Are all GFMs Created Equal? Lessons Learned

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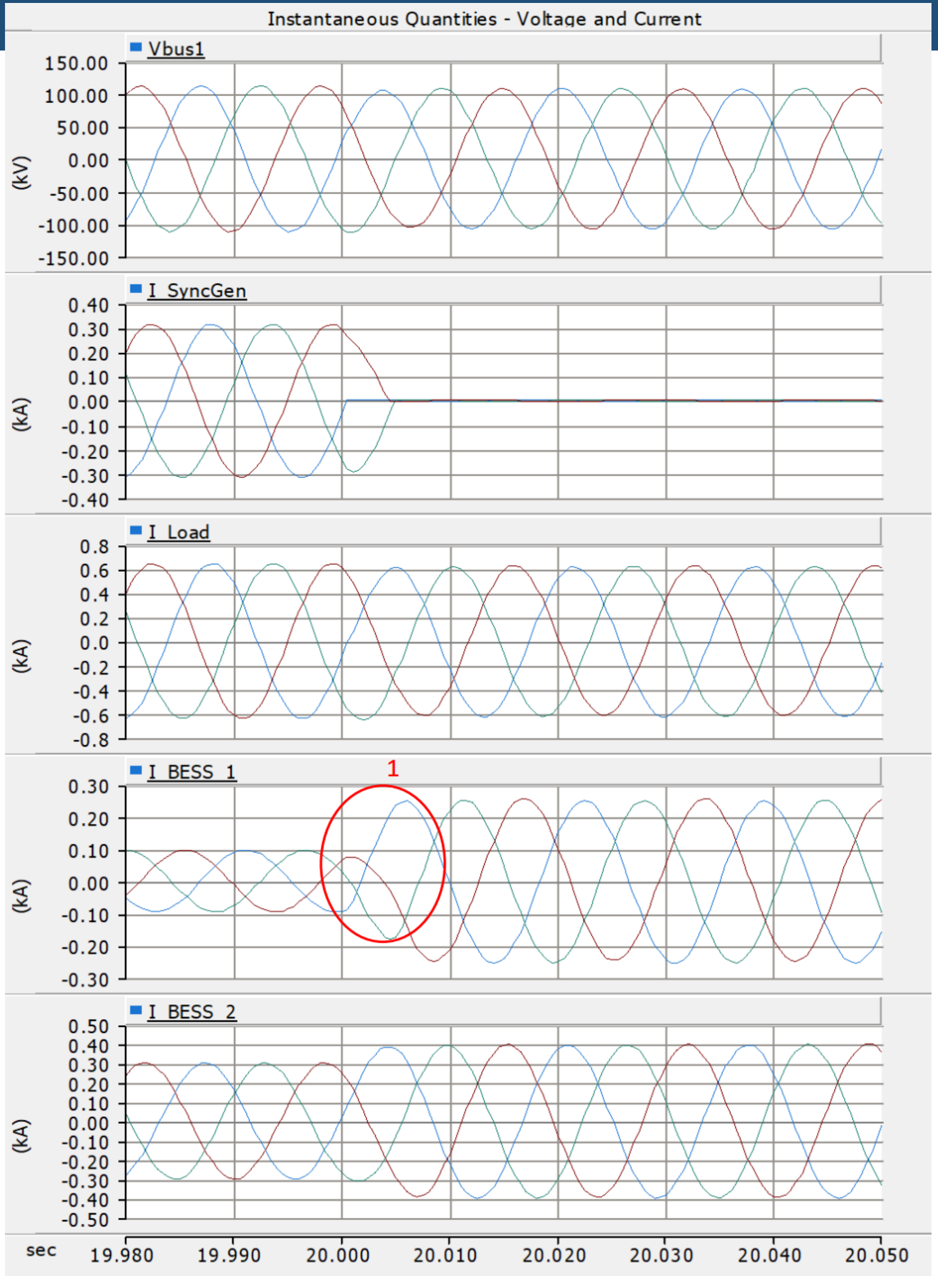
Intro

- GFM batteries are providing benefits in real systems!
- Use cases expanding beyond “voltage phasor” attributes, such as:
  - SS damping
  - Inertia
  - Statcom-like operation
- GFM testing / analysis should evolve to consider new use cases and nuanced control / performance aspects

GFM Controls - What is common between all?

- Voltage source behavior and associated benefits
    - LLSM
    - weak systems
    - phase jump power
    - fault current
- Current limitation challenge



https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Functional_Specification.pdf

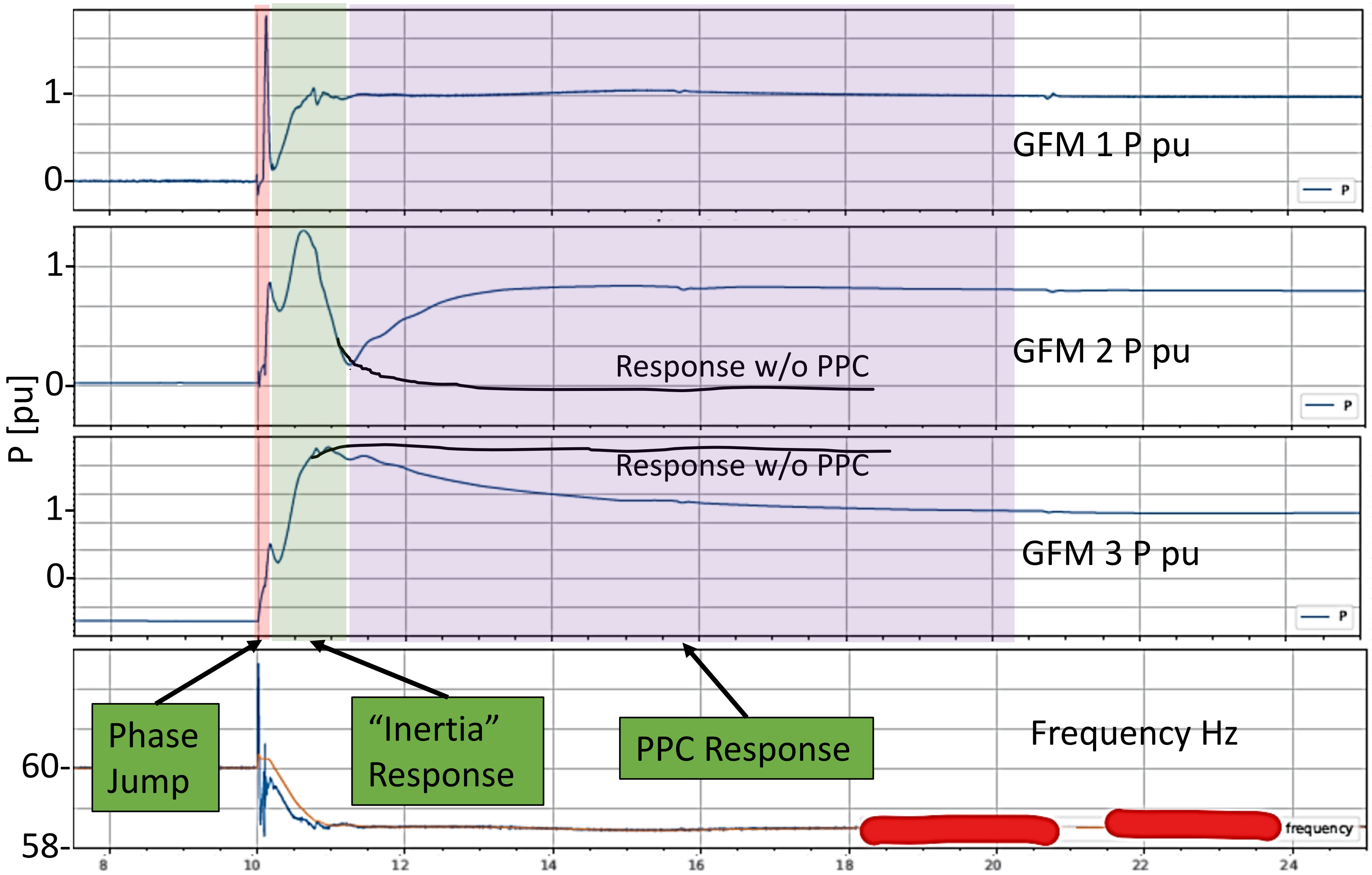
GFM Controls - What aspects are variable?

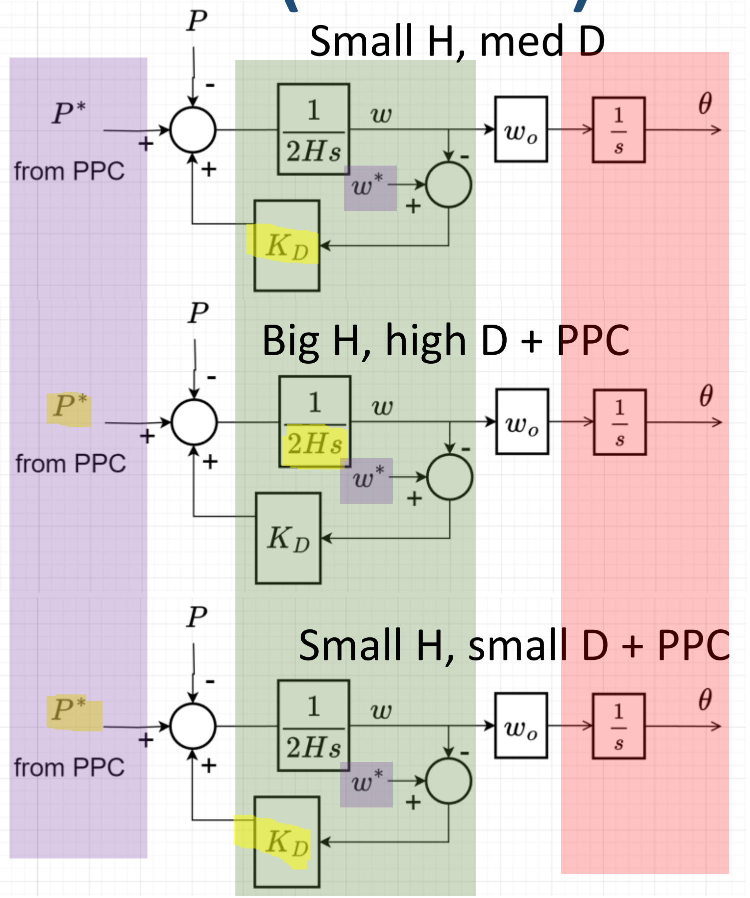
- Inertia Response
  - Multiple ways to output energy in a useful time frame, not limited to RoCoF-proportional
  - Not necessarily a GFM-only quality, depends on what your useful time frame is
- Current limiting
  - Many approaches possible (direct vs cascade control, hardware vs software, virtual impedance vs current limits)
- Frequency domain characteristics
  - Impedance is highly tunable
  - Can be used to help mitigate SSCI

Island-Wide System Analysis with GFM

- In HECO systems we have DER (lots!), UFLS, legacy plants, GFL, GFM, synchronous machines
- Full system dynamics are complex:
  - Voltage phase, magnitude and frequency all change in unexpected ways
  - Closed-loop performance of all devices in parallel
- Passing grid-forming specification tests does not mean perfect performance in the system
- Some aspects of islanded system performance not applicable to large interconnections, however elements of performance can be used to refine controls
- Note on results: some plants not in final design phase

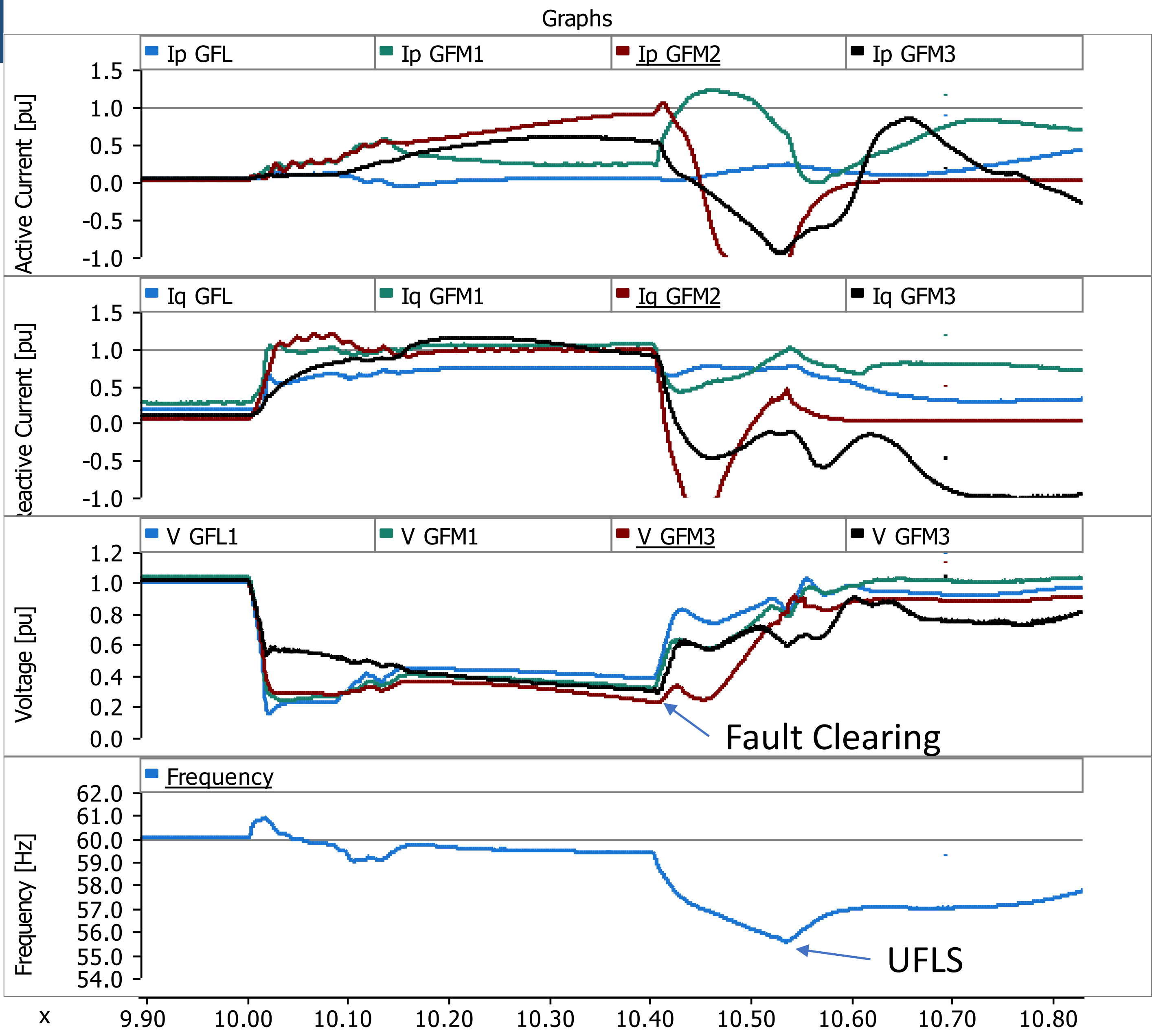
GFM Comparisons – Frequency Response (HECO)





GFM Comparisons – Fault & Recovery (HECO)

- 24 cycle transmission-level fault (not realistic in most systems)
- Weak system, very low inertia
- Lots of DER -> power generation missing at fault clearing
- Frequency changing during fault
- Very challenging condition for re-synchronization



GFM Comparisons – Fault & Recovery (HECO)

- GFL (blue):
  - Limited but stable response during and after fault.
- Note: system not N-0 stable with only GFL!

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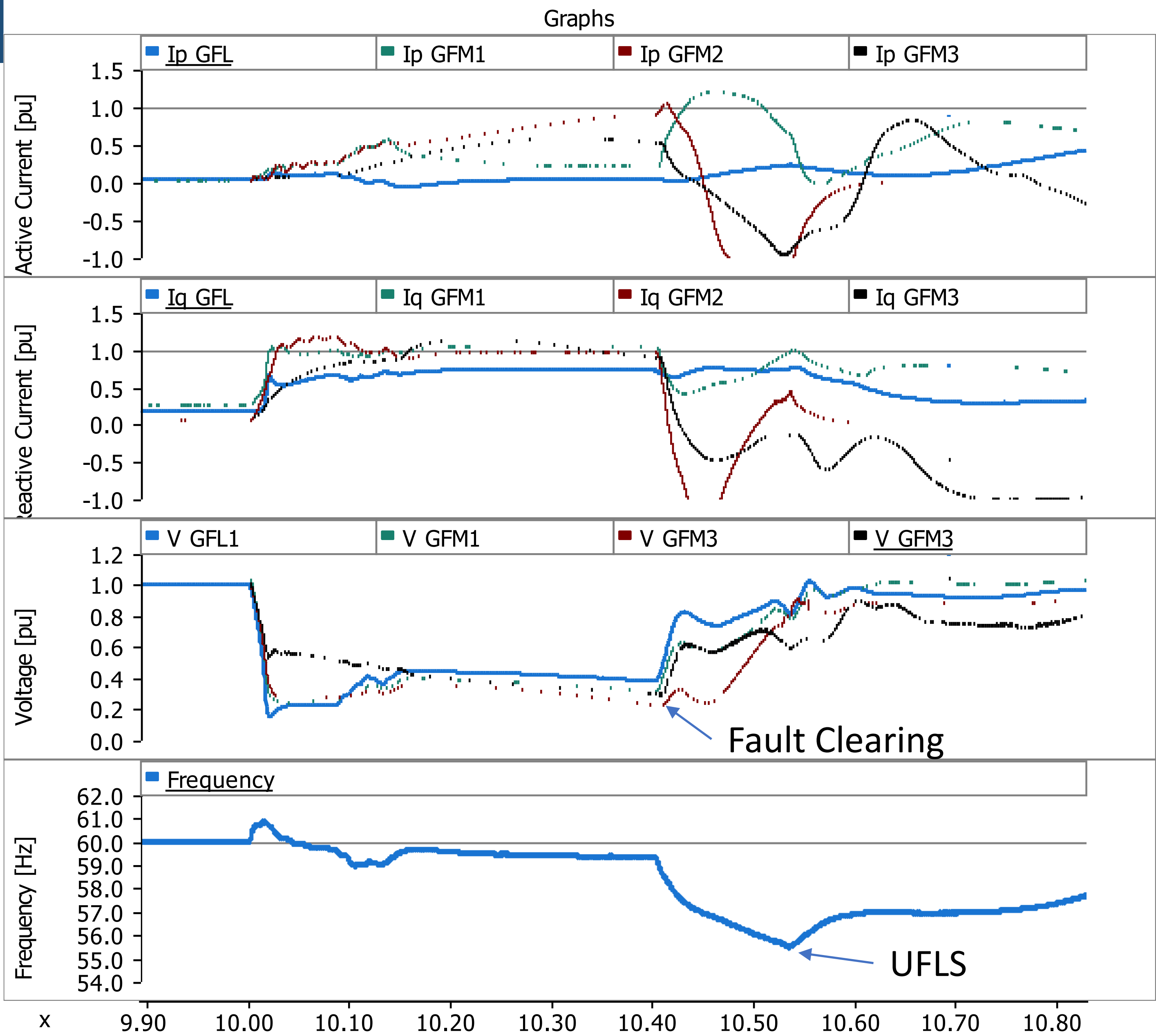
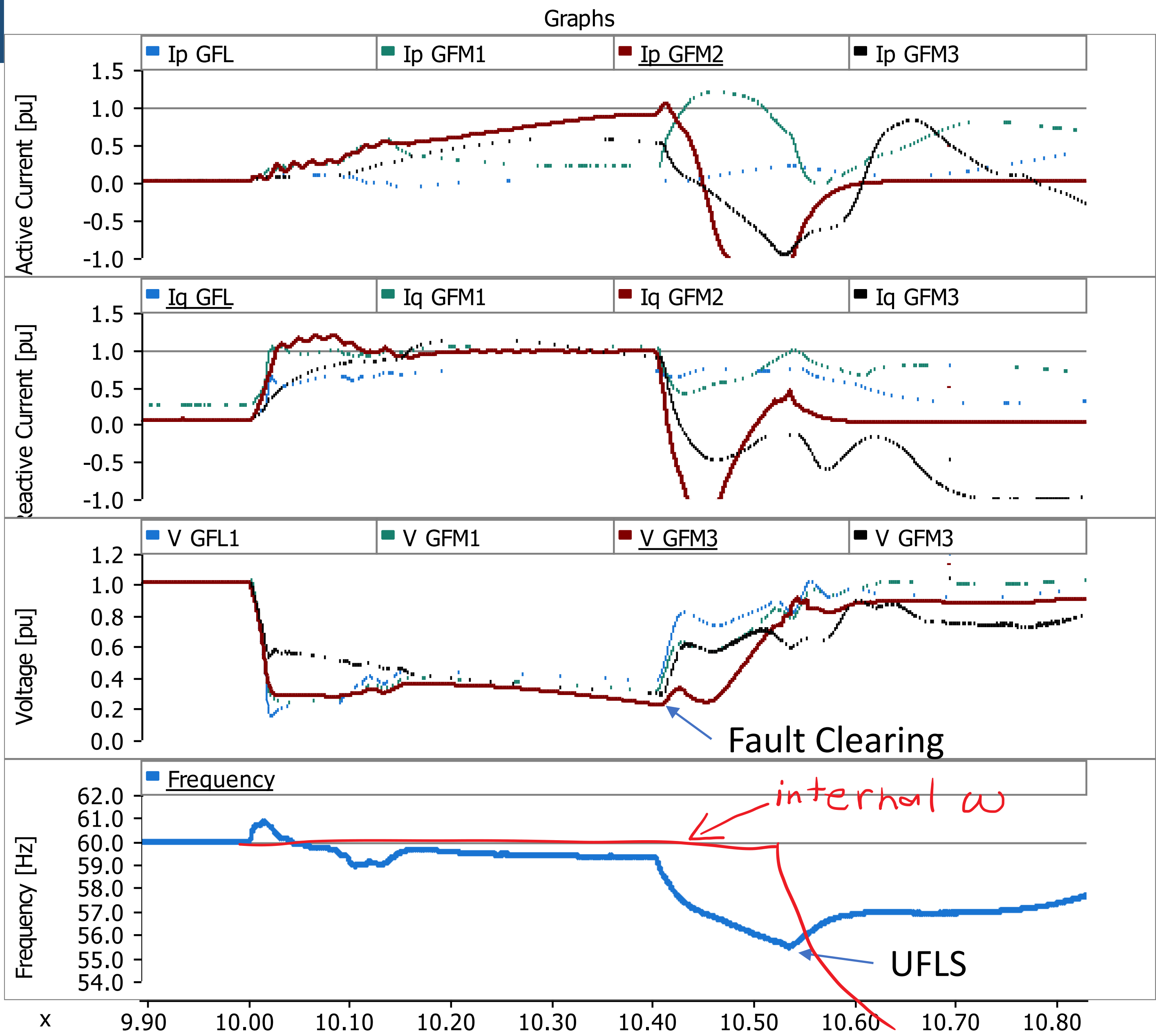


GFM Comparisons – Fault & Recovery (HECO)

- GFM2 (red):
  - High Q & some P during fault
  - Internal frequency locking during fault and recovery
  - Large negative swing in P & Q at fault clearing
  - Trips at 10.55s

Control Tuning Needed!



GFM Comparisons – Fault & Recovery (HECO)

- GFM3 (black):
  - High Q & some P during fault
  - Internal frequency locking and/or or large inertia constant leads to un-synchronized phase angle & large negative swing in P & Q at fault clearing.
  - Some P provided at 10.6s (too late!)

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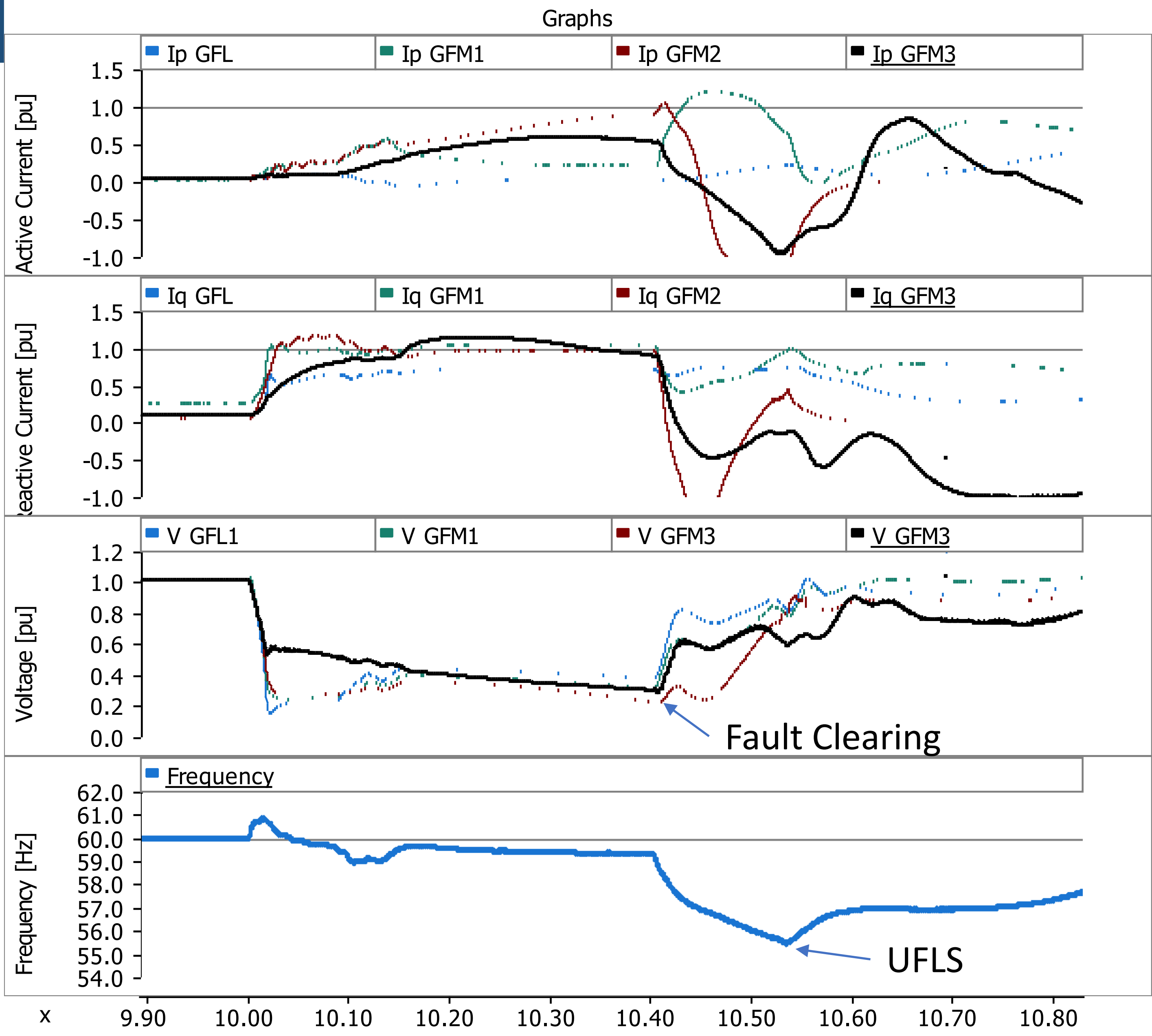
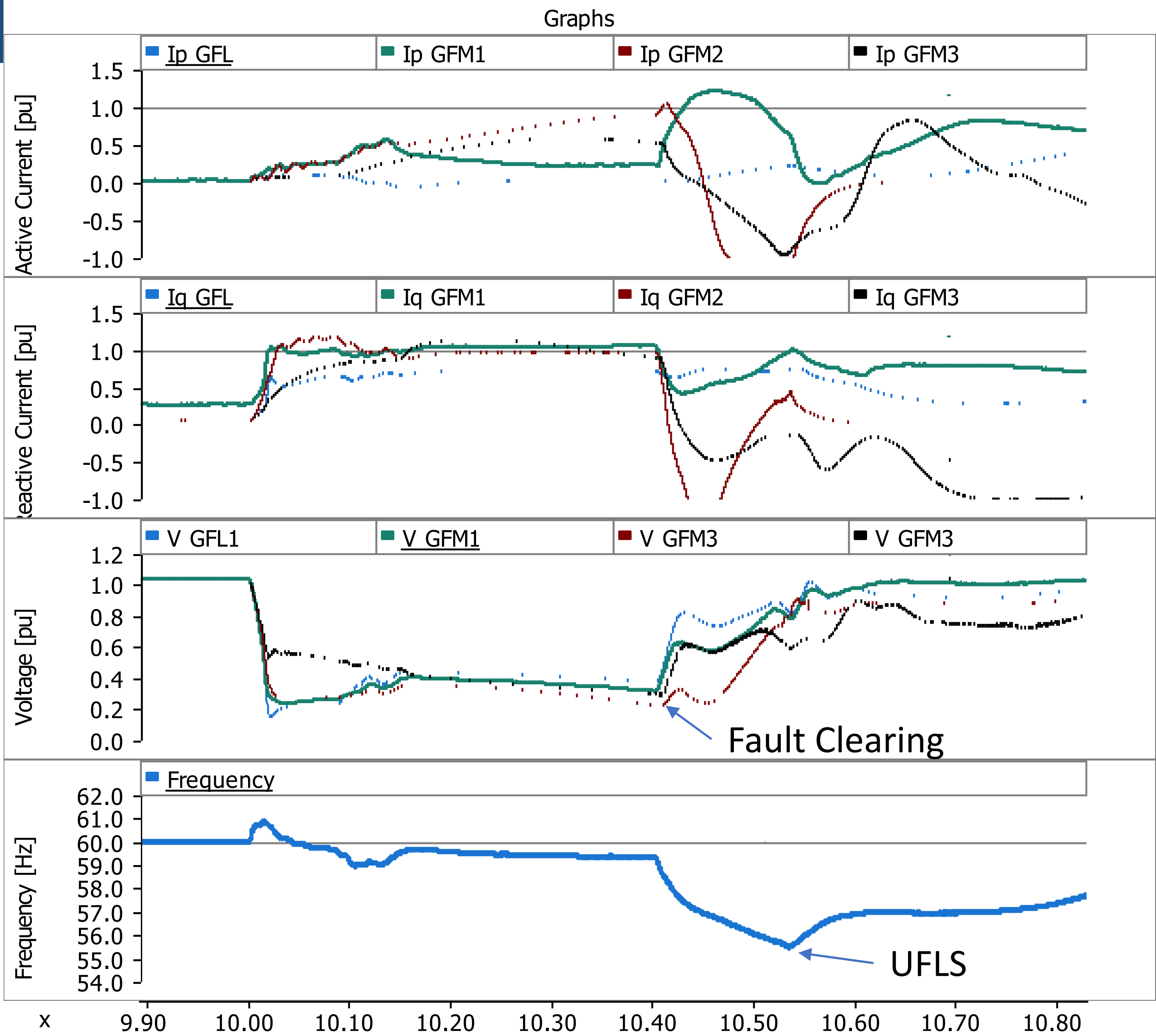
Control Tuning Needed!



GFM Comparisons – Fault & Recovery (HECO)

- GFM1 (green):
  - High Q & some P during fault
  - High P at recovery (when we need it)
  - Dip in power at 10.6s



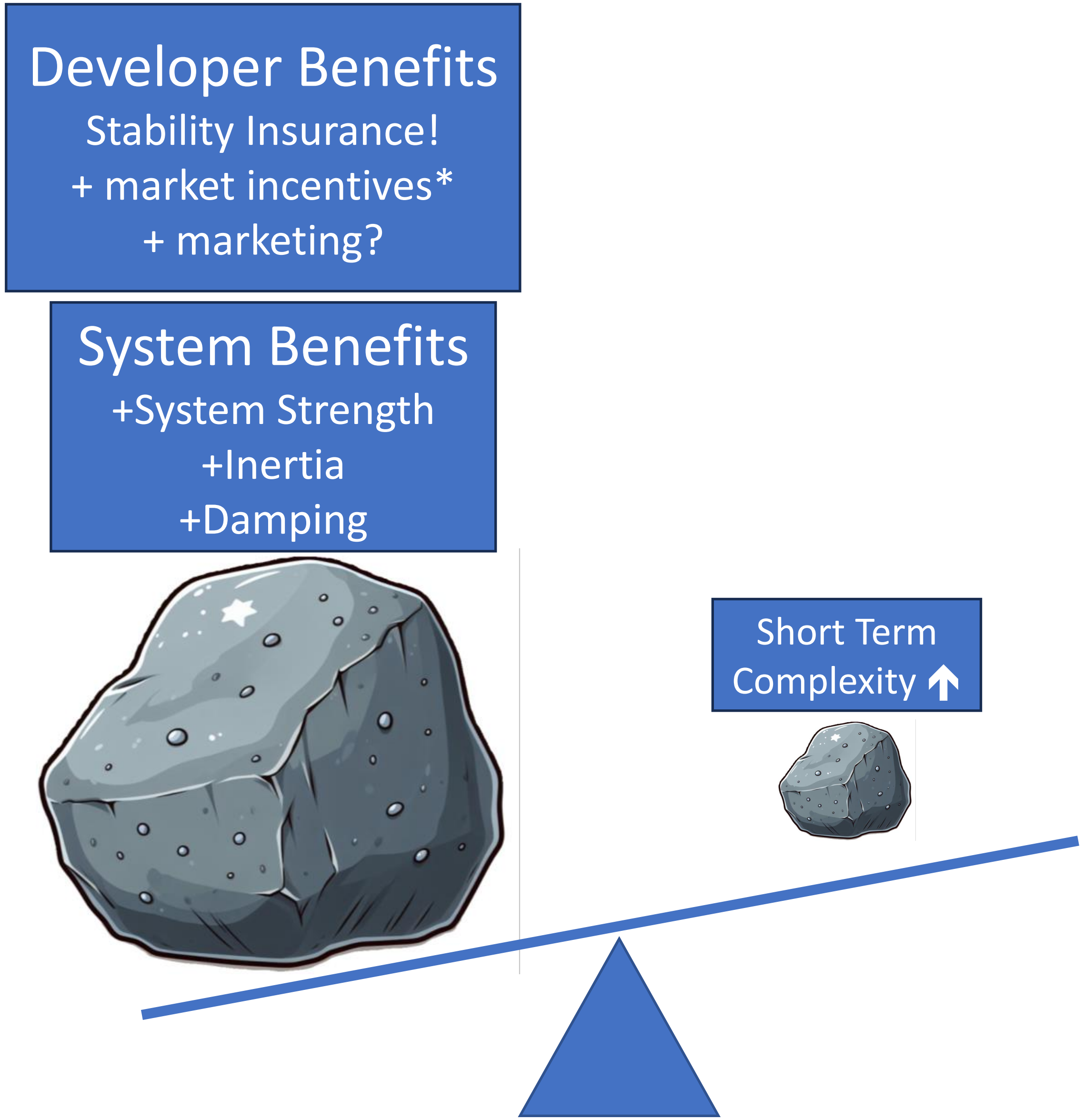
Closing Thoughts

- GFM controls have many benefits, but like any device, controls can fail during interconnection studies
- GFM controls are *highly* tunable to address performance concerns. Only thing that is fixed is voltage phasor characteristic and current limits

Closing Thoughts

- How will GFM be adopted?
  - Grid code / market changes:
    - Minimum capability requirements
    - Market incentives
  - Naturally:
    - Developer preference
    - Least cost mitigation
    - Stability insurance
- Why are we looking so closely?
  - If GFM becomes a requirement, uptake will be fast, so we need to be ready!

GFM -> Capability ↑
reliance on capability ↑
performance scrutiny ↑
short term complexity ↑ (*sometimes*)



Thank you!

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