Topics for Today:

• Announcements
  • Matlab - due latest 9am Monday..
  • Office hrs: 4:05-4:55pm M,W; 10-11am Friday
  • Office: EERC 614. Phone: 906.487.2857
  • Recommended problems from Ch.3, solutions posted
  • 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
\[ Y = \frac{1}{R + jX} \]

\[
\begin{bmatrix}
\bar{y}_{nn} & \bar{y}_{n2} \\
\bar{y}_{2n} & \bar{y}_{22}
\end{bmatrix}
\begin{bmatrix}
\bar{I}_1 \\
\bar{I}_2
\end{bmatrix} =
\begin{bmatrix}
\bar{I}_1' \\
\bar{I}_2'
\end{bmatrix}
\]
\[ Z = \frac{V_1}{I_1} \]

\[ V_1 = V_2 I_2 \]

\[ I_2 = \frac{V_1}{V_2} = \bar{c} \]

\[ I_1 = \bar{V}_1 \]

\[ I_2 = \frac{\bar{I}_2^*}{\bar{I}_1^*} = \bar{c} \]
Detailed derivations:

Basis Approach:

Develop \( \pi \)-Equiv and handle just like T-Line.

One-Line:

\[
\begin{array}{c}
1 \\
\frac{a}{1} \\
\frac{2}{3}
\end{array}
\]

per-unit

per-phase

Top-Changers

- LTC's
- Phase-Shift

\[
\begin{array}{c}
0 \\
\frac{a}{1} \\
\frac{c}{1}
\end{array}
\]

NOMINAL

\[ \text{Turns Ratio} \]

\[ \pm \text{Adjustment in phase angle (PS)} \]

or volt mag (LTC)

References

MichiganTech  Instructor: Bruce Mork  Phone (906) 487-2957  Email: bamork@mtu.edu
XFMRS - Use L-N (ΦA-N)
Per Phase Equiv.

Modify
Y55 Y56
Y65 Y66

REF

In [Ybus]

\[ y_{56} = \frac{1}{y_{66}} \]
(And \( y_{65} \))

\[ y_{55} = y_{55} + 25 \]
\[ y_{66} = y_{66} + " \]

Basis 2-winding
XFMR is simple.

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

"From" Bus

1. \[ \frac{1}{\frac{1}{C} + jX} \]
2. \[ \frac{1}{\frac{1}{C} + jX} \]
3. \[ \frac{1}{\frac{1}{C} + jX} \]
4. \[ \frac{1}{\frac{1}{C} + jX} \]

"To" Bus

\[ yse \]

\[ C \]

"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.

Instructor: Bruce Mork  Phone (906) 487-2857  Email: bamork@mtu.edu
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: 1 \[\rightarrow ? \rightarrow 2\]

\[ y_{11} = y_{SER} + y_{SH1} \]
\[ y_{12} = y_{SER} \]
\[ y_{21} = y_{SER} \]
\[ y_{22} = y_{SER} + y_{SH2} \]
TAP-CHANGERS

On One-Line Diags:

Conceptually:

Nominal Voltage Ratio

↑ off-nominal turns ratio due to Tap Changer

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

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

where
Strategically using shorts, we can isolate on the values of $[Y]$. 

\[ y_{11} = \frac{I_1}{v_1} \bigg| \bar{v}_2 = 0 \]

\[ = \frac{1}{Z_{EQ}} = Y_{EQ} = \frac{1}{R_{EQ} + jX_{EQ}} \]

\[ y_{22} = -\frac{I_2}{v_2} \bigg| \bar{v}_1 = 0 \]

\[ = \frac{1}{Z_{EQ}/1C_1^2} = |C_1^2 Y_{EQ}| \]
\[ \frac{E^2}{\frac{1}{2}c^2} = 1/c^2 \]

\[ I = \frac{E^2}{\frac{1}{2}c^2} \]

Note: \( I^2 = c^* I \times c^* = -\frac{E^2}{\frac{1}{2}c^2} \times -c^* = \frac{E^2}{\frac{1}{2}c^2} \times c^* \)
\[ y_{12} = \frac{I_1}{V_2} \bigg|_{V_1=0} = -\frac{C V_2 / Z_{EQ}}{V_2} = -C Y_{EQ} \]

\[ y_{21} = \frac{I_2}{V_1} \bigg|_{V_2=0} = -\frac{C*I_1}{V_1} = -C Y_{EQ} \]

Note: Ideal XFMR, by definition, has "C" is voltage ratio. 
\[ C = \frac{V_1}{V_{out}} \quad C = \frac{V_{2*}}{I_{1*}} \quad C = \frac{V_{1*}}{I_{2*}} \]
If we "reverse engineer" our \([Y]\) into an equivalent 2-bus network, then

\[
\begin{align*}
\bar{V}_1 & \rightarrow C Y_{EQ} \rightarrow \bar{I}_1 \\
\bar{V}_2 & \leftarrow C^* Y_{EQ} \leftarrow \bar{I}_2 \\
Y_{EQ} (1-C) & \rightarrow \bar{V}_1 \\
Y_{EQ} (1-C^2-C^*) & \rightarrow \bar{V}_2
\end{align*}
\]
Observations:

- LTC (TCUL) has a $c$ that is Real.
  :: Transfer Admittances
  \[ C_Y \text{eq} = C \cdot Y \text{eq} \]
  \[ \Rightarrow \text{Bilateral.} \quad (y_{12} = y_{21}) \]

- Phase-Shifted (PS) has complex $c$.
  :: Transfer admittances
  \[ C_Y \text{eq} \neq C \cdot Y \text{eq} \]
  \[ y_{12} \neq y_{21} \]
  \[ \text{Not \ Bilateral.} \quad \left[ Y \right] \text{ not symm. (about main diag.)} \]
- S.C. Calc
- Induced Force

\[
\begin{array}{c|c|c}
R & L & \text{feasible range} \\
\hline
0.25 - 0.5 & 12.47 \text{ KV} \\
1.0 & 69 \text{ KV} \\
\end{array}
\]

X/R ratio: \[
\begin{array}{c|c|c}
5.0 & 345 - 500 \text{ KV} \\
\end{array}
\]

\[
|Z_{\text{se}}| = |R + jXL| : \frac{5\%}{5\%}, \frac{10\%}{10\%} \text{ on 100 MVA Base}
\]
### Typical Spacings and Clearances in a Substation

**See up-to-date NESC to verify!**

<table>
<thead>
<tr>
<th>Voltage Level (KV)</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>7.5</td>
<td>1'-6&quot;</td>
<td>7½&quot;</td>
<td>8'</td>
<td>18&quot;</td>
<td>2'-6&quot;</td>
<td>7&quot;</td>
</tr>
<tr>
<td>15</td>
<td>2'</td>
<td>10&quot;</td>
<td>9'</td>
<td>3'</td>
<td>2'</td>
<td>2'-6&quot;</td>
</tr>
<tr>
<td>23</td>
<td>2'-6&quot;</td>
<td>12&quot;</td>
<td>10'</td>
<td>4'</td>
<td>2'-6&quot;</td>
<td>3'</td>
</tr>
<tr>
<td>34.5</td>
<td>3'</td>
<td>15&quot;</td>
<td>10'</td>
<td>5'</td>
<td>3'</td>
<td>4'</td>
</tr>
<tr>
<td>46</td>
<td>4'</td>
<td>1'-6&quot;</td>
<td>10'</td>
<td>6'</td>
<td>4'</td>
<td>5'</td>
</tr>
<tr>
<td>69</td>
<td>5'</td>
<td>2'-5&quot;</td>
<td>11'</td>
<td>7'</td>
<td>5'</td>
<td>6'</td>
</tr>
<tr>
<td>115</td>
<td>7'</td>
<td>3'-7½&quot;</td>
<td>12'</td>
<td>10'</td>
<td>7'</td>
<td>9'</td>
</tr>
<tr>
<td>138</td>
<td>8'</td>
<td>4'-1&quot;</td>
<td>13'</td>
<td>12'</td>
<td>8'</td>
<td>11'</td>
</tr>
<tr>
<td>161</td>
<td>9'</td>
<td>4'-10&quot;</td>
<td>14'</td>
<td>14'</td>
<td>9'</td>
<td>13'</td>
</tr>
<tr>
<td>230</td>
<td>11'</td>
<td>6'-1½&quot;</td>
<td>15'</td>
<td>16'</td>
<td>11'</td>
<td>16'</td>
</tr>
<tr>
<td>230</td>
<td>13'</td>
<td>7'-3&quot;</td>
<td>16'</td>
<td>18'</td>
<td>13'</td>
<td>18'</td>
</tr>
<tr>
<td>345</td>
<td>15'</td>
<td>8'-5½&quot;</td>
<td>18'</td>
<td>20'</td>
<td>15'</td>
<td>---</td>
</tr>
<tr>
<td>500</td>
<td>25'</td>
<td>12&quot;</td>
<td>---</td>
<td>---</td>
<td>25'</td>
<td>---</td>
</tr>
<tr>
<td>765</td>
<td>25'</td>
<td>12&quot;</td>
<td>---</td>
<td>---</td>
<td>25'</td>
<td>---</td>
</tr>
</tbody>
</table>
Eqn. 10.2

\[ i(t) = \frac{V_{\text{max}}}{12L} \left[ 5 \sin(\omega t + \phi - \theta) - \frac{R}{L^2} t \sin(\phi - \theta) \right] \]

\[ |Z| = \sqrt{\frac{R^2}{L^2} + (\omega L)^2} \]

\[ \Theta = \tan^{-1} \left( \frac{\omega L}{R} \right) \]
Input:
1. $X, R = Z_{sc}$
2. $V$: prefault voltage
3. $L$: Span Length
4. $d$: Spacing

Data Structure:
1. $t$
2. $v$
3. $i$
4. $B$
5. Find

Find = $i(L \times B)$

Steps:
3. CODING
4. Plotting