Topics for Today:

- Announcements
  - Learning Center hrs: 4:05-4:55pm W,F; + Saturday ___
  - Office: EERC 614. Phone: 906.487.2857
  - Recommended problems from Ch.3, solutions posted
  - SYNCH homework due Oct 3\textsuperscript{th}, 9am.
  - Next: Transmission Line Parameters, Chapters 4,5,6

Transformers - wrapup on off-nominal turns ratio
Synchronous Machines - Chapter 3.
  - Basic internal structure of machines, cylindrical vs. salient
  - Field windings
  - Calculation with Xd and Xq.
  - Calculation Example(s)
  - Concepts behind SYNCH exercise set.
  - S-S behavior - Xd ; Dynamic behavior - Xd’
  - Short-circuit behavior - Xd”; s-s, transient, subtransient
\[ Z = \frac{\tilde{V}}{\tilde{I}} \]

\[ \tilde{V}_1 + \tilde{V}_2 = 0 \]

\[ \pi_1 = \pi_2 \]

\[ \tilde{V}_1 \tilde{I}_1^* = \tilde{V}_2 \tilde{I}_2^* \]

\[ \tilde{I}_1^* = \frac{\tilde{V}_1}{\tilde{V}_2} = \frac{1}{\pi} \]

\[ \tilde{I}_2^* = \frac{\tilde{V}_2}{\tilde{I}_1} = \pi \]
Detailed derivations!

Basis Approach: Develop $\pi$-Equiv and handle just like T-Line.

One-Line: \[ \frac{a}{l} \]

per-unit per-phase \[ \frac{a}{l} \]

Top-Changers
- LTC's
- Phase-Shift

Nominal
\[ \frac{a}{l} \]

\[ \pm \text{ Adjustment in phase angle (PS) or volt mag (LTC)} \]
XFMRs - Use \( L-N (\phi_{A-N}) \) Per Phase Eguiv.

5 \( \rightarrow \) 6

\( \text{EP.u.} \)

\[ y_{56} = -\frac{1}{266} \]

(And \( y_{65} \))

\[ y_{55} = y_{55} + 255 \]

\[ y_{66} = y_{66} + " \]

REF

Modify

\[ y_{55} \]

\[ y_{56} \]

\[ y_{65} \]

\[ y_{66} \]

Basis 2-winding

XFMR is simple.

In \([\chi \text{bus}]\)

How about?

- LTC (or TCUL)
- Phase Shifter (PS)
Tap Changing XFMRs - Variations (p.u. representations)

"From" Bus

1. \( y_{sc} \) \( y_{sc} \) \( c:1 \)
2. \( R+jX \) \( y_{sc} \) \( c:1 \)
3. \( y_{sc} \) \( c:1 \)
4. \( 1/c \) \( y_{sc} \)

"To" Bus

\[
y_{sc} = \frac{1}{R+jX}
\]

"C" is off-nominal turns ratio. In general, C is complex.

- C is real for LTC.
- C is complex for PS.

If \(|c| \neq 1\) then magnitude change.

If C is complex, phase shift.

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Standard Approach:

\[
\begin{bmatrix}
  y_{11} & y_{12} \\
  y_{21} & y_{22}
\end{bmatrix}
\begin{bmatrix}
  V_1 \\
  V_2
\end{bmatrix}
= \begin{bmatrix}
  I_1 \\
  I_2
\end{bmatrix}
\]

Goal:

\[
y_{11} = y_{SER} + y_{SH1} \\
y_{12} = y_{SER} \\
y_{21} = y_{SER} \\
y_{22} = y_{SER} + y_{SH2}
\]
TAP-CHANGERS
On One-Line Diags:

Conceptually:

In per unit, nominal transformation "disappears"
Generically, we can describe this as a 2-node \([Y]\) as a 2-node \([Y]\) where

\[
\begin{bmatrix}
  y_{12} \\
  y_{21} \\
  y_{22}
\end{bmatrix}
= \begin{bmatrix}
  0 & 2 \\
  1 & 0 \\
  0 & 2
\end{bmatrix}
\]

\[
\begin{bmatrix}
  y_{11} \\
  y_{21} \\
  y_{22}
\end{bmatrix}
= \begin{bmatrix}
  0 & -1 \\
  1 & 0 \\
  0 & -1
\end{bmatrix}
\]

\[\text{REF} = \begin{bmatrix}
  0 & 2 \\
  1 & 0 \\
  0 & 2
\end{bmatrix}\]
Strategically using shorts, we can isolate on the values of \([Y]\).

\[
y_{11} = \frac{\bar{I}_1}{\bar{V}_1} \bigg|_{\bar{V}_2 = 0}
\]

\[
y_{22} = -\frac{\bar{I}_2}{\bar{V}_2} \bigg|_{\bar{V}_1 = 0}
\]

\[
y_{22} = -\frac{\bar{I}_2}{\bar{V}_2} \bigg|_{\bar{V}_1 = 0}
\]

\[
y_{22} = -\frac{\bar{I}_2}{\bar{V}_2} \bigg|_{\bar{V}_1 = 0}
\]

\[
\frac{1}{Z_{\text{EQ}}/|C_1|^2} = |C_1|^2 Y_{\text{EQ}}
\]
\[ \tilde{I}_1 = -\frac{C \tilde{V}_2}{2E_a}; \quad \tilde{I}_2 = -\tilde{I}_1 \times C^* = -\left[ \frac{C \tilde{V}_2}{2E_a} \right] C^* \]

Note: \[ \frac{\tilde{I}_2}{\tilde{I}_1} = C^* \]

\[ = \frac{1C^2 \tilde{V}_2}{2E_a} \]
$\frac{d}{V} = -\frac{cV_2}{Z_{\text{eq}}} = -c_T'\text{eq}$

$\frac{V_2}{V} = \frac{c''}{V_{\text{eq}}}$

$y_{12} = \frac{-V_2}{V}$

$y_{21} = \frac{-I_2}{V}$

Note: Ideal XFR, by definition, has $c''$ is voltage ratio.

$S^{\text{in}} = V, I^{\text{in}} = V_2, I^{\text{out}} = 5, V^{\text{out}}$
If we "reverse engineer" our $[Y]$ into an equivalent 2-bus network, then
Observations:
- LTC (Teul) has a c that is Real.

\[ C_{Yeq} = C^* \cdot Y_{eq} \]
\[ C_{Yeq} \uparrow \text{ Bilateral}, \quad (y_{12} = y_{21}) \]

- Phase-Shifter (PS) has complex c.

\[ C_{Yeq} \neq C^* \cdot Y_{eq} \]
\[ y_{12} \neq y_{21} \]

- Transfer admittances

\[ \mathbf{Y} \text{ not symm.} \]
\[ \text{about main diag.} \]
\[ \text{Not Bilateral.} \]
## Typical Spacings and Clearances in a Substation

See up-to-date NESC to verify!

<table>
<thead>
<tr>
<th>Voltage Level</th>
<th>Min Conductor Spacing</th>
<th>Min Switch Spacing Ph-Ph</th>
<th>Min L-L Phase Clearance</th>
<th>Min No. Bells at Deadend</th>
<th>Min Cable Size</th>
<th>Min Bus Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>KV (L-L)</td>
<td>BIL (kV)</td>
<td>Cent-Cent</td>
<td>Ph-Gnd</td>
<td>To Grade</td>
<td>Horngap</td>
<td>V Break</td>
</tr>
<tr>
<td>7.5</td>
<td>95</td>
<td>1'-6&quot;</td>
<td>7½&quot;</td>
<td>8'</td>
<td>3'</td>
<td>18&quot;</td>
</tr>
<tr>
<td>15</td>
<td>110</td>
<td>2'</td>
<td>10&quot;</td>
<td>9'</td>
<td>3'</td>
<td>2'</td>
</tr>
<tr>
<td>23</td>
<td>150</td>
<td>2'-6&quot;</td>
<td>12&quot;</td>
<td>10'</td>
<td>4'</td>
<td>2'-6&quot;</td>
</tr>
<tr>
<td>34.5</td>
<td>200</td>
<td>3'</td>
<td>15&quot;</td>
<td>10'</td>
<td>5'</td>
<td>3'</td>
</tr>
<tr>
<td>46</td>
<td>250</td>
<td>4'</td>
<td>1'-6&quot;</td>
<td>10'</td>
<td>6'</td>
<td>4'</td>
</tr>
<tr>
<td>69</td>
<td>350</td>
<td>5'</td>
<td>2'-5&quot;</td>
<td>11'</td>
<td>7'</td>
<td>5'</td>
</tr>
<tr>
<td>115</td>
<td>550</td>
<td>7'</td>
<td>3'-7½&quot;</td>
<td>12'</td>
<td>10'</td>
<td>7'</td>
</tr>
<tr>
<td>138</td>
<td>650</td>
<td>8'</td>
<td>4'-1&quot;</td>
<td>13'</td>
<td>12'</td>
<td>8'</td>
</tr>
<tr>
<td>161</td>
<td>750</td>
<td>9'</td>
<td>4'-10&quot;</td>
<td>14'</td>
<td>14'</td>
<td>9'</td>
</tr>
<tr>
<td>230</td>
<td>900</td>
<td>11'</td>
<td>6'-½&quot;</td>
<td>15'</td>
<td>16'</td>
<td>11'</td>
</tr>
<tr>
<td>230</td>
<td>1050</td>
<td>13'</td>
<td>7'-3&quot;</td>
<td>16'</td>
<td>18'</td>
<td>13'</td>
</tr>
<tr>
<td>345</td>
<td>1300</td>
<td>15'</td>
<td>8'-5½&quot;</td>
<td>18'</td>
<td>20'</td>
<td>15'</td>
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<tr>
<td>500</td>
<td>1800</td>
<td>25'</td>
<td>12&quot;</td>
<td>---</td>
<td>---</td>
<td>25'</td>
</tr>
<tr>
<td>765</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[ i(t) = \frac{V_{\text{max}}}{12i} \sin \left( \frac{ut + x - \theta}{2} \right) \]

\[ V(t) = V_{\text{max}} \sin \left( ut + x - \theta \right) \]

\[ \frac{12i}{v} = \frac{1}{2} \frac{R_{\text{eq}}}{R} \]

\[ \theta = \tan^{-1} \left( \frac{v}{l} \right) \]
Input:

1. \( x, R = \bar{Z}_{sc} \)
2. \( V = \text{prefault voltage} \)
3. \( L = \text{Span Length} \)
4. \( d = \text{Spacing} \)

Data Structure:

2. t, \( \bar{u} \), \( \bar{\delta} \), B, Find

\[ \text{Find} = i (L \times B) \]

3. CODING
4. Plotting