Fundamentals of Transmission Operations

System Stability

PJM State & Member Training Dept.

Objectives

Following this presentation, the student will be able to:

- Define stable operation
- Define the following stability modes: Steady state, Transient, Dynamic
- 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

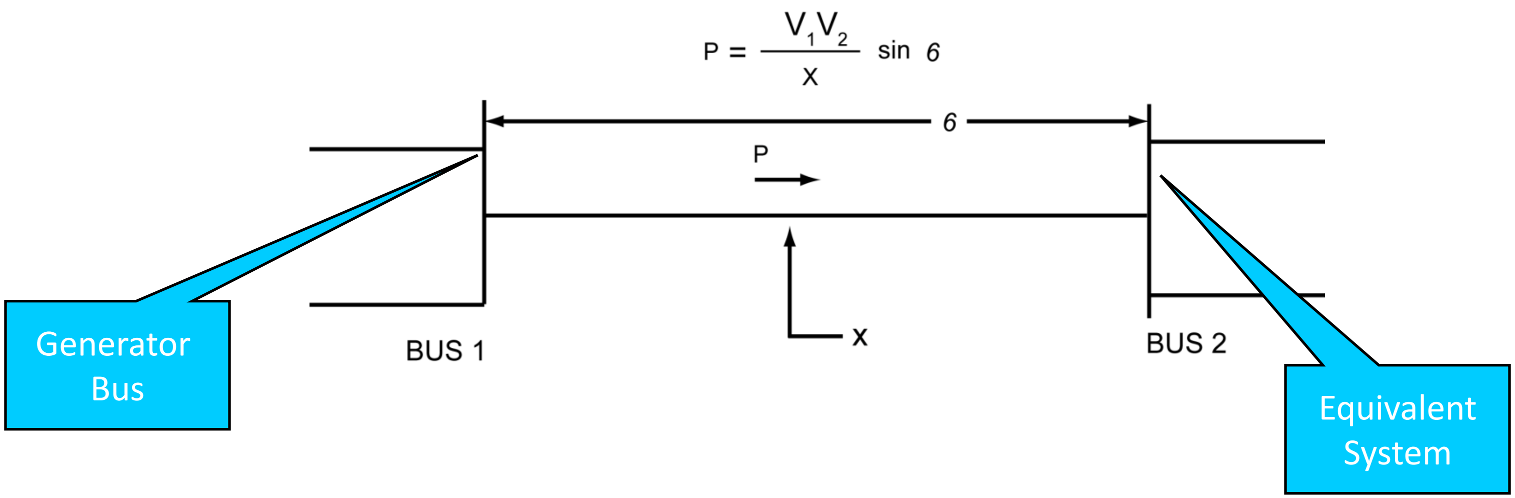
- Definition
  - Generic
    - Stability is the condition of equilibrium between opposing forces
  - In power system, Mechanical power provided to turbine = electrical power drawn by the system
- Typical Threats to Stability
  - Loss of one or more generators
  - Loss of one or more major pieces of equipment
  - System faults
  - Low voltage operation

Steady State Stability

- Definition of Steady State
  - Steady loads
  - Steady generation balanced with load
  - No disturbances
  - Small, slow changes are part of steady state

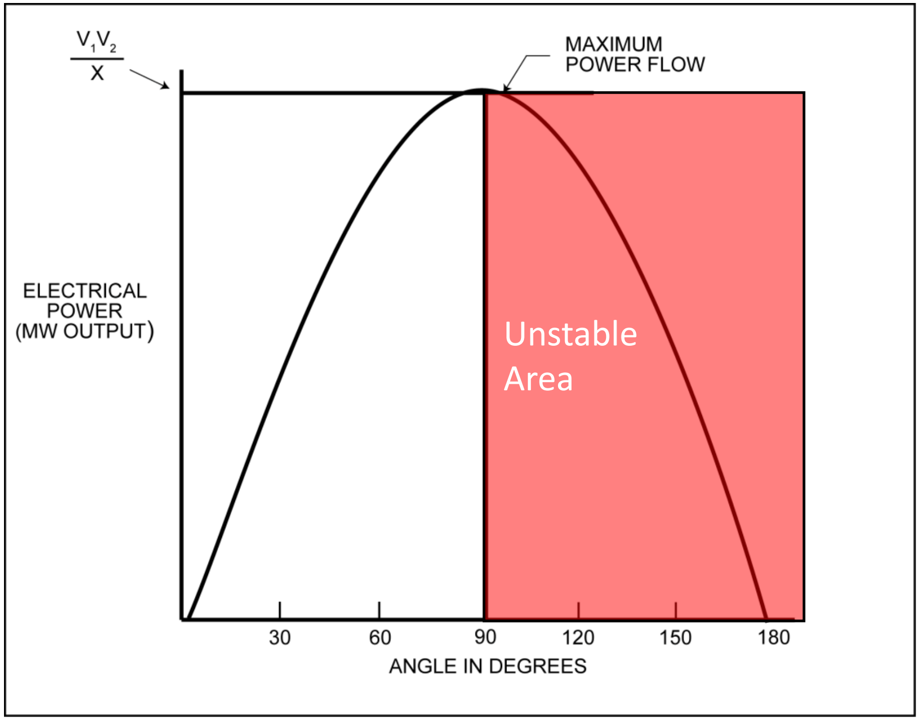
Steady State Stability

- Relationship of Phase Angle to Steady State Stability
  - Review of power flow equation



Steady State Stability

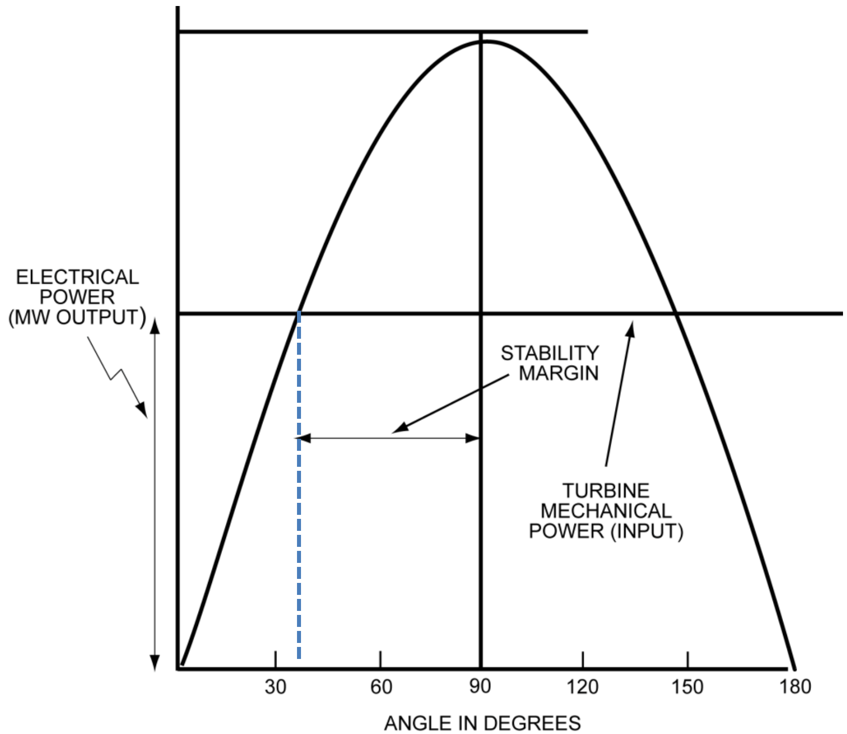
- Relationship of Phase Angle to Steady State Stability
  - Magnitude of power flow as a function of angle



Steady State Stability

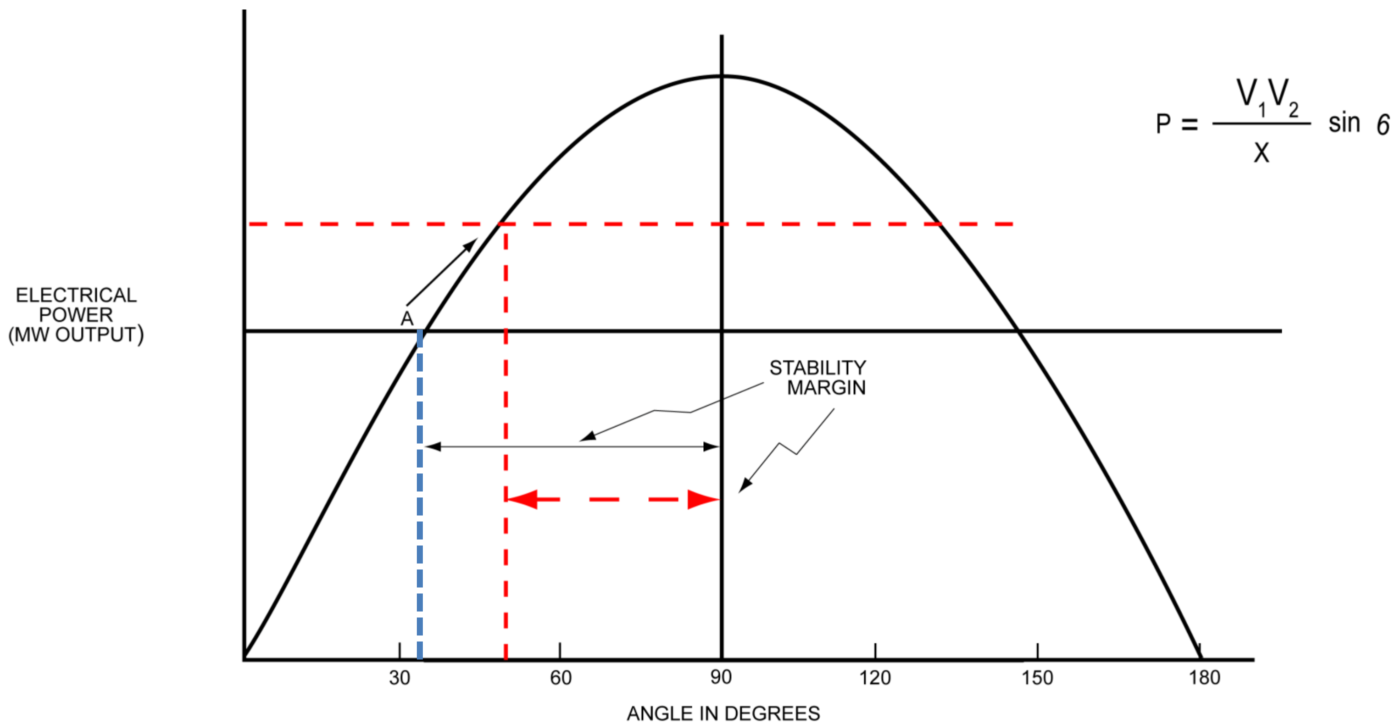
- Relationship of Phase Angle to Steady State Stability
  - Stability Margin

Difference between operating point and 90 degrees



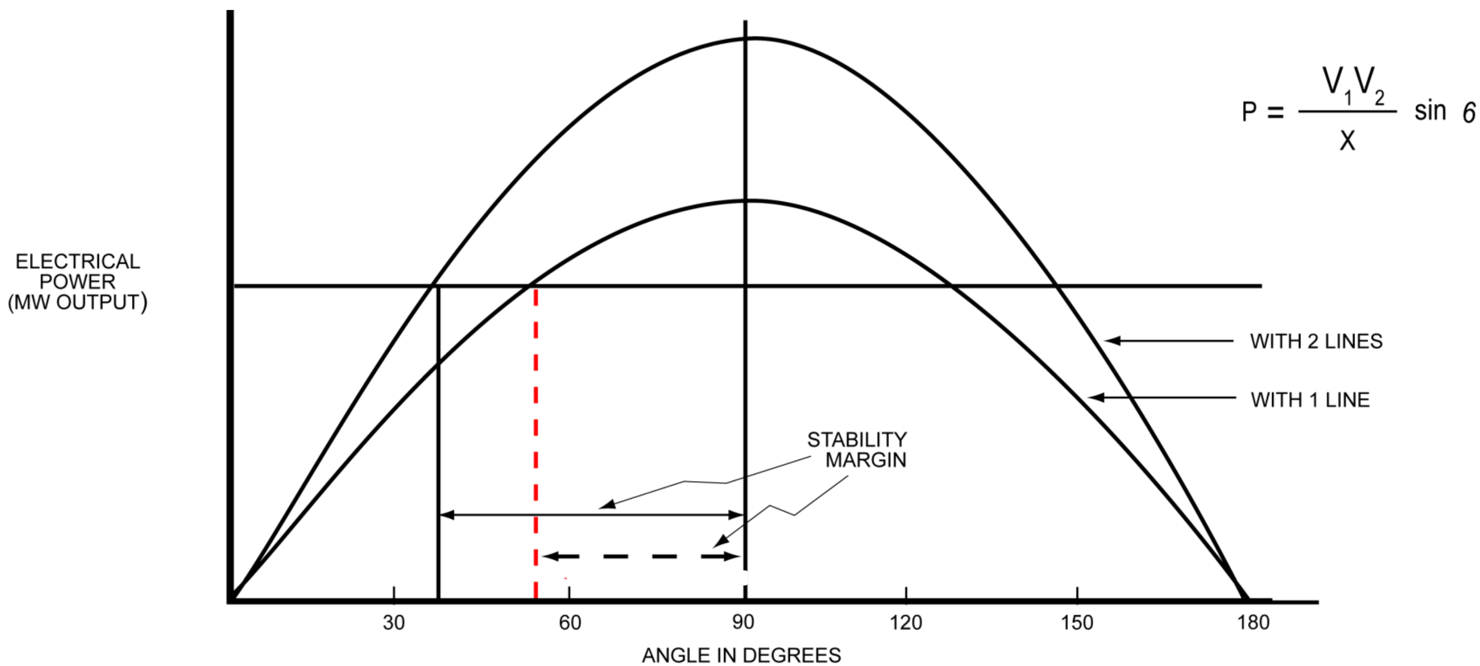
Steady State Stability

- Relationship of Phase Angle to Steady State Stability
  - Effect of varying MW output



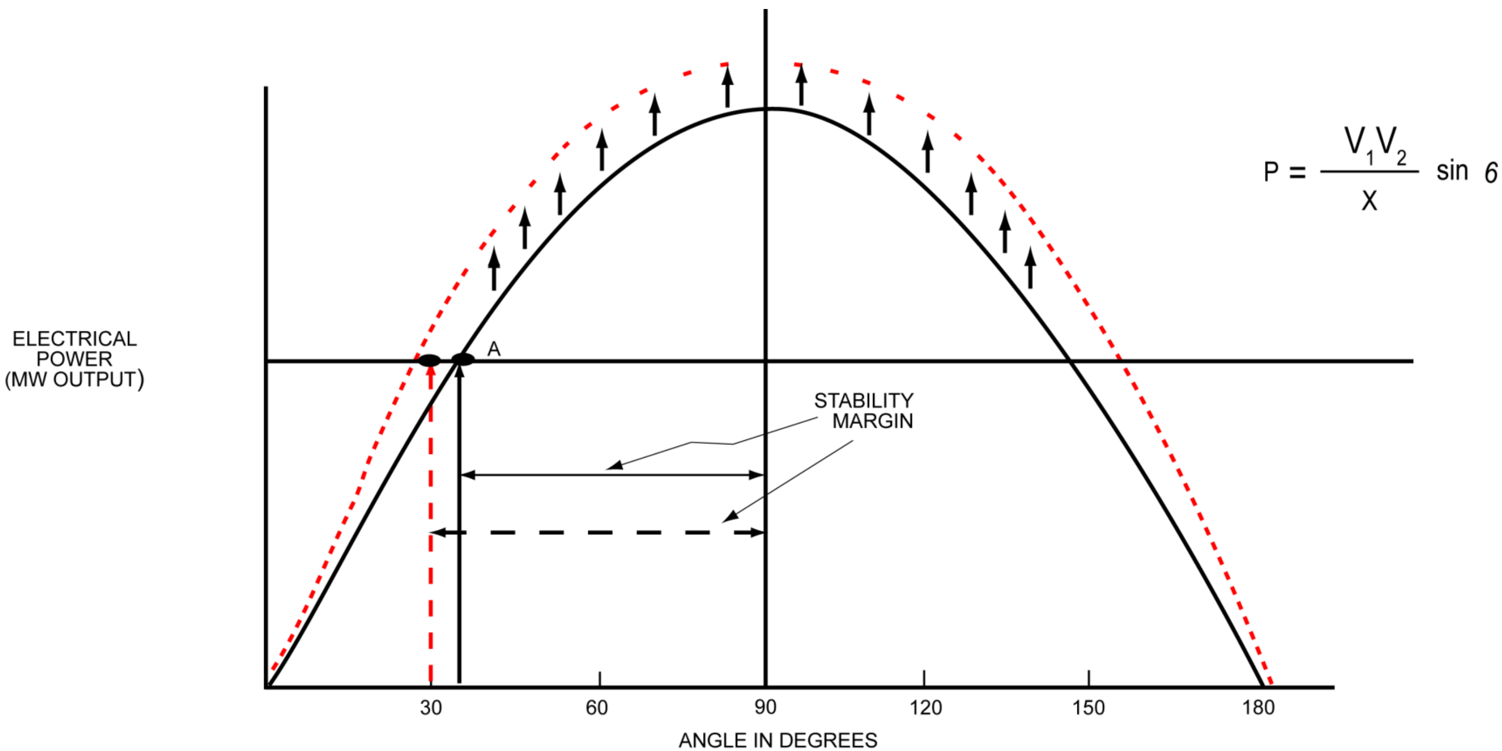
Steady State Stability

- Relationship of Phase Angle to Steady State Stability
  - Effect of removing one line from service



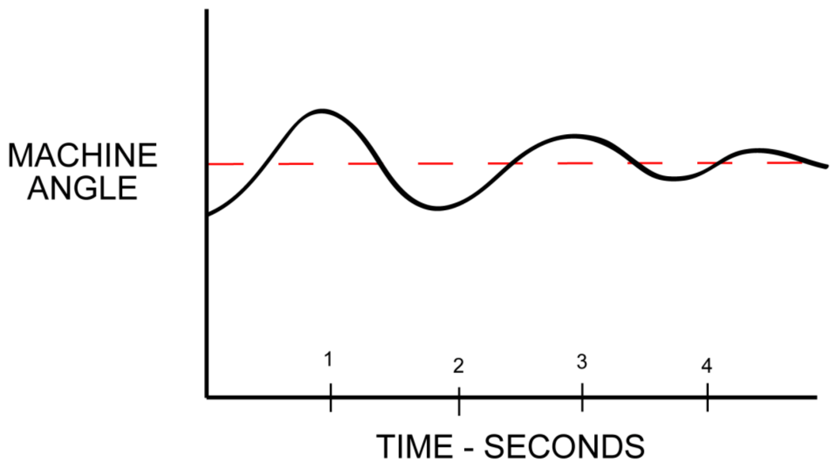
Steady State Stability

- Relationship of Voltage to Steady State Stability
  - Effect of changing machine excitation

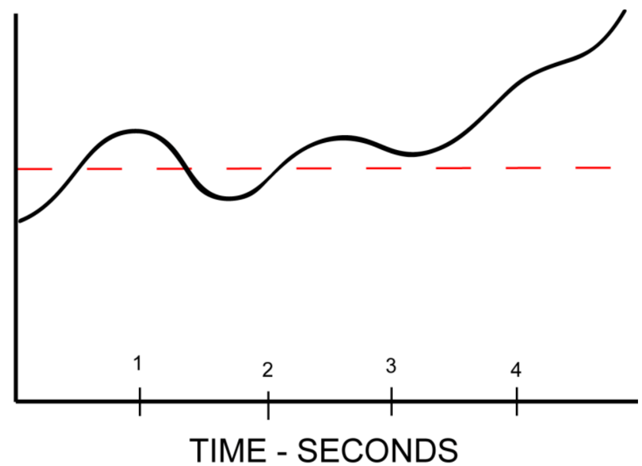


Steady State Stability

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



STEADY STATE STABILITY



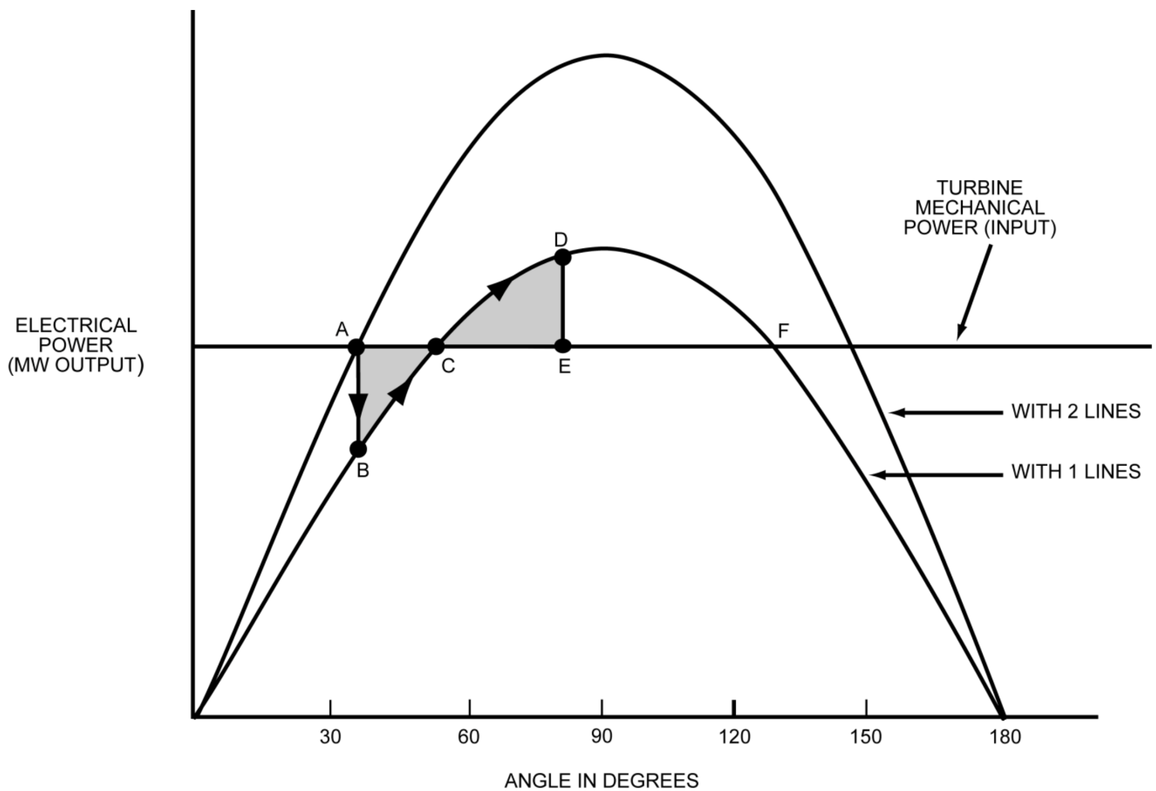
STEADY STATE INSTABILITY

Transient Stability

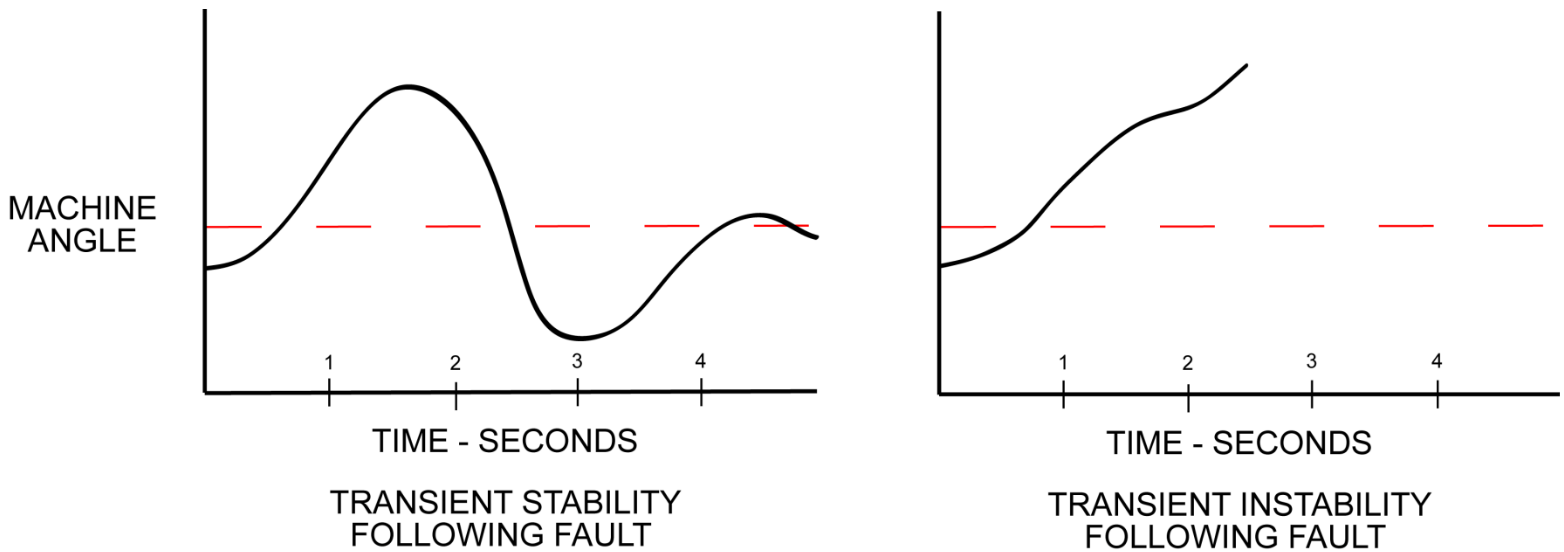
- Definition
  - The ability of a generator or group of generators to remain in synchronism immediately following a system disturbance (initial swing)
  - Transient stability is typically viewed as first swing stability
  - The first swing for a generator takes less than a second

Transient Stability

- Equal Area Criterion (Area ABC=CDE)



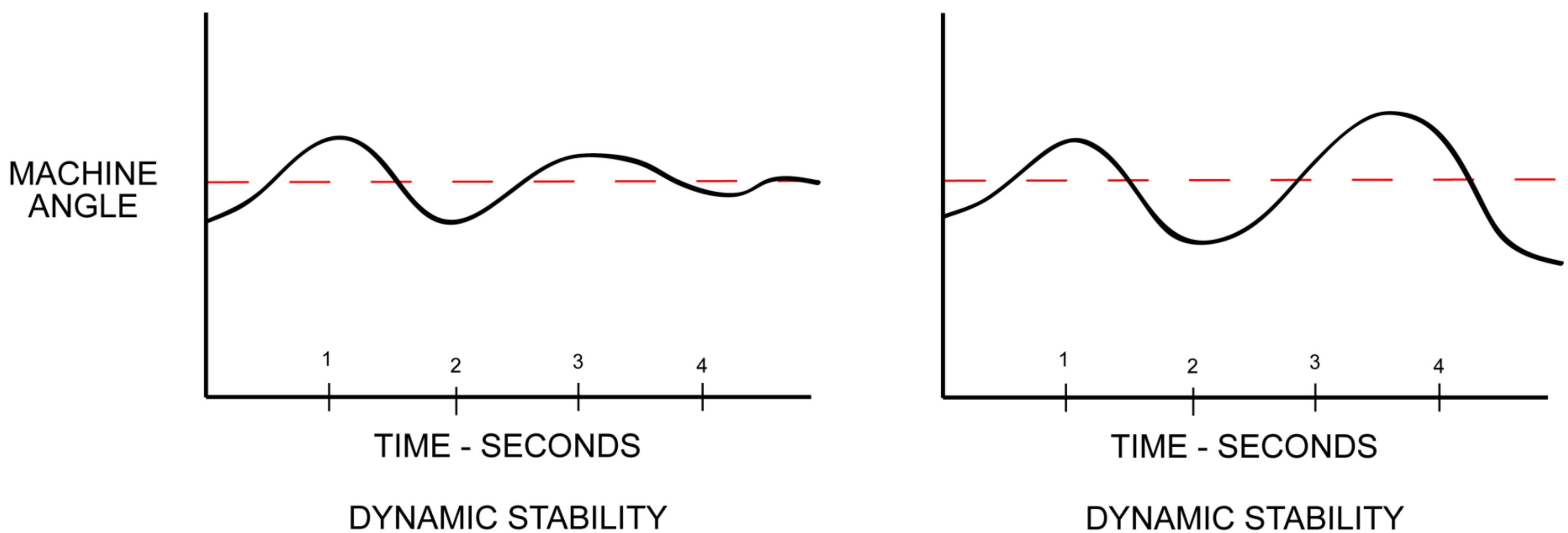
Transient Stability



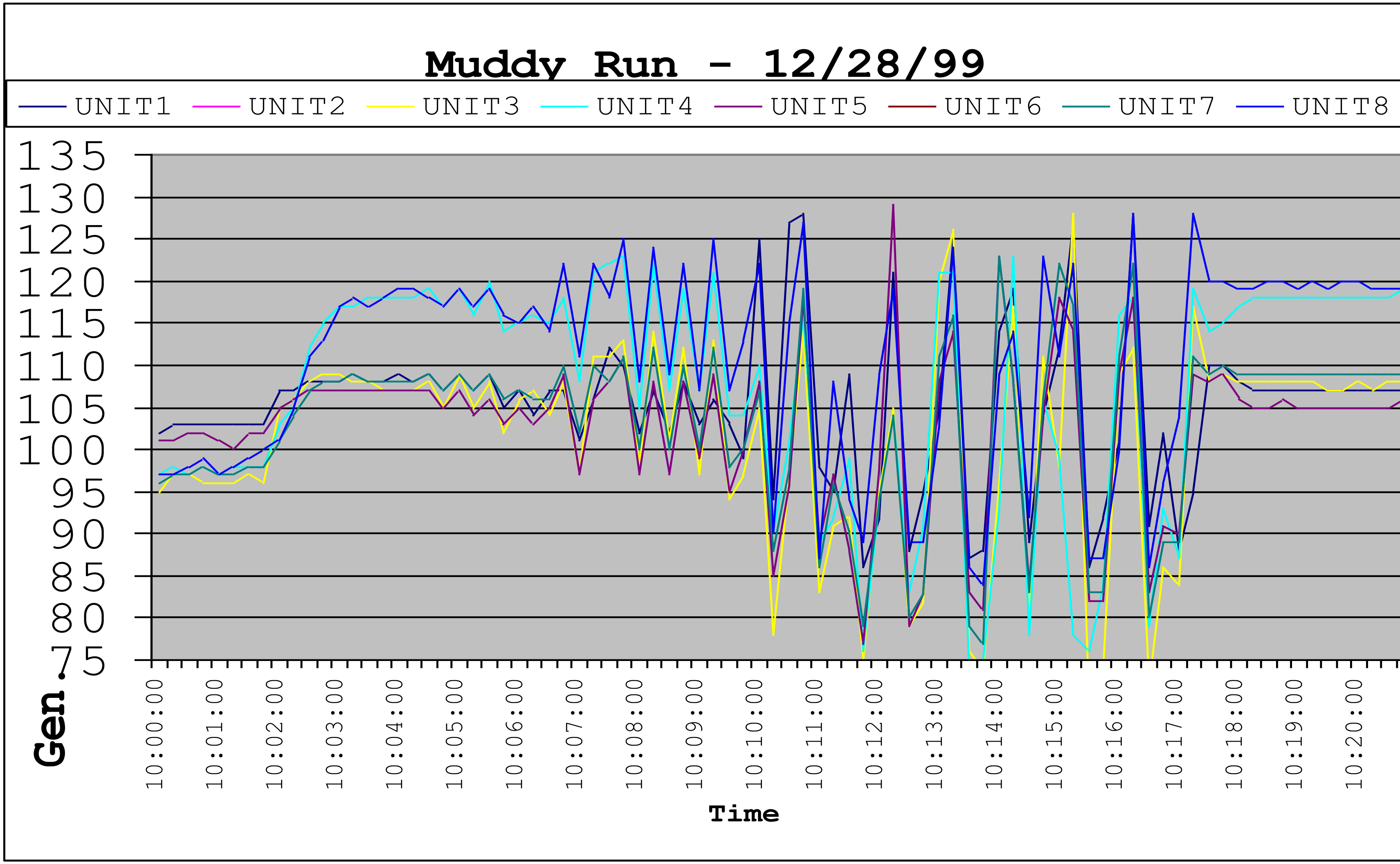
Dynamic Stability

- Definition
  - Ability of generators to damp oscillations caused by relatively minor disturbances through the action of properly tuned control systems
- Mechanisms
  - Excitation control
  - Governors
  - Protective relaying

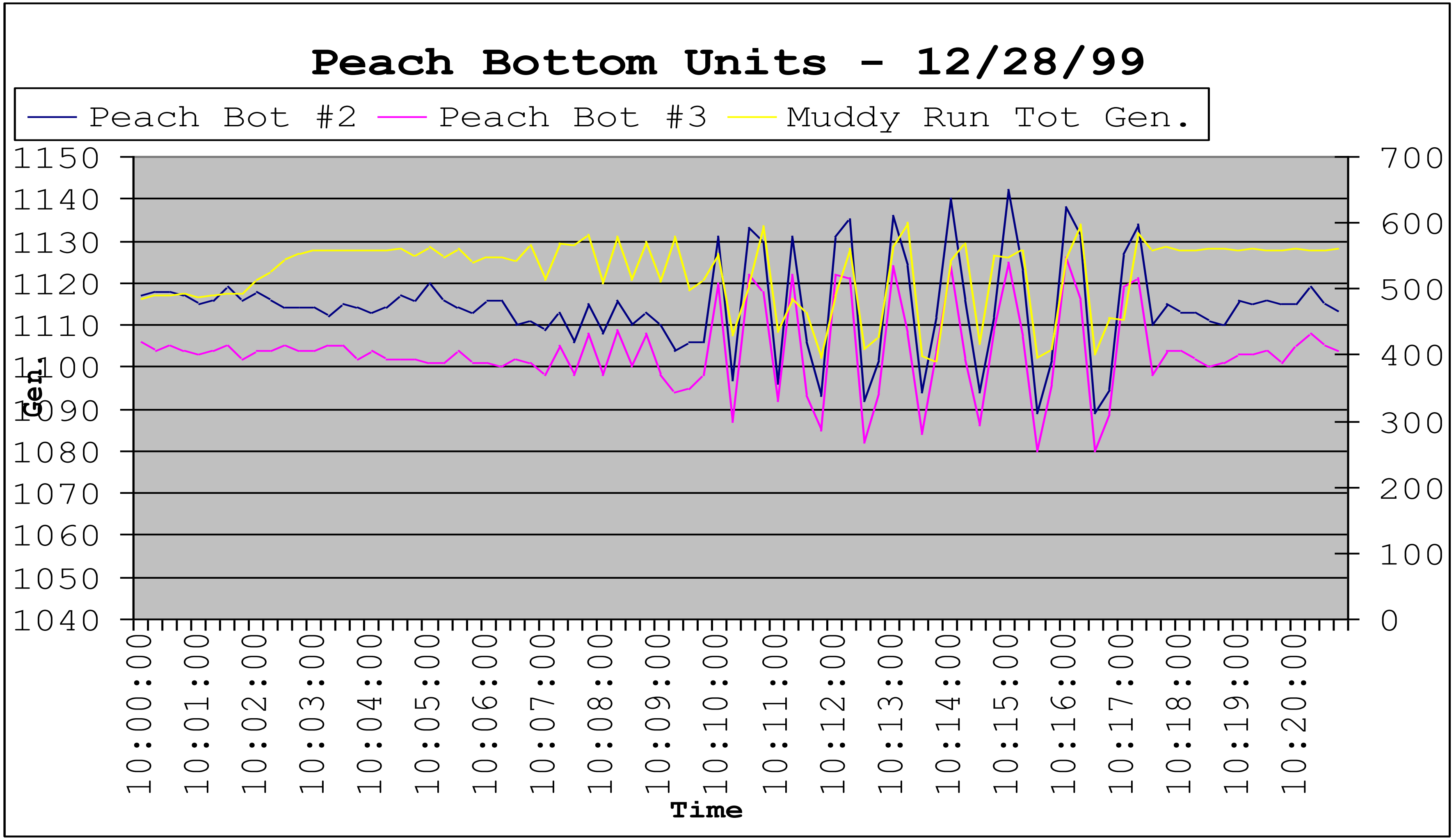
Dynamic Stability



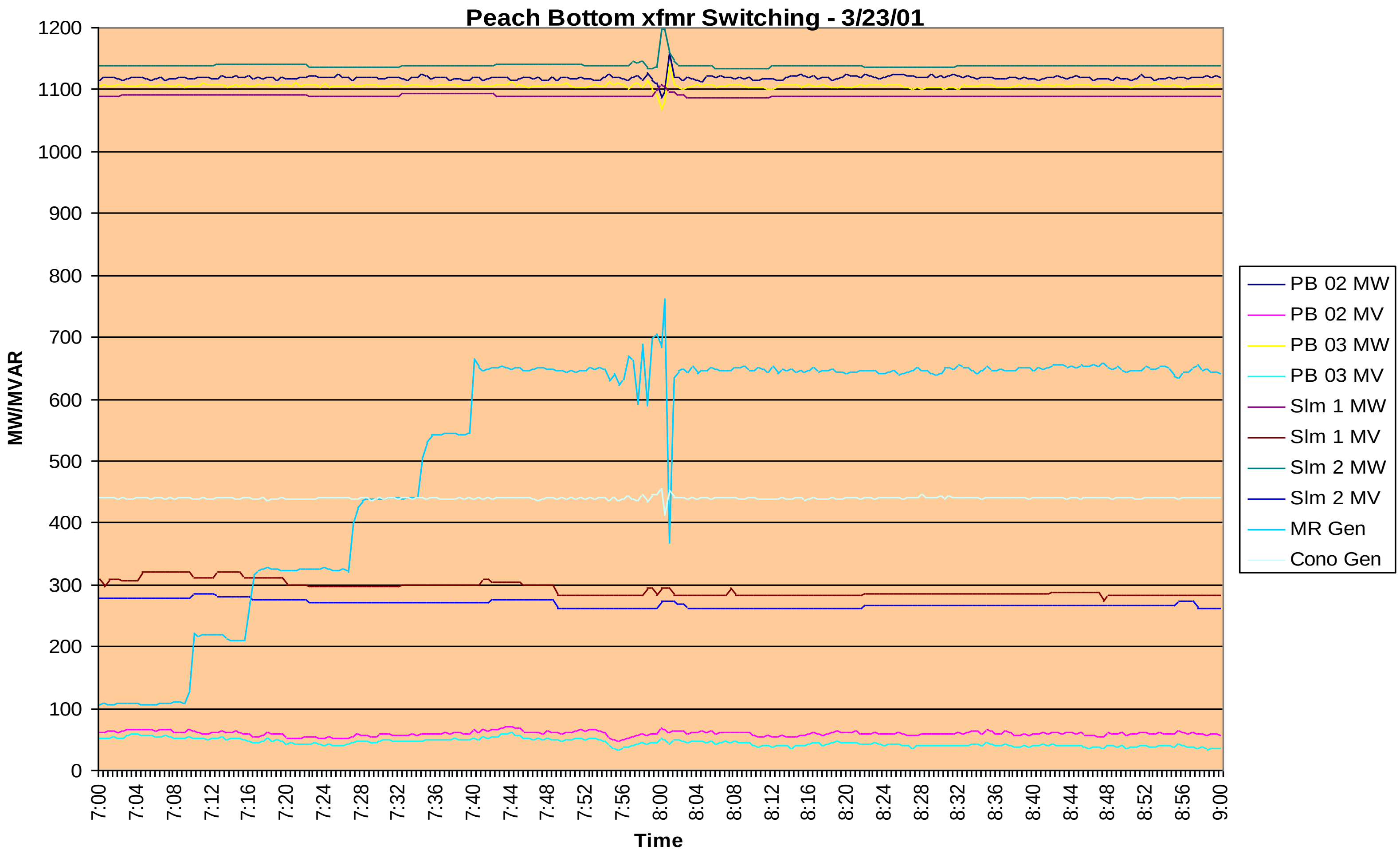
Dynamic Stability



Dynamic Stability



Dynamic Stability



Consequences of Instability

- Loss of synchronization
  - Steady state
    - phase angle exceeds 90 degrees
  - Transient
    - excessive rotor angle swings
    - units tripped following disturbance
  - Dynamic
    - continued oscillations over long periods of time
    - may damage units before they are tripped

Consequences of Instability

- 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
  - Special Relay schemes

Stability Guides

- Transmission Operations Manual – Section 5
  - Calvert Cliffs Voltage Limitations
  - Indian River #4 “Trip a Unit” Special Protection Scheme
  - Conemaugh Unit Stability
  - Conemaugh #2 Unit Stability Trip Scheme - Conemaugh-Juniata 500 kV Outage
  - PL Northern Generation Stability
  - PSE&G Artificial Island Stability
  - Rockport Operating Guide
  - Quad Cities Stability Operations
  - Many others…..

Stability and the PJM Generator Interconnection Process

- 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 generator 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

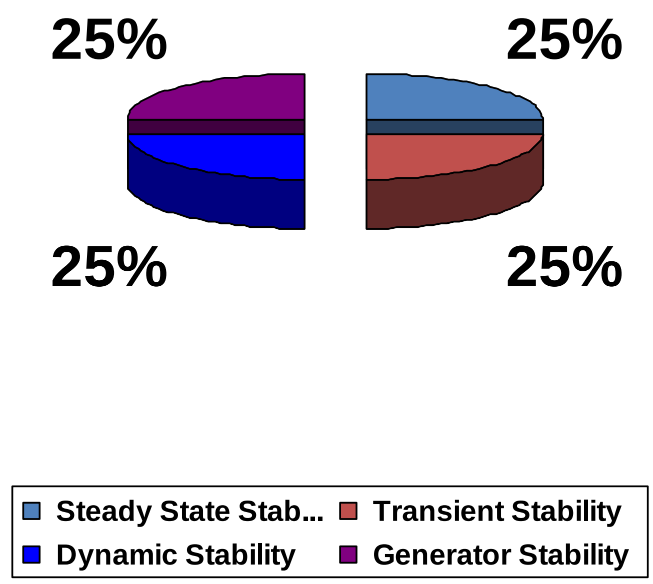
- Why are these guides so important?
  - Guides usually involve several large generators that can easily be damaged when they are operated out-of-step with the rest of the system
  - A generator that is operated out-of-step will frequently cause transmission lines to trip before the generator itself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

Stability and the PJM Generator Interconnection Process

- Conclusion:
  - 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

The ability of a generator to dampen out oscillations caused by minor disturbances is called:

1. Steady State Stability
2. Transient Stability
3. Dynamic Stability
4. Generator Stability



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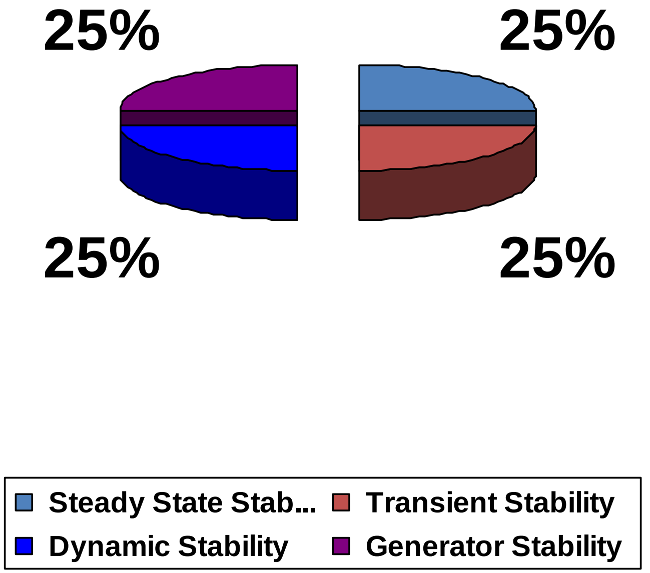
The ability of a generator to remain in synchronism immediately following a system disturbance is:

1. Steady State Stability
2. Transient Stability
3. Dynamic Stability
4. Generator Stability



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Questions?

Disclaimer:

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For additional detailed information on any of the topics discussed, please refer to the appropriate PJM manual which can be found by accessing: http://www.pjm.com/documents/manuals.aspx