Topics for Today:

• Announcements
  • ATP is on remote.mtu.edu. You may apply for ATP/ATPDraw license, verify licensing when you receive it by e-mail, and we will mail you an install CD.
  • Learning Center EERC 123: W,F 4-6pm.
  • Office: EERC 614. Phone: 906.487.2857
  • Book exercises from Ch.6,7 solutions posted, part of homework.

Chapter 6 - Shunt Capacitance Transmission Lines

• 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
  • Long Lines - more than 150 miles (240 km)
  • Compensation - shunt and series
  • Derivation of long-line equations, meaning of equations
  • Characteristic Impedance $Z_C$
  • Propagation Constant $\gamma = \alpha + j\beta$
  • Surge-Impedance Loading (SIL)
  • Wavelength, velocity, Traveling waves, reflections
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 $R, C$

\[ V_{r} = \frac{V_{s} j X_{L}}{V_{t}} R \frac{R}{j X_{L}} \]

Power transferred:

\[ P = \frac{|V_{s}||V_{t}|}{X_{L}} \sin \left( \frac{V_{r} - V_{t}}{X_{L}} \right) \]

\[ P_{\text{max}} = \frac{V_{s} V_{t}}{X_{L}} \]

Use same equation for Port of a synch machine:

\[ P_{\text{out}} = \frac{V_{g} V_{r}^{*} \sin \delta}{X_{s}} \]

\[ V_{r} L \circ \frac{j X_{s} + V_{t} 100^\circ}{-\circ} \]
\[ P_{\text{MAX}} = \frac{V_{\text{S}}V_{\text{e}}}{(X_L - X_C)X_L} \]

\[ X_C = X_L \text{ then } 100\% \text{ comp.} \]

\[ P_{\text{MAX}} = 8 \text{ (neglecting } R, \text{ Shunt)} \]

Problem: Sub synchronos Resonance

Compensation Factor: 0.2 → 0.7

Series Compensation

\[ V_{\text{s}} \xrightarrow{jX_C/2} C \xrightarrow{-jX_C} \]
Ex: 30% compensation

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

\[ P_{\text{MAX}I} = \frac{V_s V_I}{X_L} \quad P_{\text{MAX} (\text{COMP})} = \frac{V_s V_{R}}{0.7 X_L} \]

\[ \Rightarrow \quad P_{\text{MAX} (\text{COMP})} = 1.43 P_{\text{MAX}I} \]

70% comp

\[ \Rightarrow \quad P_{\text{MAX} (\text{COMP})} = \frac{V_s V_{R}}{0.3} \]

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

But....


\( f_r = \frac{1}{2\pi \sqrt{LC}} = \frac{1}{2\pi \sqrt{\frac{x_L}{x_C}}} \)

\( x_L = 2\pi f_L \)

\( x_C = \frac{1}{2\pi f_C} \)

for 30% comp

\( f_r = f_{synch} \sqrt{1.3} = f_0 \sqrt{\frac{x_C}{x_L}} = 33 \text{ Hz} \)

for 70% comp

\( f_r = 50 \text{ Hz} \)
Nat Freq, if mechanically excited
i.e. if some mech natural freq
matches an electrical nat'l 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**

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

\[ X_c \gg X_L = \text{Some Value} \geq 1. \]
Shunt Compensation:

\[ I_{\text{shunt}} = I_{\text{line}} \]

Connect Shunt Reactor at receiving end.

\[ V \]

Limit to 
\[ \leq 1.10 \text{ pu} \]
Compensates for Ferranti rise.

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

jXs

100 mi Bluebird

Dreg = 20 ft.

Xc = 16652

Xs = 12052 (typ)

Ycap = jBc

Zcap = -jXc

\[ V_R = V_s \frac{-j1665}{j120 - j1665} \]

\[ = 1.08 V_s \]
Shunt Comp Factor = \frac{B_L}{B_c} = \frac{\frac{\nu L}{\omega C_{eha}}}{11}

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

Total Shunt Admittance = 0

\[ \begin{array}{c}
+ j B_c \\
E - j B_L \\
\end{array} \Rightarrow \frac{B_L}{B_c} = 1 \\
\]

\[ Y_{\text{TOTAL}} = j B_c - j B_L = 0 \]

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

Power Transfer Capability.

\[ V_{1 \rightarrow 2} \]

\[ V_1, V_2 : \min: \frac{(95)(0.95)}{1.05} \approx 81.85 \Rightarrow 22.1\% \text{ increase!} \]
SHUNT CAPS:

- P.F. Correction (on consumer side of meter)
- Voltage Support
- Max Power Transfer (see next slide)
Voltage Regulation:

\[ VR = \frac{|VR_{HL}| - |VR_{FL}|}{1|VR_{FL}|} \]
LEAD

Note: VR can be negative for leading P.F. load.

UNITY P.F.

VR = \frac{V_{HL} - V_{FL}}{V_{FL}} = \frac{V_S - V_R}{V_R} = \text{pos. no. for Lag, Unity}
$VR$ in terms of $A \cdot B \cdot C \cdot D$

Recall:

$$VR = \frac{VR_{NL} - VR_{FL}}{VR_{FL}} = \frac{V_r/A + VR_{FL}}{VR_{FL}}$$
\[ \begin{align*}
\text{In General,} & \quad \frac{R}{A} + jX_{\text{M}-\text{cul}} = \frac{T}{Y/2} \quad \text{Rec.} \\
\text{Sent.} & \quad \frac{I}{T} \quad \text{Normal} \\
\text{Short Line} & \quad \frac{\text{Short Line}}{50 \text{ mi} (80 \text{ kw})} \\
\text{Ex. C.} & \quad \text{Ex. C.}
\end{align*} \]
\[
\frac{X}{R} \text{ ratio determines effectiveness of } k
\]

Shunt C!

\[
\tilde{V}_s, \quad Z_{bus} = \begin{bmatrix} \tilde{Z}_{KK} \end{bmatrix}
\]

If \( \frac{X}{R} = 0 \), \( \tilde{V}_s \rightarrow \tilde{I}_c \rightarrow \tilde{V}_k \rightarrow I_c R \)