

GFM Tutorial Part 1: The Basics!

ESIG Spring Technical Workshop

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ELECTRANIX

SPECIALISTS IN POWER SYSTEM STUDIES

Don't Panic!!

- “What even is Grid-Forming?”
- “Nobody can agree on a definition”
- “It is new and untested”

We're okay!

- We agree on a definition (as much as engineers can agree on anything), and we understand GFM very well now.
- We have lots of study experience and rapidly increasing amounts of field experience.
- We have well tested local requirements that work, and more formal standards are on the way.

Definitions...

- **NERC:** Grid Forming Control for BPS-Connected Inverter-Based Resources are controls with the primary objective of **maintaining an internal voltage phasor that is constant or nearly constant in the sub-transient to transient time frame...**
- **UNIFI:** GFM IBR controls **maintain an internal voltage phasor that is constant or nearly constant in the sub-transient to transient time frame.**
- **MISO:** GFM IBR shall provide autonomous, near-instantaneous frequency and voltage support by **maintaining a nearly constant internal voltage phasor in the sub-transient time frame, within the inverter's current limits and the resource's energy limitations.**
- **AEMO:** A grid-forming (GFM) inverter maintains a **constant internal voltage phasor in a short time frame**, with magnitude and frequency set locally by the inverter, thereby allowing immediate response to a change in the external grid. On a longer timescale, the internal voltage phasor may vary to achieve desired performance.
- **NESO Pathfinder:** Capability to supply Active Power which is directly proportional to the difference between the magnitude and phase of its Internal Voltage Source and the magnitude and phase of the voltage at the Grid Entry Point and the sine of the Load Angle

Other ways to think of GFM

- “Advanced Grid Support (AGS)” – ERCOT
- “Slowing down your controls so that they resist changes in the system instead of trying to quickly follow changes in the system.”
- “Another type of converter control, but with some nice inherent stabilizing properties”

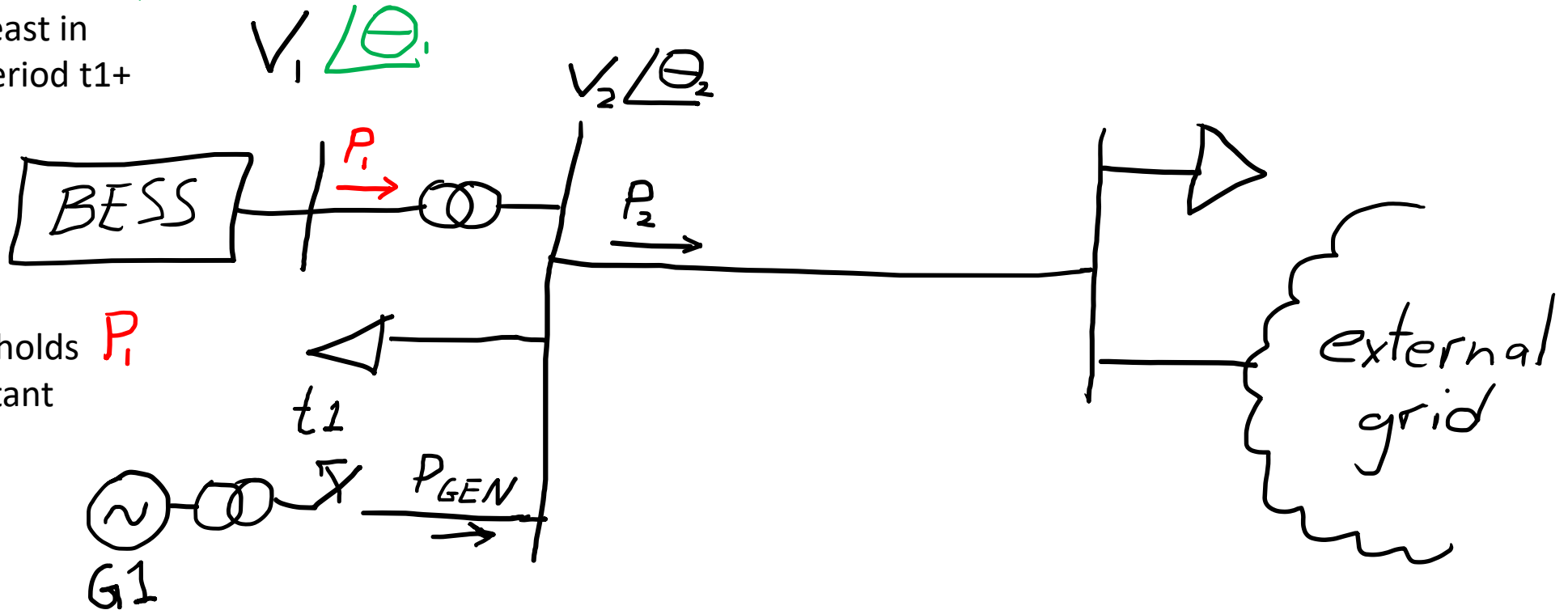
What does that actually mean?

Grid-Forming holds Θ_i constant... at least in the transient period t_1+

$$V_1 \angle \Theta_1$$

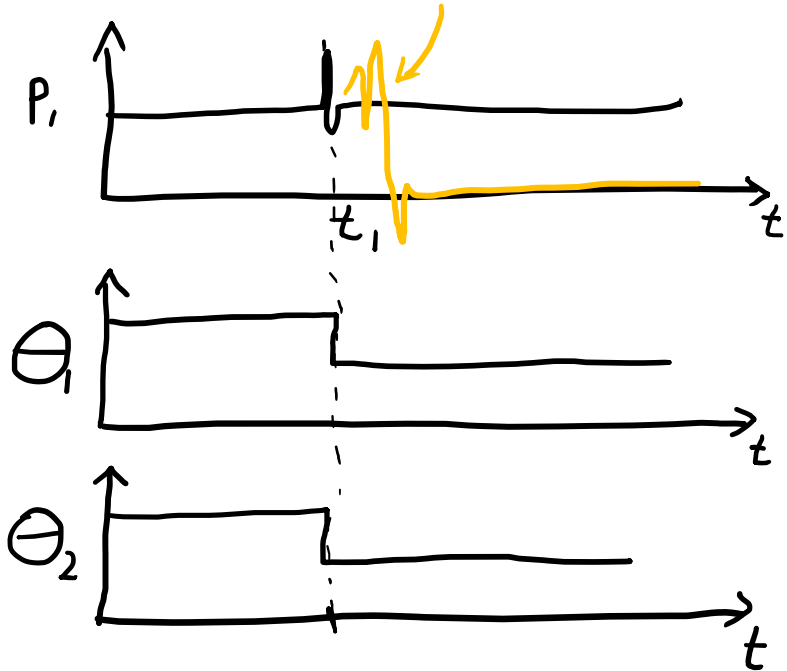
$$V_2 \angle \Theta_2$$

Grid-Following holds P_i (currents) constant during t_1+

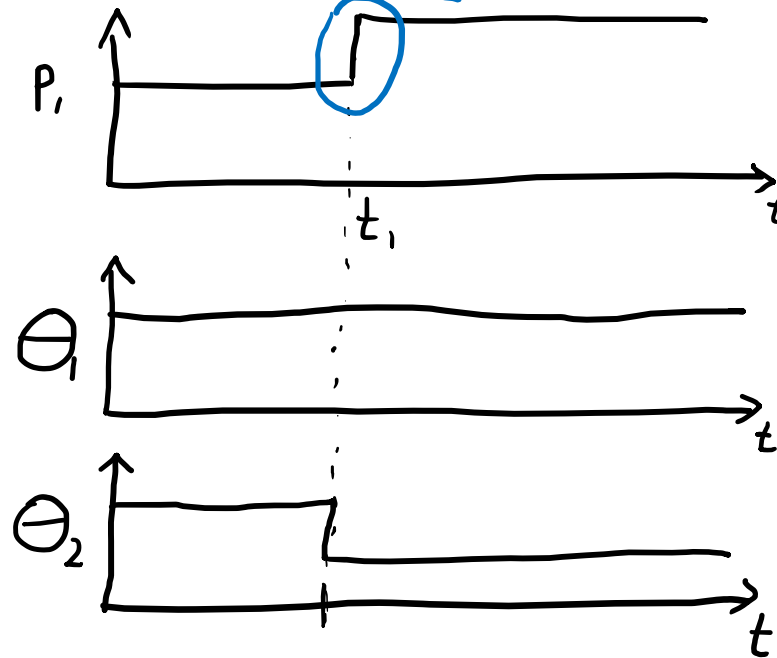


What does it look like when you disconnect the generator G1? (Island system)

Grid-Following BESS
(neglecting weak grid instability and tripping)

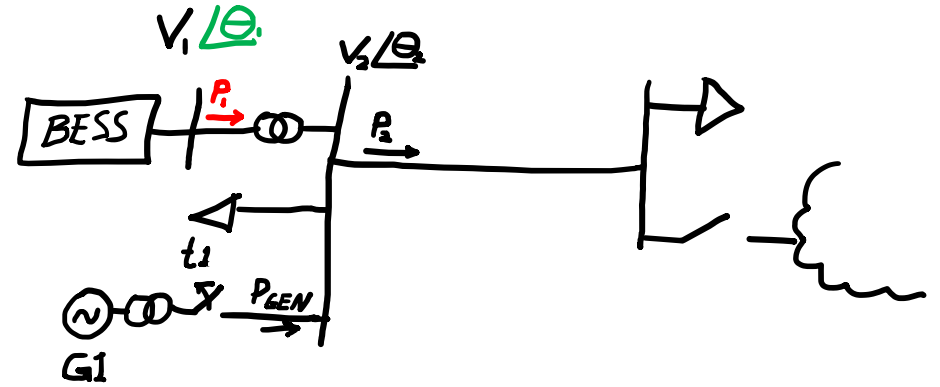


Grid-Forming BESS

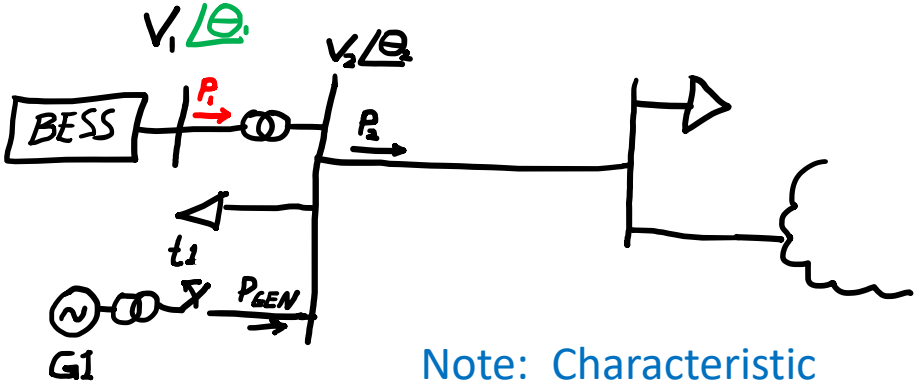


Note: Characteristic "Inertial Response"

Note: Grid-Forming BESS performance is contingent on having sufficient current and energy headroom when the angle changes!!



If we re-connect the island, and...
 add power control/grid synchronization

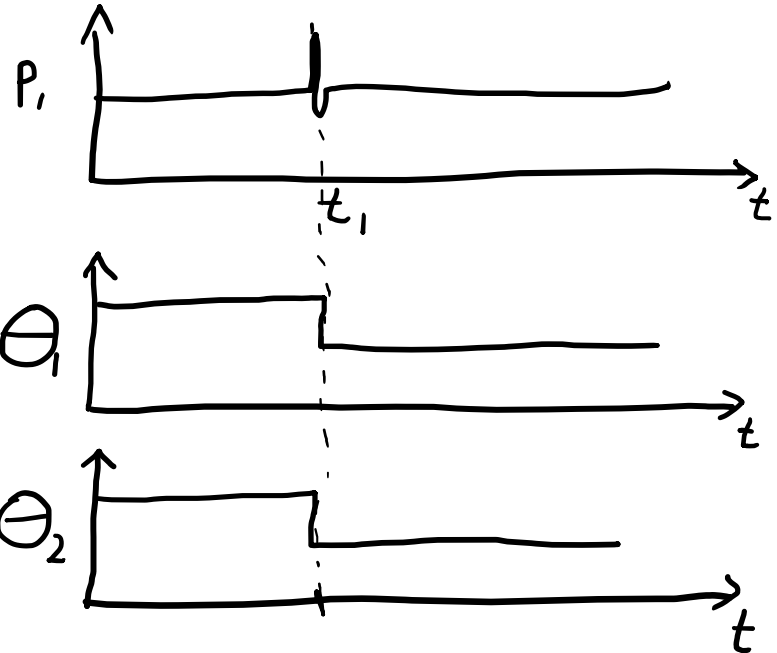


Note: Characteristic
 "Inertial Response"

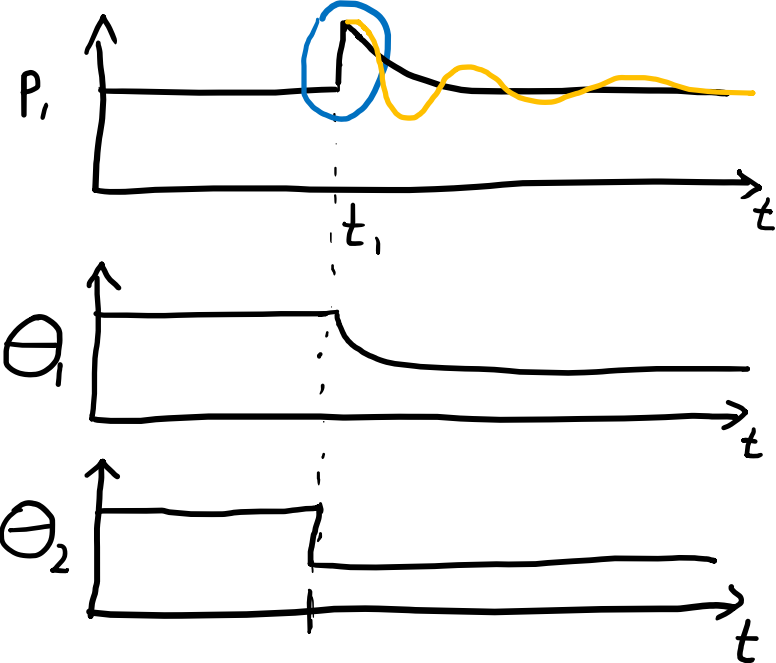
Note: Synchronous
 machine-type response
 if desired

Note: Grid-Forming
 BESS performance is
 contingent on having
 sufficient current and
 energy headroom
 when the angle
 changes!!

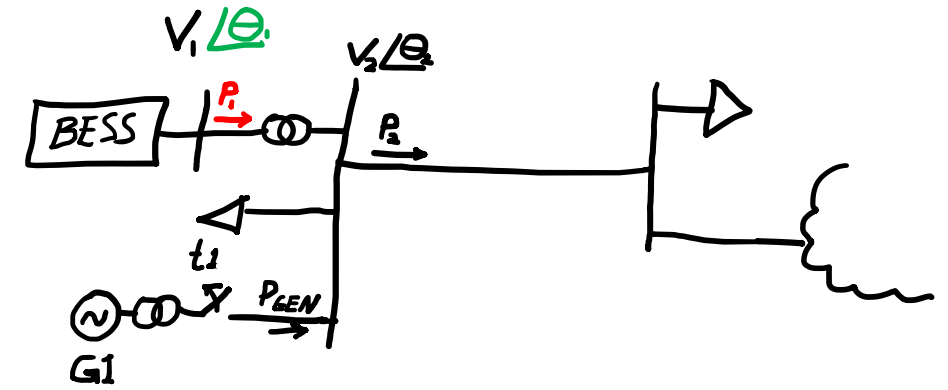
Grid-Following BESS



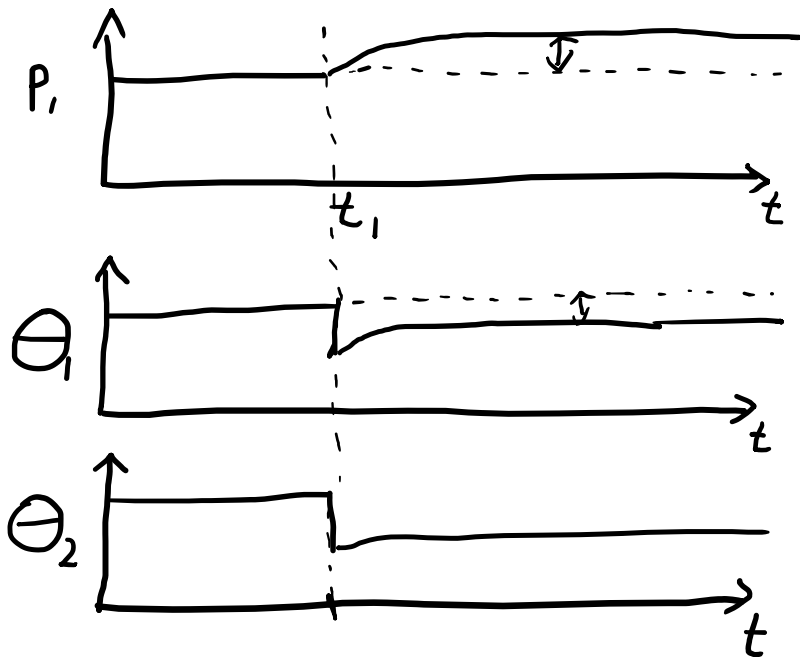
Grid-Forming BESS



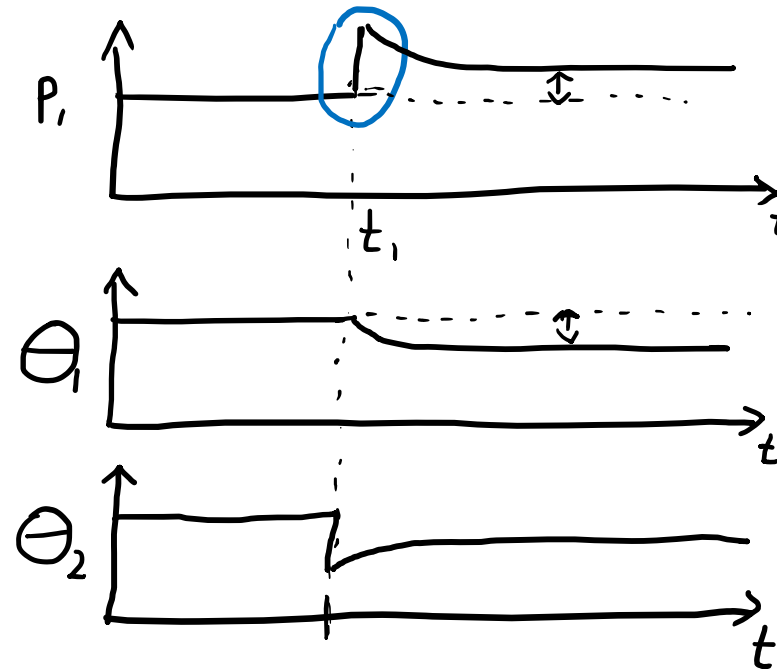
If we re-connect the island, and...
 add power control/grid synchronization, and...
 add frequency-droop control



Grid-Following BESS



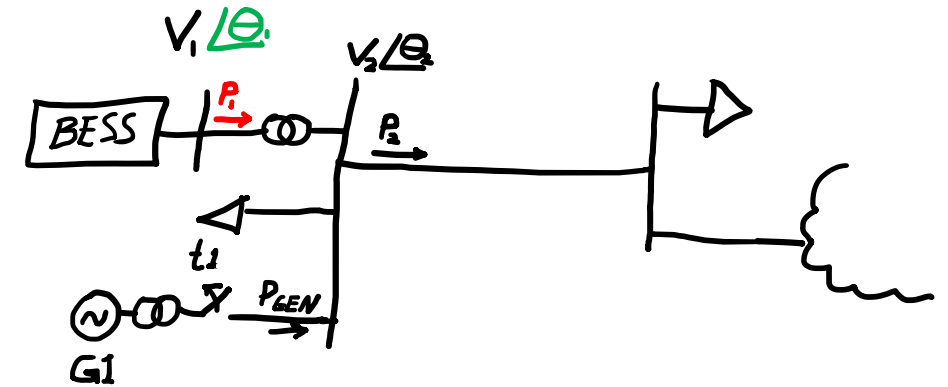
Grid-Forming BESS



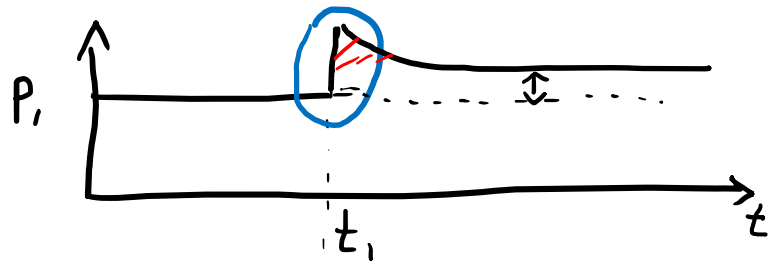
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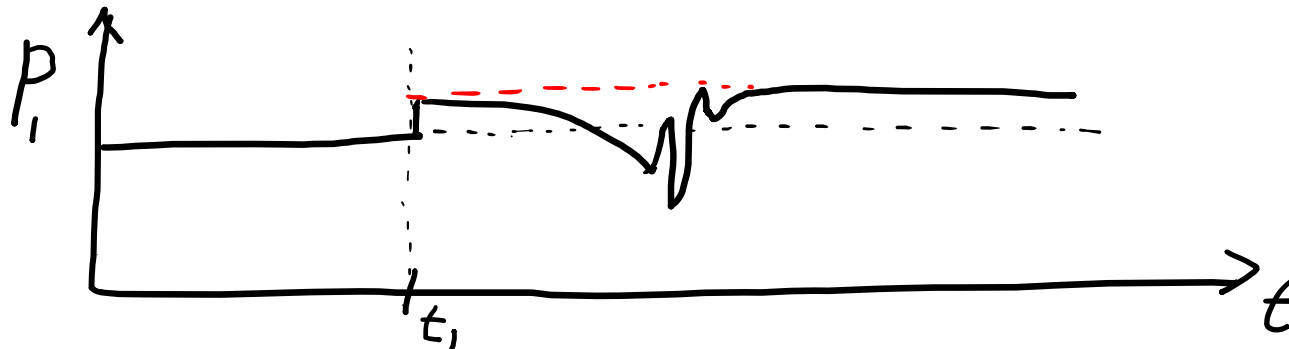
If we re-connect the island, and...
 add power control/grid synchronization, and...
 add frequency-droop control and...
 run out of current margin in the BESS?



Grid-Forming BESS (headroom available)



Grid-Forming BESS (out of current headroom!)
 (example only... response will vary!!)



Note: If BESS runs out of headroom, many things can happen... it is down to how the controls are implemented!!

Additional Reminders about GFM Resources:

1. Similar principles can be applied to the V/Q response, for GFM resources that have low (or no) active power capability.
2. GFM effect requires energy and current headroom
3. There are multiple ways to implement controls (VSM, Droop, Other). A lot can be done to shape the response for specific needs
4. For resources with energy and current headroom (like batteries), the hardware is generally similar between GFM and GFL.
5. Generally all the things that GFL can do should be expected from GFM as well!

Why is GFM generally useful?

going down! ↘

$$SCR = \frac{SCMVA}{MW_{IBR}}$$

Synchronous Machines
GFM IBRs
GFM HVDC/FACTS
GFL IBRs
GFL HVDC/FACTS

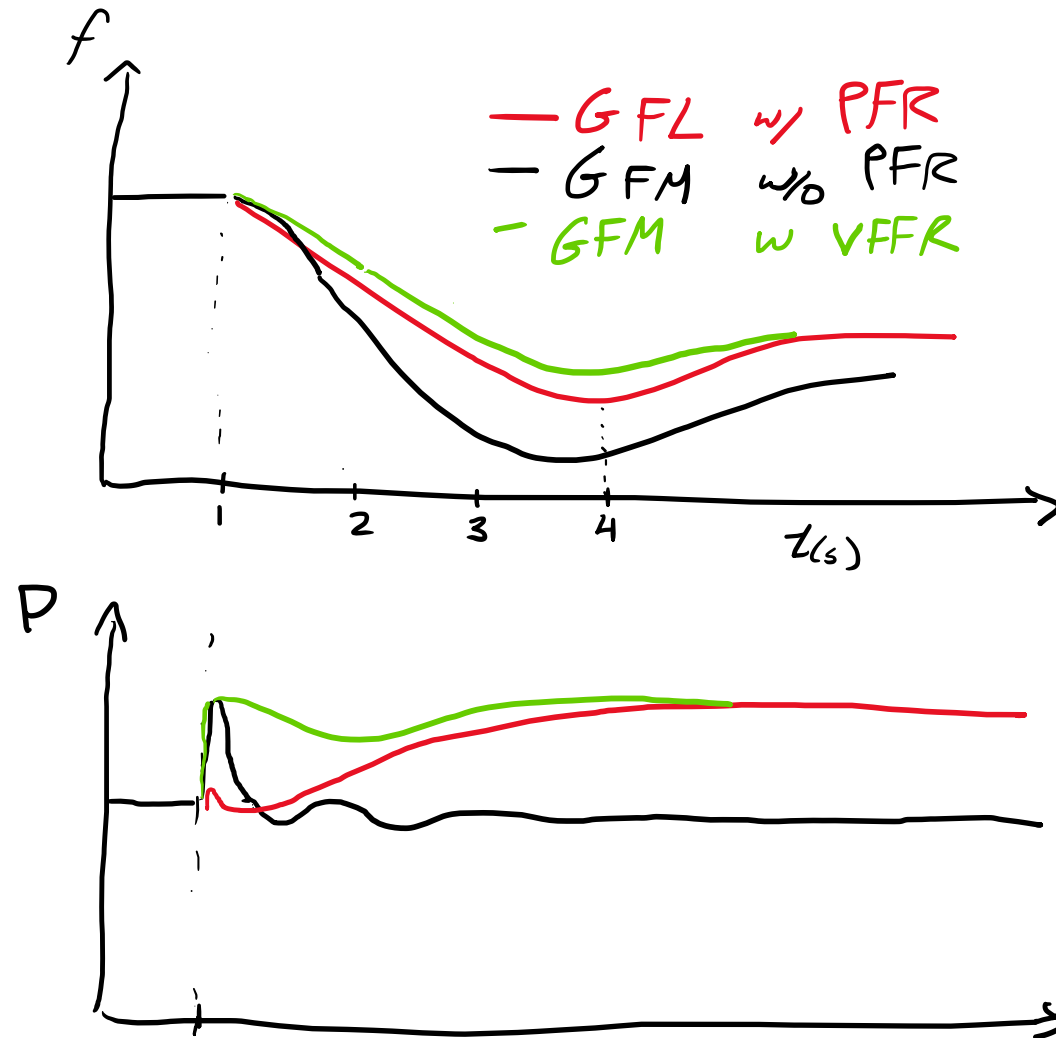
- **Note: SCR based metrics are becoming less valuable in general. Use with care or don't use at all!!**

Key Applications (in brief):

- Strengthening weak local IBR interconnections
- Adding inertia to large interconnections
- Increasing passive damping at sub-synchronous frequencies (unlocking renewables in series compensated networks)
- Automatic injection of negative sequence currents (balancing the system)
- Very fast frequency response
- Transferring system strength from one region to another (GFM HVDC)
- Improving response times and stability for reactive power devices (STATCOM etc)
- Reduction in active power fluctuation impact from data center loads

System vs. Local Inertial response

- Depending on the size or the inertia of the overall system, the key elements of needed frequency response change.
- GFM doesn't inherently provide optimal response, energy delivery needs to be coordinated across resources.
- GFL may be able to provide what you need!



Additional key technical points:

- Grid-connected GFM converter technology is currently commercially available in
 - BESS
 - STATCOM and E-STATCOM
 - HVDC
- Existing GFL BESS may or may not be upgraded to GFM at a future date, depending on vendor.
- GFM is *not* currently widely available in PV or wind technology, due to potentially large cost increment stemming from increased energy and current headroom requirements.

Next:

- Deepak will introduce controls and some other
- Requirements, testing, and more detail... this afternoon!

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Questions?

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