Intro to Fundamentals of Stability and Power System Dynamics – Part 1

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

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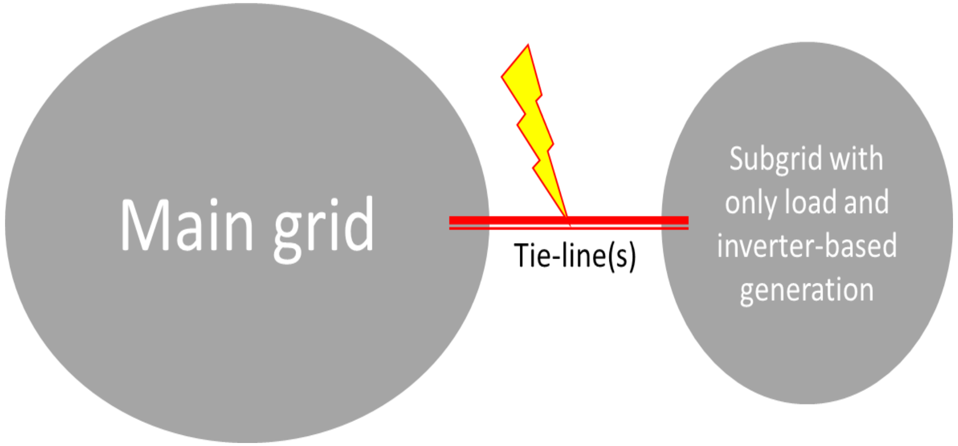
Integrated Planning: Assuring Stability in Modern Systems

Day 1: Session 3

Monday September 15, 20253

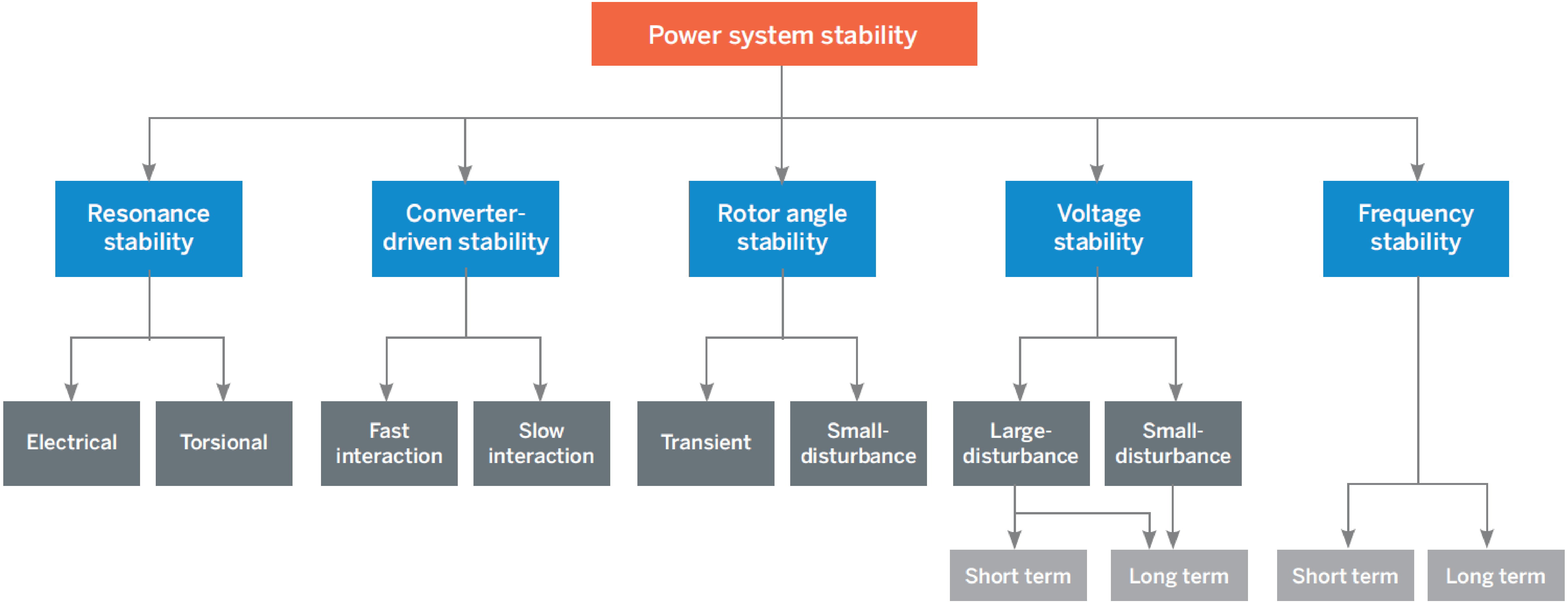
The rules of stability planning

- We live in an N-1 world
  - The are NERC rules (and alphabet soup): TPL-001; N-1, N-1-1, N-k & cascading
  - But, simply put, N-1 means **the system must tolerate the loss (trip, failure, removal,...) are ANY single element, and exhibit acceptable behavior without human intervention**
  - In practice, in the US, grid topology is such that breaking into "islands" is NOT caused by N-1 events, and as such is not a primary planning concern.
  - This is an important point in "inertia" and "frequency" discussions
  - We'll spend some time looking at what "acceptable behavior" means in practice



The language of stability: yikes

IEEE Stability Classification Hierarchy



Source: Hatziargyriou et al. (2021).

The timeframes of dynamics and stability

- From micro-seconds to hours!
- Most integrated planning questions are off this chart to the right ... i.e. much slower

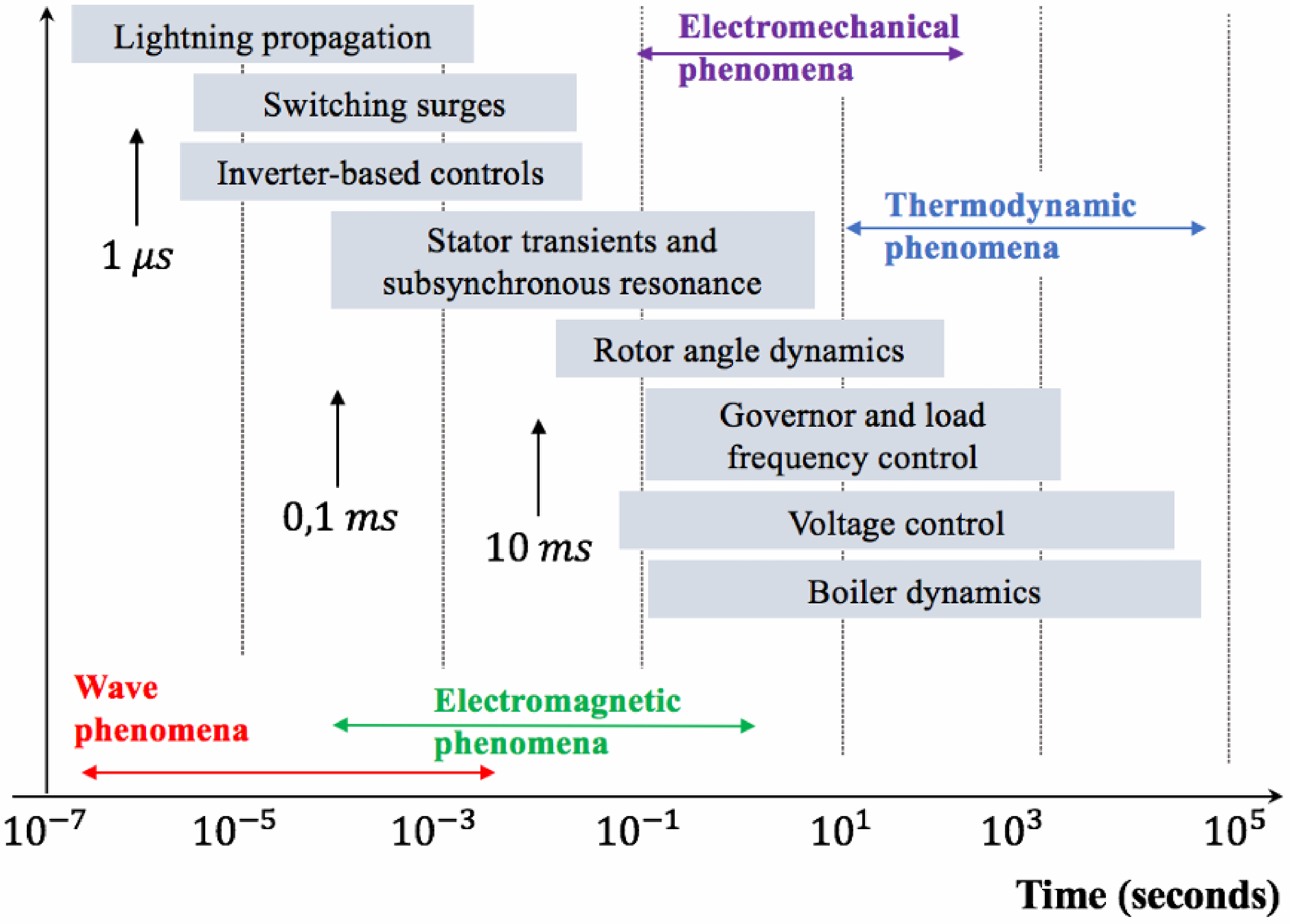


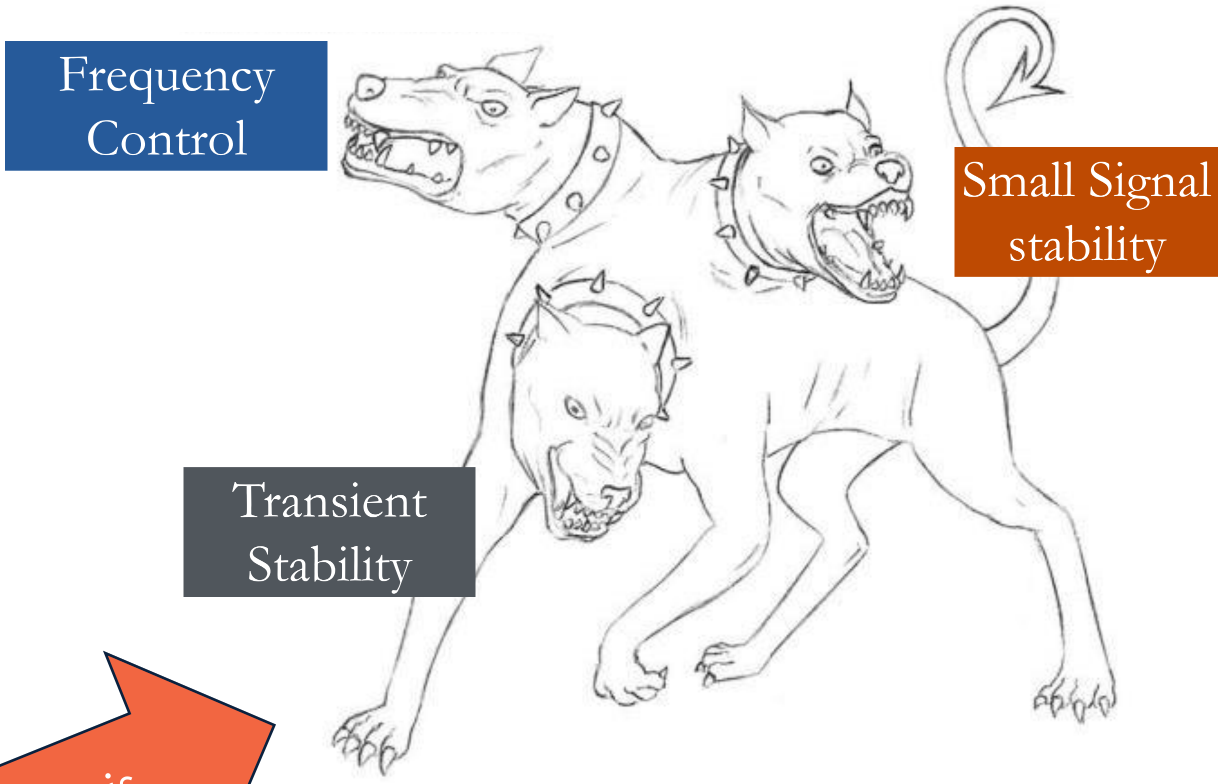
Fig. 1. Power system times scales [3].

Stability has multiple faces, but it's the same beast

- Today, we'll reduce the complexity a little, by focusing on 3 types of stability constraints (all of which must be satisfied)
- Degree to which each type is constraining varies with each system

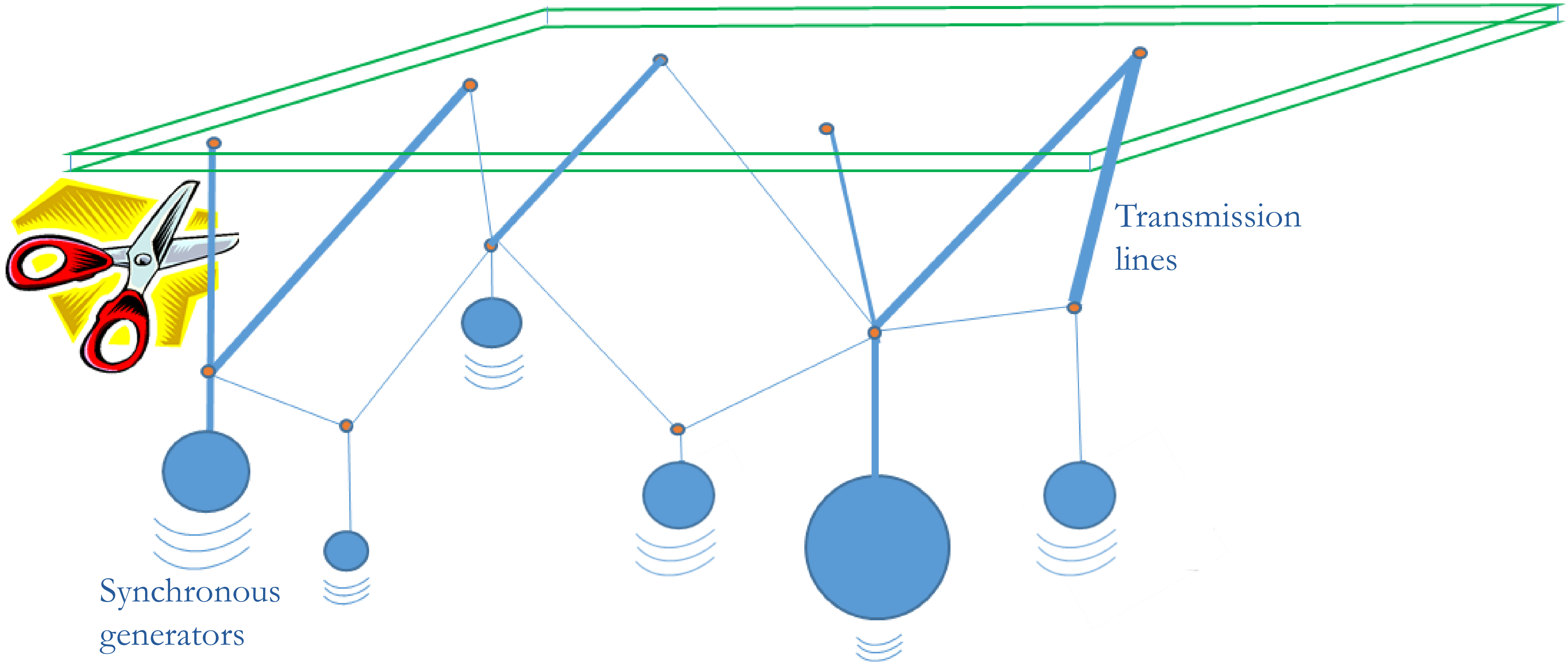
Not this

This



Dog Image Source: Drawingforall.net

Transient stability analogy



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Source: NREL/GE WWSIS 3a

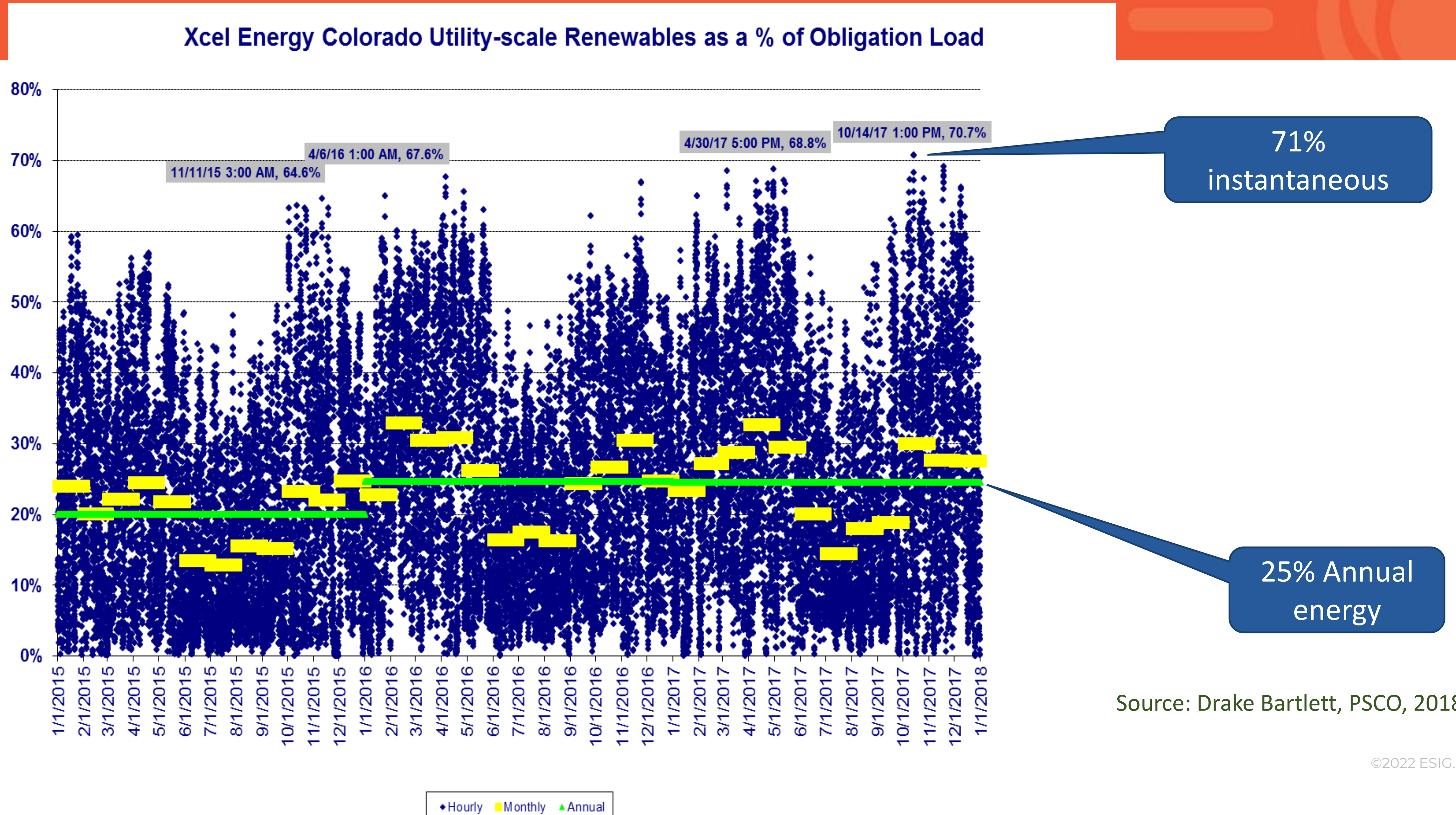
Derived from original figure by Elgerd

Moving to system dominated by inverter-based resources

Conventional synchronous resources

Inverter-based resources (IBR)

Moderate annual averages translate to high instantaneous penetrations



Source: Drake Bartlett, PSCO, 2018

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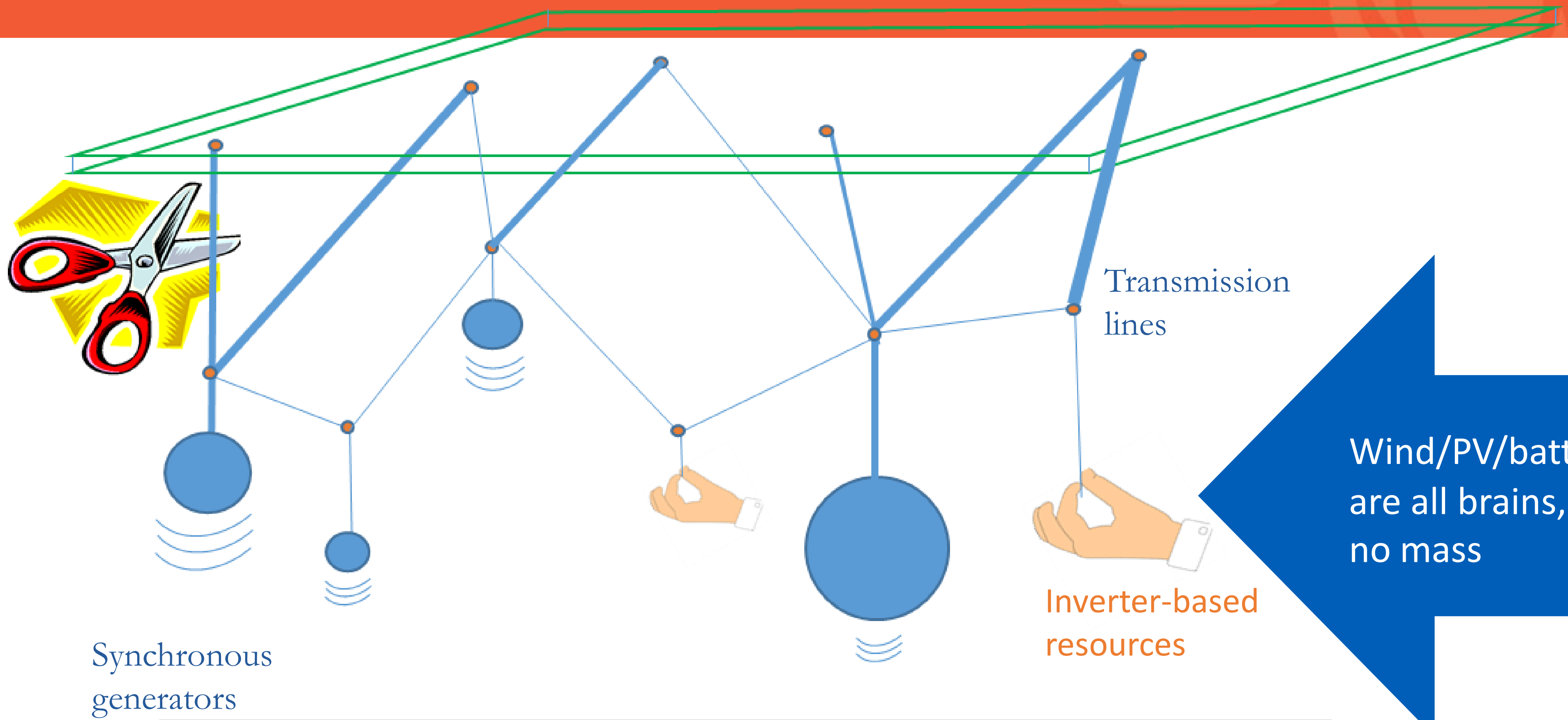
Inverter-based resources impact stability differently



Wind/PV/batteries are all brains, and no mass

Life gets “interesting” somewhere around 75% IBR instantaneous penetration

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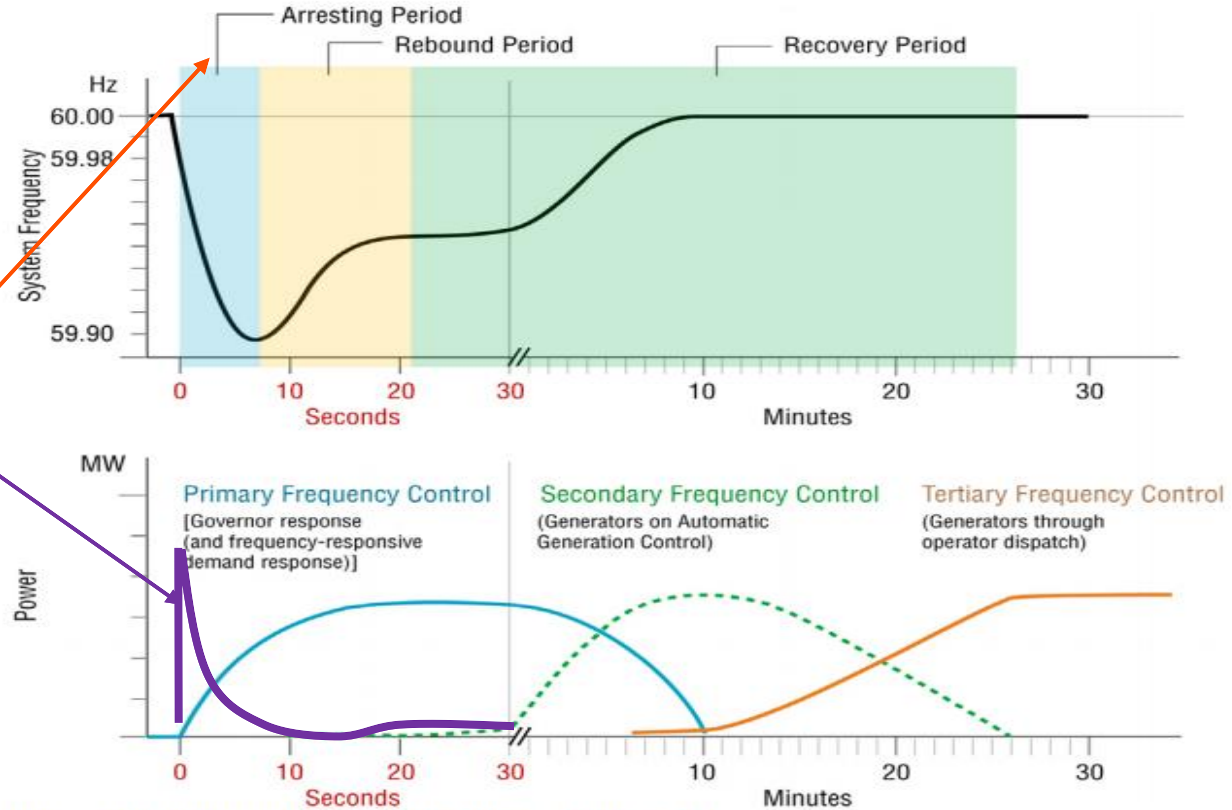
Source: Miller - NREL/GE WWSIS 3a; Derived from original figure by Elgerd

Frequency Control

- 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.
- I've 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 service must act, as shown.

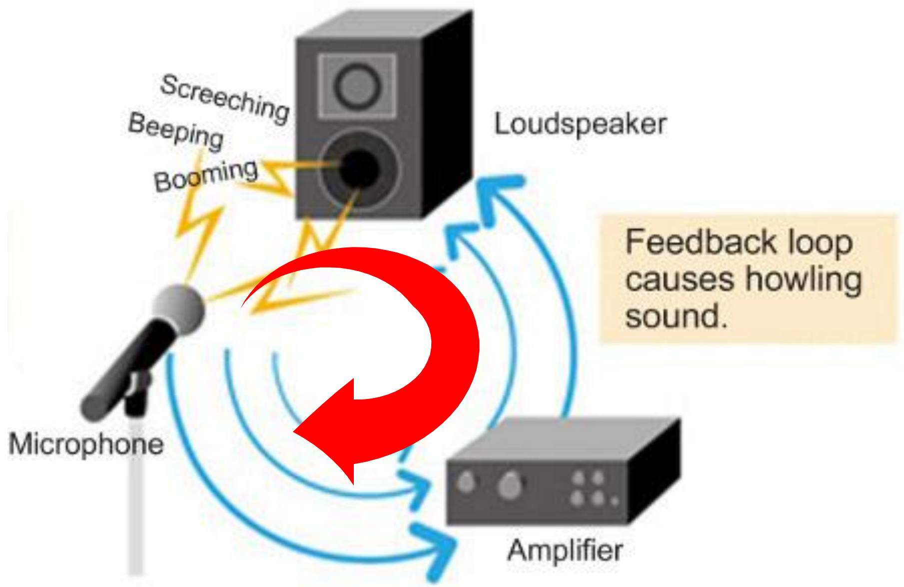


Note: Load-damping is not shown on this figure. See Footnote 31.

Courtesy 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

Small-signal Instability (aka "Oscillations")

- IBRs are incredibly agile, and can react VERY fast.
- There's an ugly side that requires great care....



Making the control too aggressive (e.g. turning up the volume) can be very BAD!

Image source: Rentics

Small signal stability in everyday life

Tacoma Narrow Bridge Collapse Nov 7, 1940

- Common theme: you're not in trouble, until you're in trouble

Parts of Tony C YouTube video Dec 9, 2006: https://youtu.be/j-zczJXSxnw

Slide from WIEB/CREPC Oct 2019

Why should you care about this?

- Inverter-based resources (IBRs) create different challenges and opportunities
  - Some instabilities today are different than the “traditional” ones
  - Interaction between many inverters adds huge complexity. Big rating devices are of particular concern.
  - Possible grid topologies/configurations are more complex, varied
  - **Good decisions, ones that impact the economics and reliability of the system, are predicated on satisfactory stability**
- The sky is NOT falling. But we need to do the studies and conduct good planning.
  - We are going to look at some practical considerations next

Thanks

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