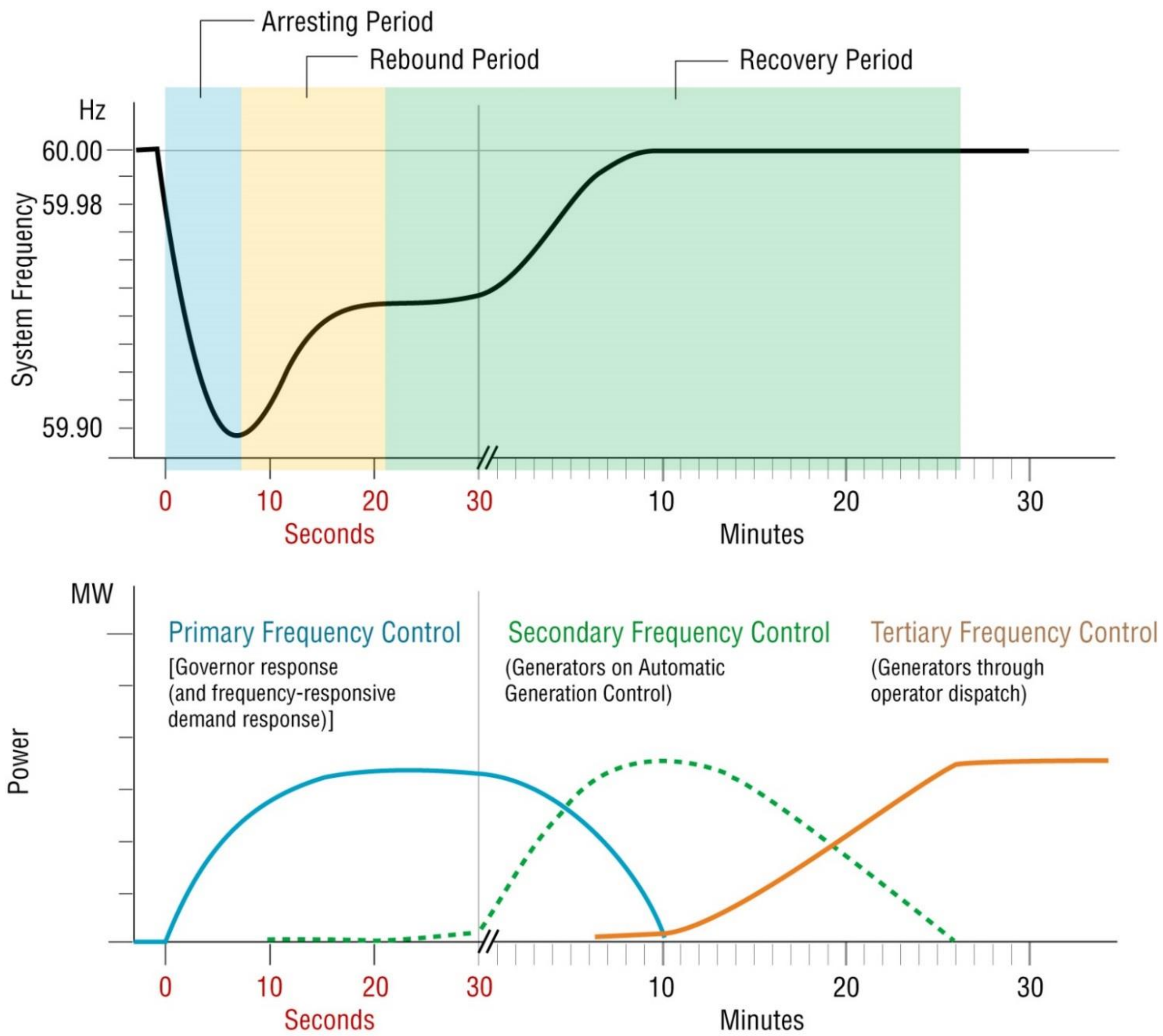


Power system frequency during normal operation (left) and following the sudden loss of generation (right):



Roles of Frequency Control Resources

- Primary frequency response is the fastest form of frequency control—it plays an irreplaceable role in arresting frequency following the sudden loss of generation
- Secondary control next seeks to replace and restore primary frequency response capability
- Tertiary control eventually replaces and restores both primary and secondary control capability

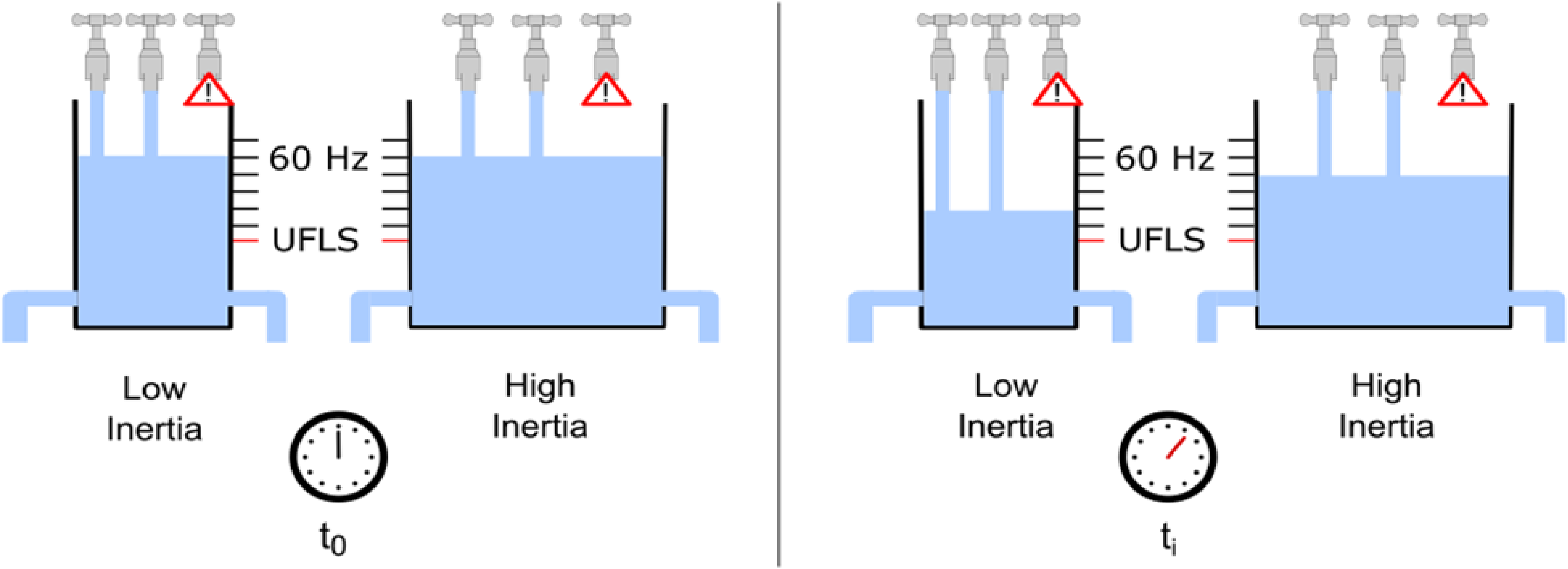


Effect of System Inertia on System Frequency

The rate at which system frequency declines (ROCOF) immediate following the sudden loss of generation is determined by:

1. The inertia of the interconnection; ***AND***
2. The size of the generation loss event that the interconnection is expected/designed to withstand

Both factors must be considered together. They are not meaningful considered apart from one another.

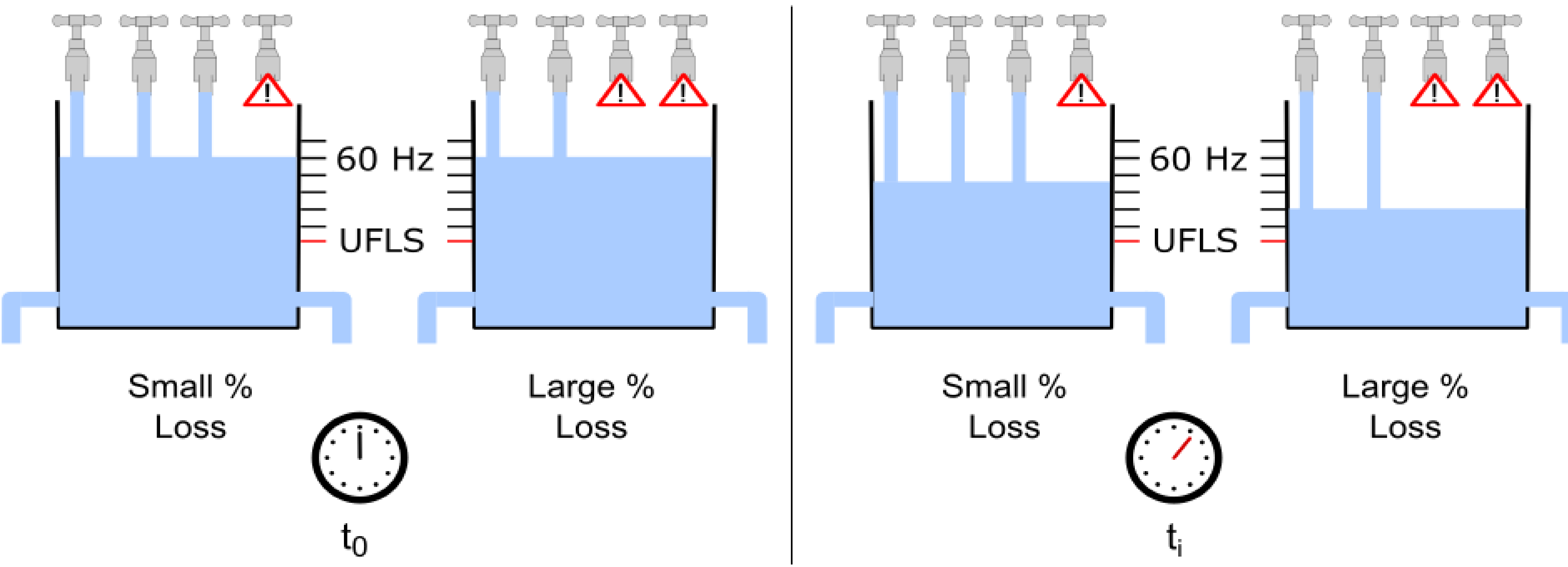


Effect of Amount of Generation Lost on System Frequency

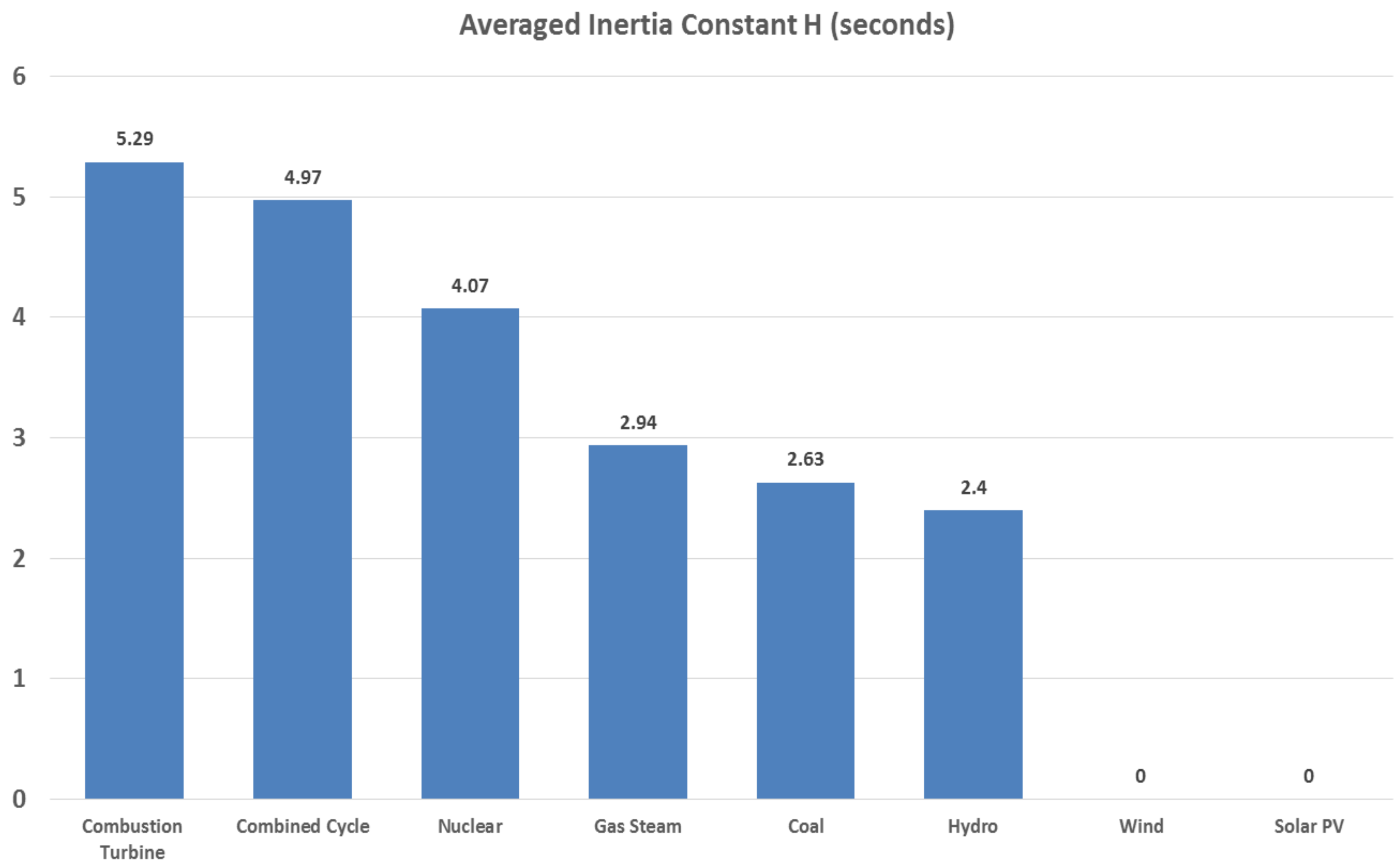
The rate at which system frequency declines (ROCOF) immediate following the sudden loss of generation is determined by:

1. The inertia of the interconnection; ***AND***
2. The size of the generation loss event that the interconnection is expected/designed to withstand

Both factors must be considered together. They are not meaningful considered apart from one another.



Inertia of Different Types of Generation



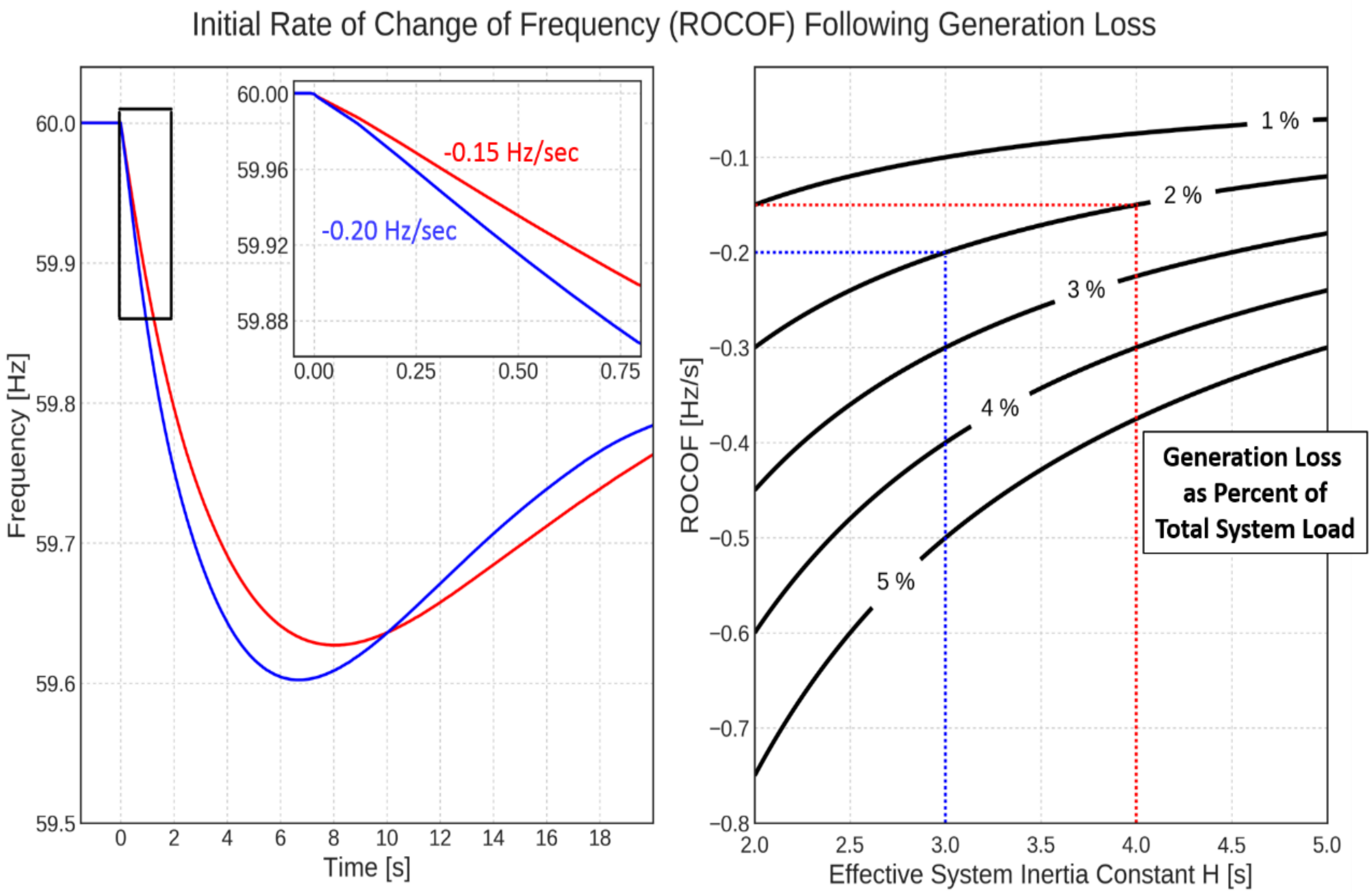
Source: S. Sharma, Renewable Integration at ERCOT (2016)

Generation Loss Design Events

Design Criteria:	Eastern Interconnection	Western Interconnection	Texas Interconnection
Generation-Loss Event	4.5 GW	2.7 GW	2.7 GW
Minimum Load – 2015	210 GW	64 GW	24 GW
Gen. Loss Event/Min Load	2.1 %	4.1 %	11.3 %

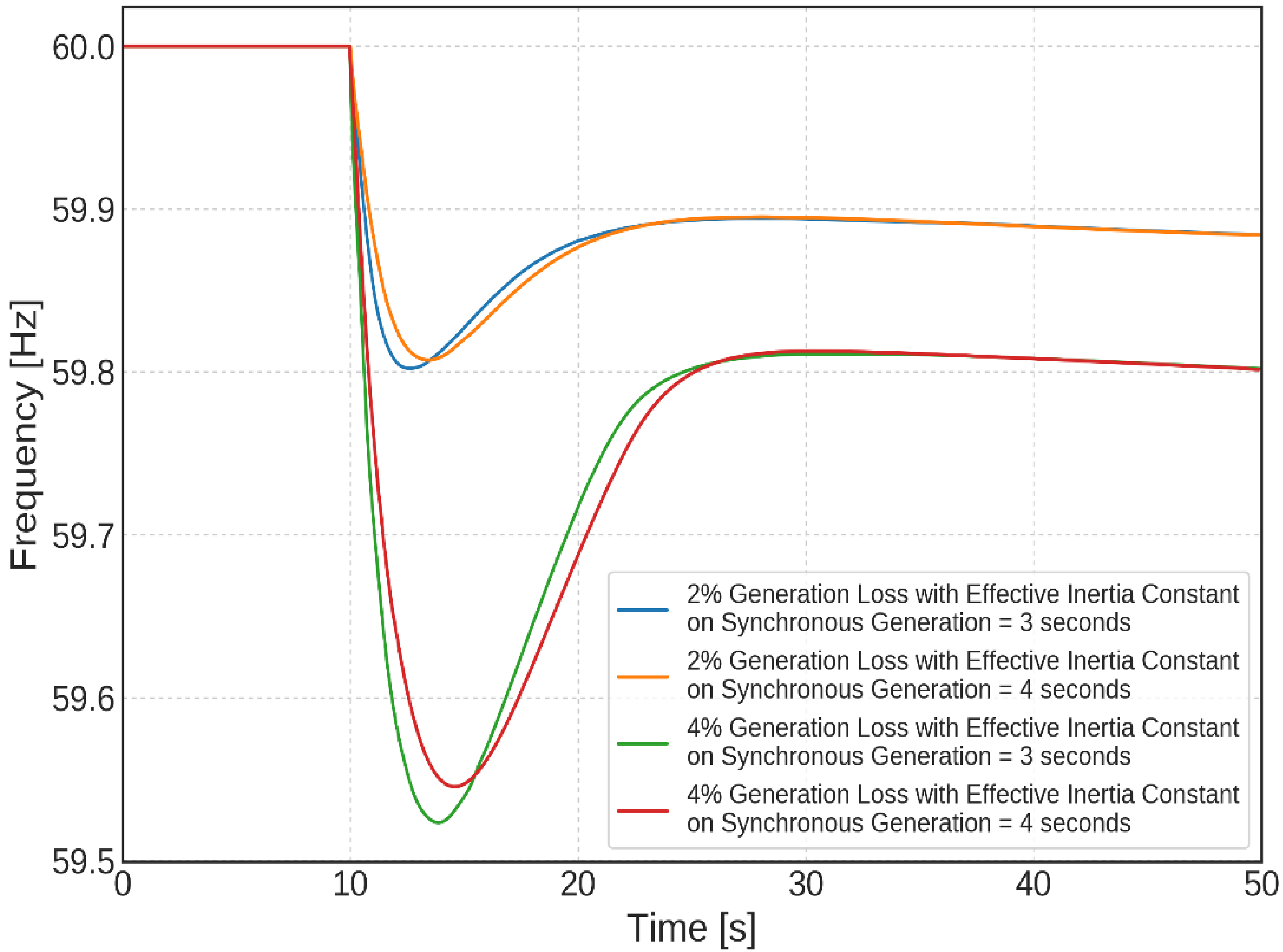
Source: Developed by LBNL from NERC 2017 Frequency Response Annual Analysis (2017) and J. Matevosyan Inertia Data (2016).

System Inertia + Generation Loss → ROCOF



The analytical relationship between effective system inertia and generation loss on the initial rate of change of frequency (ROCOF)

Relative Impact of Generation Loss versus System Inertia on Frequency Nadir



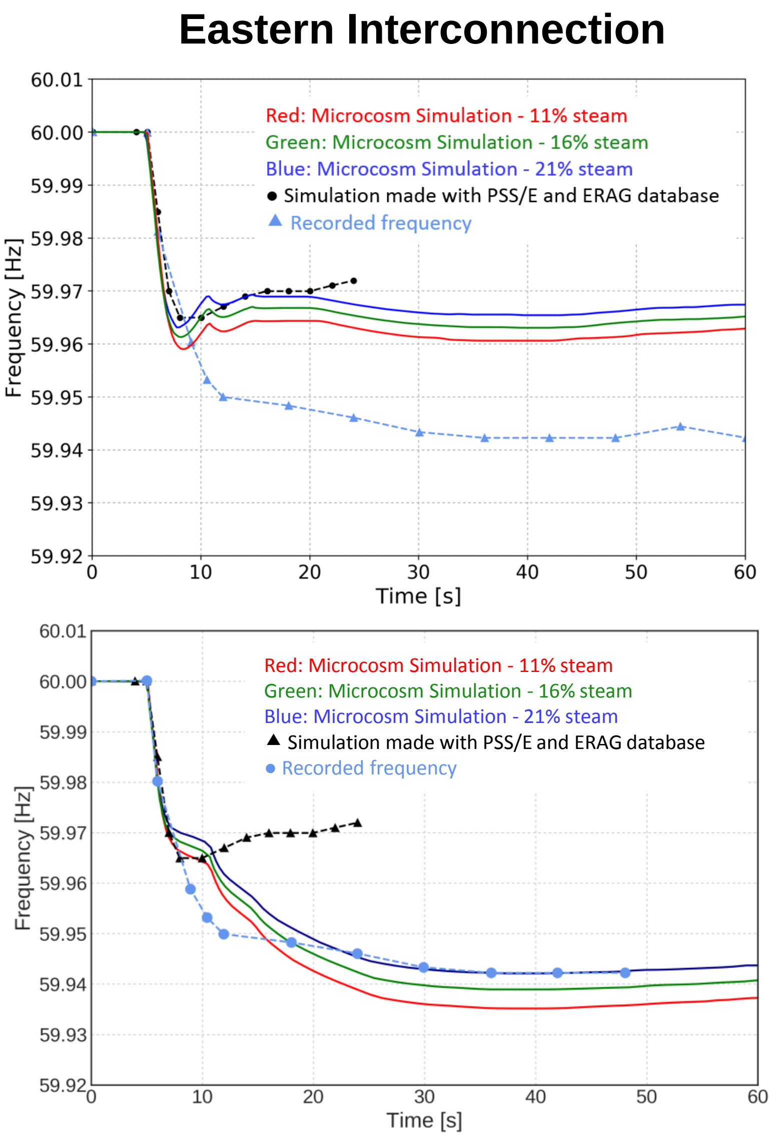
Project Study Methods

Started from, but expanded previous FERC-sponsored, LBNL modeling and simulation framework

- Used industry standard simulation tool (GE PSLF) ➞ facilitates reproducibility of results
- Examined broader range of frequency response topics ➞ sustained frequency response
- Did not model transmission system or protection

Developed a simplified and highly flexible approach to system modeling

- Conducted several 1000 parametric simulations
- Usefulness confirmed by comparison with more detailed, industry-developed interconnection planning models

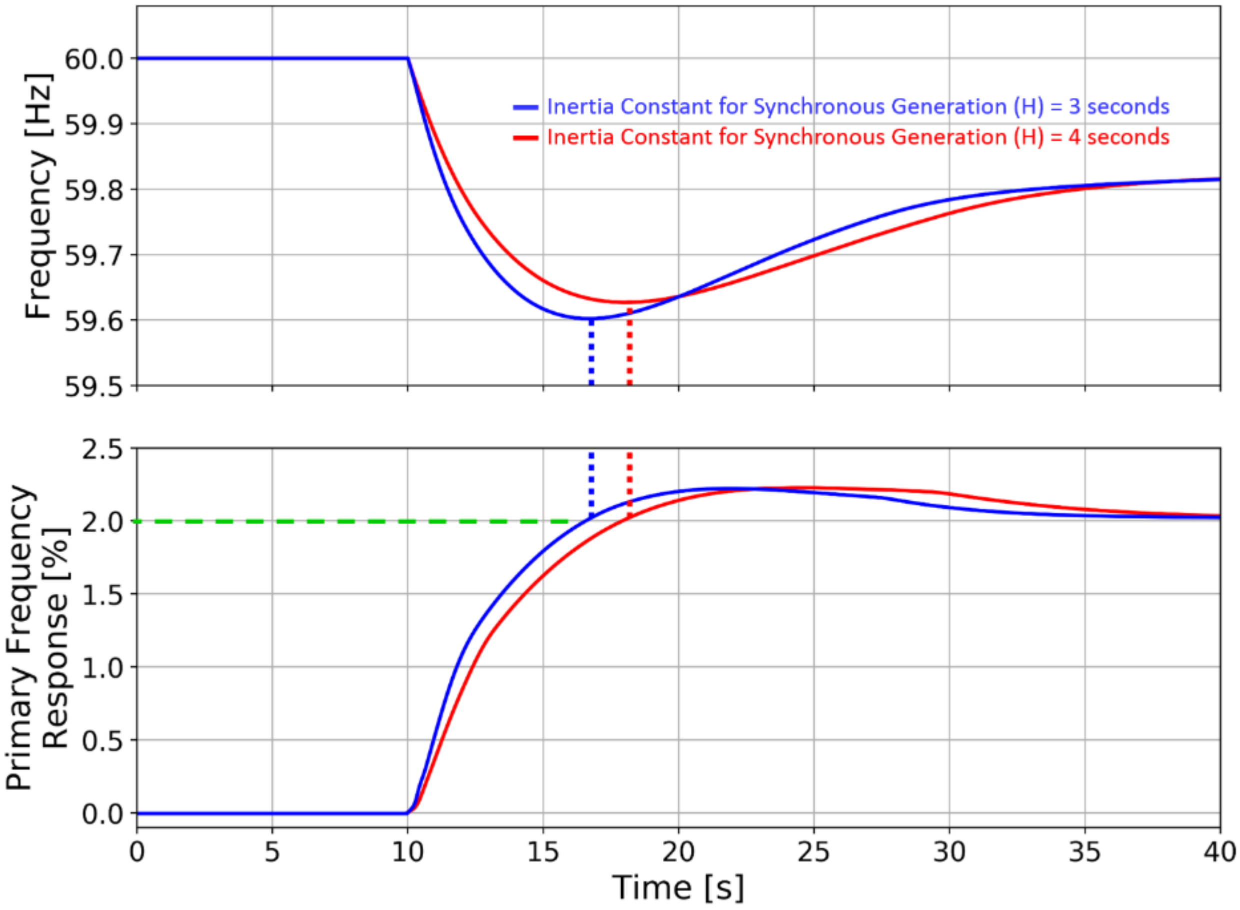


Physical Requirements for Arresting Frequency

Frequency is arrested when the amount of primary frequency response delivered equals the amount of generation lost

Finding 1:

Reserves held to provide primary frequency control must exceed the expected loss of generation



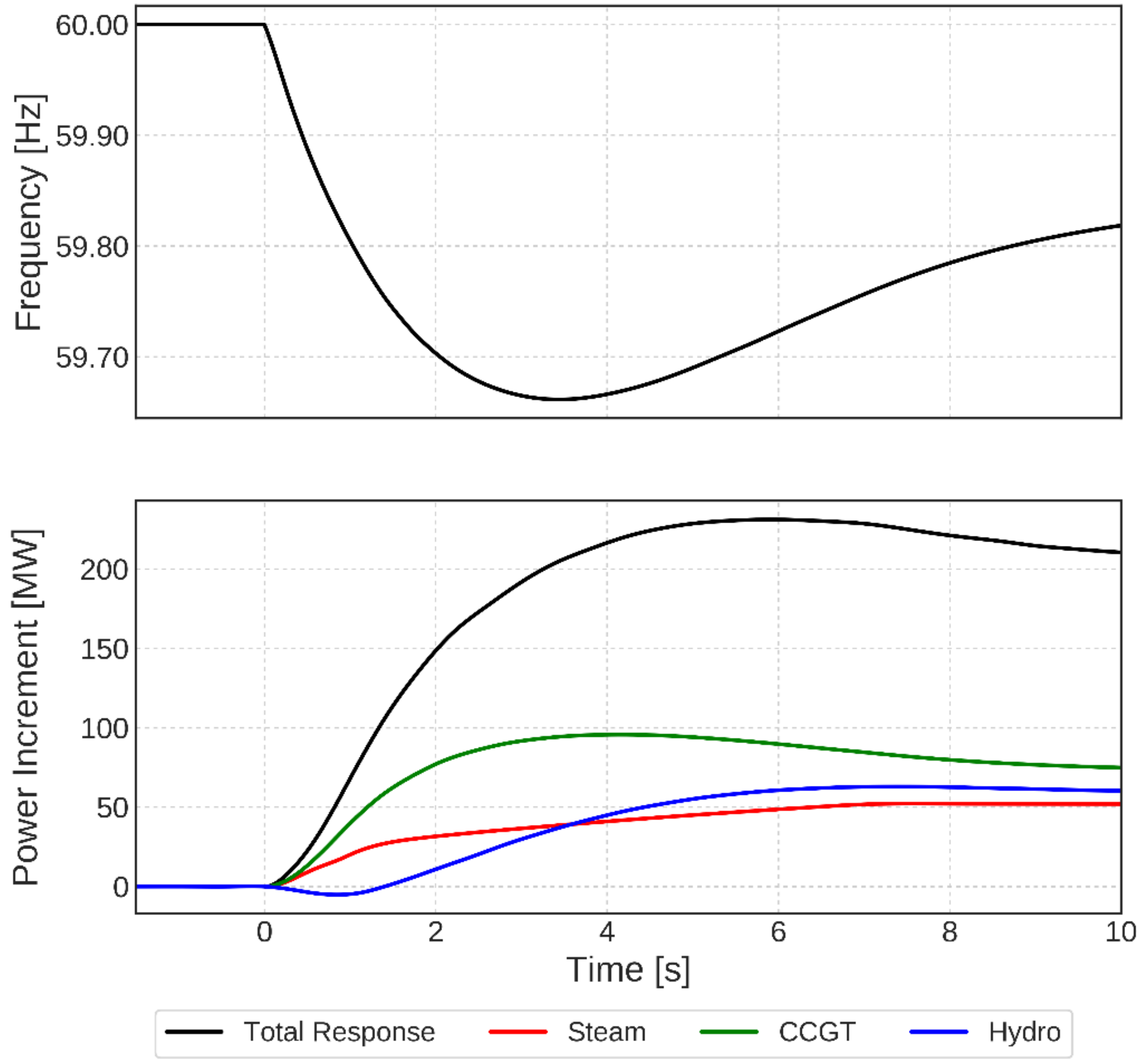
Operational Approach for Arresting Frequency

Finding 2:

Primary frequency response must be delivered quickly, which requires many participating generators

Recommendation:

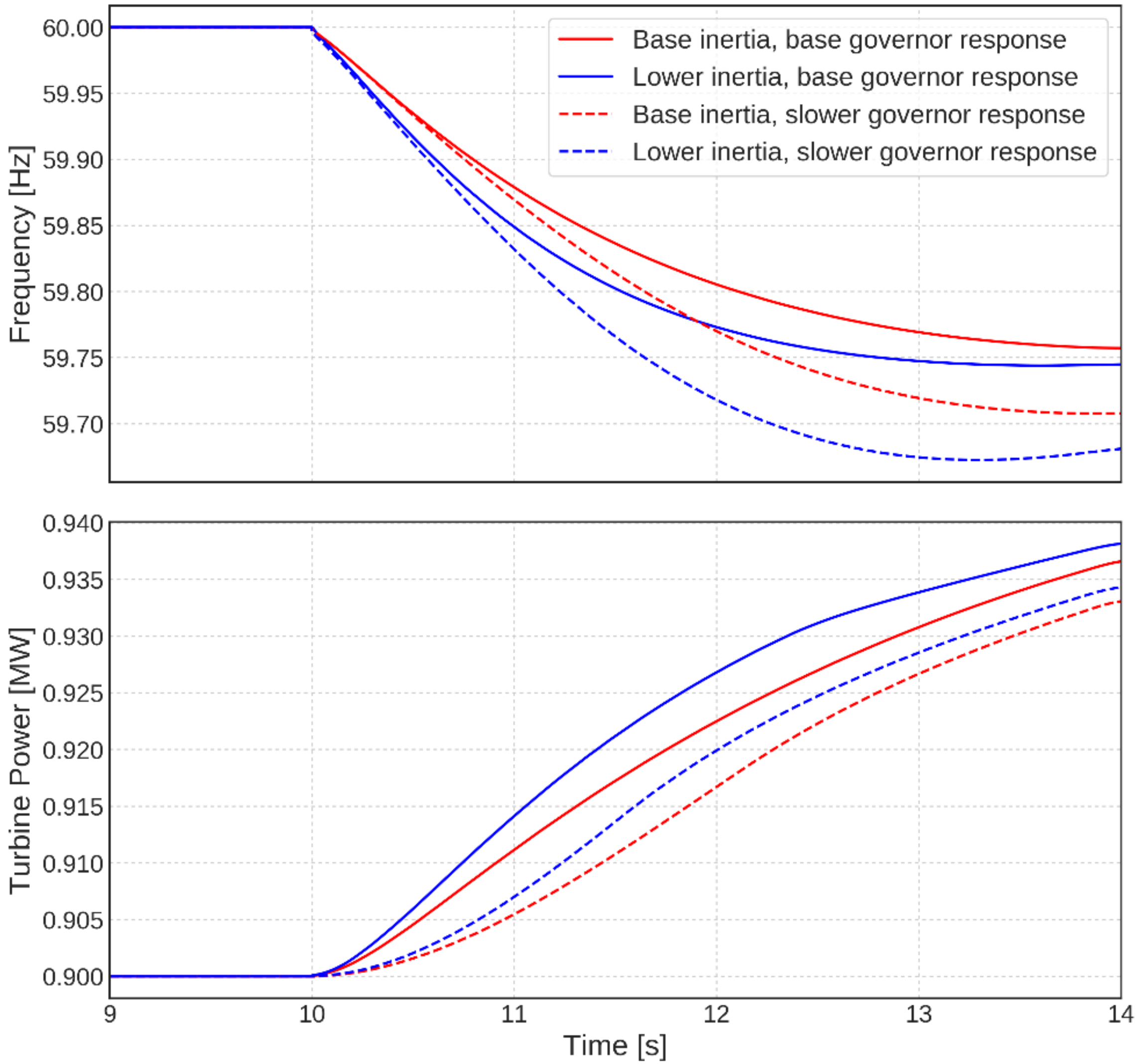
All generators, to the extent feasible, should be capable of providing sustained primary frequency response



Operational Requirements for Arresting Frequency

Finding 3:

For a given loss of generation, system inertia and the timing of primary frequency response determines how frequency is arrested

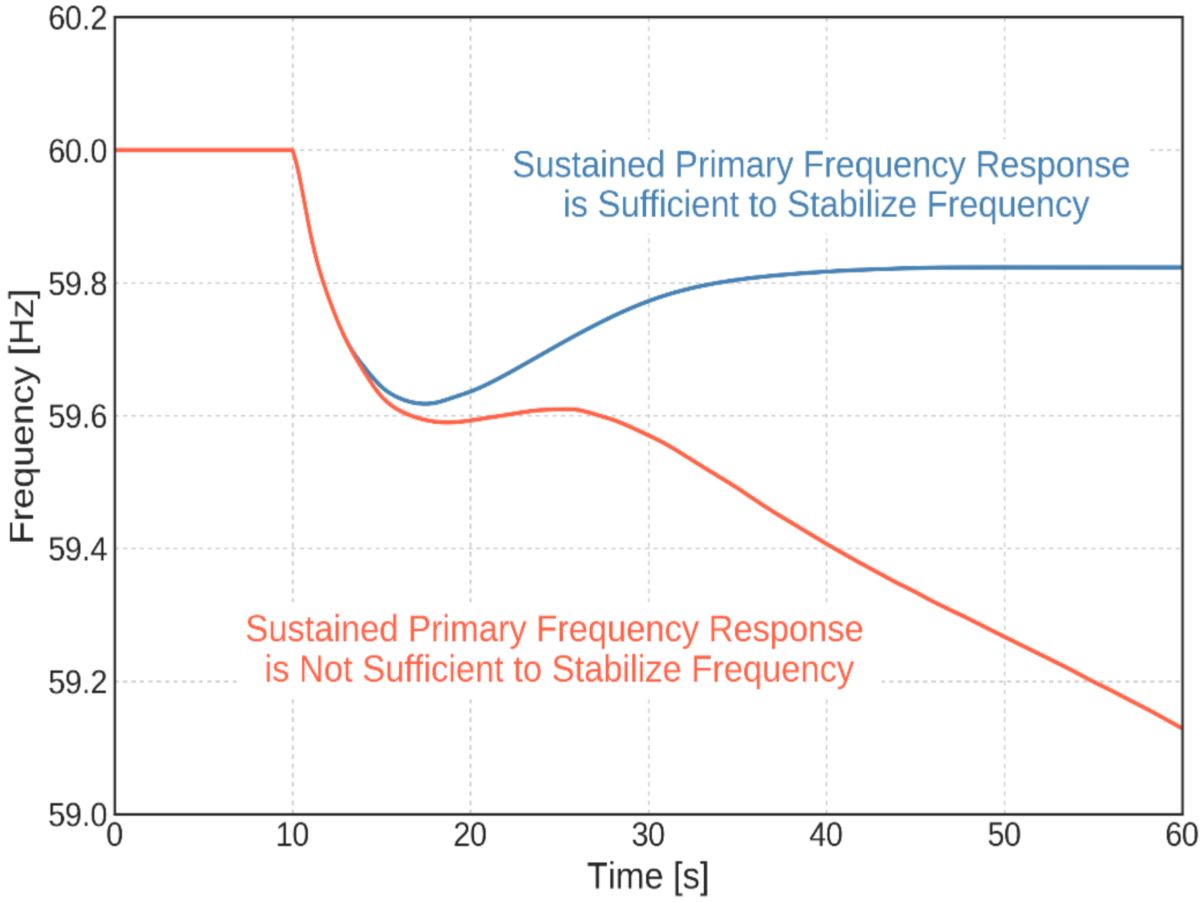


The Importance of Sustained Primary Frequency Response

Failure to sustain sufficient primary frequency response will trigger UFLS

Finding 4:

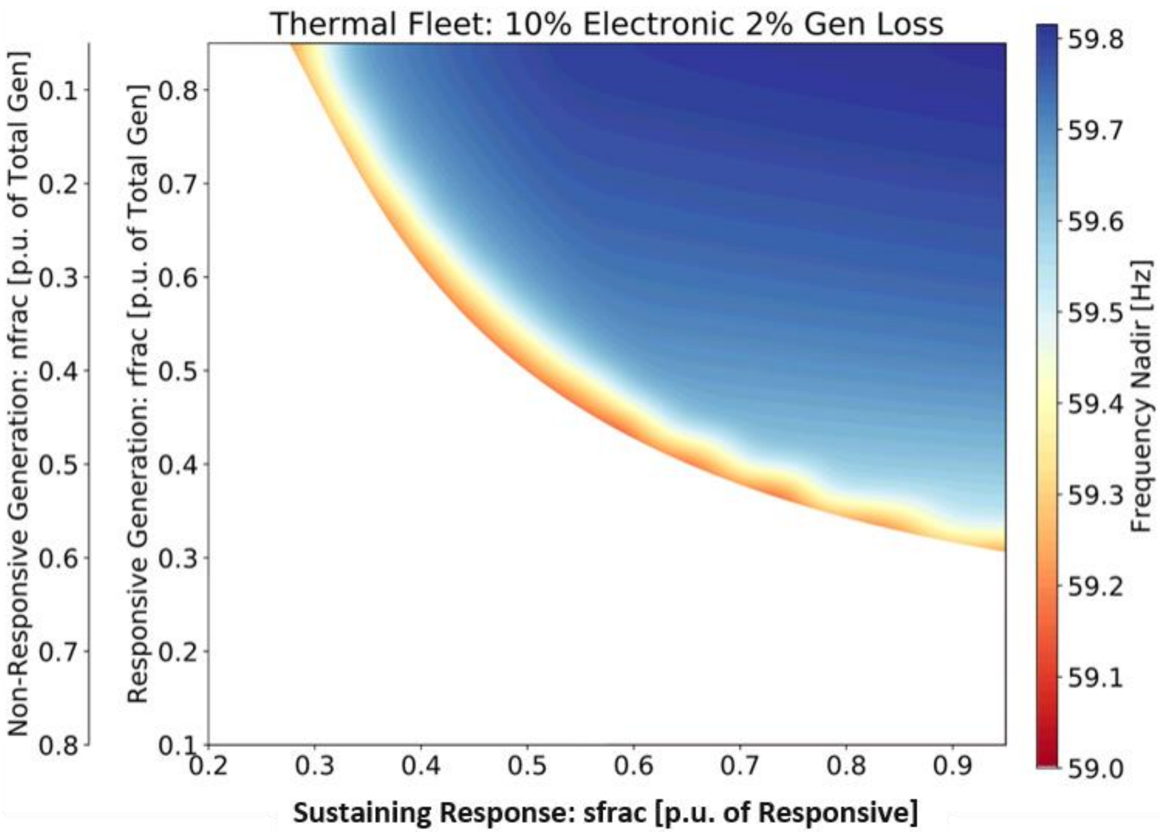
Primary frequency response must be sustained until secondary frequency response can replace it



Reliable Interconnection Frequency Response Depends on Responsive and Sustaining Primary Frequency Response

The study investigated the ability of the system to arrest the frequency decline as the function of proportion of generation in the interconnection that provides frequency control and that portion of responsive generation that provides a sustained response.

If it is anticipated that primary frequency response will not be sustained, more reserves of primary frequency response that will sustain must be kept on line

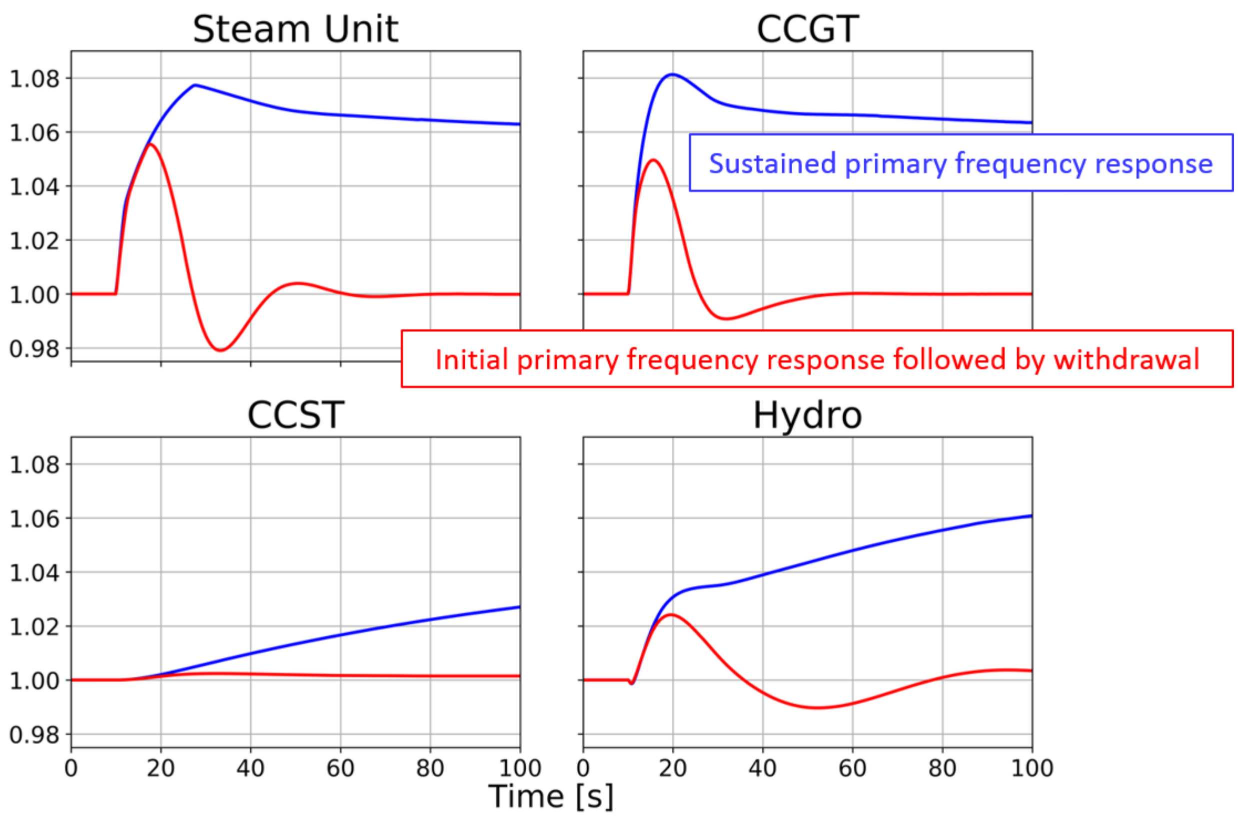


Note: White areas indicate combinations of responsive and sustaining generation that will not arrest frequency above 59Hz

Mechanisms for Non-Sustaining Primary Frequency Response: 1

Finding 5:

Plant load controllers operated in pre-selected load mode without frequency bias will withdraw and not sustain primary frequency response



Note: On these graphs, the frequency response event and the turbine-governor response begin at T = 10 seconds

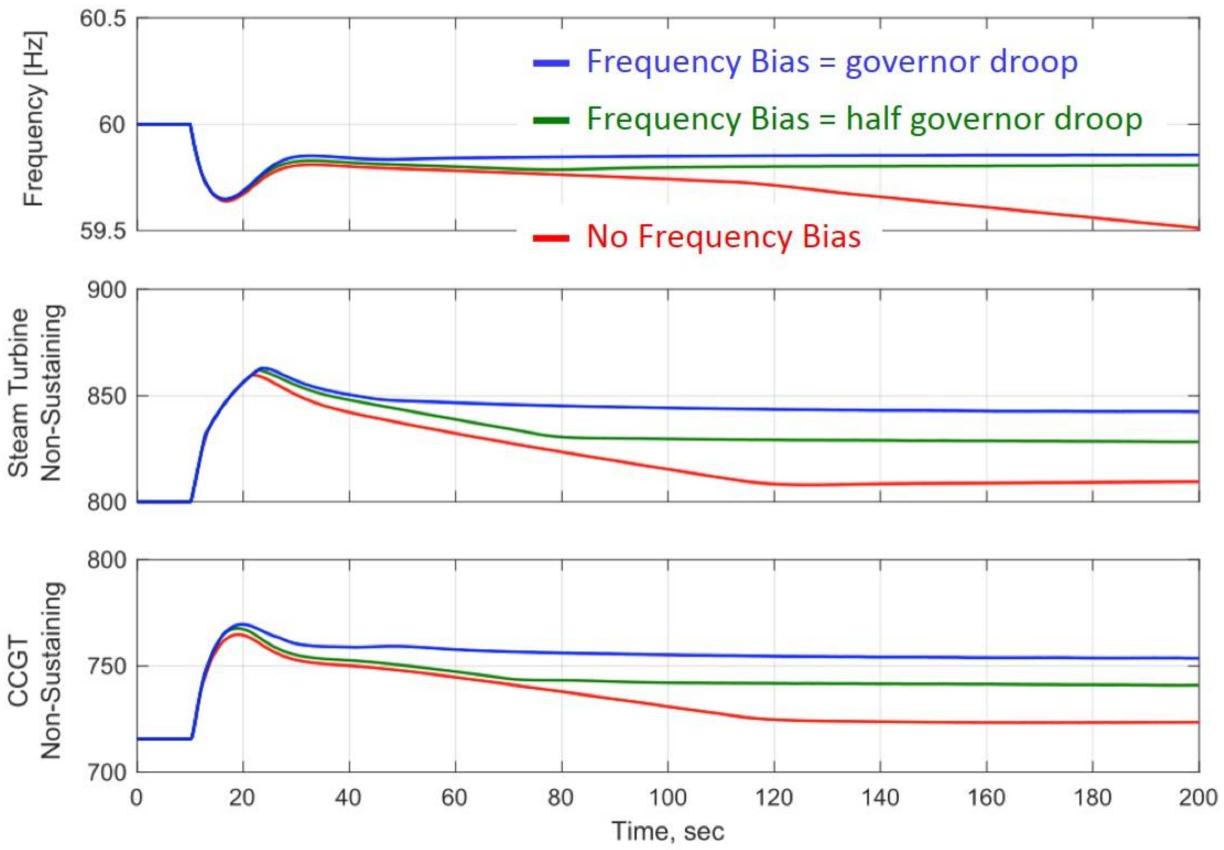
Addressing One Form of Non-Sustaining PFR

Finding 6:

Plant load controllers operated in pre-selected load mode with frequency bias* will sustain primary frequency response

Recommendation:

Barriers to adding a frequency bias to plant load controllers should be evaluated and addressed



** Not to be confused with the "Frequency Bias" term used in the ACE equation for tie-line control*

Study Findings 7-9

Finding 7: Gas turbines may not be able to sustain primary frequency response following large loss-of-generation events

Finding 8: "Synthetic inertia" controls on electronically coupled wind generation appear not to sustain primary frequency response

Finding 9: Fast demand response provides robust primary frequency response, but currently is inflexible

> **Recommendation:** *The contributions of non-traditional resources for primary frequency control (fast demand response, energy storage, and other forms of electronically coupled loads and generation, including wind and solar photovoltaic) should be studied and incorporated, as appropriate, into future operations*

Study Findings 10-11

Finding 10: Smaller deadbands on turbine-governors increase how quickly delivery of primary frequency response will begin

- Large deadbands (>300 mHz) prevent delivery of primary frequency response
- Consistent deadbands support equitable response among generators

Finding 11: Load sensitivity currently complements primary frequency response, but this sensitivity may be going away

Recommendation: *Track and address factors that are negatively influencing the sensitivity of loads to frequency*

Cross-Cutting Recommendation 1

Focused attention should be directed to understanding the aggregate frequency control performance required of the fleet of resources that must be kept on-line at all times to respond to generation-loss events. This will involve collection, maintenance, and validation of the data necessary for accurate planning and operating studies as well as collection of comprehensive data to measure trends in interconnection frequency control.

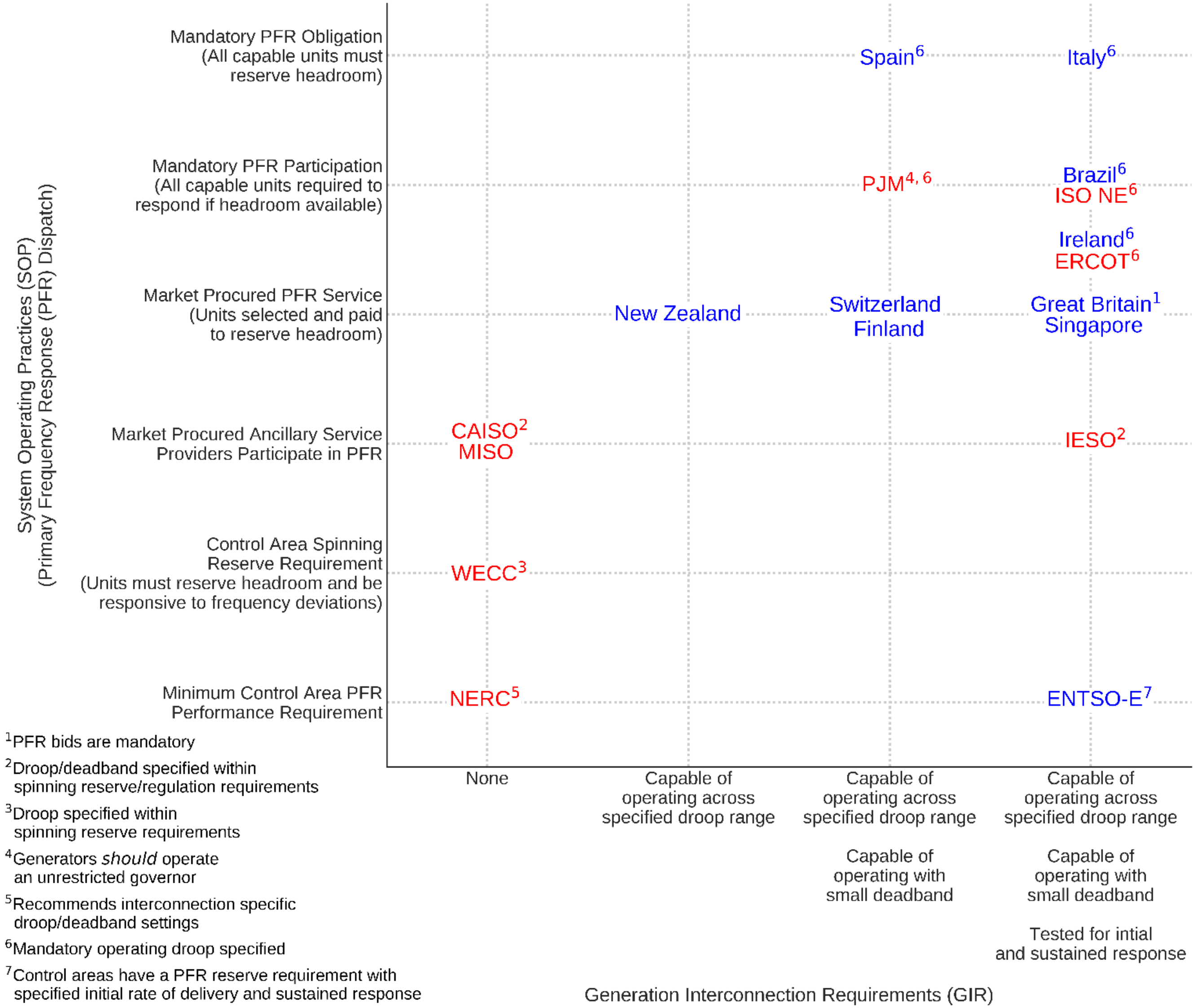
In addition to consideration of interconnection loading and inertia, this will involve taking explicit account of generator headroom and governor performance characteristics, and, directly related to these considerations, the number and location of sources relied on to provide primary frequency response.

With respect to non-governor-based sources of primary frequency response, this will require accounting for the comparable performance characteristics of these non-traditional sources that describe the quantity, speed, and in the case of load the triggering conditions of their primary control actions.

For all sources, this will also involve explicit consideration of the factors that might cause primary frequency response to not be sustained, which may lead to the need to deploy additional or distinct sources of sustaining primary frequency response.

Cross-Cutting Recommendation 2

International practices should be reviewed as options for U.S. grid operators to consider adopting to ensure continued reliable interconnection frequency response



List of Reports

- Eto, J. H., J. Undrill, C. Roberts, P. Mackin, and J. Ellis (2018). *Frequency Control Requirements for Reliable Interconnection Frequency Response.* Berkeley: Lawrence Berkeley National Laboratory.
- Undrill, J.M. (2018). *Primary Frequency Response and Control of Power System Frequency.* Berkeley: Lawrence Berkeley National Laboratory.
- Undrill, J.M., P. Mackin, and J. Ellis. (2018). *Relating the Microcosm Simulations to Full Scale Grid Simulations.* Berkeley: Lawrence Berkeley National Laboratory.
- Roberts, C. (2018). *Review of International Grid Codes*. Berkeley: Lawrence Berkeley National Laboratory.

https://certs.lbl.gov/project/interconnection-frequency-response

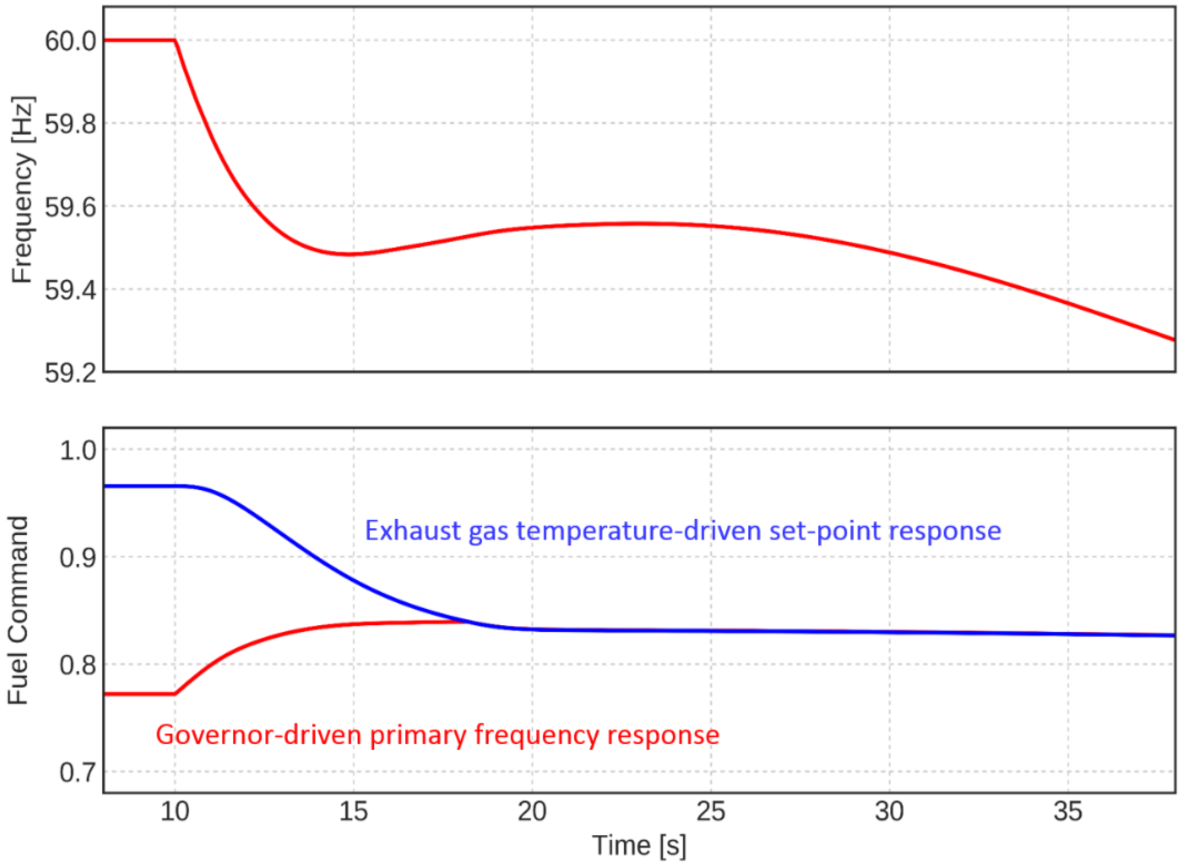
THANK YOU

Joe Eto
Lawrence Berkeley National Laboratory
jheto@lbl.gov
510 486 7284

Mechanisms for Non-Sustaining Primary Frequency Response: 2

Finding 7:

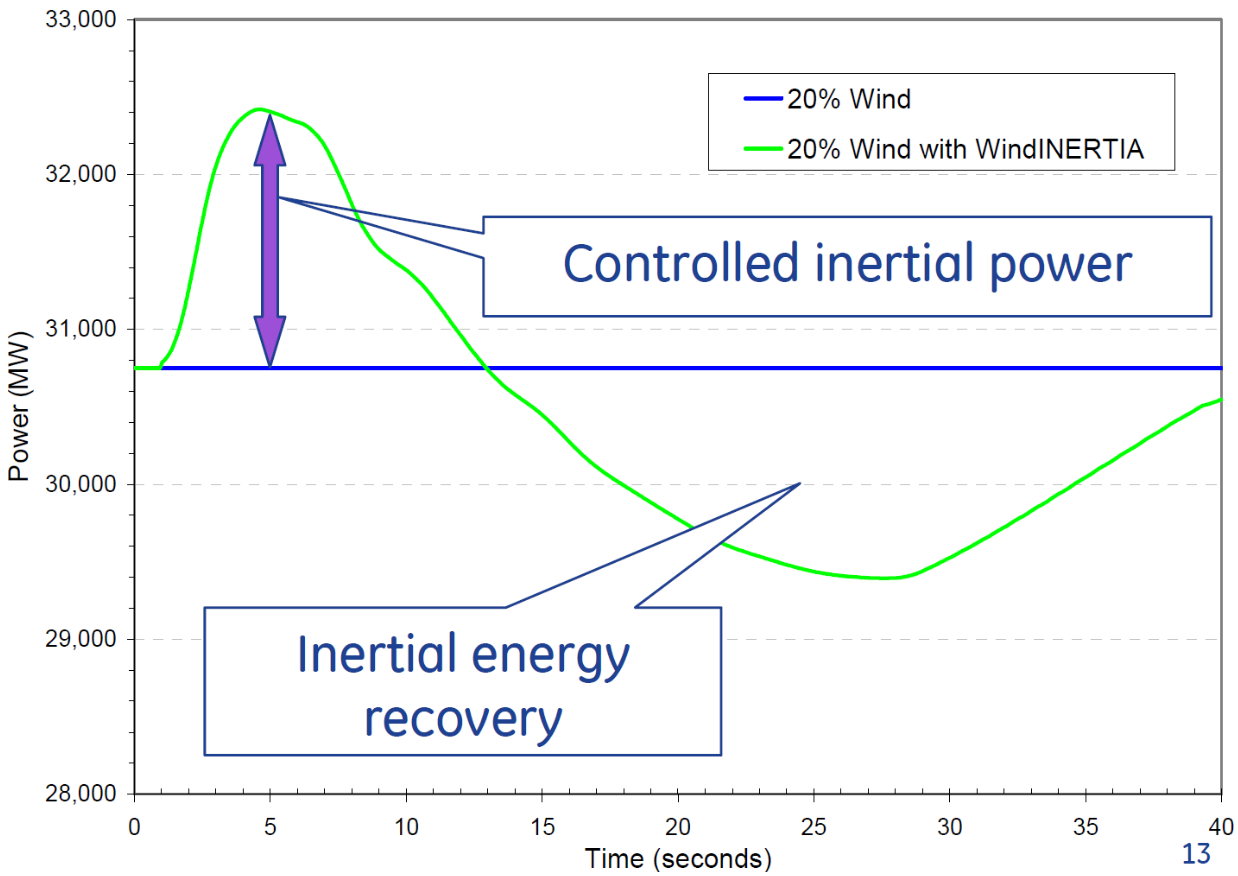
Gas turbines may not be able to sustain primary frequency response following large loss-of-generation events



Mechanisms for Non-Sustaining Primary Frequency Response: 3

Finding 8:

"Synthetic inertia" controls on electronically coupled wind generation appear not to sustain primary frequency response



Source: GE Energy, Impact of Frequency Responsive Wind Plant Controls on Grid Performance (December 2010)

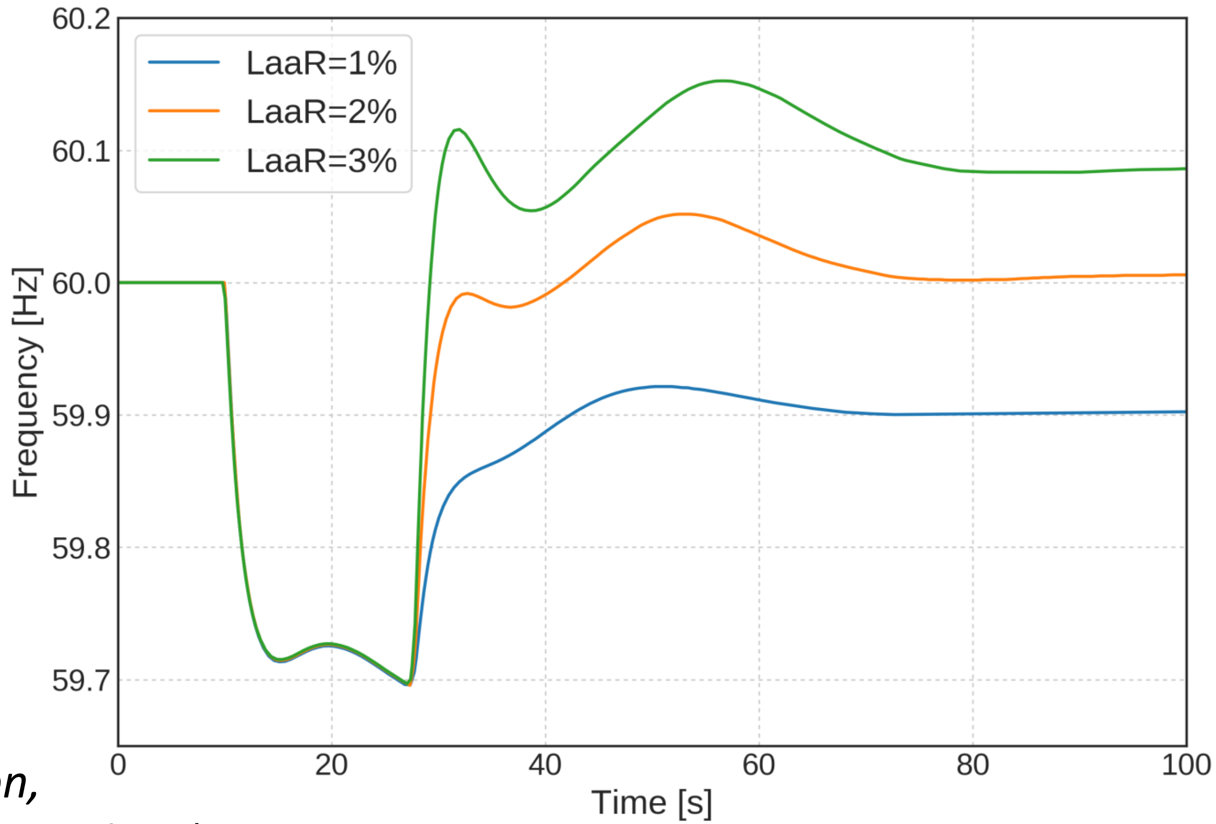
Fast Demand Response Augments Primary Frequency Response

Finding 9:

Fast demand response provides robust primary frequency response, but currently is inflexible

Recommendation:

The contributions of non-traditional resources for primary frequency control (fast demand response, energy storage, and other forms of electronically coupled loads and generation, including wind and solar photovoltaic) should be studied and incorporated, as appropriate, into future operations



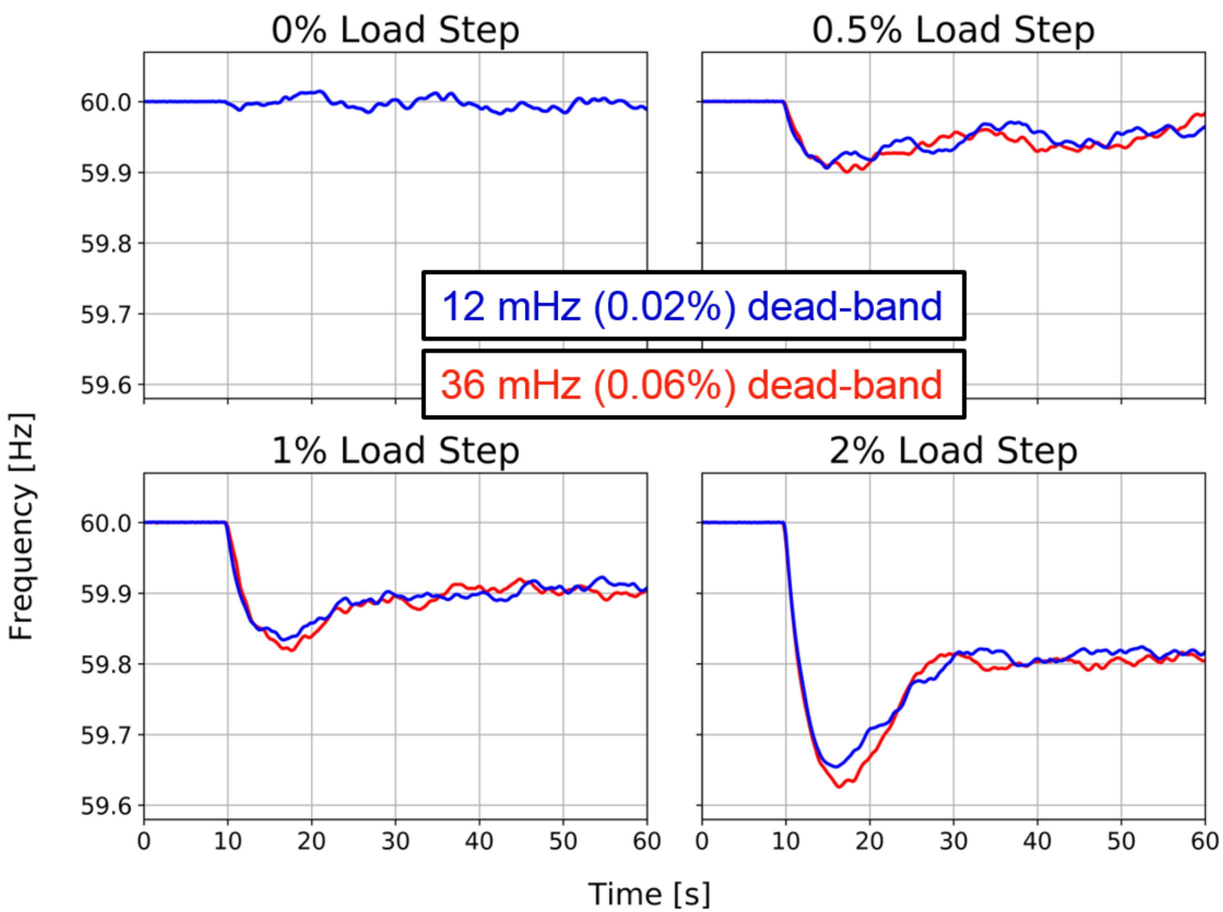
Governor Deadbands

Finding 10:

Smaller deadbands on turbine-governors increase how quickly delivery of primary frequency response will begin

Large deadbands (>300 mHz) prevent delivery of primary frequency response

Consistent deadbands support equitable response among generators



The Changing Sensitivity of Loads to Frequency

Finding 11:

Load sensitivity currently complements primary frequency response, but this sensitivity may be going away

Recommendation:

Track and address factors that are negatively influencing the sensitivity of loads to frequency