Topics for Today:

- **Announcements**
  - Expanded Term Project outline (i.e. Table of Contents + List of references (suggest about half a dozen to start with) by end of week.
  - Software: ATP/ATPDraw - print out quick start, online license application.
  - Office hrs: 2:05-2:55pm M,W,F
  - Office: EERC 614. Phone: 906.487.2857
  - Problems & all solutions: Ch.6 solns are posted.

- **Chapter 6 - Using the T-Line models**
  - Short Transmission Lines - up to 50 miles (80 km)
  - Voltage Regulation, phasor diagrams
  - Per-phase impedance diagrams (positive seq only)
  - Medium-Length Lines (50 - 150 miles)
  - ABCD parameters for Medium-lines, power flow (L18).
  - Long Lines - more than 150 miles (240 km)
  - Derivation of long-line equations, meaning of equations
  - Characteristic Impedance $Z_c$
  - Propagation Constant $\gamma = \alpha + j\beta$
Reactive Compensation

- Add a series cap

- Shunt Compensation

- First, review key concepts
  - Power Flow Limits
  - Ferranti Rise -
Power Flow thru T-Line

...if we neglect the effects of $R, C$

\[ e = j X_L \quad \tilde{V}_e = \tilde{V}_o \]

Power transferred:

\[ P = \frac{1}{2} |\tilde{V}_s||\tilde{V}_o| \sin (\angle \tilde{V}_s - \angle \tilde{V}_o) \]

\[ P_{\text{max}} = \frac{V_s V_o}{X_L} \]

Use same equation for $P_{\text{out}}$ of a synch machine:

\[ P_{\text{out}} = \frac{V_g V_T}{X_s} \sin \delta \]

\[ V_g \xrightarrow{\text{JE} \ 180^\circ} \quad j X_s + V_T 10^\circ \]
$P_{\text{MAX}} = \frac{V_s V_r}{(X_L - X_C)}$

Compensation Factor: $\frac{X_C}{X_L}$

Series Compensation

$\frac{1}{j\omega C} = -jX_c$

$X_C = X_L$

then 100% comp.

$P_{\text{MAX}} = \infty$

(neglecting $R$, Shunt $C$)

Typically $0.2 \rightarrow 0.7$

Problem: Subsynchronous Resonance
Ex: 30% compensation

\[ \frac{X_c}{X_L} = 0.3 \]

\[ P_{\text{MAX}} = \frac{V_S V_R}{X_L} \]

\[ P_{\text{MAX (COMP)}} = \frac{V_S V_R}{0.7 X_L} \]

\[ \Rightarrow 1.43 P_{\text{MAX}} \]

70% comp

\[ \Rightarrow P_{\text{MAX (COMP)}} = \frac{V_S V_R}{0.3} \]

\[ \Rightarrow 3.33 P_{\text{MAX}} \]

But....
\[ f_r = \frac{1}{2\pi f L} \]

\[ X_C = 2\pi f C \]

\[ f_r = 33.33 \text{ Hz} \]

\[ f_r = 500 \text{ Hz} \]

For 30% comp  
70% comp
Nat. Freq, if mechanically excited

i.e. if some mech. natural freq. matches an electrical natural freq., then we will "excite" this resonance.

First well-documented case:

- Salt River Project

- Careful:
  - Long HV compensated line
  - Lots of local gen
  - Lots of remote load
Ferranti Rise

Closed

\[ V_{out} = V_{in} \frac{-jX_c}{j(X_c - X_L)} \]

\[ X_c \gg X_L = \text{some value} \]

\[ V_{out} = -jX_c \]

\[ V_{in} = \text{some positive value} \]

\[ V_{in} \rightarrow V_{out} \]

\[ V_{in} \rightarrow V_{out} \]

\[ V_{in} \rightarrow V_{out} \]

\[ V_{in} \rightarrow V_{out} \]

\[ V_{in} \rightarrow V_{out} \]
Shunt Compensation:

\[ I_{\text{shunt}} = I_{\text{line}} \times \frac{1}{G} \]

Connect Shunt Reactor at receiving end.

\[ V \]

Limit to

\[ < 1.10 \text{ p.u.} \]

Compensates for Ferranti rise.

- Can also use Shunt Reactor (inductor) to hold \( V_r \) down during lightly-loaded cases.
- Too heavily loaded, low voltage
  - add cap in shunt.
Shunt Compensation

100 mi Bluebird
Deg = 20 ft.
Xc = 1665Ω
Xs = 120Ω (typ)

Line Chg:
\[ Y_{cap} = jB_c \]
\[ Z_{cap} = -jX_c \]

\[ V_R = V_s \frac{-j1665}{j120 - j1665} \]
\[ = 1.08 V_s \]
Shunt Comp Factor = \frac{B_L}{B_c} = \frac{\%L}{\omega C_{ch4}}

Total Compensation:
Add a reactor \( B_L = B_c \)

Total Shunt Admittance = 0

\[ \frac{B_L}{B_c} = 1 \]

then

\[ Y_{total} = jB_c - jB_L = 0 \]

\( Z_{shunt} = \infty \)
\[ P_{1 \rightarrow 2} = \frac{V_1 V_2}{X_L} \sin (\alpha - \beta) \]

\[ V_1, V_2 : \min: \frac{(95)(.95)}{1.05 \times 1.05} = .8185 \quad \Rightarrow \quad 22.17\% \text{ increase!} \]
IN General,

Short Line
\[ \leq 50 \text{mi} (80 \text{km}) \]

Ex. 6.1

\[ V_s^+ - \sqrt{3} + \sqrt{R} \]

Ex. 6.3

\[ V_s^+ - \sqrt{3} + \sqrt{R} \]

Neutral

\[ R + jX \]

Rec.
Voltage Regulation:

\[ VR = \left| \frac{\bar{V}_{R, NL}}{\bar{V}_{R, FL}} \right| - \left| \bar{V}_{R, FL} \right| \]

\[ \bar{V}_S = \bar{V}_{RES} + \bar{V}_L + \bar{V}_R = \bar{I}_{LOAD} R + \bar{I}_{LOAD} jX + \bar{V}_R \]
\[ V_R = \frac{V_{null} - V \ell c}{V_{null} - V_R} \]

**Diagrams:**
- Lead circuit diagram
- Cavity P.F. diagram
- Voltage relationships diagram
VR in terms of A-B-C-D.

Recall: \( VR = \frac{VR_{NL} - VR_{FL}}{VR_{FL}} = \frac{V_s/A - VR_{FL}}{VR_{FL}} \)