Topics for Today:

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

• HW#5 will be posted. Partnered exercise. Due latest Mon Feb 22nd 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
  • Re ignition
• 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

\[ Z_s \]
Compensation, VR.

Dist. VR

Trans. Tie

L.V. Caps are cheaper to mfr.
Compensation

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

21% increase
(0.95 \rightarrow 1.05 \text{ pu V})
Lightning -

90%
50%
10%

1.2 ms

Switching -

order of
500 KHz (half period) ≈ 1 ms

250 ms
DISTRIBUTED PARAMETER T-LINES

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

FOR INCREMENTAL LENGTH:

\[ I_5 = I(x) \]
\[ V_5 = V(x) \]

\[ I(x + \Delta x) = I(x) \]
\[ V(x + \Delta x) = V(x) \]

\[ Z = zL = R + jX \]
\[ Y = yL = G + jB \]
Making $\Delta x$ Very Small, \( \text{Small Z} \)

\[
\begin{align*}
\frac{dV}{dx} &= IZ \\
\frac{dI}{dx} &= V_y dx
\end{align*}
\]

Rearranging,

\[
\begin{align*}
\frac{dV}{dx} &= Z \frac{dI}{dx} \\
\frac{dI}{dx} &= \frac{V_y}{Z} dx
\end{align*}
\]  

(1) \hspace{1cm} (2)

Taking derivative of (1),

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

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

This implicit gen'l sol'n:

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

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

\[ I = A_1 \sqrt{\frac{y}{z}} e^{\sqrt{y}z_x} - A_2 \sqrt{\frac{y}{z}} e^{-\sqrt{y}z_x} \]

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

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

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

$y = \sqrt{y z_c} = \text{Propagation Const.}$

\[
V_r = A_1 + A_2 \\
I_r = \frac{A_1 - A_2}{z_c}
\]

\[
\Rightarrow A_1 = \frac{(V_r + z_c I_r)}{2} \\
A_2 = \frac{V_r - z_c I_r}{2}
\]
In hyperbolic form,

\[ \begin{align*}
\begin{bmatrix} V_s \\ I_s \end{bmatrix} &= \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \\
Y' &= Y' \left[ \frac{\tanh \left( \frac{\pi l}{2} \right)}{\pi l} \right] \\
\frac{Y'}{2} &= \frac{Y'}{2} \left[ \frac{\tanh \left( \frac{\pi l}{2} \right)}{\pi l/2} \right]
\end{align*} \]

From EQNs: