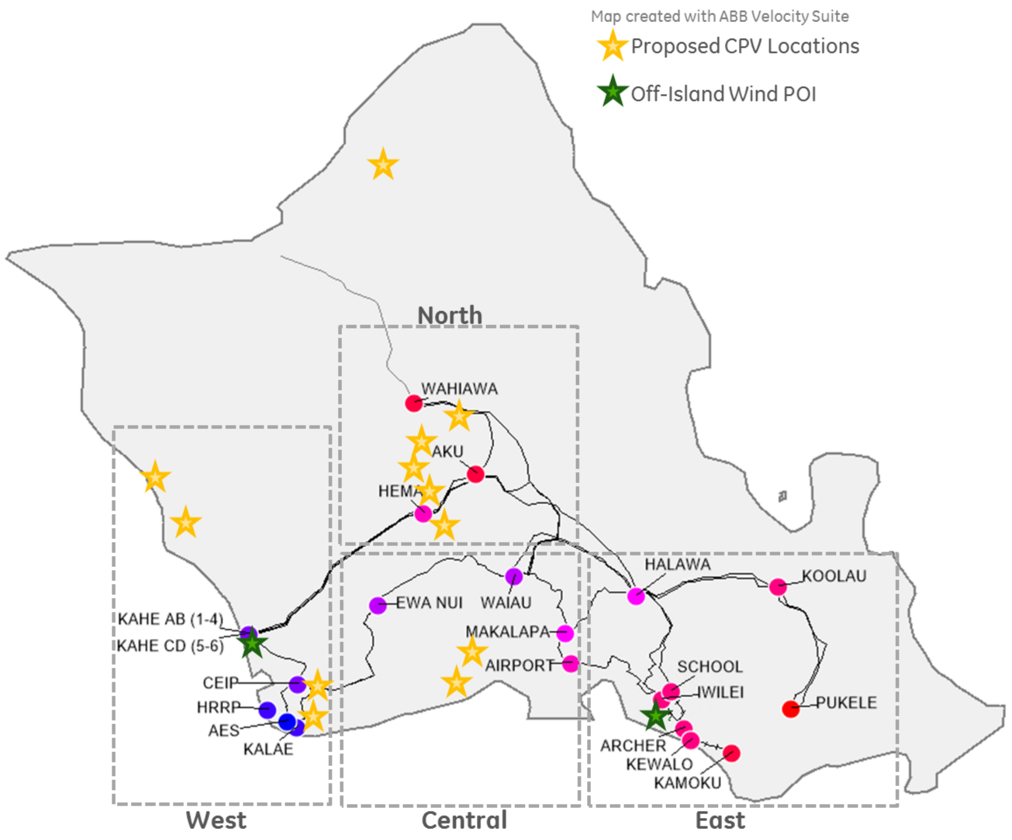
ESIG Tutorial – Part 2
Small System Analysis
GE Energy Consulting

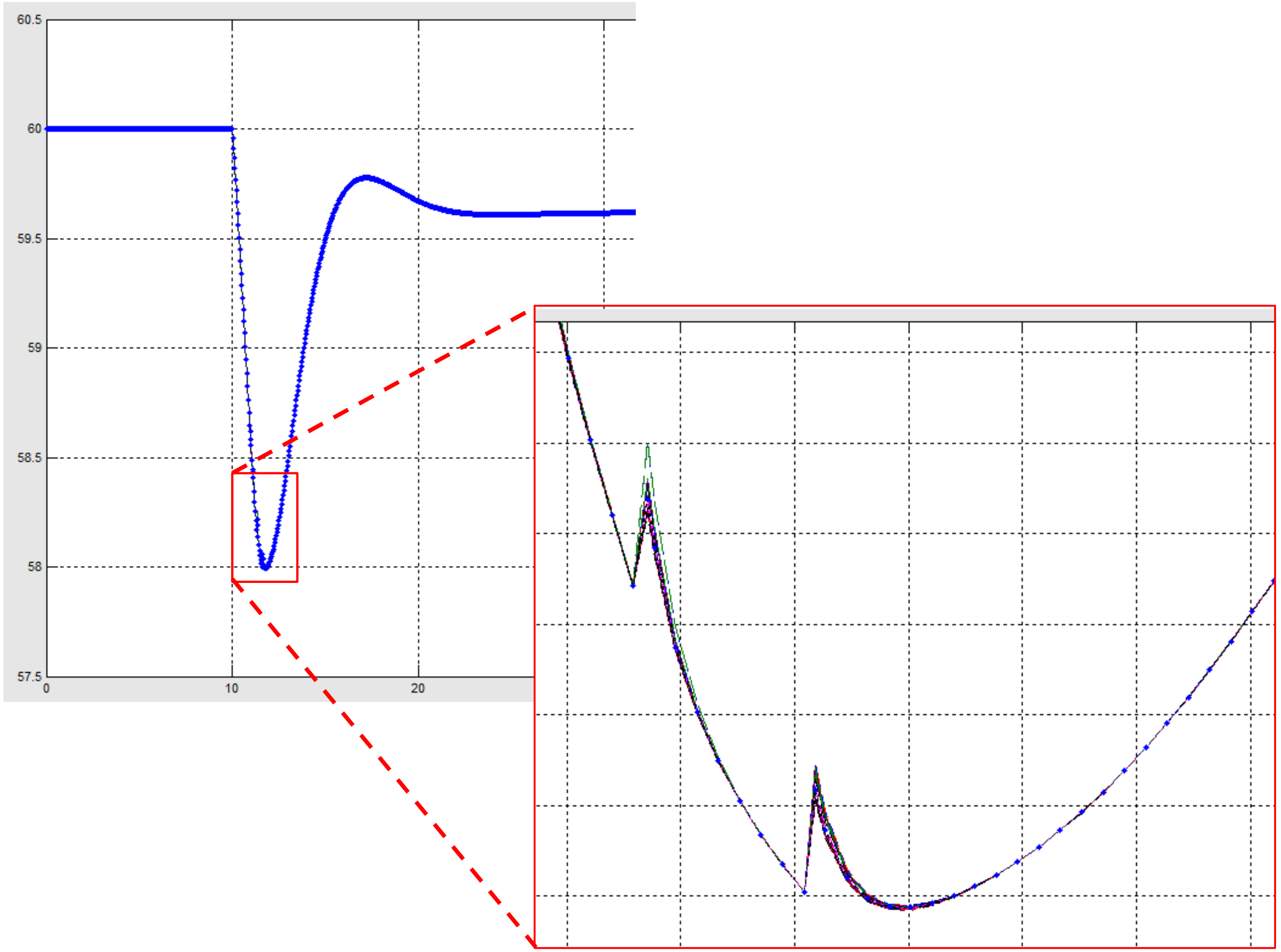
Denver, October 2018

Agenda

1. System Context
2. FFR Modeling
3. Sensitivities & Results
    1. Speed of response
    2. Tuning of FFR
    3. Rating of FFR
4. Impact & Coordination with the Thermal Fleet

Oahu – A Tightly-Coupled System

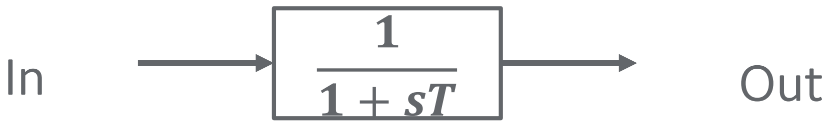




Frequency trace of every high-voltage bus on the system

Method of FFR Response

- FFR response delayed through a 1st order lag



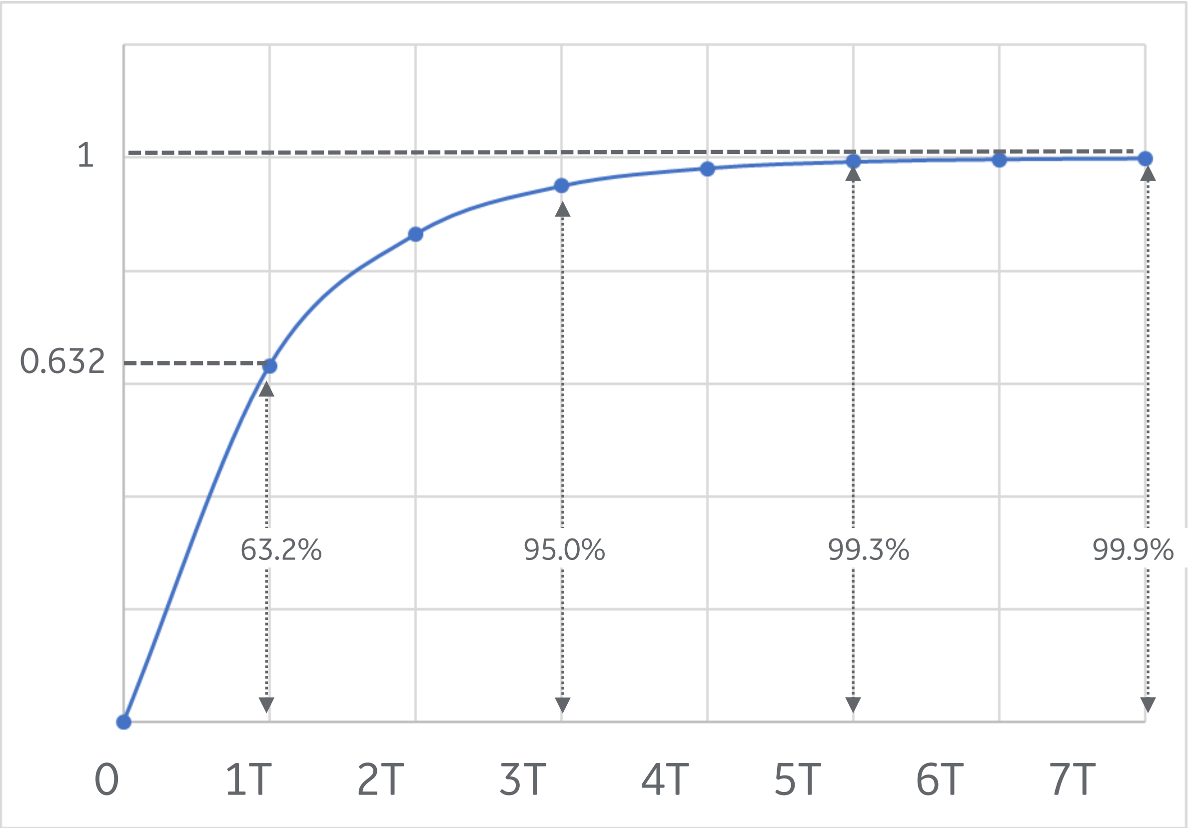
1st order lag block diagram

- 3T time constant used to reach 95% response
  - 12 cycle delay → 0.2 sec to reach 95% response
  - 30 cycle delay → 0.5 sec to reach 95% response
  - 360 cycle delay → 6 sec to reach 95% response

- HECO FFR Proposal - Frequency Response is needed to stabilize system frequency immediately following a sudden loss of generation or load. The response occurs within 12 to 30 cycles and allows time for other offline and online resources to respond or be deployed.

- ERCOT defines FFR as "a response from a resource that is automatically self-deployed and provides a **full response within 30 cycles** after frequency meets or drops below a preset threshold."
- http://www.ercot.com/content/meetings/fast/keydocs/2013/1024/ERCOT_AS_Concept_Paper_Version_1_0_as_of_9-27-13_1745.doc

$$Y = Y_o(1 - e^{\frac{-t}{T}})$$



Exponential Response Curve

Cases	Time Constant (T)
12 Cycles	.067
30 Cycles	.167
360 Cycles	2

FFR Injection Speed

Scenario

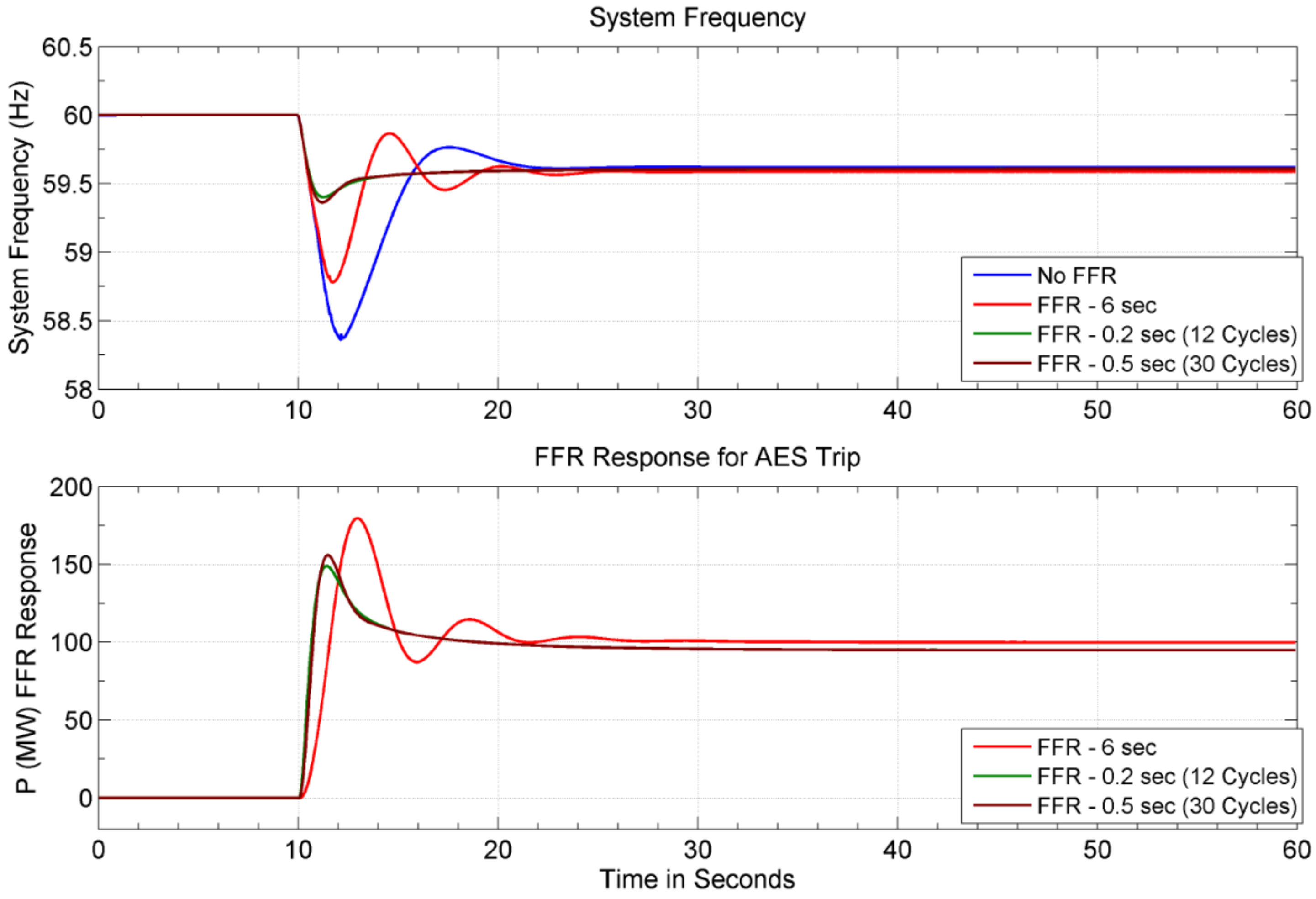
- Simulated July 2015 AES Trip event
- Assumed FFR of 200MVA w/ 1.25% droop

Comments

- FFR response is proportional to frequency change
- FFR increases nadir
- Significant difference between 6 second nadir and 12 cycle and 30 cycle nadir
- 12 cycle nadir + 30 cycle nadir show insignificant differences
- Initial FFR responses are high power, low energy

Case	Nadir (Hz)	RoCoF (Hz/s)
No FFR	58.36	0.96
360 Cycles	58.80	0.92
12 Cycles	59.40	0.83
30 Cycles	59.36	0.83

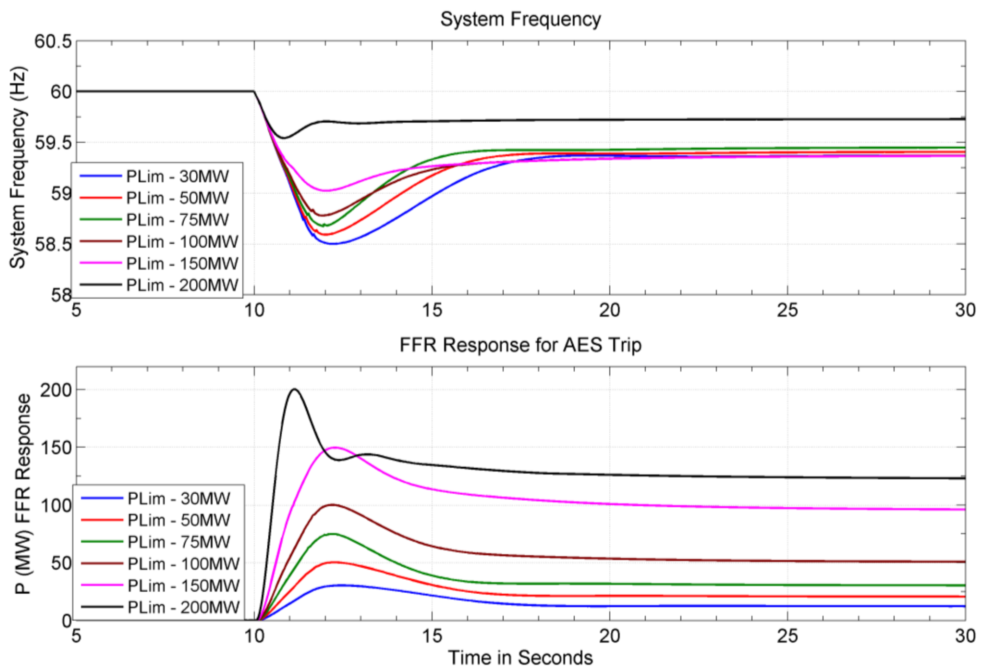
Oahu – AES Generator Trip Event



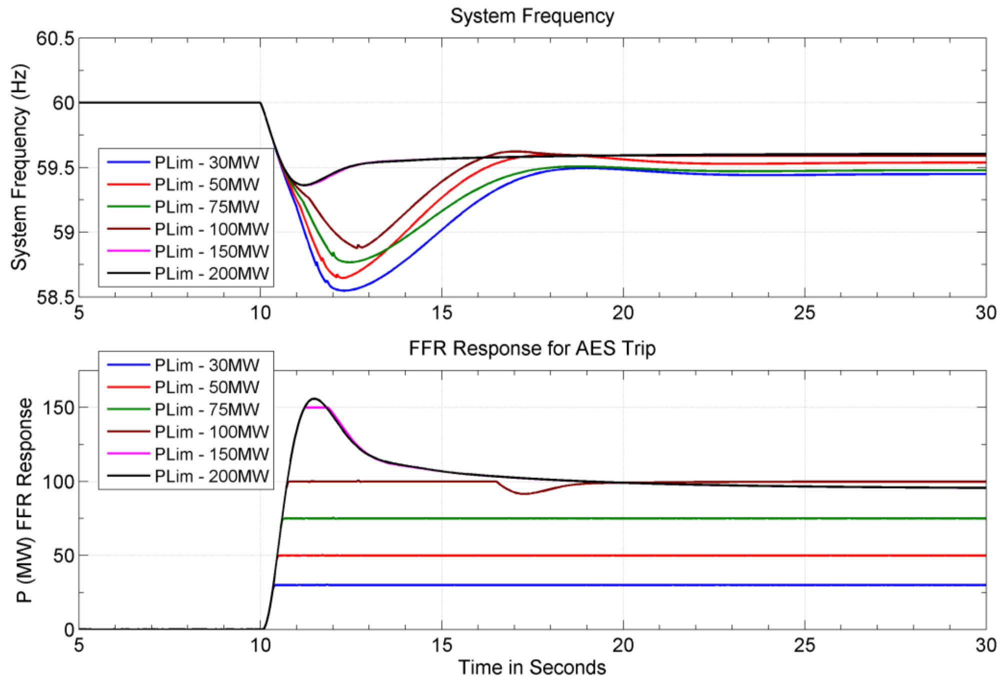
FFR Injection Control

The control of FFR is critical. Trade-offs include:

- Being stable for all conceivable operating conditions
- Being aggressive to maximize the benefit of the hardware installed



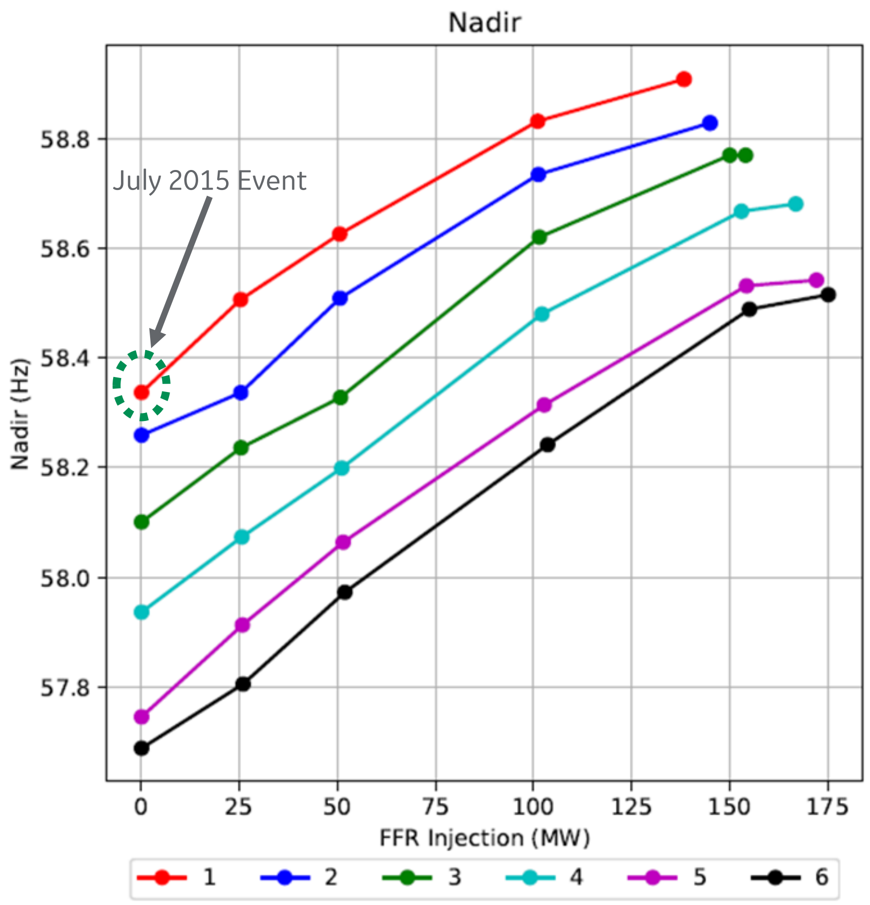
Less-aggressive FFR tuning



Aggressive FFR tuning

FFR Impact on Nadir

- Increased injections of FFR improve nadir (positive slope trend)
- Benefit of FFR diminishes with slope (flattening curves)… this is a function of
    a) Contingency Size
    b) System Inertia
    c) Speed of FFR
- The plot can be viewed as cost-benefit graph for FFR, where nadir is the benefit and FFR injection is related to system cost

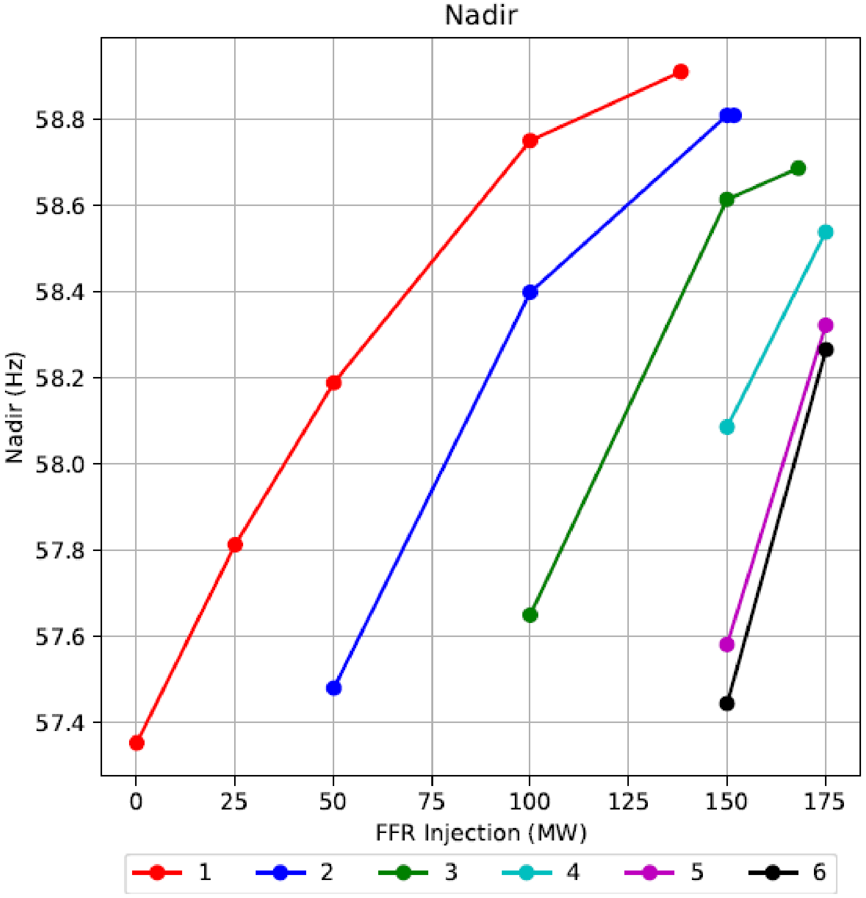


*UFLS On
*FFR Response with Baseline Controls

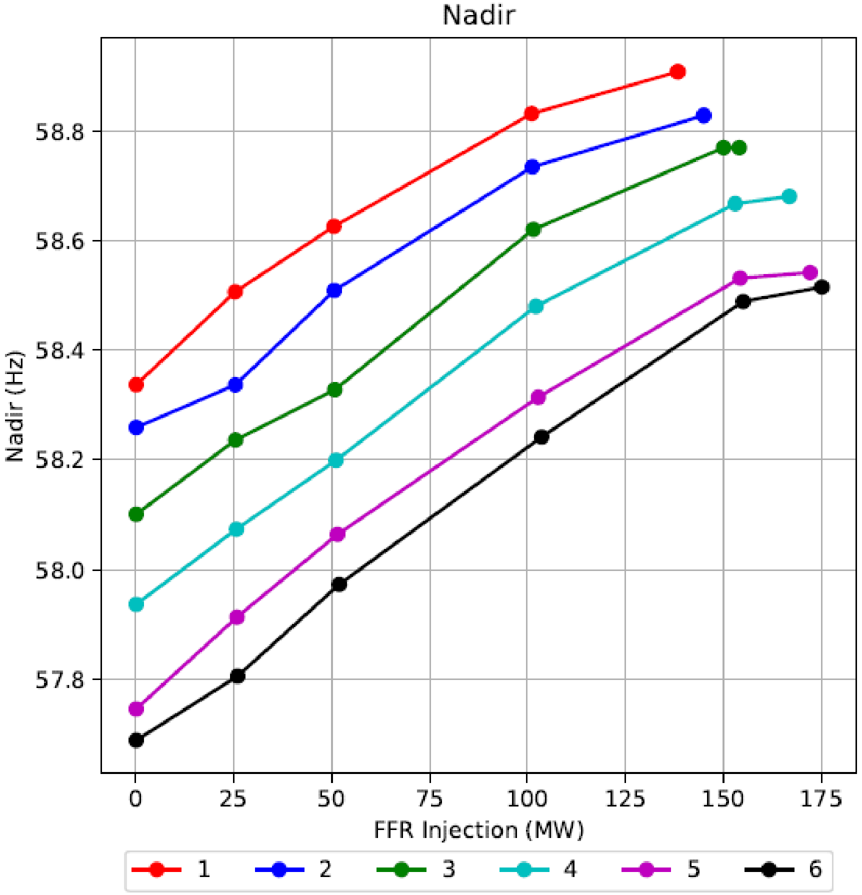
Nadir vs. FFR Rating – UFLS Sensitivity

- The steepness of the curves show the relative value
- UFLS and FFR are functionally similar
- These similar functions can be staggered in frequency so that UFLS is less likely to be called

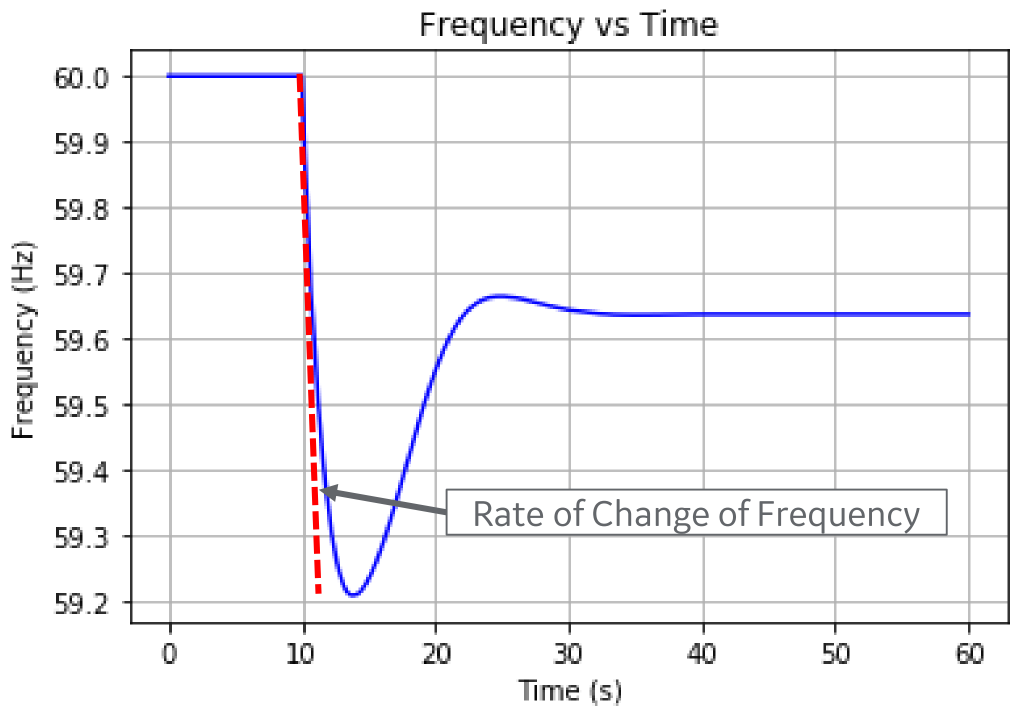
UFLS: Off

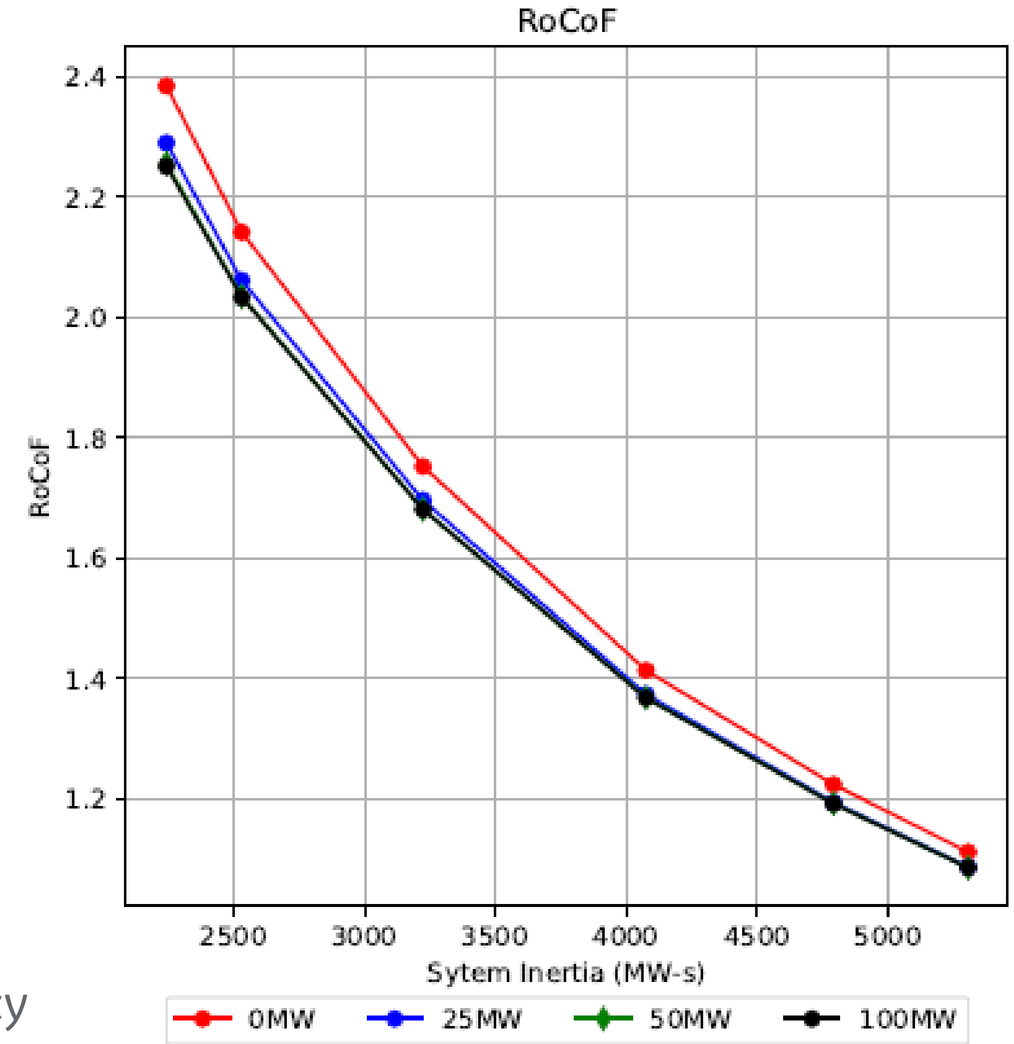


UFLS: On



FFR Impact on RoCoF



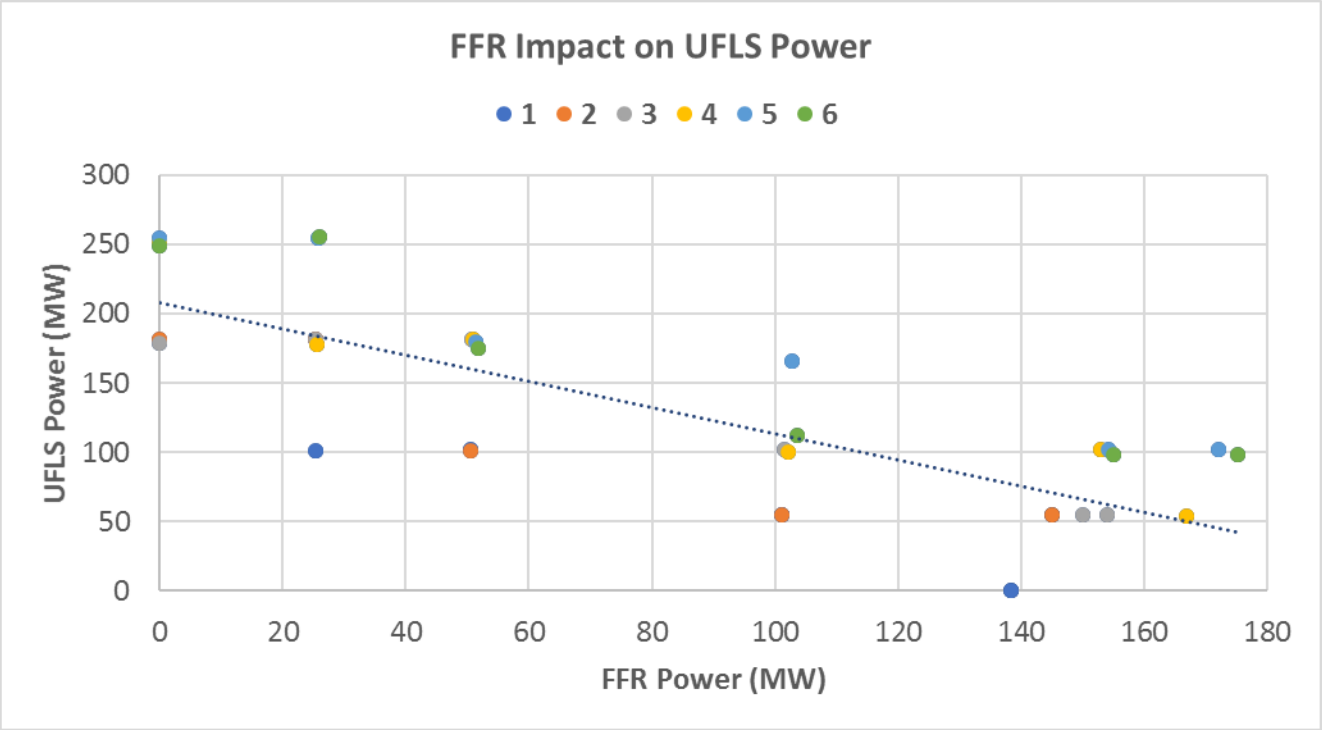


- FFR evaluated has little impact on RoCoF
- RoCoF is influenced by system inertia and contingency size
- In lower inertia systems, the impact of FFR on RoCoF is slightly more pronounced

*UFLS On
*FFR Response with Baseline Controls

UFLS and FFR Coordination

- FFR reduces the amount of under frequency load shedding required in a system
- Consistent with improving nadir

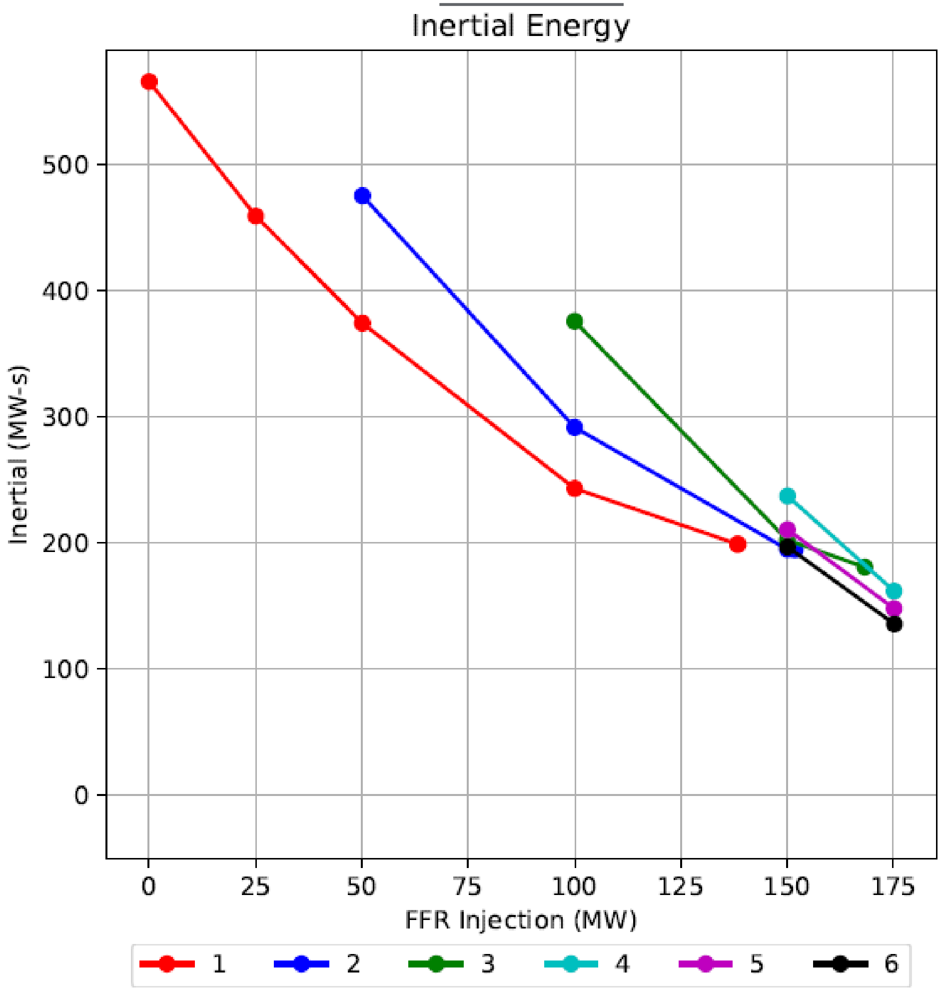


*UFLS On
*FFR Response with Baseline Controls

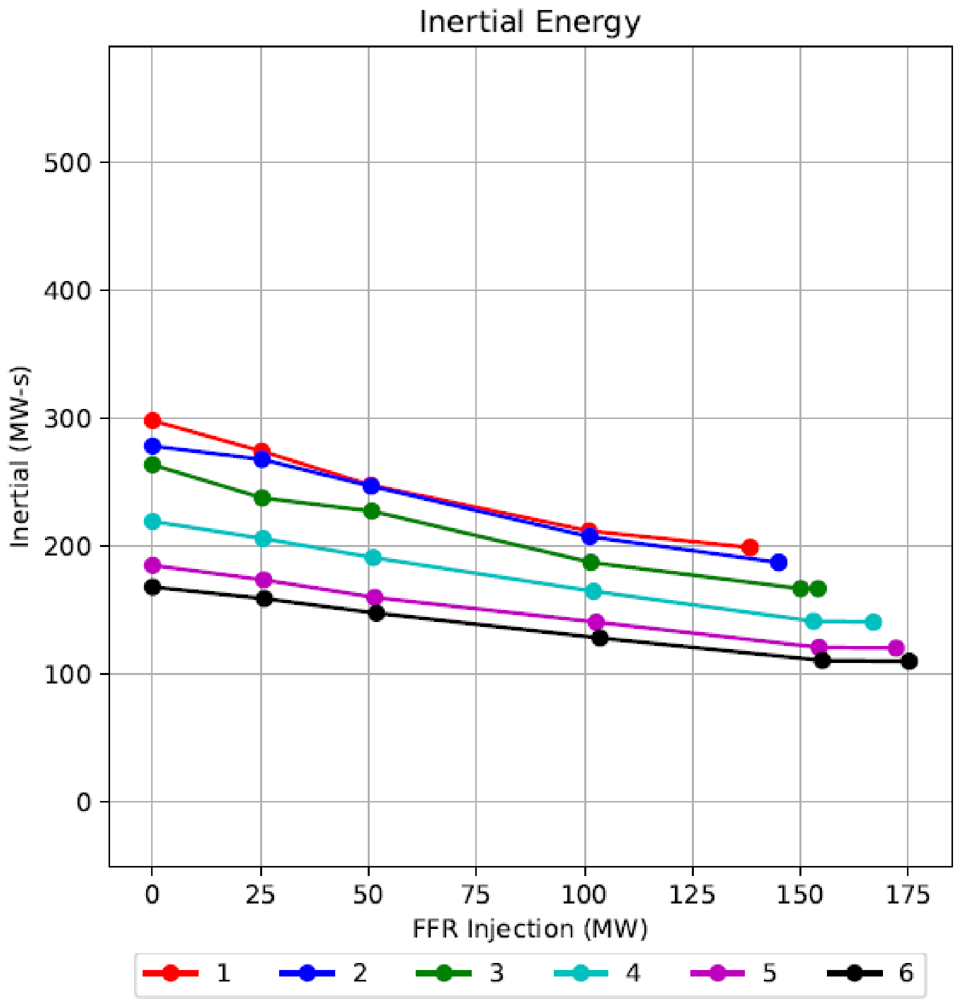
Inertial Energy vs FFR Injection

- FFR is displacing inertial energy within a scenario
- As system inertia decreases, less energy available before the nadir

UFLS: Off

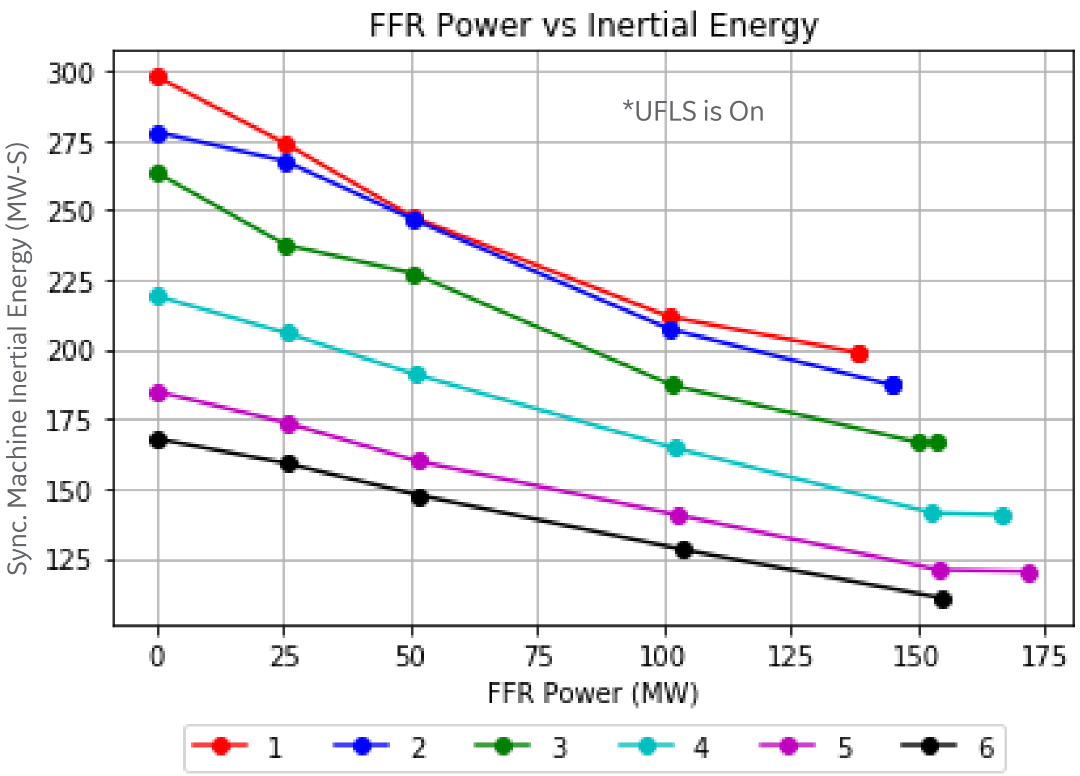


UFLS: On

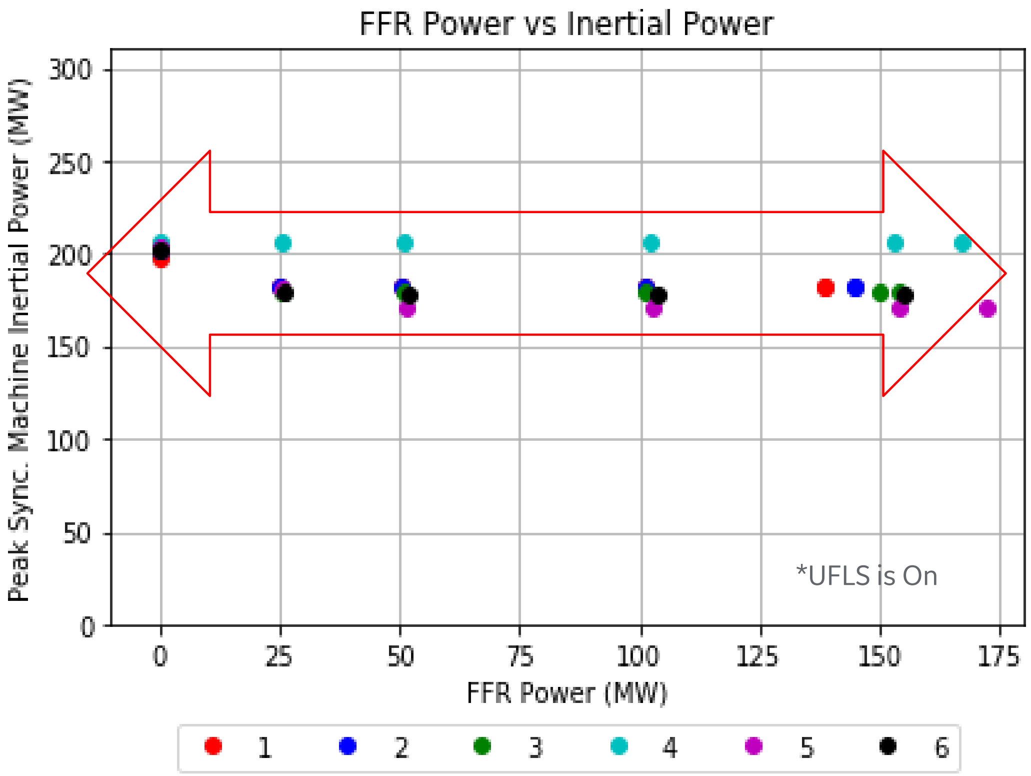


FFR Impact on the Thermal Fleet

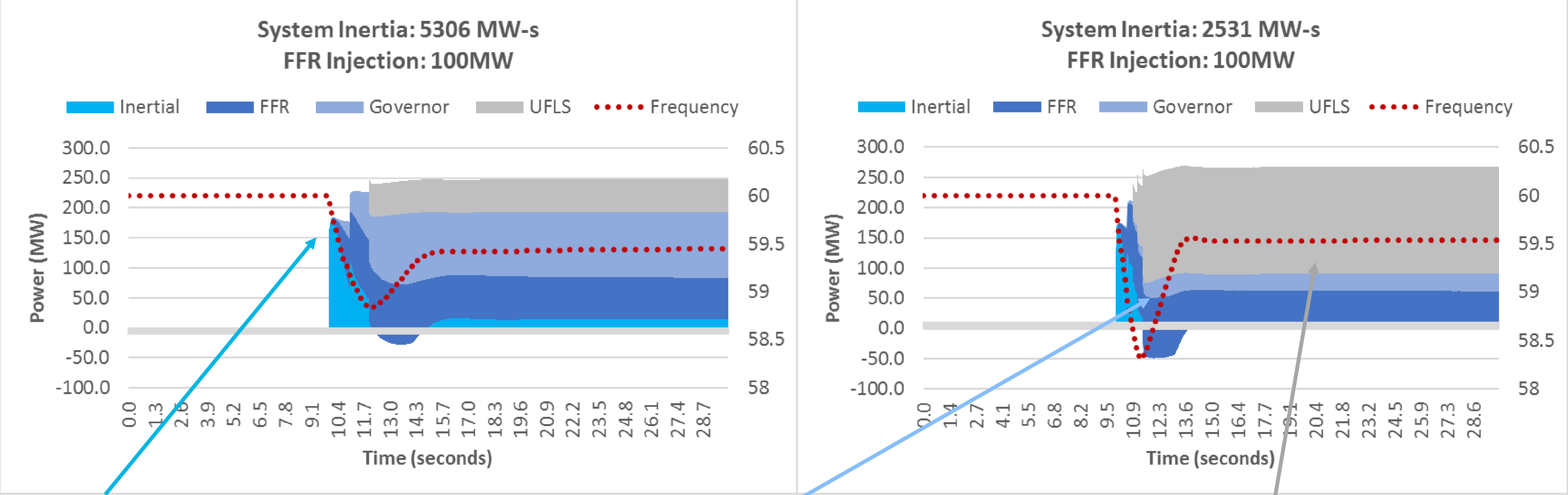
As more FFR Energy/ Power is injected into the system, the inertial energy from synchronous machines is displaced



Peak inertial power from synchronous machines stays near constant as system inertia decreases due to increasing RoCoF



System Response for Different Levels of System Inertia



Peak inertial power from synchronous machines is similar in both scenarios

Less governor response in lower inertia system, especially prior to nadir

- Fewer machines online
- System moves faster

Event is more severe without synchronous machines responding, so additional response is required. In this case, UFLS did most of the responding.

What if FFR did most of the responding...?

FFR Grid Service Analysis

Study Focus: Understanding the impact of various parameters and sensitivity on FFR responses in decreased low inertia systems

Scenarios	1	2	3	4	5	6
% Inst. Penetration	17%	20%	30%	39%	50%	53%
System Inertia (MW-s)	5306	4791	4075	3223	2531	2243

Sensitivity Parameters:

- Added Scenarios: 2, 3, 4, 6
- UFLS: On, Off
- FFR Injection Levels (MW): 0, 25, 50, 100, 150, 175
- FFR Response Type: 12 cycles, 30 cycles, GE Control
- Size of Generation Trip (MW): 200, 120, 60

Total # of Cases = 6 scenarios x 5 levels x 3 responses x 3 trip levels x 2 UFLS = 540 cases

Study details and results at tomorrow's presentation!

Backup

Oahu System Simulation Setup

FFR Injection Analysis

Scenario 1 (July 22, 2015 case)

- *17% Instantaneous Penetration*
- *Total system inertia = 5300 MW-s*
- Total Wind and Solar = 187.3 MW
- Total Generation = ~1075.2 MW
- Thermal Units Online = 13

Scenario 2

- *50% Instantaneous Penetration*
- *Total system inertia = 2500 MW-s*
- *Total Wind and Solar = 542.3 MW*
- *Total Generation = ~1075.2 MW*
- *Thermal units online = 7*

Note: Total System Inertia calculated without AES

Simulation Format

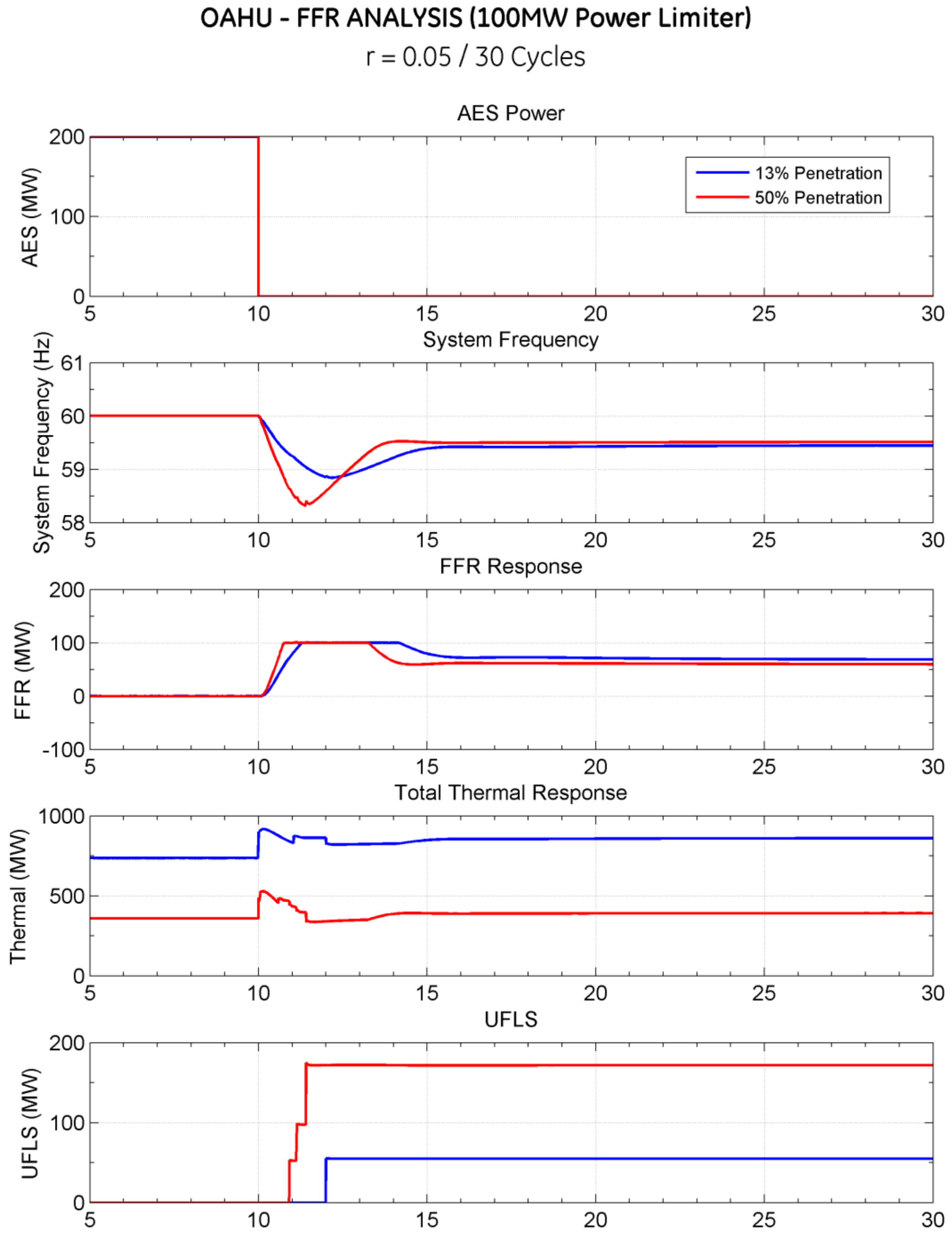
AES Unit (200MW Trips) at 10 seconds →

System frequency declines →

100MW FFR Injection (trip response) →

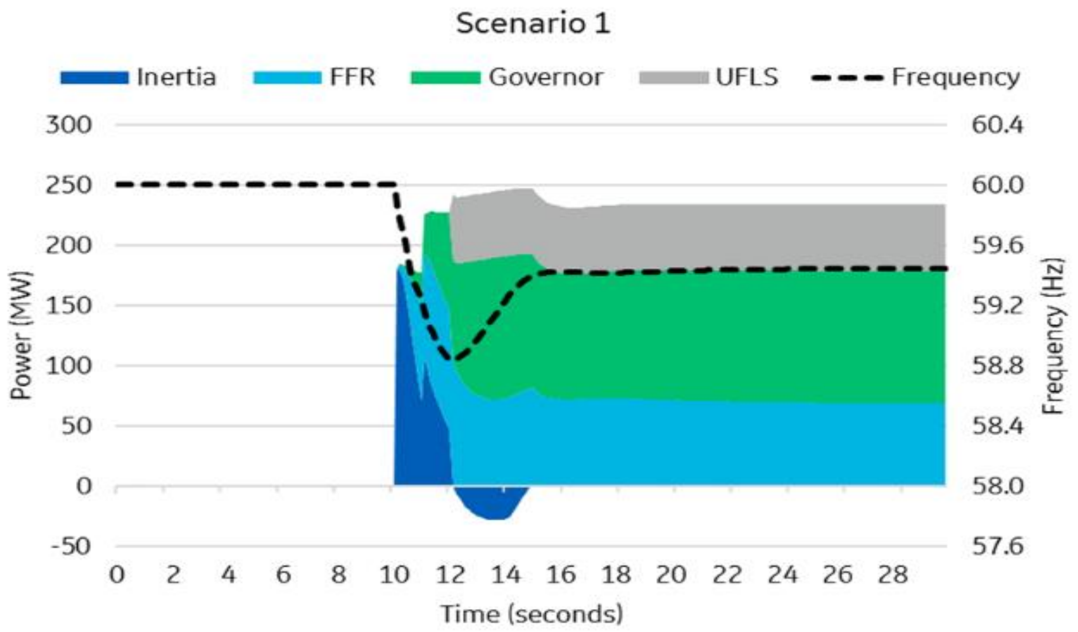
Total thermal units response →

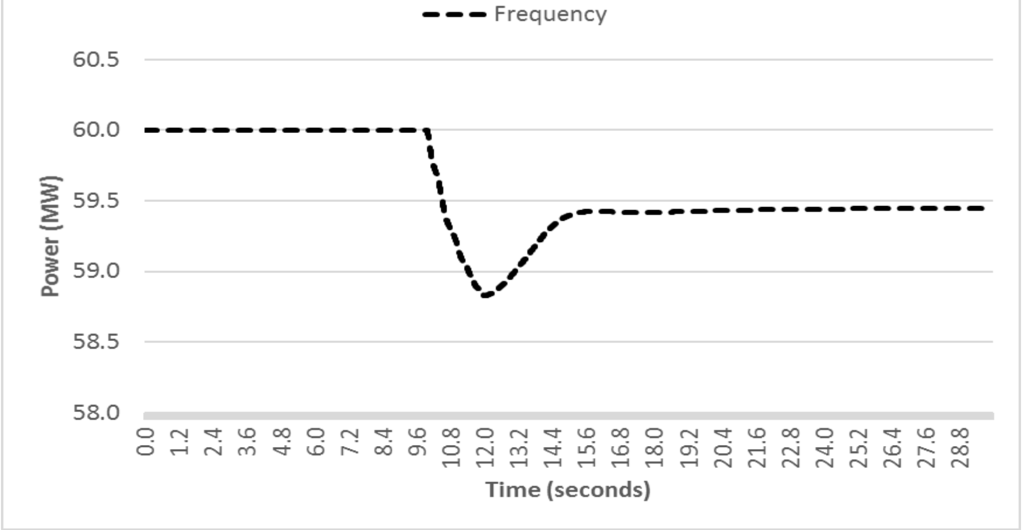
UFLS is triggered →



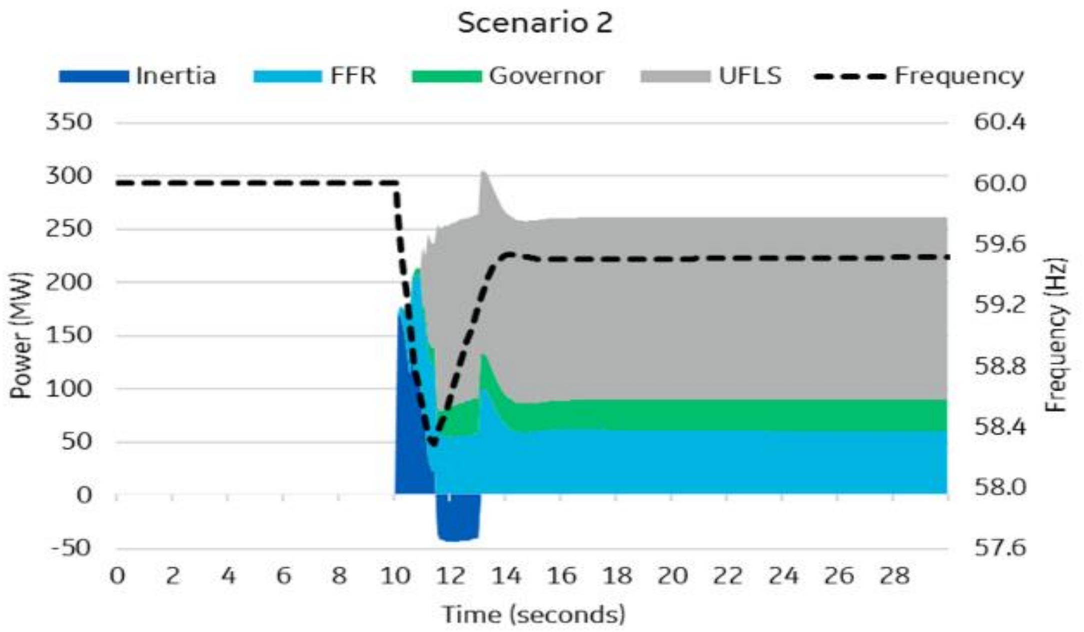
Deconstructing Frequency Response

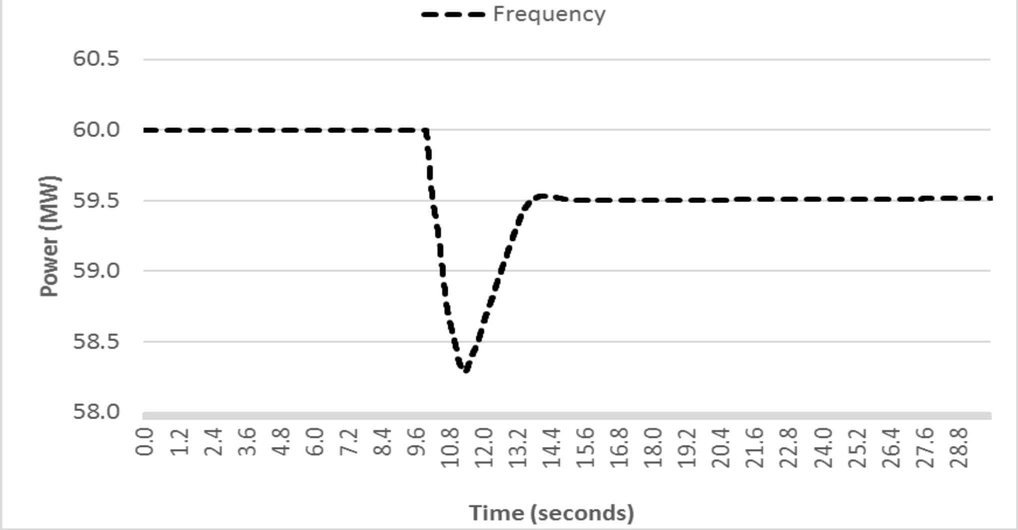
Scenario 1: 17% Inst. Penetration





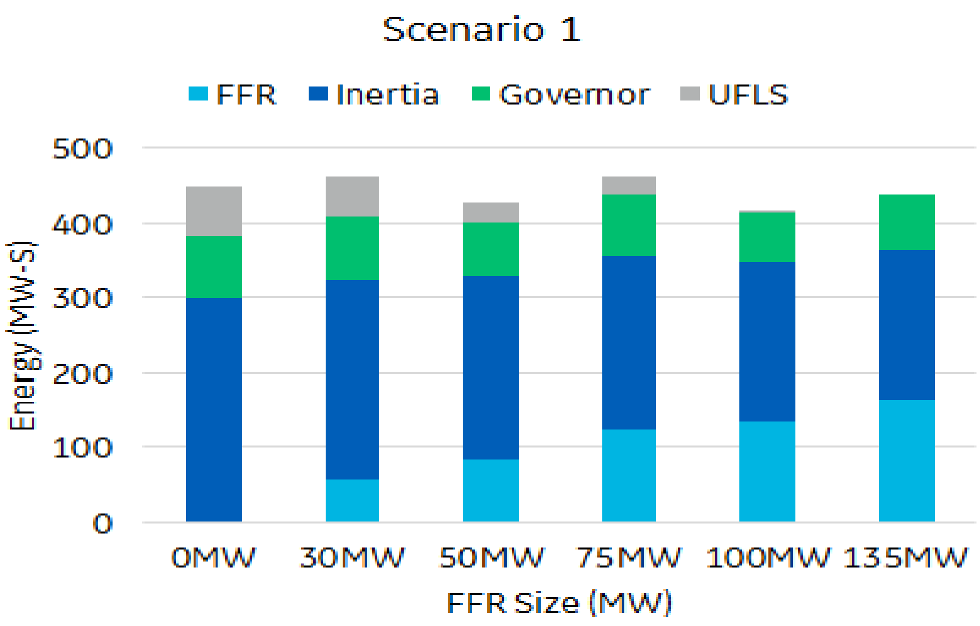
Scenario 2: 50% Inst. Penetration

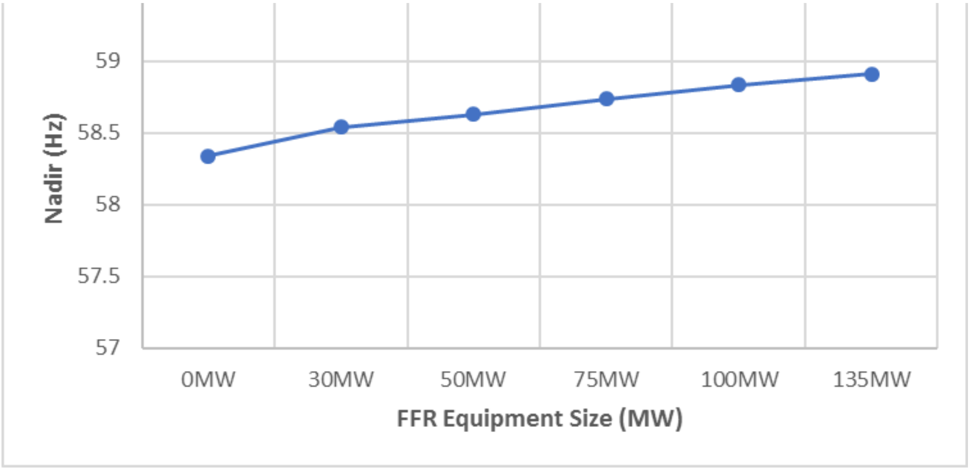




Total Arresting Energy

Scenario 1: 17% Inst. Penetration





Scenario 2: 50% Inst. Penetration