

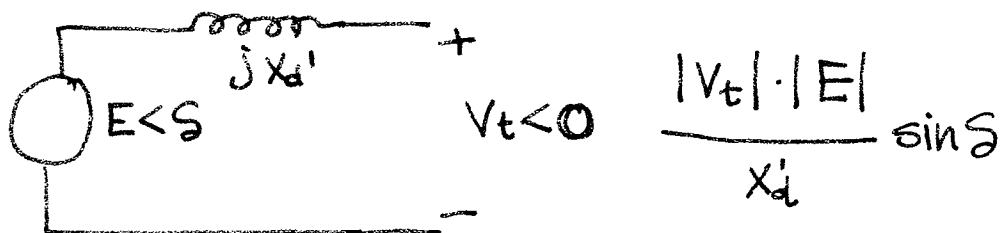
LECTURE 2/1

TRANSIENT STABILITY

Explain what the Canonical problem is

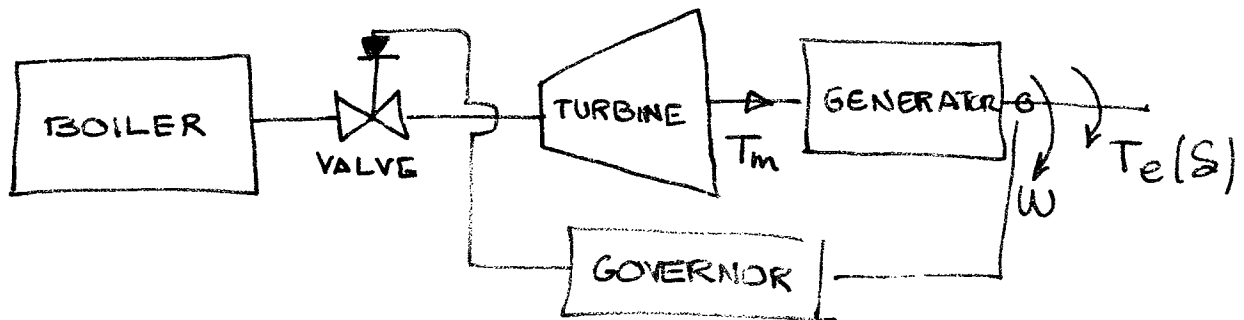
- In order to operate as an interconnected system all of the generators (and other synchronous machines) must remain in synchronism with one another.
- Keep in mind that the frequency of the system is ~~high~~ intimately related to the speed at which machines turn.
- Synchronism requires that (for two pole machines) the rotors turn at exactly the same speed.
- Loss of sync results in a condition in which no net power can be transferred between the machines.
- A system is said to be transiently unstable if following a disturbance one or more of the generators lose sync.

SIMPLEST GENERATOR



δ is the power angle (remember 430!)

Generator mechanical block



Newton's second law:

$$J \cdot \frac{d^2 \delta}{dt^2} = T_m - T_e(\delta) - T_D$$

- T_D : Damping torque
- T_e : Electric torque
- T_m : Mechanical torque.

$$T_e(\delta) =$$

Power = torque x angular speed

$$T_m = J \cdot \frac{d^2 \delta}{dt^2} + T_e(\delta) + T_D$$

when the generator is turning at ω_s speed, we get:

$$T_m \omega_s = \left(J \cdot \frac{d^2 \delta}{dt^2} + T_e(\delta) + T_D \right) \omega_s = P_m$$

$$M \ddot{\delta} + D \dot{\delta} = P_m - \frac{E_a V_{\infty}}{X_d}$$

Let's assume initially there is no damping $b=0$

$$P_m - P_e(\delta) = J \cdot \frac{d^2 \delta}{dt^2} \omega_s \rightarrow \alpha$$

P_m is the mechanical power input which we assume constant

$$\theta_m = \omega_s t + \delta$$

$$\omega_m = \frac{d\theta_m}{dt} = \dot{\theta}_m = \omega_s + \dot{\delta}$$

$$\alpha_m = \dot{\omega}_m = \ddot{\delta}$$

$$P_m - P_e(\delta) = J \omega_s \alpha_m = J \omega_s \ddot{\delta}$$

Inertia of the machine
at sync speed

Convert to per unit by dividing by rating S_B

$$\frac{P_e}{S_B} - \frac{P_e(\delta)}{S_B} = \frac{J \omega_s \ddot{\delta}}{\omega_s} \cdot \frac{J \omega_s \ddot{\delta}}{S_B} \cdot \frac{2\omega_s}{2\omega_s}$$

$$\frac{P_e}{S_B} - \frac{P_e(\delta)}{S_B} = \frac{J \omega_s^2}{2 S_B} \cdot \frac{1}{\pi f_s} \ddot{\delta}$$

$$\frac{J \omega_s^2}{2 S_B} \triangleq H : \text{per-unit inertia constant (sec)}$$

$$M = \frac{H}{\pi f_s} \quad \text{then} \quad P_m - P_e(\delta) = M \cdot \ddot{\delta}$$

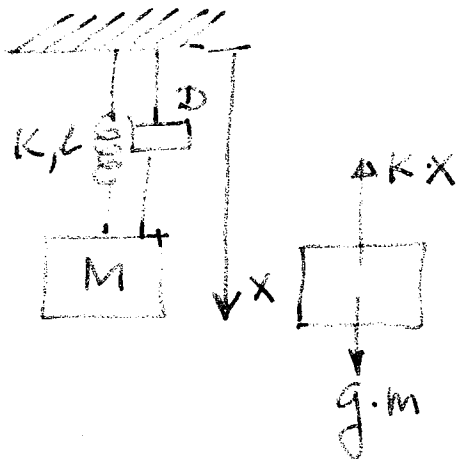
where all the quantities are in pu.

$$P_m - P_e(s) = M \cdot \ddot{S}$$

Adding damping we get: $P_m - P_e(s) = M \ddot{S} + D \dot{S}$

This eq is analogous to a mass suspended by a spring

nonlinear
spring



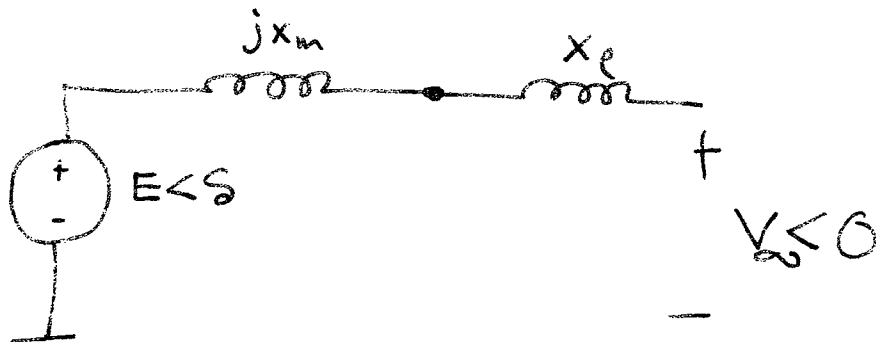
$$-K \cdot x + g \cdot m = M \cdot \ddot{x} + D \dot{x}$$

$$M \ddot{x} + D \dot{x} =$$

$$M \ddot{x} = -D \cdot \dot{x} - K(x - l) + M g$$

This is why the $M \ddot{S} = P_m - P_e(s)$ is the so-called swing equation.

SINGLE - MACHINE INFINITE BUS



$$M \ddot{S} + D \dot{S} = P_m - \frac{E V_0}{X_d' + X_f} \sin S$$

If we include a dissipative term, then the energy should decrease over time

$$V(\theta, \dot{\theta}) = \frac{1}{2} M(\dot{\theta})^2 + P_m(\theta^0 - \theta) + \frac{E V_\infty}{X_m + X_l} (\cos \theta_0 - \cos \theta)$$

$$\dot{V}(t) = \frac{d}{dt} \left(\frac{1}{2} M \dot{\theta}^2 + P_m \theta + \frac{E V_\infty}{X_m + X_l} \sin \theta \right) =$$

$$= \dot{\theta} \left(M \ddot{\theta} + P_m + \frac{E V_\infty}{X_m + X_l} \cos \theta \right) = -D(\dot{\theta})^2$$

$-D\dot{\theta}$

Dissipative.

