Export Stability in Weak Grids

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SPP Workshop - May 24, 2021

Agenda

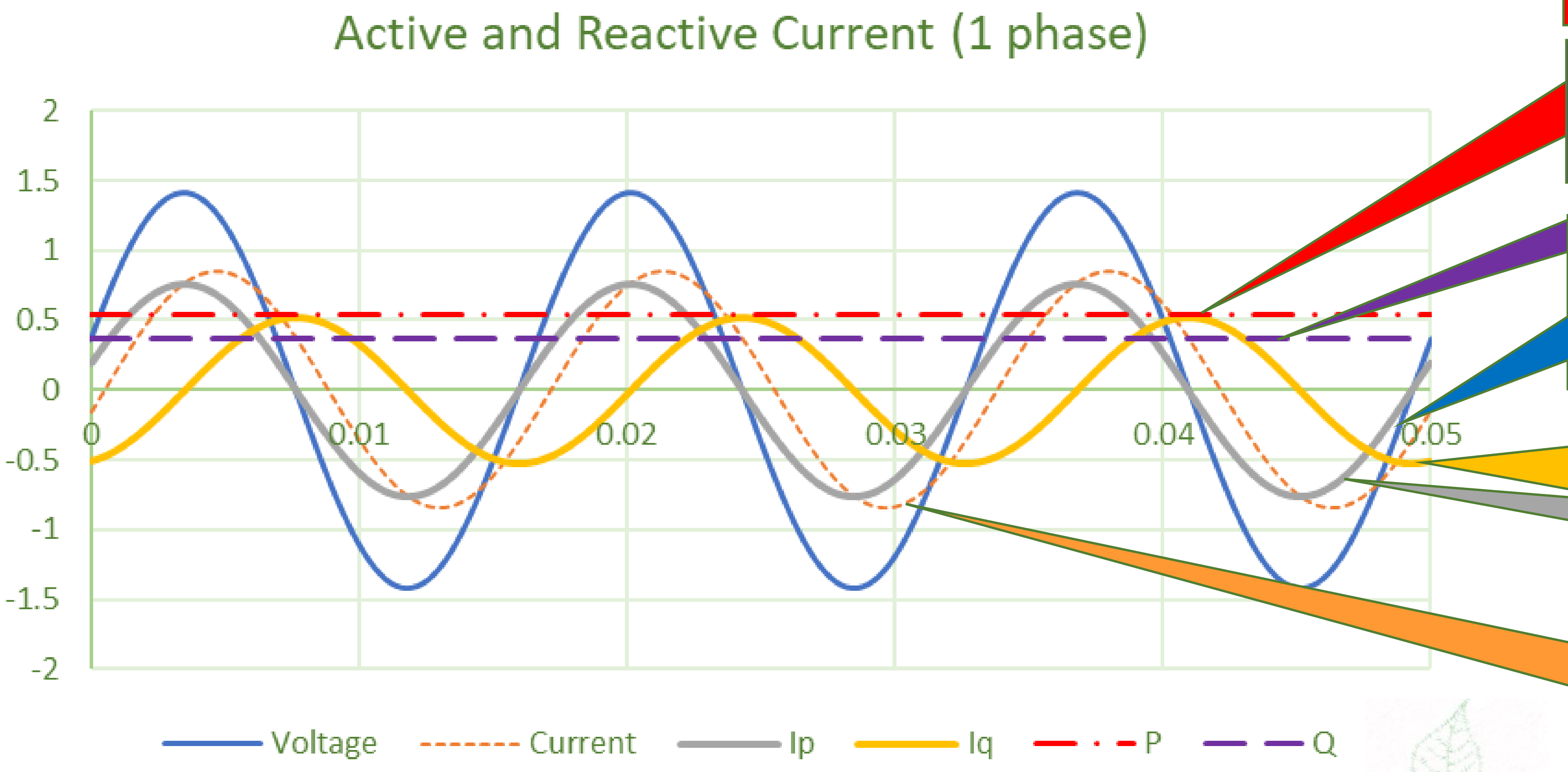
- Overview synchronization of inverter-based resources (IBRs)
- Limitations of IBR stability models
- Weak grid export study
- Mitigation options – pushing the limits with grid-following inverters, synchronous condensers

This is now up-to-date, but doesn't reflect the advertised outline much

Some really basic stuff (sorry)

- Wind, PV, and batteries interface to the grid through an inverter. Inverters behave differently from synchronous generators during a disturbance.
- All commercially available utility-scale wind and PV today, use grid-following inverters.
- Today, we will start there
- Grid forming inverters are expected to be part of the path forward.
- Today, we will discuss them as well

The anthropomorphic inverter



1. Power regulator, including frequency control: “give me this much power”

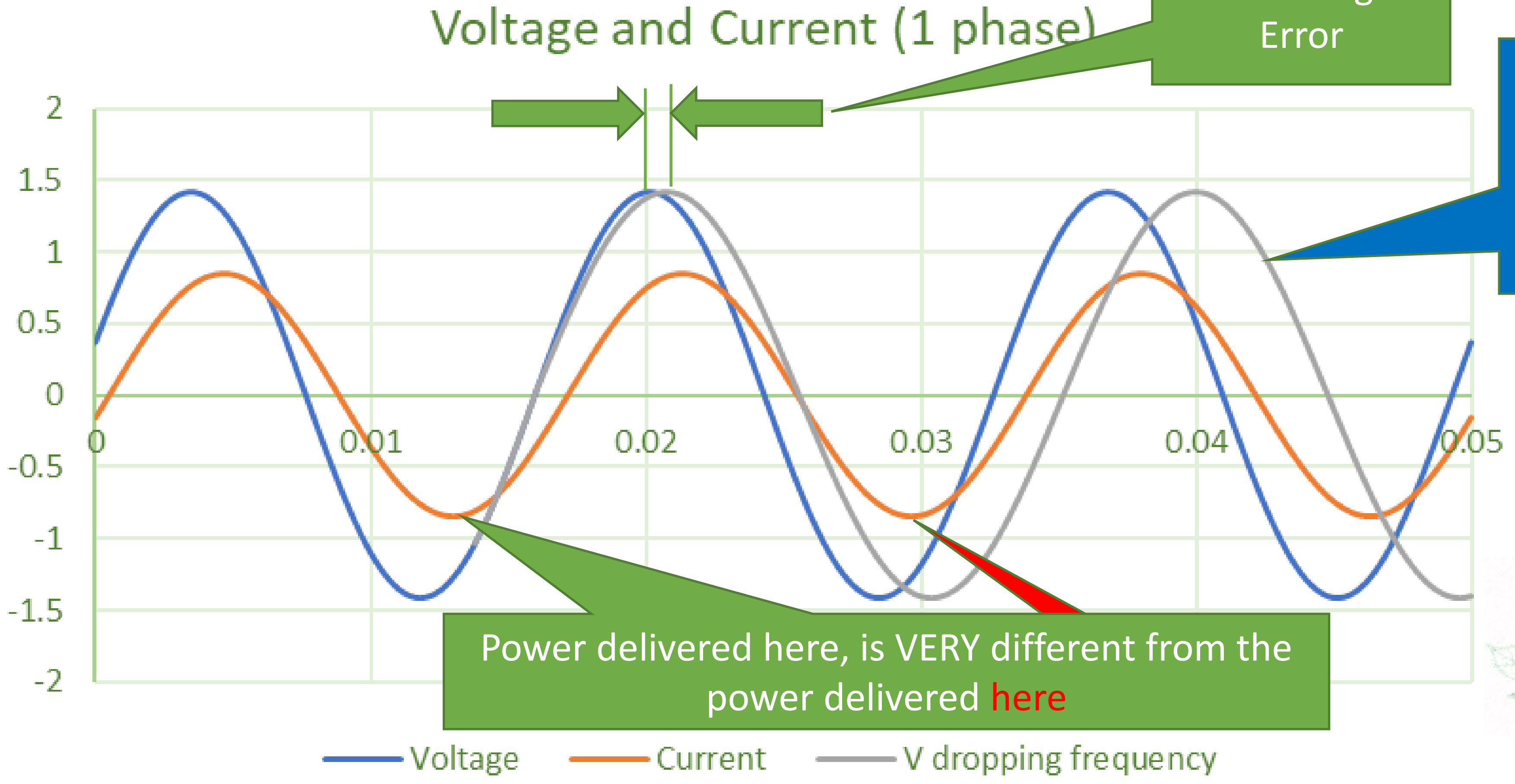
2. Voltage regulator: “give me this much reactive power”

3. Phase Locked Loop (PLL): “the voltage magnitude and angle is HERE”

4. Current regulator: “inject this much power current (Ip) and reactive current (Iq)”

5. Firing control: “inject this current at this phase angle”

Keeping up!



Phase Angle Error

It’s the job of the Phase Locked Loop (PLL) to track the voltage magnitude and angle

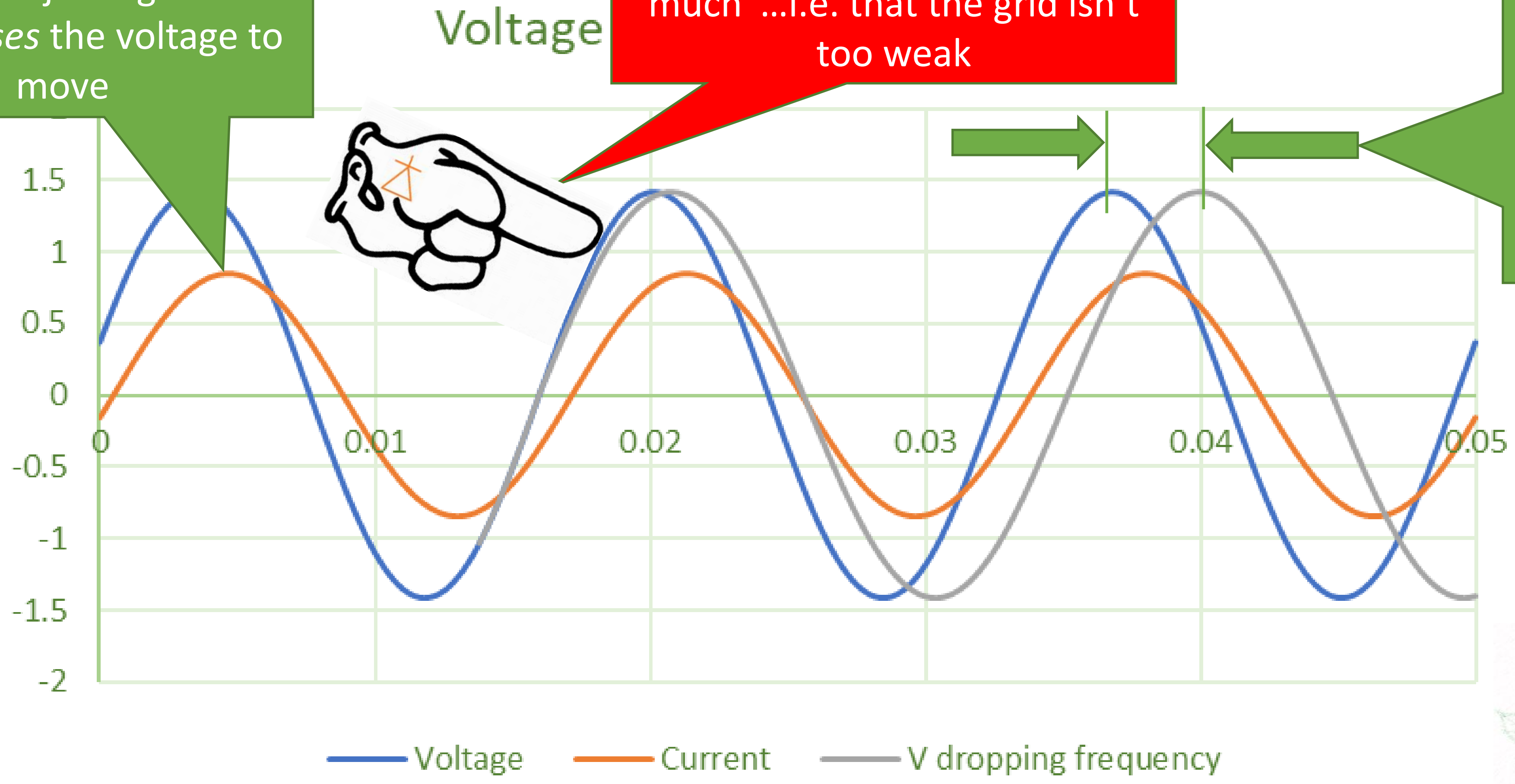
Power delivered here, is VERY different from the power delivered here

Self-inflicted pain

The act of injecting current here *causes* the voltage to move

Control design and stability is based on the assumption that the voltage won’t move “too much”…i.e. that the grid isn’t too weak

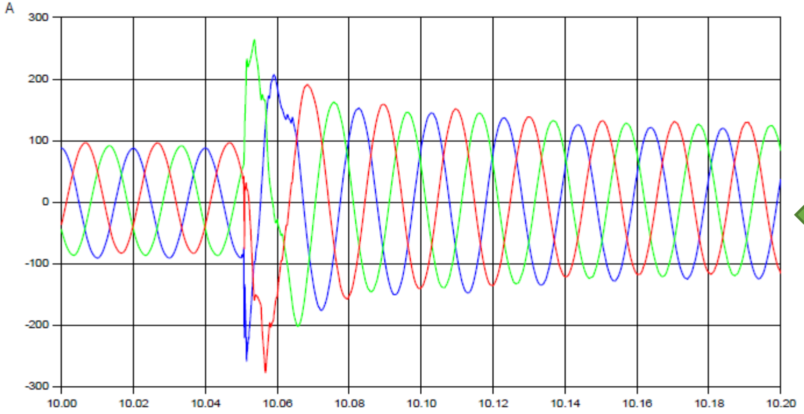
When the voltage moves too much, the current control either can’t keep up or it gets confused: i.e. it becomes unstable



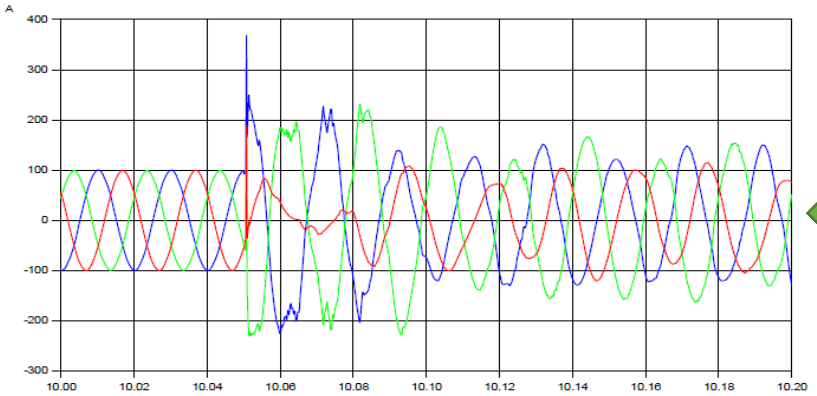
It’s not that simple

- Real life intrudes
- Waveforms can be difficult
- Even in normal systems, it can take a few cycles to figure out what’s going on
- So, there’s a limit to how fast you can make things act with confidence

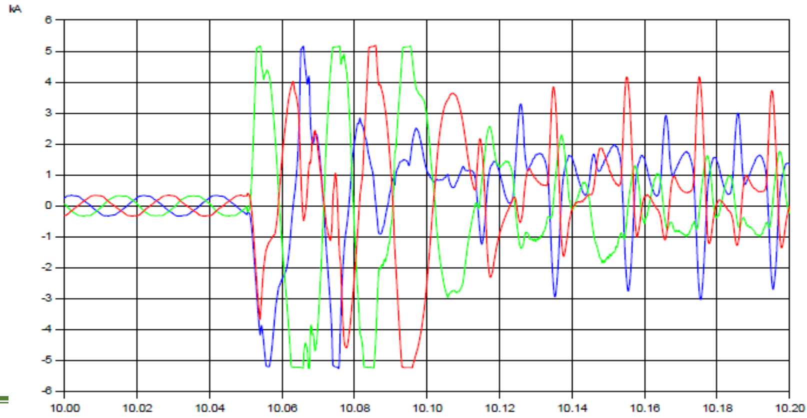
Some fault current examples



Balanced 3 phase fault



2 phase fault



2 phase fault, at v low initial current

Limitations of Stability Models
(a.k.a. what could go wrong?)

- Simulations crash.
  - These models are numerically challenging for the equation solvers.
  - Crashes are a measure of stress. But a crude one.
  - A simulation crash is a yellow flag, but NOT firm evidence of instability

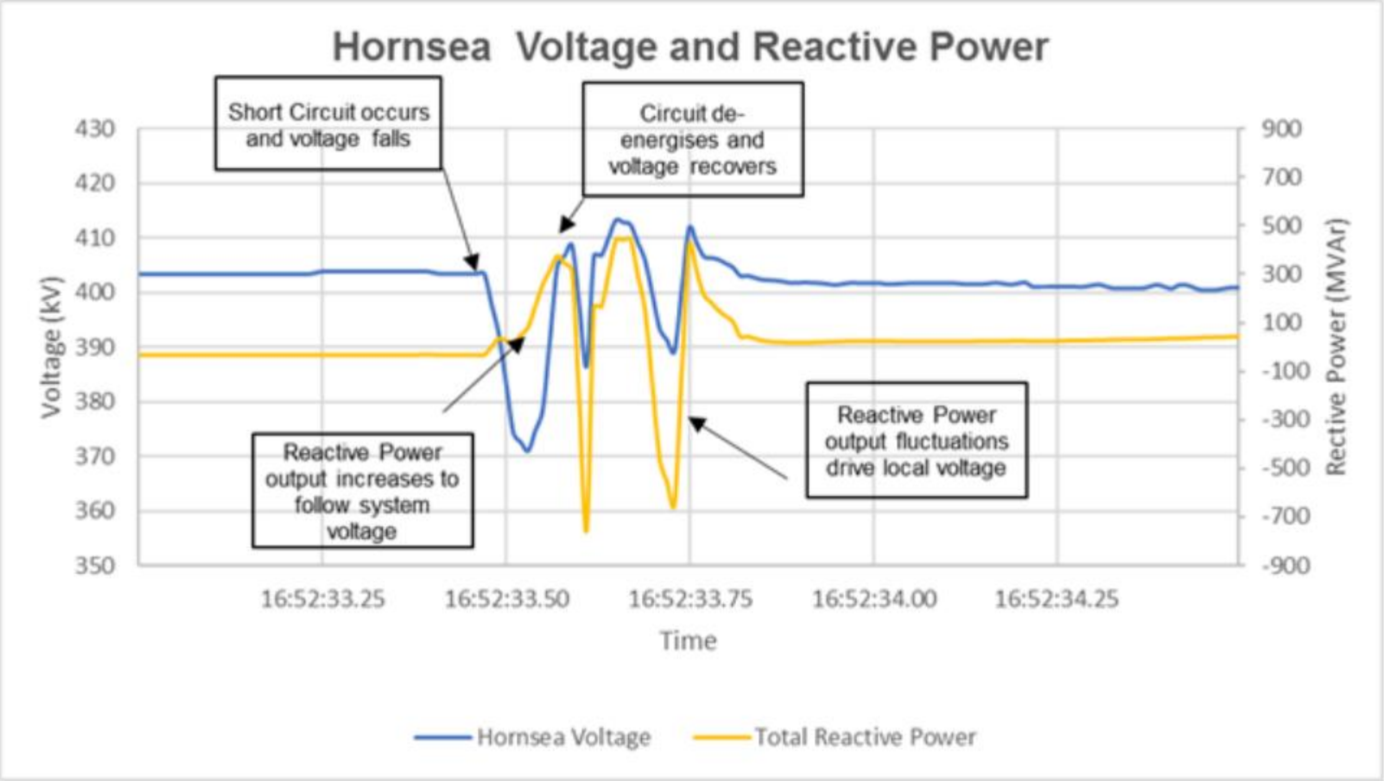
- High frequency oscillations.
  - Fast oscillations, i.e. anything above about 3-5Hz, isn't very meaningful for stability (phasor) analysis.
  - Again, a yellow flag, but NOT firm evidence of instability
  - "Traditional" oscillatory frequencies can be misdiagnosed with IBR dynamics
- False assurance.
  - Stability models may make the results optimistic. Ouch
  - Assumption of "perfect" PLL performance is one culprit

Sometimes, detailed, point-on-wave, EMT analysis is needed. (e.g. PSCAD…)

- It's not simple.
- Opportunities for garbage results abound.

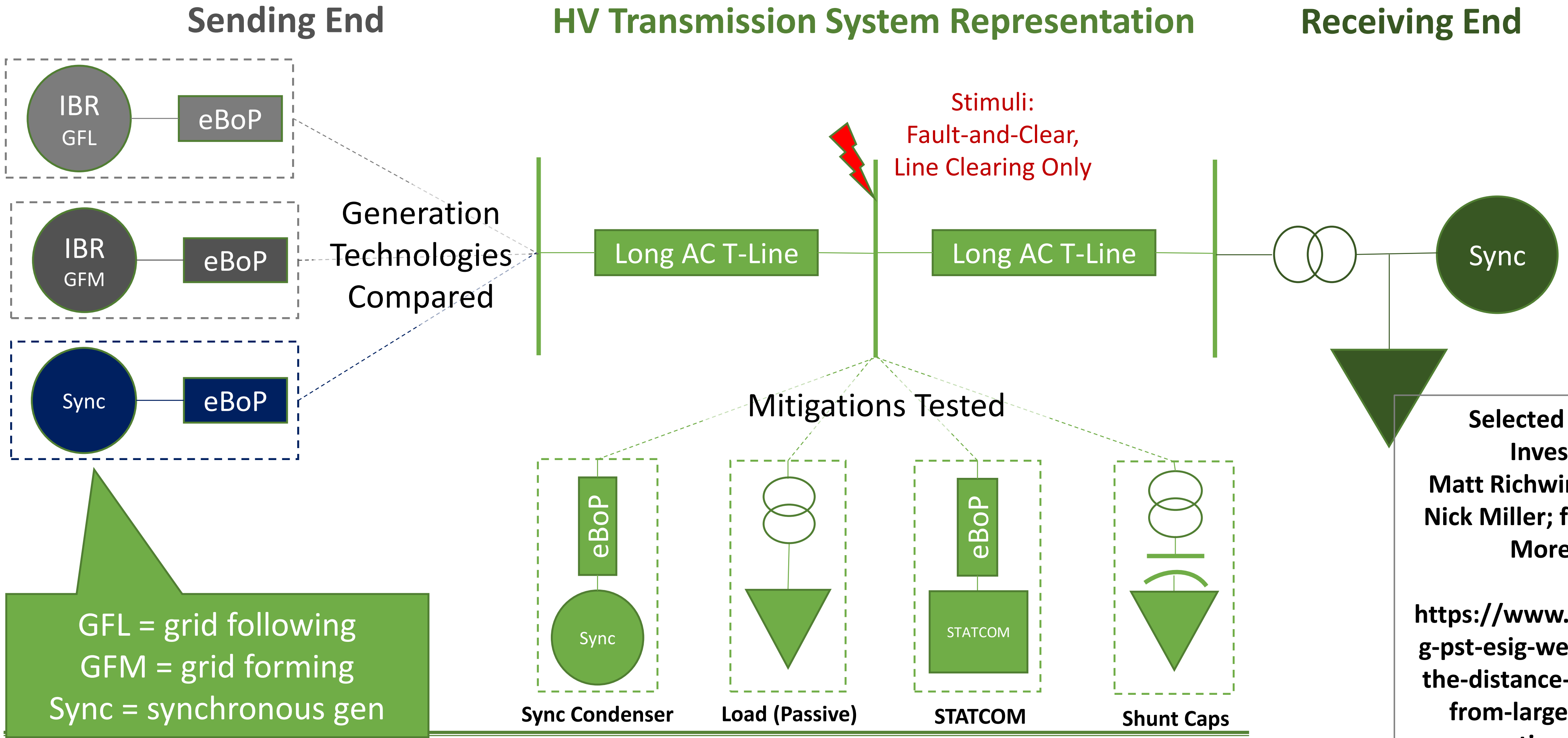
Example: UK Blackout August 9, 2019

- Huge 800 MW offshore, AC connected wind plant
- Small event: Shouldn’t have tripped
- UFLS activated; ~1M customers affected.
- Ugly: Some rail customers stranded for 6+ hours
- V/Q regulator not tuned for weak grid
- OEM quickly retrofit with more appropriate weak grid controls
- ~10Hz instability; outside of PSS/e, etc. simulation bandwidth



Source: National Grid ESO LFDD 09/08/2019 Incident Report
https://www.ofgem.gov.uk/system/files/docs/2019/09/eso_technical_report_-_appendices_-_final.pdf

Weak Grid Export:



GFL = grid following
GFM = grid forming
Sync = synchronous gen

Selected results of new Investigation by Matt Richwine, Telos Energy & Nick Miller; funded by GridLab. More details at:

https://www.esig.energy/event/g-pst-esig-webinar-series-going-the-distance-moving-ac-power-from-large-inverter-based-generation-pockets-to-load-centers/

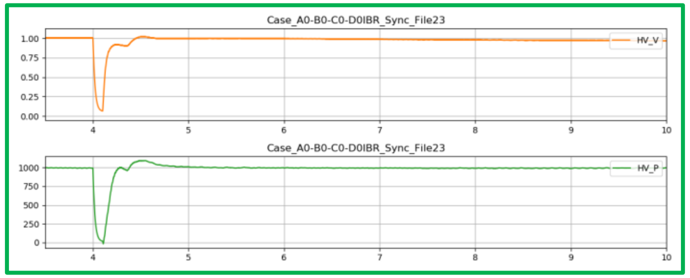
Grid Strength Impact

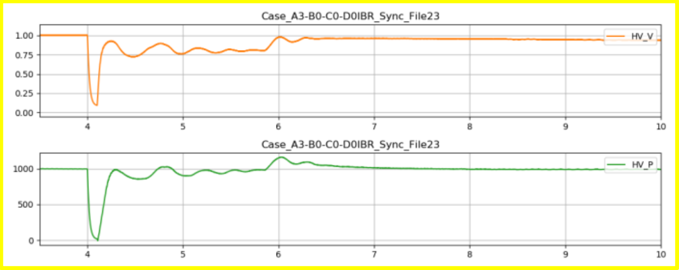
Soft Grid (SCR = 2.2)

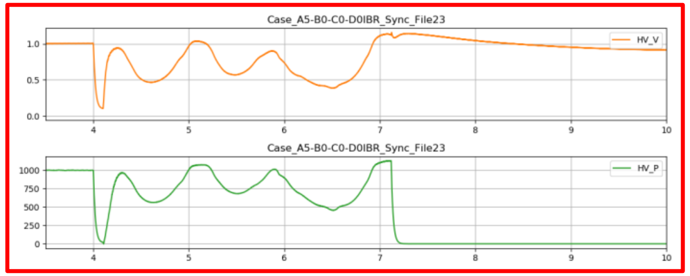
Marginal Grid (SCR = 1.4)

Weak Grid (SCR = 1.1)

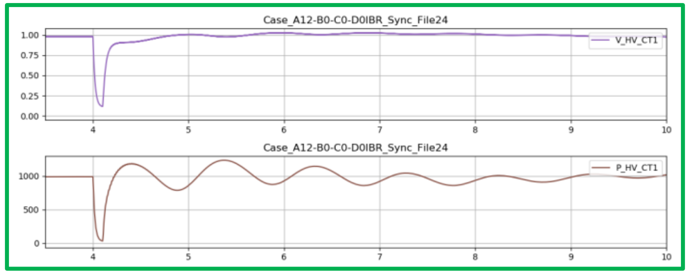
GFL-IBR

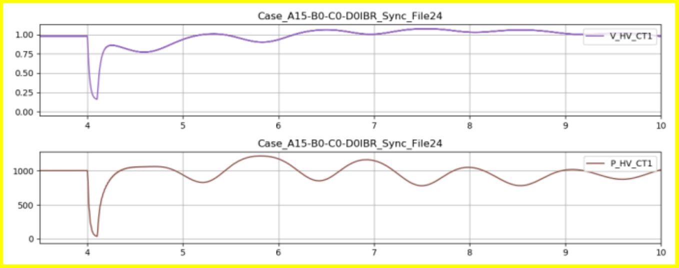


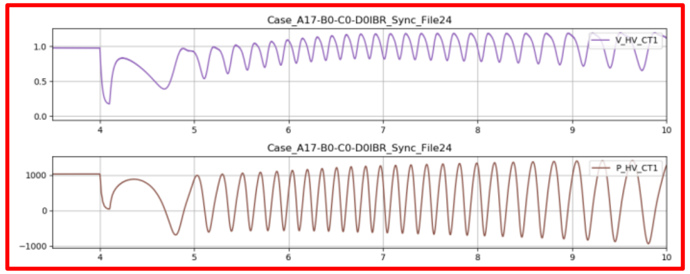




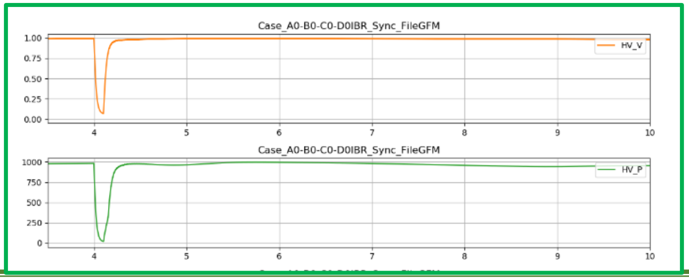
Synchronous Generator

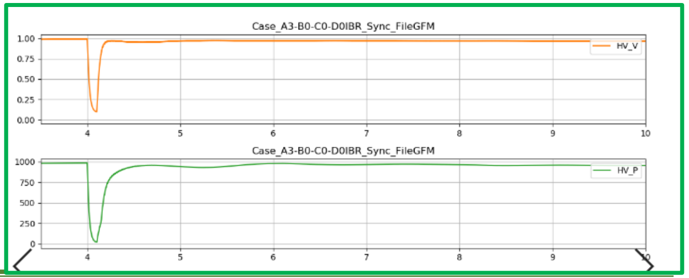


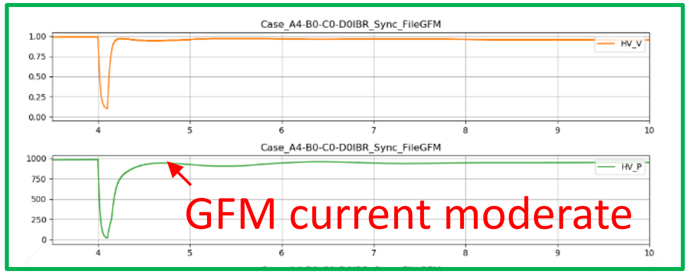




GFM-IBR



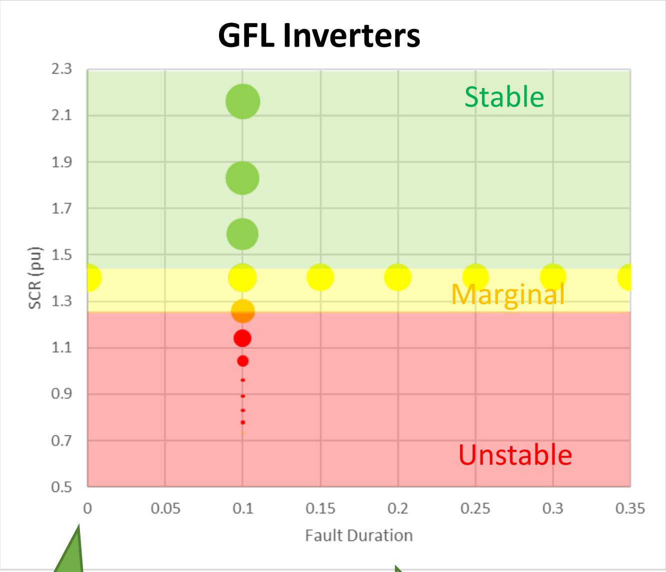


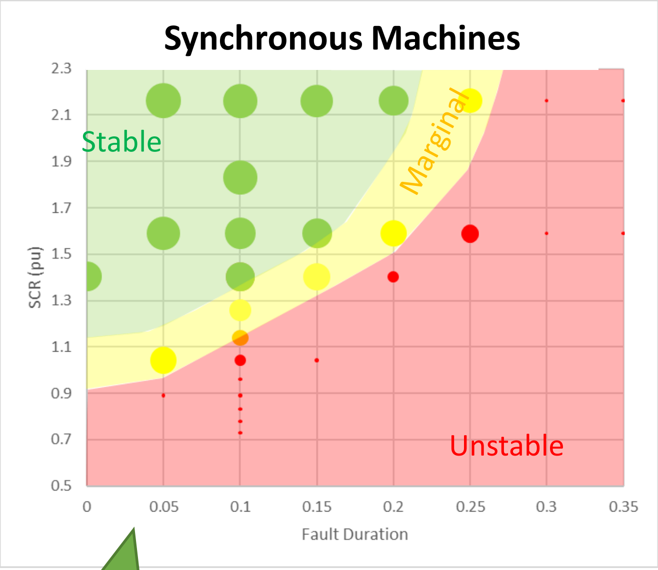


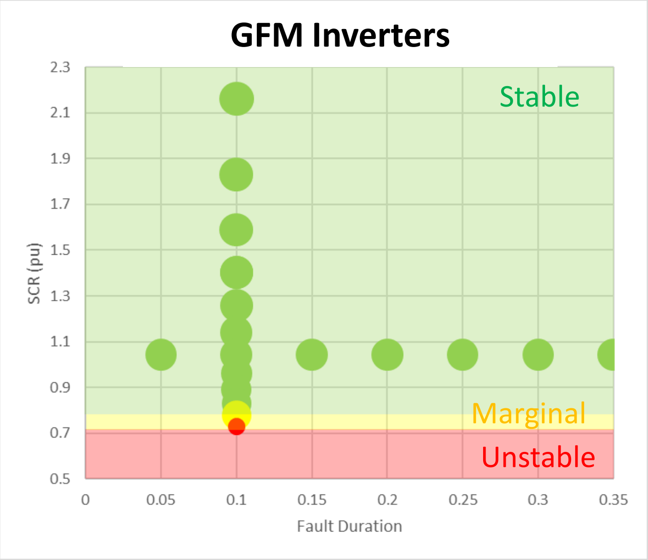
GFM current moderate

Stability behavior (and bounds) are different

Stronger grid







More severe events

Today’s inverters are quite sensitive to grid strength, but NOT to fault duration

Grid strength, and therefore synchronizing torque important; fault duration dictates stability of first swing

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

…many questions remain

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.
- 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

There is a continuum of integration challenge:

	●	■	◆	◆◆
Application Difficulty	Easy	Care required Regularly done	Special Care High communication & coordination burden	Special, non-standard Extreme coordination with OEM
Attributes	• Stiff Grid (SCR ~>5) • Limited complexity	• Moderate Grid (SCR ~3-5) • Some complexity	• Weak Grid (SCR ~1.2-3) • High complexity	• Very Weak or Zero Grid (SCR 0 -~ 1.2) • Islanding or near island required
Modeling Requirements	Standard PSS/e Modeling	Weak Grid PSS/e; application tuning	PSCAD; specialty PSS/e models	GFM PSCAD; TBD

Thanks

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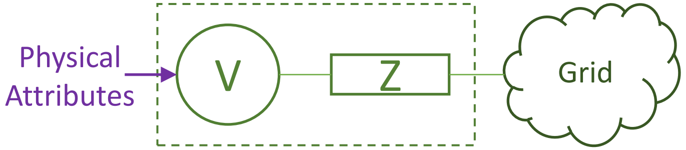
Brief Technology Overview

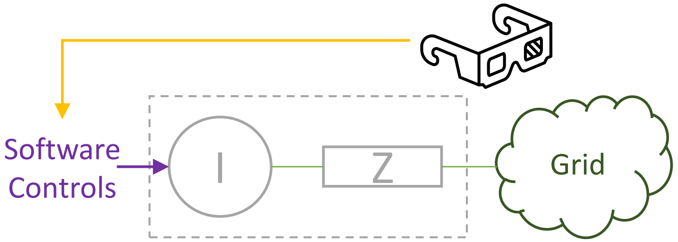
Synchronous Machines (SM)

- Behaves like a voltage source (inherent, physics-defined response)
- Stored energy in rotating mass and magnetic field (relatively small amount – seconds at rated)
- Ability to release energy quickly (3-5x current rating)



Grid-Following Inverters (GFL)

- Behaves like a current source (sense-then-respond, software-defined response)
- Stored energy varies (cycles at rated for PV, more with wind, hours with battery)
- Limited ability to release energy (1 – 1.5x current rating)



Grid-Forming Inverters (GFM)

- Behaves like a voltage source (inherent-like, software-defined response)
- Stored energy varies (cycles at rated for PV, more with wind, hours with battery)
- Limited ability to release energy (1 – 1.5x current rating)