Topics for Today:

- Course Info:
  - Web page: [http://www.ee.mtu.edu/faculty/bamork/ee5220/](http://www.ee.mtu.edu/faculty/bamork/ee5220/)
  - Software - Matlab. ATP/EMTP [ License - [www.emtp.org](http://www.emtp.org) ] ATP tutorials posted on our course web page
  - [EE5220-L@mtu.edu](mailto:EE5220-L@mtu.edu) (participation = min of half letter grade, 5%)

- HW#5 will be posted. Partnered exercise. Due latest Mon Feb 26th 9am.
  - Section 12.4 - detailed derivation for capacitor
  - Prob 5.3 - first do ATP simulation, then Hand Calculations
  - Prob 5.6

- Term Project - proposed topic(s) by end of next week, via short e-mail.

- Circuit Breakers - Interruption issues
  - Restrike
  - Reignition

- Cap and Reactor application
  - Dist system
  - Autotransformer tertiary
  - HV direct connection

- Transmission Lines - development of T-Line equations
Cap Application
- LV, on customer side of meter
  ⇒ Penalty for low P.F. ⇒ P.F. Correction

\[ Z_L \]

\[ Q_{cap} \]

\[ Q_{new} \]
Compensation, VR
Dist. VR

Trans. Tie

L.V. Cops are cheaper to ref.
Compensation

- Shunt
  - Voltage Support
  - Power Transfer
    \[ P_{1-2} = \frac{V_1 V_2 \sin(\delta_1 - \delta_2)}{X_{12}} \]
  - Stability

Bus

21% increase
(.95 \rightarrow 1.05 \text{pu.V})
Shunt Comp: Reactors closing

Long T-line

Ferranti: Rise

Ref: EE5280
Series Comp: $C$

\[ P_{1-2} = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2) \]

$X_L - X_C$
Lightning -

order of

500 kHz!
(half period)
≈ 1 ms

Switching -

250 ms
DISTRIBUTED PARAMETER T-LINES

- "LONG LINES" (>250km @ 60Hz)
- FOR LIGHTNING, EVEN VERY SHORT LINES ARE MODELED AS DIST-PARAM.

FOR INCREMENTAL LENGTH:

\[ I_s = I(x) \]
\[ V_s = V(x) \]
\[ Z = zL = R + jX \]
\[ Y = yL = G + jB \]
Making $\Delta X$ Very Small,\newline
\[ \begin{cases} 
    dV = IX dx \\
    dI = Vy dx 
\end{cases} \quad \text{(Small Z)}
\]

Rearranging,
\[ \begin{cases} 
    \frac{dV}{dx} = Ix^2 \\
    \frac{dI}{dx} = Vy 
\end{cases} \quad (1)
\]

Taking derivative of $(1)$,

\[ \frac{d^2V}{dx^2} = \frac{dI}{dx} z \]
Substituting into (2)

\[
\frac{d^2V}{dx^2} = \sqrt{y^2}
\]

This implicit gen'l sol'n:

\[
V = A_1 e^{\sqrt{y^2}x} + A_2 e^{-\sqrt{y^2}x}
\]

Since \( I = \frac{dV}{dx} \)

\[
I = A_1 \sqrt{\frac{y}{2}} e^{\sqrt{y^2}x} - A_2 \sqrt{\frac{y}{2}} e^{-\sqrt{y^2}x}
\]

at \( x = 0, \) \( V = V_R, \) \( I = IR \)

\[
V(0) = V_R = A_1 + A_2
\]

\[
I(0) = IR = \sqrt{\frac{y}{2}} A_1 - \sqrt{\frac{y}{2}} A_2
\]
Defining $\bar{z}_c = \sqrt{\frac{\bar{z}}{y}} = \text{Char Imp.}$

$\bar{y} = \sqrt{y \bar{z}} = \text{Propagation Const.}$

$V_R = A_1 + A_2$

$I_R = \frac{A_1 - A_2}{\bar{Z}_c}$

$\Rightarrow A_1 = \frac{(V_R + \bar{Z}_c I_R)}{2}$

$A_2 = \frac{V_R - \bar{Z}_c I_R}{2}$
In hyperbolic form,

From EQNs:

\[
\begin{bmatrix}
V_S \\
I_S
\end{bmatrix} = \begin{bmatrix}
A & B \\
C & D
\end{bmatrix} \begin{bmatrix}
V_R \\
I_R
\end{bmatrix}
\]

If we match \([A \ B]\) with \(\Pi\)-Eqn

\[
z' = z \left[ \frac{\sinh (\tau_1)}{\tau_1} \right]
\]

\[
y' = y' \left[ \frac{\tanh (\tau_1/2)}{\tau_1/2} \right]
\]