Topics for Today:

• Announcements
  • Matlab order - online students let us know if you’re delayed.
  • Office hrs: 2:00-3:00pm M,W,F
  • Office: EERC 614. Phone: 906.487.2857
  • Recommended problems from Ch.3, solutions posted

• Transformers and circuits w/transformers
  • Paralleling of transformers
    • Proportioning of MVA flow for unequal MVA size, unlike impedances
    • Circuit calculations for above cases
    • Design and operations issues
  • Phase shifting transformers
  • Remaining topics will be covered again in context of system operation & analysis, i.e. Chapters 7 and 8. We can introduce main concepts here:
    • Per phase Pi-equivalent for off-nominal turns ratio, phase shifts, etc.
    • Incorporation in system admittance matrix for short-circuit and load flow
Next Lecture: Synchronous Machines - Chapter 3

- Recommended problems & solns for Ch.3 are posted.
- Phasor diagrams - unity, lag, lead
- Salient rotor machines - calculation with Xd and Xq.
- Calculation Example(s)
- P & Q flows thru transmission lines
- More on admittance matrix [Y] construction
Screw moves into page.
**ABB POWER T & D COMPANY, INC.**

**THREE PHASE 60 HERTZ 130000 KVA 69000 KVA LINE AUTO TRANSFORMER**

**CLASS 2A/FA INSULATING INSULATION**

**WINDING**

<table>
<thead>
<tr>
<th>138000</th>
<th>ORG. Y VOLTS</th>
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</thead>
<tbody>
<tr>
<td>69000</td>
<td>ORG. Y VOLTS</td>
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**65°C AVG. RISE**

<table>
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<tr>
<th>50000/66666 KVA</th>
<th>50000/66666 KVA</th>
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<tbody>
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<td>50000/66666 KVA</td>
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**ORIGINAL INSTRUCTION BOOK**

RNP-11061

**SERIAL**

XLL7952

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**POS. SEQ. IMPEDANCE**

4.6% AT 5000 KVA, 138000 TO 69000 VOLTS

**ZERO SEQ. IMPEDANCE**

3.27% AT 10131 KVA, 138000 TO 69000 VOLTS

**ZERO SEQ. IMPEDANCE**

2.83% AT 10131 KVA, 69000 TO 69000 VOLTS

**FULL WAVE IMPULSE TEST LEVEL**

H-WDG 650 KV, X-WDG 350 KV, HOXO NEUT. 110 KV, TERTIARY 110 KV.

**APPROX. WEIGHT IN LBS.**

CORE AND COILS 102200, CASE 88100, FIELD 127200, TOTAL 317500

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**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**

**WINDING**

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**H-WINDING**

- LIGHTN. ARMS (3-TOTAL)
- PHASE A
- PHASE B
- PHASE C

**X-WINDING**

- LIGHTN. ARMS (3-TOTAL)
- PHASE A
- PHASE B
- PHASE C

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**REPAIRED IN ST. LOUIS, MO., U.S.A.**

NP# XLL7952-10 SUB A
Admittance Approaches

\[ \begin{bmatrix} \vec{y}_{11} & \vec{y}_{12} \\ \vec{y}_{21} & \vec{y}_{22} \end{bmatrix} \begin{bmatrix} \vec{V}_1 \\ \vec{V}_2 \end{bmatrix} = \begin{bmatrix} \vec{I}_1 \\ \vec{I}_2 \end{bmatrix} \]

\[ \vec{V}_1 + 0 \]

\[ \vec{I}_1 \]

\[ \vec{I}_2 \]

\[ \vec{V}_2 \]

\[ \text{injected!} \]
\[ A = L \]

\[ \begin{bmatrix}
  1 & 2 \\
  3 & 4
\end{bmatrix} \]
\[ Z = \frac{\overline{V}}{\overline{I}} \]

\[ \overline{S}_1 = \overline{S}_2 \]

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

\[ \overline{I}_2^* = \frac{\overline{V}_1}{\overline{V}_2} = \overline{c} \]

\[ \overline{I}_1^* = \frac{\overline{I}_2^* \overline{I}_1^*}{\overline{I}_2^*} = \overline{c} \]
Detailed derivations!

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

One-Line: \[ \begin{array}{c}
\text{per-unit} \\
\text{per-phase}
\end{array} \]

Top-Changers:
- LTCs
- Phase-Shift

LTC's

NOMINAL

\( \pm \) Adjustment
in phase angle (PS)
or volt mag (LTC)
XFMRs - Use L-N (\(OA-N\))
Per Phase Eqn.

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

\[ y_{55} = y_{55} + y_{56} \]
\[ y_{66} = y_{66} + y_{66} \]

Modify:
\[ y_{55}, y_{56}, y_{65}, y_{66} \]

REF

In [4bus]

Basis 2-winding
XFMR is simple.

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

From Bus

From Bus

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

1. \( \frac{y_{sc}}{c : 1} \)
   \( (R+jX) \)

2. \( \frac{c : 1}{y_{sc}} \)

3. \( \frac{c : 1}{y_{sc}} \)

4. \( \frac{y_{sc}}{c} \)

"c" is off-nominal turns ratio. In general c is complex. C is real for LTC. C is complex for PS. If |c| ≠ 1 then magnitude change. If c is complex, phase shift.
**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:

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 \([Y]\)

where

\[
\begin{bmatrix}
y_{11} & y_{12} \\
y_{21} & y_{22}
\end{bmatrix}
\begin{bmatrix}
\bar{V}_1 \\
\bar{V}_2
\end{bmatrix}
= \begin{bmatrix}
\bar{I}_1 \\
-\bar{I}_2
\end{bmatrix}
\]
Strategically using shorts, we can isolate on the values of \([Y]\).

\[
y_{ii} = \frac{\bar{I}_i}{\bar{V}_i} \bigg| \bar{V}_2 = 0
\]

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

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

\[
= \frac{1}{Z_{\text{EQ}}/|C|^2} = |C|^2 Y_{\text{EQ}}
\]
\[
\begin{align*}
y_{12} &= \frac{\tilde{I}_1}{\tilde{V}_2} \bigg|_{\tilde{V}_1 = 0} = -\frac{c\tilde{V}_2 / Z_{EQ}}{\tilde{V}_2} = -cy_{EQ} \\
y_{21} &= -\frac{\tilde{I}_2}{\tilde{V}_1} \bigg|_{\tilde{V}_2 = 0} = -\frac{c\tilde{I}_2}{\tilde{V}_1} = -cy_{EQ}
\end{align*}
\]

**Note:** Ideal XFR, by definition, has "C" is voltage ratio. 
\[C = \frac{\tilde{V}_1}{\tilde{V}_{out}} = \frac{\tilde{I}_2}{\tilde{I}_1} \Rightarrow \tilde{I}_2 = c\tilde{I}_1, \tilde{V}_{out} = c\tilde{V}_1, \tilde{S}_{in} = \tilde{V}_1\tilde{I}_1^* = \tilde{V}_{out}\tilde{I}_2^* = S_{out}\]
If we "reverse engineer" our $[Y]$ into an equivalent 2-bus network, then

\[ \overline{V}_1 \rightarrow CY_{EQ} \rightarrow \overline{I}_2 \]

\[ \overline{I}_1 \rightarrow CY_{EQ} \rightarrow \overline{I}_2 \]

\[ C^*Y_{EQ} = y_{21} \]

\[ Y_{EQ}(1-C) \]

\[ Y_{EQ}(1-C^2-C^1) \]

REF
Observations:

- LTC (TCUL) has a c that is Real.
  \Rightarrow Transfer Admittances
  \[ \frac{C}{Y_{eq}} = \frac{C}{Y_{eq}} \]
  \Rightarrow Bilateral. \( Y_{12} = Y_{21} \)

- Phase-Shifter (PS) has complex c.
  \Rightarrow Transfer admittances
  \[ \frac{C}{Y_{eq}} \neq \frac{C}{Y_{eq}} \]
  \Rightarrow \( Y_{12} \neq Y_{21} \)

\[ Y \text{ not symm. (about main diag.)} \]