Topics for Today:

- Questions from last lectures?
- Questions/Comments on Assignment #8?

Topics for Today:
- Intro to Power System Operation
- Frequency Control, droop characteristic
- Intro to $[Z_{BUS}]$ and short-circuit studies

Assign #9
- Run Aspen tutorial (manuals in lab)
- Perform small system study
- Work in pairs
- Write short but complete report

Term Proj
Round rotor machine: Given the synchronous reactance \( X_s \), the magnitude of \( E_f \) in per unit, and the mechanical input power in per unit, and the per unit bus voltage (assumed an angle of 0°).

Reference direction out of the machine terminals.

Neglect the armature resistance and give \( I_a \) and the phasor currents for both cases below. Set up a spreadsheet program to solve for the values needed to draw the voltage phasor diagrams.

**PART I**

**Figure 6.10. Turbine-generaotor-excitation system.**

Governor (steam flow to the turbine = machinery power input). Two parameters you will be able to directly control are the excitation (magnitude of \( E_f \)) and the voltage \( V_f \) real and reactive power, and PF. Just as a power plant, the only interactions between torque angle \( \theta \), internal
As shown in Section 11.2, turbine-governor control eliminates rotor accelerations.

Governors are also available [3].

Block diagrams for steam turbines-governors with retard and hydro turbine-governors are typical. Values are $T_1 = 0.10$ and $T_2 = 1.0$ seconds. $T$ is a time constant. Typical values are $T_g = 0.10$ and $T' = 1.0$ seconds. $1/(T_2 + 1)$ blocks account for time delays, where $s$ is the Laplace operator and accounts for the fact that turbines have minimum and maximum outputs. The Figure 11.5 turbine-governor block diagram.

Figure 11.5

![Diagram of turbine-governor block diagram]

Chapter 11: Power System Controls

Figures from Glover & Sarma, 2012.
System Operation -

Automatic Generator Control (AGC)

For equilibrium (const. speed/freq.)

System

\[ P_{G\,TOT} = P_{L\,TOT} + P_{LOSS\,TOT} \]

[Control Area]

Your Util. \[ \rightarrow \] Neighbor

Including Ties,

\[ P_{G\,TOT} = P_{L\,TOT} + P_{TIE\,TOT} + P_{LOSS\,TOT} \]
The above equation then becomes

\[ \left( z^2 g + \frac{g^2}{2} \right) - \left( z^2 \phi + \frac{1}{2} \phi^2 \right) = \left( z^2 w^2 + \frac{1}{2} w^2 \right) \]

Neglecting losses and the dependence of load on state increase in total mechanical power of both areas, the dependence (1.2.4) for each is the same for both areas. Adding (1.2.4) for each, the steady-state solution.

Since the two areas are interconnected, the steady-state power flows between the areas are:

\[ \text{Area 1 to Area 2: } P^\text{tie1} \]

\[ \text{Area 2 to Area 1: } P^\text{tie2} \]

**Example 11.3**

**Figure 11.6**
Power Pools - Group of Utils that operate under Collective control. Municipals seem most common.
ACE, Control Heirarchy

ISO, Reliability

Council (MAPP, MAIN, etc)

POOL

Local Unit

INDIV Unit
ACE - Area Control Error

Difference between scheduled and actual tie line flows.
ACE is "biased" to include frequency effects... i.e.
actual system freq vs. desired freq (or fsynch).

Look at indiv. unit.
\[ P_n = T_w \]
\[ T_w = \frac{P_e}{R} \]
\[ \Delta P_{\text{ref}} \text{ set to give } f = 1.0 \text{ per unit at } p_m = 1.0 \text{ per unit} \]
\[ \Delta f \text{ set to give } f = 1.0 \text{ per unit at } p_m = 0.50 \text{ per unit} \]

\[ \Delta f \text{ is in Hz and } \Delta p_m \text{ is in MW. When } \Delta f \text{ and } \Delta p_m \text{ are given in per-unit, however, } R \text{ is also in per-unit.} \]

11.1 Turbine-governor response to frequency change at a generating unit

A 500-MVA, 60-Hz turbine-generator has a regulation constant \( R = 0.05 \) per unit based on its own rating. If the generator frequency increases by 0.01 Hz in steady-state, what is the decrease in turbine mechanical power output? Assume a fixed reference power setting.

\[ \Delta f_{\text{p.u.}} = \frac{\Delta f}{f_{\text{base}}} = \frac{0.01}{60} = 1.6667 \times 10^{-4} \text{ per unit} \]

Then, from (11.2.1), with \( \Delta P_{\text{ref}} = 0 \),
\[ R = 0.05 \text{ p.u.} = 5\% \]
\[ \Delta f = +0.01 \text{ Hz} \]
\[ \Delta f_{\text{pu}} = \frac{0.01}{60} = 1.667 \times 10^{-4} \text{ p.u.} \]

\[ (\Delta P)(-R) = \Delta f \]
\[ \Delta P = \Delta f \left( \frac{1}{R} \right) \]
\[ = (1.667 \times 10^{-4})(\frac{1}{0.05}) \]
\[ = -3.33 \times 10^{-3} \text{ p.u.} \]

@ 500 MVA Base,
\[ \Delta P = -1.67 \text{ MW} \]
Basics on $[Y]$ & $[Z]$

Note: $[Y_{bus}]$ is nodal admittance matrix.

$$[Y_{bus}] [V_{node}] = [I_{int}]$$

$$[Z_{bus}] = [Y_{bus}]^{-1}$$

$$[Z_{bus}] = \begin{bmatrix}
Z_{11} & Z_{12} & \cdots & Z_{1N} \\
Z_{21} & Z_{22} & \cdots & Z_{2N} \\
\vdots & \vdots & \ddots & \vdots \\
Z_{N1} & Z_{N2} & \cdots & Z_{NN}
\end{bmatrix}$$

$Z_{kk}$ = Thévenin "Driving Point" $Z$'s
$Z_{jk}$ = Transfer impedances.
Possible to find a given $Z_{jk}$

\[
\begin{bmatrix}
Y_{Bus}
\end{bmatrix}
= \begin{bmatrix}
Z_{Bus}
\end{bmatrix}^{-1}
\]

\[
\begin{bmatrix}
Z_{Bus}
\end{bmatrix}
\begin{bmatrix}
I
\end{bmatrix}
= \begin{bmatrix}
V
\end{bmatrix}
\]

\[
\begin{bmatrix}
\vdots & 0 & \vdots
\end{bmatrix}
\begin{bmatrix}
0
\vdots
0
\end{bmatrix}
= \begin{bmatrix}
V_1
V_2
\vdots
\end{bmatrix}
\]

$Z_{22} = \frac{V_2}{I_2}$
If system is in $[Y_{sus}]$ formation

$$
\begin{bmatrix}
Y_{sus}
\end{bmatrix}
\begin{bmatrix}
V_2
\end{bmatrix}
= 
\begin{bmatrix}
0 & 10 \\
10 & 0
\end{bmatrix}

\Rightarrow z_{22} = \frac{V_2}{I_2}
$$