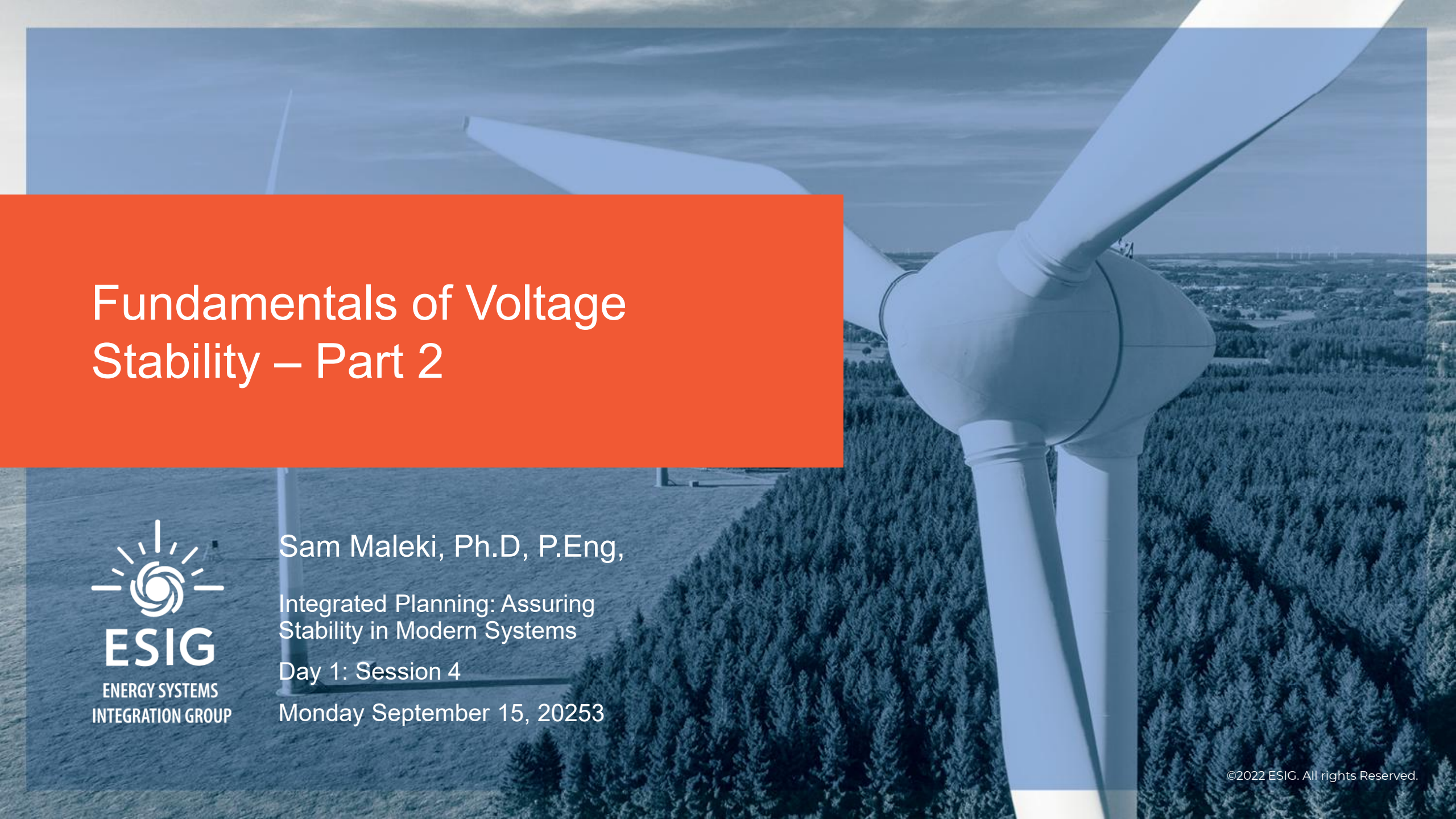
Fundamentals of Voltage Stability – Part 2



Sam Maleki, Ph.D, P.Eng,

Integrated Planning: Assuring Stability in Modern Systems

Day 1: Session 4

Monday September 15, 20253

ESIG
ENERGY SYSTEMS INTEGRATION GROUP

Sam Maleki, Ph.D., P.Eng,

ESIG

- Director and Co-Founder, Electromentors (Advanced Education)
- 15+ years experience with focus on the system wide stability
- 100+ hours of advanced training materials
  - PSCAD, GFM, HVDC, Data_Centers, IBRs
  - First Data Center BootCamp in Canada!
  - Partial Discharge
  - Electromentors.com

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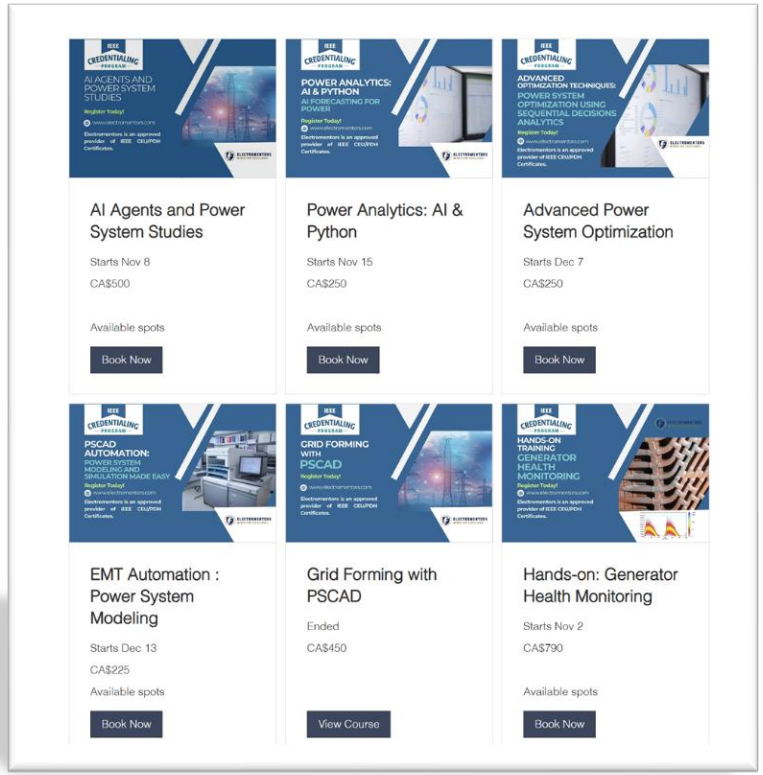


outline

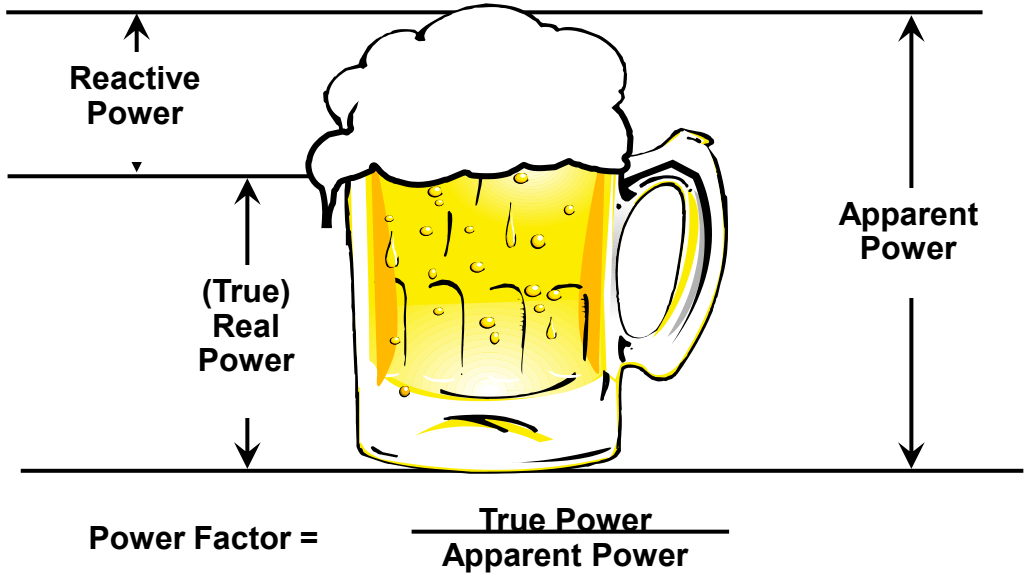
- **Fundamentals**
  - Normal people don't think about VARs (but Iberia shows how important it is. So pay attention!)
  - NERC list-o-blackouts: **voltage dominates**
  - Conditions that create risks; Rules and risks
    - Under excitation and stability
- **Limits on getting power from Region A to Region B. Not as simple as it sounds**
  - Thermal limits
    - shallow dive on weather, DLR, etc.
  - PV curve, related
    - QV, Power angle
  - Line capacity reservations
- **IBRs and Voltage support**
- **Large Loads and Data Centers**
  - Voltage support
  - Stability Concerns
  - Ancillary Services from Large Loads

Quick tutorial on reactive power

- “Normal” people don’t like to think about “imaginary” power:
  i.e “reactive” power, aka “Q”, aka “VARs”
- But, it is easy to understand that keeping the voltage within acceptable bounds is important
- “Acceptable” is complicated, but most of the time, it means about +/- 5% of “nominal”
- Let’s take a closer look....

Real vs reactive power

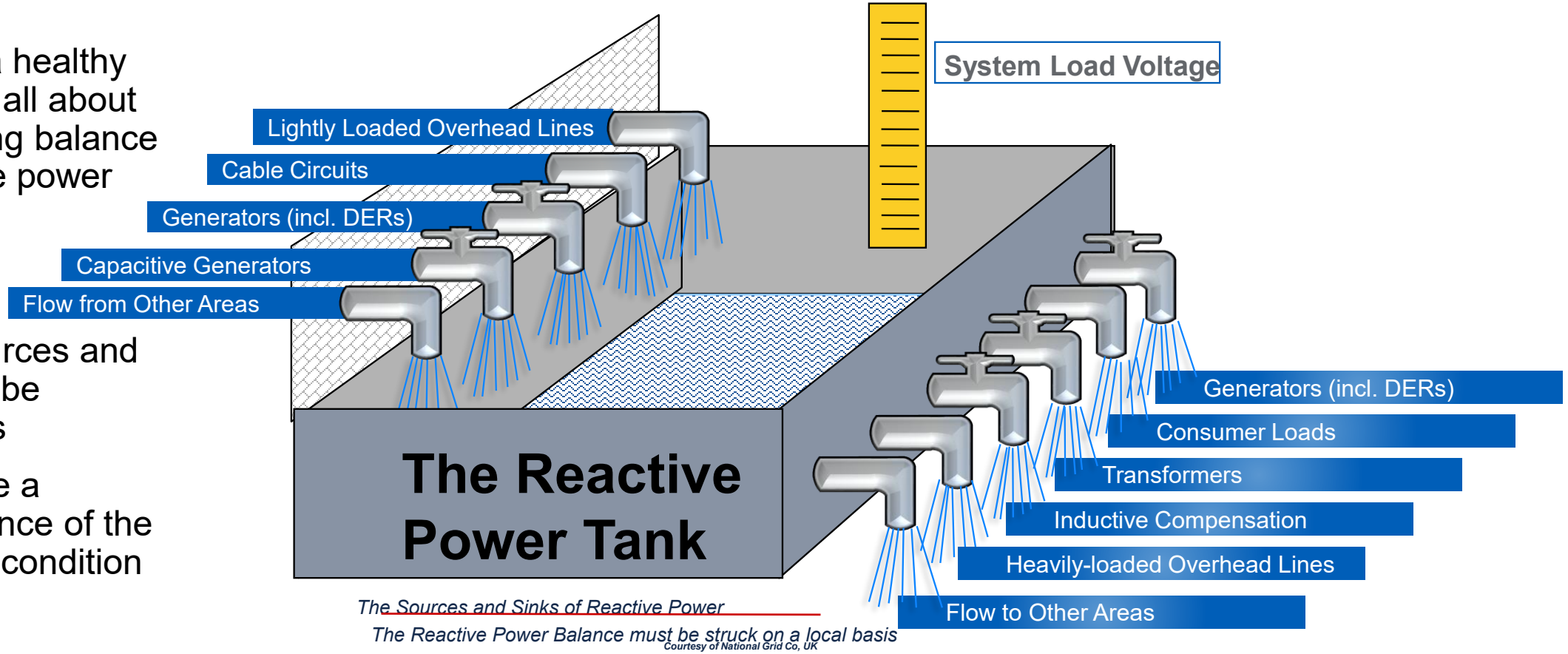
- **Real power**
  - **Voltage and current are in phase**
    - *Real power does work, like heat, light, motion*
    - *Real power is actual net energy from the generator to your light bulb*
  - **Measured in Watts**



- **Reactive power**
  - **An AC power phenomenon**
  - **Voltage and current are out of phase**
    - *Reactive power doesn't do work – it sustains the electromagnetic field*
    - *Makes voltage transformation possible*
    - *Reactive power has a current but no net energy reaches the load*
    - *Wires must be properly sized for this reactive current*
  - **Measured in VARs**

Reactive Power – Voltage Control

- Keeping a healthy voltage is all about maintaining balance of reactive power
- Some sources and sinks can be controllers
- Others are a consequence of the operating condition



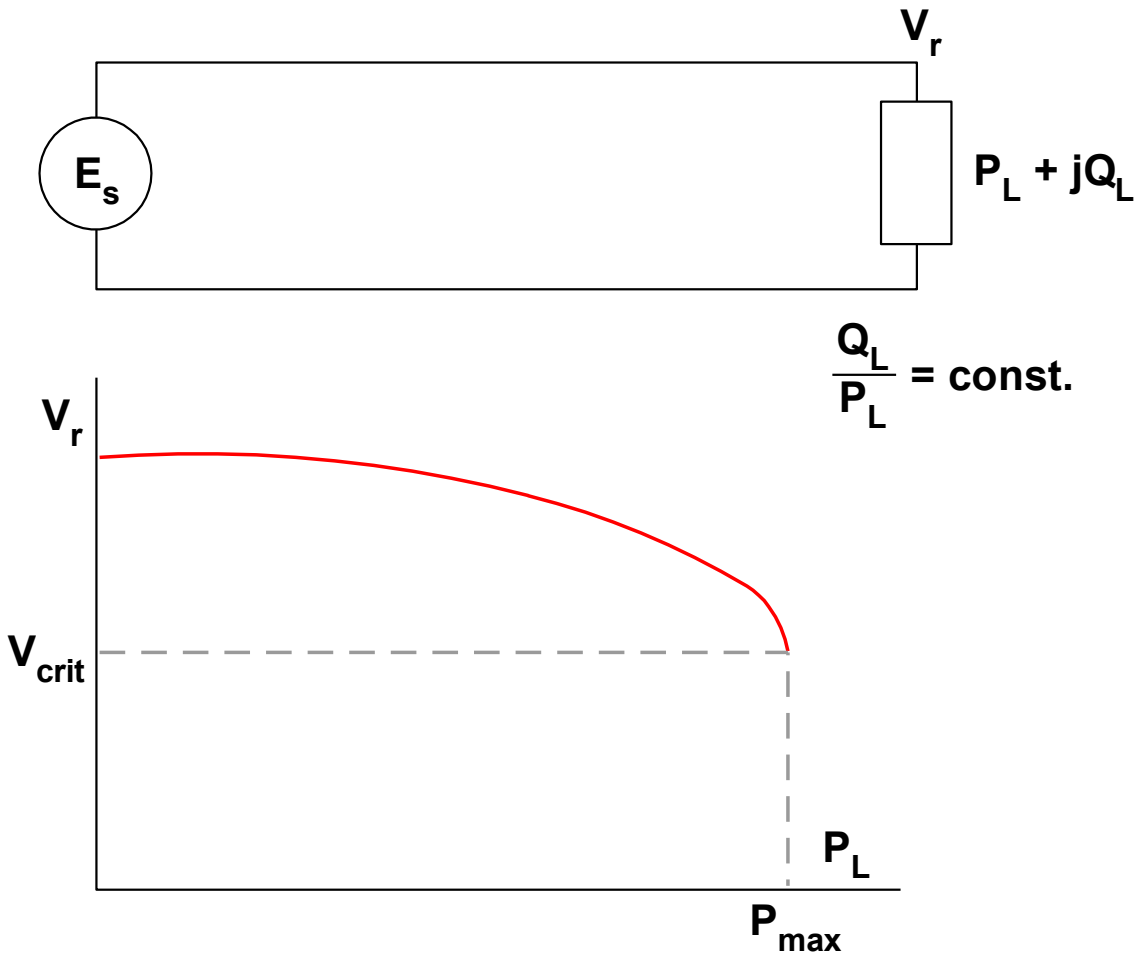
Graphic: J. MacDowell, GE Energy Consulting, 2018

Location, location, location

- Keeping voltage healthy everywhere is critical
  - Where power is generated
  - Where power is consumed
  - In between
  - Voltage control is a local worry:
- **Mitigation of problems needs to be nearby**
- Location, location, location!
- Different resources provide control (per the Q tank)
  - Traditionally most Q control came from synchronous generators and grid connected devices (like capacitors)
  - IBRs (wind, PV, batteries, DERs) can provide voltage reliability services (even when they aren't generating MW) ... Remember Nick's comments about the Iberian Blackout

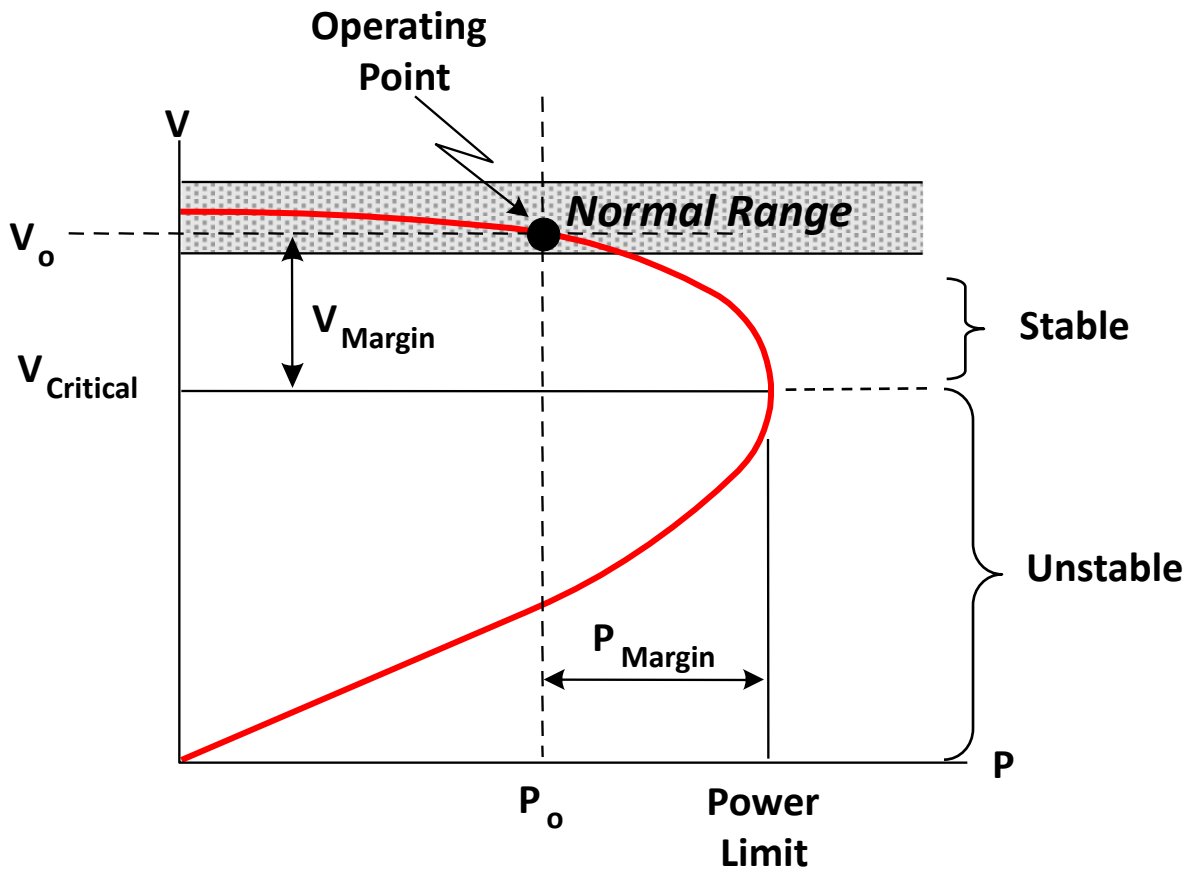
Basics of Voltage Stability

- Send power from “strong” source (s)
- Thru “the grid”
- To receiving (r) end (L – the load)
- The more power sent, the more the voltage sags
- There’s a limit



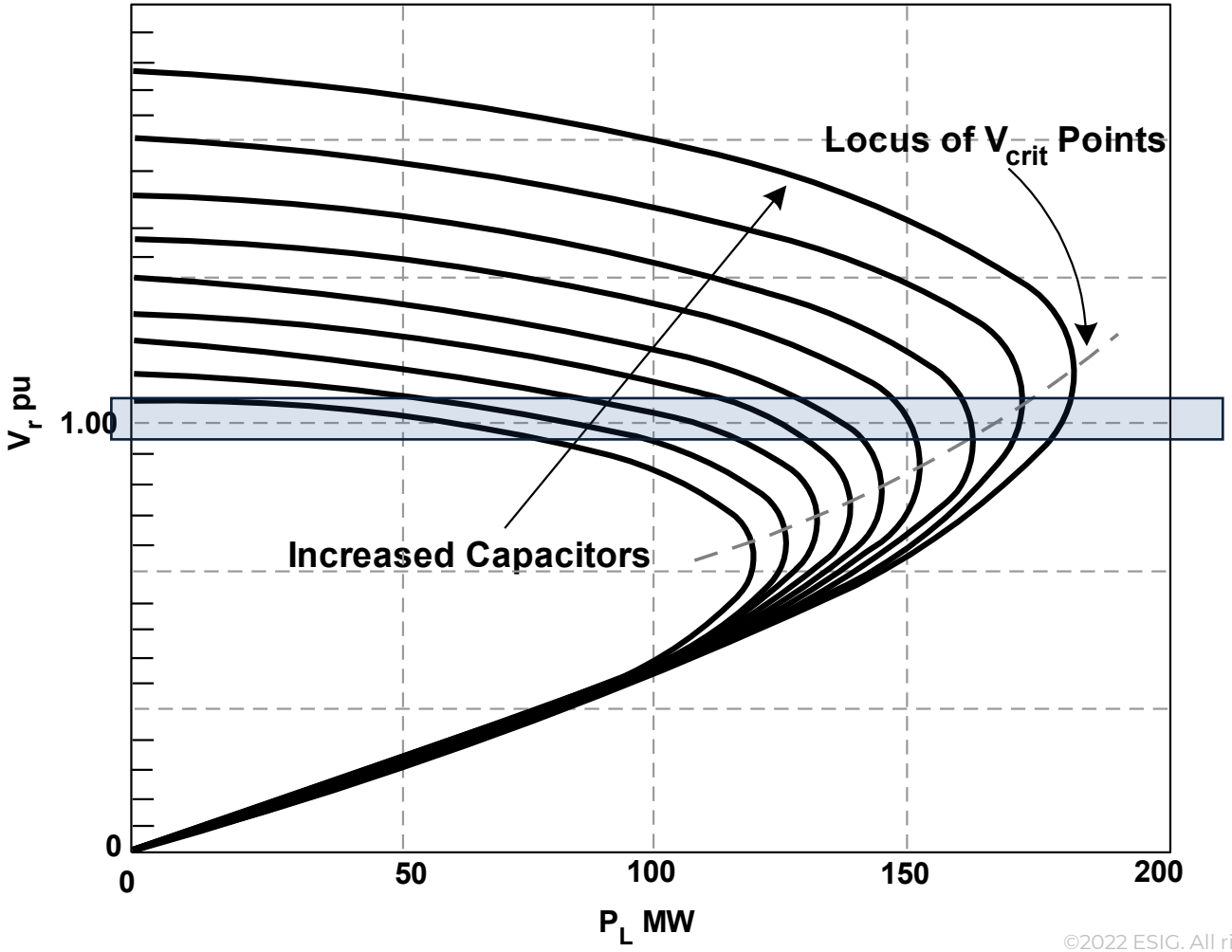
Classical Power Limit: The PV Curve

- Stay away from the end of the "nose"
- OK....but,
- Economics often drive the desire to transfer more power....i.e. to approach the nose.
- Keeping the voltage with "normal" range as more power is transferred is complicated

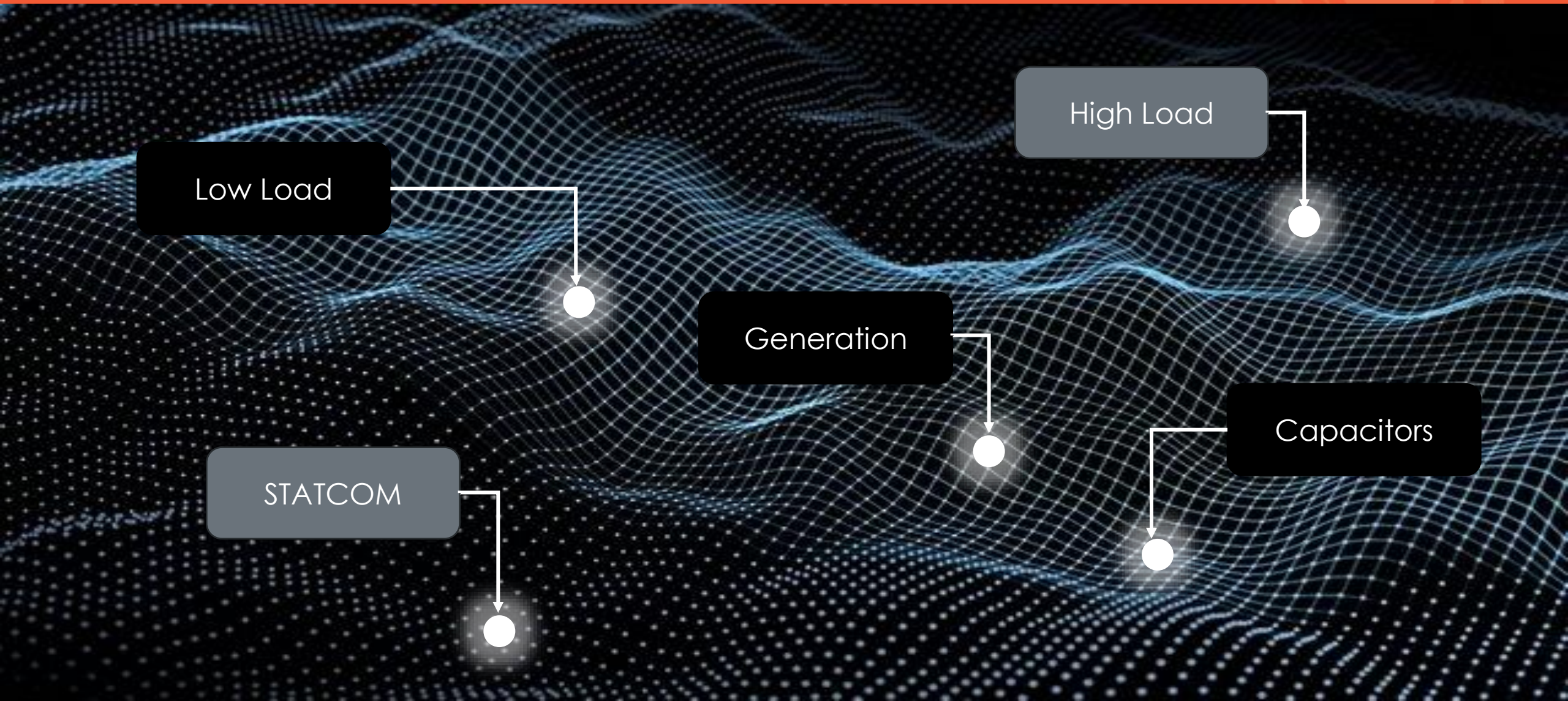


Grid connected devices increase transfer capability…and add risk

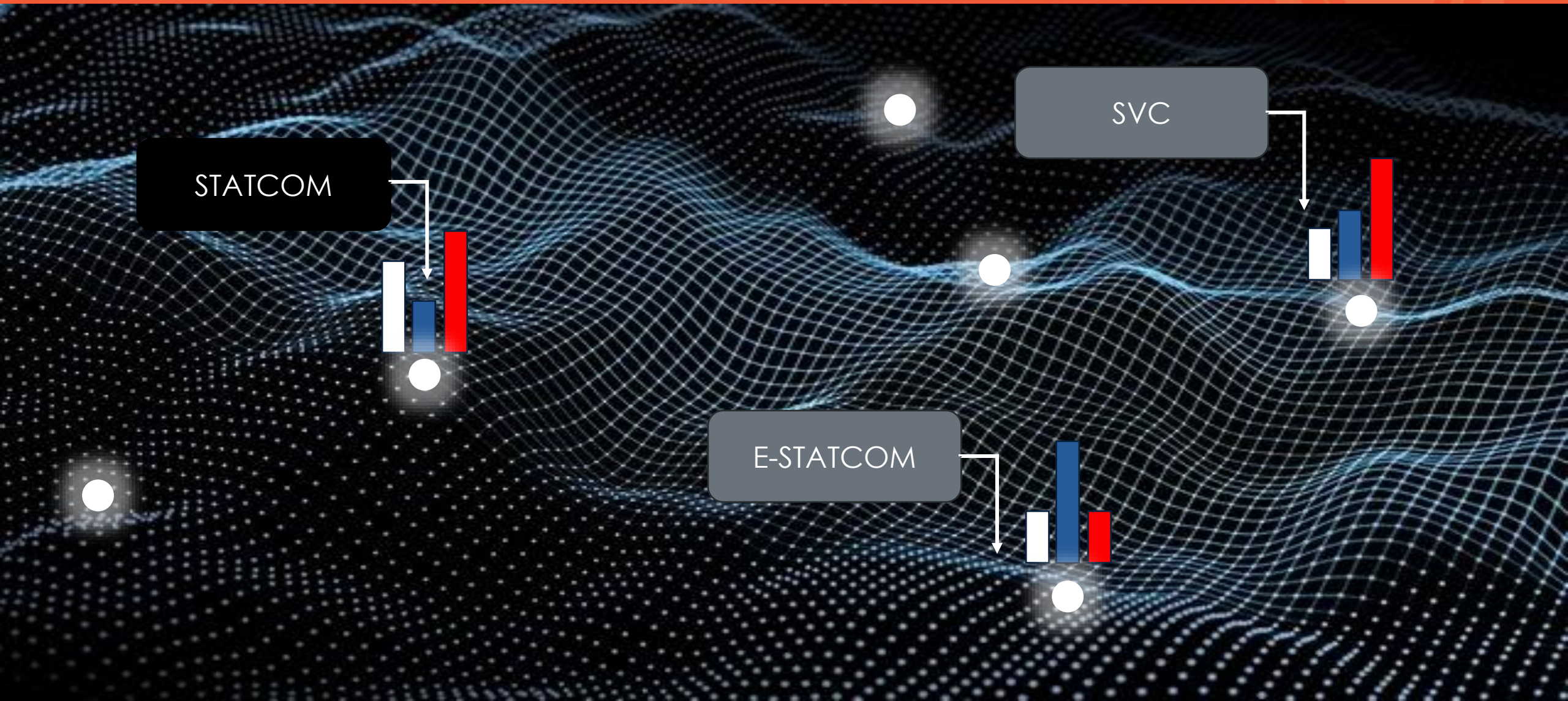
- Add capacitors, increase the maximum
- Get closer to the “brink”
- There’s a whole body of expertise around how get more power but stay “safe”



More Complicated than it looks in 2D



Small Signal Analysis (Location, Location, Location)

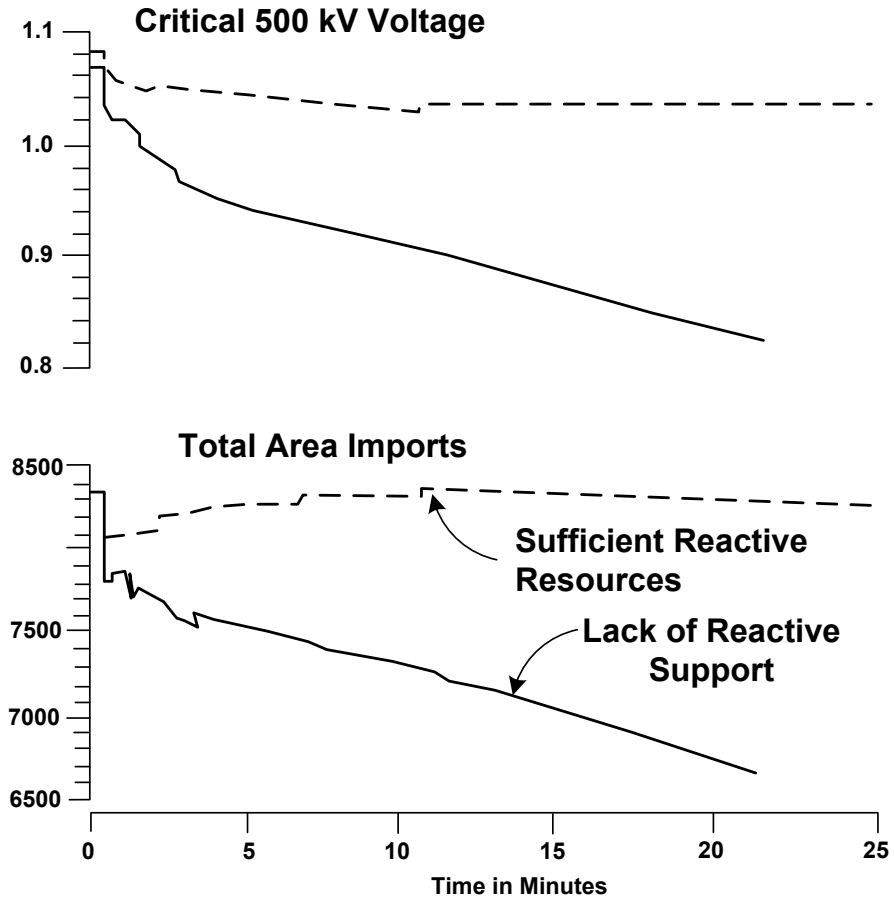


Voltage failures come in different time frames

- Slow Voltage Collapse
  - Driven by slow-acting equipment such as transformers and generator (OEL) protection
- Fast Voltage Collapse
  - Driven by load response to fault/weakened system conditions
- System Separation
  - Weak system connecting two strong systems
  - Disturbance causes strong systems to separate, resulting in voltage collapse in center (We'll talk about this more under frequency)

An example of slow voltage collapse

- Study of the US Northwest
- A failure (solid line) and a solution (dotted line)
- Note this is a collapse ... The voltage dropped and the power dropped
- “We” worry a lot about this.
- But, in Spain, the voltage went uncontrollably HIGH...
- “We” worry a lot less about that risk...



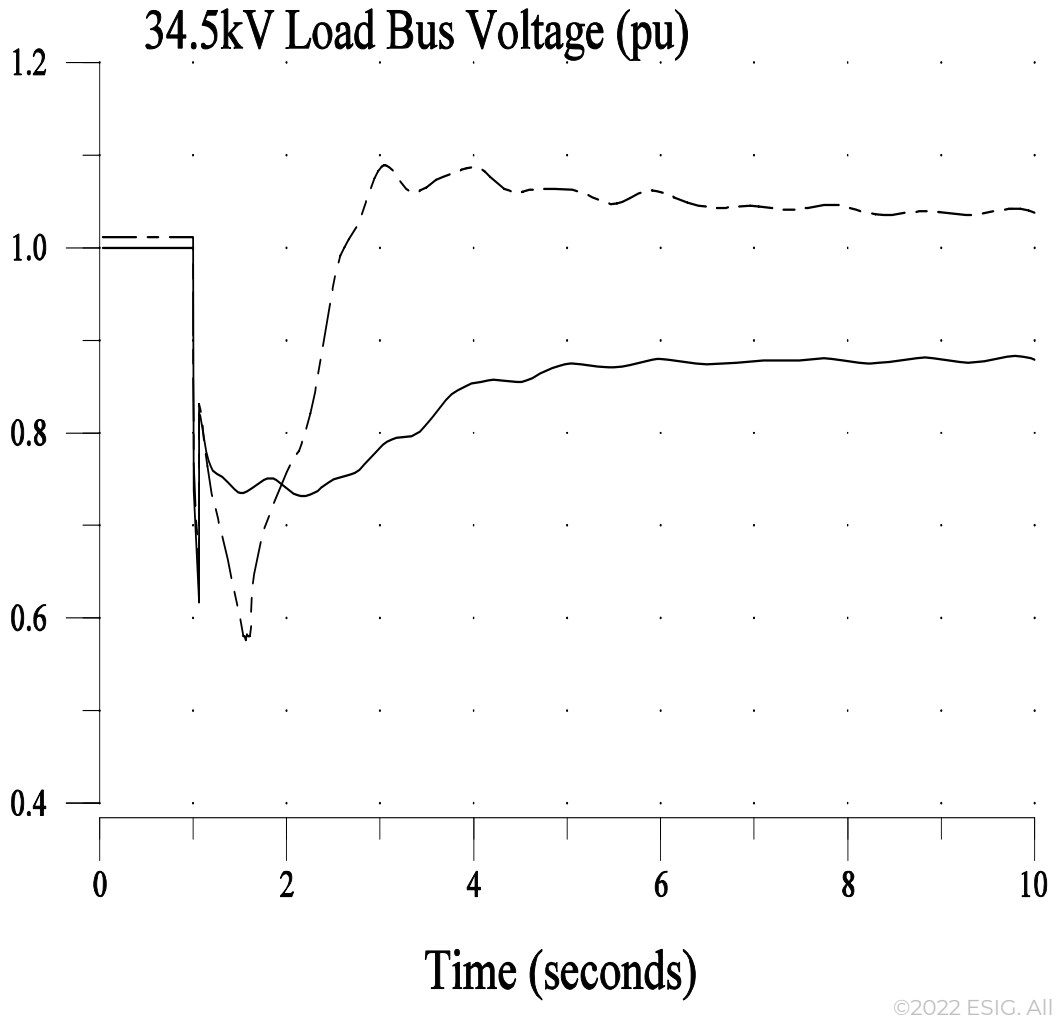
Example From System Simulation

Source:
Voltage Stability of the
Puget Sound System
Under Abnormally
Cold Weather Conditions

N.W. Miller – GE
R. D’Aquila – GE
K.M. Jimma – Puget Sound Power & Light
M.T. Sheehan – Puget Sound Power & Light
G.L. Comegys – Bonneville Power Administration

Fast Voltage Collapse

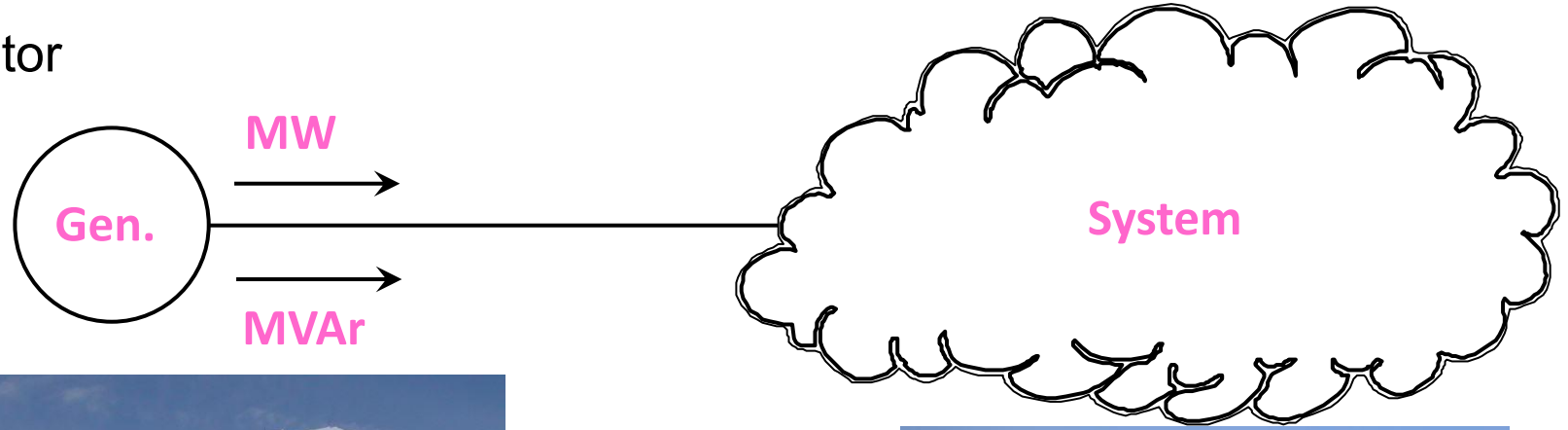
- A fast drop in voltage (10s of cycles to a few seconds) following a system fault
- Dynamic response of loads can delay or prevent voltage recovery – Induction Motors
- Failure of IBRs to “ride-through” can cause either low or high voltage
- Big loads are a risk: Uncontrolled loss-of-load can lead to high voltage condition



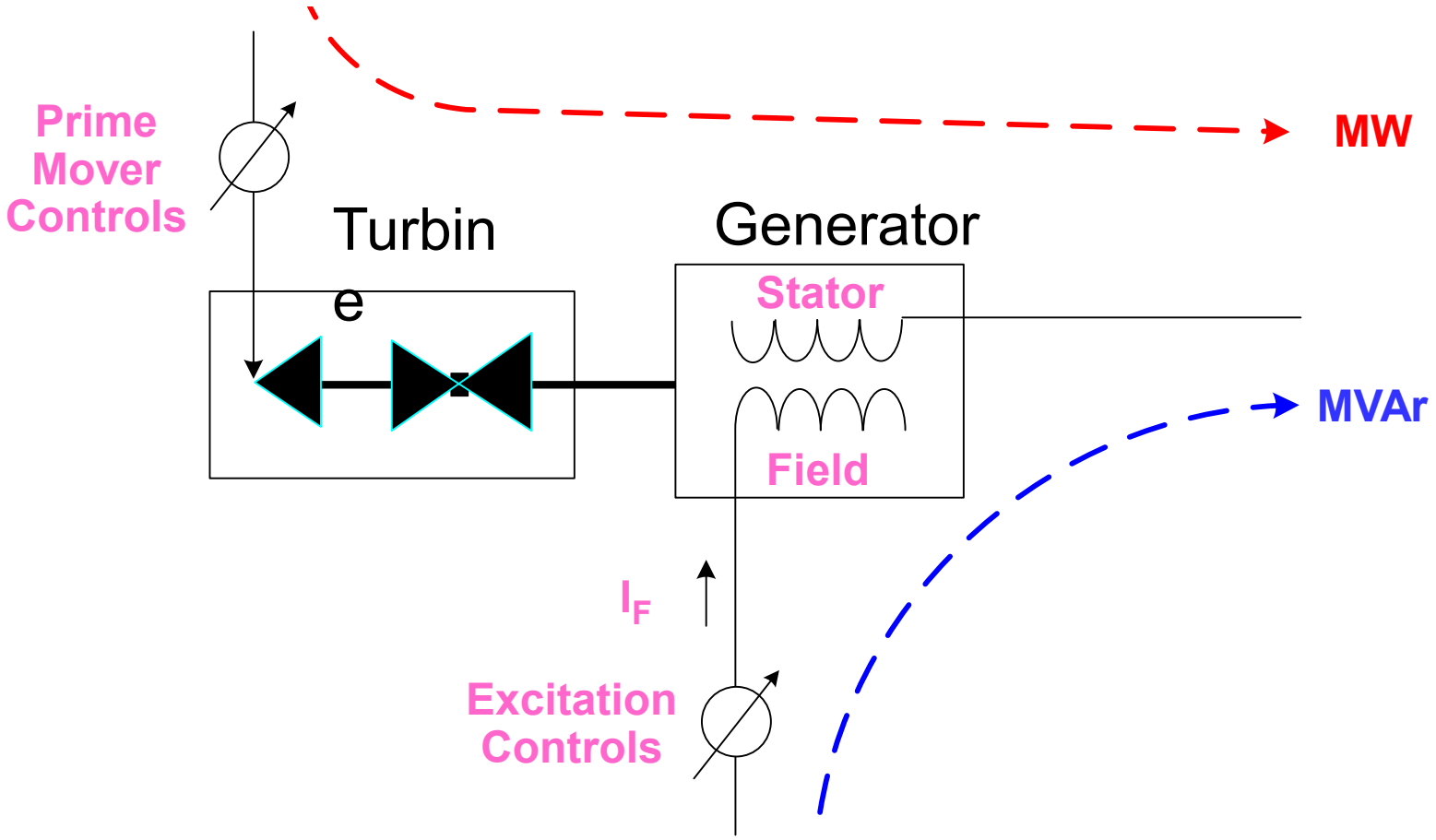
Synchronous Machines and Reactive Power (and a look at the Iberian blackout)

Two important commodities produced by a turbine-generator unit:

- Active Power (“P” MW)
- Reactive Power (“Q” MVAr)

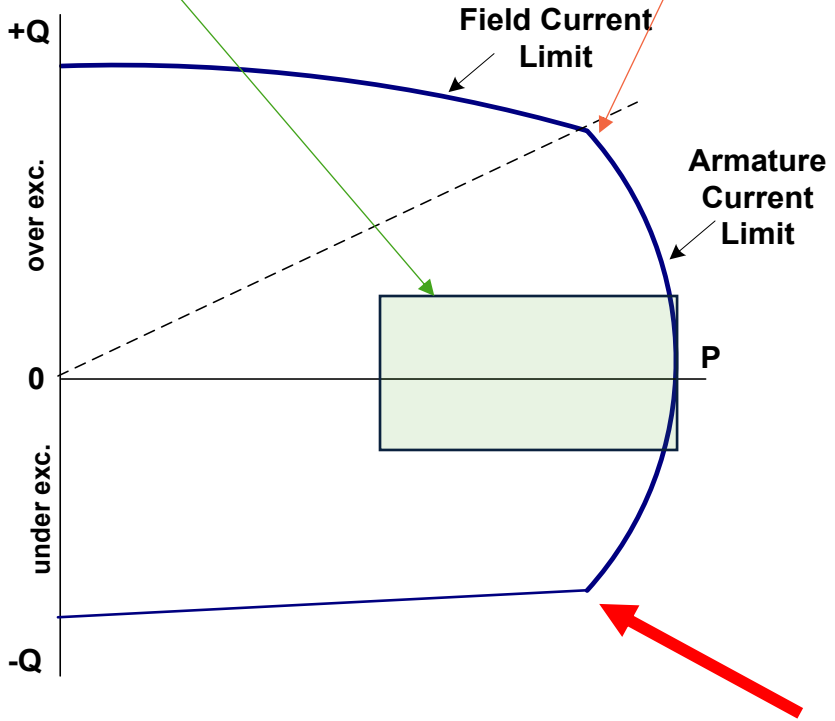


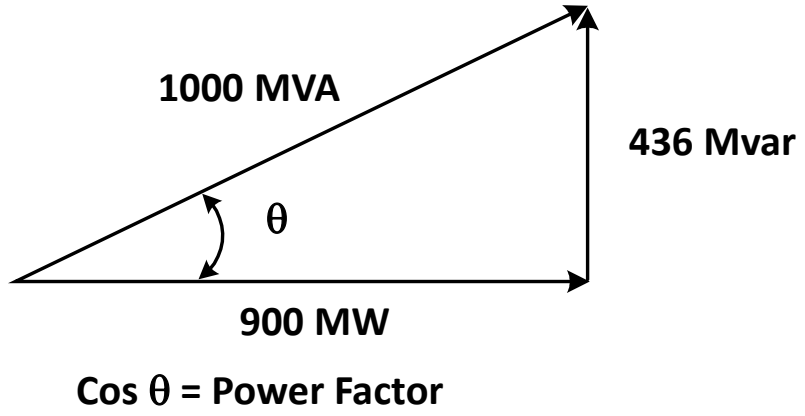
The reactive power generated is largely determined by the field current



The field has limits, high and low

- "normal" is a pretty narrow range
- "we" often worry about high = "over" excited limits

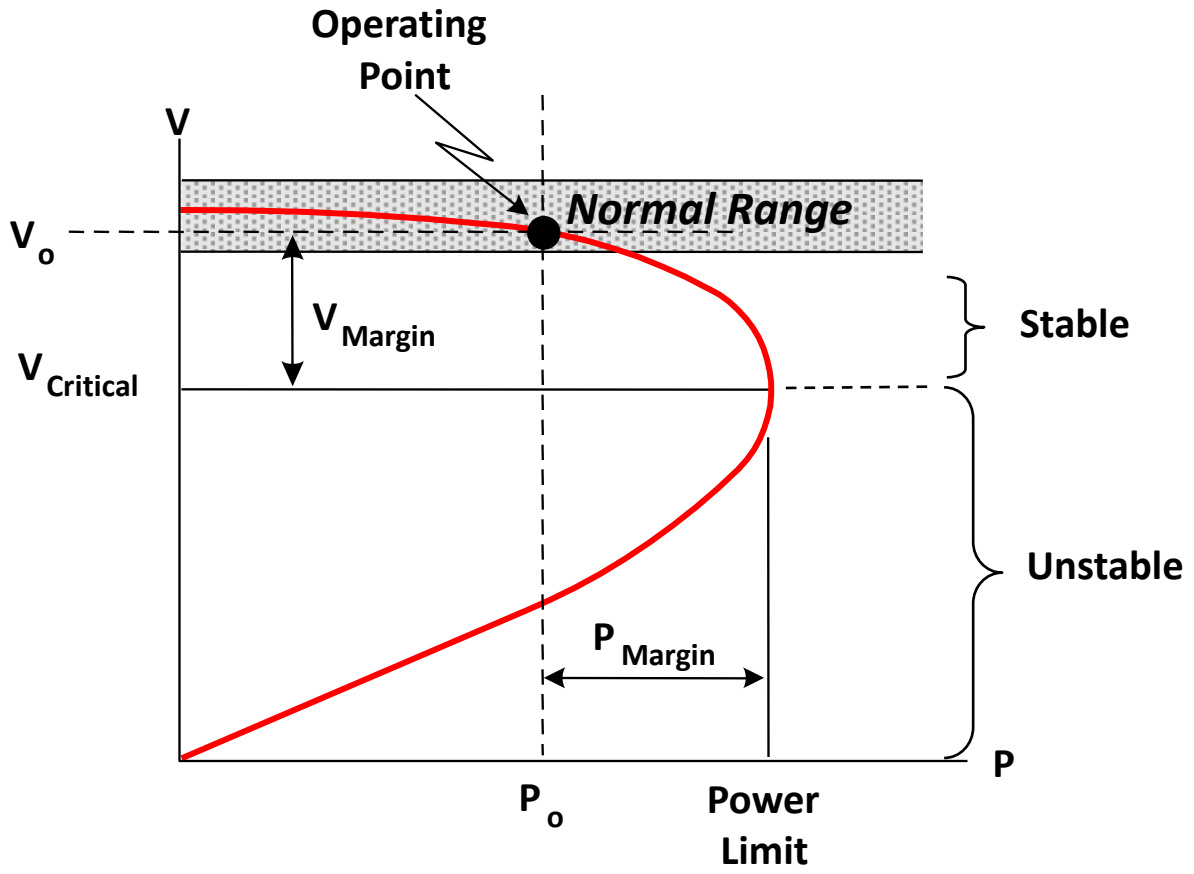




- But the Iberian blackout involved low "under"...where the synchronous machines are less stable

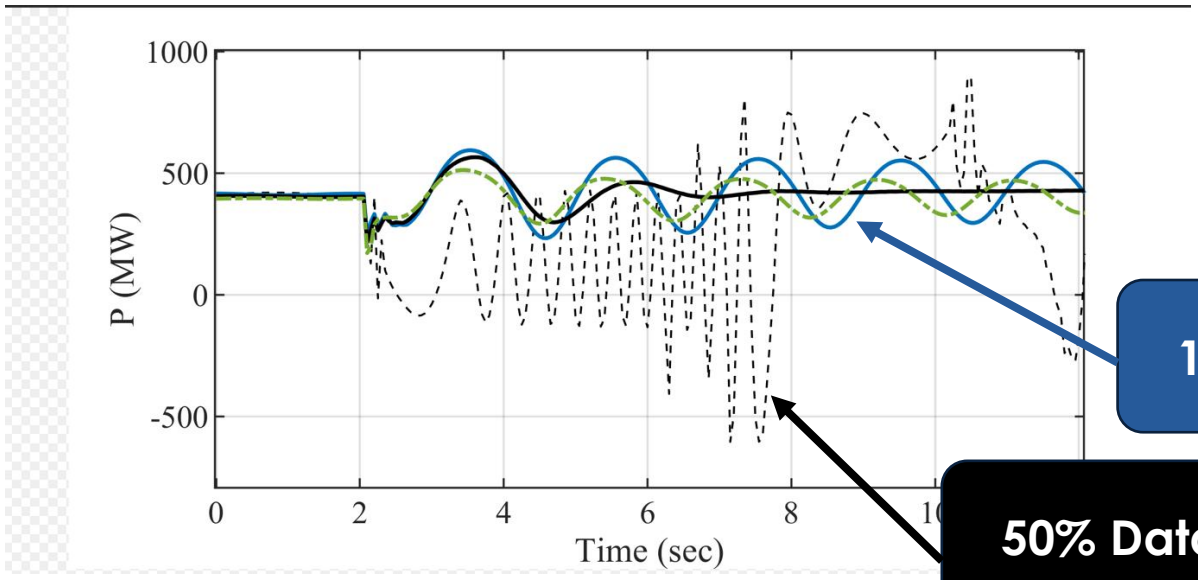
Large Loads (Data Centers)

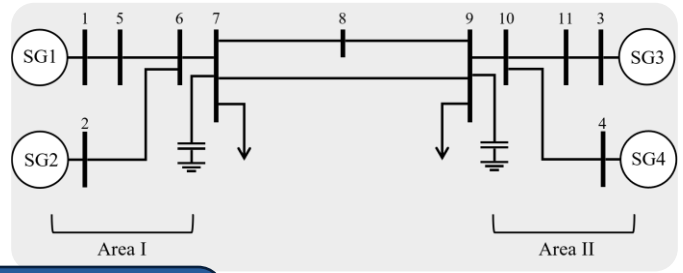
1GW+
Toronto Power Demand ~5 GW



Large Loads and Voltage Control

Active **voltage control** at the load side can have a **drastic results on the stability**!
With Hyper Scalers, it basically **shift the stability perspective from Generators to loads!**





10% Data Center

50% Data Center

Conventional Loads

10% Data Center Load

50% Data Center Load

Voltage Stability synopsis:

Voltage Stability is:

- Threatened by severely stressed networks.
- Preserved by strategic var reserve policies.
  - Traditionally concerns about having enough to keep voltage “up” to acceptable levels has been the main focus
  - Iberia and other events increase the need to focus on having enough to keep voltage “down” to acceptable levels
- Everybody’s concern – planners, operators and policy makers.
- Location, Location, Location! Each point has its own characteristic and needs!
  - Small Signal Analysis
- Large Load can help, we just need to ask the right question
  - The can even help in stabling the system but we need incentives

Thanks

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