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EE 521: Analysis of Power Systems

Lecture 15
Intro to Stability Concepts

Fall 2009

Mondays & Wednesdays 5:45-7:00

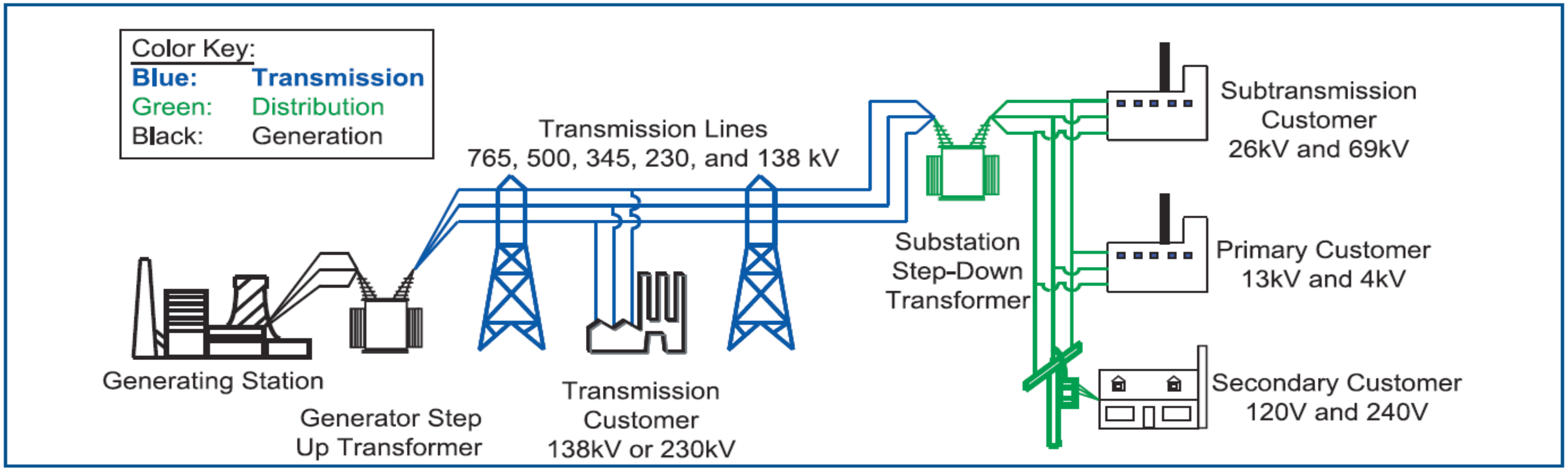
August 24 – December 18

Test 216

Topics

- Why to study stability problems
- Types of power system stability problems
  - Angular stability
    - Transient stability
    - Small signal stability
  - Voltage stability
    - Large-disturbance voltage stability
    - Small-disturbance voltage stability
- Power-Angle Equation
- Power-Voltage Curve

Power System Structure



- Power flow studies the network, with generation and load given – steady state analysis
- What about sudden changes in generation and load?
- What about sudden changes in the network?

Power System Stability

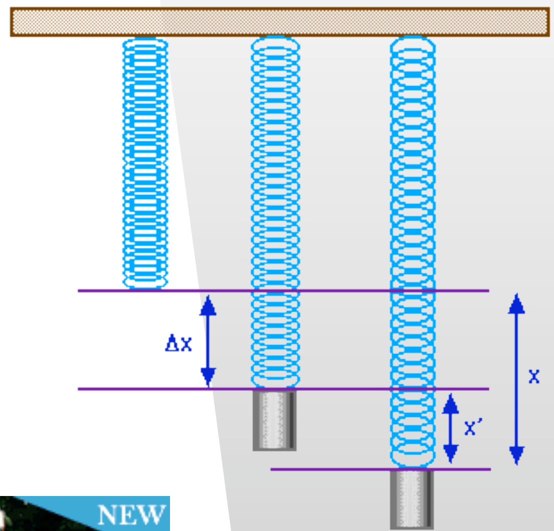
- Power system stability studies the behavior of power systems under conditions such as sudden changes in generation or load or short circuit on transmission lines
  - The study evaluates the impact of disturbances on the behavior of power systems

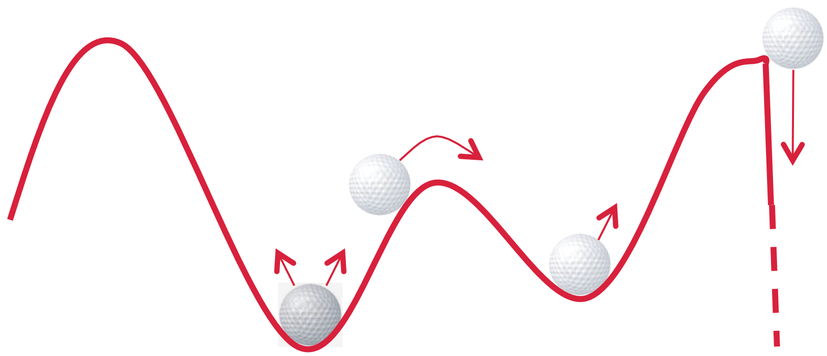
Power System Dynamics

- Power systems are highly dynamic
  - Constant energy conversion from one form to another
    - Generation: natural energy forms (potential, thermal, kinetic) → kinetic energy → electricity
    - Load: electricity → useful forms (light, mechanical, thermal)
  - Constant balance of generation and load
    - No large storage of electricity
- Therefore, power system stability is an important and challenging problem
  - More complex due to interconnection and new technology
  - Less margin due to economic and environmental constraints

Dynamic System Examples

- Can it reach a steady state?
- Can it remain in a steady state?





Power System Stability Categories

	Generation (Angle Stability)	Load (Voltage Stability)	
Large Disturbance	Transient Stability	Large Disturbance Voltage Stability	*Can the system reach a steady state?*
Small Disturbance	Small Signal Stability	Small Disturbance Voltage Stability	*Can the system remain at a steady state?*
	How much power can be transferred from the generator to the system?	*How much power can be transferred from the system to the load?*	

Analytical Tools for Stability Studies

- Slide rules and mechanical calculators
- Network analyzers
  - Scaled model of a real system
- Electronic analog computers
- Digital computers
- High performance computers
  - Parallel computing hardware and software

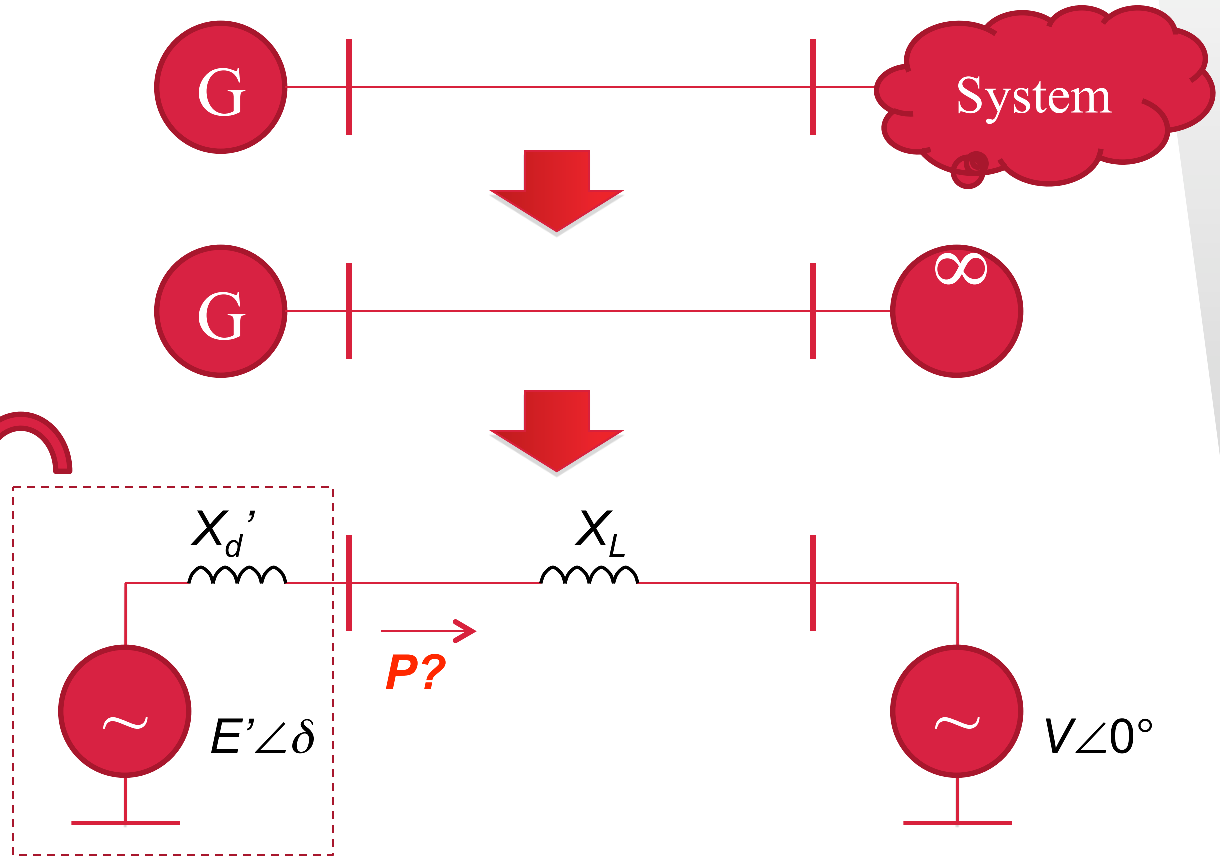
Purposes of Stability Studies

- Planning
  - Transmission expansion (new lines, new substations, …)
  - Voltage support (Var supply)
- Design
  - Control design: excitation, Power System Stabilizers, FACTS devices
  - Relay settings
- Operation
  - Transfer limits
  - Load shedding schemes
  - Remedial action schemes

Generator Stability (Angle Stability)

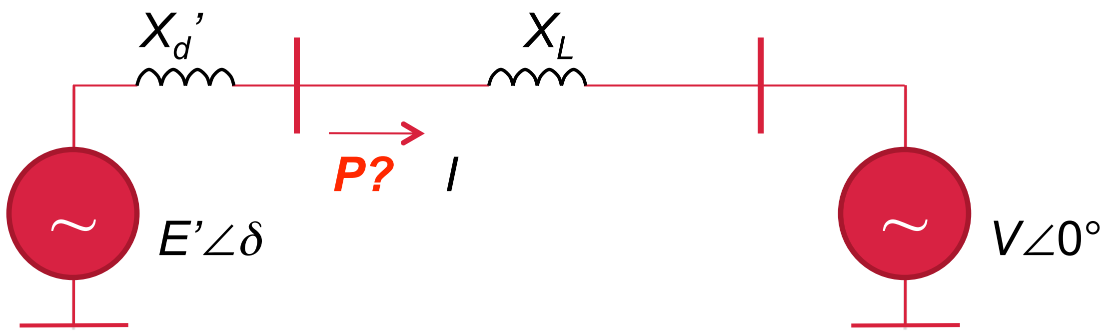
- Study the interaction between a generator and the system.
  - How much power can be transferred to the system?
- The dynamics of generators are represented by differential equations
- Numerous coupled differential equations are necessary to fully model a generator
- Numerical integration is a common method to solve the differential equations

Single-Machine-Infinite-Bus System

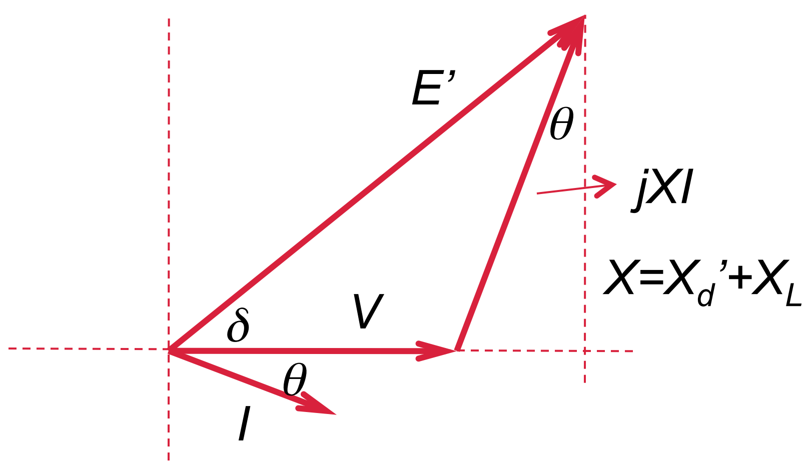


Machine (generator) is modeled as an internal voltage behind its transient reactance.

Power-Angle Equation



Phasor diagram:



By definition:

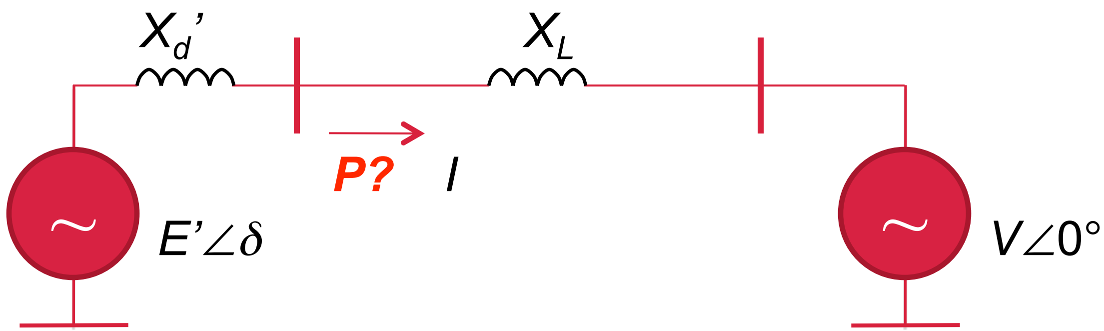
$$P = VI\cos\theta$$

From the phasor diagram:

$$XI\cos\theta = E'\sin\delta$$

$$\boxed{P = \frac{E'V}{X}\sin\delta = \frac{E'V}{X'_d + X_L}\sin\delta}$$

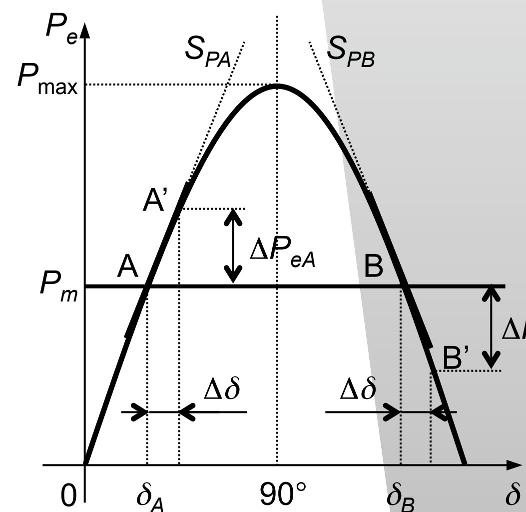
Maximum Power Transfer



$$P = \frac{E'V}{X}\sin\delta = \frac{E'V}{X_d' + X_L}\sin\delta$$

Observations:

1. Maximum power transfer at $\delta = 90°$.
2. With a given mechanical power input P_m to the generator, the operating point, i.e. δ, can be found at the intersection point.
3. There exist two operating points. Only the smaller one is stable.



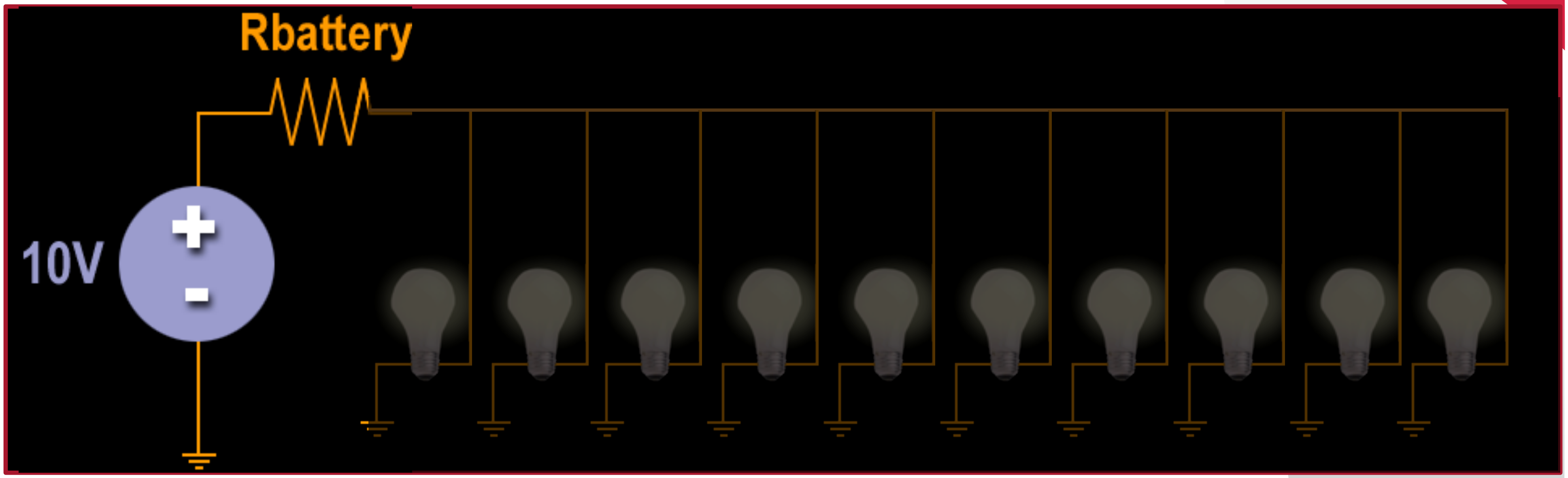
Example: Power-Angle Equation

- See notes.
  - Normal operation.
  - 3-phase-ground fault.
  - Tripping a line to clear the fault.

Load Stability (Voltage Stability)

- Study the interaction between the system and the load.
  - How much power can be transferred to the load from a system without voltage collapse?
- Voltage stability is highly affected by load characteristics
  - ZIP load (algebraic equations)
  - Motor load (differential equations)
- Load modeling is very challenging due to diversity, variability, and aggregation.
  - Many efforts are ongoing (e.g. WECC)

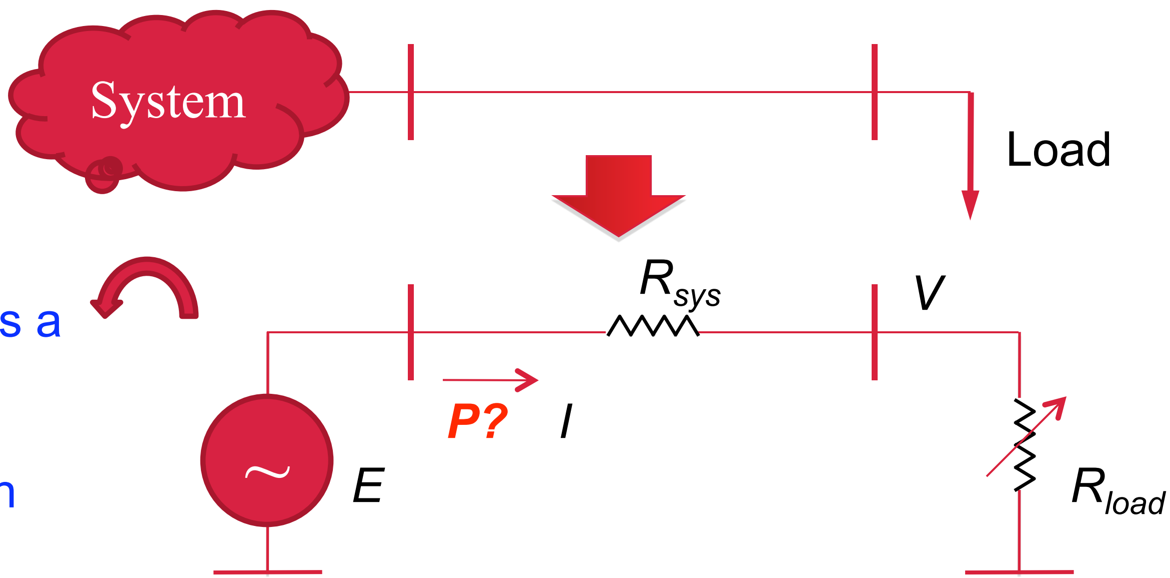
Bulb Examples



- 10 Volt battery
  - Internal resistance of 1 Ohm
- 20 Watt Light bulbs
  - Each light bulb resistance is 5 Ohms

Why the room becomes darker with more bulbs added?

Power-Voltage Curve



System is modeled as a constant voltage source with an impedance

$$P = VI = V\frac{E-V}{R_{sys}} = \left(\frac{E}{R_{sys}}\right)V - \left(\frac{1}{R_{sys}}\right)V^2$$

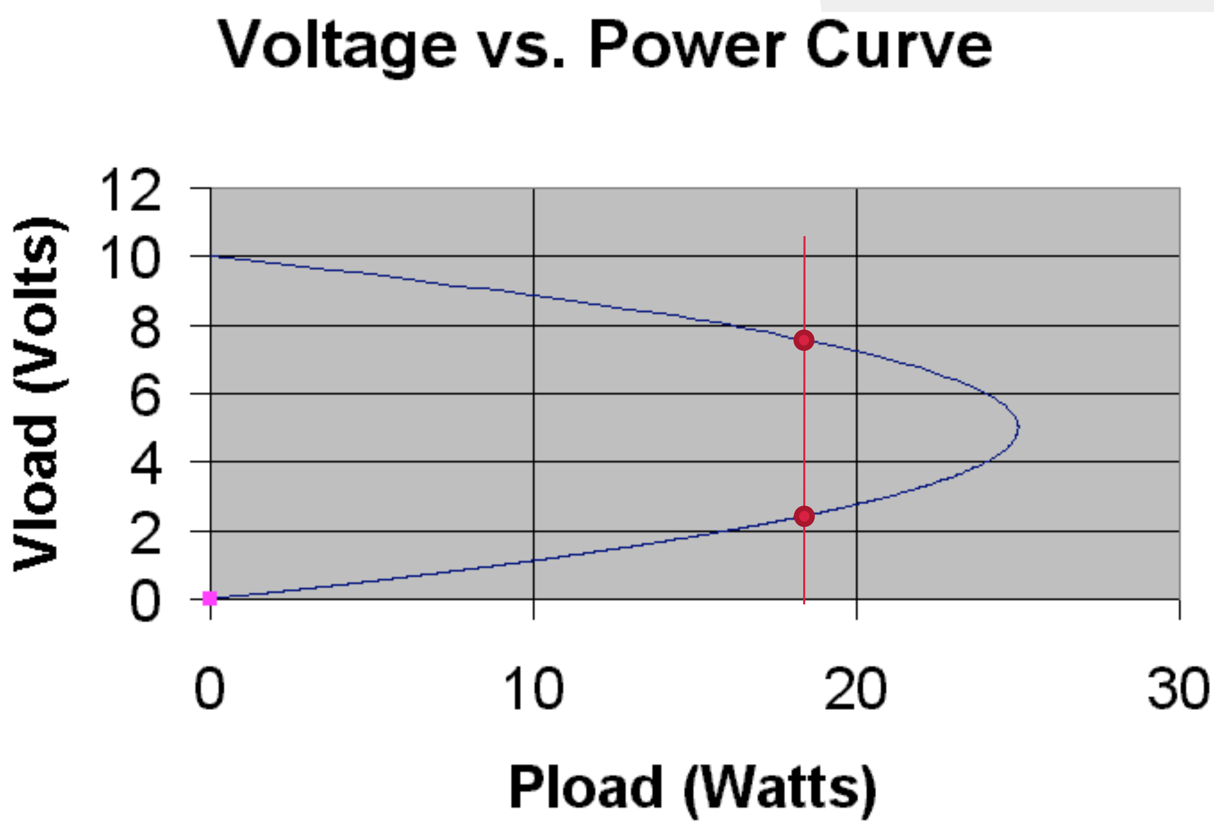
$$\boxed{\left(\frac{1}{R_{sys}}\right)V^2 - \left(\frac{E}{R_{sys}}\right)V + P = 0}$$

Maximum Power Transfer

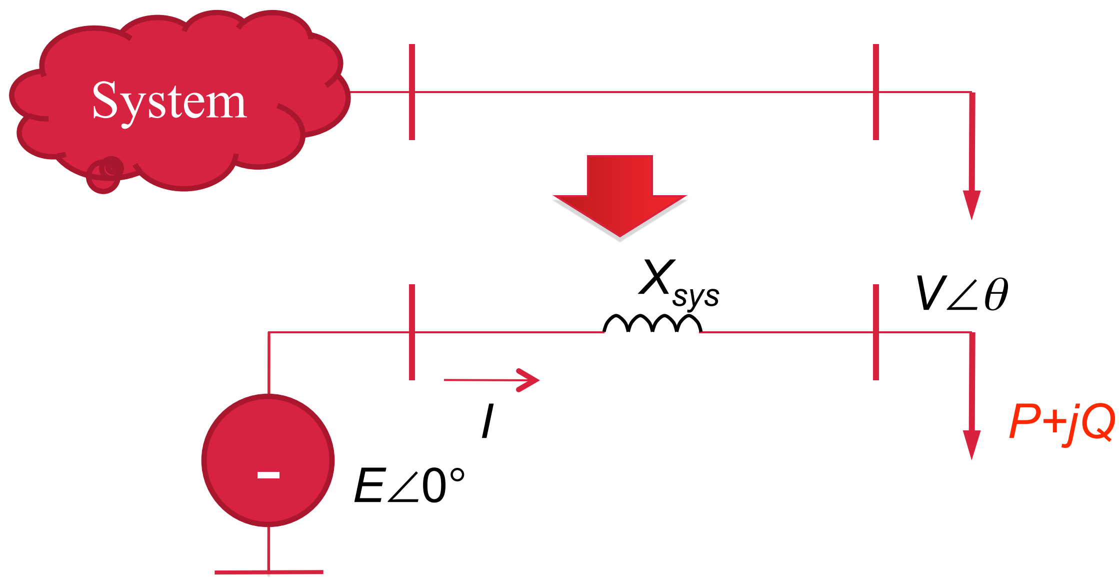
$$\left(\frac{1}{R_{sys}}\right)V^2 - \left(\frac{E}{R_{sys}}\right)V + P = 0$$

Observations:

1. Maximum power transfer at $V = E/2$, i.e. $R_{load} = R_{sys}$.
2. With a given constant load P_{load}, the operating point, i.e. V, can be found at the intersection point.
3. There exist two operating points. Only the higher voltage point is feasible.



Power-Voltage Curve for AC Systems



Assignments (due: October 26):

1. Derive the power-voltage equation with a purely resistive load, i.e. $Q = 0$.
2. Determine maximum power transfer.
3. Determine the condition where the maximum power transfer occurs.

Questions?