Transmission ITP

System Stability

PJM State & Member Training Dept.

Objectives

Students will be able to:

- Define:
  - Stable operations
  - Instability
  - Steady State Stability
  - Dynamic Stability
  - Transient Stability
- Discuss the actions that may be taken by the System Operator that will impact the stability of the system
- Discuss how instability threatens the system

Stable Operation

- Generic:
  - Stability is the condition of equilibrium between opposing forces
- In the power system:
  - Mechanical Power = Electrical Power
- Following a disturbance:
  - Mechanical Power = Electrical Power + Acceleration Power
- Maximum amount of power that can be transferred without a loss of synchronism is defined as the power, or stability limit
  - Critical value of power transfer

Transmission System MW Flow and Power Angle

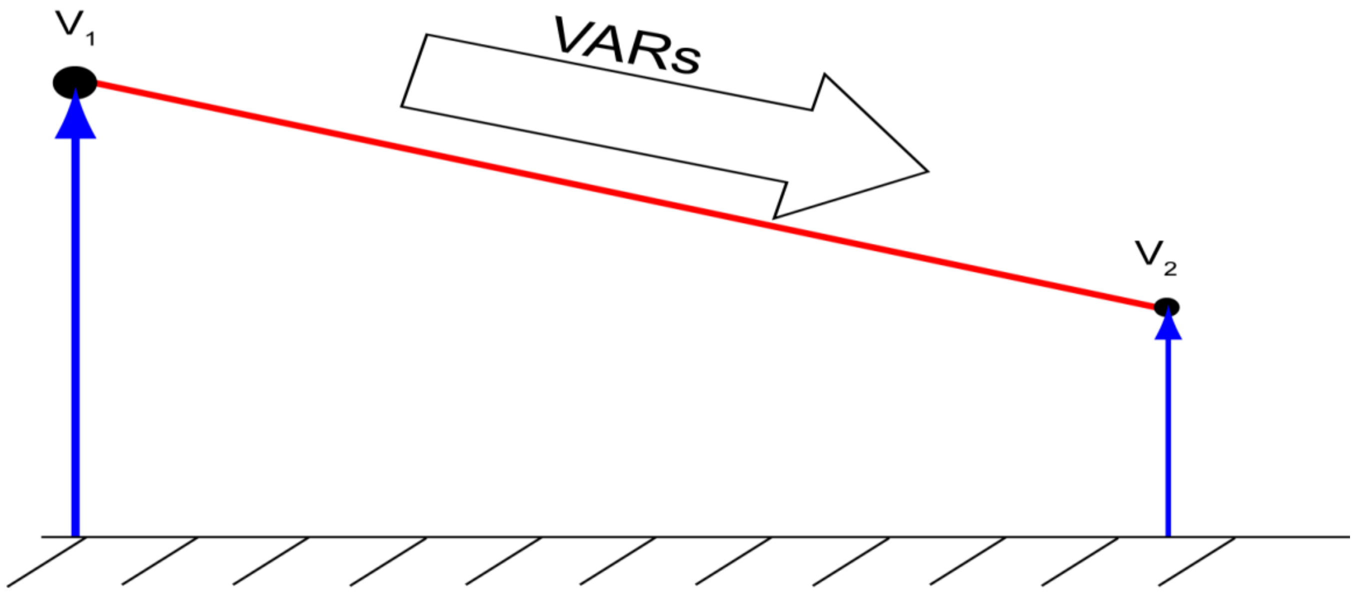
- Angular differences must exist between two buses in order for MW to flow
- If $\delta = 0$, then $P_{Transfer} = 0$
- δ is the driving force for MW flow
- δ can also indicate direction of MW flow
- MWs flow "downhill" with respect to δ **(to a point)**
- Restated: Buses with high δ flow MW towards buses with lower δ

(to a point)

MVAr Flow and Voltage

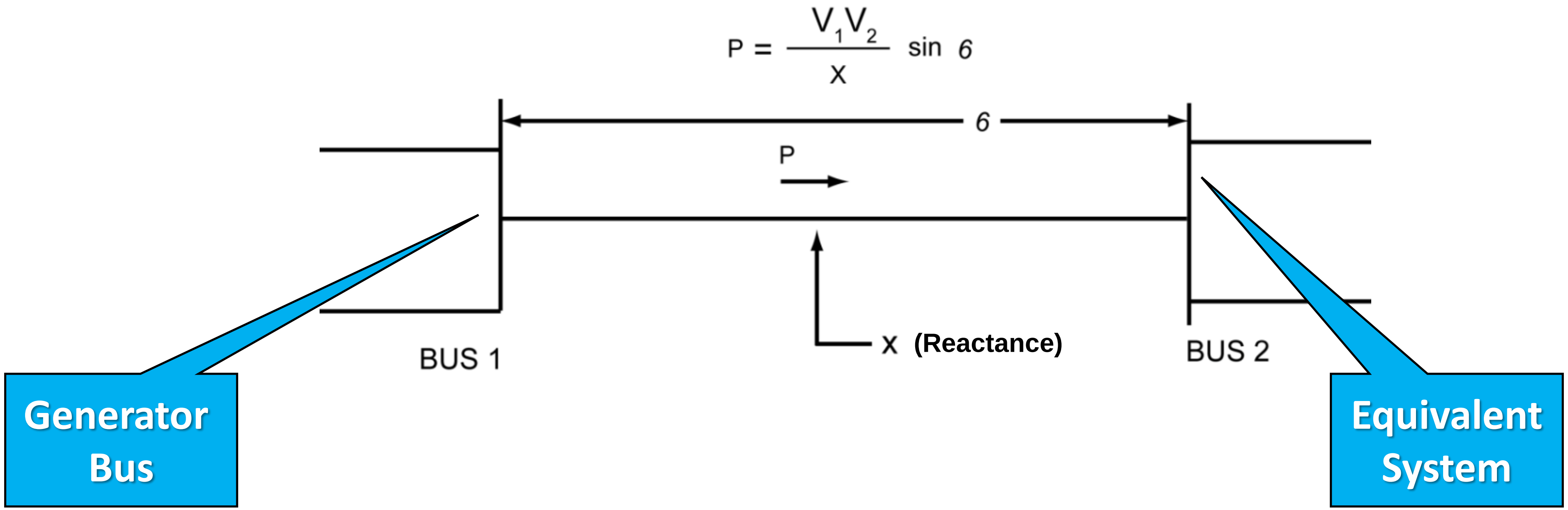
VAr / Voltage Relation

- MVArs flow "downhill" based on voltage
- Flow from high per unit voltage to low per unit voltage

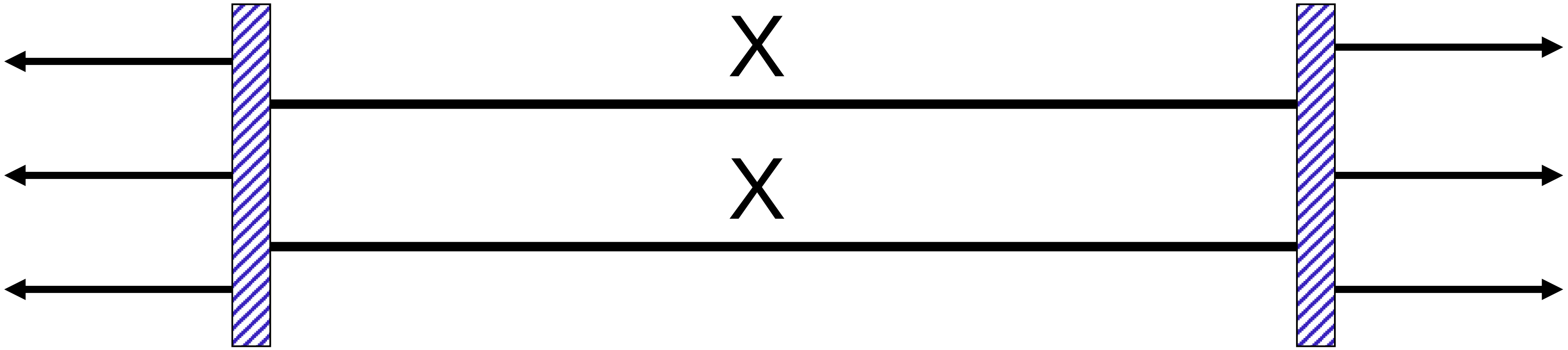


Power Transfer Capability

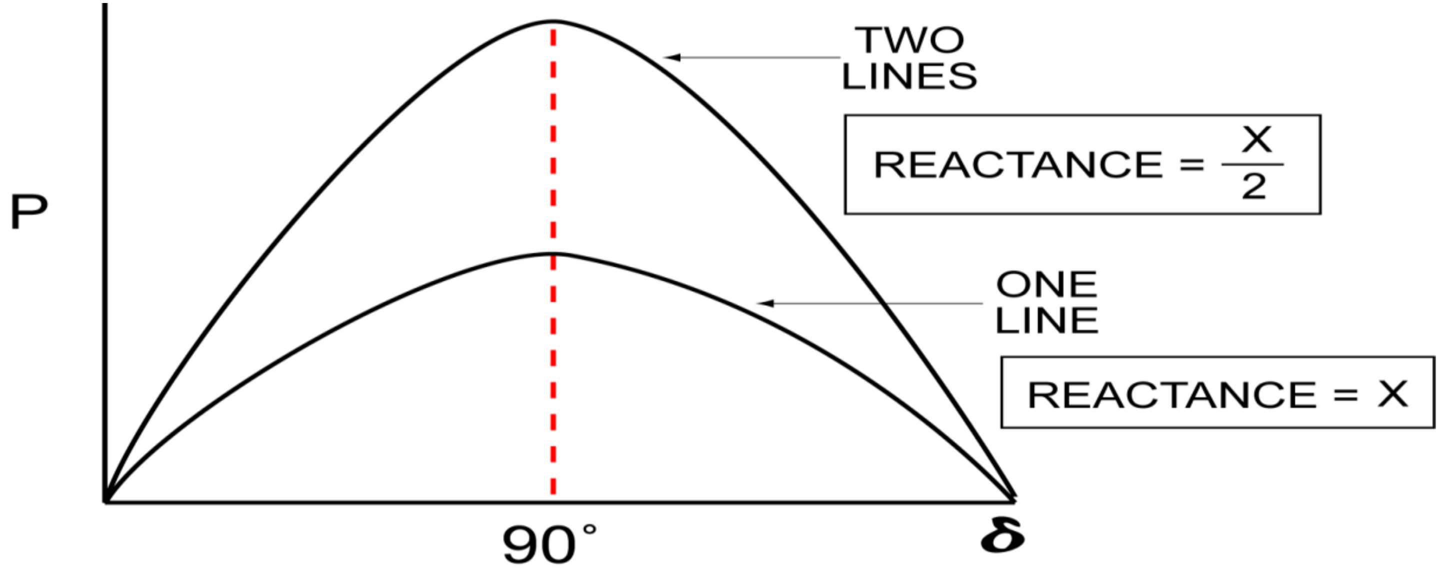
- MW flow between buses is determined by phase angle difference between voltages at the buses
- Phase angle difference between voltages is called Power Angle which is represented by the symbol δ



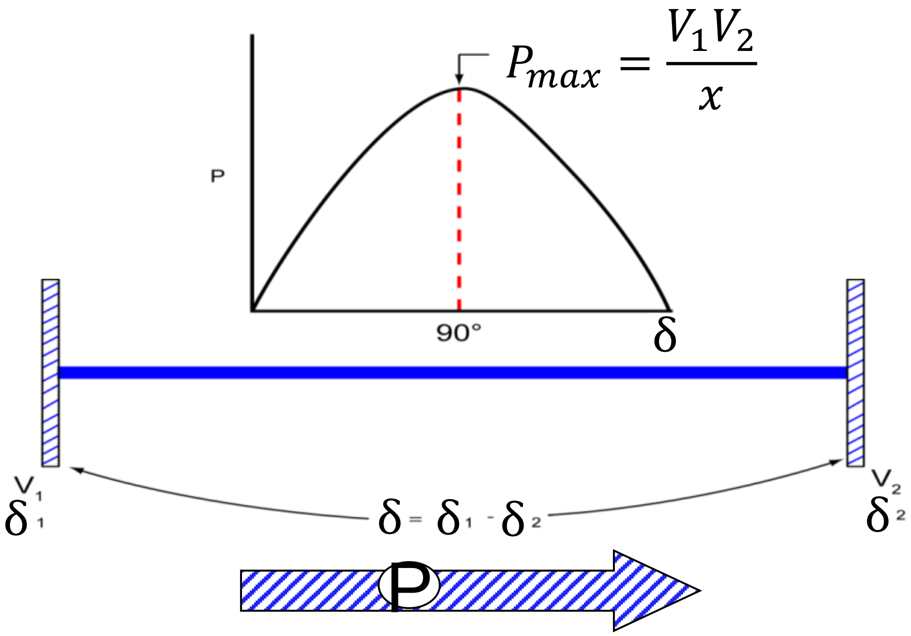
Calculating Reactance



$$P = \frac{V_1 V_2}{X} \sin 6$$

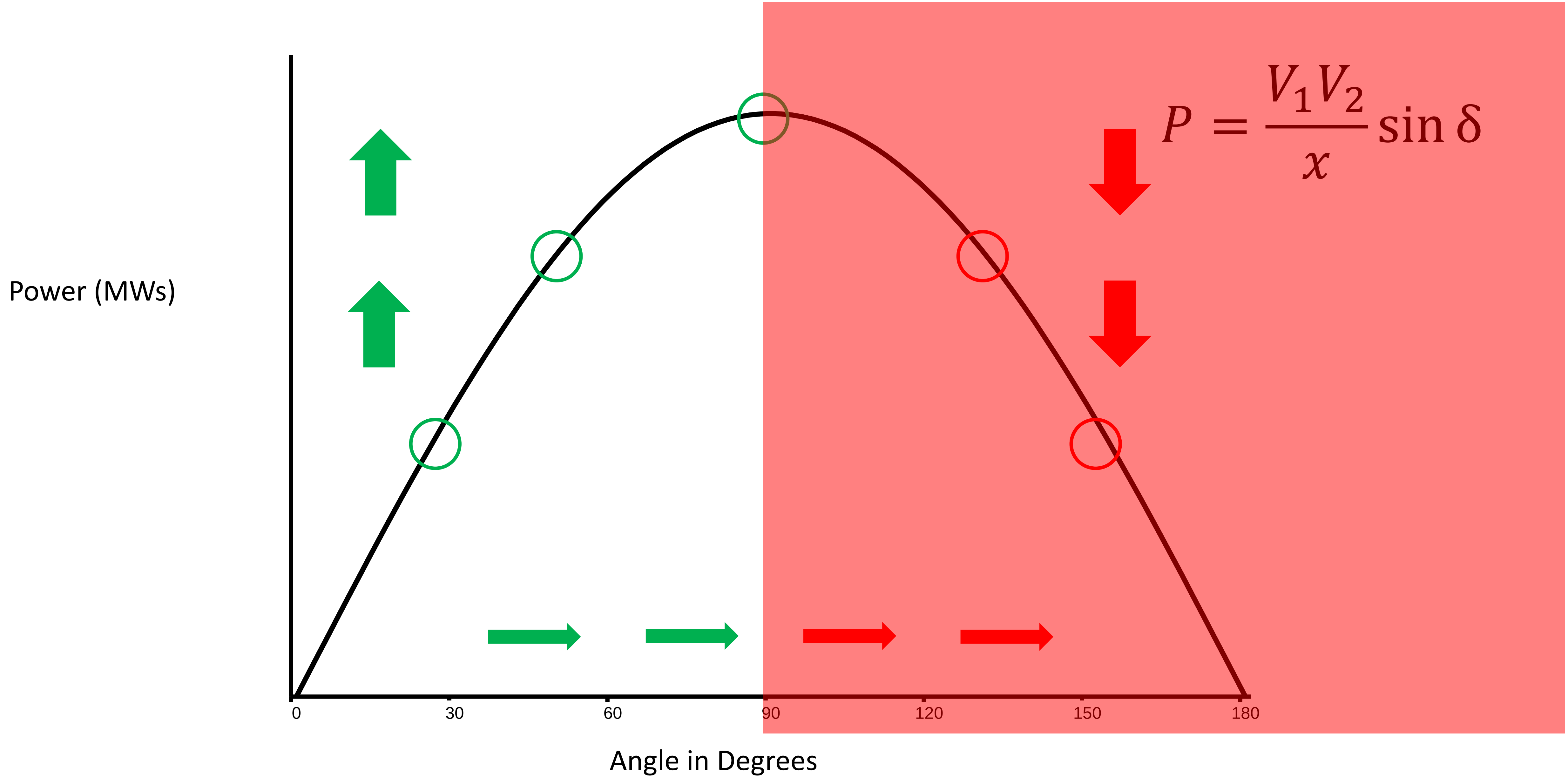


MW Flow, Power Angle and the Stability Limit



$$P = \frac{V_1 V_2}{x} \sin \delta$$

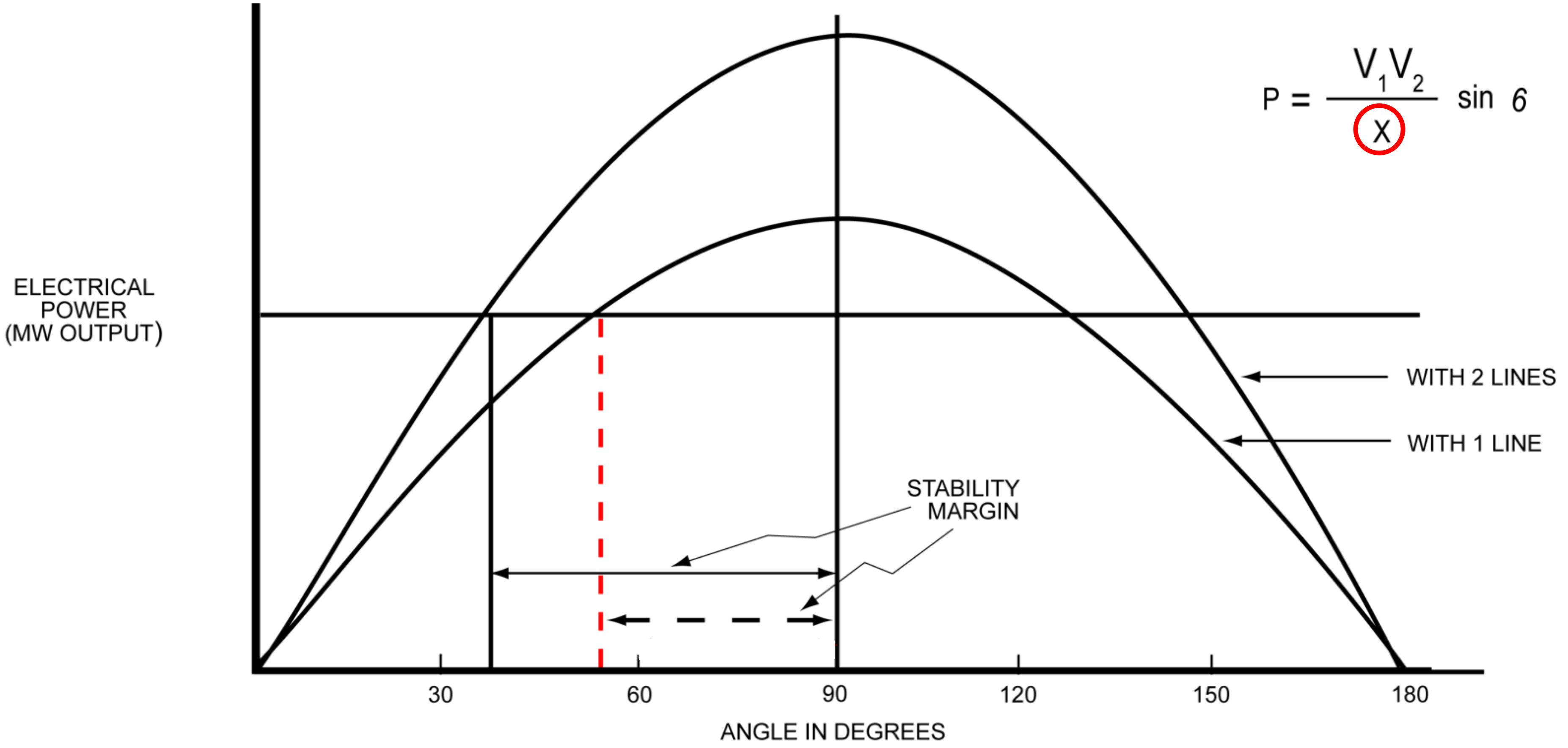
- P_{Max} is the steady state stability limit
- Occurs when δ =90º
- Increasing beyond this point can lead to a loss of synchronism
- Increasing power angle δ only increases power transfer P up to a point!



Power (MWs)
$$P = \frac{V_1 V_2}{x} \sin \delta$$
0
30
60
90
120
150
180
Angle in Degrees

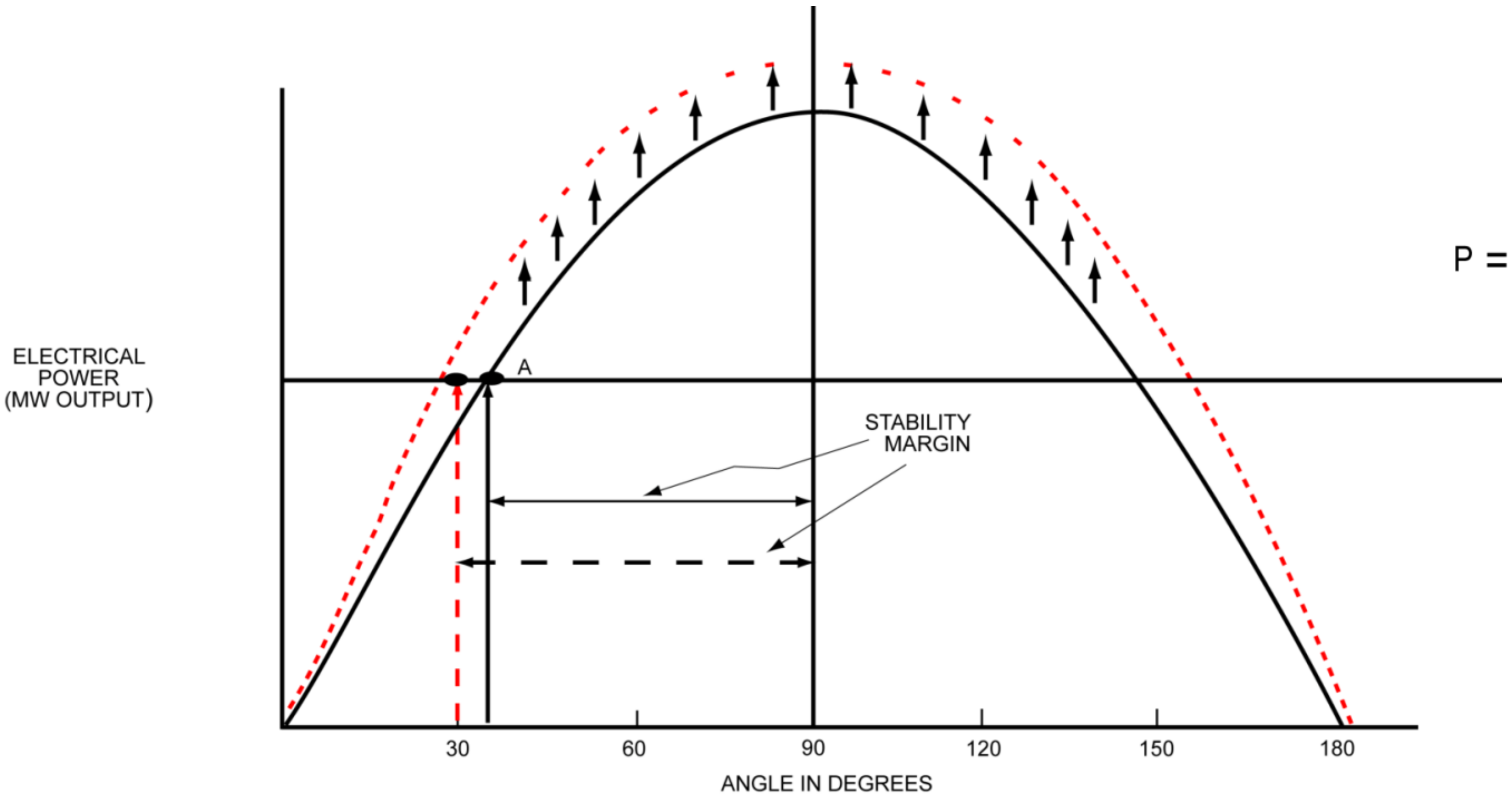
Stability Margin

- Effect of removing one line from service



Stability Margin *(con't)*

- Relationship of Voltage to Stability



$$P = \frac{V_1 V_2}{X} \sin \delta$$

Steady State Stability

- Ability of the system to withstand small changes or disturbances from equilibrium without the loss of synchronism
  - Stable loads
  - Balanced generation with said loads
  - Small, gradual changes
  - No emergency conditions
- Consistent voltages at, or near, nominal values with AVRs in service

Steady State Instability

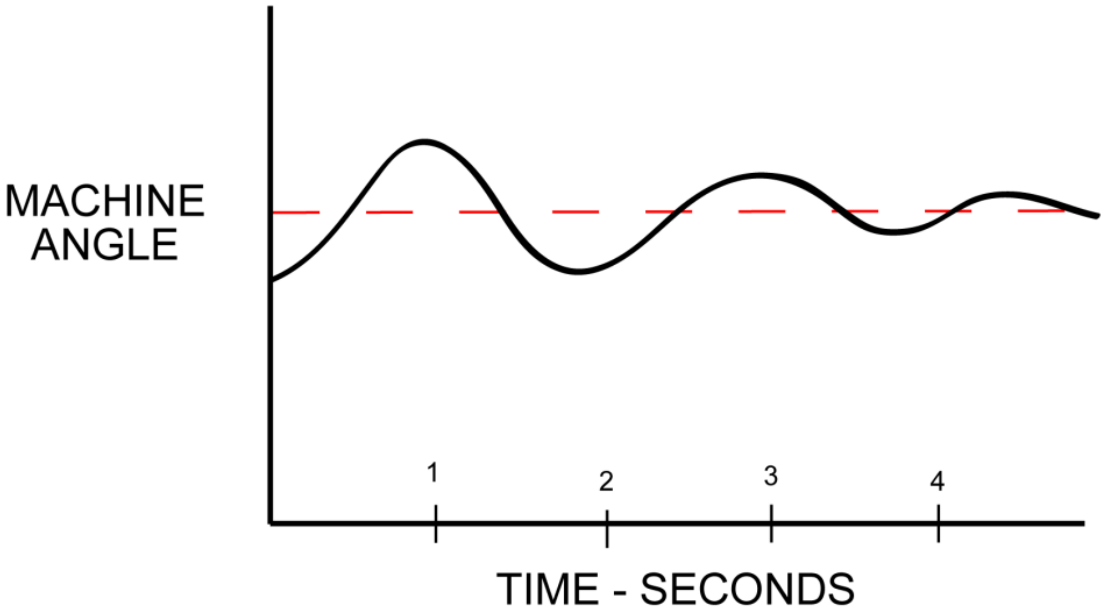
- Generator or circuit loading causes power angle to exceed 90° and System is forced into a condition where there is no equilibrium condition
  - Power transfer actually reduces as increase in phase angle will result in a power transfer reduction
  - Receiving system sees decline in frequency and sending system sees reduction in load (begins to speed up)
  - Speed difference of system accumulates into angle difference
  - If receiving system does not speed up – generators will “slip a pole” and result in a loss of synchronism

Steady State Instability *(con't)*

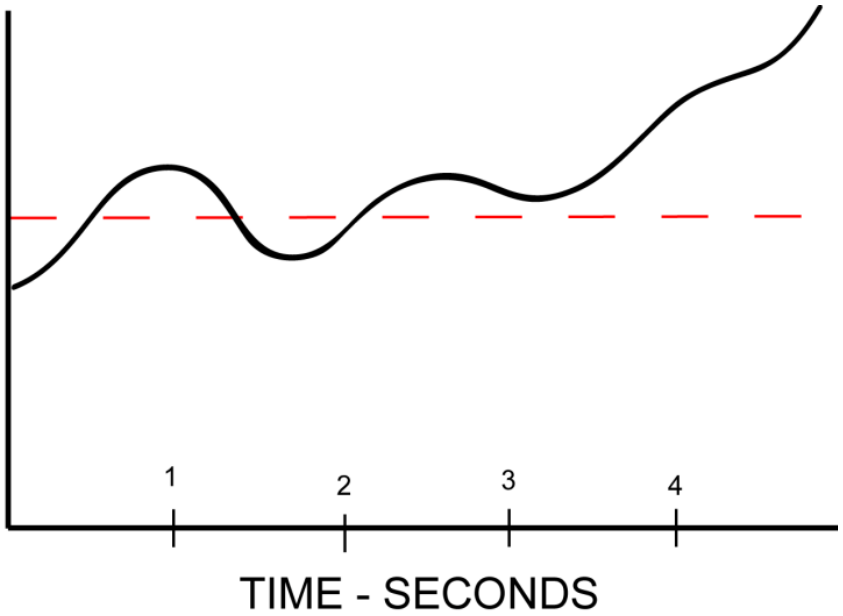
- Length of the line can affect the loadability or maximum power transfer of a transmission circuit
- Not very common in general – especially on a tightly interconnected system, like PJM's, where most transmission circuits are relatively short

Steady State Stability/Instability

$$P = \frac{V_1 V_2}{X} \sin 6$$

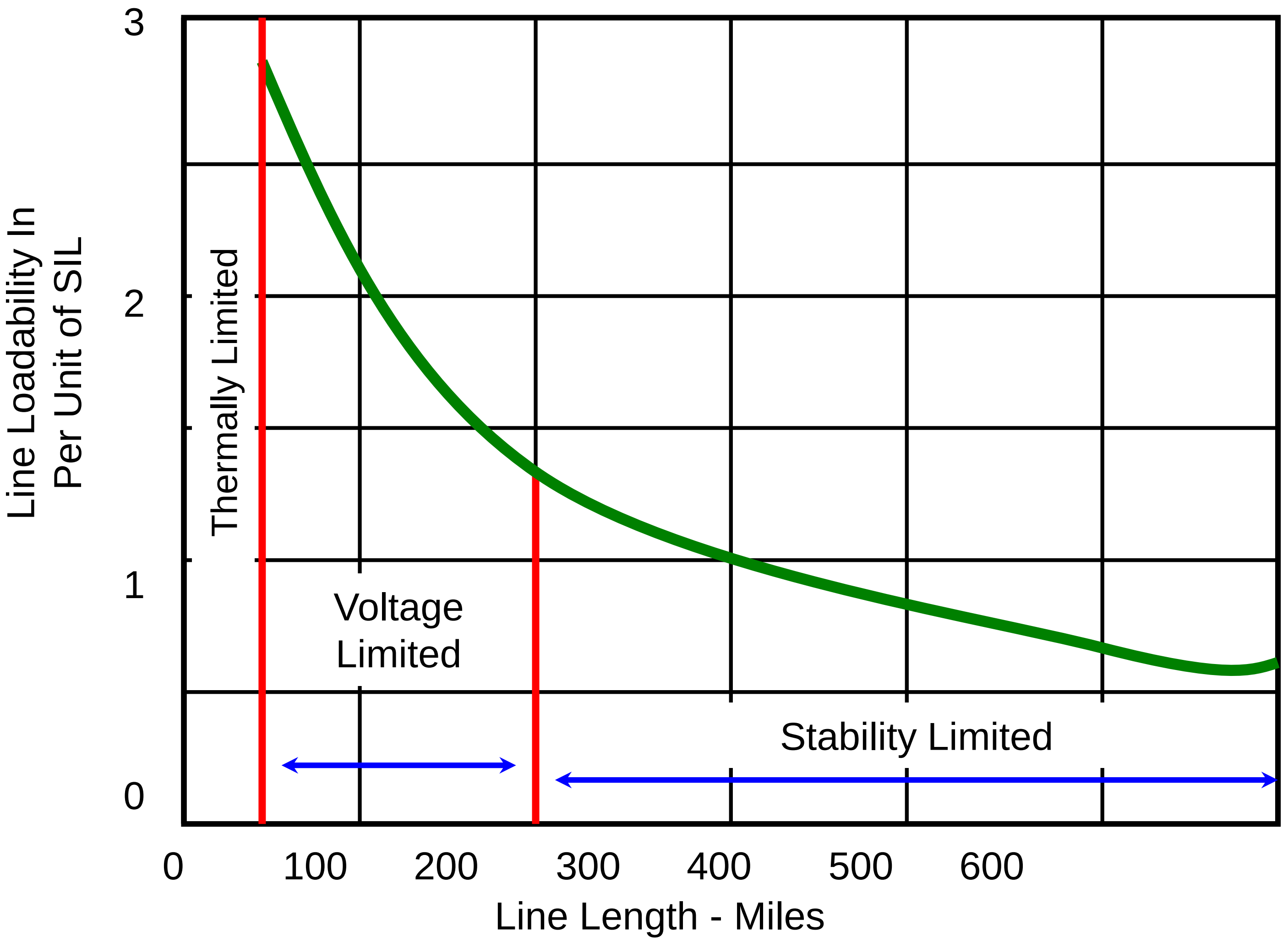


STEADY STATE STABILITY



STEADY STATE INSTABILITY

High Voltage Transmission Line Loadability



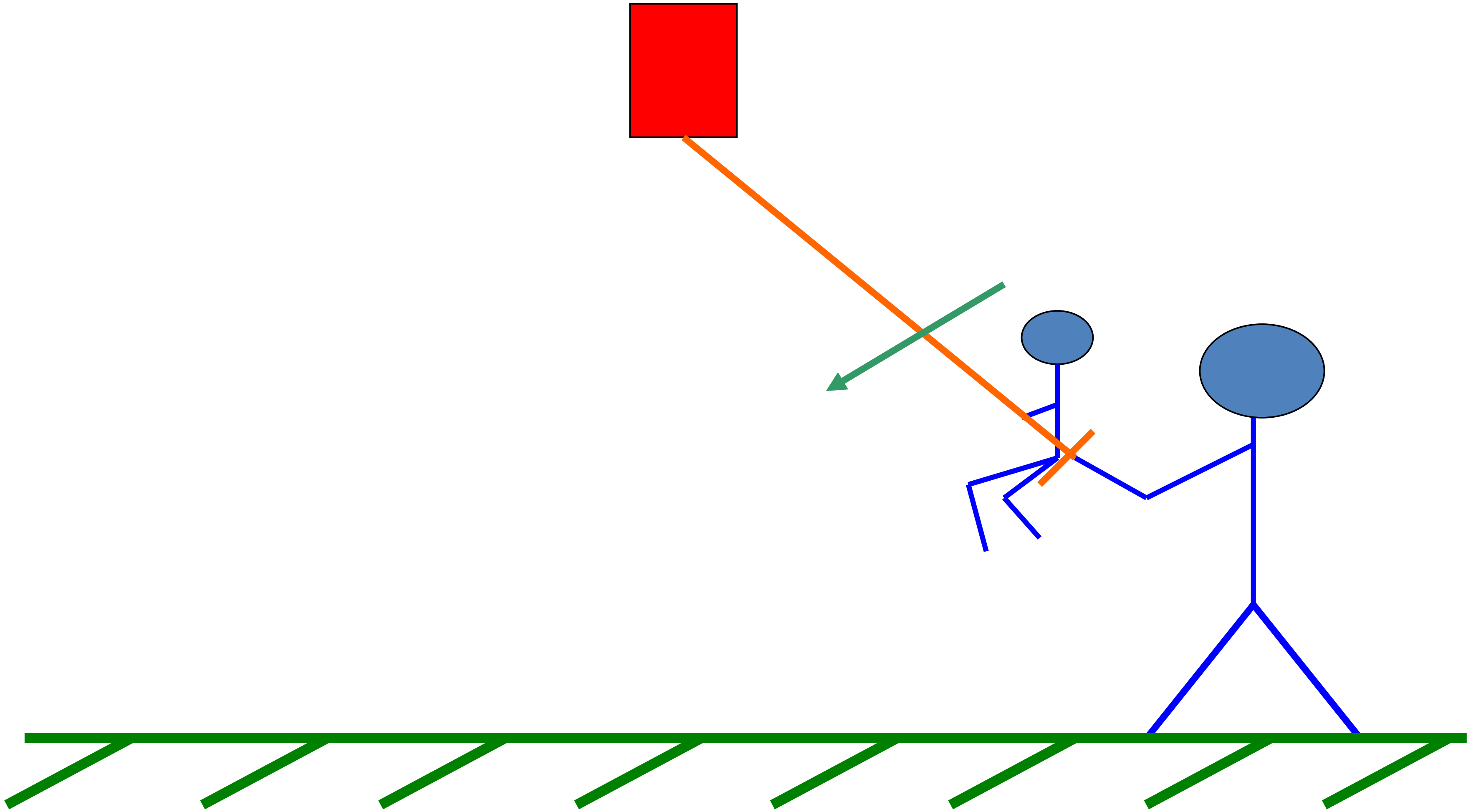
Dynamic Stability

- Takes into account automatic voltage regulators and governor response
  - Ability of generators to damp oscillations
    - Caused by relatively minor disturbances
    - Through the action of properly tuned control systems
  - Mechanisms
    - Excitation control through the use of Automatic Voltage Regulators
    - Automatic Governor Control
    - Protective Relaying

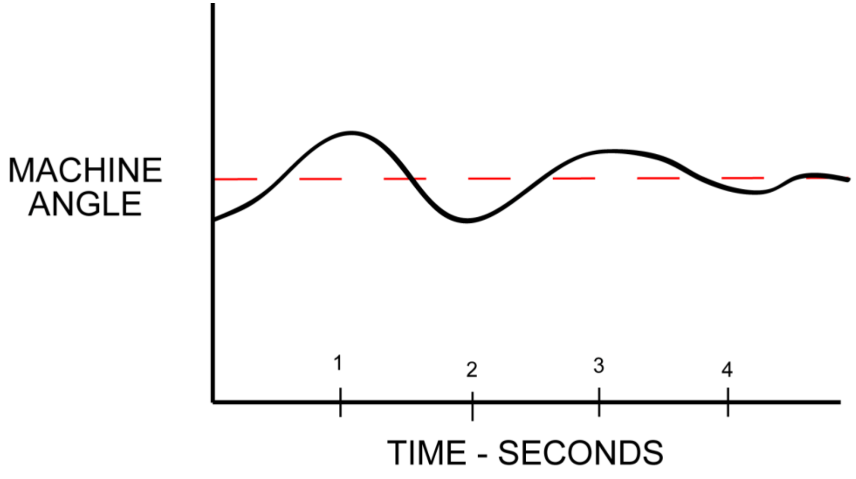
Dynamic Instability

- (In)Ability of generator(s) to damp out oscillations caused by disturbances
- This hunting or steadily growing oscillations can lead to a loss of synchronism
- Oscillations may show-up as real or reactive power flow fluctuations
- Fast acting exciters tuned to same frequency as oscillations resulting from disturbance may compounds the instability
- Installation of power system stabilizers can eliminate problem
- Characterized by Concern is with “negative damping” vs. “positive damping”

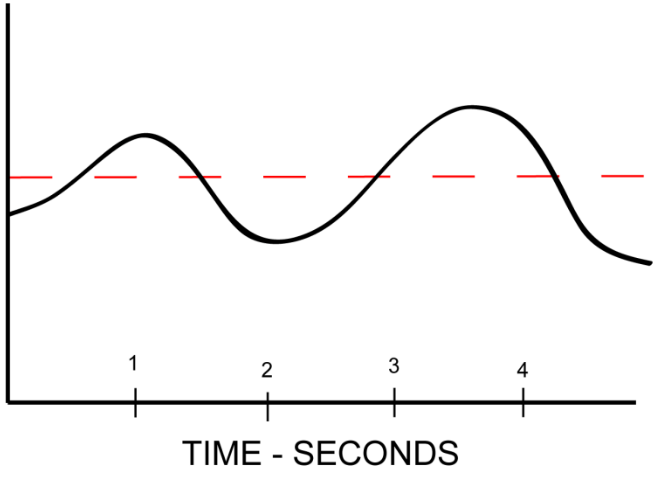
Analogy of Dynamic Instability



Dynamic Stability/Instability



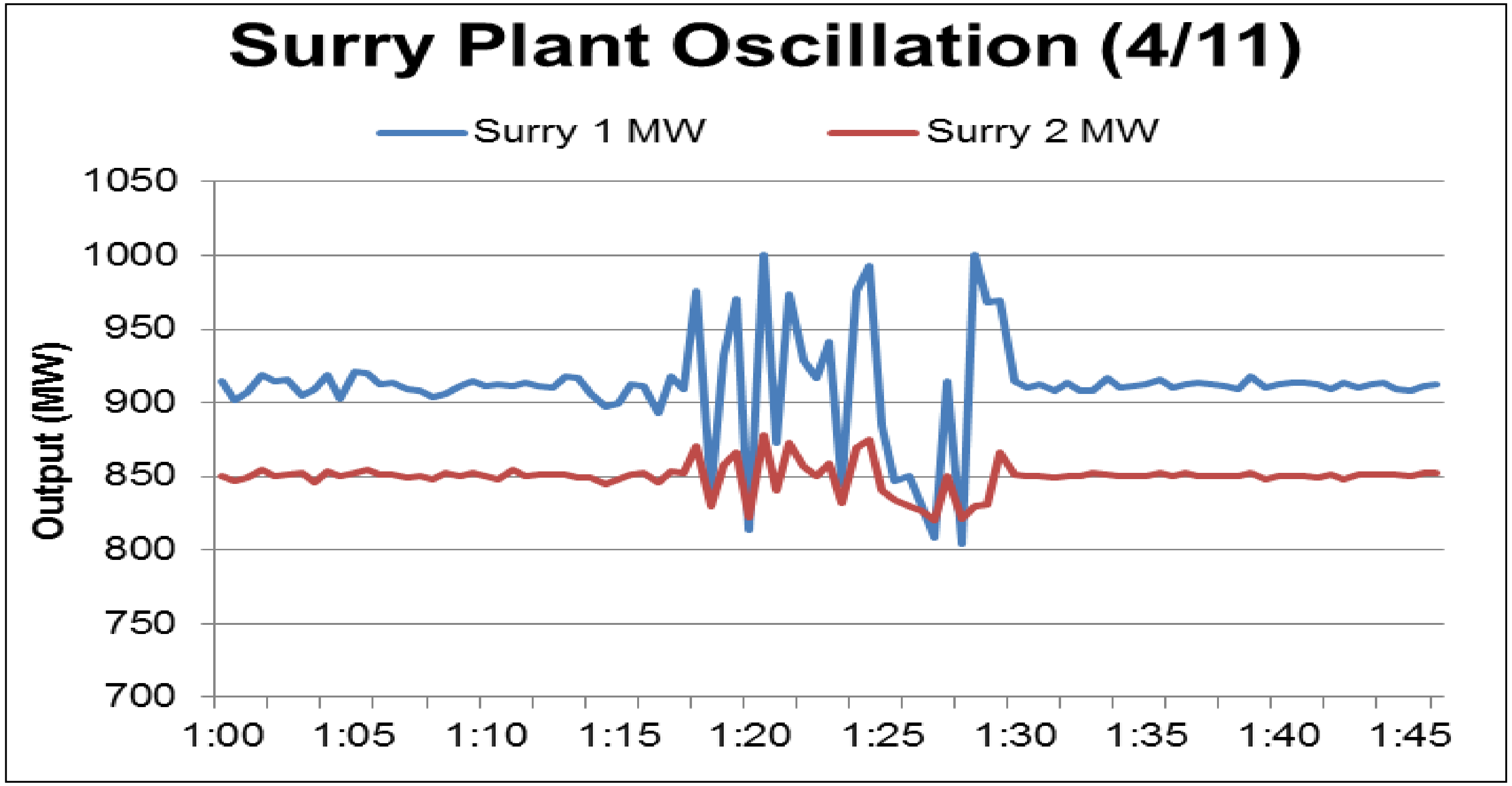
DYNAMIC STABILITY



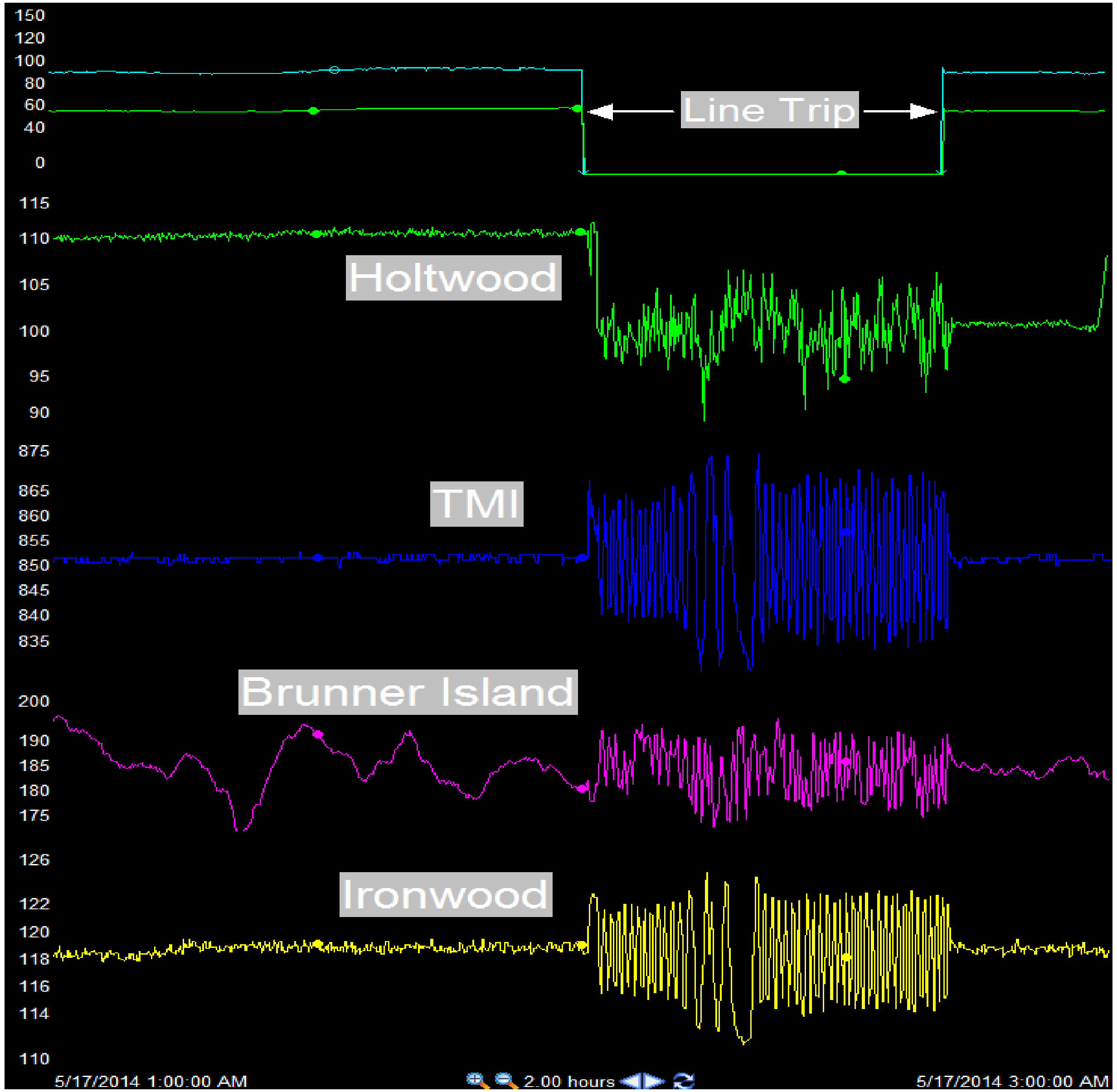
DYNAMIC STABILITY

DYNAMIC INSTABILITY

Dynamic (In)Stability: Surry 2011



Dynamic (In)Stability: Holtwood 2014



6269

Transient Stability

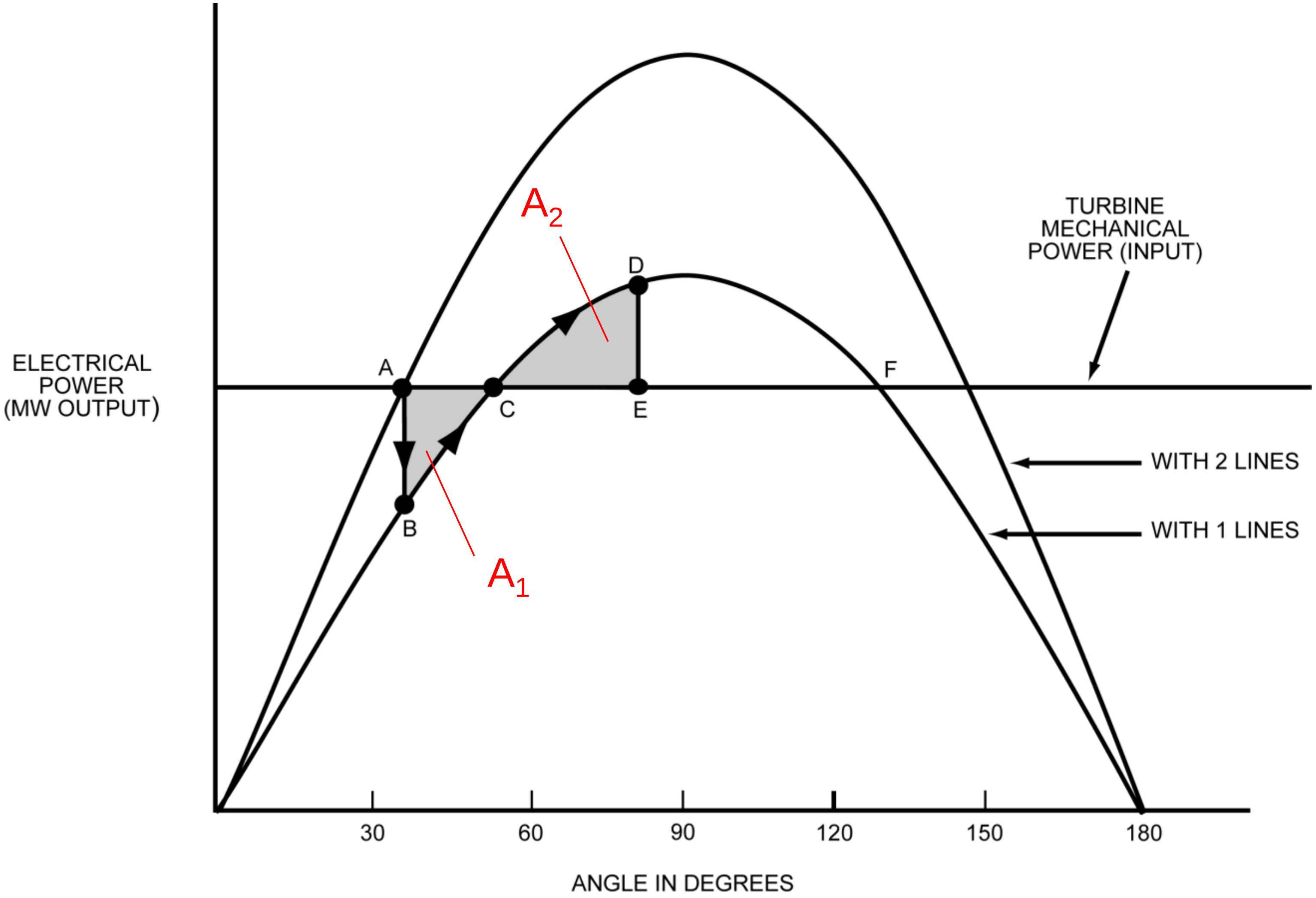
- The ability of a generator or group of generators to remain in synchronism immediately following a severe and sudden system disturbance (initial swing)
- Transient stability is typically viewed as "first swing" stability
- The first swing for a generator takes less than a second
- Considers the inherent mechanical and electromagnetic characteristics of the synchronous machines and the impedance of the circuits connecting them

Transient Instability

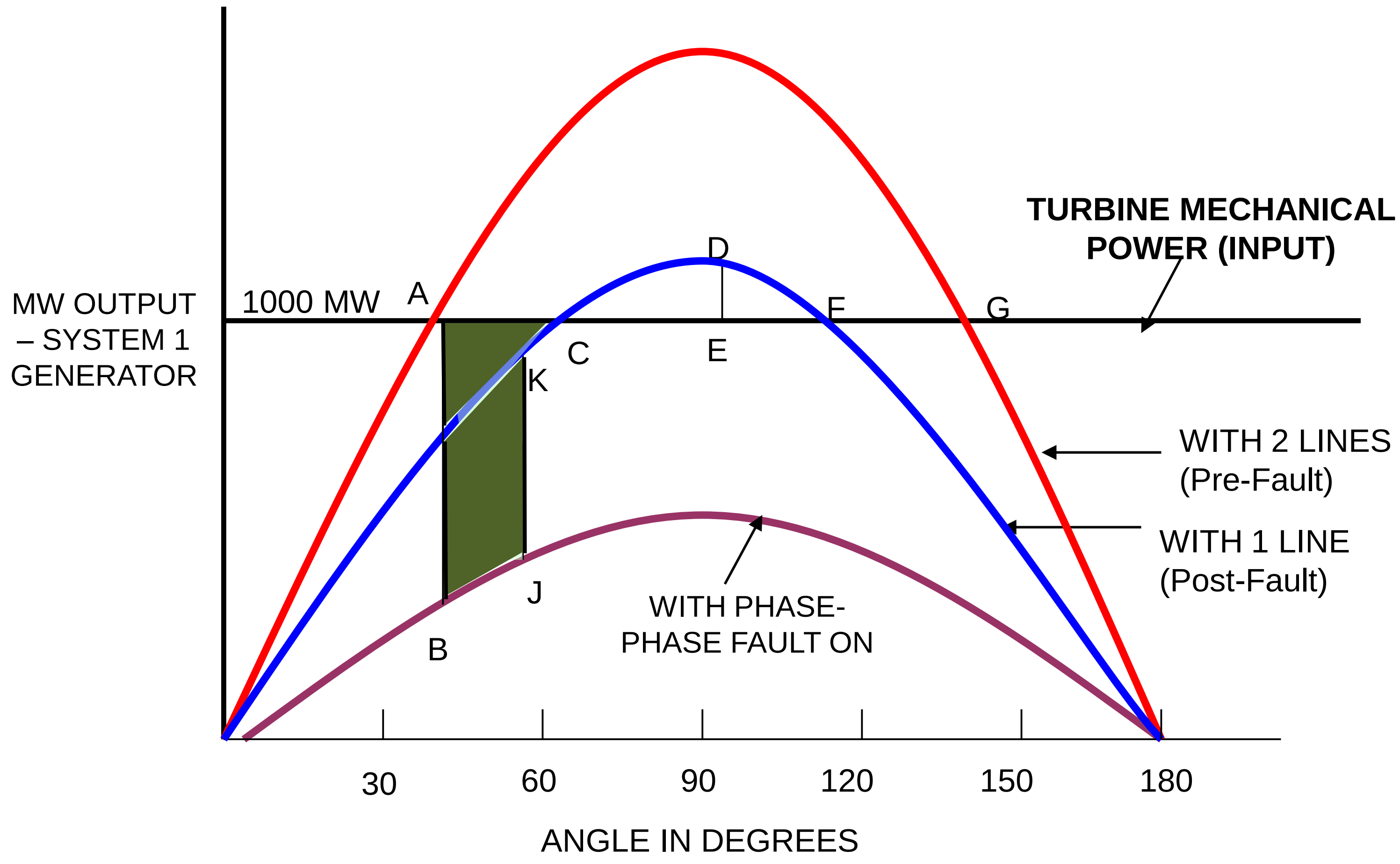
- Inability of system generators to remain synchronized following a significant disturbance (usually a fault)
- Upon the disturbance – generator rotors accelerate then decelerate before new operating point is reached
- System is transiently stable if Accelerating Area ≤ Decelerating Area
- Multiple types of faults, examples:
  - Three-phase (Most severe)
  - Single phase (Less severe)
- Equivalent impedances involved in different faults varies

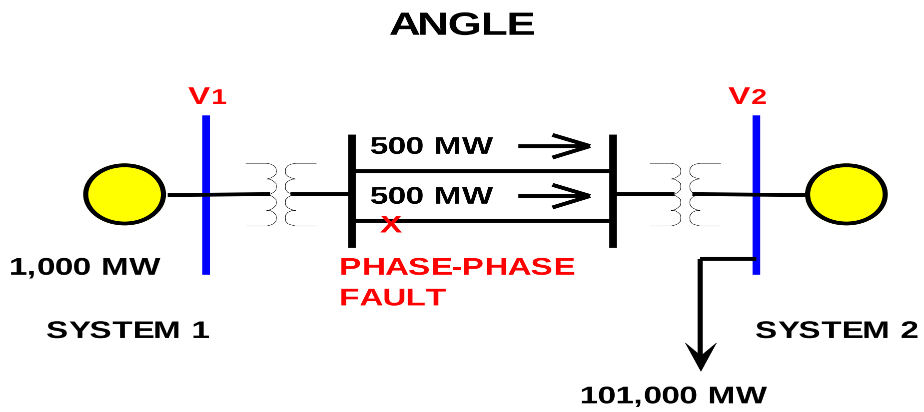
Transient Stability

- Equal Area Criterion (Area ABC=CDE)



Equal Area Criterion: Fault On *(con't)*

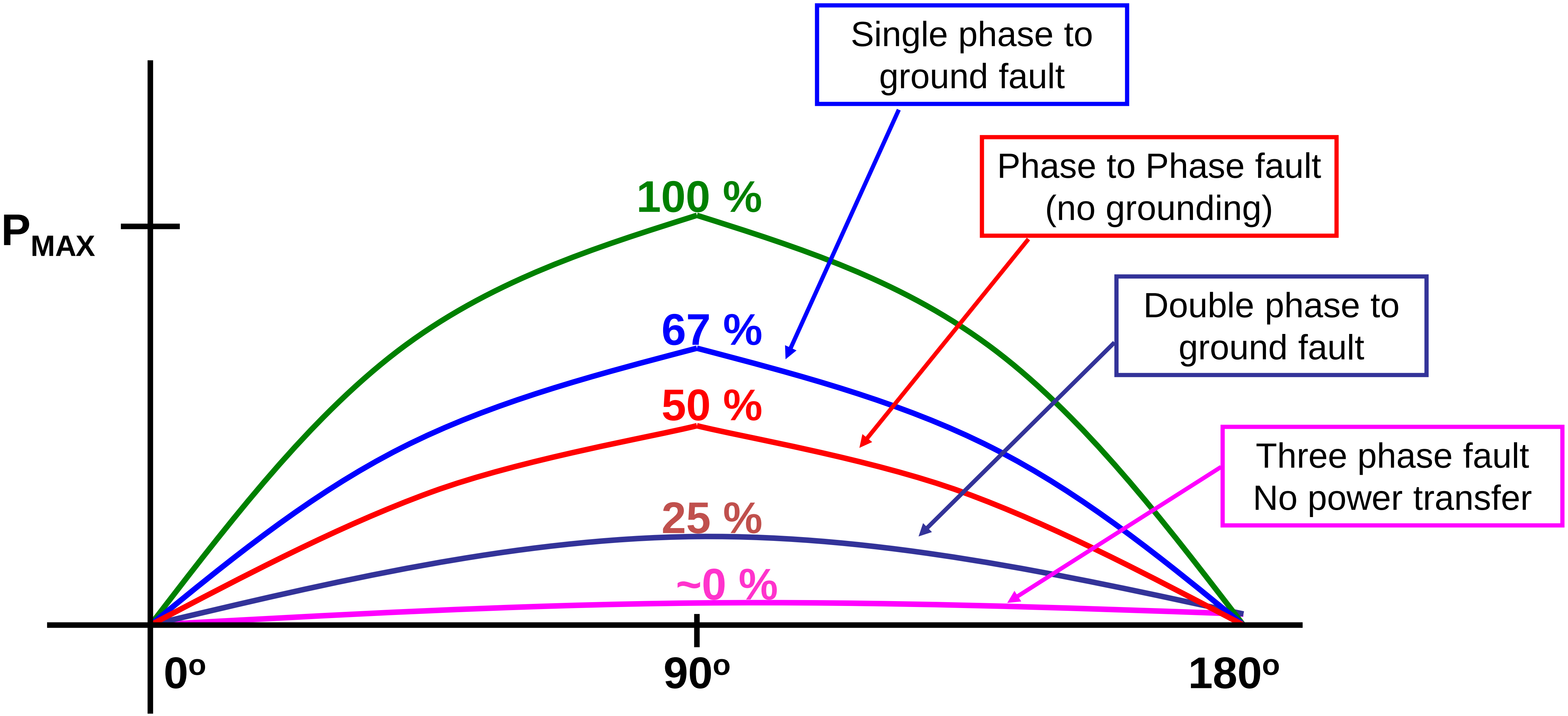




Remember: The longer the fault, the longer B-J gets and the more accelerating area you have. Longer durations faults are worse. Makes sense, right?

Phase-Phase Fault Followed by Trip of 1 Line

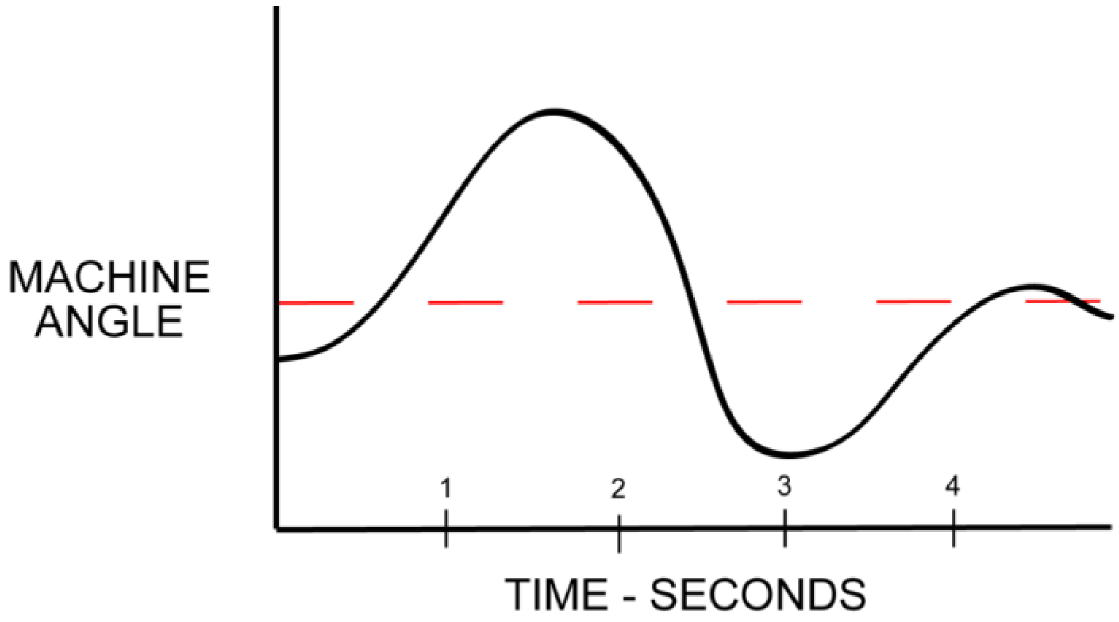
Effects of Fault Types on Power Transfer (Single line)



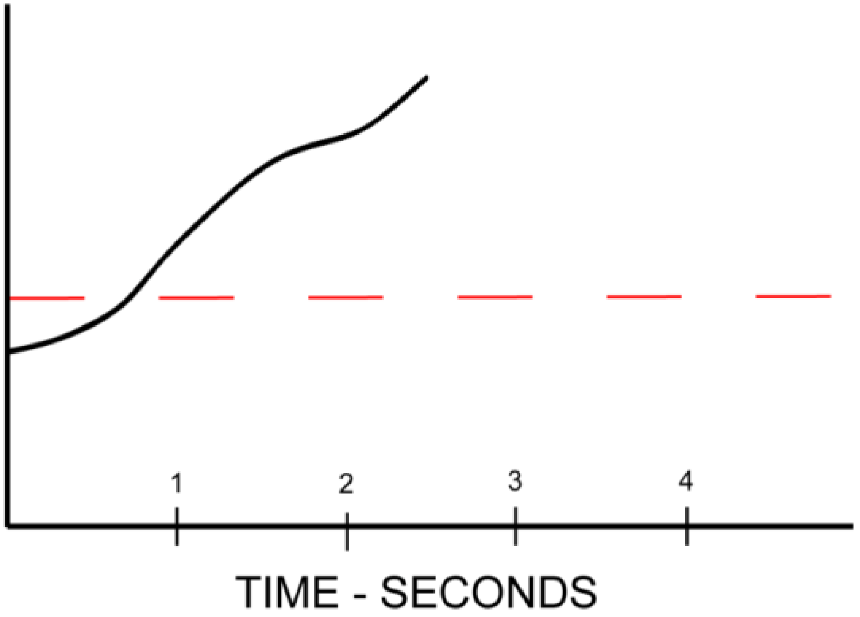
Transient Stability: Helping your margins

- Limit transfers
- Assure AVRs + PSSs in service
- Raise generator/transmission voltage
- Restore Transmission to service
- Restore Reclosing and Applicable RASs

Transient Stability/Instability

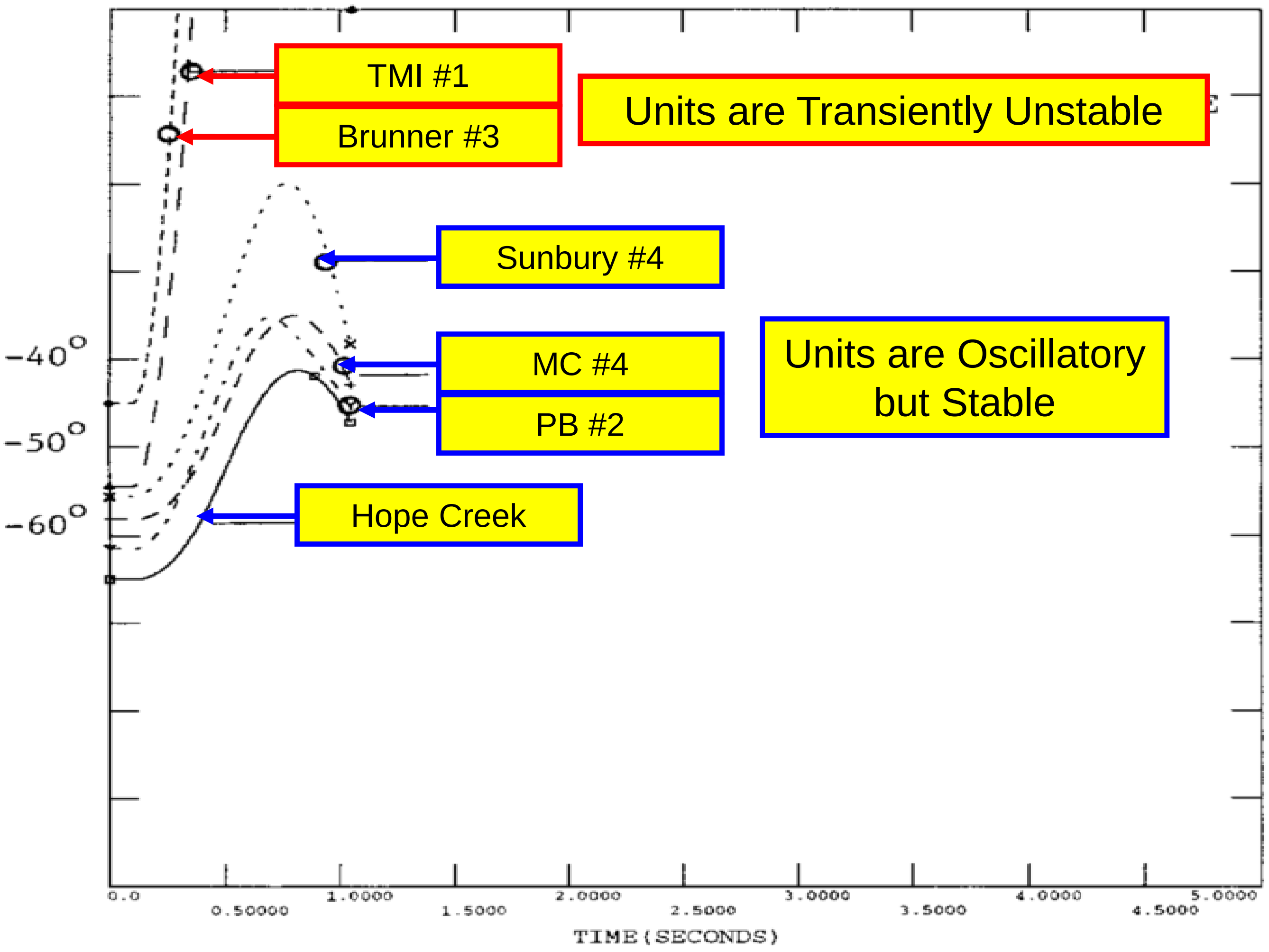


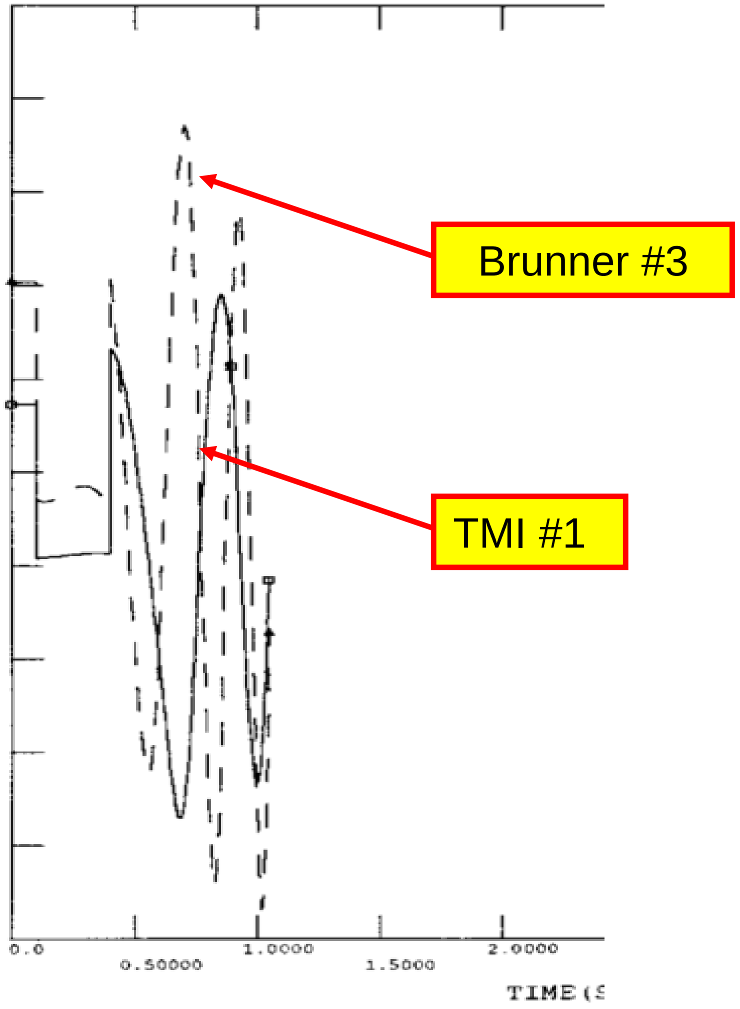
TRANSIENT STABILITY
FOLLOWING FAULT



TRANSIENT INSTABILITY
FOLLOWING FAULT

Transient Instability Example





Typical Threats to Stability

- Loss (or gain) of one or more generators
- System faults/facility outages
- Low voltage operation
- High Transfers
- Automatic Voltage Regulator & Power System Stabilizer Outages
- Relay Scheme Outages
- Load changes

Operator Actions Affecting Stability

- Awareness
- Generator MW output
  - Decrease MW output to increase stability
- Generator MVAr output
  - Increase MVAr output to increase stability
- Lines in service - system strength
  - Put more lines in service to increase stability
- Arm special relay schemes

Consequences of Instability: Loss of synchronization

- Steady State
  - Phase angle exceeds 90 degrees
- Dynamic
  - Continued oscillations over long periods of time
  - Damage to units before they are tripped
- Transient
  - Excessive rotor angle swings
  - Units tripped, possibly damaged, following disturbance

Stability Guides

- Transmission Operations Manual 03 – Section 5
  - What do these guidelines contain?
    - Unit restrictions for each outage that affects stability
      - Tripping schemes
      - Generator MW output restrictions
      - Generator MVAR output restrictions

Stability and the PJM Generator Interconnection Process

- How are these guides developed?
  - Guidelines are based on detailed stability studies that consider severe fault conditions (N-1) that occur under each significant outage condition (N-2) in the area of concern
  - Guidelines are developed under very conservative assumptions of generation dispatch and load level

Stability and the PJM Generator Interconnection Process

- When are these guides updated and developed?
  - Guides will be updated every time a new equipment (generator or transmission) locates in vicinity of problem
  - Anytime an area becomes concentrated with a large amount of generation relative to the transmission outlet capability of the area,
    a detailed stability study will be performed to see if an operating guide
    is needed

Stability and the PJM Generator Interconnection Process

- Why are these guides so important?
  - Guides usually involve several large generators that can be damaged when they are operated out-of-step with the rest of the system
  - A generator that is operated out-of-step can cause transmission lines to trip before the generator itself trips off-line
  - When several large generators are operated out-of-step, cascading outages and widespread load loss can result due to the fluctuations in power flows, voltage and frequency

In Summary

- Stability has not yet become the most significant system limitation
- Operators need to be aware of the importance of why stability operating guides are developed and why they will be updated much more frequently than in the past

Bonus: Real Time Stability Tools!

- **DSA Monitor**: *Dynamic Security Assessment*
  (EMS equivalent is “Disp Mon” and “Exec Ctrl” screens)

- **TSA/TSAT**: *Transient Stability Analysis Tool*
  (EMS equivalent is “SA”)

- **PSAT**: *Powerflow & Short-circuit Analysis Tool*
  (EMS equivalent is Study “Powerflow”)

- **PCM**: *Preventive Control Measure*
  (EMS equivalent is “AO” report)

Questions?

PJM Client Management & Services

Telephone: (610) 666-8980

Toll Free Telephone: (866) 400-8980

Website: www.pjm.com

The Member Community is PJM's self-service portal for members to search for answers to their questions or to track and/or open cases with Client Management & Services

Resources & References

Bergen, A. & Vittal, V. (2000). *Power System Analysis* (2 ed.). Prentice Hall, Inc.

Radhakrishna, C. (1981). *Transient Stability Analysis.* Retrieved from https://ieeexplore.ieee.org/document/4110615/

Rustebakke, H. (1983). *Electric Utility Systems and Practices* (4 ed.). Wiley-Interscience.