Comparison of FFR to Synchronous Machines Sources

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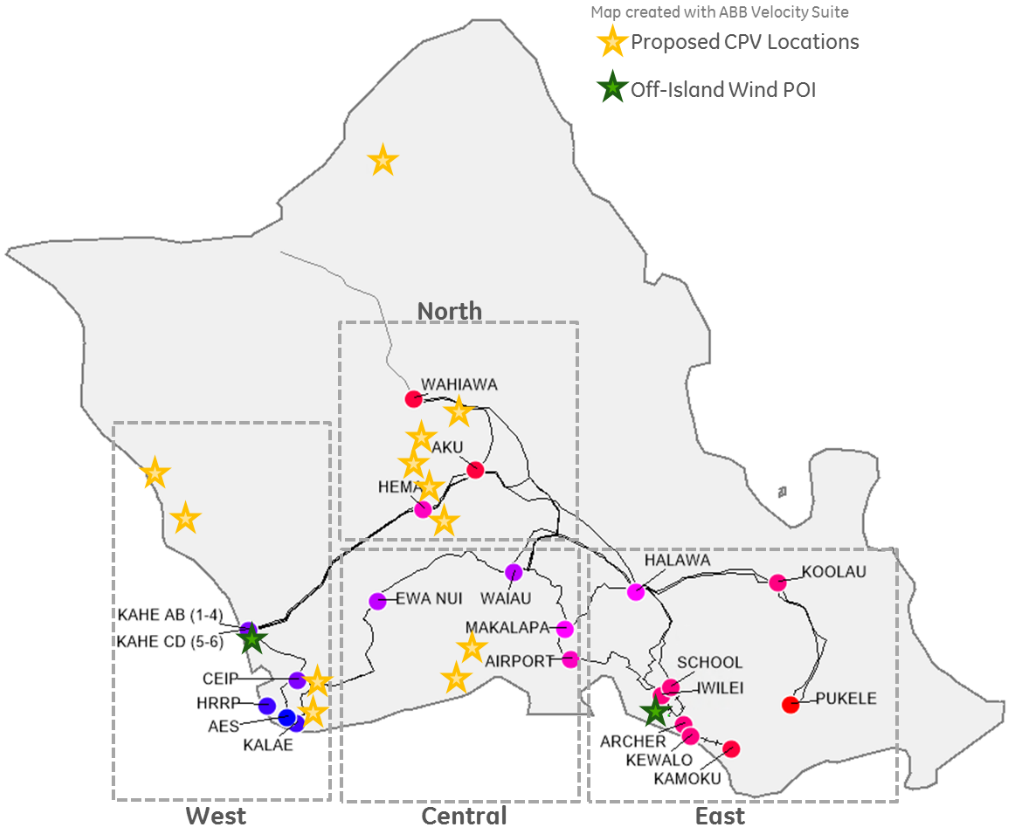
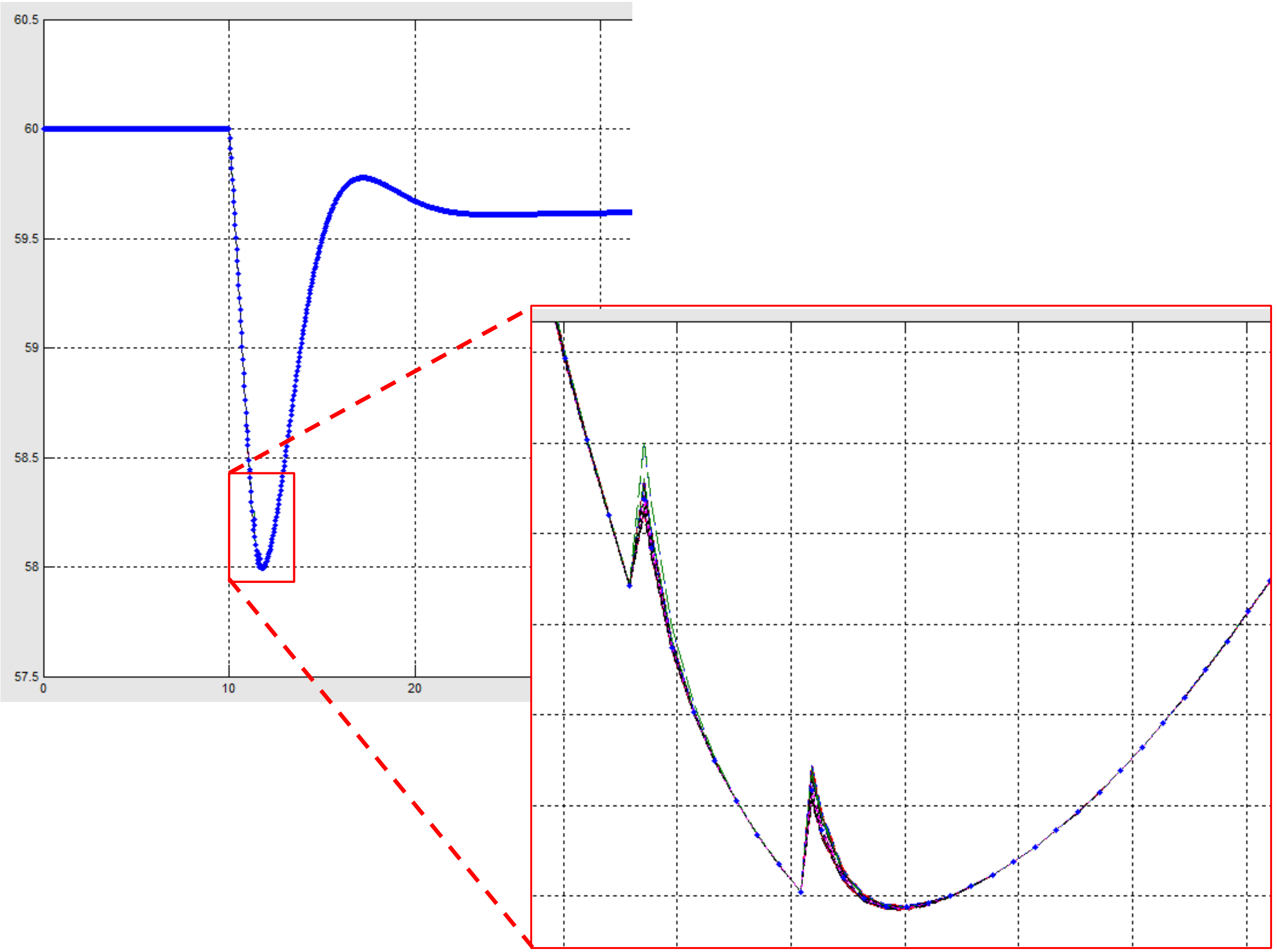
Agenda

1. FFR Impact on System Performance
2. FFR Interplay with the Thermal Fleet
3. FFR Equivalency Approach

Oahu – A Tightly-Coupled System





Frequency trace of every high-voltage bus on the system

FFR Grid Service Analysis

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

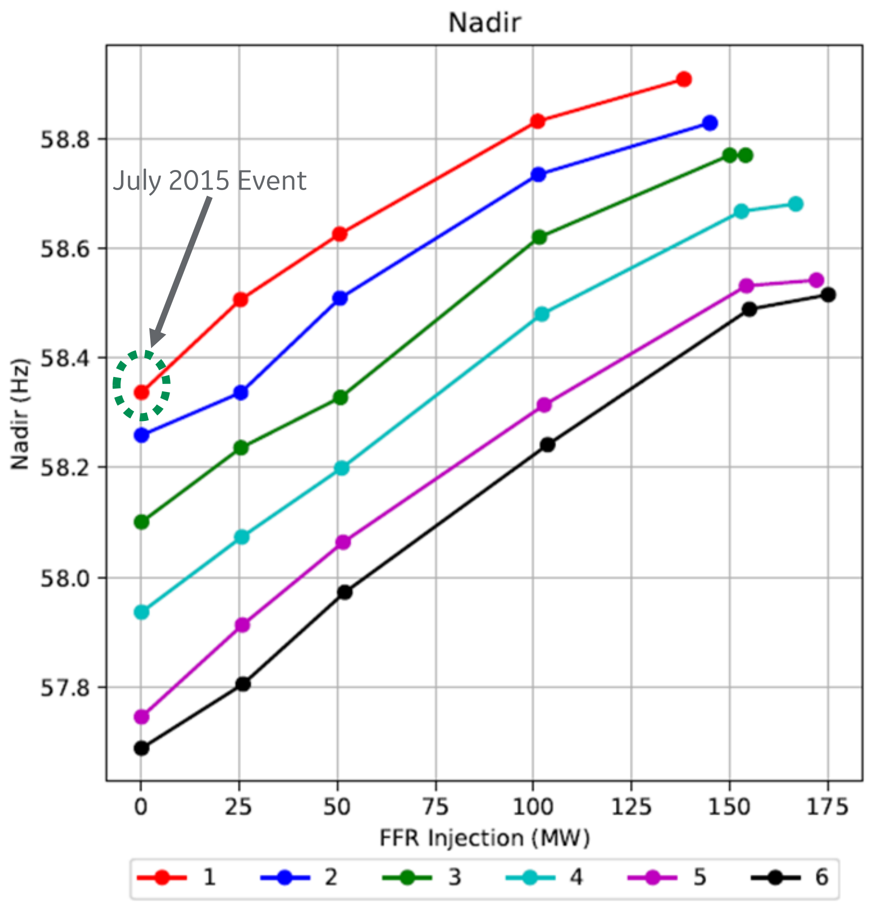
Scenarios	1	2	3	4	5	6
% Inst. Penetration	17%	20%	30%	39%	50%	53%
System Inertia (MW-s)	5306	4791	4075	3223	2531	2243

Sensitivity Parameters:

- FFR Injection Levels (MW): 0, 25, 50, 100, 150, 175
- FFR Dynamic Model: Similar to a solar plant model, proportional frequency droop with 0.5 sec response time

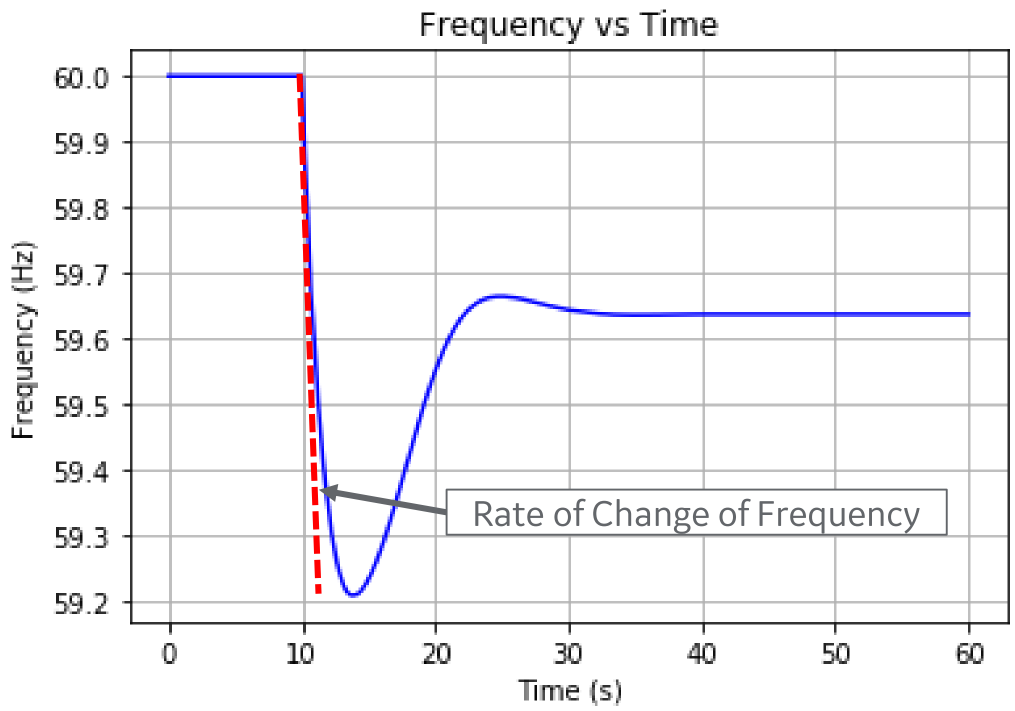
FFR Impact on Nadir

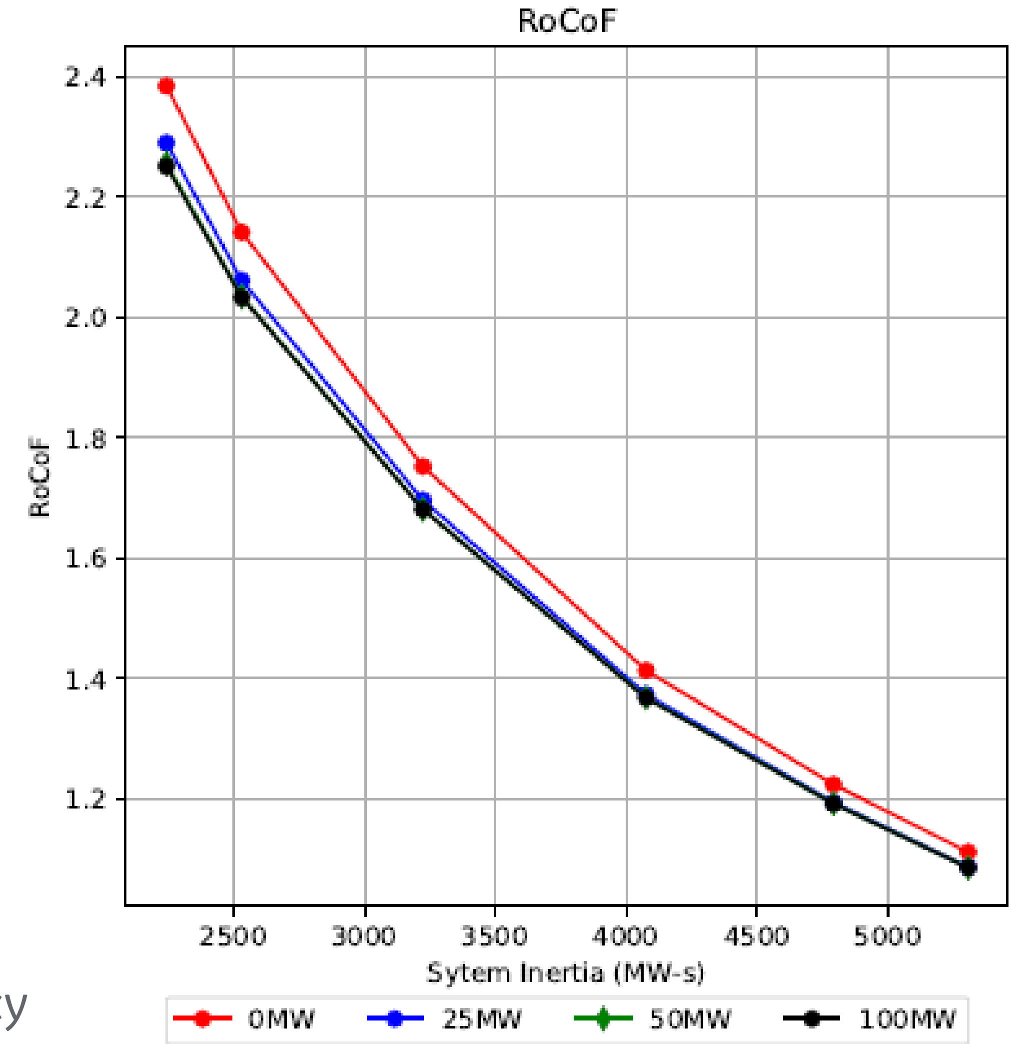
- Increased injections of FFR improve nadir (positive slope trend)
- The response of the system is a function of:
    a) Contingency Size (fixed)
    b) System Inertia (varied)
    c) Speed of FFR (fixed)
    d) Size of FFR (varied)
- The plot can be viewed as cost-benefit graph for FFR, where nadir is the benefit and FFR injection is related to system cost



*UFLS On
*FFR Response with Baseline Controls

FFR Impact on RoCoF



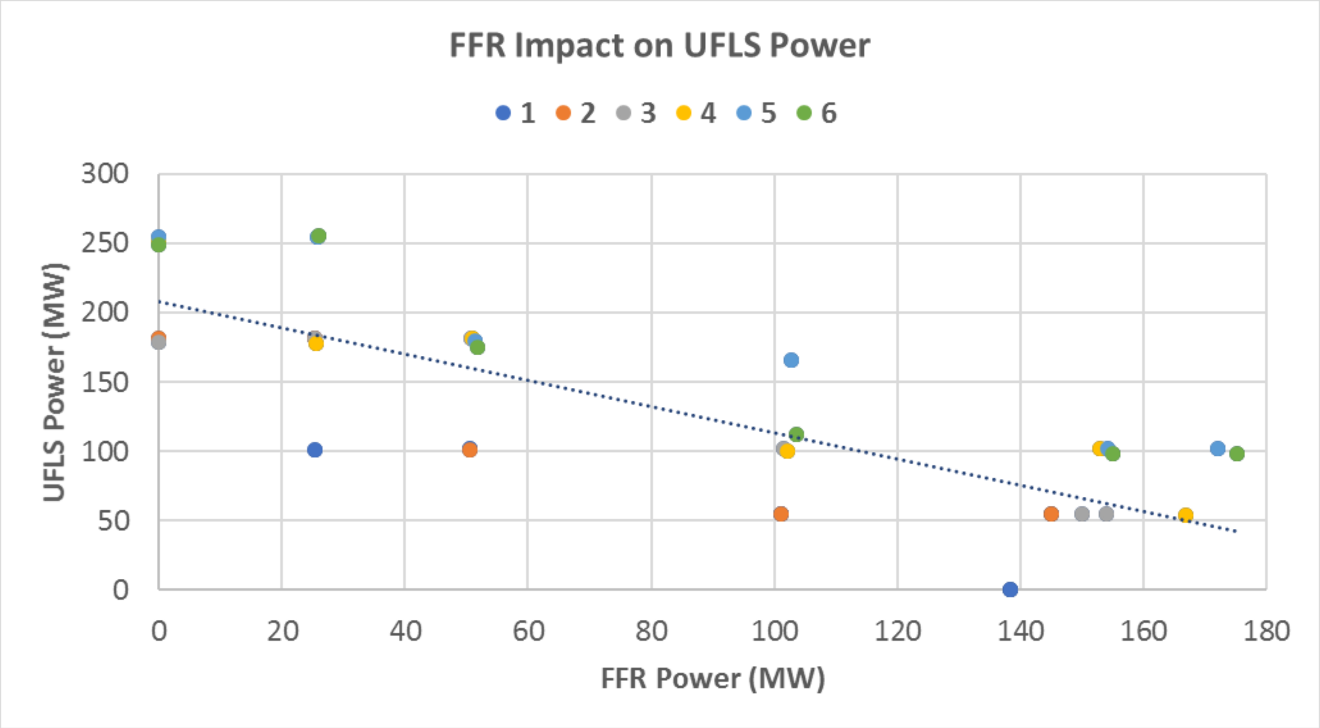


- FFR evaluated has little impact on RoCoF
- RoCoF is influenced by system inertia and contingency size

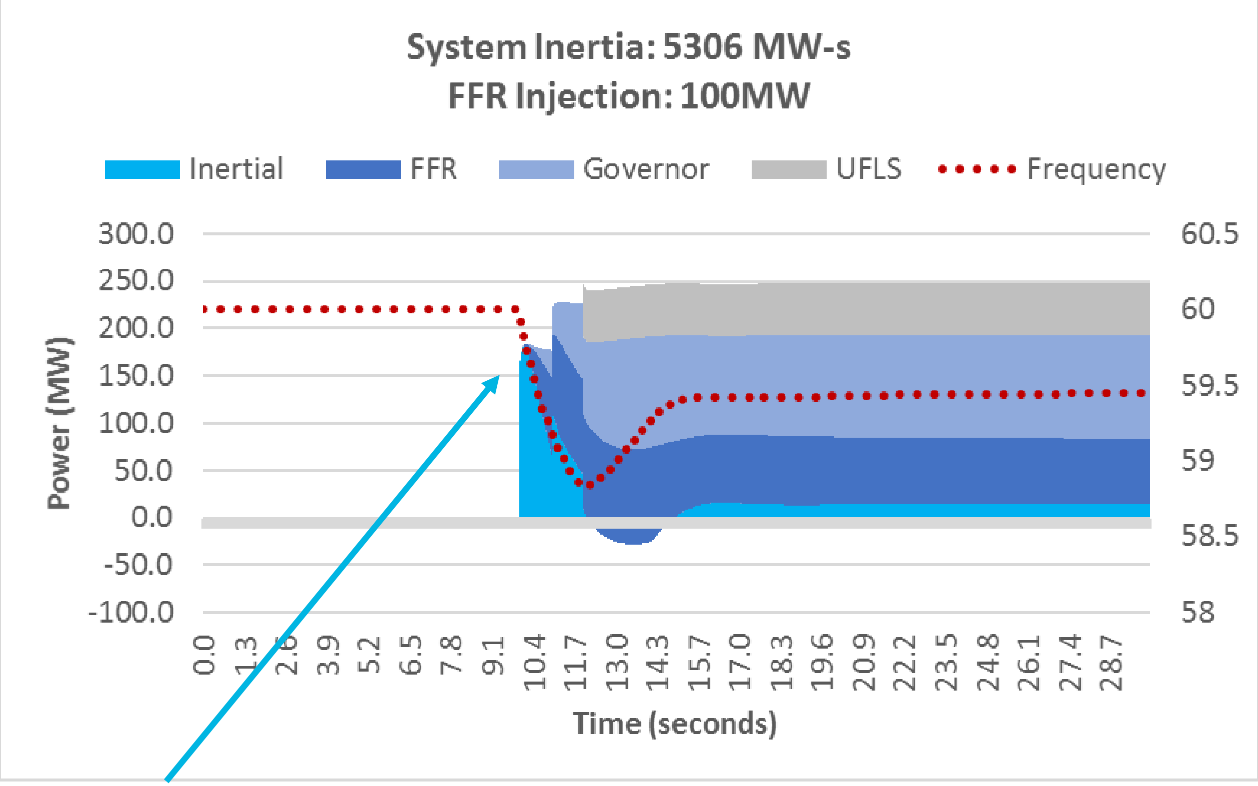
*UFLS On
*FFR Response with Baseline Controls

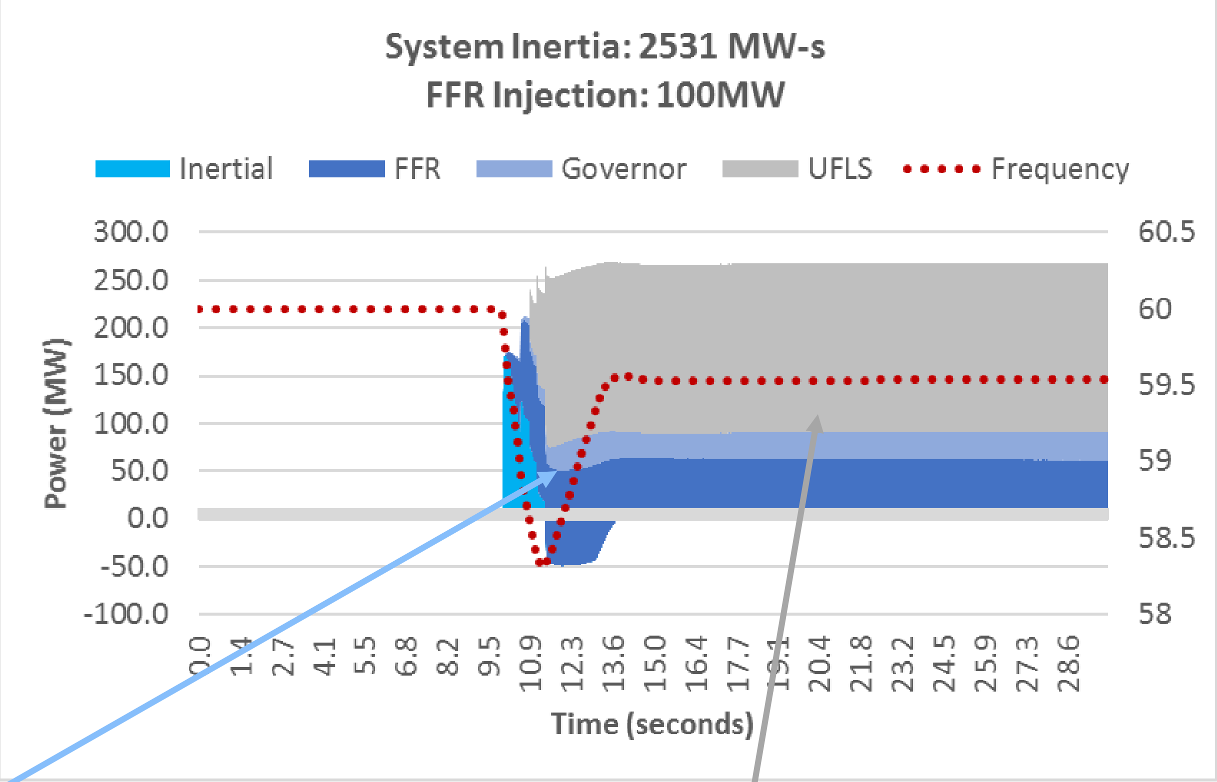
UFLS and FFR Coordination

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



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

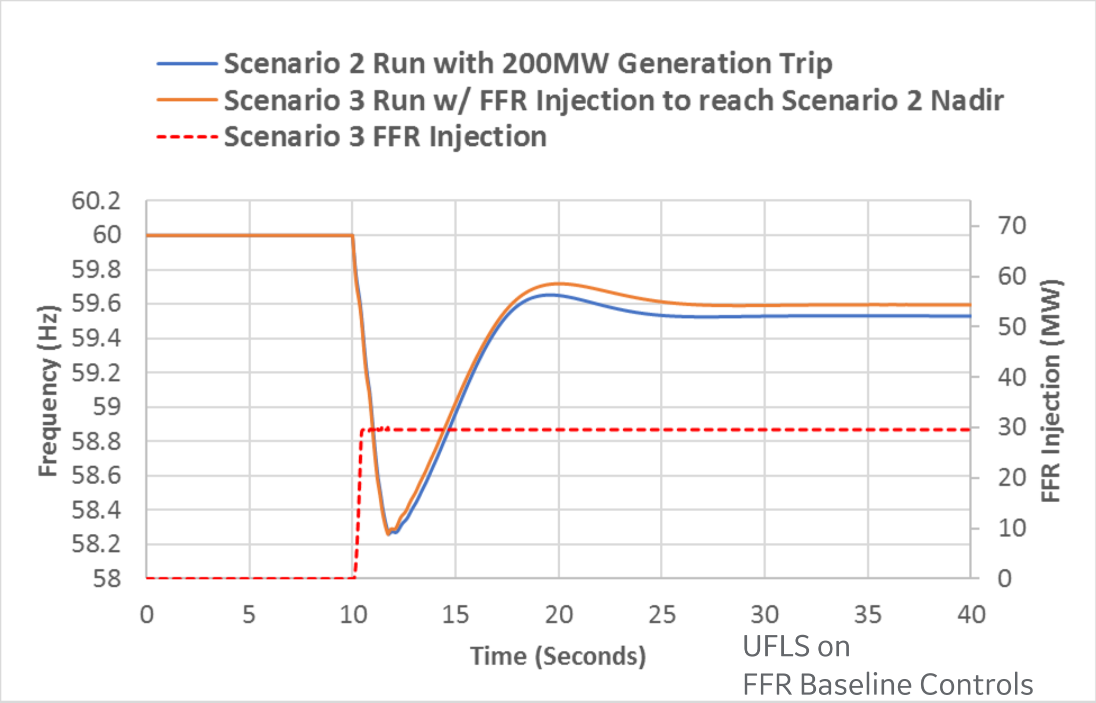
Event is more severe without synchronous machines responding, so additional response is required. In this case, UFLS did most of the responding.

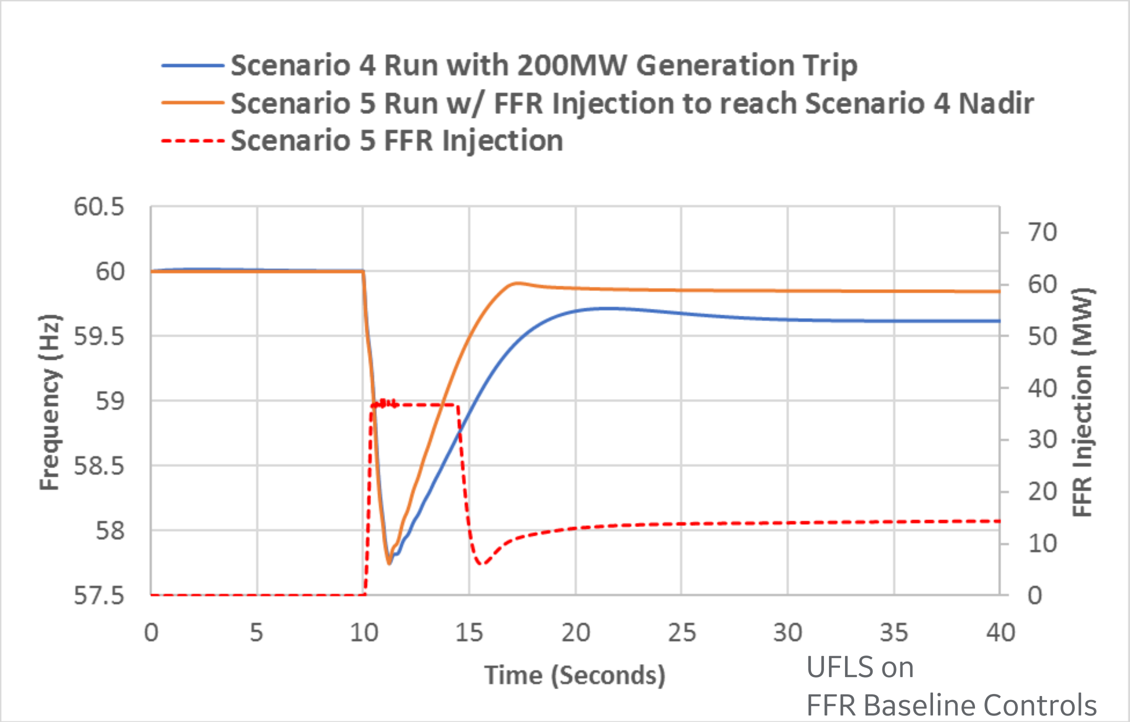
What if FFR did most of the responding...?

FFR Equivalency Approach

Analysis Method:

- Remove a synchronous machine (replace MW generation with renewable generation)
- Increase the FFR MW response until the nadir for the same generation-loss event returns to the previous value





FFR Equivalency Findings

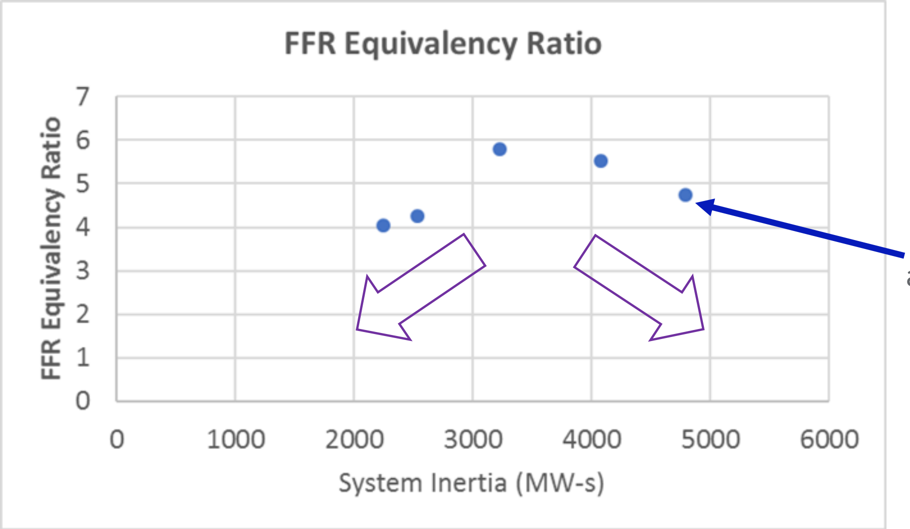
- FFR "equivalency" can be viewed as the amount of FFR MW injection per thermal unit MW

  Higher FFR Eq. → FFR More Impactful

- FFR equivalency ratio assumes an average unit inertia of 4.3 (based on Oahu)

- The "Time to System Collapse" is the time for system frequency to reach 57Hz for a given RoCoF

$$T_{collapse} = 3Hz/RoCoF$$

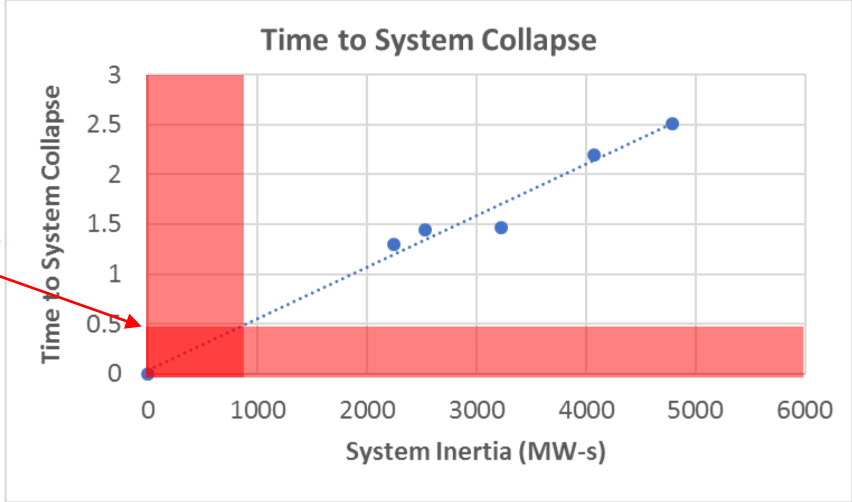


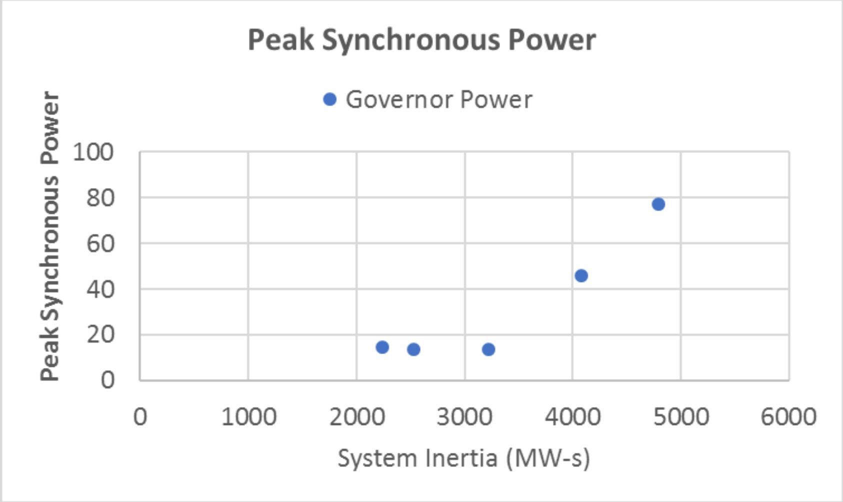
~5 MW of synchronous machines are needed to achieve the same response as 1 MW of FFR

Declining trend due to decreasing time to respond

Declining trend due to governors being more effective

Fastest stable FFR detection & response time





At some point…
FFR cannot respond fast enough AND be stable to be effective by itself

FFR Study Conclusions

FFR Systems Impact

- FFR improves system response to loss of generation events – but there are diminishing returns
- FFR reduces UFLS action on system during loss of generation events
- FFR has little impact on RoCoF

FFR Equivalency

- FFR is generally more effective than synchronous machines, MW-for-MW
- For extremely low inertia systems, FFR (and UFLS) will be less effective (and ultimately ineffective) when responding autonomously by detecting frequency changes

"Grid Forming" control technologies can help overcome this limitation for extremely fast systems

Thank You

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