GFM Applications

Topic Change

Functional Definitions

Grid-Following: Most inverter based resources currently in service rely on fast synchronization with the external grid (termed Grid-Following) in order to tightly control their active and reactive current outputs. If these inverters are unable to remain synchronized effectively during grid events or under challenging network conditions, they are unable to maintain controlled, stable output.

What technology uses Grid-Following?

- *Current generation wind turbines*
- *Current generation transmission connected PV*
- *DER*
- *Most BESS applications*
- *LCC HVDC*
- *Most VSC HVDC*
- *last generation STATCOMs and SVCs*

Functional Definitions

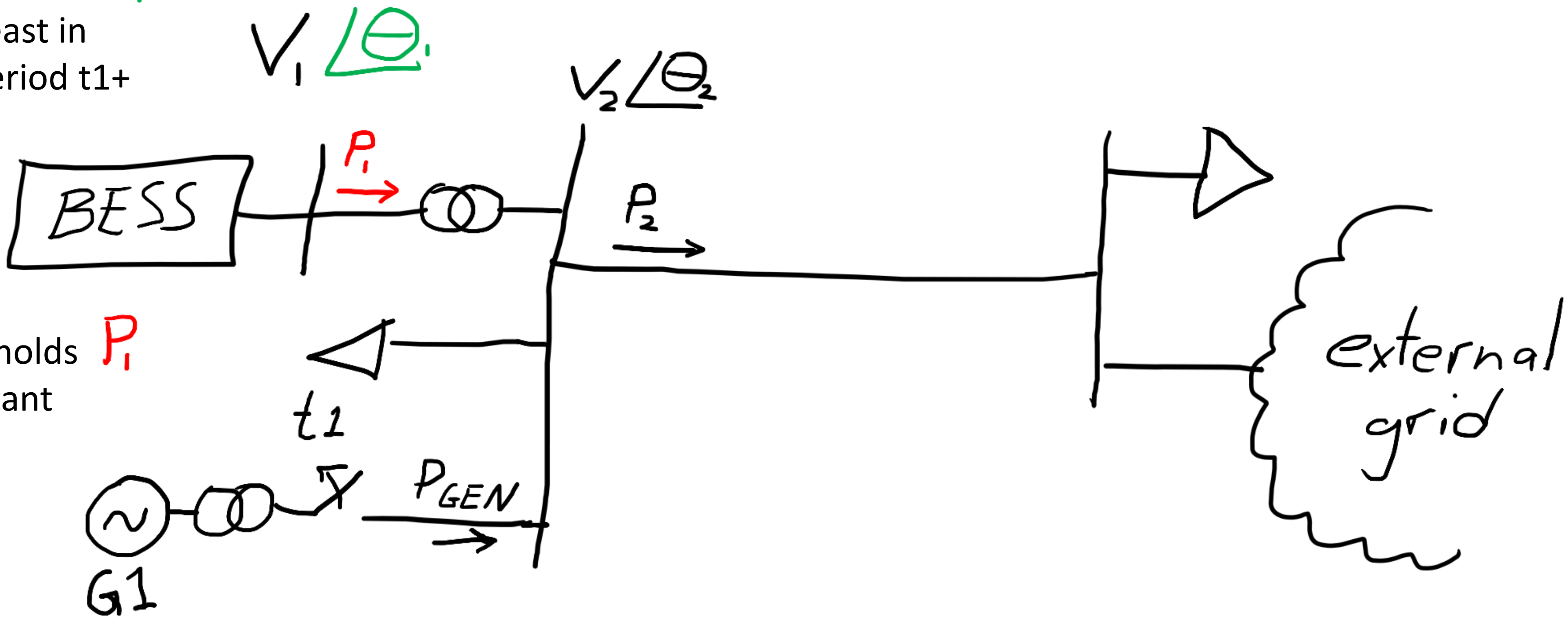
Grid-Forming: *Grid-Forming resources do not require very fast synchronism with the external grid to produce a predictable output. Instead of output currents being their primary control objective, they maintain control of an internal voltage phasor.*

In some applications (eg. Black start or microgrid applications), this voltage phasor is held relatively constant, allowing the plant to operate in an island as the sole frequency determining element. In other applications (eg. bulk grid connected applications), the voltage phasor may be controlled to maintain synchronism with other elements and also control active and reactive currents. There are many ways to implement this type of control, but common to all of them is a constant voltage phasor in the sub-transient to transient time frame, which provides a degree of stability in the controls during challenging network conditions.

← Potentially good for weak grids and high IBR penetration!!

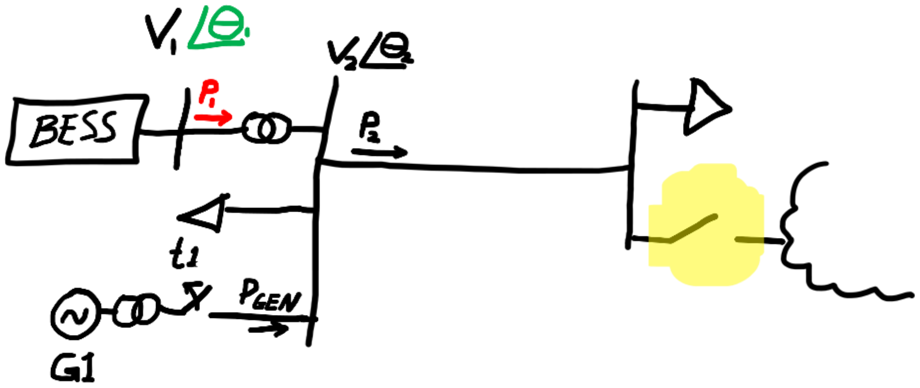
What does that actually mean?

Grid-Forming holds Θ_1 constant… at least in the transient period t1+

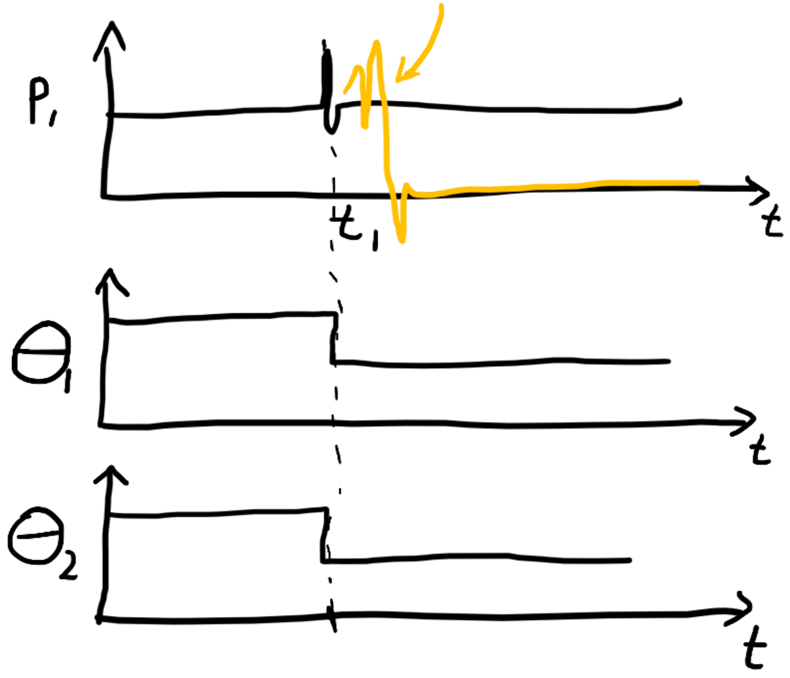


Grid-Following holds P_1 (currents) constant during t1+

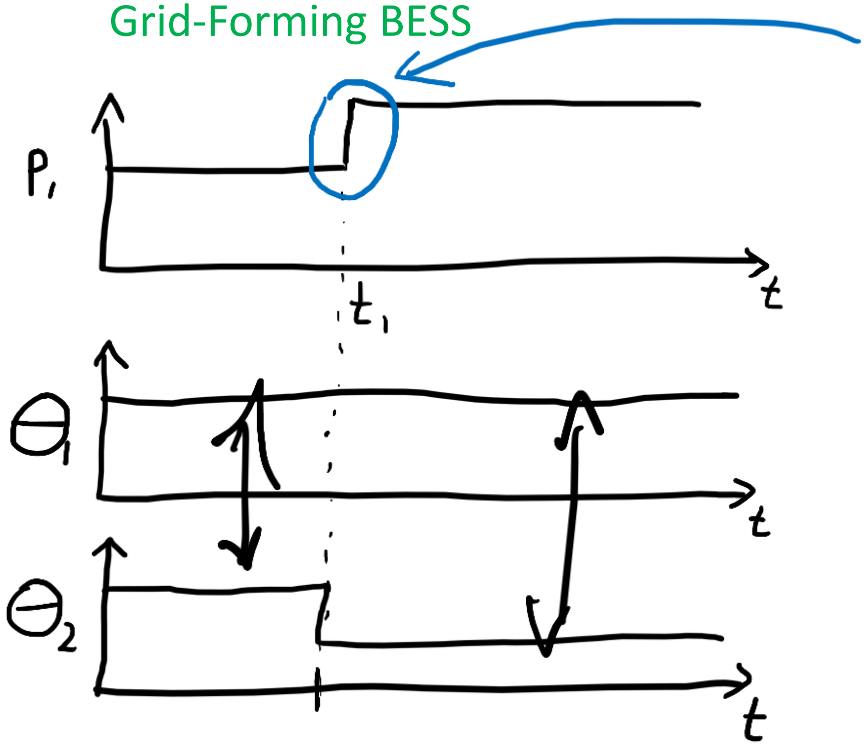
What does it look like when you disconnect the generator G1? (Island system)



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



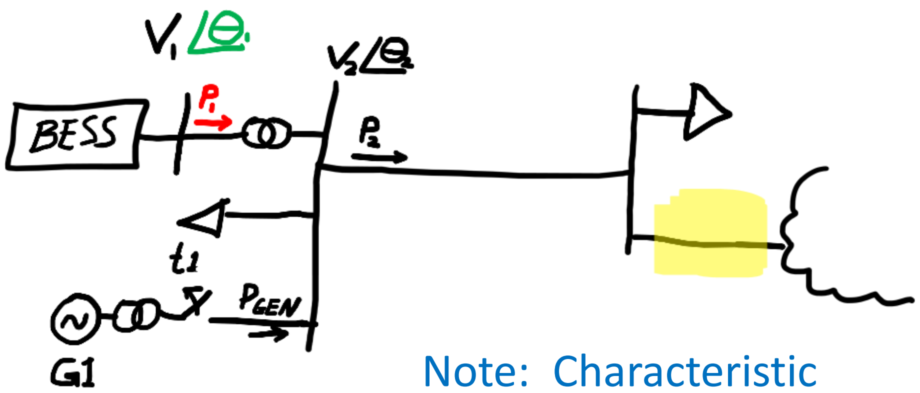
Grid-Forming BESS



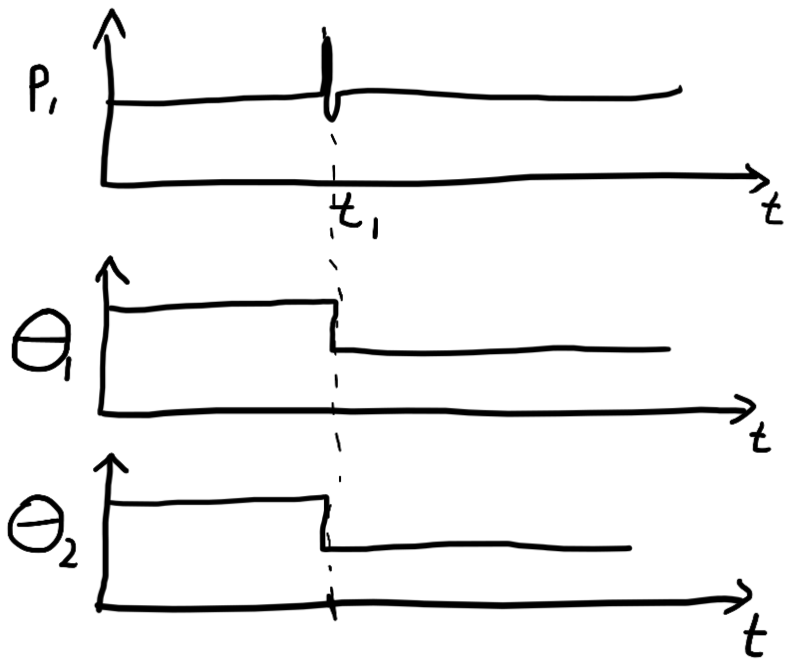
Note: Characteristic "Inertial Response"

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

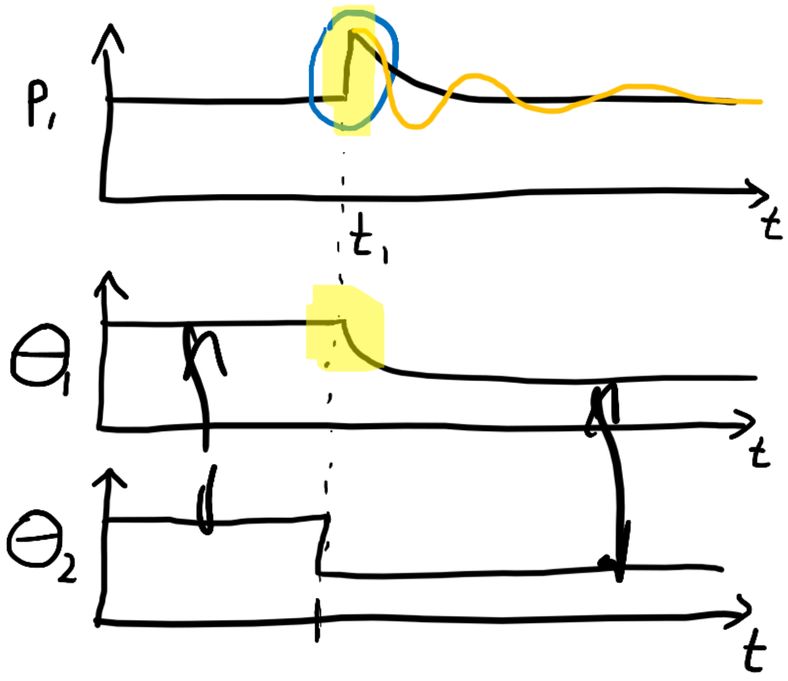
If we re-connect the island, and…
add power control/grid synchronization



Grid-Following BESS



Grid-Forming BESS

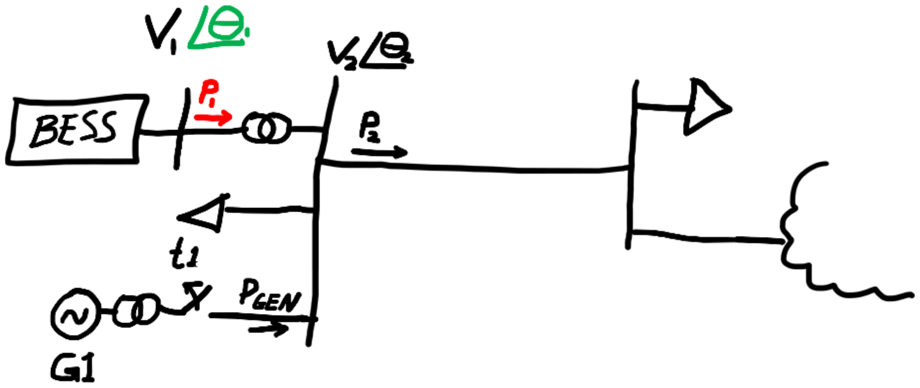


Note: Characteristic "Inertial Response"

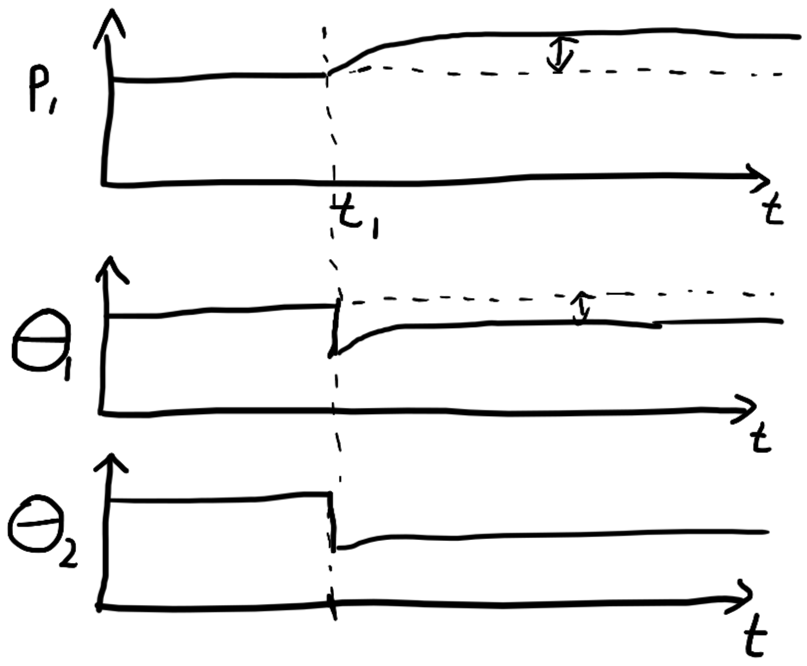
Note: Synchronous machine-type response if desired

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

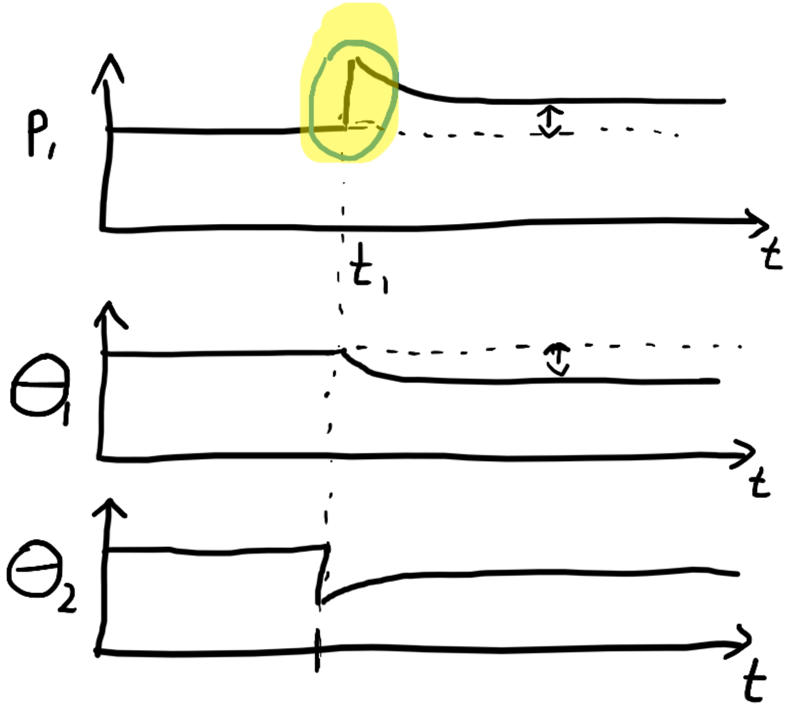
If we re-connect the island, and…
add power control/grid synchronization, and…
add frequency-droop control



Grid-Following BESS



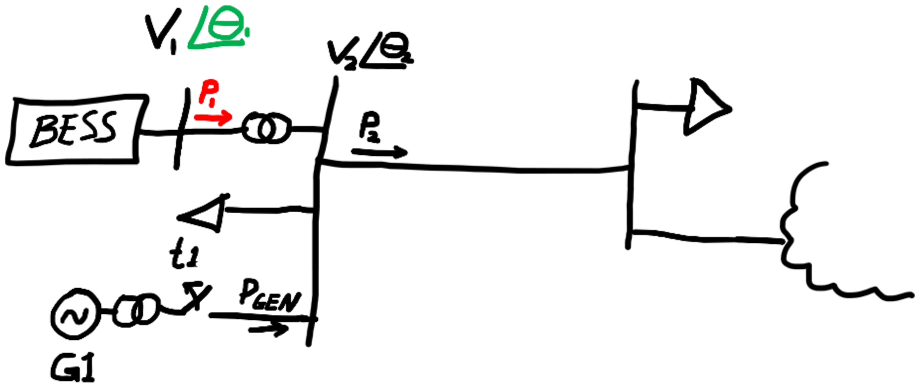
Grid-Forming BESS



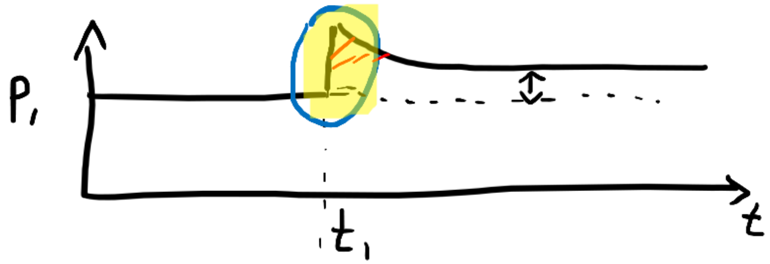
Note: Characteristic "Inertial Response"

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

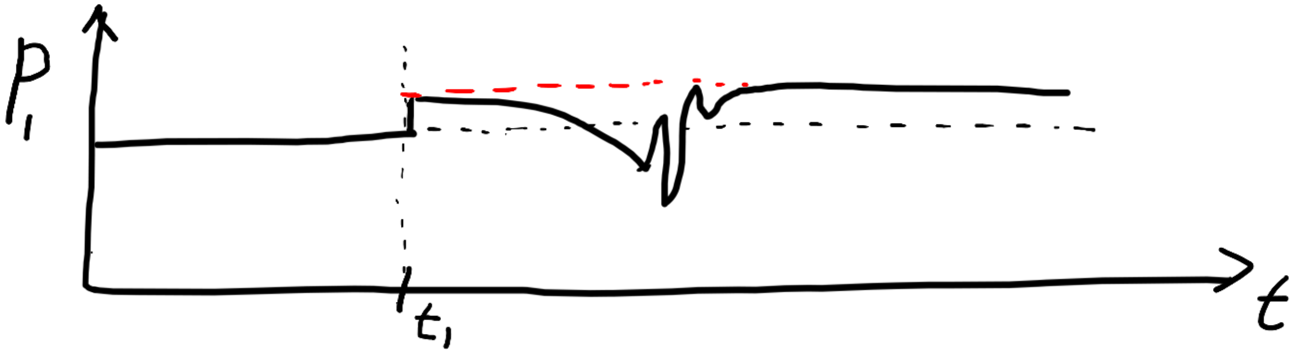
If we re-connect the island, and…
add power control/grid synchronization, and…
add frequency-droop control and…
run out of current margin in the BESS?



Grid-Forming BESS (headroom available)

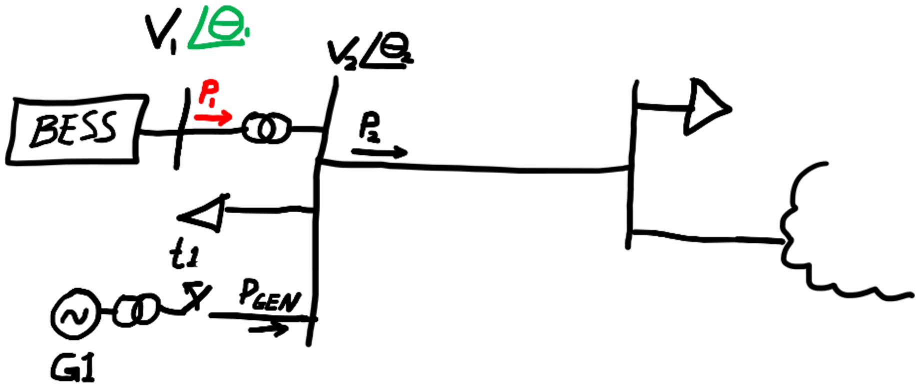


Grid-Forming BESS (out of current headroom!)
(example only… response will vary!!)

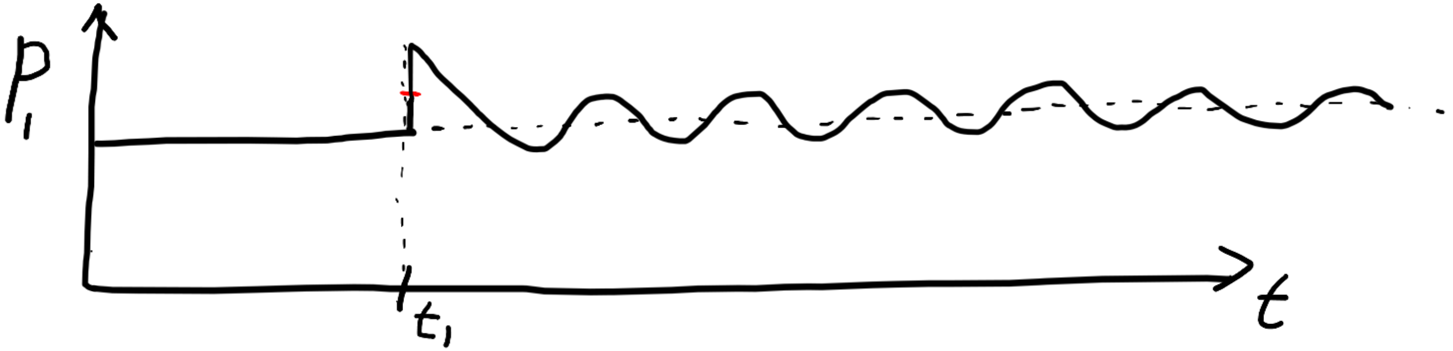


Note: If BESS runs out of headroom, many things can happen… it is down to how the controls are implemented!!

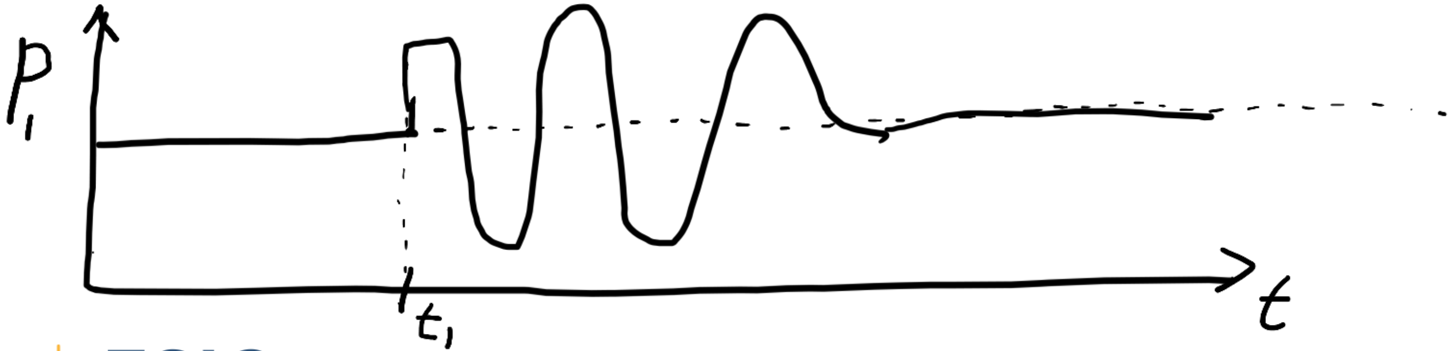
What else could possibly go wrong with GFM? A few things seen in recent studies…



Undamped oscillation or inter-machine modes



Interaction between entry and exit of FRT modes with nearby devices (GFL *and* GFM!)



Voltage control and droop, frequency control and droop settings all need to be correct and coordinated…

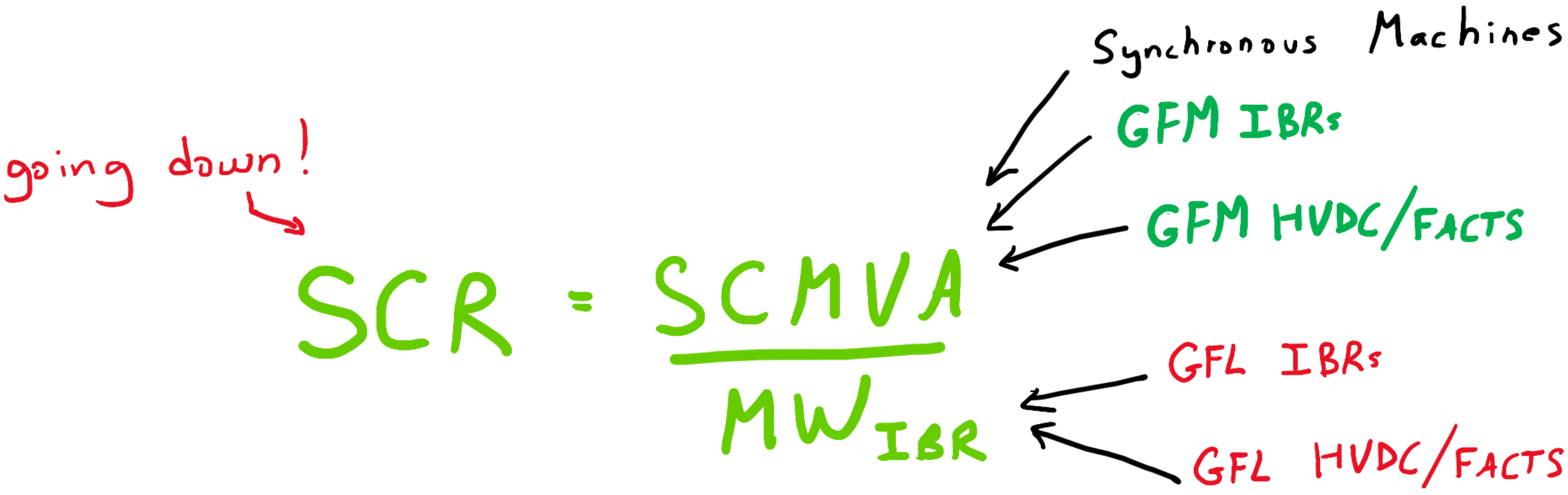
…and other things!!

Everything depends on the controls!!!

Additional Reminders about GFM Resources:

1. GFM effect requires energy and current headroom
2. There are multiple ways to implement controls (VSM, Droop, Other). A lot can be done to shape the response for specific needs
3. For resources with energy and current headroom (like batteries), the hardware is generally similar between GFM and GFL.
4. Generally all the things that GFL can do should be expected from GFM as well!

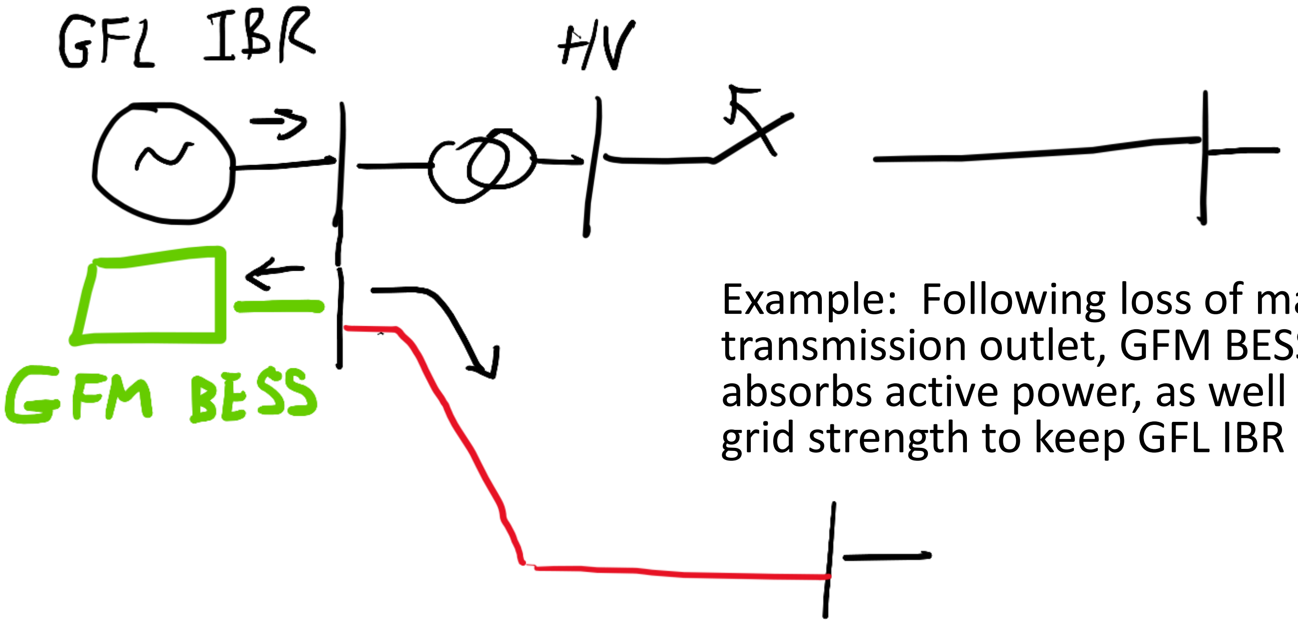
Pressing need for GFM is simple… the "Killer App"



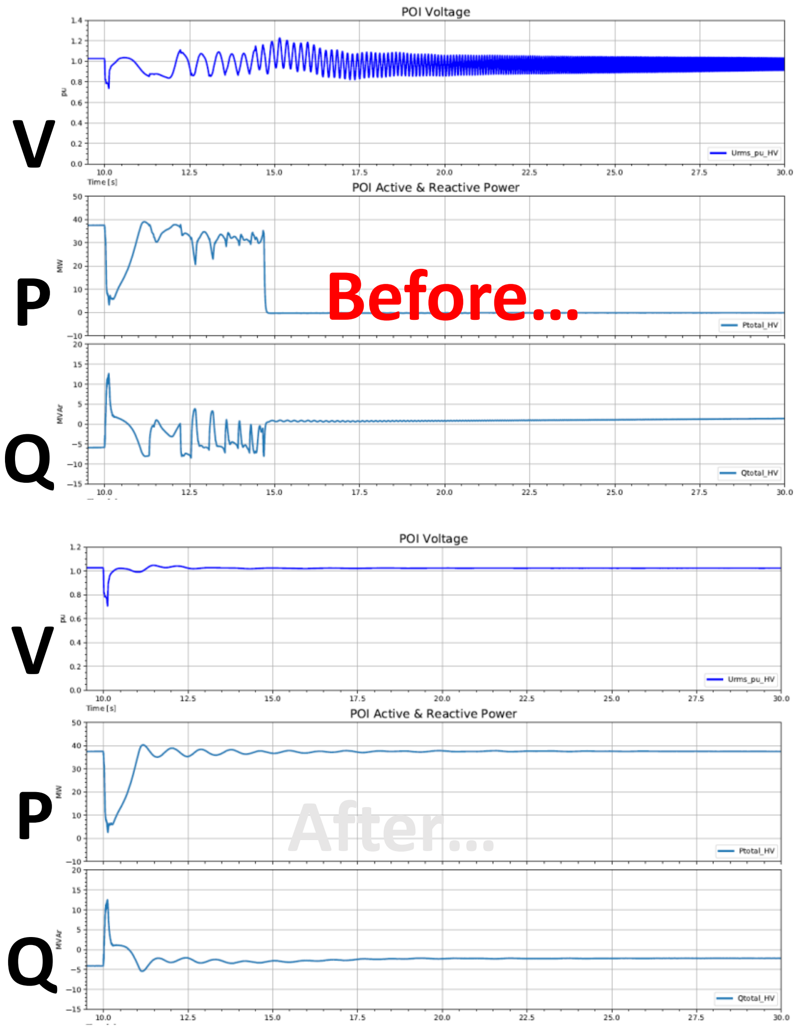
- ***Note: SCR based metrics are becoming less valuable in general. Use with care or don't use at all!!***

Increasing transmission capacity and local SCR

- For load or generation regions constrained by short term transmission overloads, GFM BESS can "catch" the system

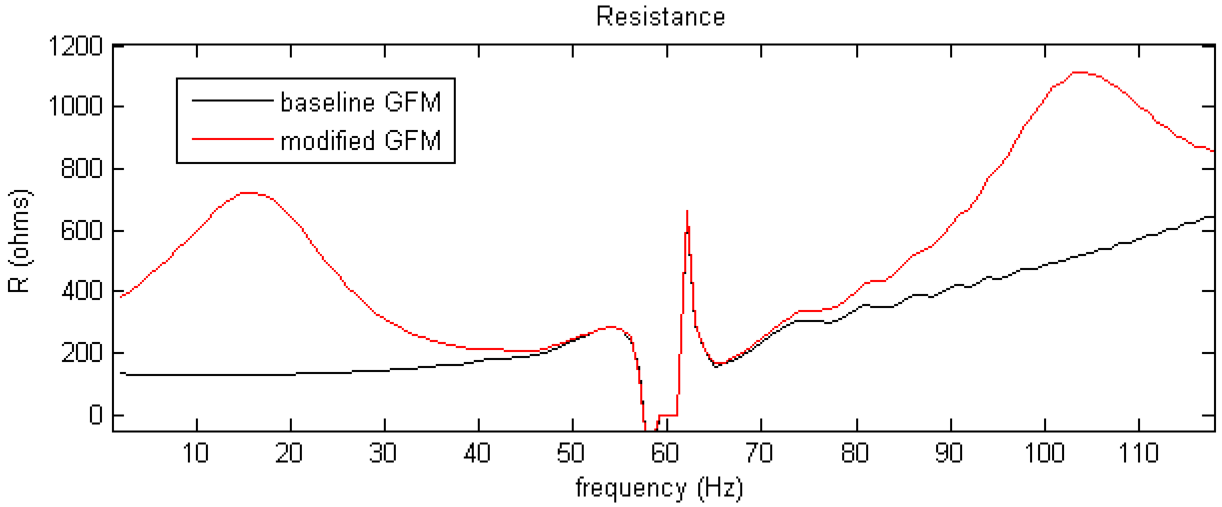


Example: Following loss of main transmission outlet, GFM BESS quickly absorbs active power, as well as providing grid strength to keep GFL IBR online.



Power system damping, including SSCI

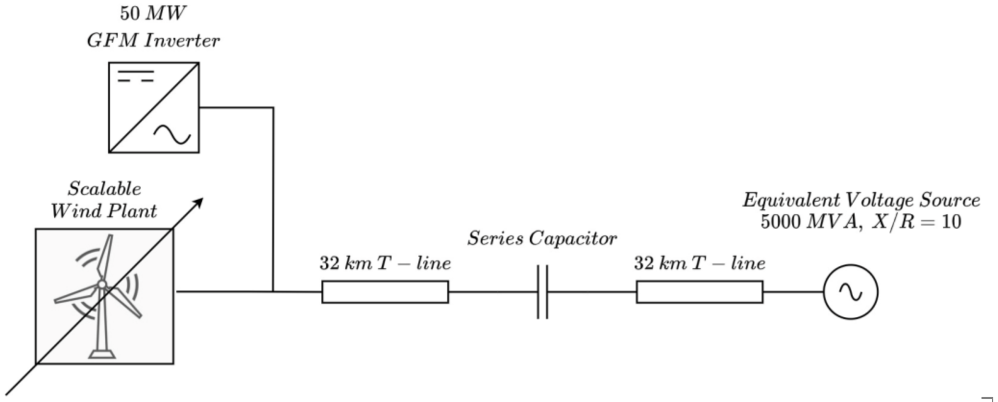
- GFM generally providing positive system damping in sub-synchronous frequency range
- Minor control changes (e.g. virtual impedance) can increase damping impact

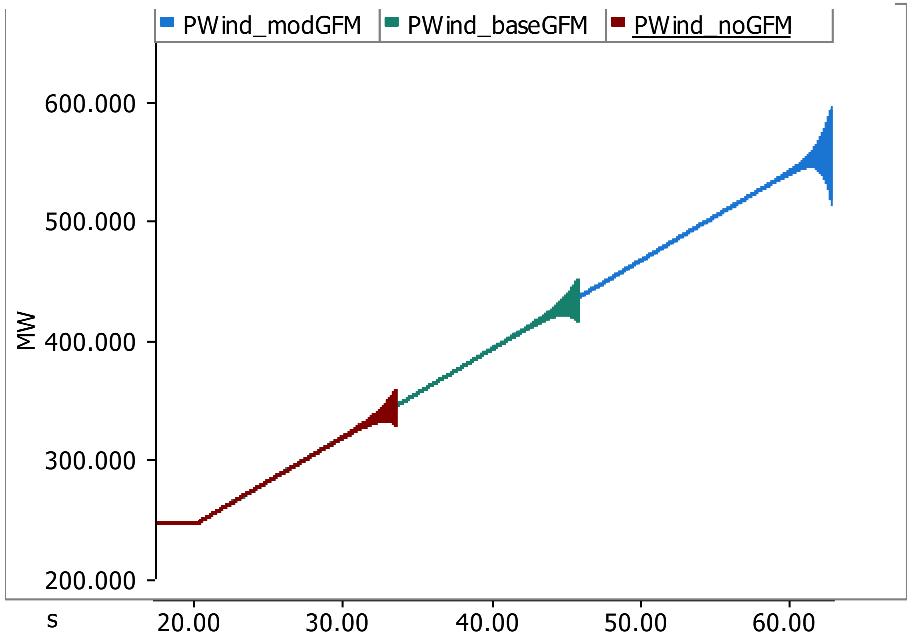


Credit: Research effort by Lukas Unruh – standby for paper or contact lu@electranix.com

Power system damping, including SSCI

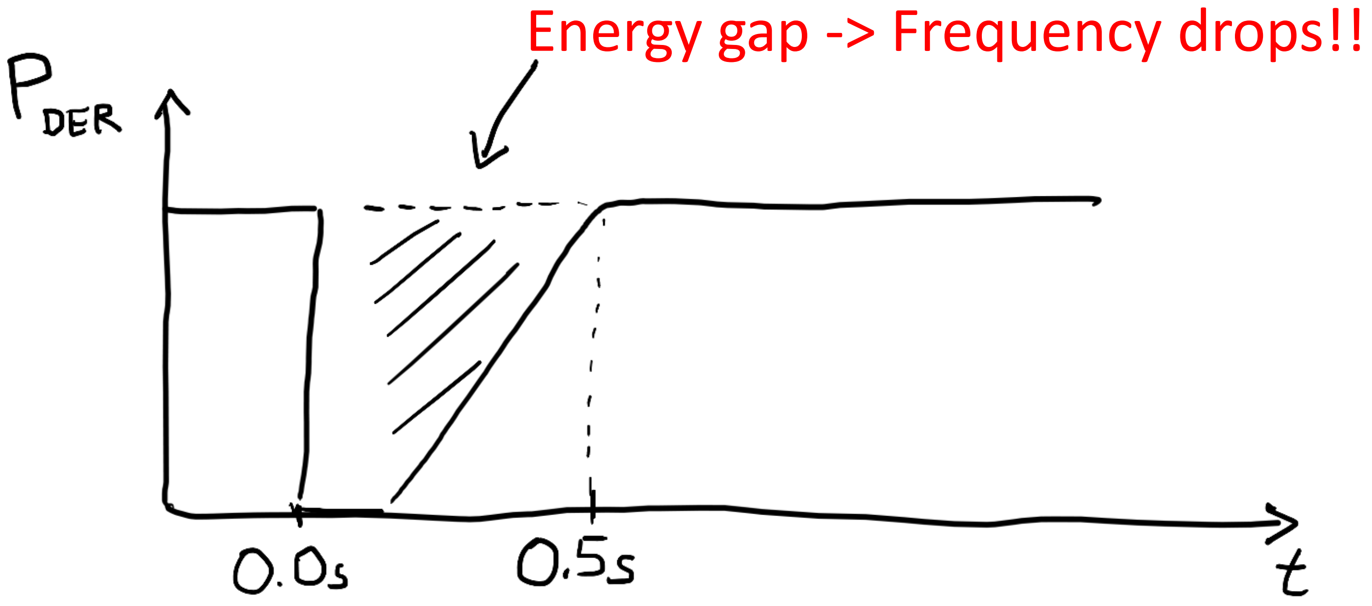
- Research example shows GFM stability benefits in series compensated system with Type 3 Wind Plant
- Stable limit of Wind Plant MW output increased by 200 MW with addition of 50 MW GFM
- Relatively small amount of GFM may provide substantial stability benefits

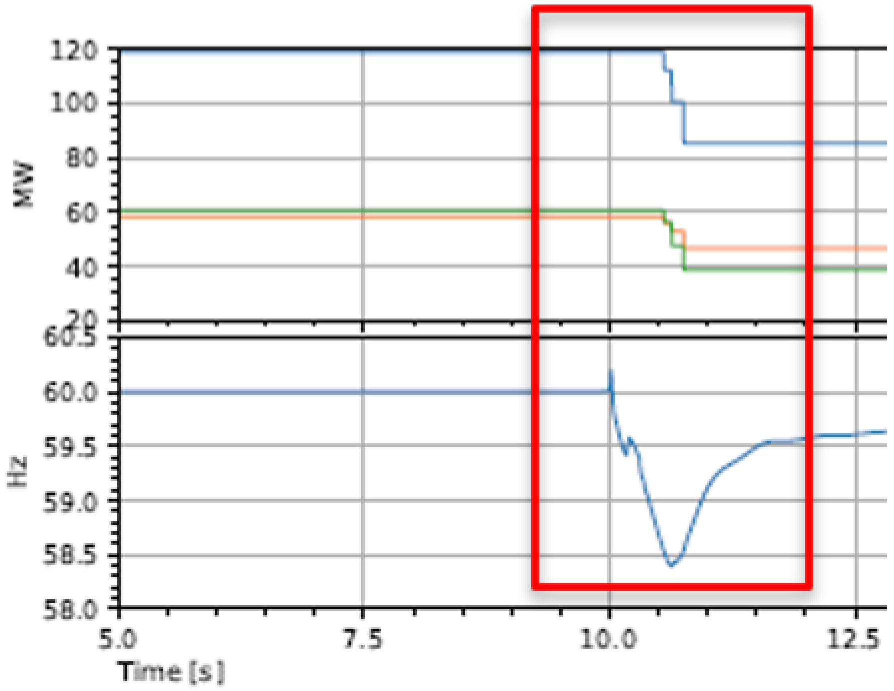




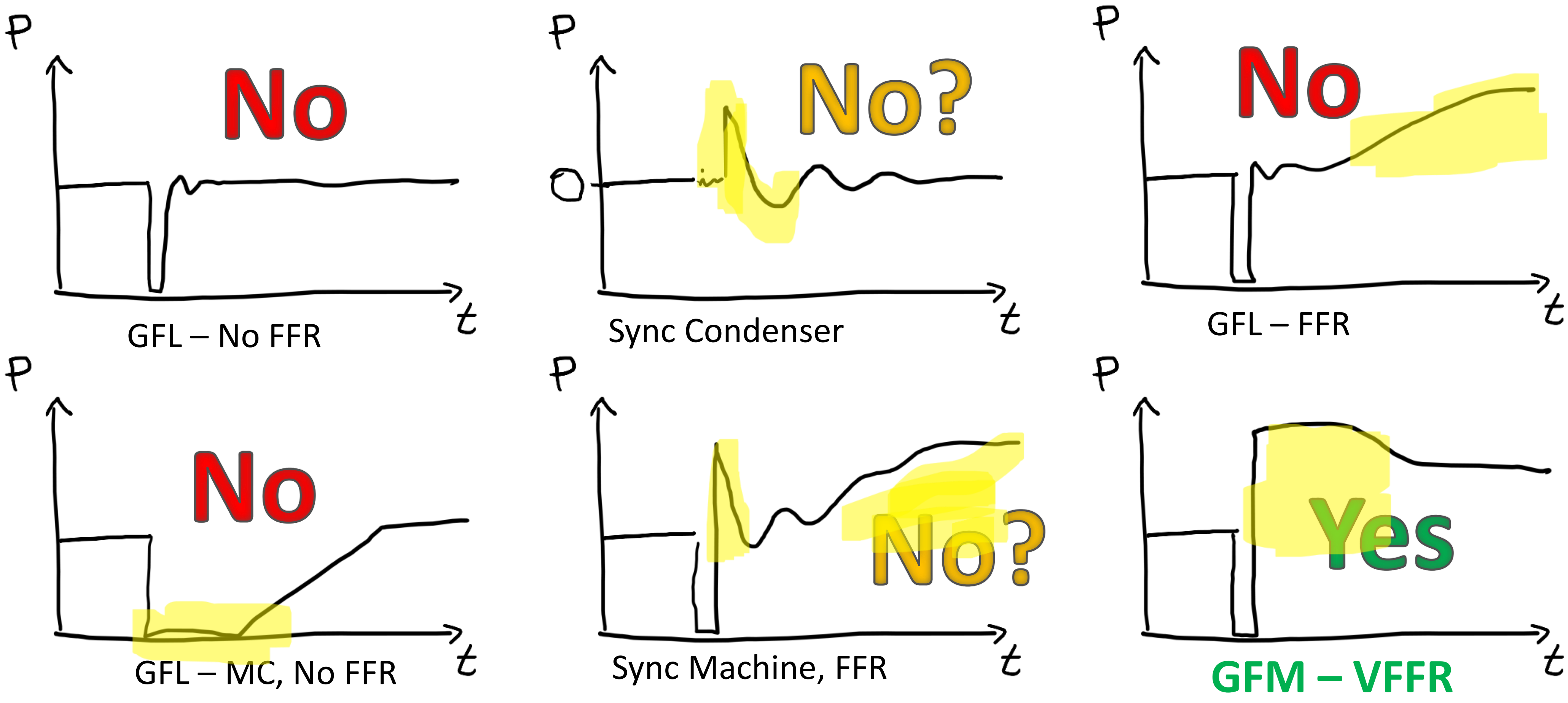
Very Fast Frequency Response Needed!

HECO: 50-70% DER penetration, with approximately 0.5 pu UV block threshold, short MC, and recovery ramp rate of 2.2 pu/s.





Very Fast Frequency Response Provided!



The following apply to *all* resources, GFM and GFL
(Ref: New NERC guide!)

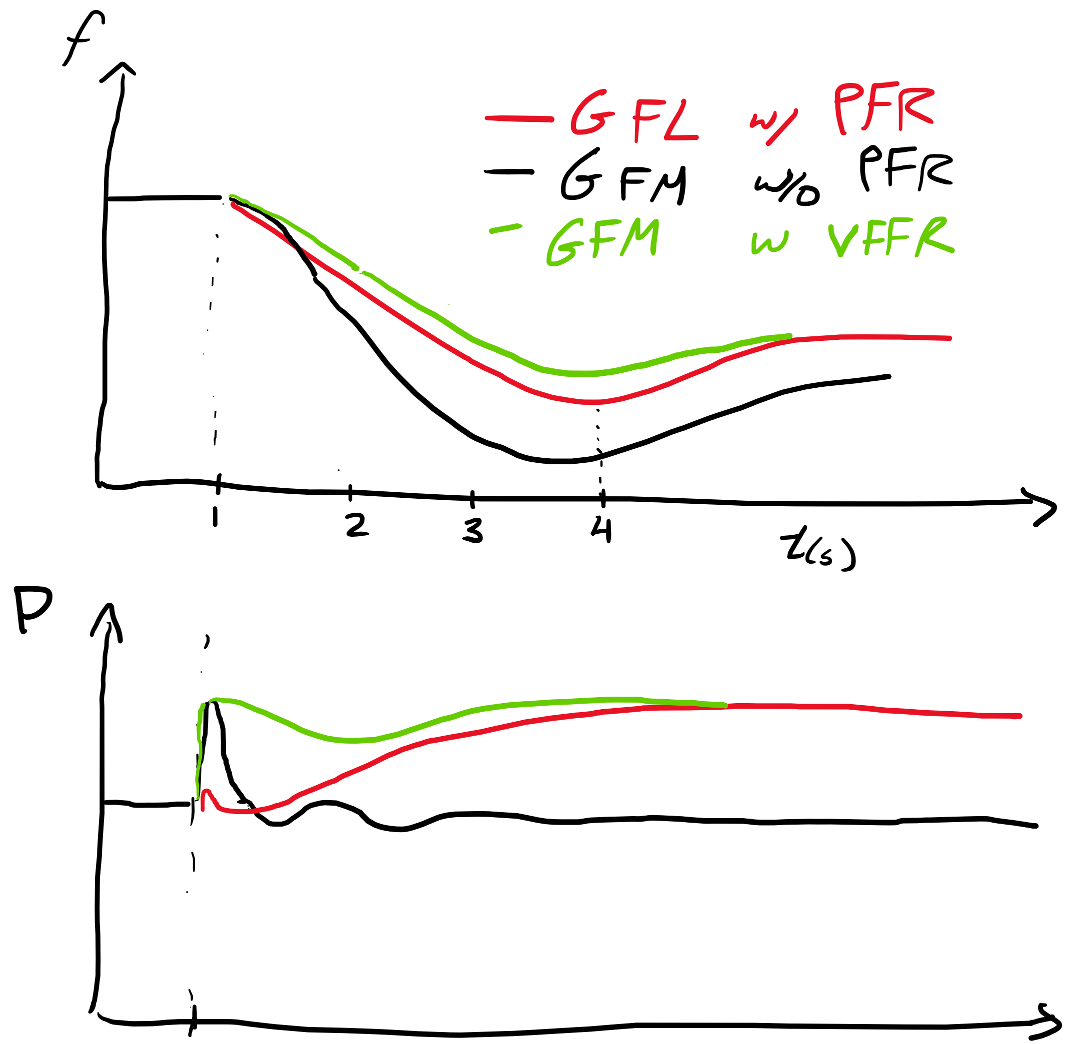
- **Dispatchability:** Capability of the facility to be dispatched (or curtailed) to a specific active power set point
- **Steady-State Voltage Control:** Capability of the facility to control steady-state voltage at the point of interconnection to a specific voltage schedule (set point and operating band)
- **Dynamic Reactive Power Support:** Capability of the facility to provide dynamic reactive support in response to normal and emergency grid conditions within the expected ride-through performance range
- **Active-Power Frequency Control:** Capability of the facility to respond to changes in system frequency by changing active power output when the resource has available headroom/tailroom
- **Disturbance Ride-Through Performance:** Capability of the facility to ride through normal grid disturbances within a defined set of parameters or expectations including faults, small and large disturbances, and phase jumps
- **Fault Current and Negative Sequence Current Contribution:** Capability of the facility to provide fault current, including negative sequence current to mitigate unbalanced voltage conditions
- **Security:** Capability of the facility to ensure cyber and physical controls are in place to ensure resilience to potential threats.

Additional Functional Specs for GFM BESS

1. **GFM-Specific Voltage and Frequency Support:** GFM shall provide autonomous, near-instantaneous frequency and voltage support by maintaining a nearly-constant internal voltage phasor in the sub-transient time frame.
2. **Seamless Transition between Islanded and Grid-Connected Operation:** GFM shall be able to seamlessly respond (based only on its local measurements) to changes from a larger synchronous grid condition to an islanded grid condition with no synchronous machines (and back again), and continue to help maintain nominal voltage and frequency up to its equipment capabilities. Beyond the sub-transient time frame, GFM shall adjust its power output to maintain synchronism with other resources.
3. **Ability to Stably Operate with Loss of Last Synchronous Machine:** GFM shall be able to stably operate through and following the disconnection of the last synchronous machine in its portion of the power grid.
4. **Phase Jump Performance:** GFM shall resist near-instantaneous voltage phase angle changes by providing appropriate levels of active and reactive power output in the sub-transient time frame.
5. **System Strength:** GFM shall reduce the change in voltage for a given change in current in the sub-transient time scale (i.e., improve the strength of the local network of connection).

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, it needs to be tuned.
- GFL may be able to provide what you need!



Additional key technical points:

- GFM is currently commercially available in BESS technology.
- Cost for GFM is expected to be marginally higher than GFL in BESS in the short term, and eventually there may be no cost difference. Some OEMs are already saying there is no cost difference.
- Existing GFL BESS may or may not be upgraded to GFM at a future date, depending on vendor.
- GFM is currently being advertised as available by 2 STATCOM vendors
- 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.