Large System Perspective on Inertia, Frequency and Stability

ESIG Workshop

Everything You wanted to Know About Inertia, but Were Afraid to Ask

October 1, 2018 -- Denver

Nick Miller

Acknowledgements

My participation made possible by:

GridLAB

Many of the results presented are from NREL reports of work
Sponsored by DOE EERE:

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

That was performed at GE Energy Consulting:

imagination at work

Thanks.

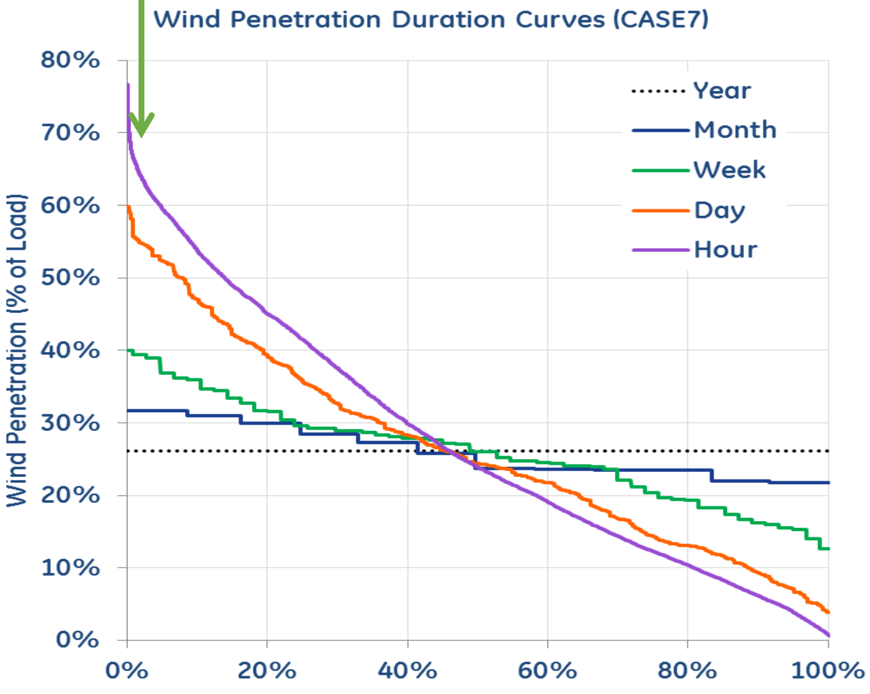
We don’t need to wait long until we have a serious challenge

- Wind Penetration Duration Curve for study scenario for 30% Wind Energy (annual)

The question isn’t

- “100% Inverters ALL the time?”
- It’s “100% Inverters EVER?”
- Only Instantaneous Penetration counts

“oh, we’ll never get to 100% inverters”…. REALLY?



Source: NSPI Renewable Integration Study
http://www.nspower.ca/site-nsp/media/nspower/CA%20DR-14%20SUPPLEMENTAL%20REIS%20Final%20Report%20REDACTED.pdf

HickoryLedge

Repurposed slide from our IEEE P&E Article “A future without inertia is closer than you think”,
Thomas Ackermann, Thibault Prevost, Vijay Vittal, Andrew J. Roscoe, Julia Matevosyan, Nicholas Miller* .

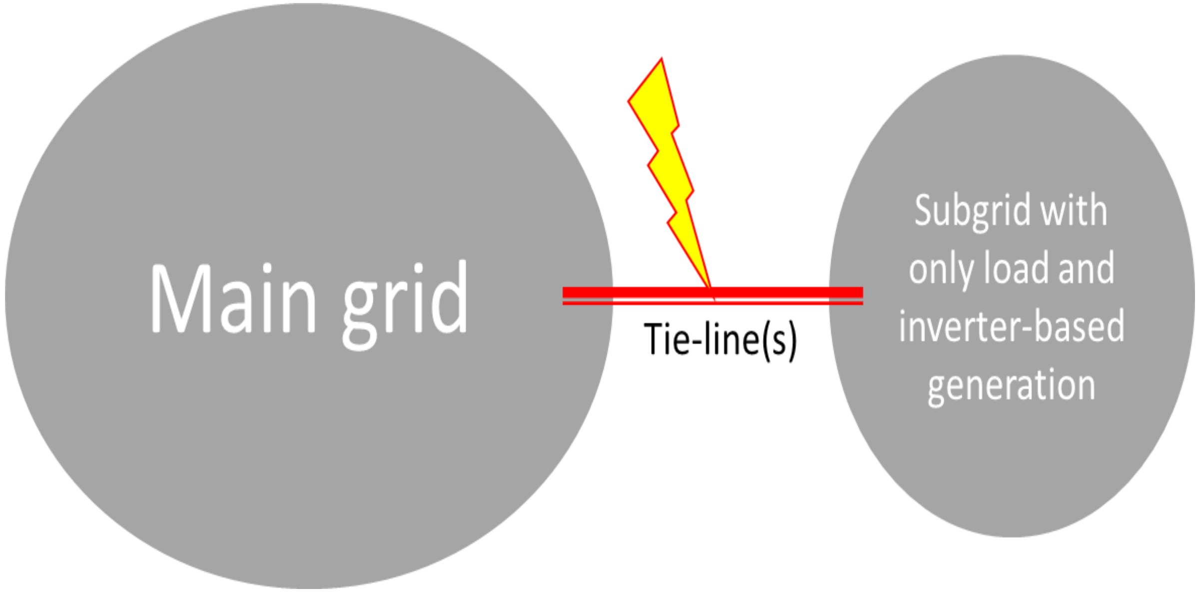
And, by the way, we live in an N-1 world

a.k.a. Do you have to give up when a (big) island forms?

- Suppose, that a corner or end of your system has lots of wind & solar, some load, little economic synchronous generation, and ties to the rest of the grid:

- Do you have to give up, if you separate?

- Today, answer is “yes”.



Repurposed slide from our IEEE P&E Article “A future without inertia is closer than you think”, Thomas Ackermann, Thibault Prevost, Vijay Vittal, Andrew J. Roscoe, Julia Matevosyan, Nicholas Miller* .

Low Inertia vs Event Size vs Speed of PFR

- Some perspective from new 2018 LBNL document:

Frequency Control Requirements for Reliable Interconnection 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

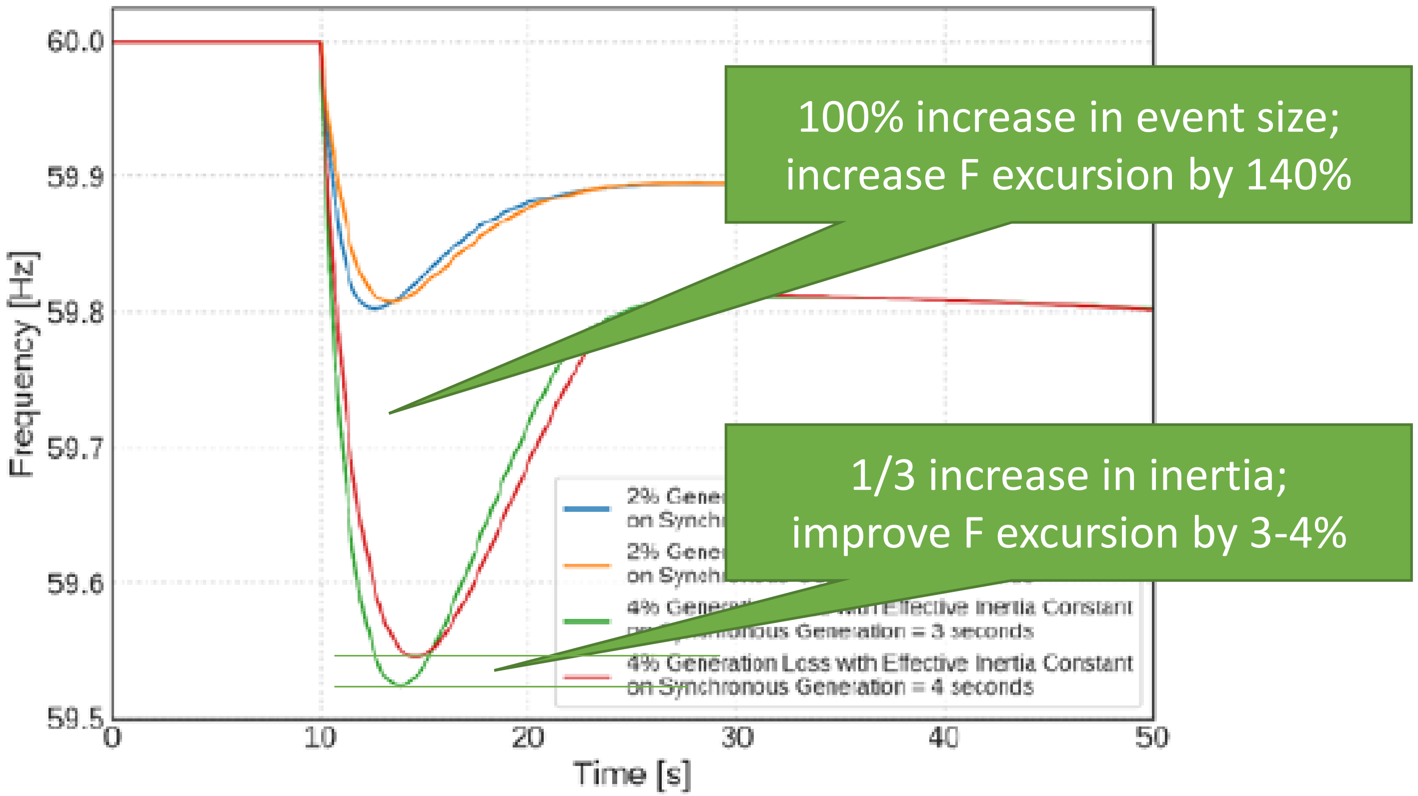


Figure ES - 5. The Relative Impacts of Generation Loss versus System Inertia on Frequency Nadir

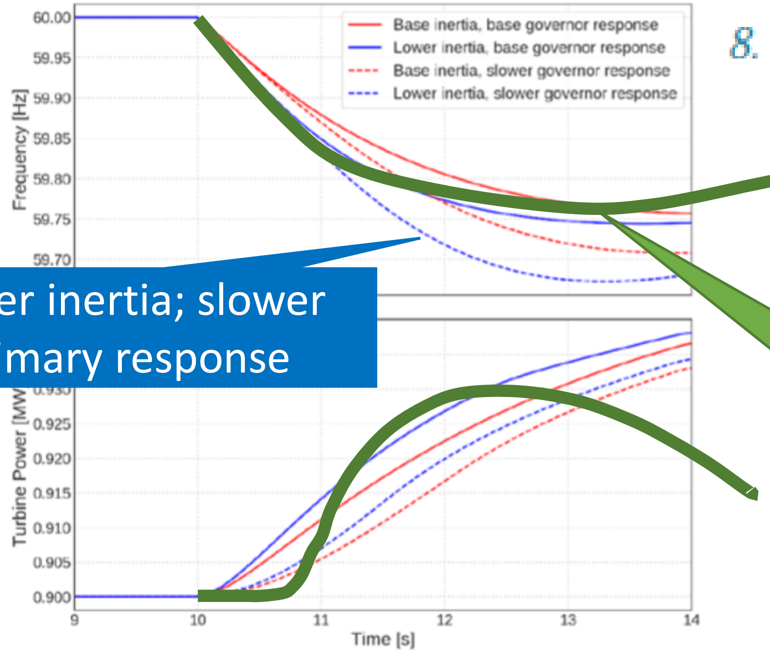
Source: Developed by LBNL from Undrill (2018): Primary Frequency Response and Control of Power System Frequency

Controls from Inverter-based resources

Some *clippings* from the LBNL 2018 report… and my commentary: these issues are getting a lot of attention!

3. For a given loss of generation, system inertia and the timing of primary frequency response determine how frequency is arrested.

If they are slow to respond, they may require augmentation by faster responding reserves.



Lower inertia; slower primary response

Lower inertia; slower primary response plus "synthetic inertia"

Figure ES - 3. System Inertia and the Speed of Primary Frequency Response Determine the Nadir at Which Frequency is Arrested

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

8. "Synthetic inertia" controls on electronically coupled wind generation appear not to sustain primary frequency response.

True. Hence the name. Could easily have read:
8. "Synthetic Inertia" controls are similar to synchronous inertia in that they do not sustain Primary Frequency Response

without headroom. As noted above, "synthetic inertia," which, based on the literature, is a form of primary frequency control provided by wind generation without reserving headroom and is then quickly withdrawn is not a substitute for sustained primary frequency response.

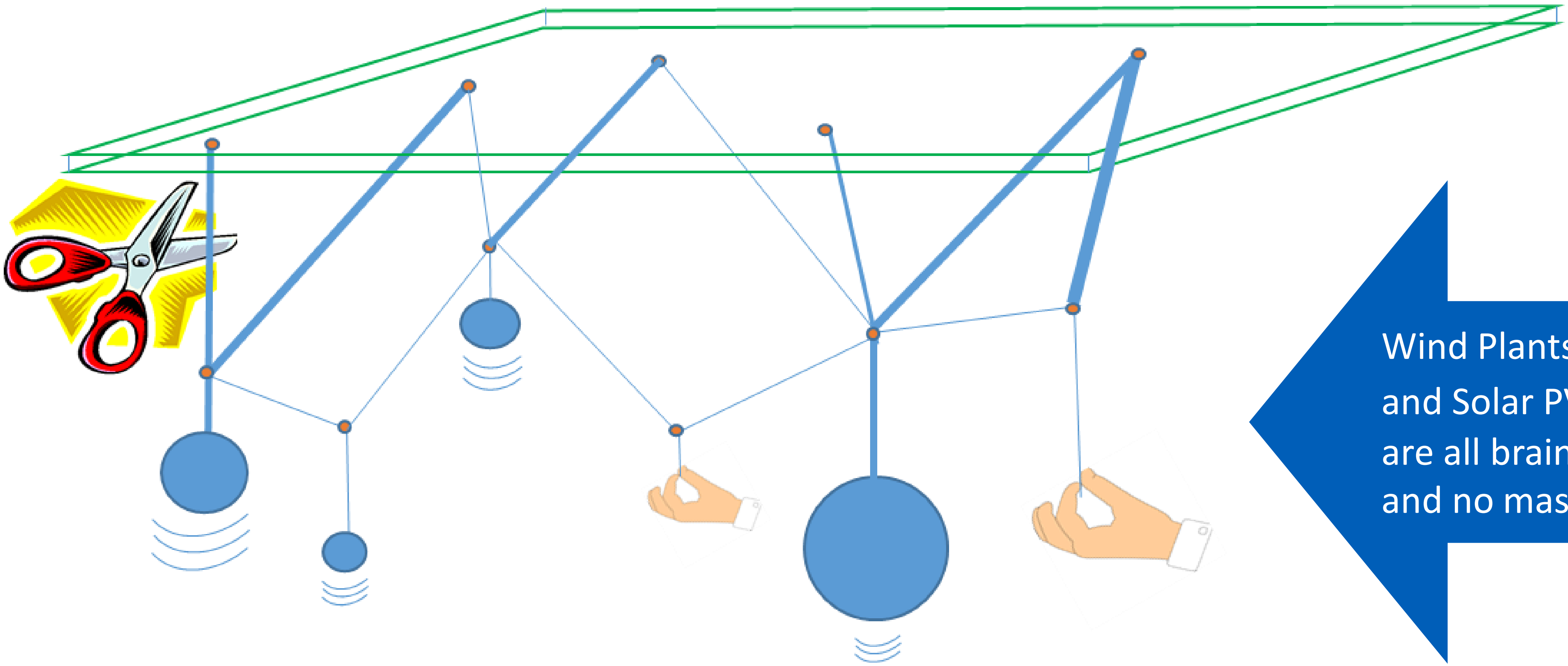
With Headroom and "synthetic inertia", wind generation is faster than most synchronous generation and provides sustained primary frequency response.

Controls from Inverter-based resources

Opportunity and Risks:

- In general, inverter-based resources:
  - Solar PV
  - Wind
  - Variable Speed Pumped Hydro
  - Batteries
  - And some classes of controlled loads
  - Can be faster and more flexibly controlled to specific frequency behaviors
- Faster, more adaptive, more customized controls could produce big reliability and economic benefits.
- We could also screw up. But power system fundamentals haven’t changed.
- We can more forward and get it right.

Is it stable?

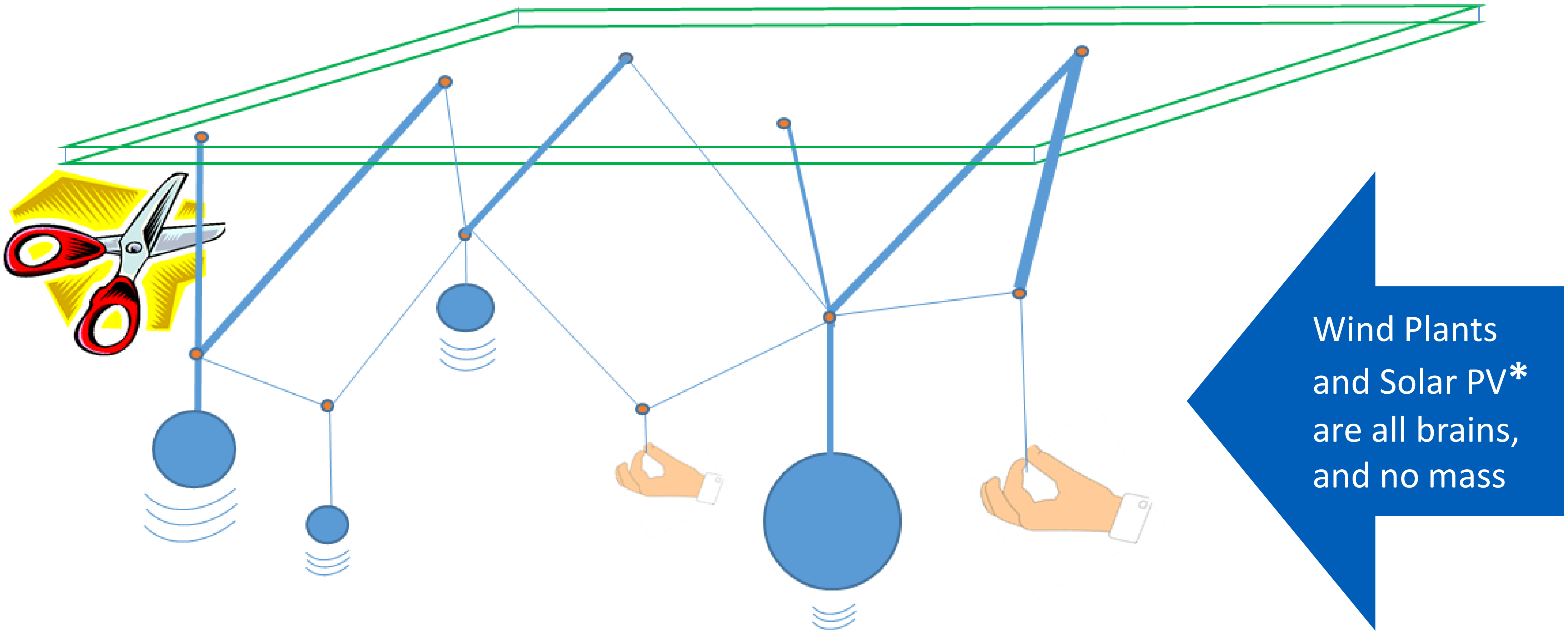


Wind Plants and Solar PV* are all brains, and no mass

* And all other inverter-based resources, including batteries

Source: NREL/GE WWSIS 3a   Derived from original figure by Elgerd

Is it stable?



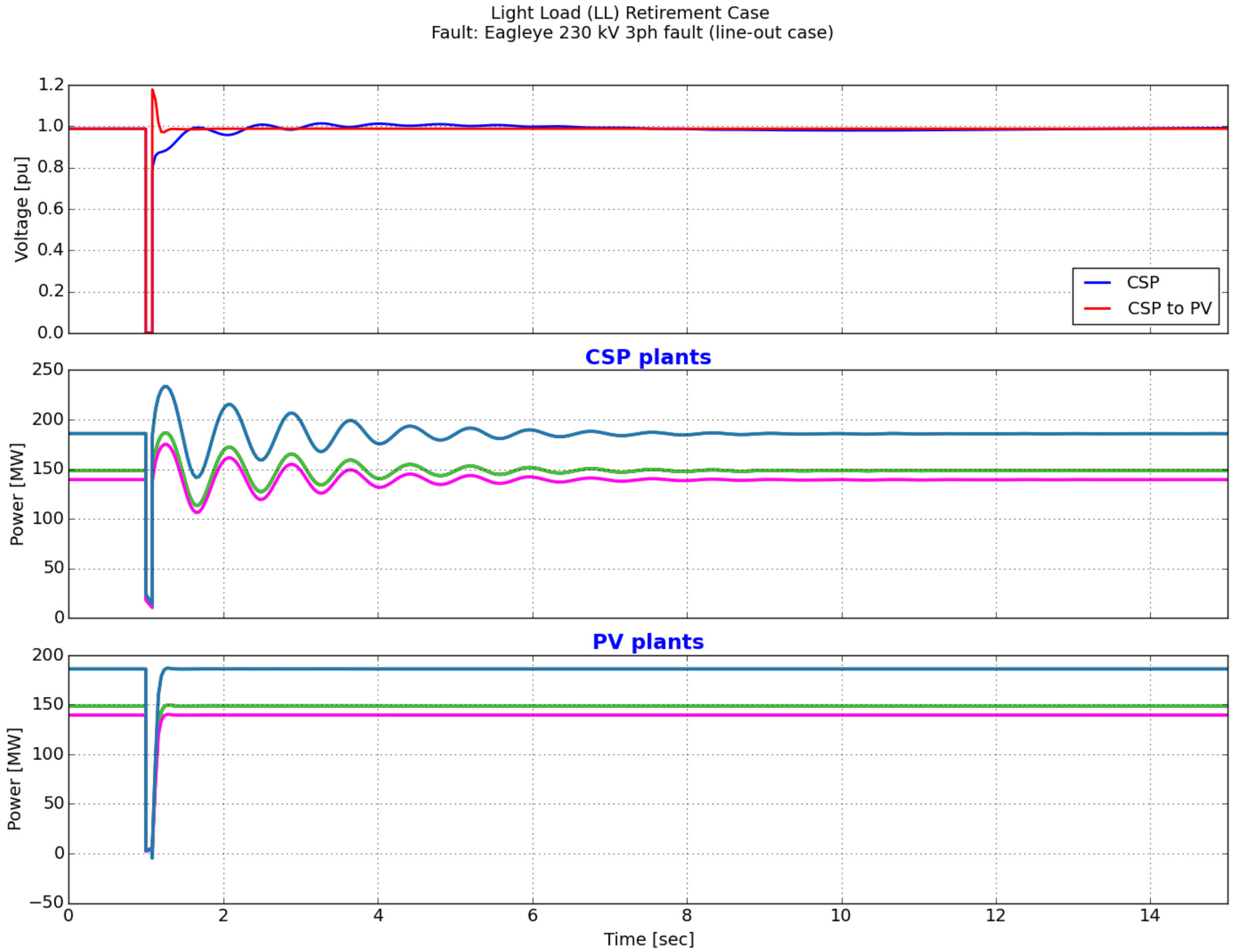
* And all other inverter-based resources, including batteries

Inertia is NOT always your friend

- Taking advantage 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.

A few illustrations

- This is from newly released work funded by DOE
- We looked at dynamics of Solar PV vs Synchronous CSP
- The executive summary was just released
- https://www.nrel.gov/docs/fy18osti/70782.pdf

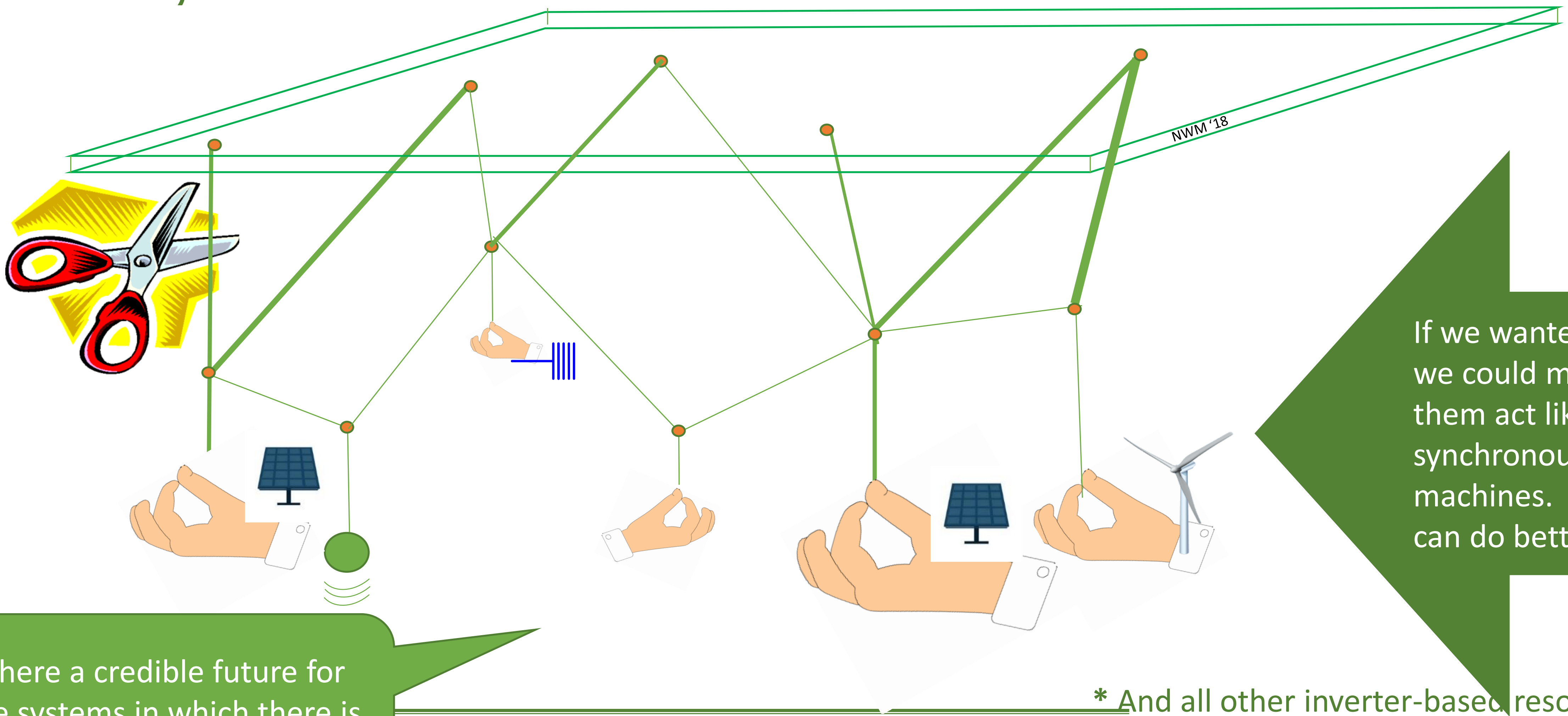


Transient stability of CSP compared to PV in a low-grid-strength location

HickoryLedge

Source: NREL/TP-5D00-70782
July 2018

Is it stable when the vast majority, but not 100%, are inverters?



If we wanted to, we could make them act like synchronous machines. But we can do better!

Is there a credible future for large systems in which there is ***never*** synchronous machines?

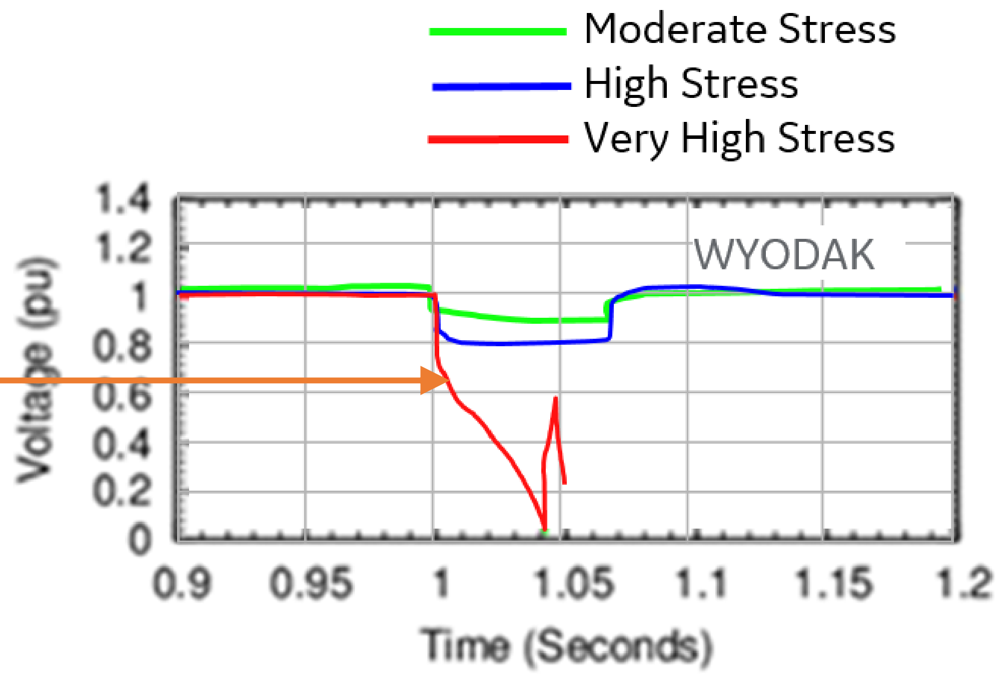
* And all other inverter-based resources, including solar PV and batteries

Derived from original figure by Elgerd

Paradoxically: Grids are both stronger and more brittle.

Stability limits tend to be **higher – that is good for reliability and economy.**

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



We need better :

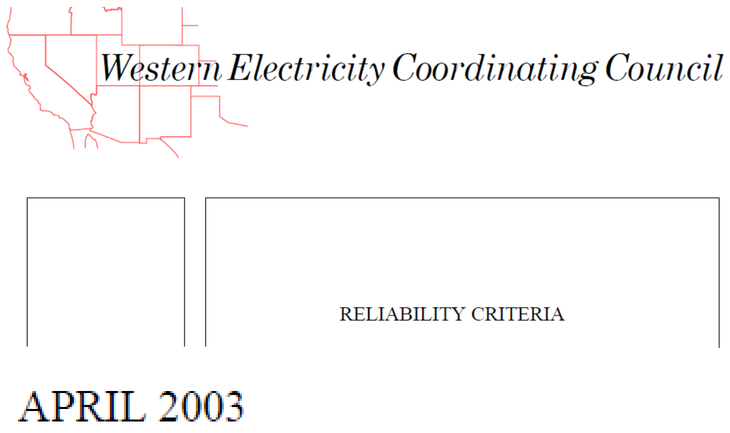
- Understanding
- WTG (and inverter) controls
- Simulation tools
- Predictive tools and metrics

The world looks different as we *approach* "Zero Inertia Systems"

Source: NREL/GE WWSIS 3a

Are we using the right metrics?

Voltage dips, Onion curves, Proximity indicators and other oddities….


Western Electricity Coordinating Council

RELIABILITY CRITERIA

APRIL 2003

This would have given no indication of risk for the fail on the previous slide.

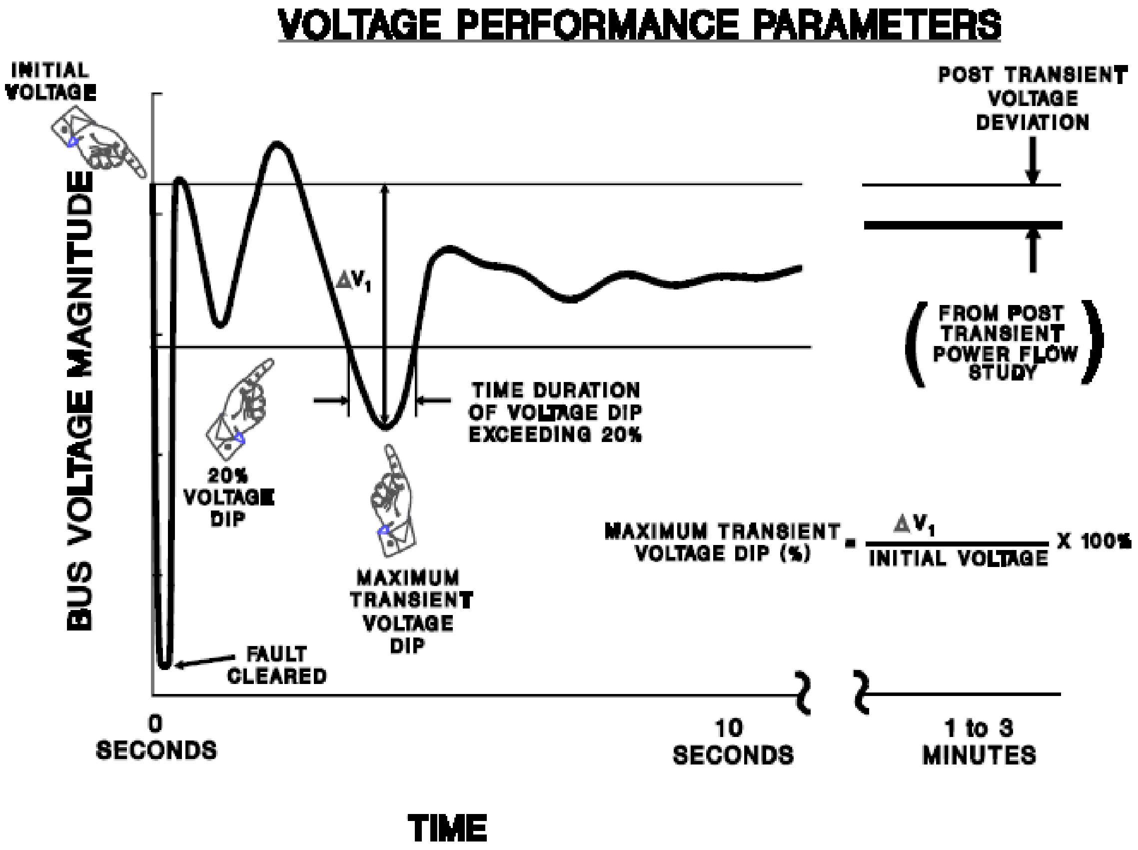
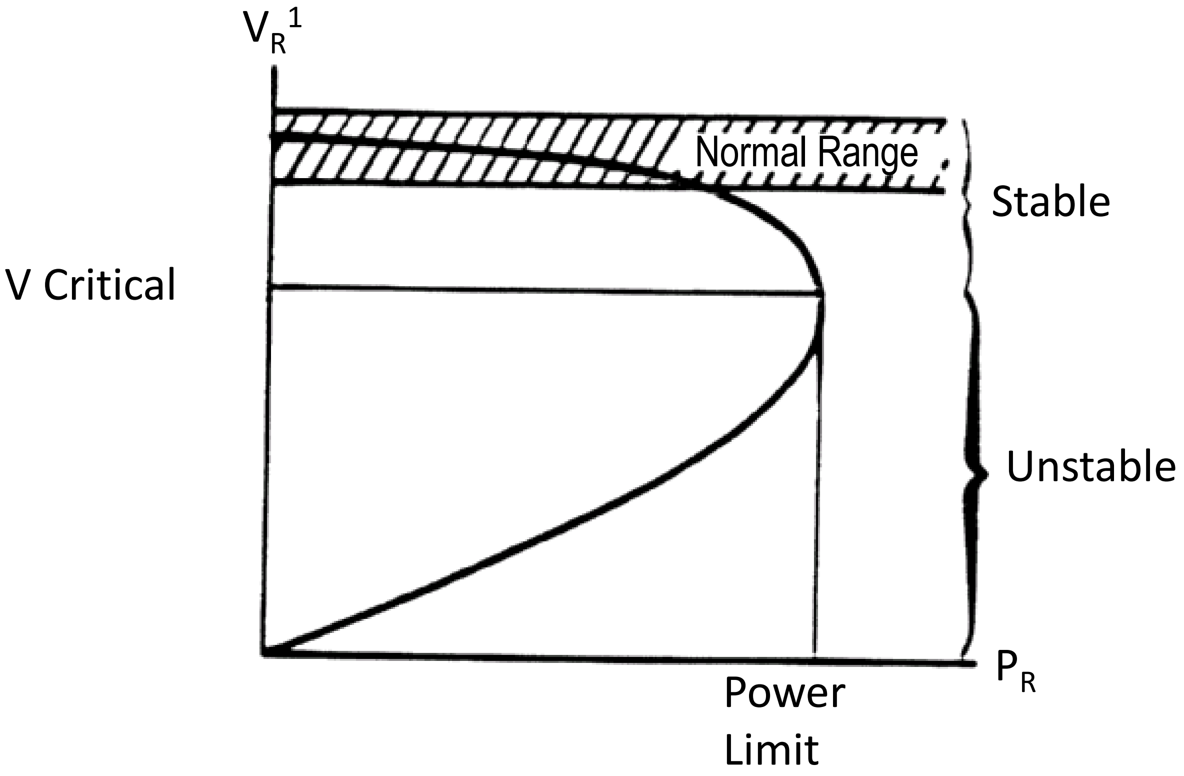


Figure W-1

Classical Power Limit Curve: "Nose Curves"



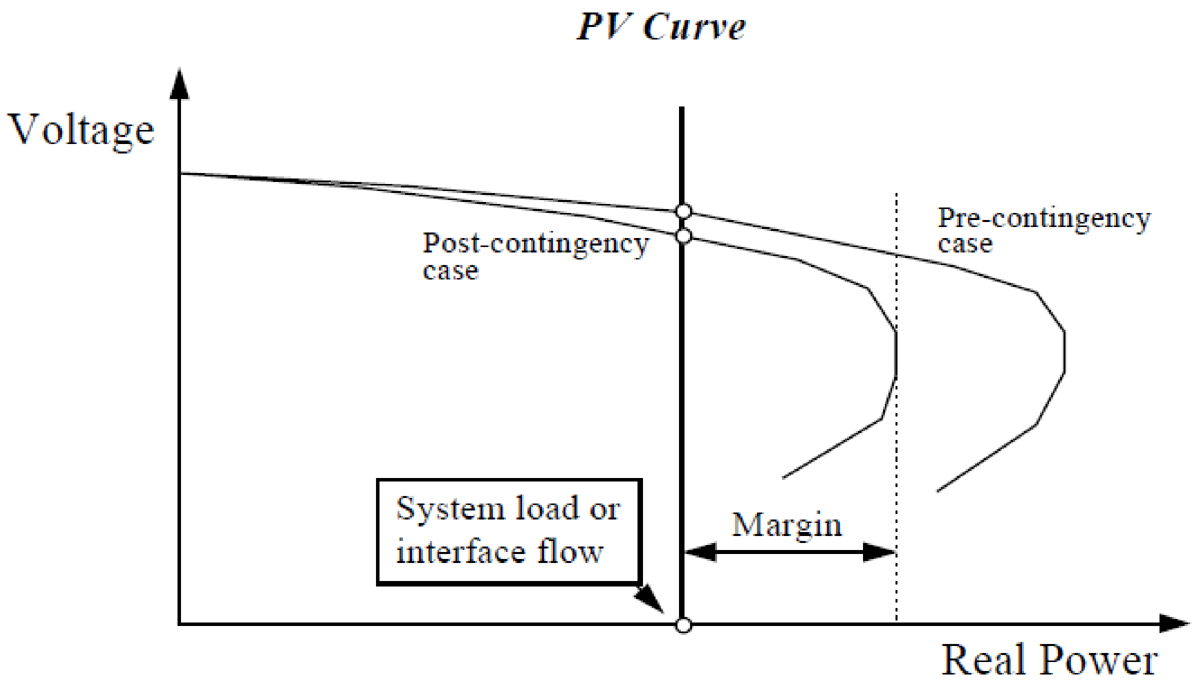


Figure 8.1 - P-V Curve

These are static, and segregate P from Q…. Sufficient?
Not obviously so.

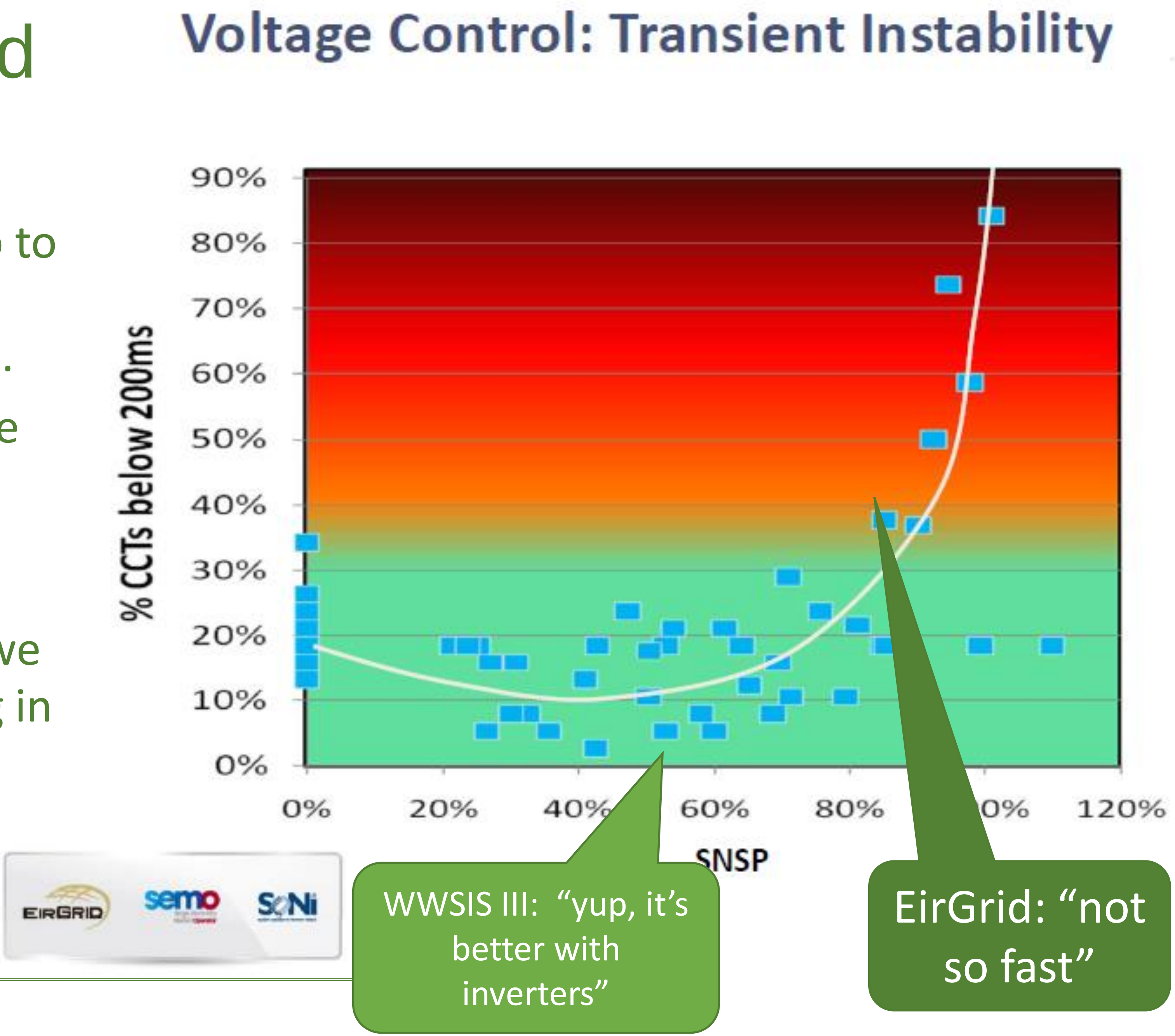
VOLTAGE STABILITY CRITERIA, UNDERVOLTAGE LOAD SHEDDING STRATEGY, AND REACTIVE POWER RESERVE MONITORING METHODOLOGY

FINAL REPORT

Final Report – May 1998

EirGrid: to 75% and beyond!

- In the near term, big systems up to (say) 75% are being found to be manageable, even well behaved.
- But, things get funky somewhere between 75% and 100%
  (Jon O' has been telling us that for years…we're catching up).
- And, yes there are times when we (Xcel, SSP, ERCOT, …) are closing in on the 75% level occasionally.



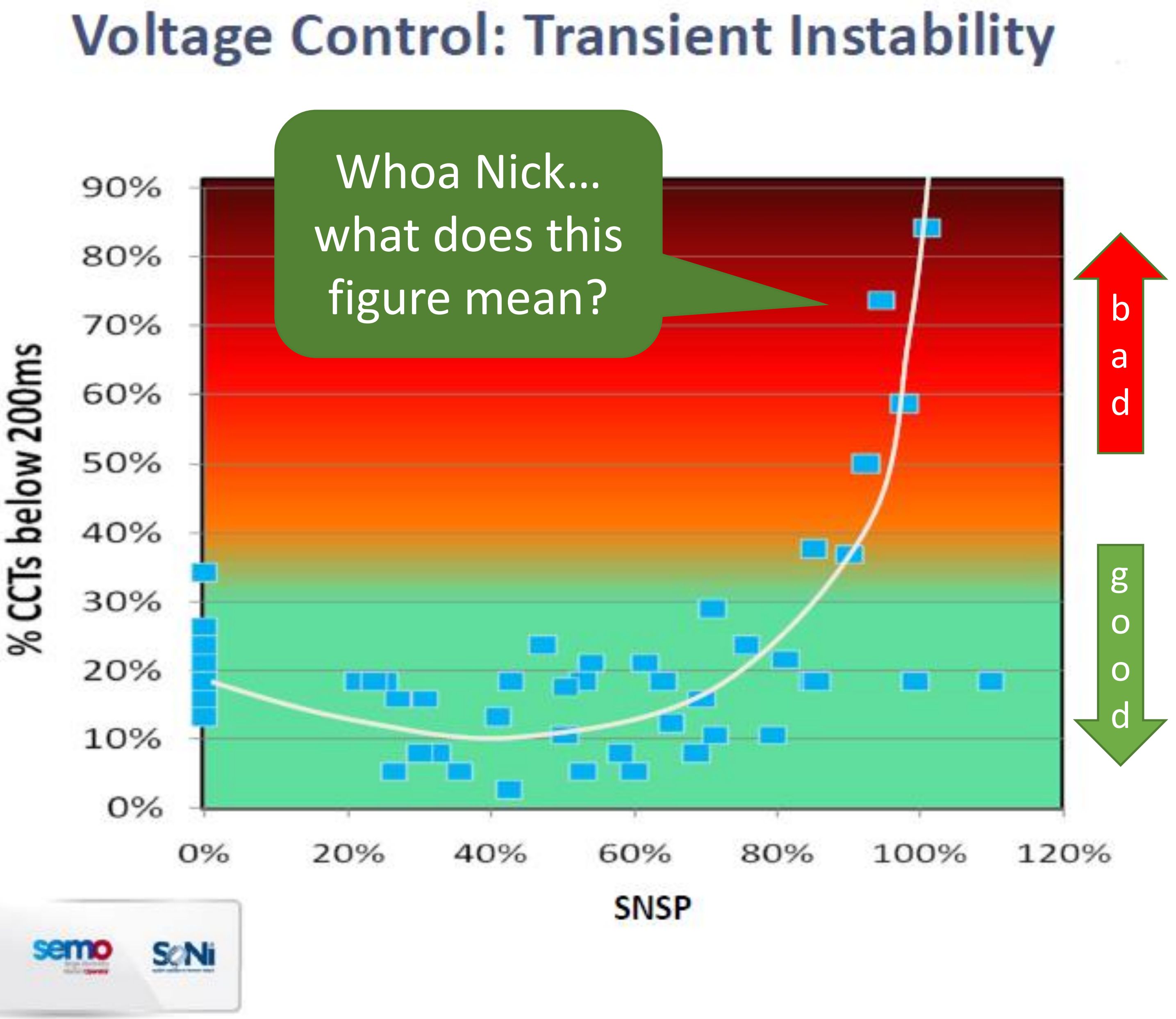
Source: EirGrid, Jon O'Sullivan c. 2013

HickoryLedge

EirGrid: to 75% and beyond!

How to read this (according to Nick):

- Critical Clearing Time (CCT) is metric of stability.
- Longer CCTs = “more” stable.
- CCT is meaningful for a single operating condition and specific fault (and clear) event.
- For any operating point (i.e. 1 blue box point in the figure), there are many faults to worry about.
- The more faults that have short CCTs (e.g. <200ms), the less stable (bad) the system.
- The “best” stability for EirGrid is around 40-50% SNSP… a proxy for how much wind power is supplying load



Source: EirGrid, Jon O’Sullivan c. 2013

Control matters!

- One size does not fit all… at least not the best fit.
- Consider:
- in a considerable number of US application studies and specific cases, it has a been found that managing voltage and reactive current takes priority over active current and maintain active power injection
  - The WWSIS III study showed comparisons where controls prioritizing Q over P during and immediately following the fault resulted in dramatically better frequency and stability performance
- But, EirGrid (next slide) has found that active power should take priority
- There are multiple factors governing stability and frequency; some of them are in tension.
- The balance isn't always the same in every system or situation

FoR: Instability Mitigation Measures

This WTG control strategy is "best" for EirGrid (as studied)

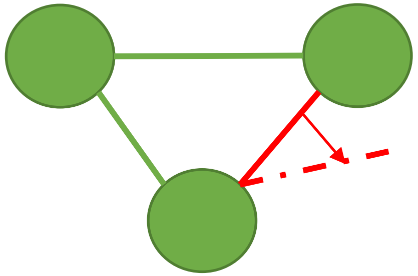
This WTG control strategy has generally been better in weaker North American applicaitons

Source: Jon O'Sullivan EirGrid

Options

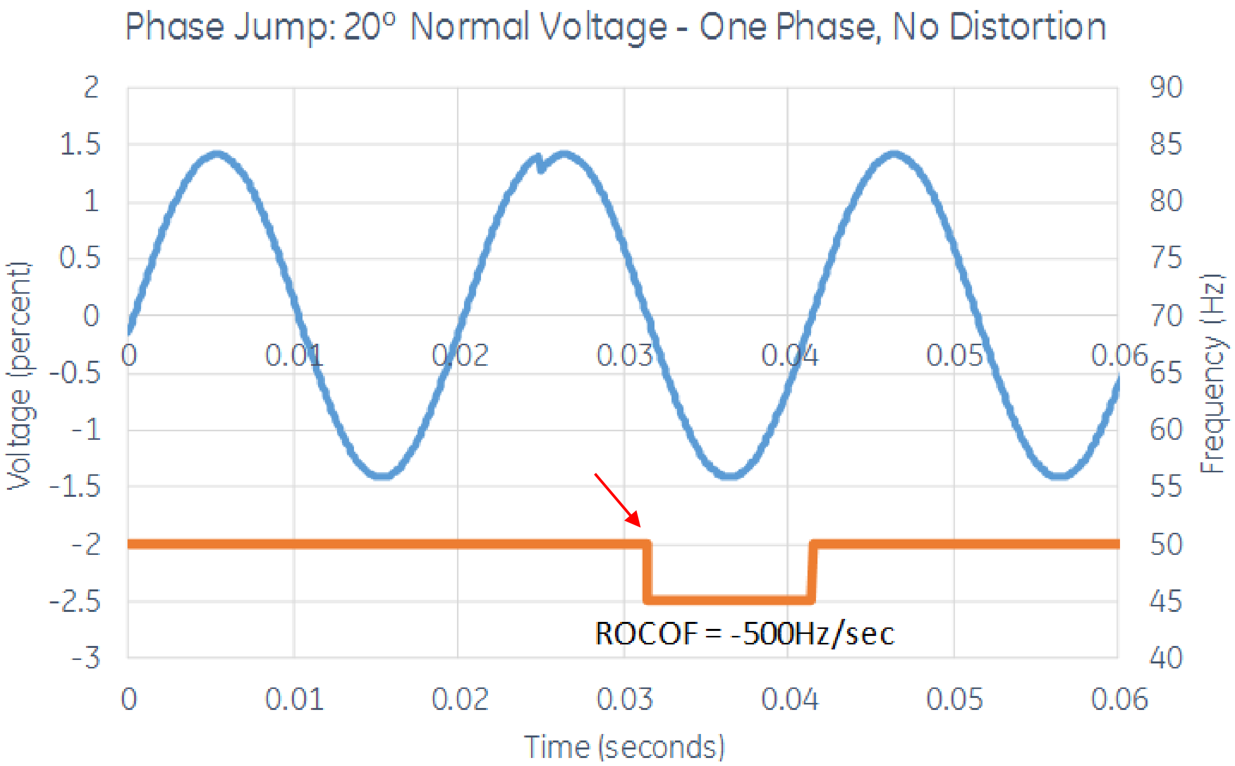
- Maintain inertia
  - Keep synchronous machines running that would otherwise not run
  - Find other sources of synchronous inertia
- Speed up frequency response
  - Faster PFR (on synchronous machines)
  - FFR and other clever frequency controls, especially on inverters
- Make inverter behavior “better”
  - Grid forming inverters and Virtual synchronous machines
  - “other”

looking beyond *Frequency*:



For *this particular* behavior:

- frequency is useless and meaningless.
- (absolute) angle is (briefly) meaningful, and *may be* useful.
- For any significant duration, absolute angle is meaningless. Only relative angle has useful information
- Can we use absolute angle (very fast) and relative angle (more slowly):
  - In addition to frequency?
  - Instead of frequency?
- We've got a *lot of work to do,* before we can answer confidently.



Control evolves

- We've been here before: it took stability problems to cause the US industry to invest in high response excitation.
- High response excitation caused damping problems. We introduced PSS to correct the problem caused by synchronous machines with long time constants and high inertia
- We've learned to live with synchronous machines, but it doesn't mean their behavior is always desirable or optimal.
- With inverters, we aren't stuck with the characteristics of synchronous machines, and have a broader spectrum of options to make the system work better
- Why make your Ferrari drive like a dumptruck?
- One size doesn't fit all….

Thanks

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