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 beginning of this week.
  - Software: online students - apply for ATP/ATPDraw license, verify licensing when you receive it by e-mail, and we will mail you the install CD.
  - Office: EERC 623. Phone: 906.487.2857
  - Recommended problems & all solutions: Ch.7 solns posted.

- Chapter 6 - Recap, a few last items...
  - Case Study of Series Compensation - 500-kV Forbes Line
  - Propagation Constant $\gamma = \alpha + j\beta$
  - Reflection Coefficients, Use of bounce diagrams

Chapter 7 - Network Equations, Admittance Approaches
- $[Y]$ for Transformer Representation, 2-winding, 3-winding
- $[Y]$ for lines and loads
- How's your linear algebra? Time to make use of it...
- Basic strategy for building up $[Y]$ for whole network
500-kV Line - May be fun to model...
Good Morning,

The 500 kV transmission line that goes from Duluth (Forbes Substation) to Winnipeg (Dorsey Substation) is series compensated for about 25% of the XL. The series capacitors are located near the line's mid-point at Rosoe, MN. We also have shunt reactors on the Duluth end to help control the Ferranti rise.

The next 500 kV line to the south from Duluth (Forbes substation) to Minneapolis (Chisago County substation) is series compensated at the Chisago Co end. I'm not sure how much compensation that is, but it is probably in the same range. The also have shunt reactors at Chisago County.

Both of these series capacitors were added as part of a project that nearly doubled the line's transfer capacity. In this case, the transfer capacity is not limited solely by the line impedance, but by the steady state export limit from Manitoba to the US which is based on over-all transfer capability of the 500 kV system plus the 230 kV tie lines that operate in parallel with the 500 kV.

One of the biggest issues with series compensated lines is the voltage rise across the capacitors during short circuits and the associated high fault currents that are created by the low X series impedance. To help with this, the series caps have flash-over gaps or non-linear resistors (varistors) across them to quickly remove (short) them during faults. This produces an interesting short circuit analysis problem since the solution is time variant as the varistor or gap conducts. Programs line ASPEN OneLiner develop steady state short circuit calculations and are not suited for time variant solutions (you have to pick which machine characteristic to use - transient or sub transient). To solve the series cap problem, ASPEN does an iterative solution where it solves the case with zero conduction in the gap and then uses the voltage rise across the cap to calculate a gap conduction. It then recalculates a new short circuit value based on that gap conduction and then repeats the process until it sees minimal change in the solution.

Tom
Close look at $x = \alpha + j\beta$

$x = \sqrt{\frac{2y}{V(1.2+j0.6)}}$ rad/mi

$= \frac{0.00212}{\text{mi}}$ $+ j \frac{0.00212}{\text{mi}}$

$= \left\{ \begin{array}{l}
0.00034 \text{ neper/mi} \\
+ j 0.00034 \text{ neper/mi}
\end{array} \right.$

Tells us how much attenuation/mi.

For 2.58 mi, attenuation = 0.085 or 8.5%.

The wave will experience the wave will experience.

$y$
Reflections

Voltage Reflection Coefficient:

\[ \frac{V_R^-}{V_R^+} = \frac{Z_a - Z_c}{Z_a + Z_c} = P_R \quad \frac{Z_s - Z_c}{Z_s + Z_c} = P_s \]

Current Reflection Coefficient

\[ \frac{i_R^-}{i_R^+} = -\frac{V_R^-}{V_R^+} = -P_R \]

\[
\begin{align*}
R
\end{align*}
\]
"Bounce Diagrams" Refer to end of Lecture 1 notes...

\[ P_S = -1 \]

\[ P_R = +1 \]
2-winding Xfmr

Y-Ys (0° phase shift)

(Bus 5) A

\[ \begin{bmatrix} Y_1 \end{bmatrix} = \begin{bmatrix} \frac{1}{55 + \frac{1}{2s}} & \frac{1}{5} & 5 & 1 \\ \frac{1}{5} & \frac{1}{55 + \frac{1}{2s}} & \frac{1}{5} & \frac{1}{5} \\ \frac{1}{5} & \frac{1}{5} & \frac{1}{2s} + \frac{1}{2s} & \frac{1}{2s} \\ \frac{1}{5} & \frac{1}{5} & \frac{1}{2s} & \frac{1}{2s} + \frac{1}{2s} \end{bmatrix} \text{10-bus system} \]
3-Winding XFMRs

See Section 2.8 in text.

NAME PLATE EX.
(See last page).

EACH LEG OF CORE
Refer to section 2.8 in text...

\[ Z_{ps} = Z_p + Z_s \]
\[ Z_{pt} = Z_p + Z_T \]
\[ Z_{st} = Z_s + Z_T \]
\[ \Rightarrow \begin{align*}
Z_p & \quad Z_s \\
Z_T & \quad Z_T
\end{align*} \]

Fictitious node, \([Y]\) is 4x4.

Often negative 3

Per-Phase "Star" equiv
- All transfer impedances are positive! OK for most S.C. and load-flow calcs.
- Neg \(Z_s\) can cause trouble in some computer simulations.

When building \([Y]\) for system, be aware!
- \(Z_s\) is often negative, but \(Z_{ps} = Z_p + Z_s\) is always positive.
- Node in star equivalent does not physically exist.
**CAUTION:**

DO NOT ATTEMPT TO HANDLE, INSTALL, USE OR SERVICE THIS TRANSFORMER BEFORE READING INSTRUCTION BOOK XLL7952-12. TO DO SO MAY LEAD TO BODILY INJURY OR PROPERTY DAMAGE OR BOTH.

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**CONNECTIONS**

<table>
<thead>
<tr>
<th>WINDING</th>
<th>VOLTS</th>
<th>MAY BE CHANGED</th>
<th>CONNECTS</th>
<th>RE-ENERGIZED TAP CHANGE</th>
<th>CONNECTS</th>
<th>POSITION</th>
<th>LOG-TAP CHANGER</th>
<th>CONNECTS</th>
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<tbody>
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<td>ULTRA DE</td>
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This is a repair of original Westinghouse Transformer Serial RNP-1061.

CONDUCTOR MATERIALS - E.Y. Cu., E.Y. Cu., TERR. Cu.

VOLTAGE AND CURRENT RATINGS FOR DIFFERENT POSITIONS OF LOG-TAP CHANGER ARE SHOWN BETWEEN THOSE LISTED ABOVE.

THE 30°C LIGHT LOAD TEST 72 HOURS WILL BE PERFORMED ON THE FIRST SHUTDOWN OF THE TURNS RATING.

THE TRANSFORMER MUST NOT BE ENERGIZED FROM ANY VOLTAGE SOURCE WHEN RE-ENERGIZED TAP CHARGERS ARE OPERATED.

THE TRANSFORMER TANK AND THE LOG-TAP CHANGER TANK ARE DESIGNED TO WITHSTAND COMPLETE VACUUM EITHER INDIVIDUALLY OR TOGETHER, WHILE VACUUM IS APPLIED TO EITHER OR ALONE. THE PRESSURE IN THE OTHER MUST NOT BE GREATER THAN TRANSFORMER PRESSURE.

THE MAXIMUM CONTINUOUS CURRENT RATING OF THE CONDUCTOR WINDING IS 318.7 AMPS FOR 50000 KVA RATING.

THE TERTIARY WINDING INDUCTANCE MIGHT BE DETERMINED EITHER SIMULTANEOUSLY TO THREE-SEASON OR THREE-SEASON OF LOG-TAP CHANGER, IF AN IMPEDANCE IS PLACED.

The diagram shows the connections and tap changes for the transformer, including the primary and secondary windings, as well as the tertiary winding. The table provides details on the tap changes and their corresponding connections.
T-Lines

Example:
Build [4].

\[ B_e = \omega C \]
\[ Y = jB_e \]

Cops implied that

\( \frac{B_e}{2} = j0.05 \text{pu} \Rightarrow 2X_c = -j20 \text{pu} \)

\( Z_{sc} = 0.08 + j0.2 \text{pu} \)

\( Y_{sc} = \frac{1}{Z_{sc}} \)

\( 4.64 L-68.2^\circ \text{pu} \)

Add a load.
$\sqrt{4.596 \cdot 67.97^\circ} = 4.64 \cdot 111.8^\circ$

What happens if we attach a load at $2.22$ ?

If we assume

Load is given $N = 1.0$ p.u.

for $V = 1.0$ p.u.

approximate $Z_{LOAD}, Y_{LOAD}$

"LOAD" = 1.0 + j0.5 p.u. = $S$

$A = V_1 = \frac{V}{x} = \frac{V}{\sqrt{3}}$

$\theta = \frac{V}{x}$

$\theta = \frac{V}{\sqrt{3}}$

$\theta = \frac{V}{\sqrt{3}}$

$\theta = \frac{V}{\sqrt{3}}$
\[ Y_{\text{load}} = 1.0 - j0.5 \text{ p.u.} \]

How to add effect into \([Y]\)?

\[
[Y] = \begin{bmatrix}
4.596 \ -67.97^\circ & 4.64 \ 111.8^\circ \\
4.64 \ 111.8^\circ & 5.48 \ -60.22^\circ 
\end{bmatrix}
\]

Note: Since load is connected to Bus 2 (Bus 2 - Gnd) then only \(Y_{zz}\) is affected.

\[ Y_{zz} \text{ (new)} = Y_{zz} \text{ (old)} + Y_{\text{load}} \]