Topics for Today:

- Announcements
  - Everyone have a book now?
  - Room B45 is open from 9am onward.
  - Office hrs: 1:30-2:30pm, Mon, Wed, Fri
  - Office: EERC 623. Phone: 906.487.2857
  - Ch. 1 Solutions posted on web page. Finish by Sept. 5th.
  - Set of pre-req / review exercises given by tomorrow

- Completing the Chapter 1 / Review:
  - Per Unit system
  - Symmetrical Components: a, [A], pos, neg, zero components
  - Sequence networks

- Chapter 2 - Transformers and circuits w/ transformers
Figure 2.11 Alternating emf applied (a) to a purely inductive element and (b) to a purely capacitive element.

Table 2.1

<table>
<thead>
<tr>
<th>Circuit diagram</th>
<th>Calculated from $EI^* = S = P + jQ$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(Active)</strong></td>
<td>If $P$ is $+$, emf supplies power</td>
</tr>
<tr>
<td>$E$</td>
<td>If $P$ is $-$, emf absorbs power</td>
</tr>
<tr>
<td>$I$</td>
<td>If $Q$ is $+$, emf supplies reactive power ($I$ lags $E$)</td>
</tr>
<tr>
<td>Generator action assumed</td>
<td>If $Q$ is $-$, emf absorbs reactive power ($I$ leads $E$)</td>
</tr>
<tr>
<td><strong>(Passive)</strong></td>
<td>If $P$ is $+$, emf absorbs power</td>
</tr>
<tr>
<td>$E$</td>
<td>If $P$ is $-$, emf supplies power</td>
</tr>
<tr>
<td>$I$</td>
<td>If $Q$ is $+$, emf absorbs reactive power ($I$ lags $E$)</td>
</tr>
<tr>
<td>Motor action assumed</td>
<td>If $Q$ is $-$, emf supplies reactive power ($I$ leads $E$)</td>
</tr>
</tbody>
</table>
\[ \dot{I}_{na} = -I_{an} \]

\[ S_{\text{out}} = \dot{V}_{an} \dot{I}_{na} = P_{\text{out}} + jQ_{\text{out}} \]

\[ S = \ddot{V} \dot{I}^* = P + jQ \]

But... How to apply?

\[ S_{\text{in}} = \dot{V}_{an} \dot{I}_{an} = P_{\text{in}} + jQ_{\text{in}} \]
Per Unit Value = \( \frac{\text{Actual Value}}{\text{Base Value}} \) pu or p.u.
or \( 97 \% \)
p.u. \times 100 = \( 97 \% \)

Base MVA usually 100 MVA (Given)

Base Voltage: \( V_{LL,\text{BASE}} = \) Nominal \( V_{LL} \) in a particular part/zone of system

KEY Point: \( V_{LN,\text{BASE}} = \) Nominal \( V_{LN} \) ....

\[
|S| = 3 \sqrt{3} V_{\phi} I_{\phi} = 3 V_{\phi} I_{\phi} = \sqrt{3} V_{LL} I_{\text{LINE}} = 3 V_{LN} I_{\text{LINE}}
\]

\[
I_{\text{BASE,LINE}} = \frac{S_{3\phi}}{\sqrt{3} V_{LL}} = \frac{100 \times 10^6}{\sqrt{3} \times 345,000} = 167.4 \text{A}
\]
\[ I_{\text{LINE}} = I_0, \text{Y} \]

\[ V_{\text{BASE, L-L}} = V_0, \text{DELTA} \]

\[ V_{\text{BASE, L-L}} = V_0, \text{DELTA} \]

\[ V_{\text{BASE, L-L}} = V_0, \text{DELTA} \]

\[ \frac{V_{\text{L-L}}}{I_{\text{L-L}}} = \frac{199.2\,\text{kV}}{1190\,\Omega} \]

\[ Z_{\text{BASE, Y-WE}} = \frac{\sqrt{3}}{I_{\text{L-L}}} \]

\[ \text{in each "zone"} \]
Transformers

$\bar{Z}_s$ can be "transferred" or referred to primary:

Transferring $\bar{Z}_s$ to primary:

$$\bar{Z}_p = \bar{Z}_s \left[ \frac{N_1}{N_2} \right]^2 = \bar{Z}_s \left[ \frac{V_1}{V_2} \right]^2$$

Both circuits have same transfer impedance.
Per unit Vs & Is are same on each side, i.e., "get rid" of xfmr when we do p.u. calculations.

Exception: phase shifts in A-Y xfmrs, PS xfmrs, etc.
Symmetrical Components

- Deal w/ unbalanced 3φ situations.
- Real-world situation:  
  a) unbalanced load currents flowing thru system,
  b) also unbalanced faults: L-G, L-L, L-L-G,
  c) unbalanced 2φs.

\[ \text{Ex:} \]

\[ \begin{align*}
V_c & \quad V_a \\
I_c & \quad I_a \\
V_b & \\
V_{c1} & \quad V_{b1} \quad \text{pos} \\
V_{a1} & \quad V_{b2} \quad \text{neg} \\
V_{c2} & \\
V_{ca0} & \quad V_{bo0} \quad \text{zero} \\
V_c & \quad V_a \\
V_b &
\end{align*} \]
Per Phase Analysis is typical – no need to track Q and \( \phi \). If \( \phi_a \) is known and each stage is symmetrical, it is convenient to define \( r_a \): 

\[ V_{b1} = \frac{V_{a1} a}{V_{o2}} \]

\[ V_{c1} = V_{(o)} \]

\[ V_{o} = V_{b0} + a^2 V_{a1} + a V_{a2} \]

\[ V_{o} \sqrt{2} = V_{b0} + a V_{a1} + a^2 V_{a2} \]

Note: \( V_{a0} = V_{b0} = V_{c0} \)
\[
\begin{bmatrix}
\vec{V}_a \\
\vec{V}_b \\
\vec{V}_c \\
\end{bmatrix} = 
\begin{bmatrix}
1 & 1 & 1 \\
1 & a & a^2 \\
1 & a^2 & a \\
\end{bmatrix}
\begin{bmatrix}
\vec{V}_{a0} \\
\vec{V}_{a1} \\
\vec{V}_{a2} \\
\end{bmatrix} = [A]
\begin{bmatrix}
\vec{V}_{a0} \\
\vec{V}_{a1} \\
\vec{V}_{a2} \\
\end{bmatrix}
\]

\[
\begin{bmatrix}
\vec{V}_p \\
\vec{I}_p \\
\end{bmatrix} = [A]\begin{bmatrix}
\vec{V}_s \\
\vec{I}_s \\
\end{bmatrix}
\]

\[
[A]'[V_p] = [A]'[A][V_s]
\]

\[
[V_s] = [A]'[V_p]
\]
The per-unit sequence networks in Figure 8.19(b), have the following features:

1. The per-unit impedances do not depend on the winding connections. That is, the per-unit impedances on the Y–Y, Y–Δ, Δ–Y, or Δ–Δ arms do not depend on the winding connections.

2. A phase shift is included in per-unit sequence networks. For the Δ–Δ network, the phase shift is 30°. For negative sequence, the phase shift is 30°.

3. Zero-sequence currents can flow in the Y–Δ connection, and correspond to leaving or entering the Δ winding. However, no zero-sequence current in the Δ winding.

The phase shifts in the positive- and negative-sequence networks in Figure 8.19(b) are represented by the phase shift of 30°. Also, the zero-sequence network is at the Y side for zero-sequence current to enter or leave the Δ side.

The per-unit sequence networks in Figure 8.19(c), have the following features:

1. The positive- and negative-sequence impedances are the same as those for the Δ–Δ connection, and the zero-sequence impedances do not depend on the winding connections.

2. Zero-sequence currents cannot flow in the Δ–Δ connection, though they can circulate with the Δ–Δ connection.

**EXAMPLE 8.7 Solving unbalanced three-phase networks using per-unit sequence components**

A 75-kVA, 480-V, Δ/208-V Y transformer is connected between the source and load. The per-unit source impedance is 0.10 per unit, and the load current is 200 A. The leakage reactance is neglected. Using the transformer and the per-unit sequence networks and currents, calculate the per-unit sequence voltages and currents.

**SOLUTION** The base quantities are...