EE 742
Power System Dynamics, Stability and Control

Y. Baghzouz
ECE Department
UNLV

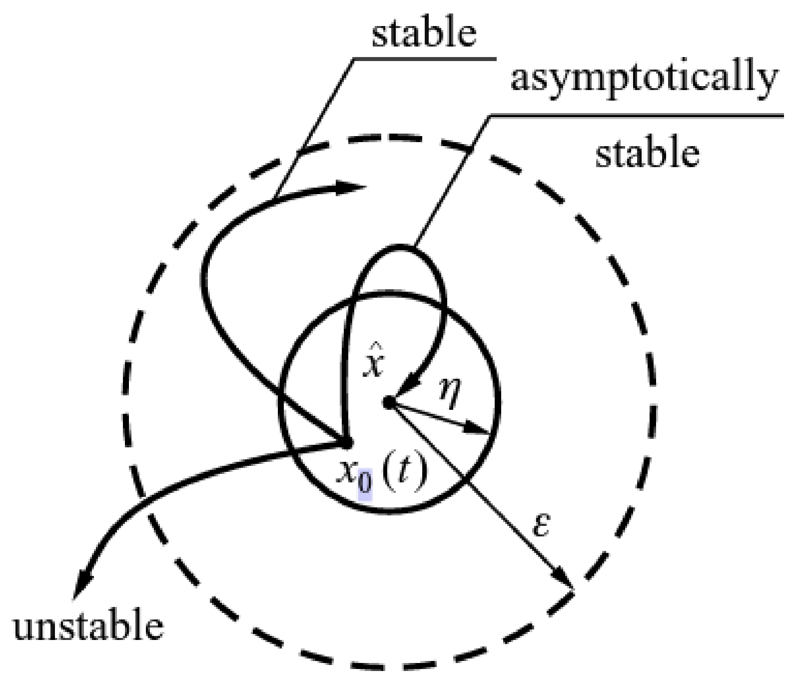
Course Content

- **Part I:** (Chapters 1–3) introduction, power system components, steady-state operation
- **Part II:** (Chapters 4–10) electromagnetic phenomena, electromechanical dynamics (small and large), wind power, Solar Power, voltage stability, frequency stability and control, stability enhancement.
- **Part III:** (Chapters 11–14) advanced system modeling, multi-machine systems, simulation tools, model reduction and equivalents.

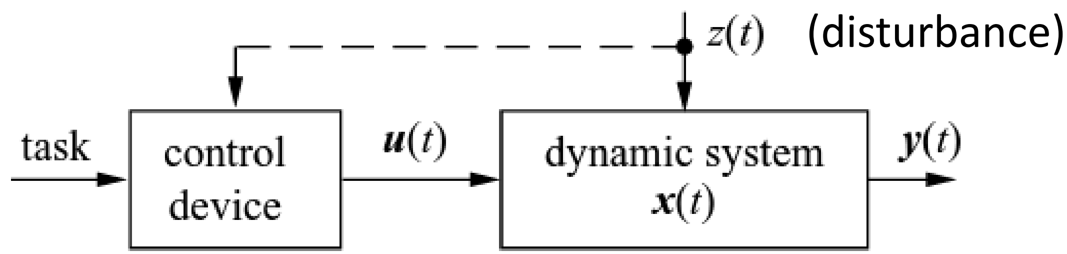
Some definitions related to stability analysis

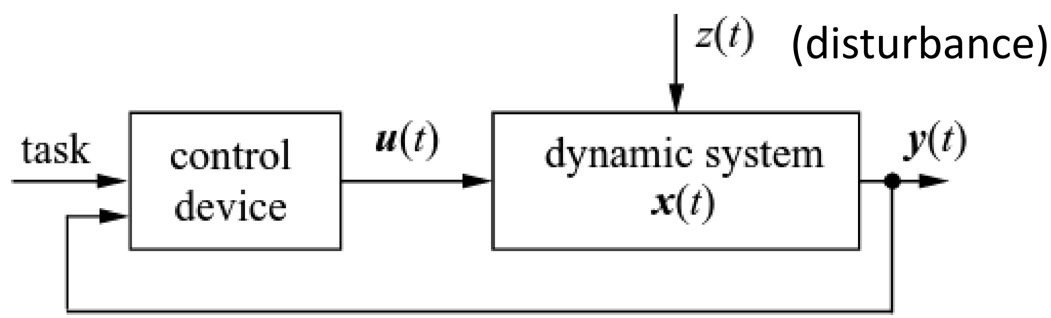
- *System state*: describes the system's operating conditions.
- *State variables*: are the minimum set of variables $x_1, x_2, \ldots, x_n$ uniquely defining the system state.
- *State vector*: state variables written as a vector $\mathbf{x} = [x_1, x_2, \ldots, x_n]^T$.
- *State space*: a normalized space of coordinates corresponding to the state variables.
- *Static system*: when its state variables are time invariant.
- *Dynamic system**: when its state variables are functions of time.
- *Linear system*: can be modeled by $\dot{\boldsymbol{x}} = \boldsymbol{A}\,\boldsymbol{x},$ where ***A*** is a square matix.
- Non-linear system: can be modeled by $\dot{\boldsymbol{x}} = \boldsymbol{F}(\boldsymbol{x})$ where ***F(x)*** is a vector of nonlinear functions.
- *Equilibrium point:* $\boldsymbol{F}(\hat{\boldsymbol{x}}) = 0 \quad \text{or} \quad \boldsymbol{A}\,\hat{\boldsymbol{x}} = 0.$

- *Disturbance:* an un-intentional event affecting the system
- *Stable system, asymptotically stable, unstable* (see state variable trajectory in Figure below).
  - The stability of a linear system <u>does not</u> depend on the size of the disturbance.
  - The stability of a nonlinear system <u>generally depends</u> on the size of the disturbance.
- *Critical disturbance:* The largest disturbance for which a nonlinear system remains stable.



- *Control:* action affecting a dynamic system which aims to achieve a particular behavior.
- *Control signal:* $\boldsymbol{u}(t)$ - affects the system to achieve a desired output.
- *Output signal:* $\boldsymbol{y}(t)$ - serves to assess whether or not the desired goal is achieved.
- *Open loop and closed loop controls:* (see figure below)
- Nonlinear system with controls: $\dot{\boldsymbol{x}} = \boldsymbol{F}(\boldsymbol{x}, \boldsymbol{u})$ and $\boldsymbol{y} = \boldsymbol{G}(\boldsymbol{x}, \boldsymbol{u})$,
- Linear system with controls: $\dot{\boldsymbol{x}} = \boldsymbol{A}\,\boldsymbol{x} + \boldsymbol{B}\,\boldsymbol{u}$ and $\boldsymbol{y} = \boldsymbol{C}\,\boldsymbol{x} + \boldsymbol{D}\,\boldsymbol{u}$.

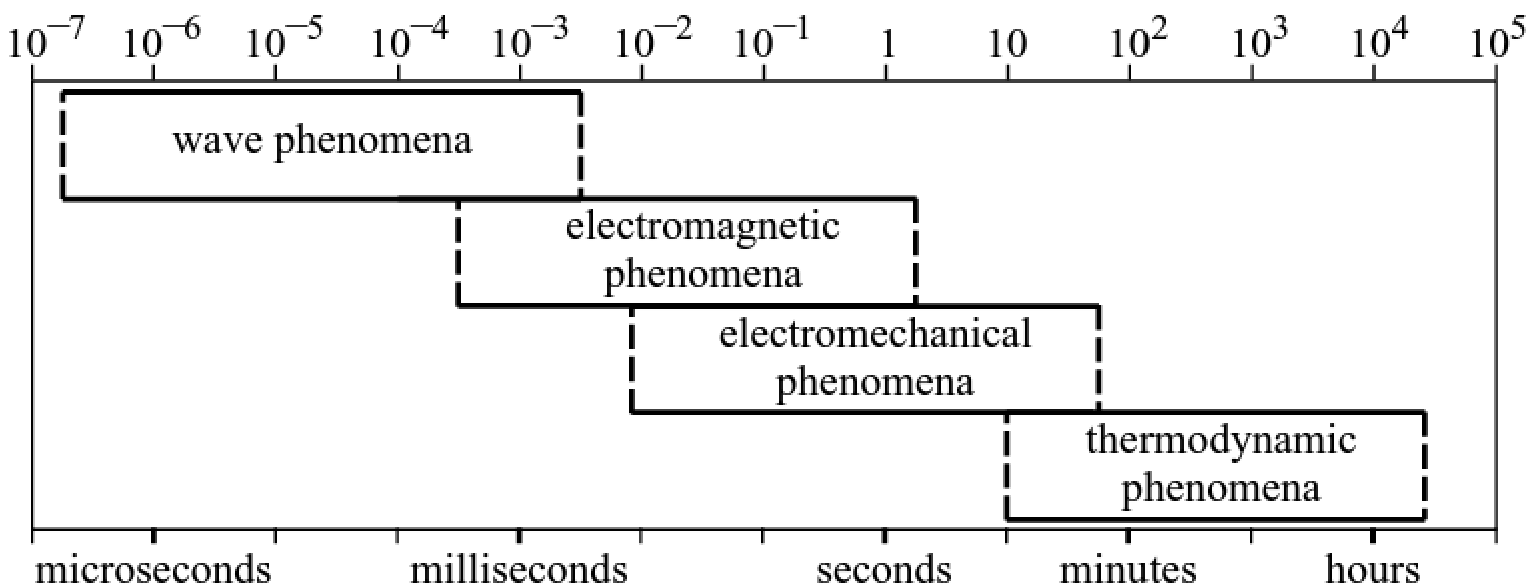




Classification of power system dynamics

(based on time frame or physical character)

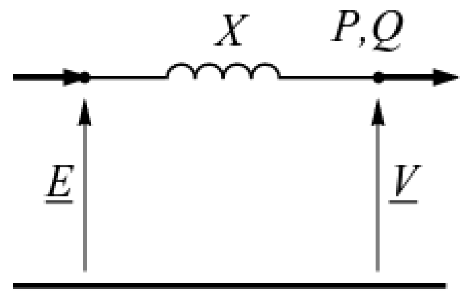
- *Wave or surge:* caused by lightning strikes or switching surges in high voltage transmission lines.
- *Electromagnetic:* dynamics that takes place in the machine windings following a disturbance (e.g., a fault)
- *Electromechanical:* oscillation of the rotating masses of the generators following a disturbance.
- *Thermo-dynamics:* changes which result from the boiler control actions (AGC) following a disturbance.

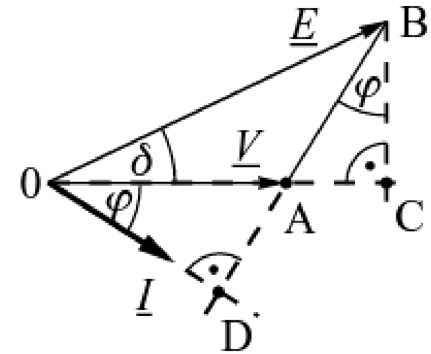


Real and Reactive Power Characteristics in a network element

- P-δ

$$P = \frac{EV}{X}\sin\delta.$$

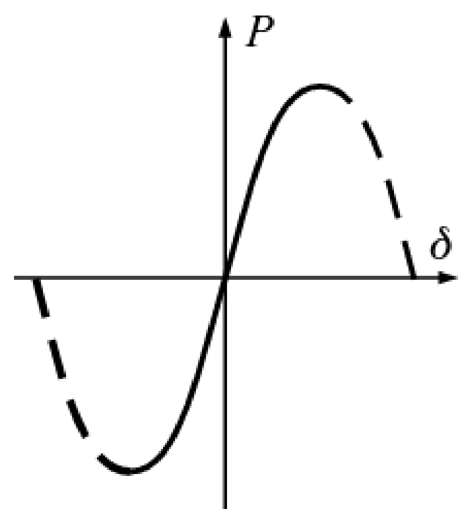


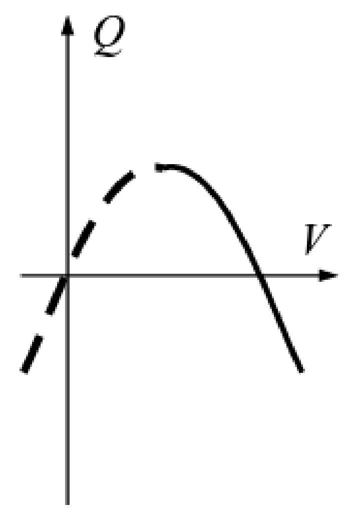


- Q-V

$$Q = \frac{EV}{X}\cos\delta - \frac{V^2}{X}.$$

$$Q = \sqrt{\left(\frac{EV}{X}\right)^2 - P^2} - \frac{V^2}{X}.$$

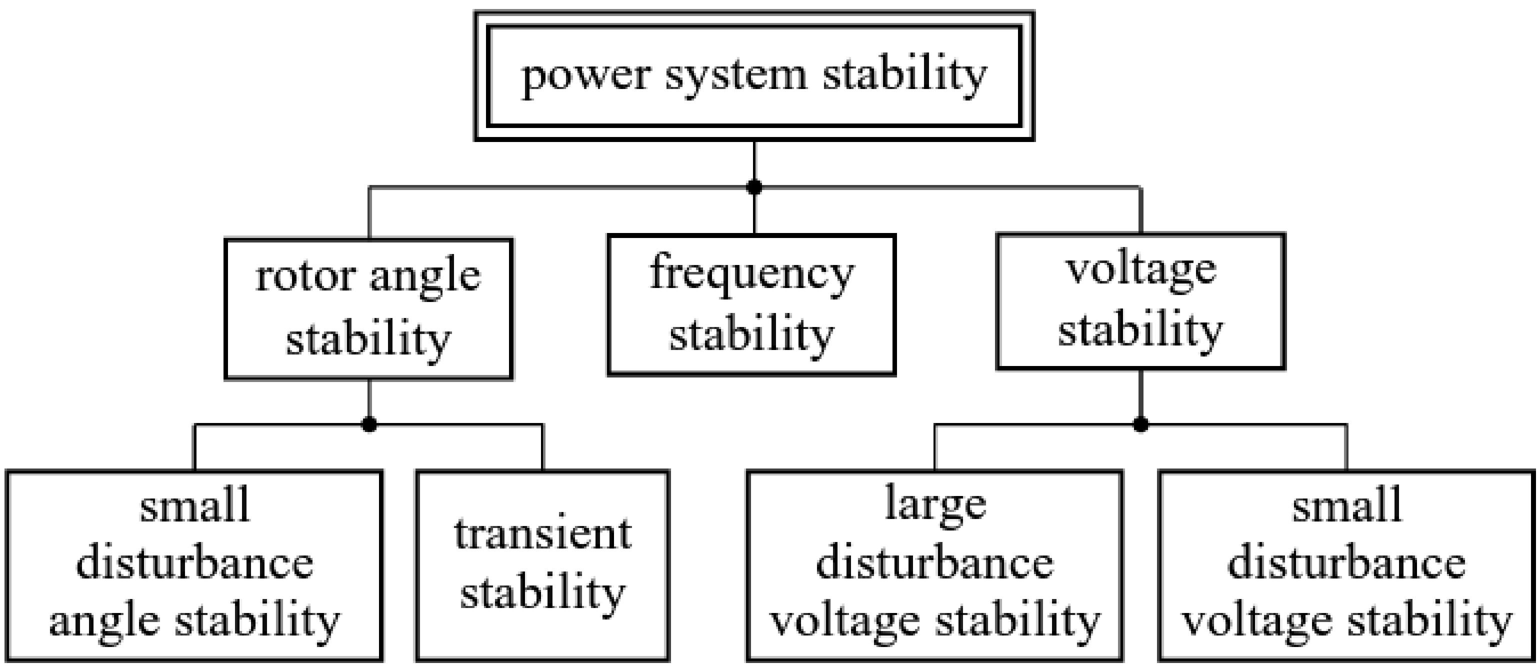




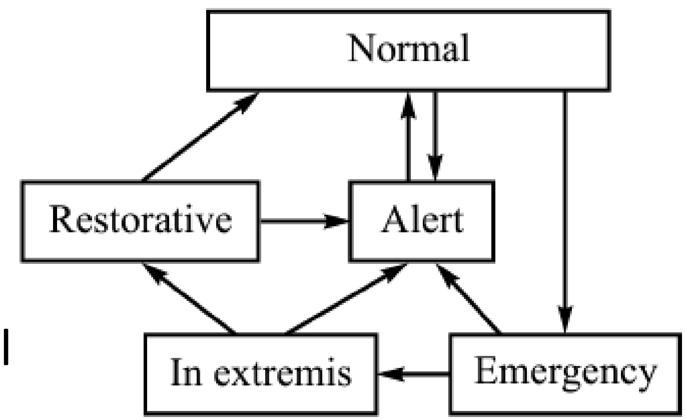
HW # 1

- Derive the active and reactive power expressions for the following cases:
  a) When a resistance R is added in series with X.
  b) When the line is purely resistive with resistance R.

- *Power system stability:* ability to regain an equilibrium state after being subjected to a disturbance. Stability depends on both the initial conditions and the size of the disturbance.
- *Classification of power system stability:*
  - *Rotor angle stability: (Small and large disturbances)*
  - *Frequency stability:*
  - *Voltage stability: (Small and large disturbances)*
- *Power system security*: ability of a power system to survive plausible contingencies without customer service interruption.
- *Contingencies:* set of imminent disturbances.



- *System operating states:*
  - *Normal state:* all system variable are within their technical constraints
  - *Alert state:* when one or more variables exceed their limits, but the system is still intact. Preventive action is needed to restore to normal state.
  - *Emergency state:* system is still intact, but the violation of constraints is more severe. Preventive actions are necessary.
  - *In extremis state:* system is no longer intact (e.g. tripped generators, load shedding. Partial blackout).
  - *Restorative state:* state where control actions are taken to reconnect all facilities.



- *System security analysis:*
  - *Static security assessment (SSA):* determine bus voltages and line power flows due to contingencies.
  - *Dynamic security assessment (DSA):* determine rotor (power) angle, voltage and frequency stability and voltage excursions due to contingencies.

Components of dynamic security assessment