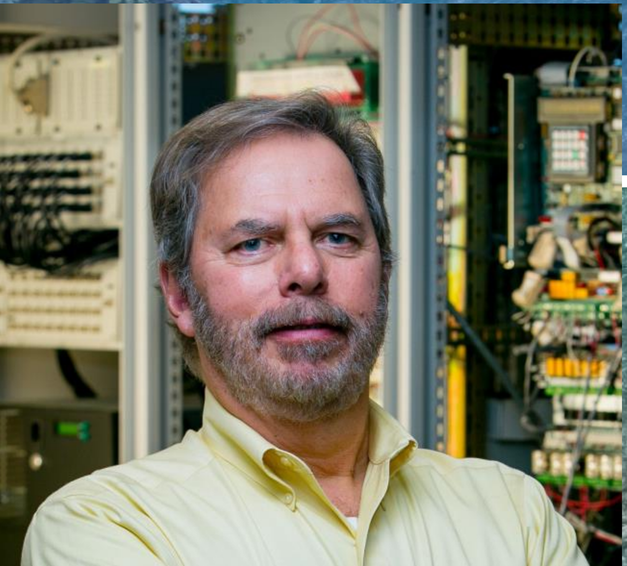
Grid-Forming Inverter-Based Resources Webinar

Export Stability: Comparing Grid-Following IBR, Grid-Forming IBR, and Synchronous Machines



Nick Miller, HickoryLedge LLC

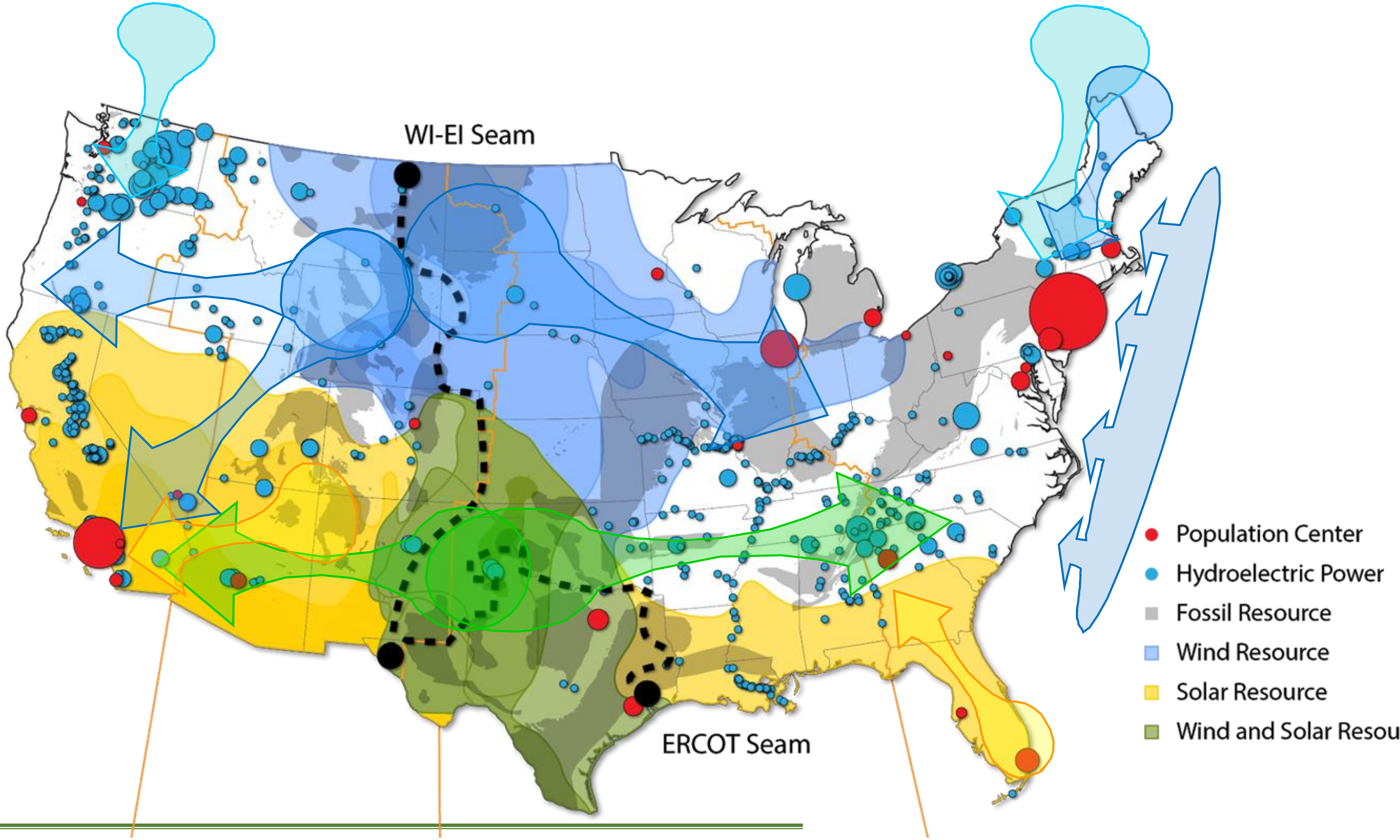
Wednesday, October 13

ESIG

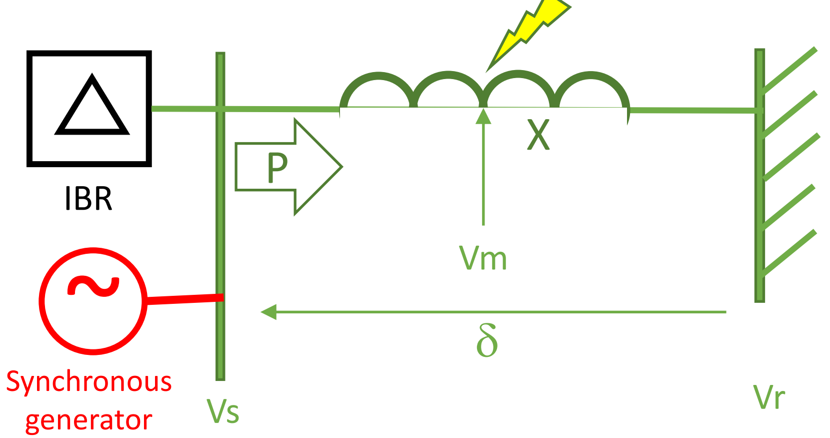
ENERGY SYSTEMS INTEGRATION GROUP

Export from resource rich regions is critical

- Stability issues in the 1st line of challenges
- Transmission is and will be a critical resources
- We must use it to the utmost efficacy

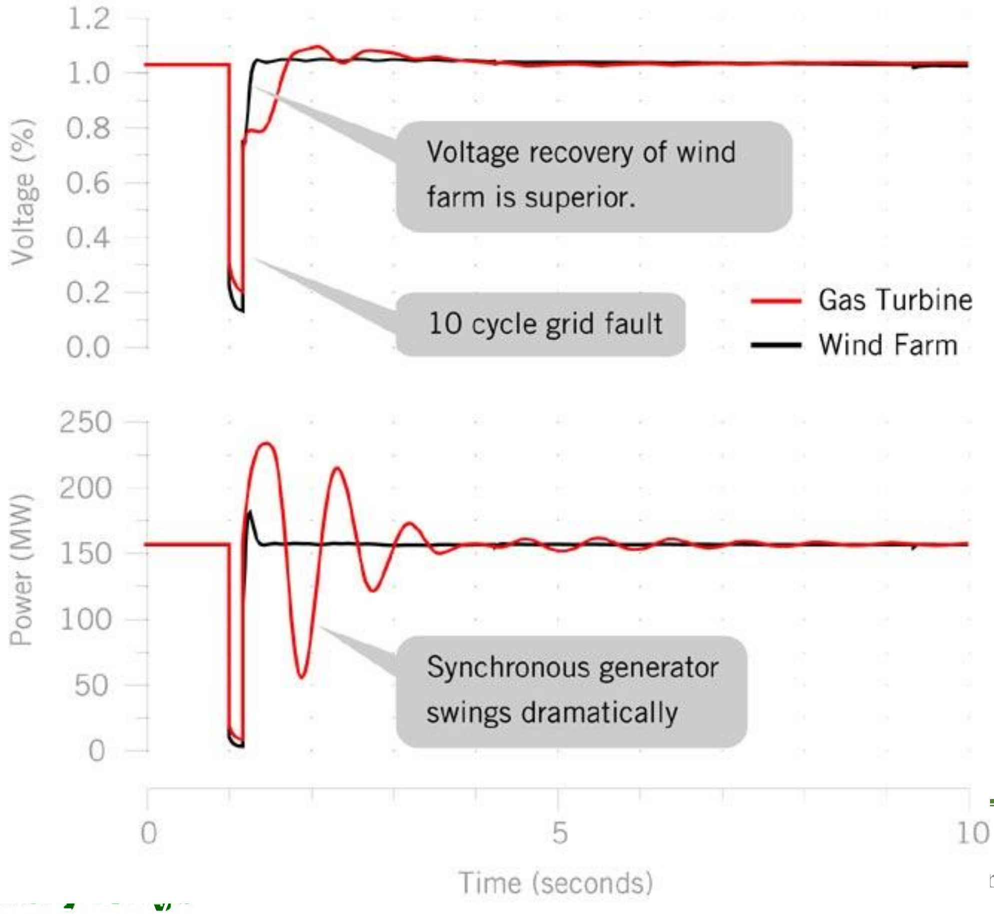


IBR plants can be more stable than conventional synchronous generators

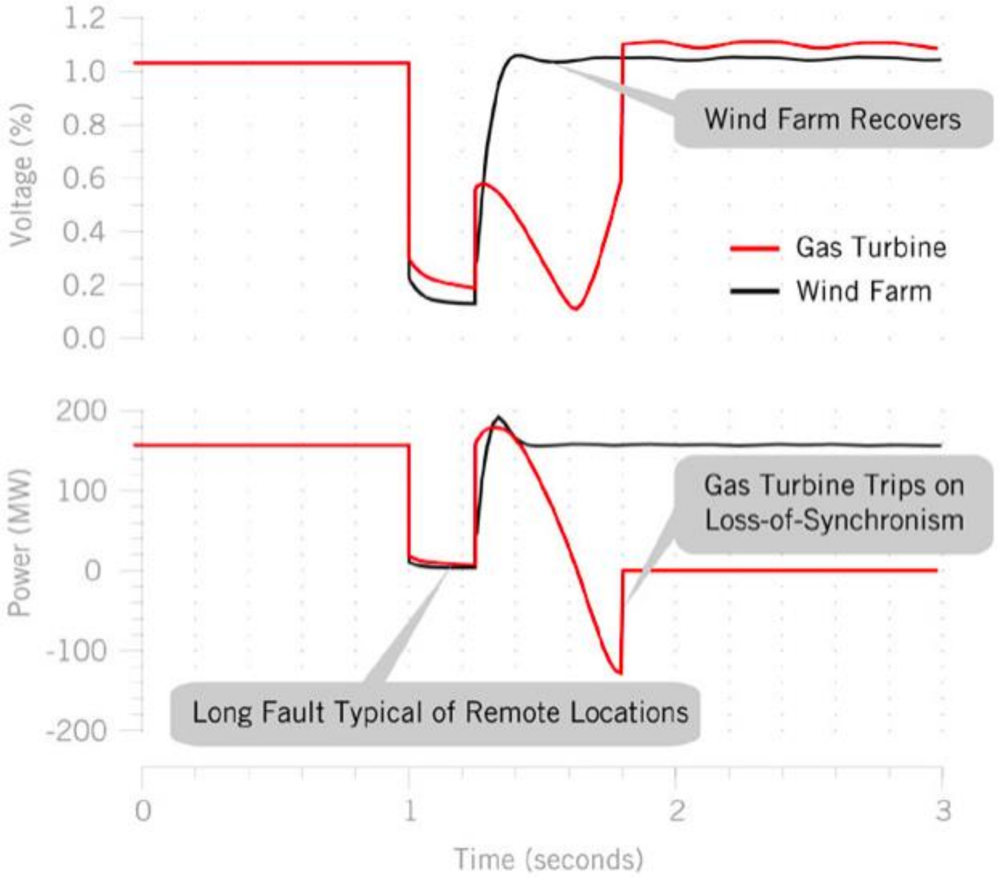


I've been using this figure for close to 20 years!

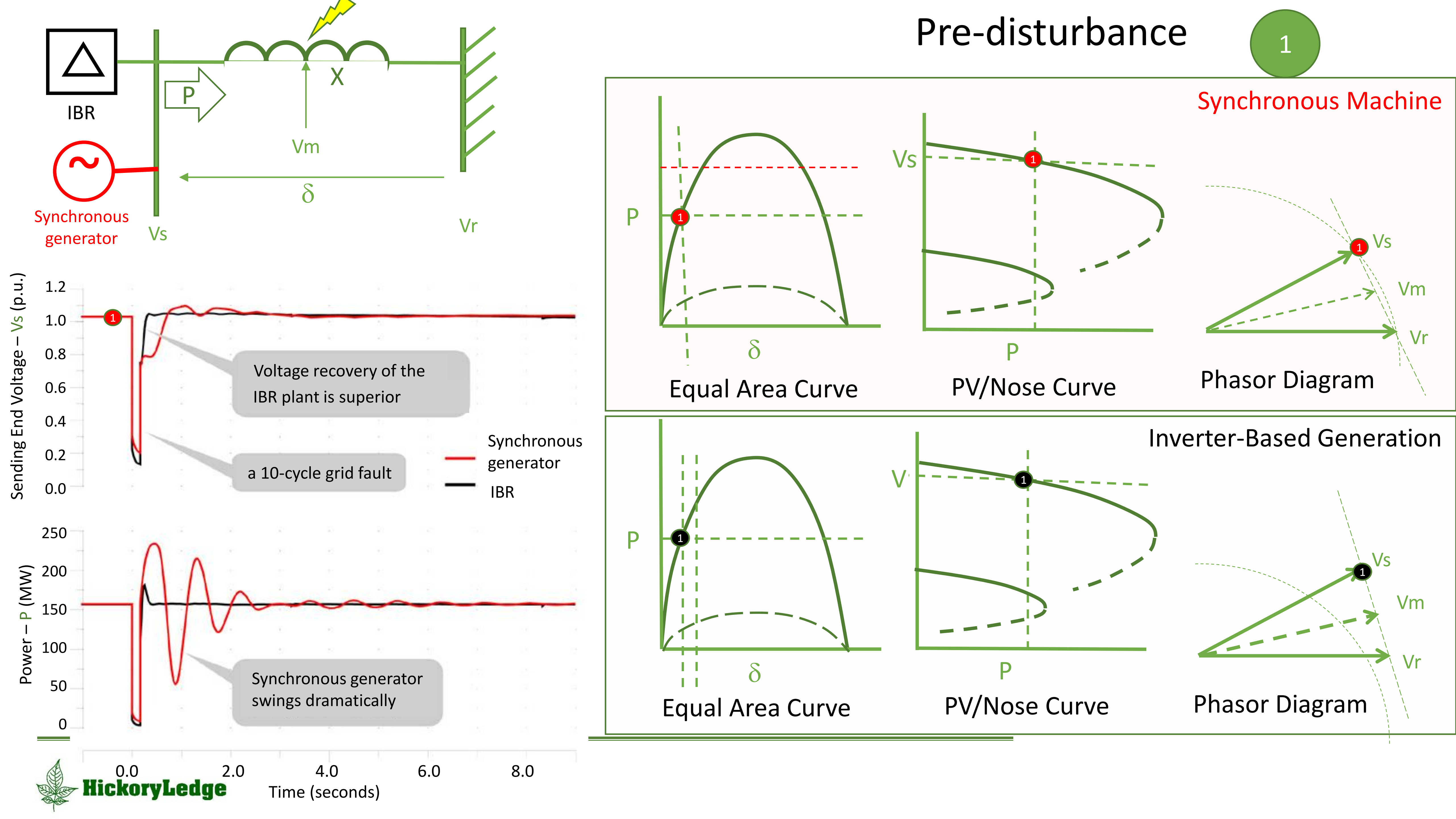
Primary Cleared Fault



Delayed Clearing Fault

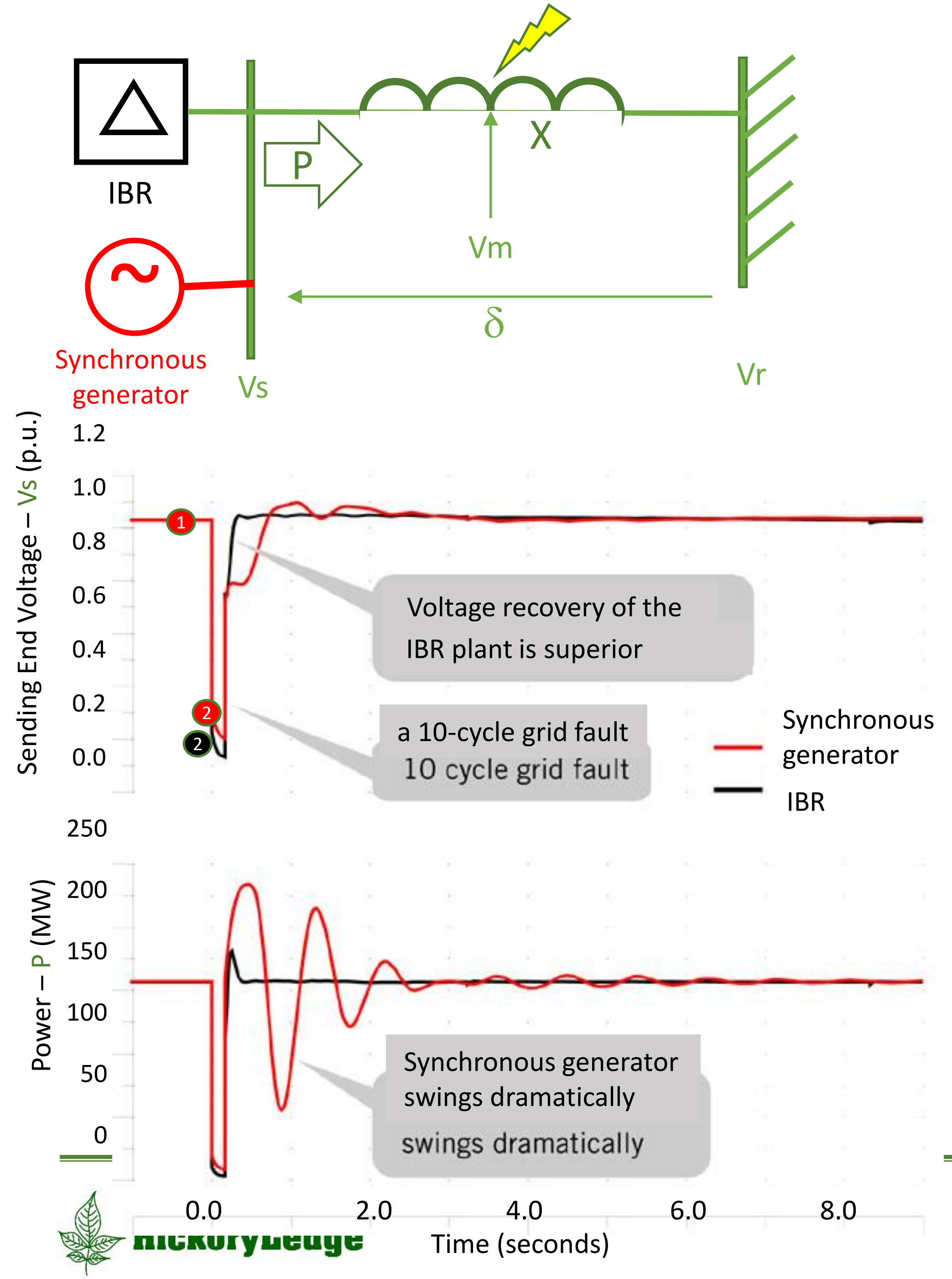


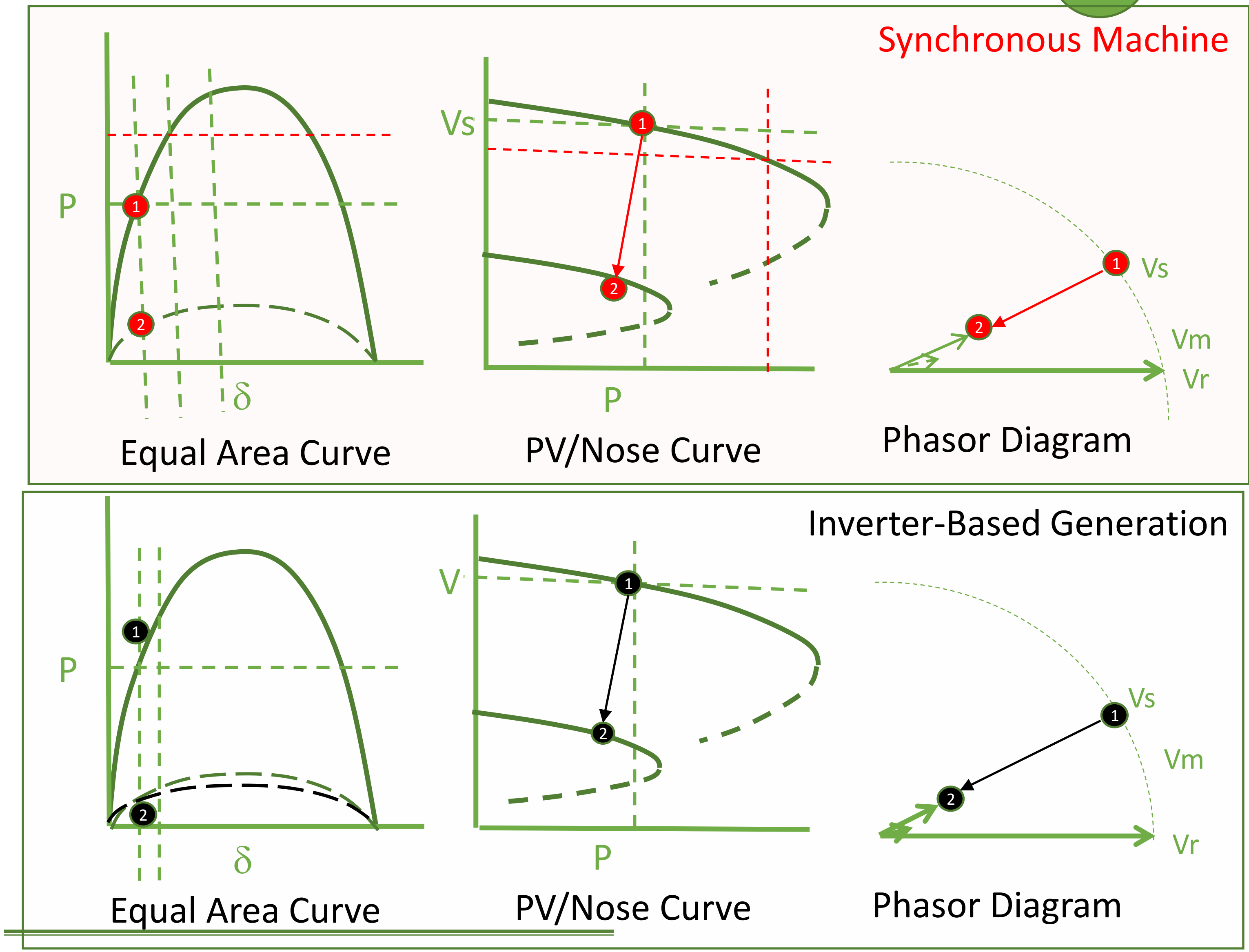
Pre-disturbance



Fault inception

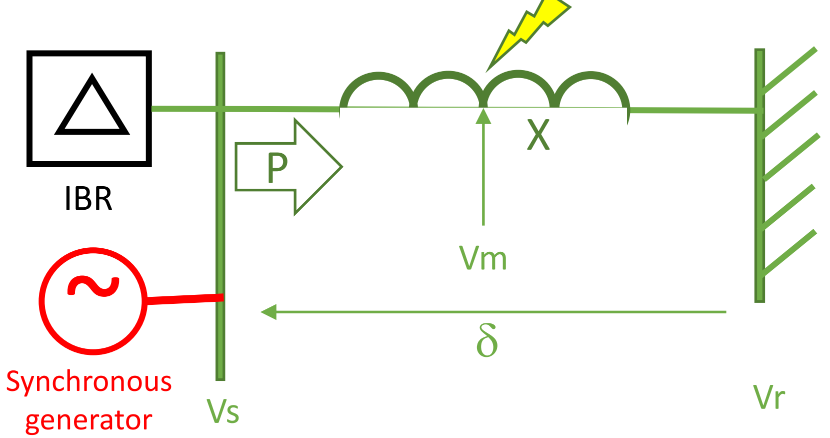
2

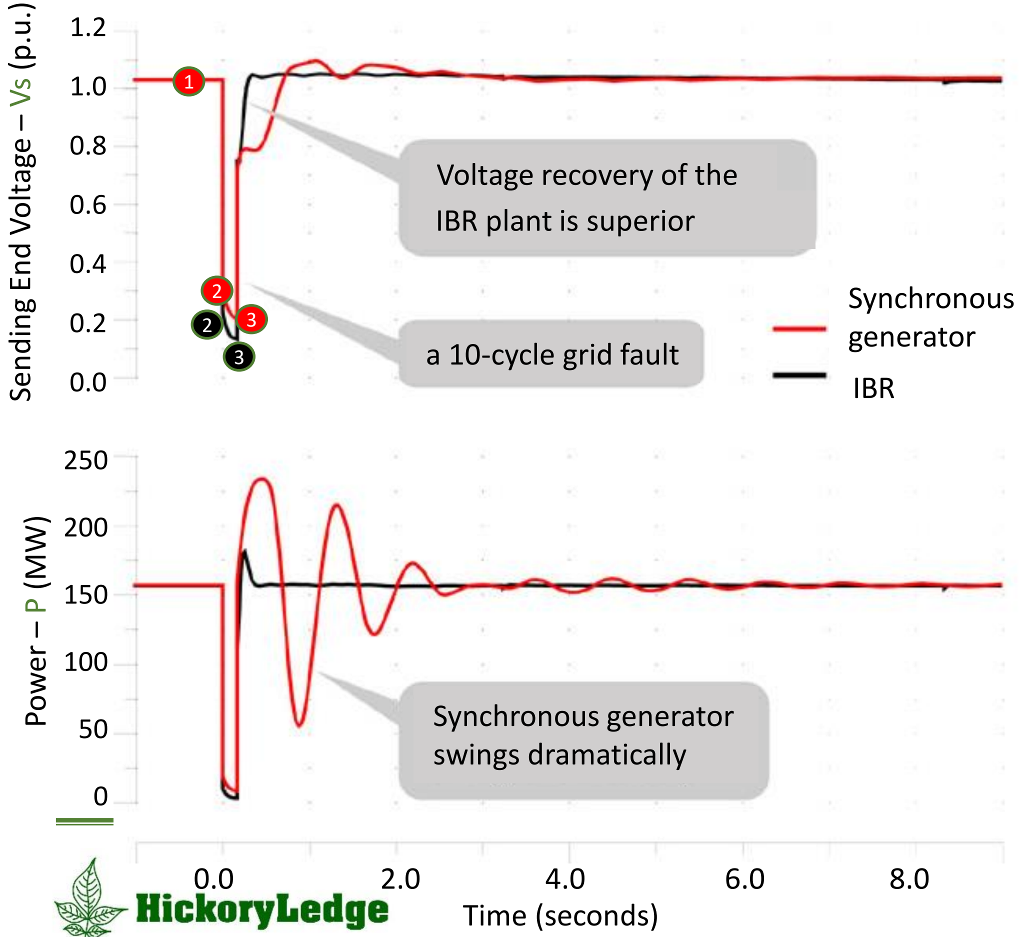


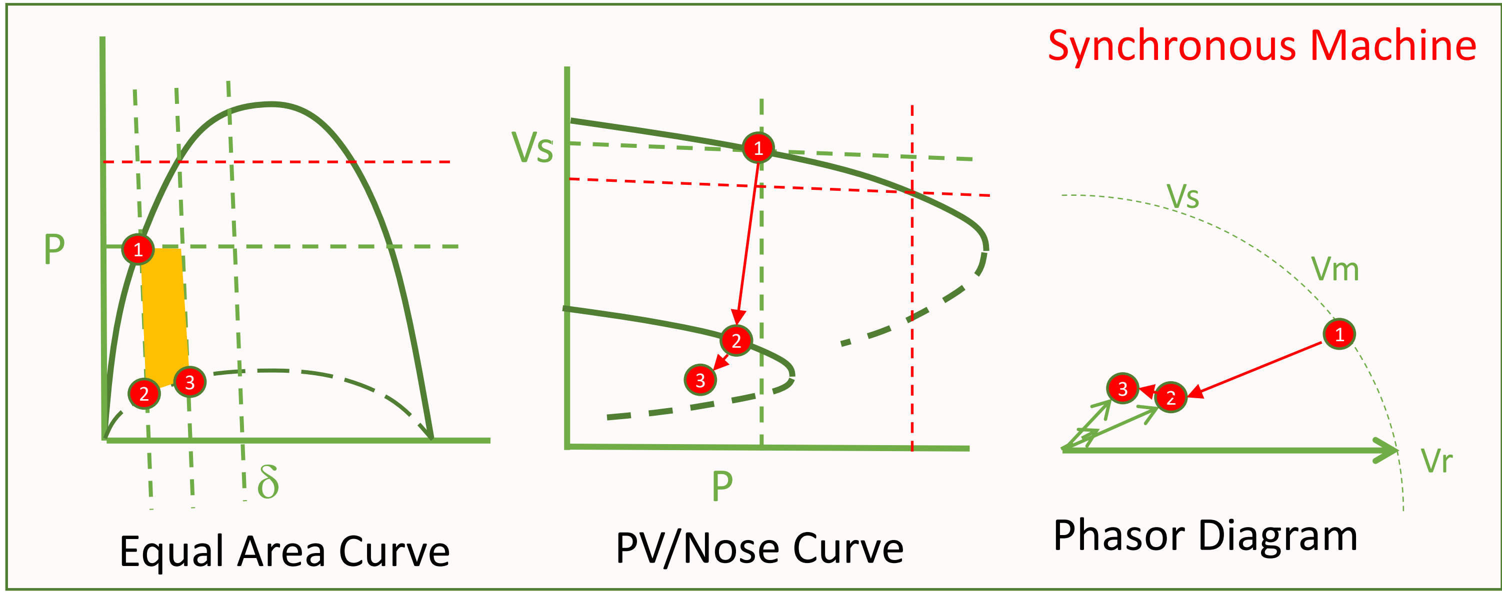


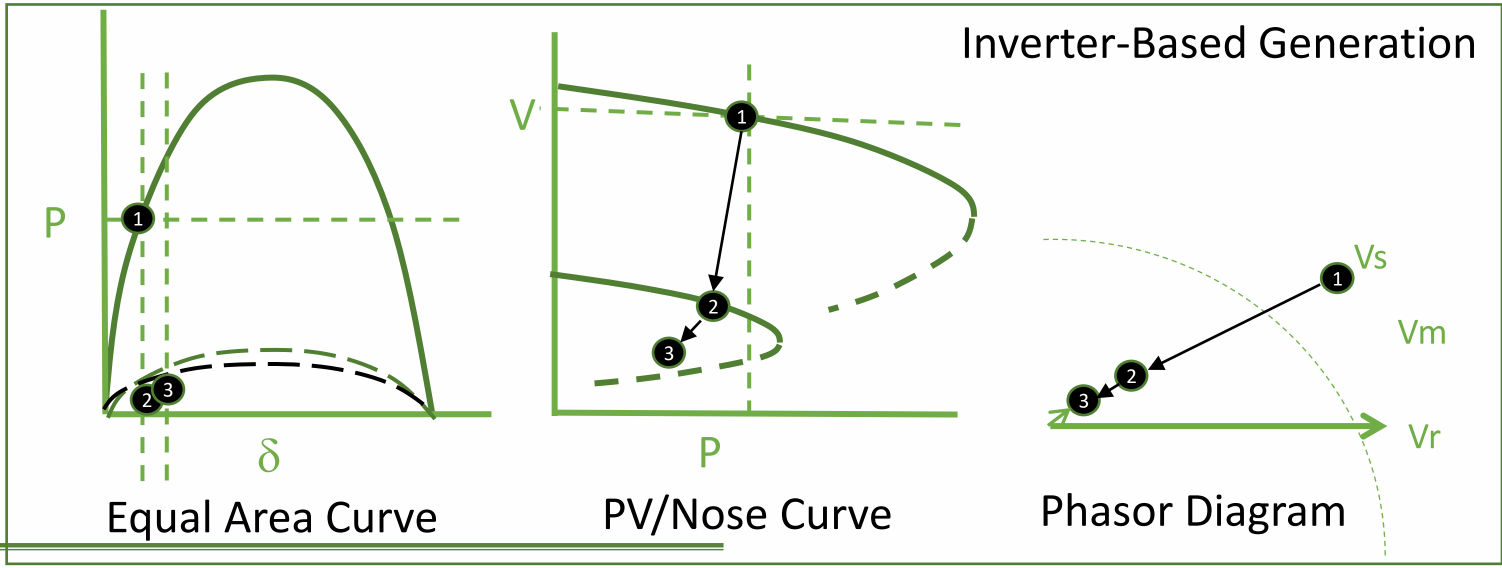
Immediately before Fault Clearing

3









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Immediately after Fault Clearing

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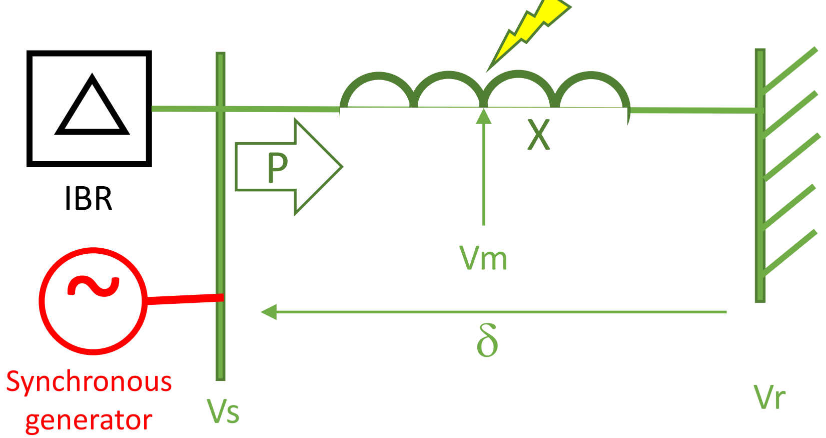

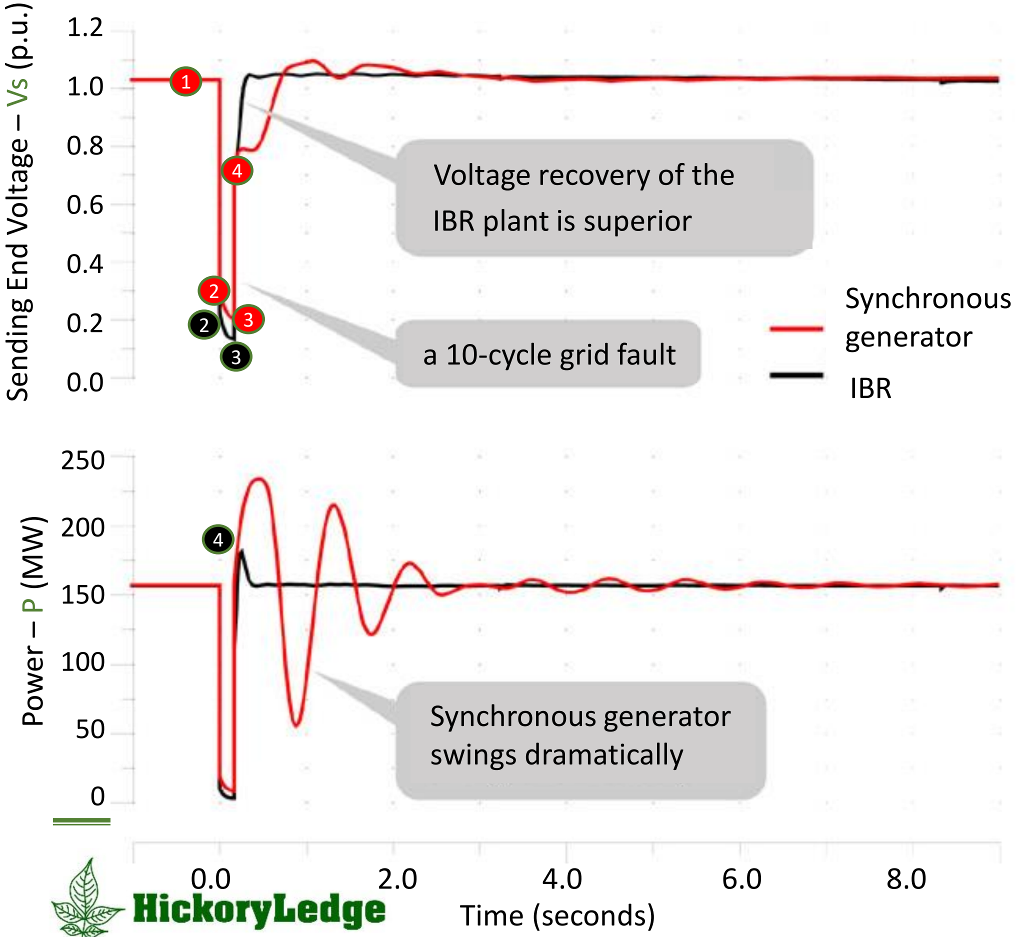

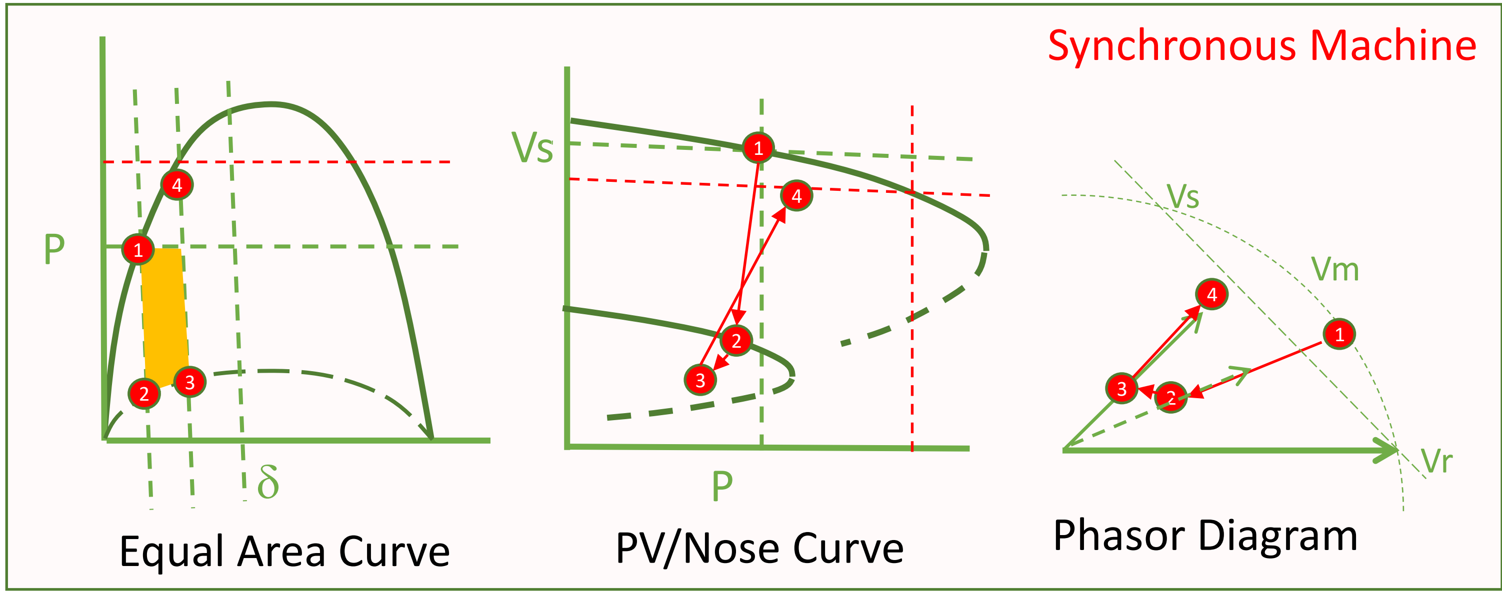

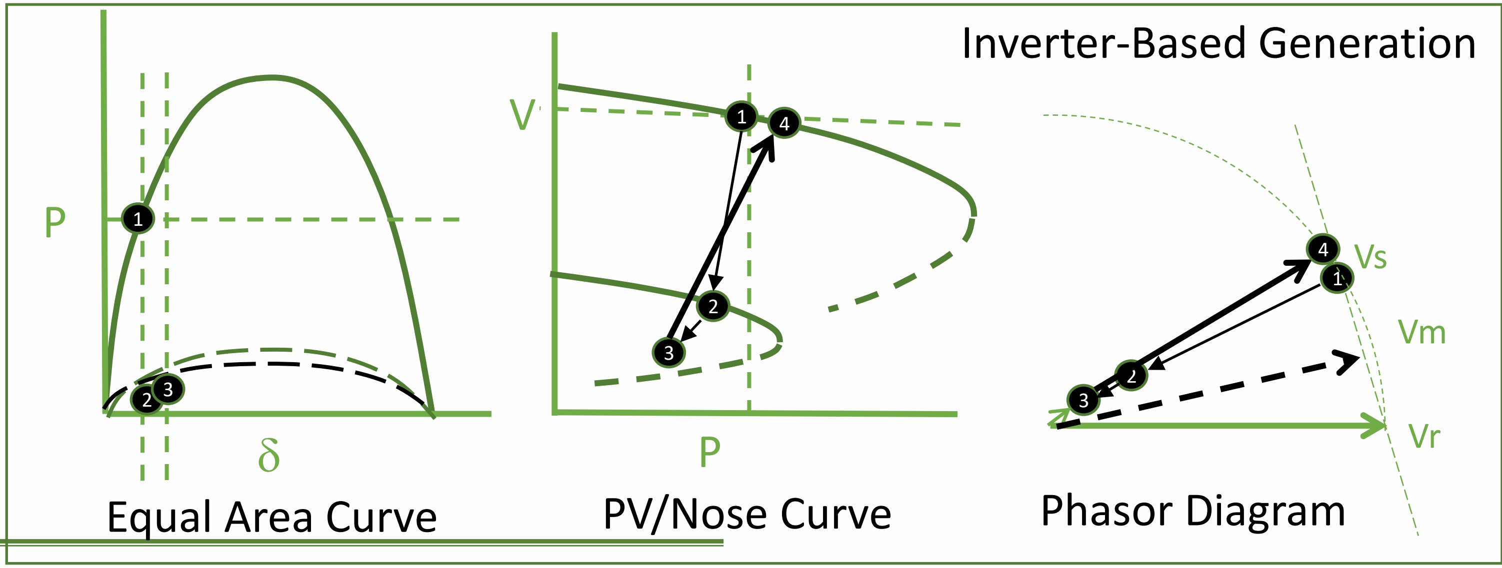

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Immediately after Fault Clearing

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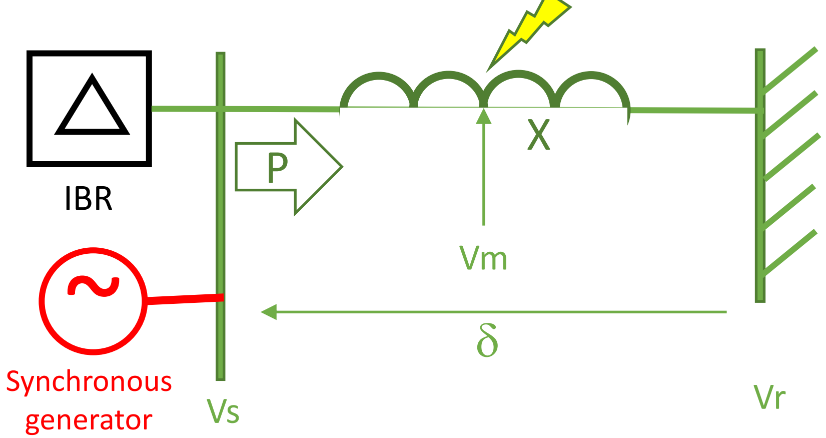

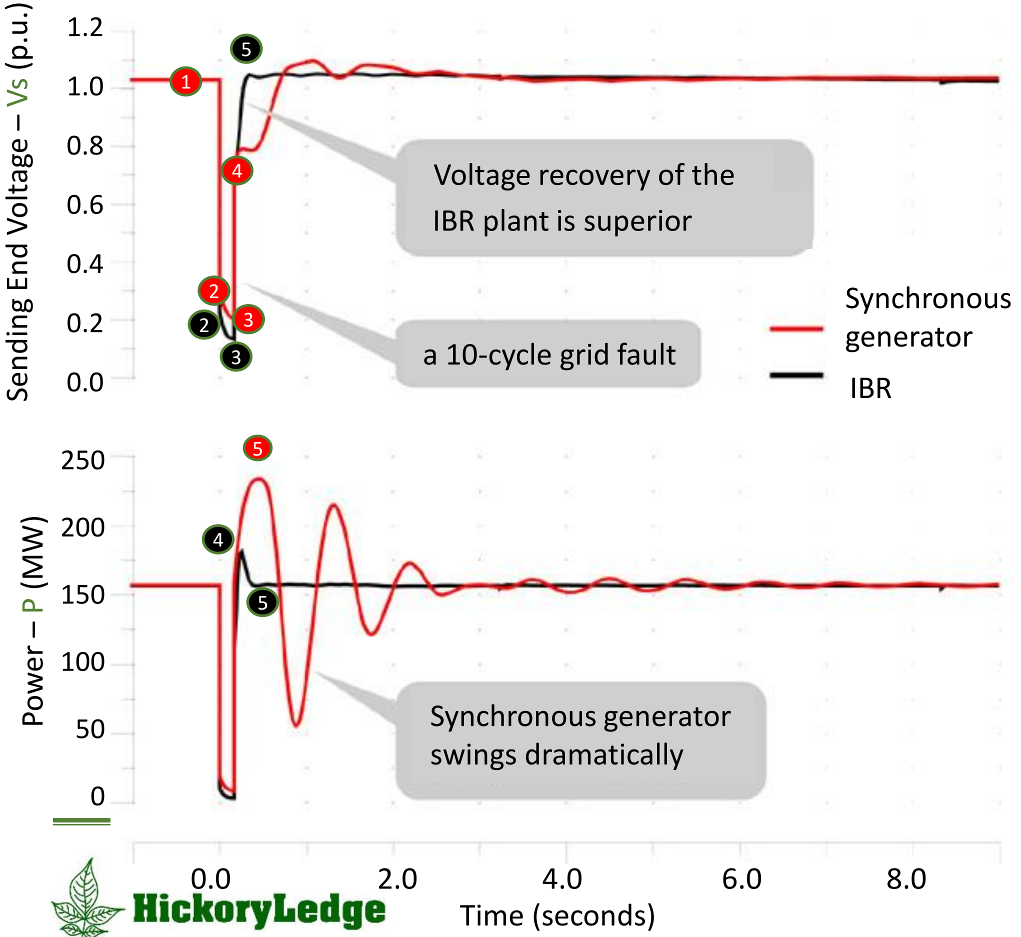

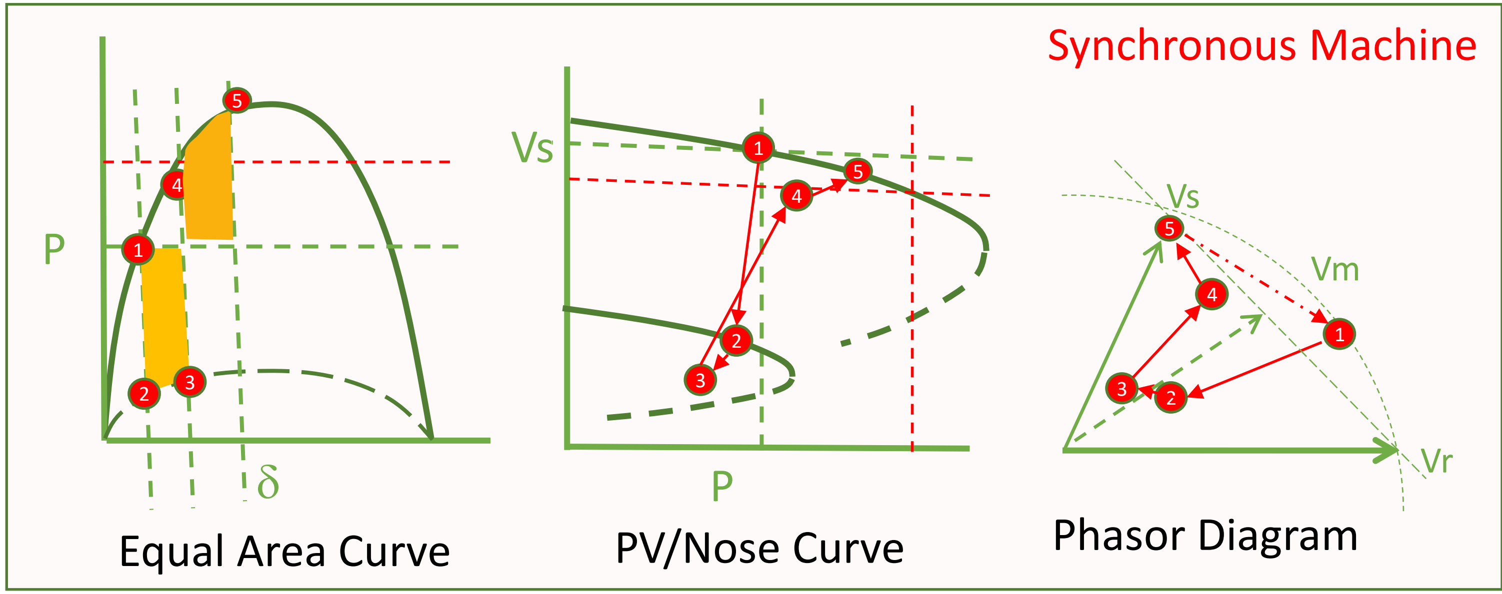

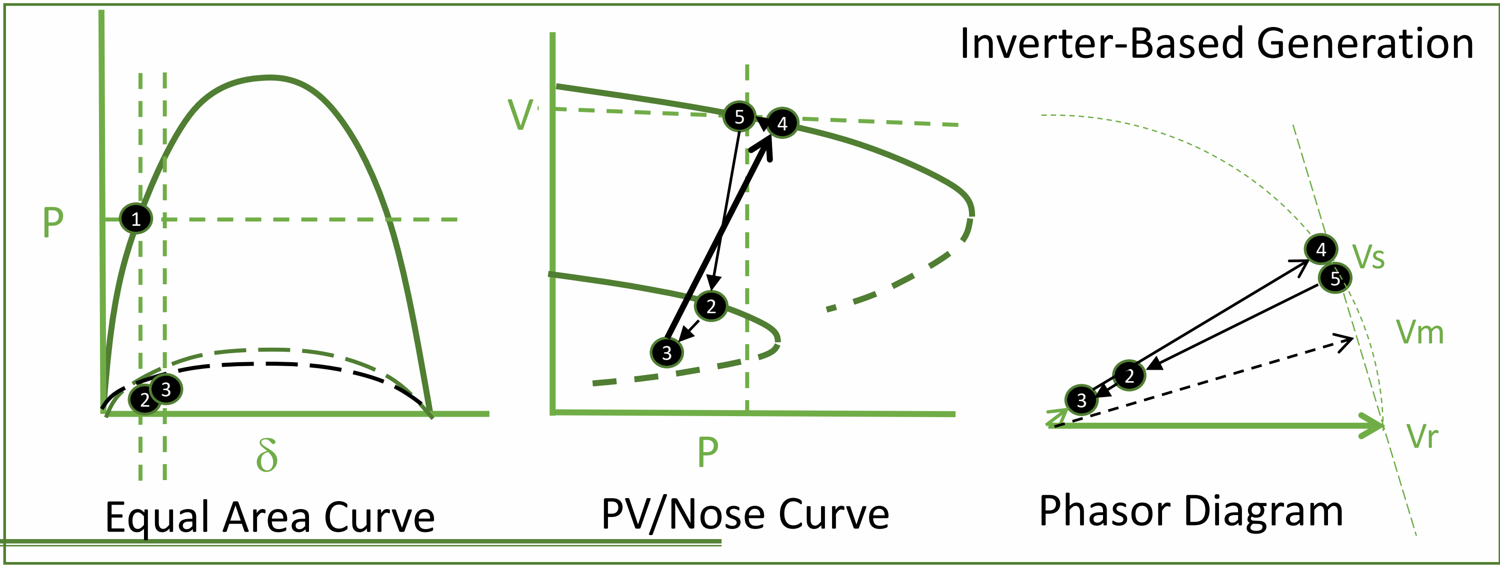

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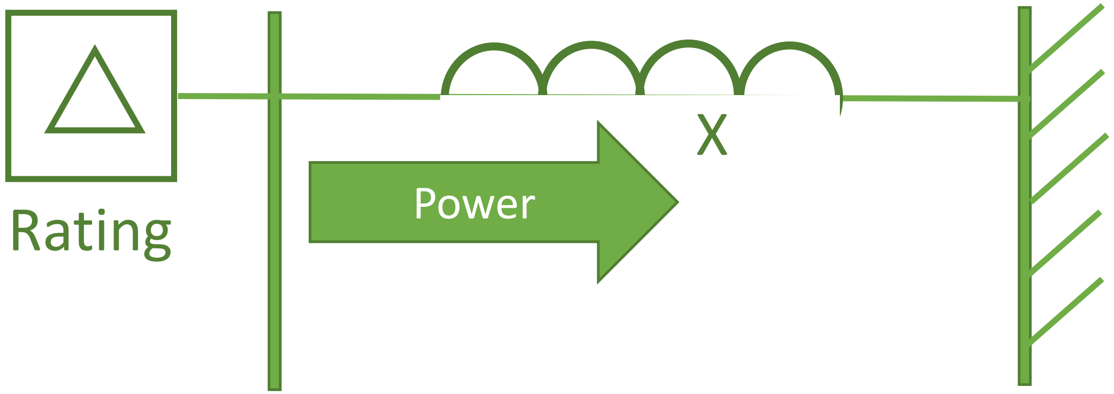
eSCR (effective short circuit ratio) and beyond: basics

Short Circuit Ratio is a convenient way to talk about the strength of the grid, it's not about faults

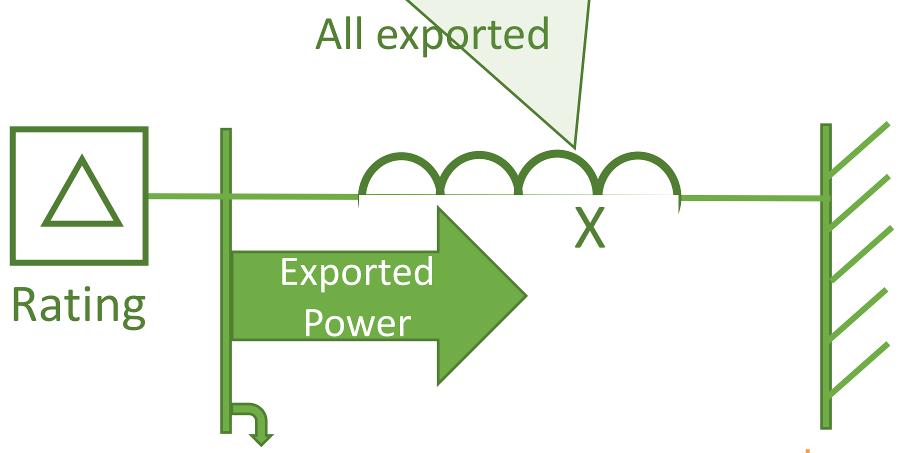
1. SCR Bigger X (more impedance) = weaker grid
2. Short circuit strength is the inverse of X
3. X gets bigger with distance
4. X gets smaller with more transmission; higher voltage ratings
5. "weak" is relative:
6. If the devices are big, i.e. "rating" is large, relative to the short circuit strength, the **short circuit ratio** is low, and grid is weak
7. There are several clever analytical techniques to calculate weighted/equivalent/composite/effective short circuit ratio.

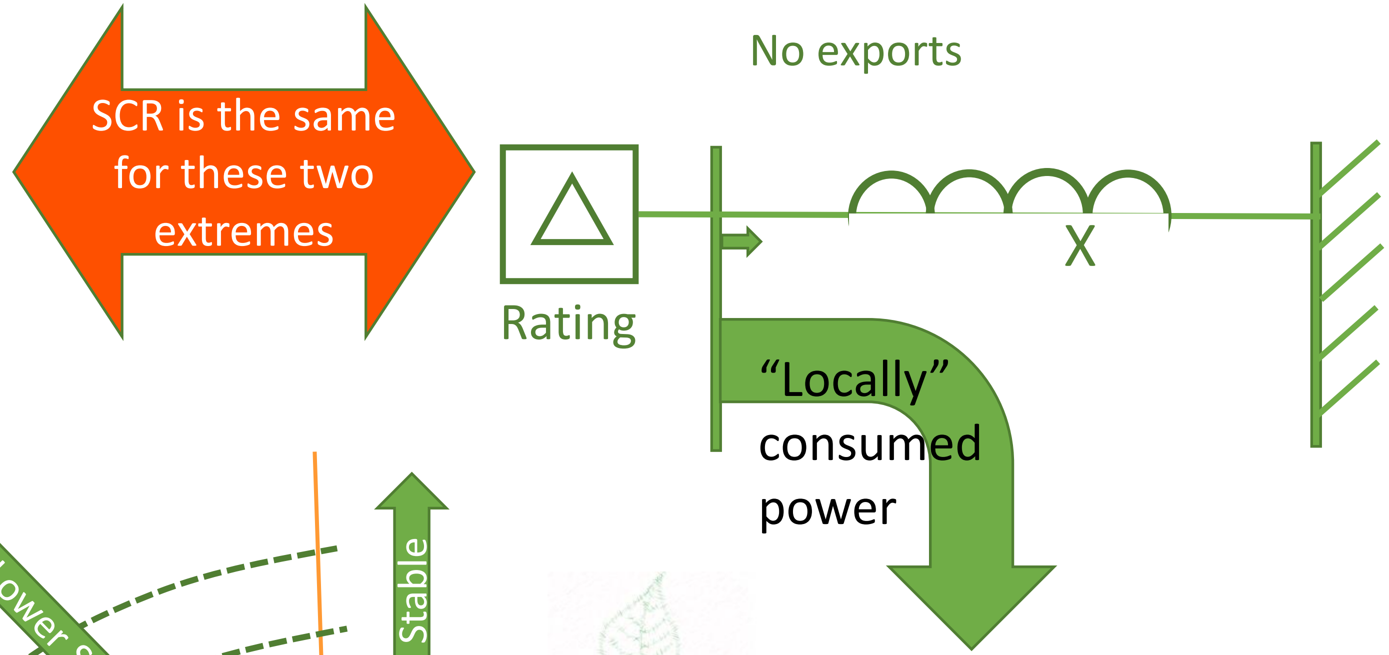


- All things being equal, the lower the short circuit ratio, the harder it is to stay stable.
- All things are never equal.

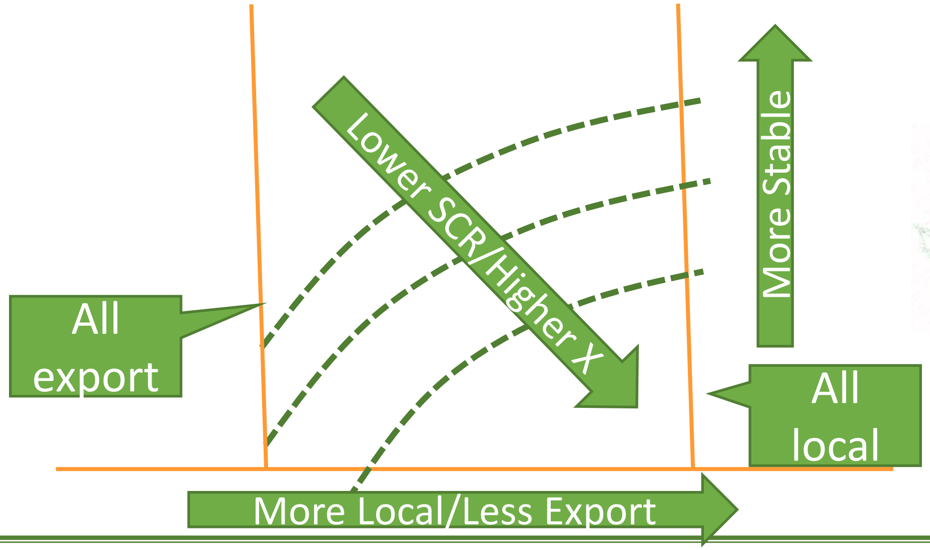
It is on this is the problem that we are focused today

eSCR and beyond: Where is the power going?





- This isn't getting much discussion (says Nick)
- Today's Canaries are mostly exporting
- In future, some systems will have much more "local" consumption.

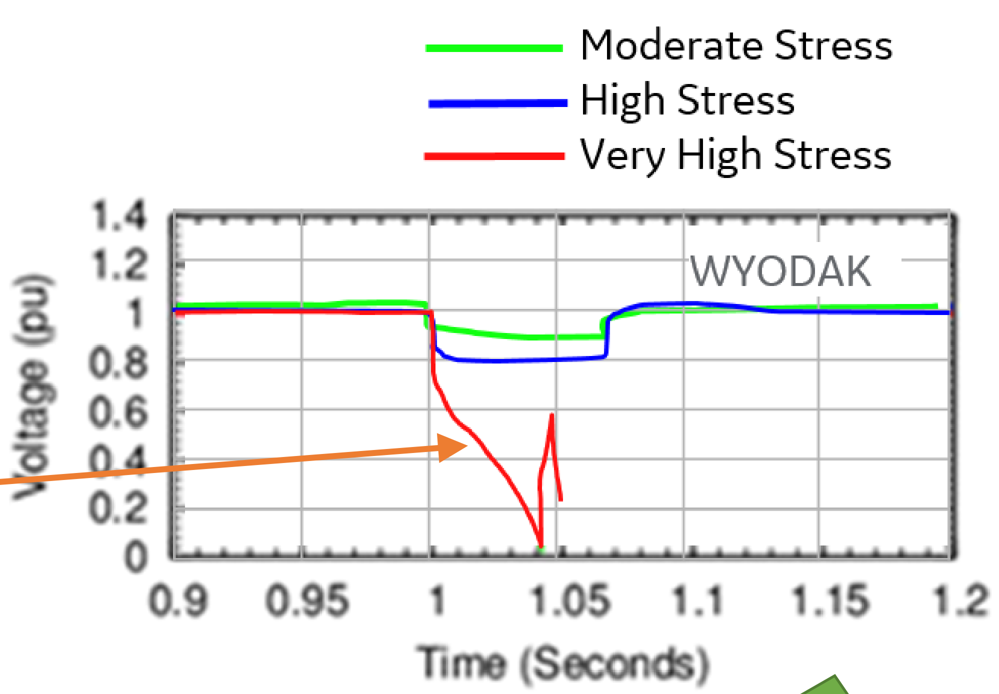


Note the absence of numbers: we (the industry) have not adequately explored this relationship.

Paradoxically: Grids are both stronger, but may be more brittle.

With SOA grid-following inverters, stability limits tend to be **higher – that is good for reliability and economy.**

But, when the grid fails, it **may fail faster and with less warning**



We need better :

- Understanding
- WTG (and inverter) controls
- Simulation tools
- Predictive tools and metrics

- Condenser conversion "fixed" this; be careful of transient stability
- Weak grid WTG controls fixed this particular problem

Source: Miller; NREL/GE WWSIS – Low Levels of Synchronous Generation" December 2015

Pushing the limits out with Grid Following Inverters: today's toolbox

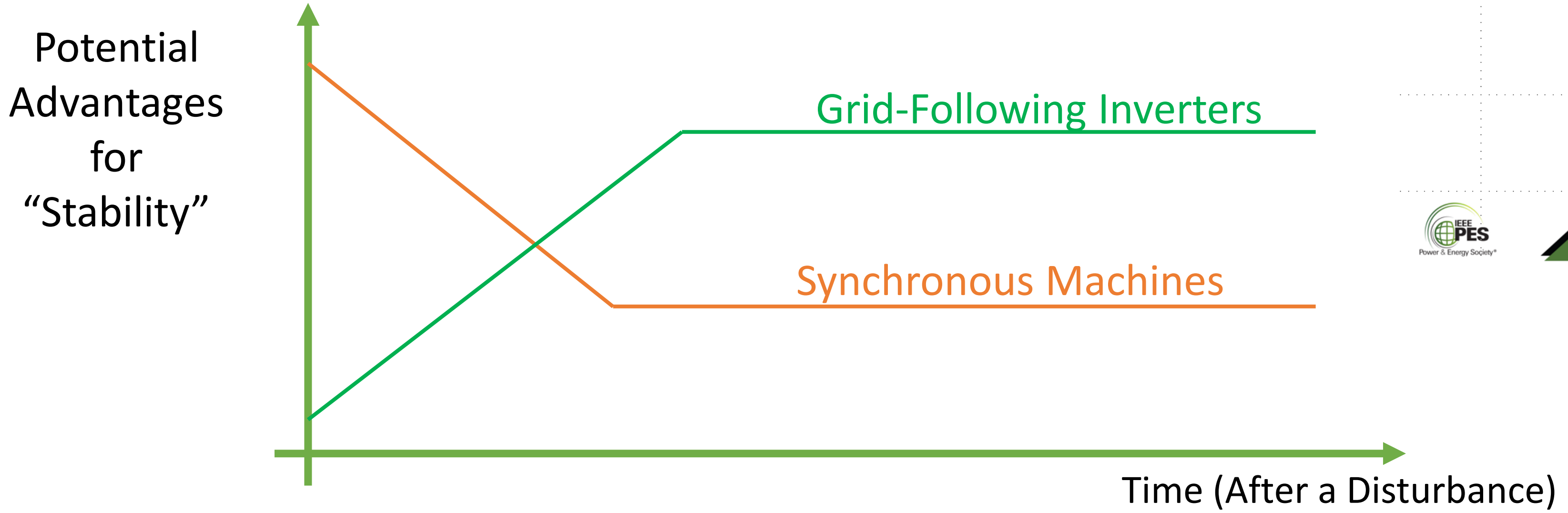
- Better inverter controls. ("more robust controls")
  - Grid following inverters have gotten spectacularly better for high penetration and weak grids in recent years.   Tolerate lower eSCR
  - This trend of improvement will continue, though a degree of diminishing return is expected: *The network "entitlement" can't be exceeded*
- Additional transmission ("more wires").
  - New AC or DC lines
  - More power, additional circuits on existing right-of-way
- Synchronous condensers ("stiffer grid")
  - Improve all aspects of eSCR.   Watch for new stability problems.
- Grid Enhancing Technologies ("use the wires better")
  - power flow control, dynamic line ratings, and topology optimization
  - Series and advanced compensation

GFM & Export: Our Theory

Grid-Forming Inverter Technologies for High Renewable Grid Applications Panel Session

Matthew Richwine, Telos Energy
Nicholas Miller, HickoryLedge

IEEE PES GM 2021 Virtual Meeting



Very short time frames (<~0.1 sec):

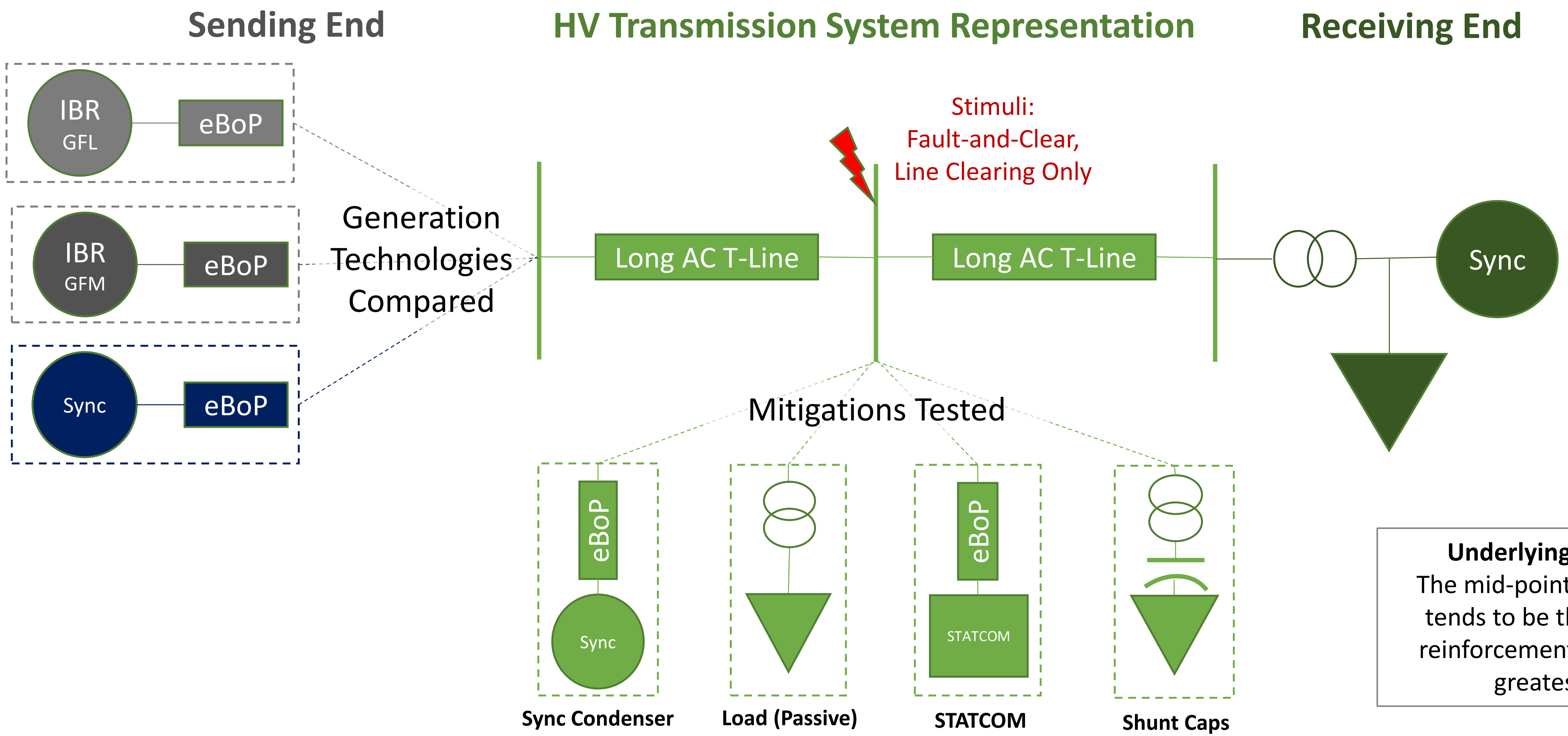
- GFL closed-loop controls are challenged to maintain stability margin
- Synchronous machines have an inherent "open-loop" behavior that is stable

Longer time frames (> ~0.1 sec):

- GFL have developed advanced control strategies that can provide voltage regulation, active power response, transient stability, and damping that are as good or better than synchronous machines
- Synchronous machines may be subject to first-swing instability and may lack damping, some of which can be mitigated (for instance, PSS)

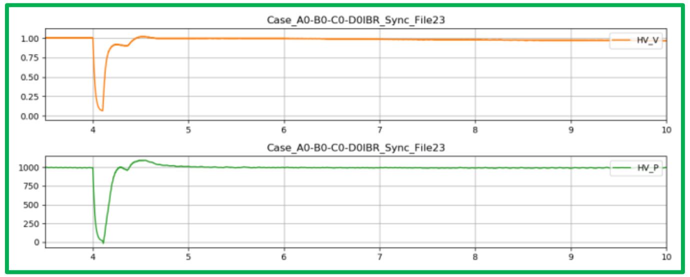
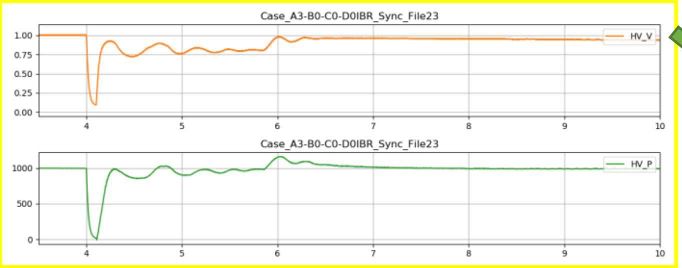
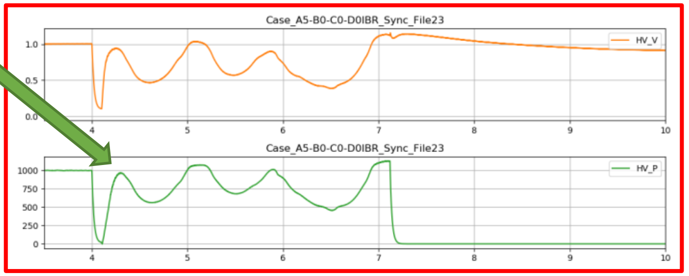
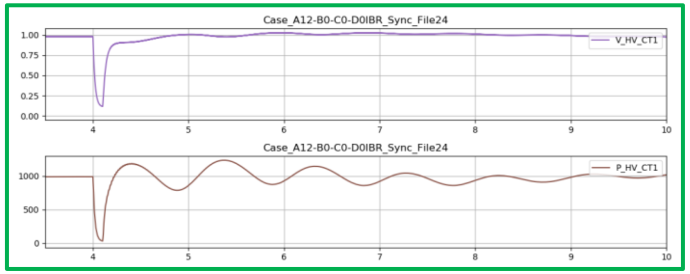
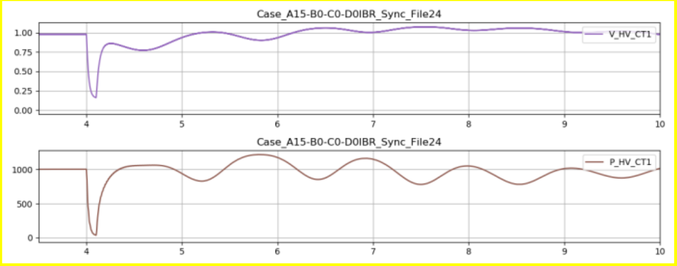
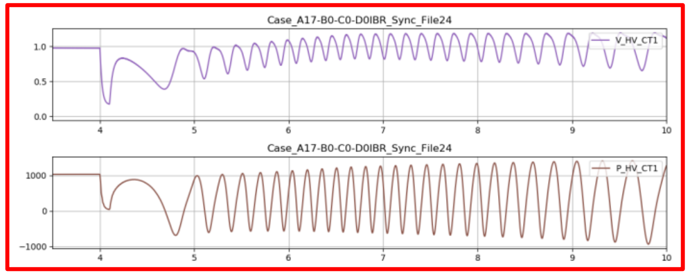
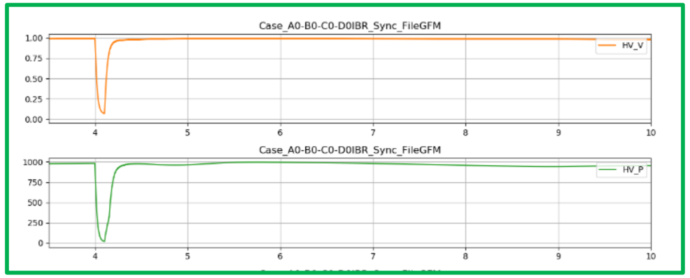
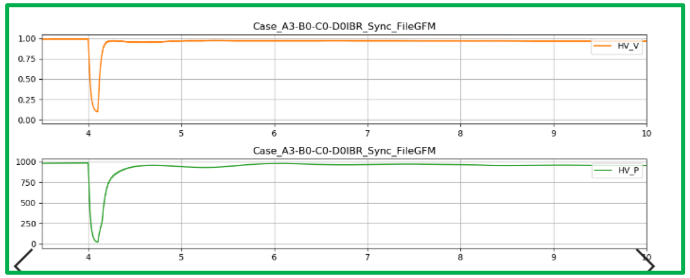
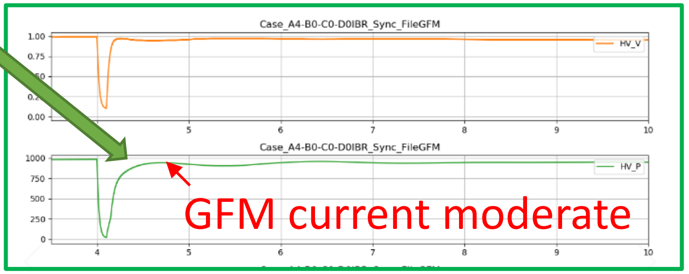
Can GFM offer better performance *for exporting power from IBR rich resource areas?*

Our Approach



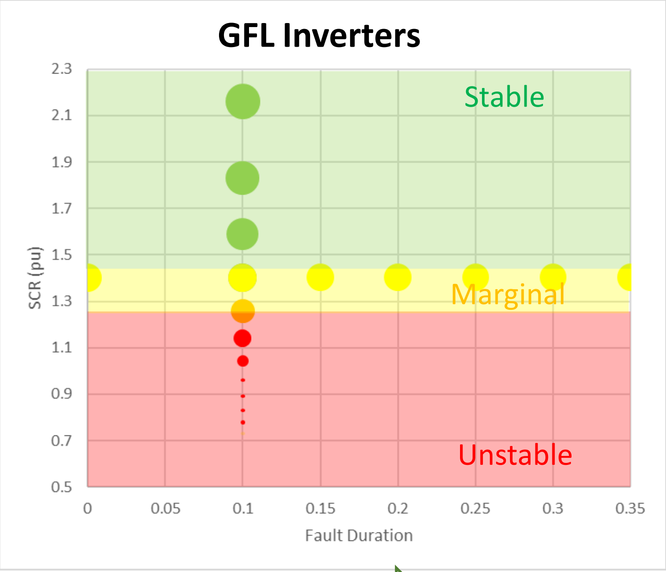
Underlying assumption:
The mid-point of transmission tends to be the “soft” spot – reinforcements here yield the greatest benefit

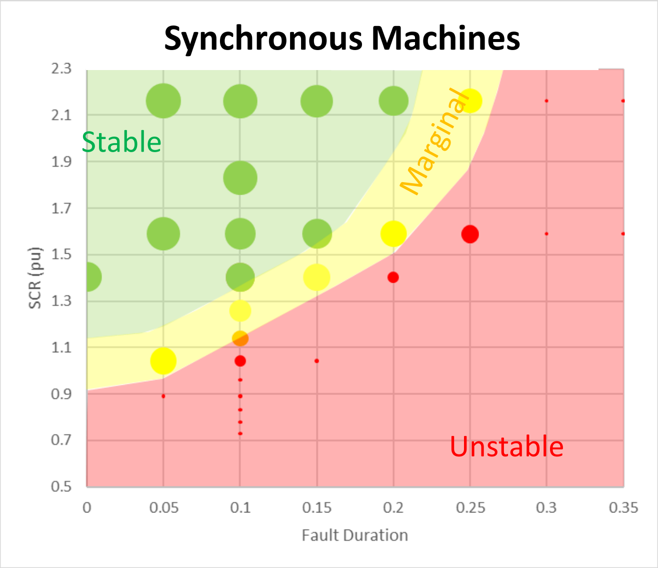
Grid Strength Impact

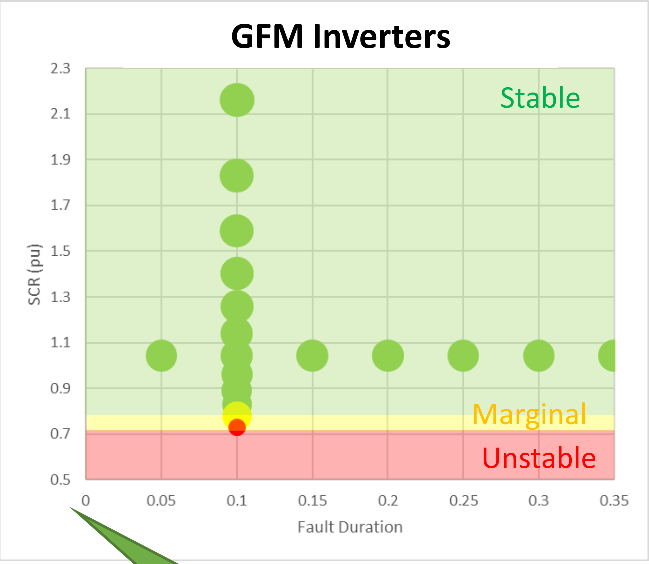
	Soft Grid (SCR = 2.2)	Marginal Grid (SCR = 1.4)	Weak Grid (SCR = 1.1)
GFL-IBR			
Synchronous Generator			
GFM-IBR			

Technology Performance Comparison

Stronger grid

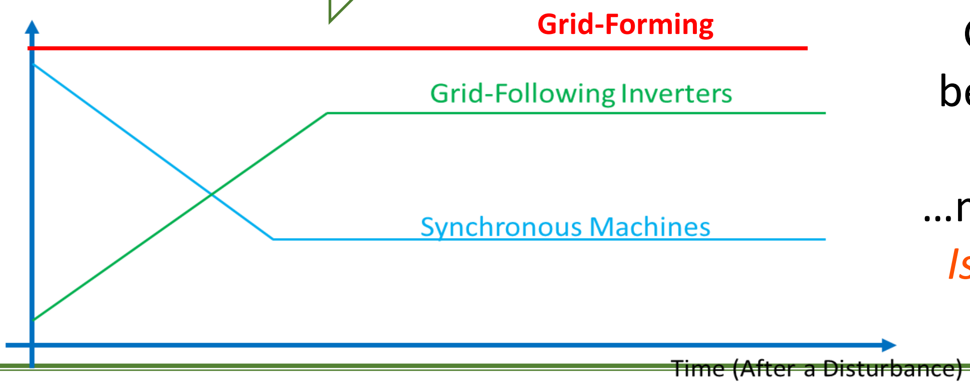






More severe events

Potential Advantages for "Stability"



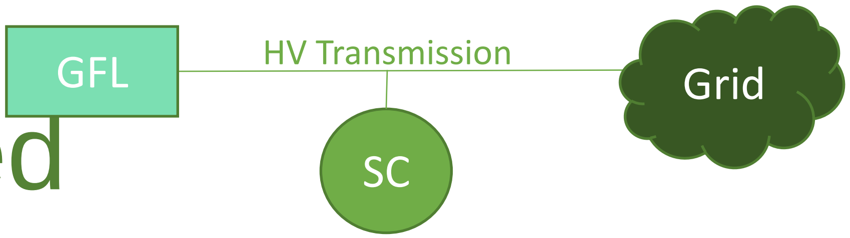
GFM inverters **show promise** for being the "best of both worlds" for grid stability

…many questions remain, especially:

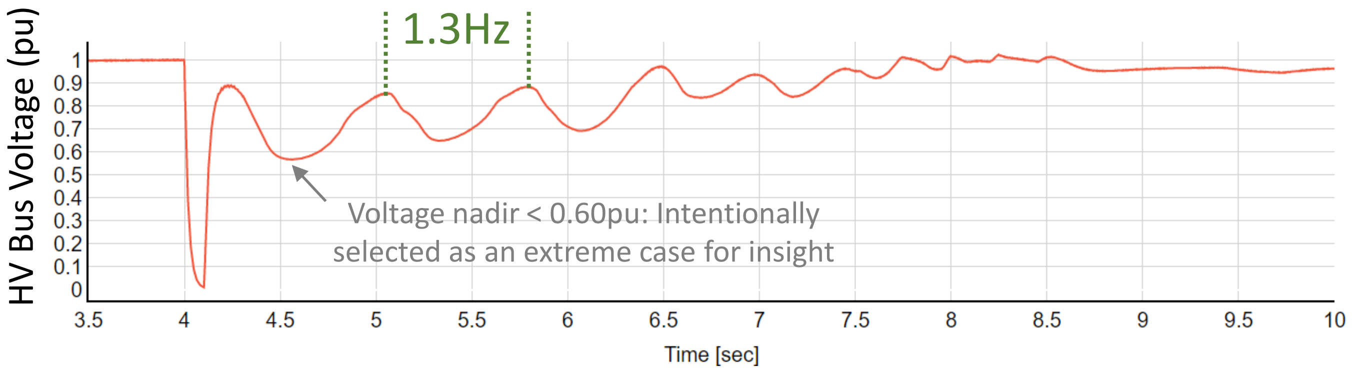
Is this observed GFM performance edge intrinsic or controls?

Whoa! Power angle curve and nose curve maxima still apply. *(this calc of SCR based on MVA. MW based would show higher values)*

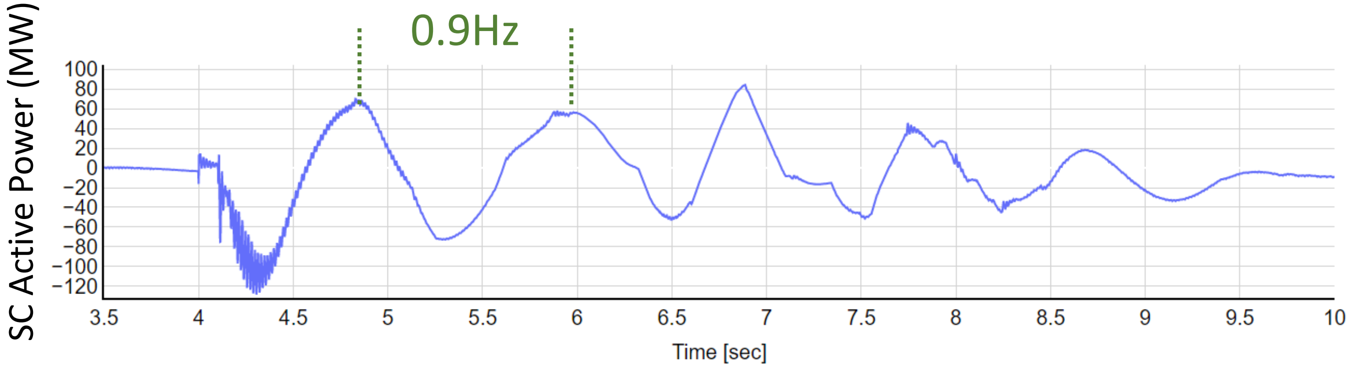
Dynamics Can Get Complicated



Consider the case: GFL + synchronous condenser



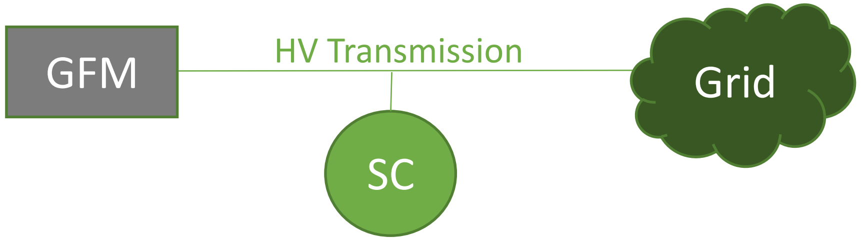
Voltage swings, dominated by the control of GFL



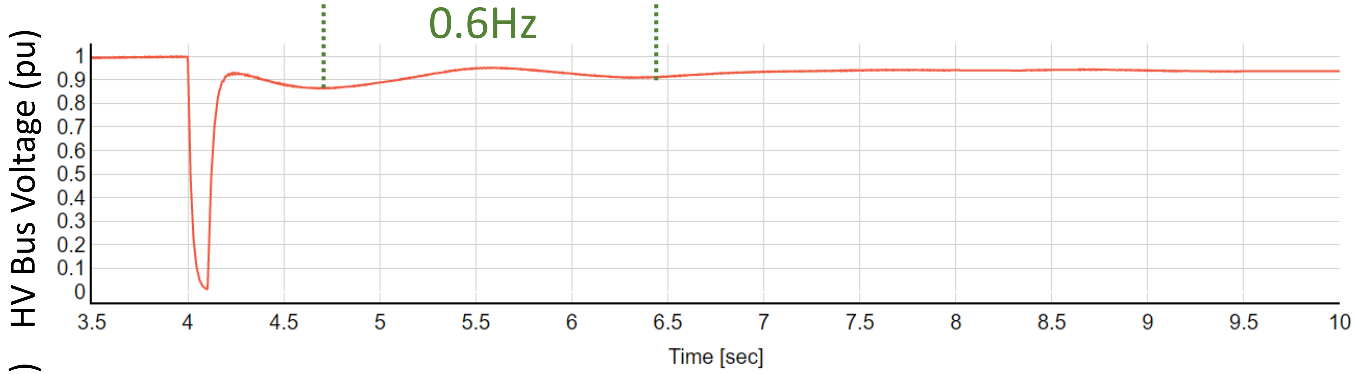
Power swings of the condenser, dominated by electro-mechanical swings of synchronous condenser

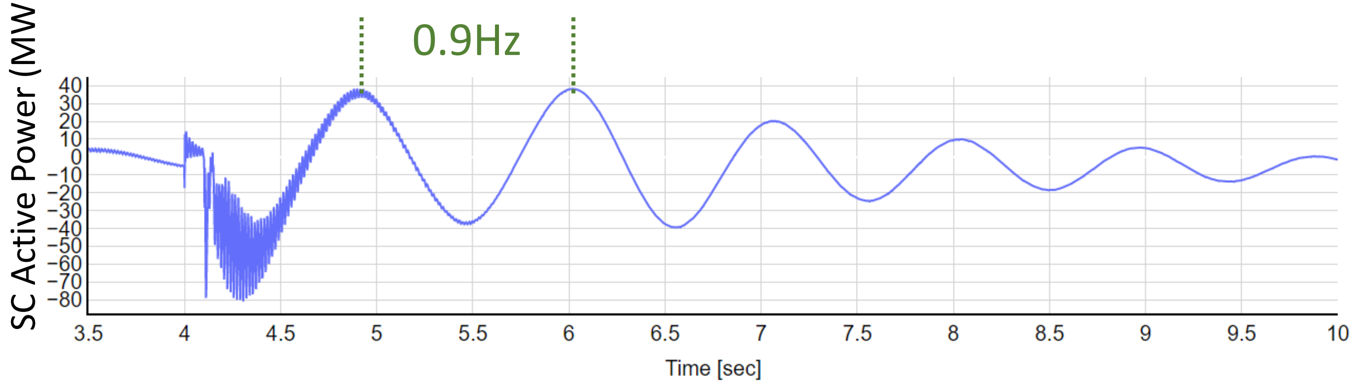
Two distinct modes observed → GFL is interacting with the synchronous condenser, resulting in complex dynamics

Dynamics: SC + GFM



Consider the case: GFM + synchronous condenser





The simulation conditions were identical to those used for GFL + SC

Voltage swings are **much smaller** relative to the GFL + SC case

Power swings of the condenser are roughly half the magnitude as the GFL + SC case

Simpler, sinusoidal dynamics → GFM is more decoupled from synchronous condenser (less interaction)

Summary of Key Findings

Characterizing Resource Performance

- Sync machines and GFL can have similar stability limits for power transfer
- This GFM shows improved stability over both GFL and sync machines; GFM swings benign
- Sync machines are sensitive to fault duration; IBR are not → CCT may be a misleading stability metric for IBR
- GFM shows similar step characteristics to synchronous machines, but behavior in-limit is different. High current rating not needed for good stability performance.

Characterizing Network Mitigations

Control or Intrinsic?

- All technologies are sensitive to grid strength
- The transmission network tends to be "soft" in the middle; and for the GFL, soft at the sending end, too
- Sync condensers improve GFL stability, but location matters, and sync condensers introduce additional dynamics!
- Complex relationship between fault location, SC location, SC inertia, and IBR controls. SC at the IBR resource may not always best for stability!

More to Come

- Generalize findings for a variety of IBR and HV transmission systems (this analysis is a starting point; single IBR + simple topology; single snapshot of both GFL & GFM controls here).

Grid Forming Inverters Reality Check:

- The elephant in the room relative to 100% inverters is "ever", not "always"
  - And yes, there are places that are getting close today.
  - Pockets or regions of 100% exporting power are real now, and will become common-place.
- The reality that this is NOT cooked.
  - The BESS experience isn't that big yet. And BESS isn't PV or wind.
  - It's not that simple.   OEMs and others are actively chipping away for wind and PV
- There isn't a (single) "GFM" available.
  - Yes, we need to get moving, faster, better
  - No, we don't have all the technical issues resolved.
  - Yes, GFM can reasonably be expected to produce substantial benefits in some regards.
  - Yes, GFM performance can be worse than grid-following, especially if you're not careful.
  - No, we can't expect GFM to make all the grid problems go away
- Many unintended consequences there are.
  - Shouldn't and can't just replicate synchronous machines.
  - We can and must do better: There is every reason to expect good outcomes:
  - Don't panic and carry on
  - More studies, more demonstrations, more lab work, more investment! -   are all happening

Thanks

nicholas.miller@hickoryledge.com

HickoryLedge

Matt Richwine

Matthew.Richwine@telos.energy

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GridLAB