INTRODUCTION TO POWER SYSTEM STABILITY

OUTLINE

1. **Basic Concepts, Definitions and Classification of Power System Stability**

2. **Conceptual Relationship between Power System Stability, Security and Reliability**

3. **Challenges to Stable and Secure Operation of Power Systems in the New Industry Environment**

4. **Comprehensive Study Procedures and Tools for Stability Analysis**

Basic Concepts

- **Power System Stability denotes the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with all system variables bounded so that the <u>system integrity</u> is preserved**

  - ☞ **Integrity of the system is preserved when practically the entire power system <u>remains intact</u> with no tripping of generators or loads, except for those disconnected by isolation of the faulted elements or intentionally tripped to preserve the continuity of operation of the rest of the system**

- **Stability is a condition of <u>equilibrium between opposing forces</u>:**
  - ☞ **instability results when a disturbance leads to a sustained imbalance between the opposing forces**
  - ☞ **instability is a run-away or run-down situation**

Basic Concepts

- The power system is a highly nonlinear system which operates in a constantly changing environment:
  - ☞ loads, generator outputs, topology and key operating parameters change continually

- When subjected to a disturbance, the system stability depends on:
  - ☞ the nature of the disturbance, as well as the initial operating condition

- The disturbances may be small or large:
  - ☞ small disturbances in the form of load changes occur continually
  - ☞ large disturbances of a severe nature, such as a short-circuit on a transmission line or loss of a large generator

Basic Concepts

- **Following a transient disturbance, if the power system is <u>stable</u> it will reach a new equilibrium state with <u>practically the entire system intact</u>:**
  - ☞ **faulted element and any connected load disconnected**
  - ☞ **actions of automatic controls and possibly operator action will eventually restore system to normal state**

- **On the other hand, if the system is unstable, it will result in a <u>run-away</u> or <u>run-down</u> situation; for example,**
  - ☞ **a progressive increase in angular separation of generator rotors, or**
  - ☞ **a progressive decrease in bus voltages**

- **An unstable system condition <u>could lead to</u> <u>cascading outages</u>, and a shut-down of a major portion of the power system**

Need for Classification of Stability

- **Power system dynamic performance is influenced by a wide array of devices with different response rates and characteristics**

- **Instability may be <u>manifested in many different ways</u> depending on system configuration and operating conditions**

  ☞ **<u>mode of instability</u> depends on which set of balancing forces experience a sustained imbalance**

- **Due to the high dimensionality and complexity of the system, it is essential to make simplifying assumptions and to analyze specific problems using the right degree of detail**

- **Not very effective to study power system stability as a single problem**

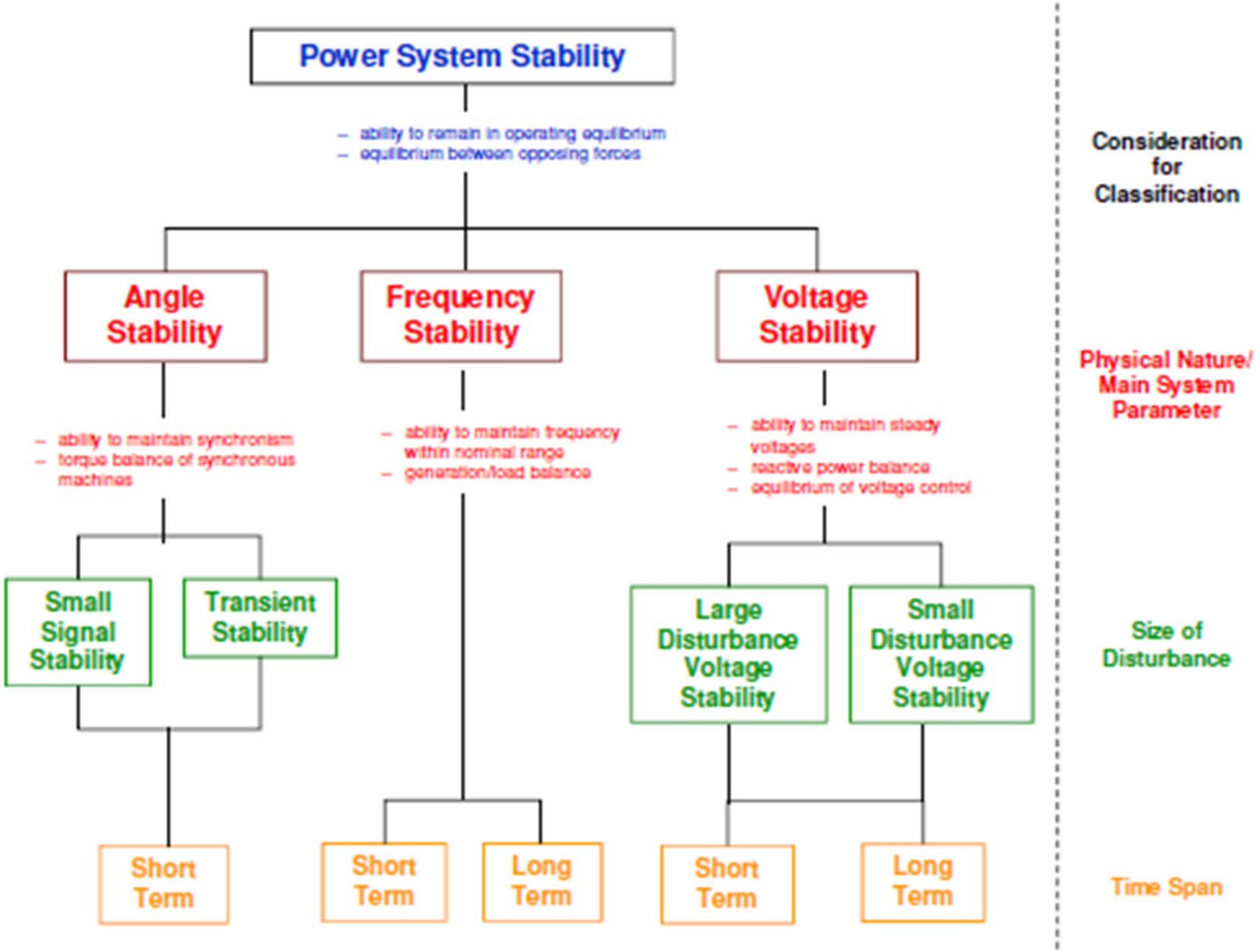
Classification of Power System Stability

- **Classification of stability into various categories greatly facilitates:**
  - ☞ **analysis of stability problems**
  - ☞ **identification of essential factors which contribute to instability**
  - ☞ **devising methods of improving stable operation**

- **Classification is based on the following considerations:**
  - ☞ **physical nature of the resulting instability**
  - ☞ **size of the disturbance considered**
  - ☞ **devices, processes, and the time span involved**

- **We should always <u>keep in mind the overall stability</u>**
  - ☞ **solutions to problems of one category should not be at the expense of another**

Classification of Power System Stability



Rotor Angle Stability

- **Ability of interconnected synchronous machines to remain in synchronism under normal conditions and after being subjected to a disturbance**

- **Depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system**

- **If the generators become unstable when perturbed, it is as a result of**
  - ☞ **a run-away situation due to torque imbalance**

- **A fundamental factor is the manner in which power outputs of synchronous machines vary as their rotor angles swing**

- **Instability that may result occurs in the form of increasing angular swings of some generators leading to loss of synchronism with other generators**

Rotor Angle Stability

- **Under steady-state conditions, there is equilibrium between electromagnetic and mechanical torques**

- **If the system is perturbed, this equilibrium is upset, causing acceleration or deceleration of the rotor**

  ☞ **synchronism is maintained through development of <u>restoring forces</u>**

- **Change in electrical torque can be resolved into two components:**

$$\Delta Te = (T_S \bullet \Delta\delta) + (T_D \bullet \Delta\omega)$$

  ☞ **T_S is the <u>synchronizing torque</u> coefficient**

  ☞ **T_D is the <u>damping torque</u> coefficient**

- **Lack of synchronizing torque results in <u>aperiodic</u> <u>instability</u>**

- **Lack of damping torque results in <u>oscillatory</u> <u>instability</u>**

Transient Stability

- **Term used traditionally to denote large-disturbance angle stability**

- **Ability of a power system to maintain synchronism when subjected to a severe transient disturbance:**
  - ☞ **resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power-angle relationship**
  - ☞ **stability depends on the initial operating condition, severity of the disturbance, and strength of post-fault transmission network**
- **A wide variety of disturbances can occur on the system:**
  - ☞ **varying degree of severity and probability of occurrence**
  - ☞ **the system is, however, designed and operated so as to be stable for a selected set of contingencies**
    - ➢ **usually, transmission faults: L-G, L-L-G, three phase**

Small-Signal (Angle) Stability

- **Small-Signal (or Small Disturbance) Stability is the ability of a power system to maintain synchronism under small disturbances:**
  - ☞ **such disturbances occur continually on the system due to small variations in loads and generation**
  - ☞ **disturbance considered sufficiently small if <u>linearization</u> of system equations is permissible for analysis**
  - ☞ **instability that may result can be of two forms:**
    - ➢ **aperiodic increase in rotor angle due to lack of sufficient synchronizing torque**
    - ➢ **rotor oscillations of increasing amplitude due to lack of sufficient damping torque**

- **Corresponds to Liapunov's first method of stability analysis**

Voltage Stability

- **Ability of power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition**

- **A system experiences voltage instability when a disturbance, increase in load demand, or change in system condition causes:**
  - ☞ **a progressive and uncontrollable fall or rise in voltage of some buses**

- **Main factor causing voltage instability is the inability of power system to maintain a proper balance of reactive power and voltage control actions**

- **The driving force for voltage instability is usually the <u>loads</u>. Following a condition of reduced transmission system voltages,**
  - ☞ **power consumed by the loads tend to be restored by the action if distribution voltage regulators, tap changing transformers, and thermostats**

Voltage Stability

- **The possible outcome of voltage instability:**
  - ☞ **loss of load in the area where voltages reach unacceptably low levels, or**
  - ☞ **loss of integrity of the power system**

- **Progressive but rapid drop in bus voltage can also be associated with rotor angles going out of step:**
  - ☞ **voltages at points close to the electrical center reach very low values**
  - ☞ **a much faster phenomenon**
  - ☞ **not a voltage instability phenomenon**

- **In contrast, sustained fall of voltage related to voltage instability occurs where rotor angle stability is not an issue or the cause:**
  - ☞ **usually a slower phenomenon**

Frequency Stability

- **Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load.**
- **It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load.**
- **Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads.**

Frequency Stability

- **Ability to maintain steady frequency within a nominal range following a disturbance resulting in a significant <u>imbalance between system generation</u> <u>and load</u>:**
  - ☞ **instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads**
  - ☞ **determined by the overall response of the system as evidenced by its mean frequency rather than relative motions of rotors of generators**
- **In a small "island" system, frequency stability could be of concern for any disturbance causing a significant loss of load and/or generation**
- **In a large interconnected system, frequency stability would be of concern only following a severe system upset resulting in the system splitting into one or more islands**
- **Generally, frequency stability problems are associated with inadequacies in equipment responses, poor coordination of control and protection systems**

Relationship Between the Concepts of Reliability, Security and Stability of a Power System

- **Stability: refers to the continuance of intact operation following a disturbance**
  - ☞ **depends on the operating condition and the nature of the physical disturbance**

- **Security: the degree of risk in the ability to survive imminent disturbances (contingencies) without interruption of customer service.**
  - ☞ **depends on the system operating condition as well as the contingent probability of disturbances.**

- **Reliability: probability of satisfactory operation over the long run**
  - ☞ **denotes the ability to supply adequate electric service on a nearly continuous basis, with few interruptions over an extended time period**

Essential Differences Between the Three Aspects of Power System Performance

- **Reliability is the overall objective in power system design and operation**
  - ☞ **To be reliable the power system must be secure most of the time.**

- **To be secure the system must be stable but must also be secure against other contingencies that would not be classified as stability problems, e.g. damage to equipment such as an explosive failure of a cable, fall of transmission towers due to ice loading or sabotage.**

- **As well, a system may be stable following a contingency, yet insecure due to post-fault system conditions resulting in equipment overloads or voltage violations**

Essential Differences Between the Three Aspects of Power System Performance

- System security may be further distinguished from stability in terms of the resulting consequences.

  ☞ For example, two systems may both be stable with equal stability margins, but one may be relatively more secure because the consequences of instability are less severe

- Security and stability are time-varying attributes which can be judged by studying the performance of the power system under a particular set of conditions.

- Reliability, on the other hand, is a function of the time-average performance of the power system; it can only be judged by consideration of the system's behaviour over an appreciable period of time.

Design and Operating Criteria for Power System Security

- For reliable service, a power system must remain intact and be capable of withstanding a wide variety of disturbances
- Impractical to achieve stable operation for all possible disturbances or contingencies
- The general practice is to design and operate the power system so that the more probable contingencies can be sustained without loss of system integrity
  - ☞ "Normal Design Contingencies"
  - ☞ loss of any single element, either spontaneously or proceeded by a fault
- This is referred to as the "N-1 criterion" because it examines the behaviour of an N-component grid following the loss of any one major components
- Events that exceed the severity of normal design contingencies can in fact occur:
  - ☞ "Extreme Contingencies"
  - ☞ measures should be taken to minimize their occurrence and impact

Power System Stability: Historical Perspective

- Recognized as an important problem for secure system operation since the 1920s

- Major concern since the infamous November 9, 1965 blackout of Northeast U.S.A. and Ontario, Canada
  - ☞ criteria and analytical tools used worldwide until now largely based on the developments that followed this blackout

- Presents many new challenges for today's power systems

Traditional Approach to Power System Stability

- Focus on "transient (rotor angle) stability"

- System designed and operated to withstand

  - ☞ loss of any single element preceded by single-, double-, or three-phase fault
  - ☞ referred to as "N-1" criterion

- Analysis by time-domain simulations of selected operating conditions
  - ☞ scenarios based on judgment/experience

- Operating limits based on off-line studies

  - ☞ system operated conservatively within pre- established limits

Challenges to Secure Operation of Today's Power Systems

- Power systems are more complex
  - ☞ national/continental/regional grids
  - ☞ many processes whose operations need to be coordinated; thousands of devices requiring a harmonious interplay
  - ☞ complex modes of instability

- "Deregulated" market environment
  - ☞ many entities with diverse business interests
  - ☞ system expansion and operation driven by economic drivers
  - ☞ lack of coordinated planning!
  - ☞ power systems pushed "harder"; more frequent changes in power flow patterns

Comprehensive Study Procedures and Tools

- **All categories of system stability should be considered**
- **Stability depends on the harmonious interplay of all elements of the power system:**
  - ☞ **knowledge of the characteristics of individual elements is essential for the understanding and study of power system stability**
- **Proper selection and coordination of controls and protective equipment are of paramount importance**
- **Analytical tools and system models should be validated against measured response**
- **Analytical tools should:**
  - ☞ **not only determine if system stable or unstable**
  - ☞ **but also provide insight into factors influencing stability**