Fundamentals of Frequency Stability and Dynamics – Part 3

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Integrated Planning: Assuring Stability in Modern Systems

Day 1: Session 5

Monday September 15, 20253

ESIG
ENERGY SYSTEMS
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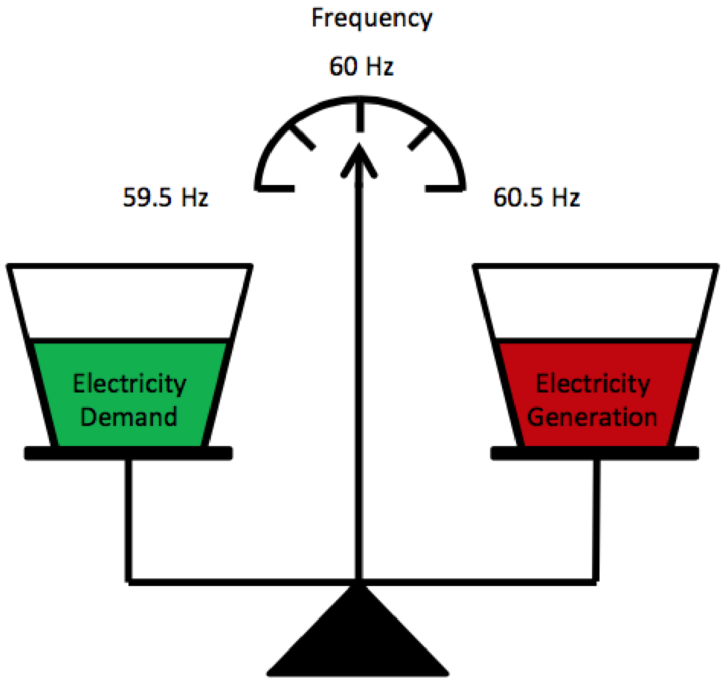
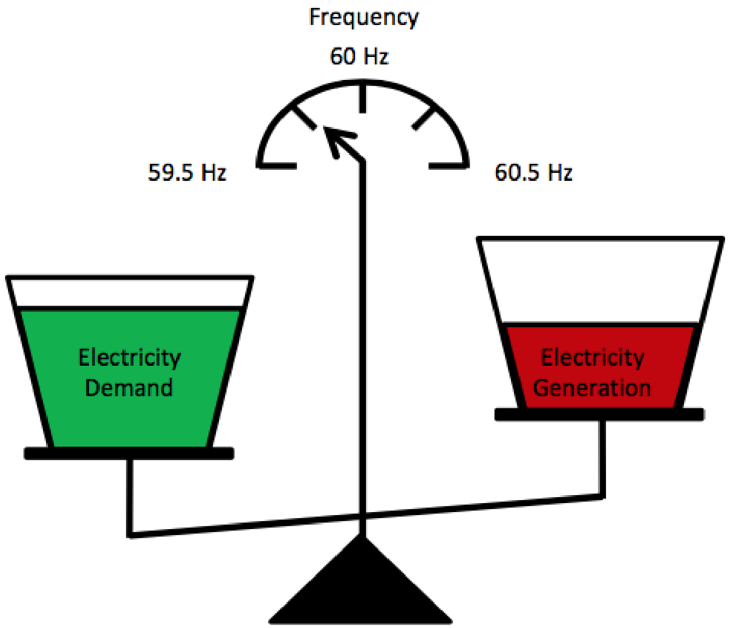
Frequency STABILITY

- Frequency is a function of interconnection-wide balance between supply and demand

Generation and demand are balanced: 60 Hz



Not enough generation: underfrequency



N. Miller, Western Wind and Solar Integration Study Phase 3, NREL, 2014

Frequency Control: time frames

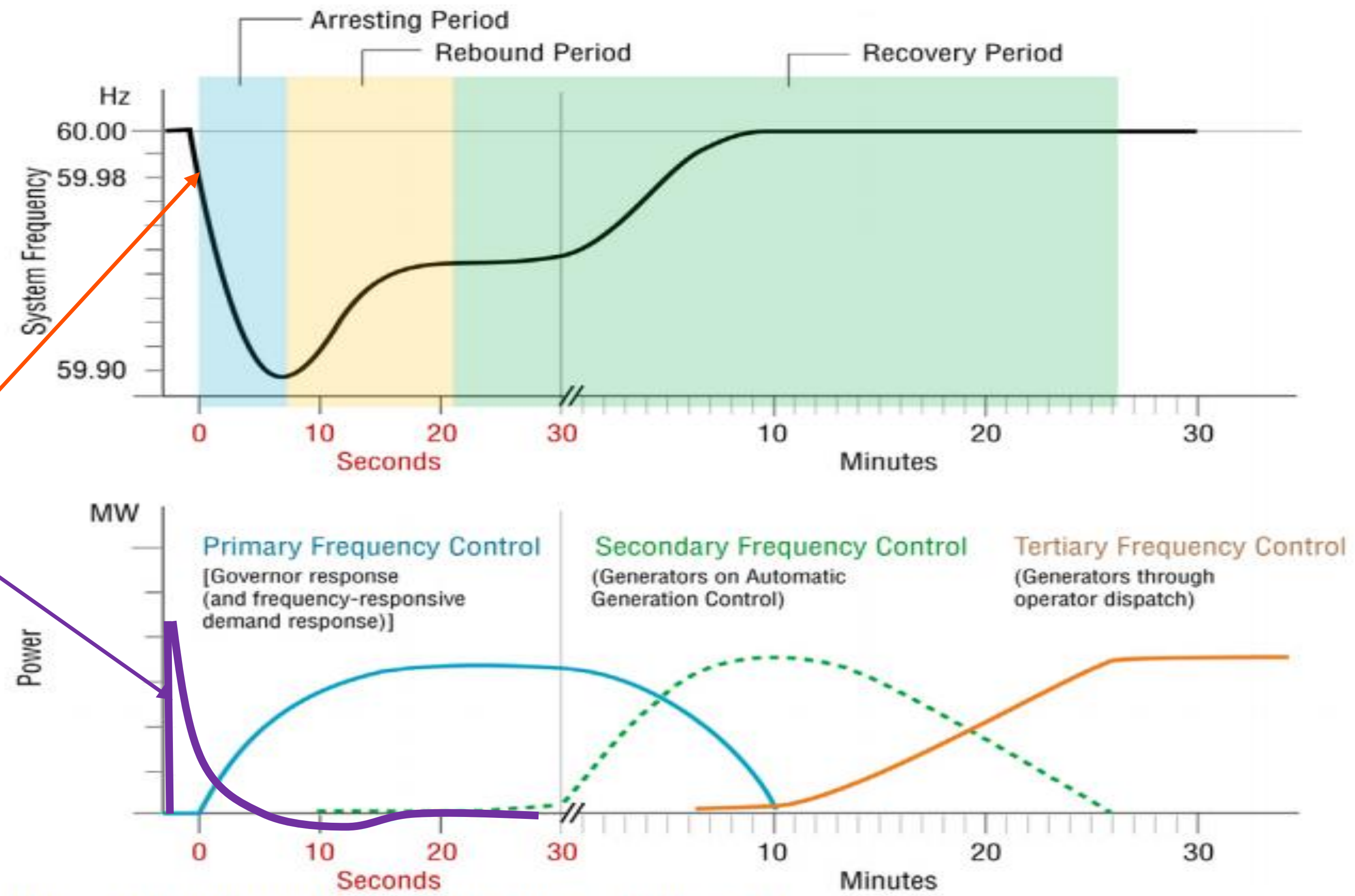
This NERC figure is widely used to show the relationship between the system needs and services that meet them.

Traditionally inertia hasn't been a "service" – with synchronous machines it is intrinsic and uncontrolled; uncontrollable.

We have added **inertia** to the NERC figure here. It by definition goes to zero at the frequency nadir (minimum)

The RoCoF: Rate-of-change-of-frequency – i.e. "how fast is the frequency dropping", is given by MW loss/Inertia.

The amount of inertia ONLY affects RoCoF. **Inertia alone only buys time** to act. Other services must act, as shown.



Note: Load-damping is not shown on this figure. See Footnote 31.

Adapted: J. Eto, J. Undrill, M. O'Malley et al, "Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation", 2010

Low Inertia vs Event Size vs Speed of Primary Frequency Response

- “Size” of the event dominates
- If there isn’t enough arresting power, then everything after is moot
- Speed matters. It always has.
- Big changes in inertia have a relatively/comparatively small impact on the frequency nadir
- Biggest events tend to be loss of really big generating stations…which are becoming less common

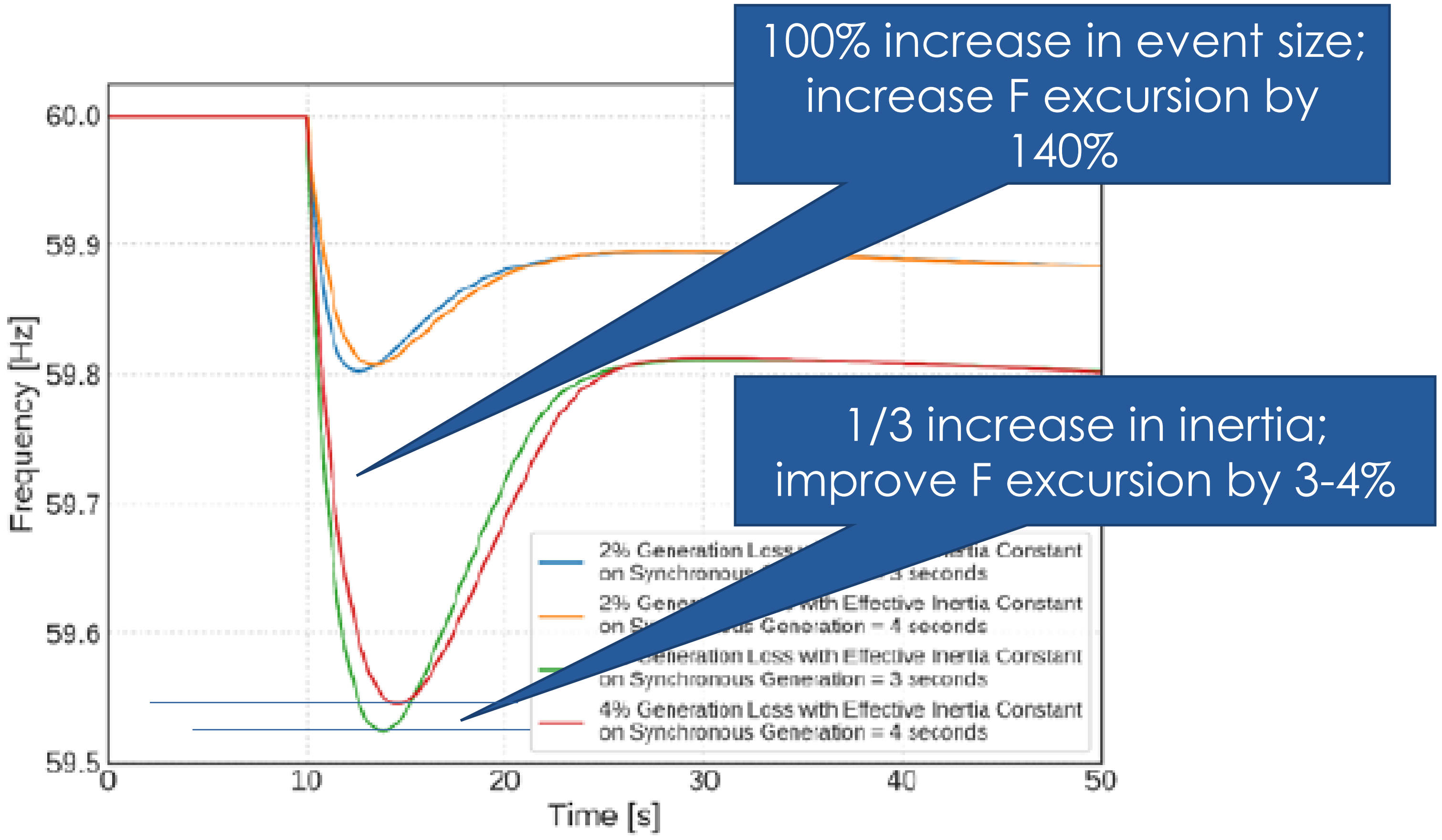
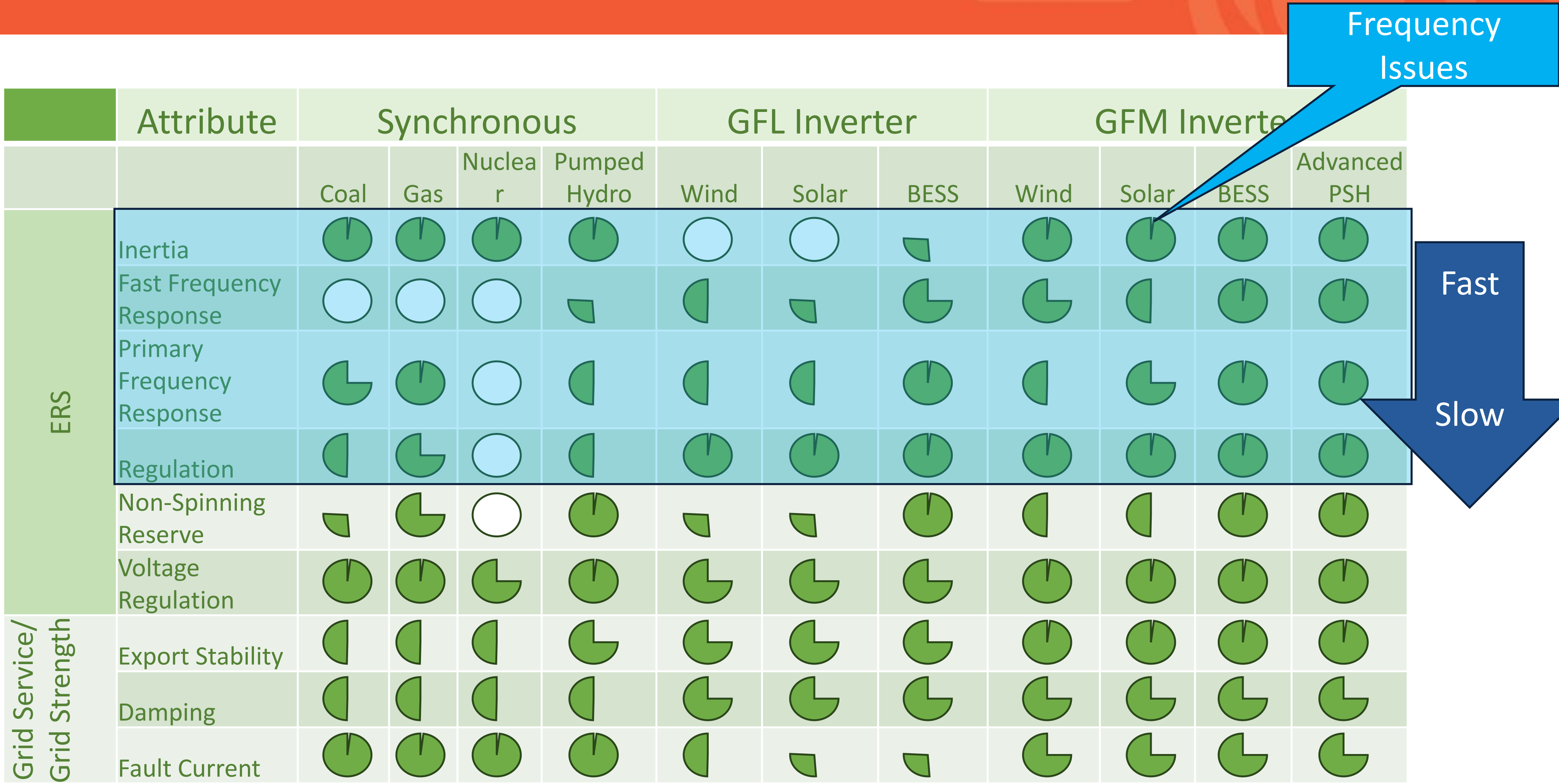


Figure ES - 5. The Relative Impacts of Generation Loss versus System Inertia on Frequency Nadir

Source: Developed by LBNL from Undrill (2018): Primary Frequency Response and Control of Power System Frequency

Many resources contribute to managing system frequency

- Frequency response varies with resources
- All the time frames are important
- Inverter-based resources (IBRs) are better than synchronous resources in some regards

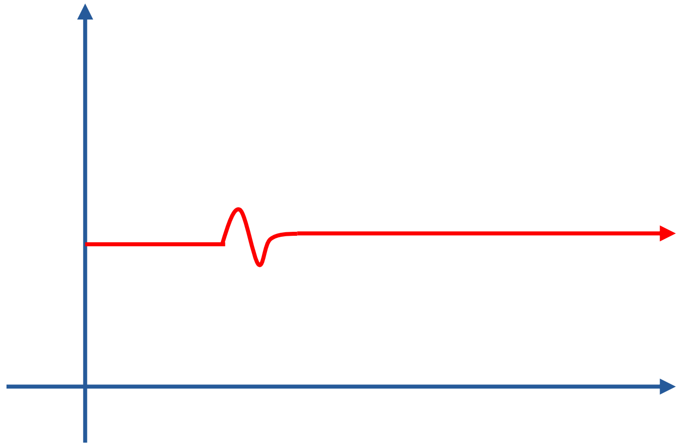


Frequency: much more than “inertia”

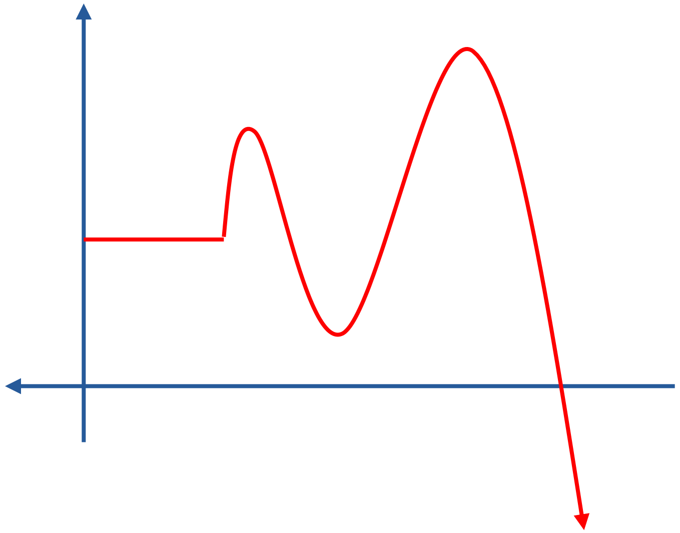
- There are many misconceptions about “inertia”
- Many resources contribute to managing system frequency
- Take advantage of the speed and programmability of power electronics
- Asynchronous power plants are more stable than conventional synchronous generators
- There’s a ton of cool behaviors possible…we’re still learning to exploit them
- We have a significant decoupling from the “traditional” time constants that dominate(d) grid dynamics.

“Inertia” is a poor shorthand for all things frequency and all things stability. So don’t do it!

Inertia and Damping



Quick tutorial on grid strength

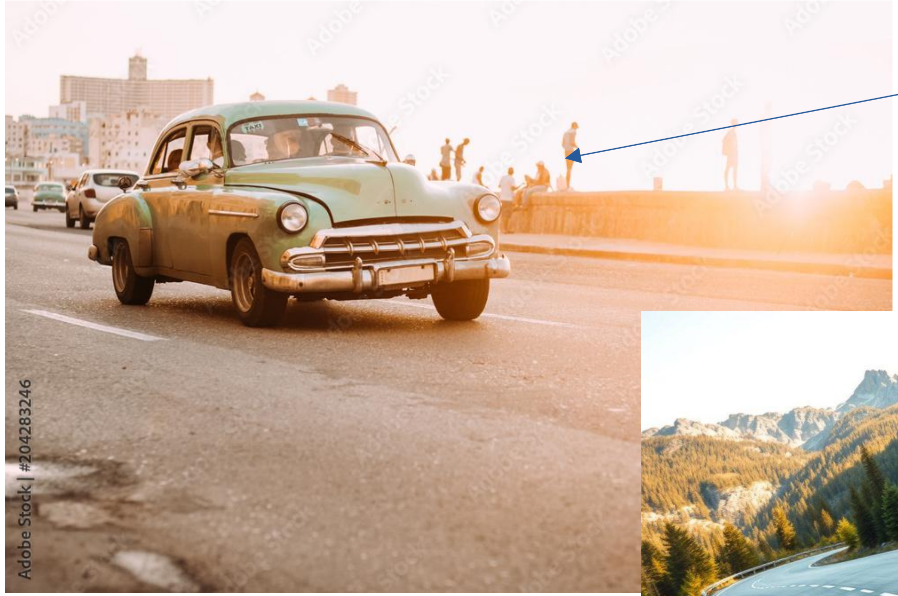


Inertia and Damping

Disturbance

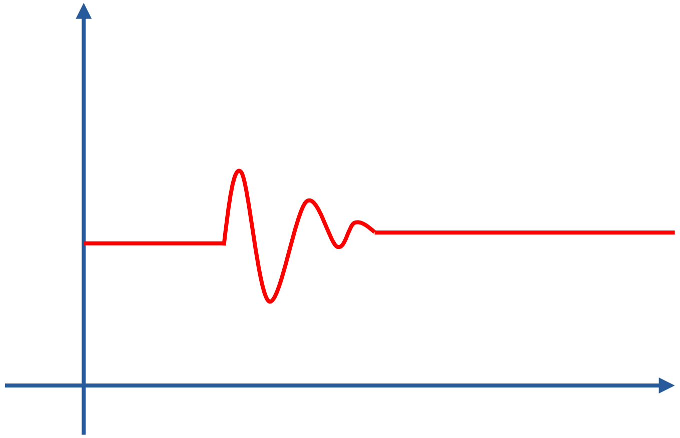
Inertia and Damping

Inertia and Damping



GFL

GFM



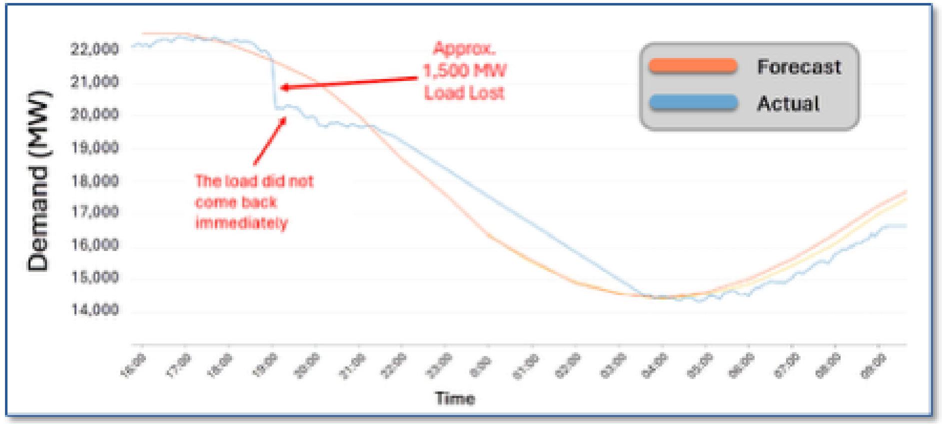
Disturbance

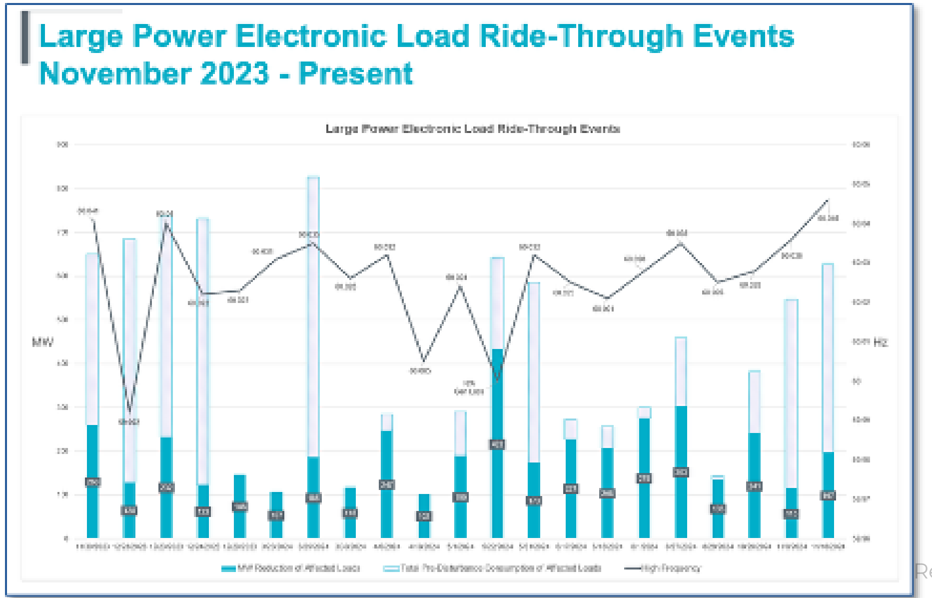
I'm Following

Follow me!

Frequency Stability with Very Large Loads

- Dynamic behavior of huge new data center loads is causing great concern
- Behavior is not well understood, not uniform
- NERC and many others are paying close attention
- This event is a “canary in the coal mine”: Unexpected disconnect and reconnect of massive load
- What if it was 10x bigger???

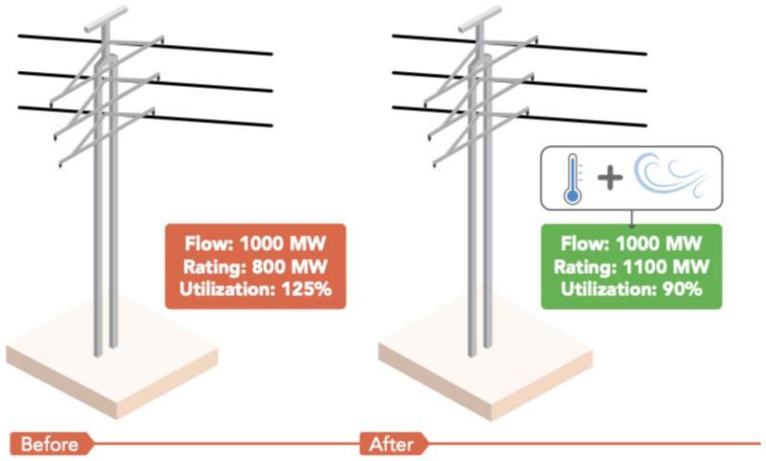




NERC LLTF 2025; P. Gravois, ERCOT, NERC LLTF, 12/12/24

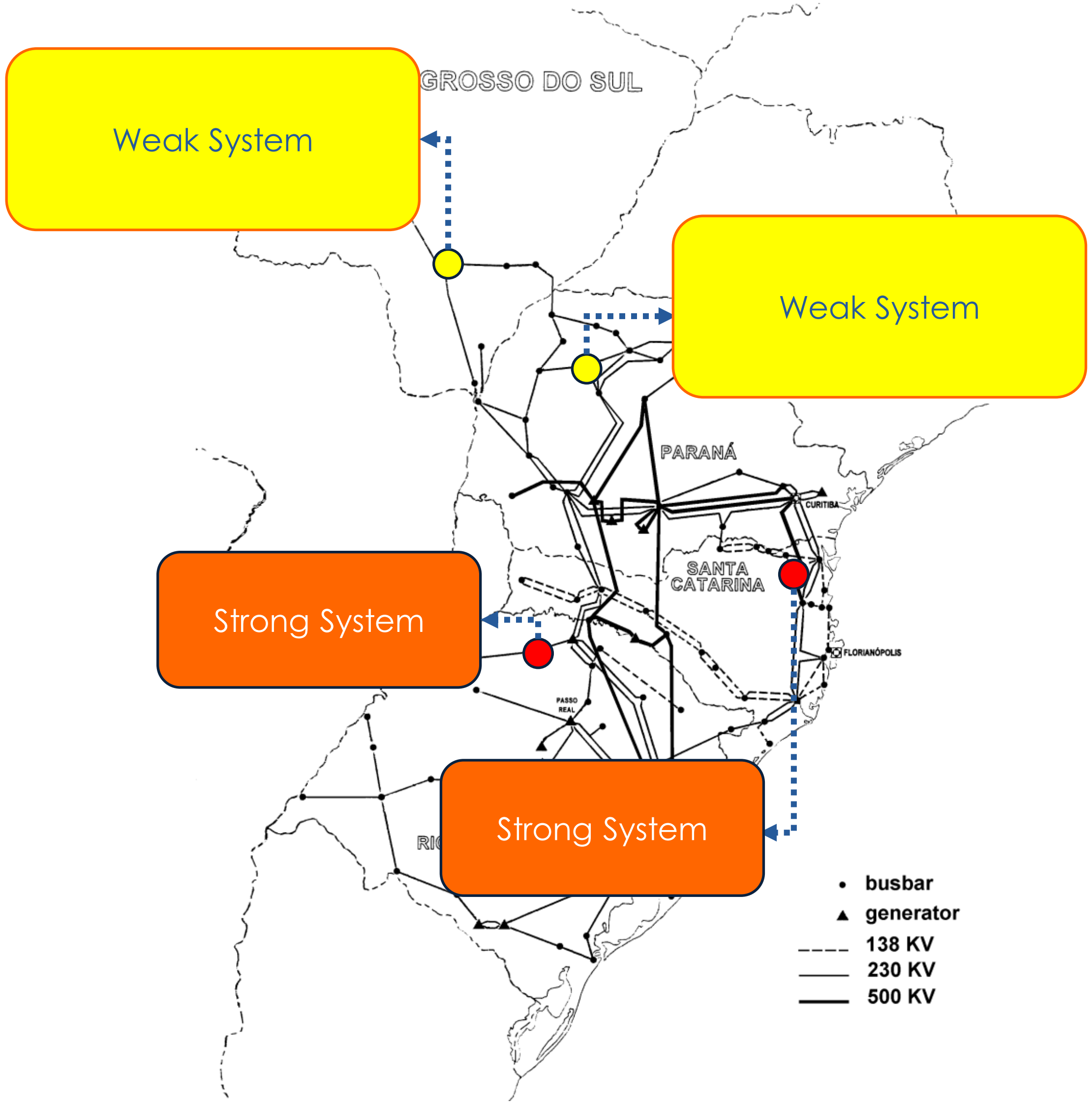
Mitigation Methods

- Voltage and Frequency Ride through
- Weak systems! We need inertia!
  - Do we actually need it that much?!
- Add more lines and Synchronous Condensers
  - Alternatives: Flexible Loads, Grid Enhancing Technologies (GETs)
  - Ask Loads for help!



Source: https://watt-transmission.org/what-are-grid-enhancing-technologies/

It is more than only weak and Strong



Location Matters and we have the tools! (Fundamentals)

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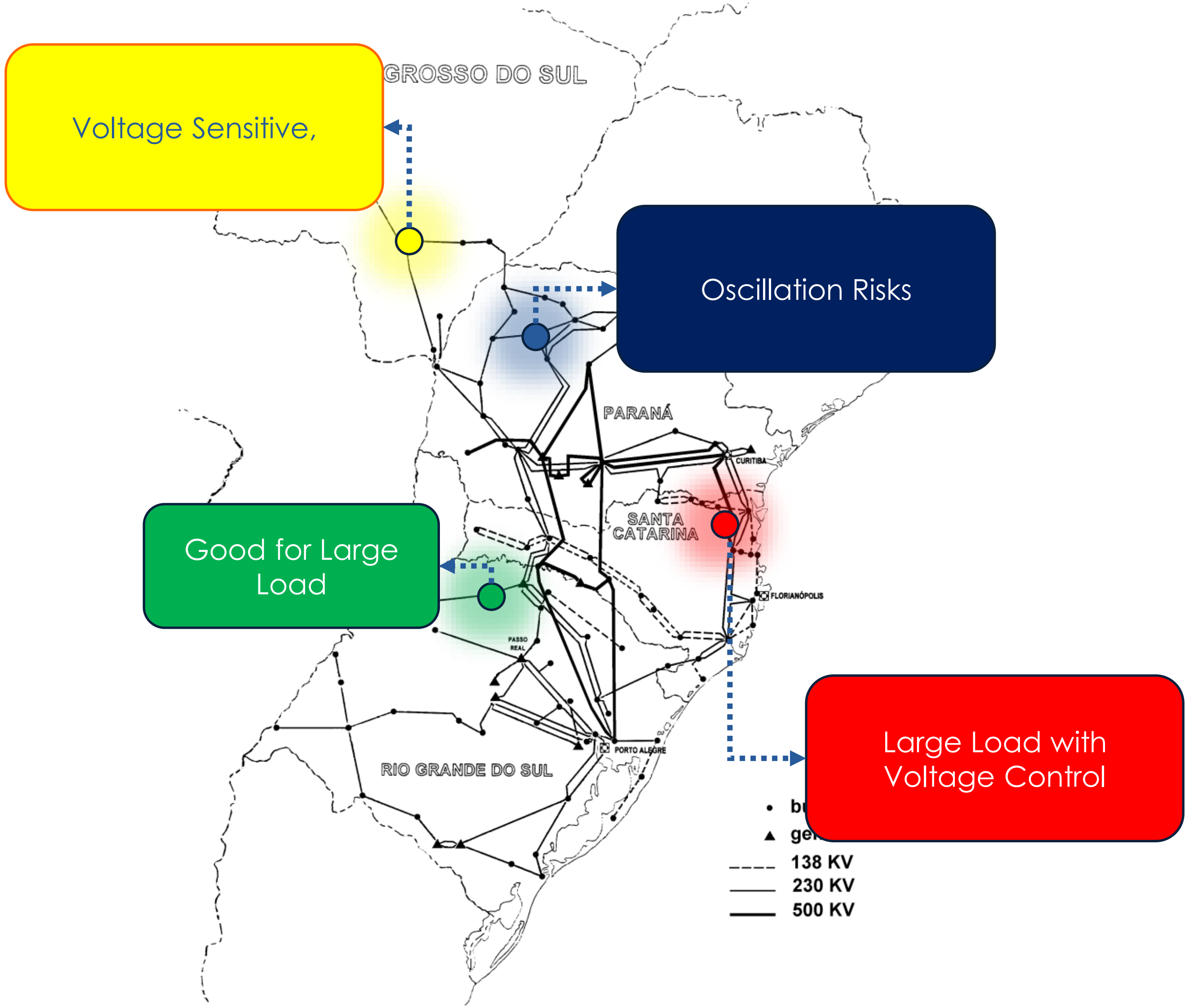
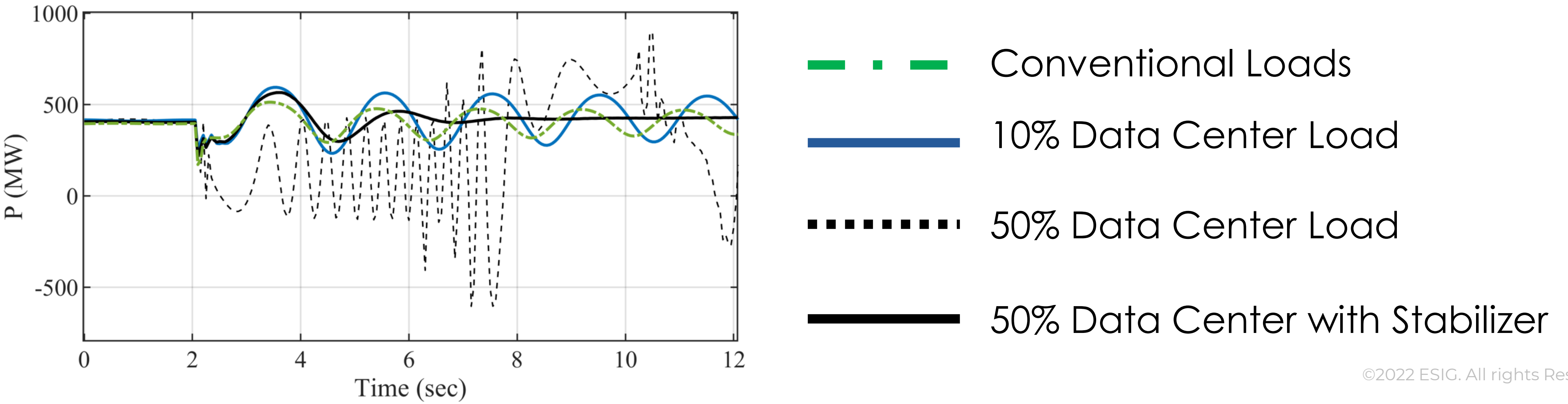
Small Signal Analysis (fundamentals)



Inertia or Damping?

- **Large Loads will dictate the Stability!**
- **We need to ask for the right services**
  - **Voltage?**
  - **Frequency?**
  - **Damping?**
- **Can loads be GFM?! They Can Actually,**
- **Any market for these services?**



Takeaway: Large Loads can help!

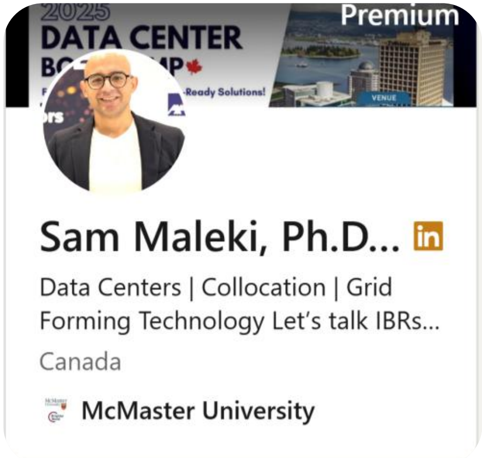
- Large loads have (some) capability to be controlled very rapidly.
- They can help if we know what we want.
- How exactly you want us to behave?
  - Frequency Ride through
  - Voltage Ride through
  - Frequency regulation/response
  - Voltage Regulation
- Flexible loads
  - Will you pay us for all these?
  - We need incentives
  - We need more collaborations

Frequency Stability Lessons Learned

- Inertia isn't always a friend – remember that inertia is not controllable
- We need inertia but we need **damping** more!
- It is more than a weak or strong grid! **Small Signal Analysis** can help
- Faster isn't always better; "fast enough" is a better philosophy
- Future grid stability can be dictated by **Large Loads**!
- The advent of GIGANTIC power electronic loads (e.g. Data Centers) adds **new dimension** that we are not fully prepared for.
  - We need to ask them the **right requirements**
  - We need to think of new **market for these ancillary services**

Thank you!

- Damping and Inertia are not the same, we need more damping rather than inertia
- IBRs caused so many challenges, Large Loads will do even more!
- Voltage Over Correction Conceals the hidden stability risk (Majority of the black outs)
- Large Loads can help the system if we ask them to and we provide incentives (voltage support, damping, load and generation balancing, etc.)
- Contact: Sam.Maleki@electromentors.com



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