EE 5200 - Lecture 4 Thursday Sep 4, 2003

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

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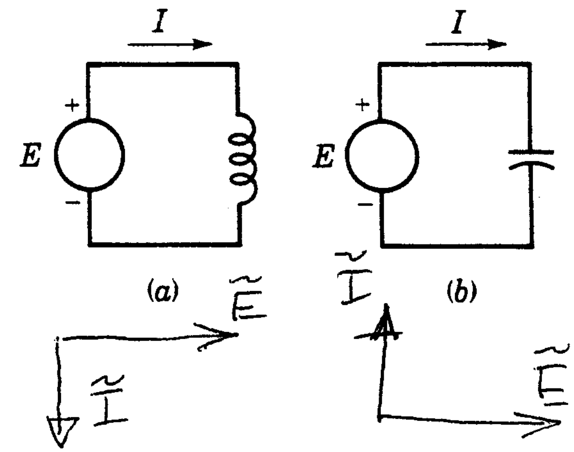
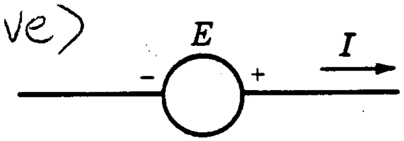
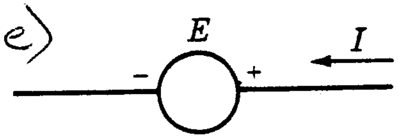
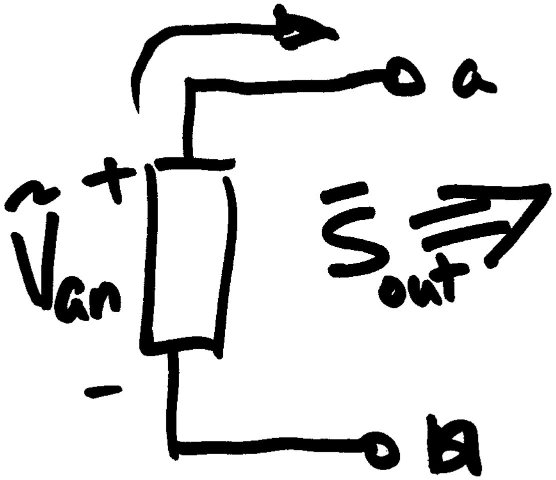


Figure 2.11 Alternating emf applied (*a*) to a purely inductive element and (*b*) to a purely capacitive element.

Table 2.1

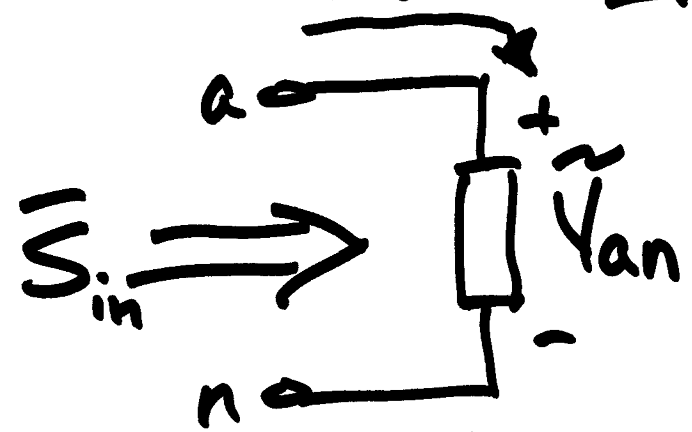
Circuit diagram	Calculated from EI^* $= \bar{S} = P + jQ$
(Active)  Generator action assumed SOURCE	If P is $+$, emf supplies power If P is $-$, emf absorbs power If Q is $+$, emf supplies reactive power (I lags E) If Q is $-$, emf absorbs reactive power (I leads E)
(Passive)  Motor action assumed LOAD	If P is $+$, emf absorbs power If P is $-$, emf supplies power If Q is $+$, emf absorbs reactive power (I lags E) If Q is $-$, emf supplies reactive power (I leads E)

$\tilde{I}_{na} = -\tilde{I}_{an}$



ACTIVE

$\tilde{I}_{an} = -\tilde{I}_{n}$



PASSIVE

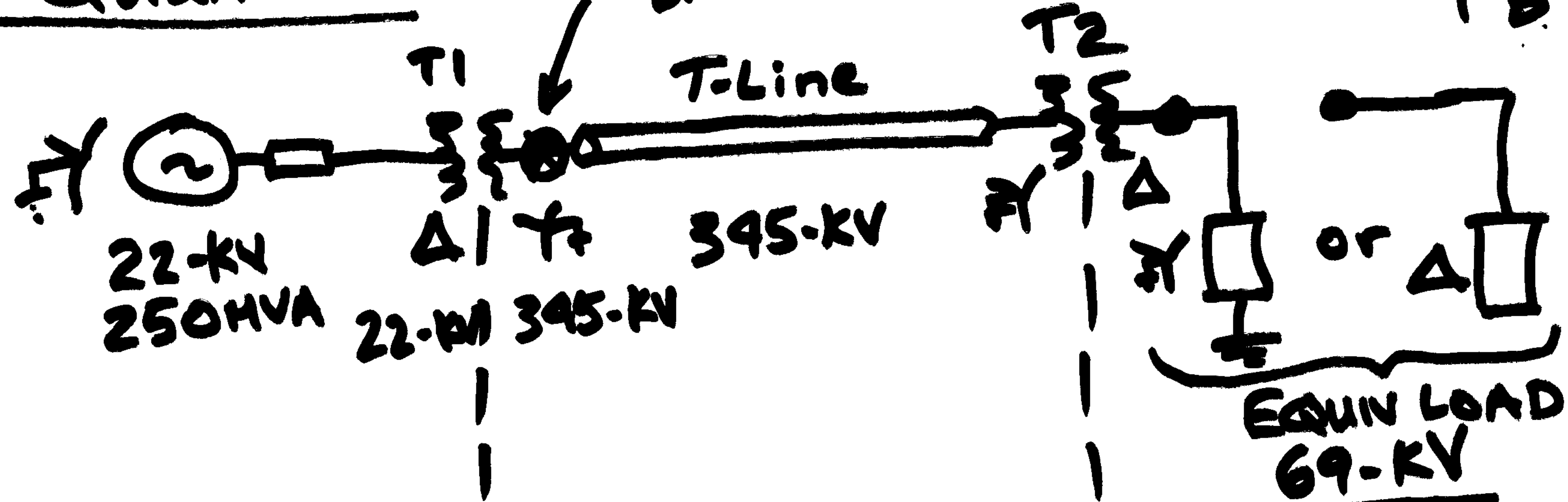
$$\boxed{\bar{S} = \tilde{V}\tilde{I}^* = P + jQ}$$

But... How to apply?

$$\bar{S}_{out} = \tilde{V}_{an}\tilde{I}_{na}^* = P_{out} + jQ_{out}$$

$$\bar{S}_{in} = \tilde{V}_{an}\tilde{I}_{an}^* = P_{in} + jQ_{in}$$

Per Unit Quantities



BASE QTY			
$S_{BASE}^{3\phi}$	100 MVA	100 MVA	100 MVA
V_{L-L}	22 KV	345 KV	69 KV
V_{L-N}	12.7 KV	199.2 KV	39.8 KV
I_{LINE}	2624 A	167.4 A	836.7 A
$I_{\phi,\Delta}$	1515 A	96.6 A	483.1 A
Z_Y	4.84 Ω	1190 Ω	47.6 Ω
Z_Δ	14.5 Ω	3571 Ω	142.8 Ω

EXPLANATION OF BASE VALUES GIVEN ON FOLLOWING PAGES...

$$\text{Per Unit Value} = \frac{\text{"Actual Value"}}{\text{Base Value}} \quad \text{pu or p.u. or \%}$$

$$\text{p.u.} \times 100 = \%$$

Base MVA usually 100 MVA (Given)

Base Voltage: $V_{LL,BASE}$ = Nominal V_{LL} in a particular part/zone of system

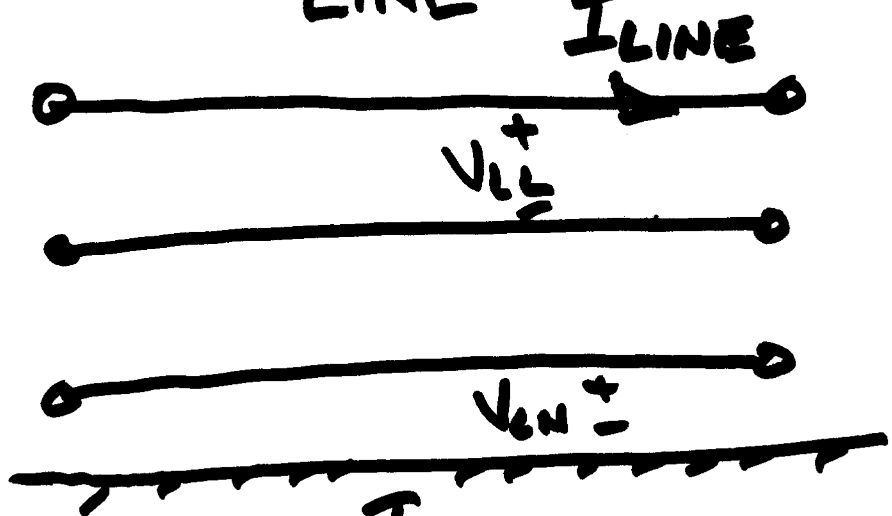
KEY Point:

$V_{LN,BASE}$ = Nominal V_{LN} ....

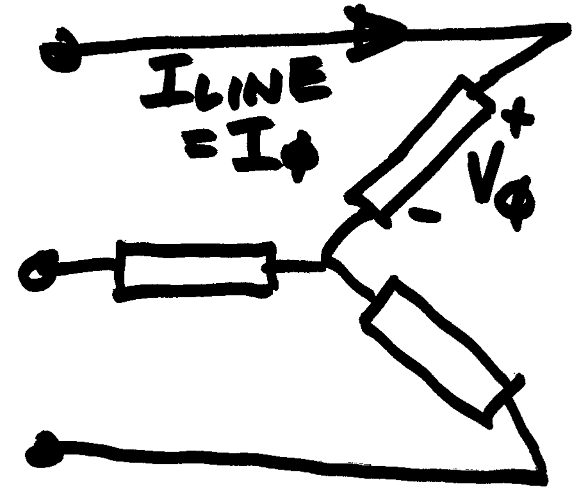
$$\boxed{|\bar{S}| = |3 \tilde{V}_\phi \tilde{I}_\phi^*| = 3 V_\phi I_\phi = \sqrt{3}\, V_{LL} I_{LINE} = 3 V_{LN} I_{LINE}}$$

$$\therefore I_{BASE,LINE} = \frac{S_{3\phi}}{\sqrt{3}\, V_{LL}} = \frac{100 \times 10^6}{\sqrt{3} \times 345{,}000} = \underline{\underline{167.4\text{A}}}$$

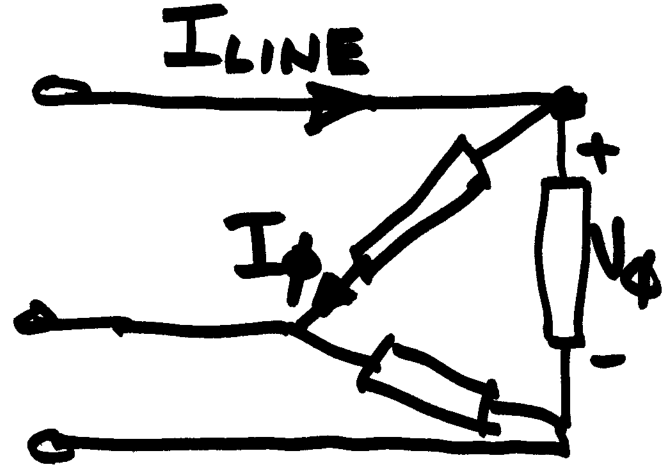
ALONG LINE



AT WYE



AT DELTA



$$I_{BASE,LINE} = I_{\phi,WYE}$$

$$V_{BASE,L\text{-}L} = V_{\phi,DELTA}$$

$$V_{BASE,L\text{-}N} = V_{\phi,WYE}$$

$$I_{BASE,DELTA} = \frac{I_{BASE,LINE}}{\sqrt{3}}$$

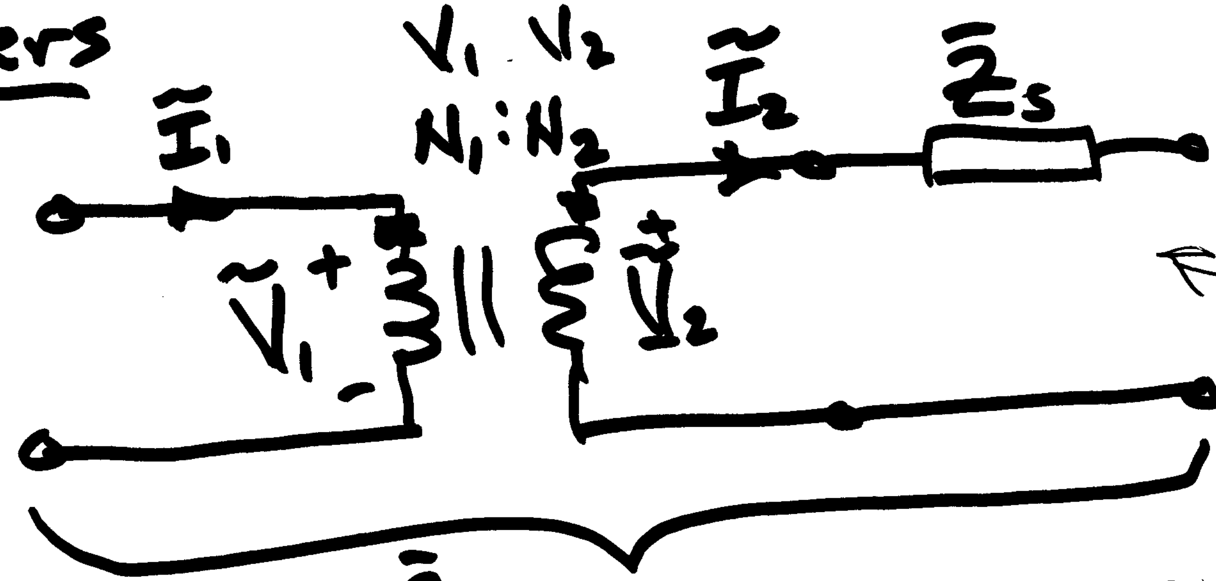
$$Z_{BASE,WYE} = \frac{V_{LN}}{I_{LINE}} = \frac{199.2\,KV}{167.4} = 1190\,\Omega$$

IN EACH "ZONE"

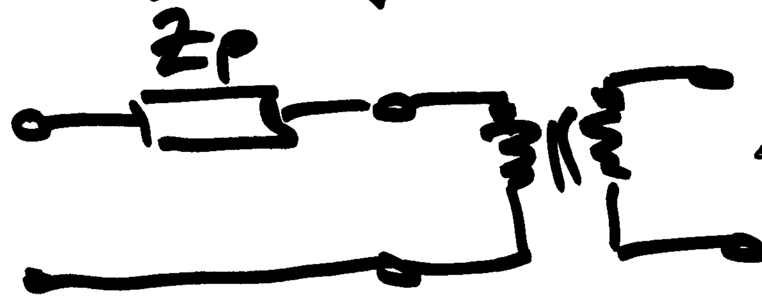
$\left\{ \begin{array}{l} \text{Sources, Loads,} \\ \text{XFMRS, Thev. Equiv.} \end{array} \right.$

$$Z_{B,\Delta} = \frac{V_{LL}}{I_{\phi,\Delta}}$$

Transformers



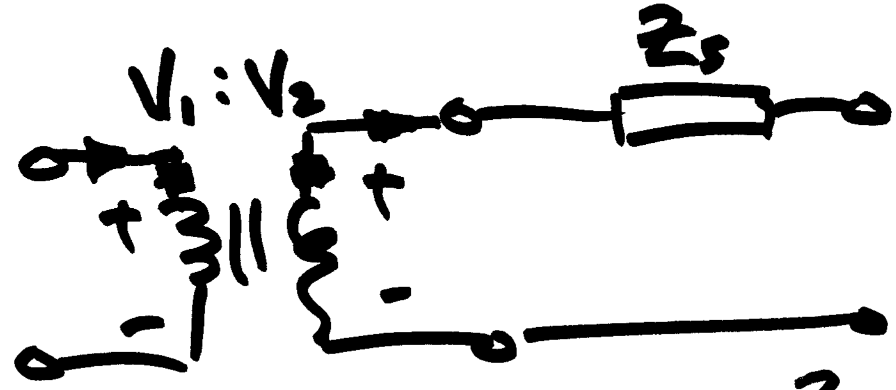
$\bar{Z}_s$ can be "transferred" or referred to primary:



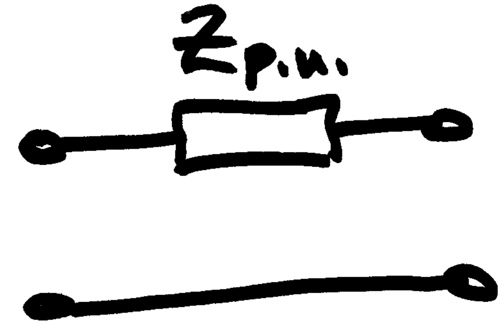
Both circuits have same transfer impedance.

Transferring Z_s to primary:

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



Per Unit Representation: $\Longrightarrow$



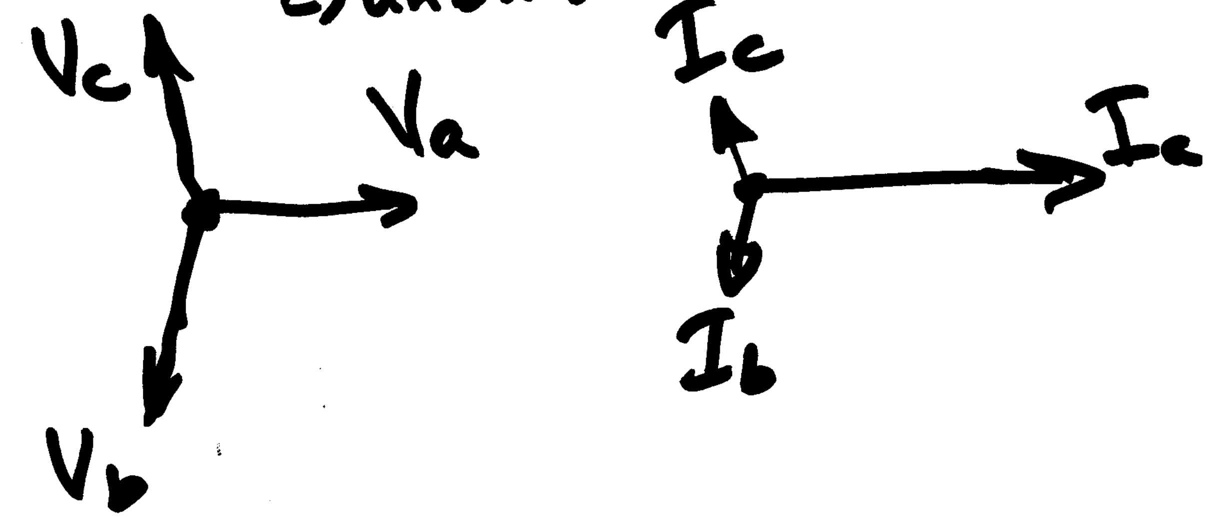
Per unit Vs & Is are same on each side, ∴ "get rid" of xfmr when we do p.u. calculations.

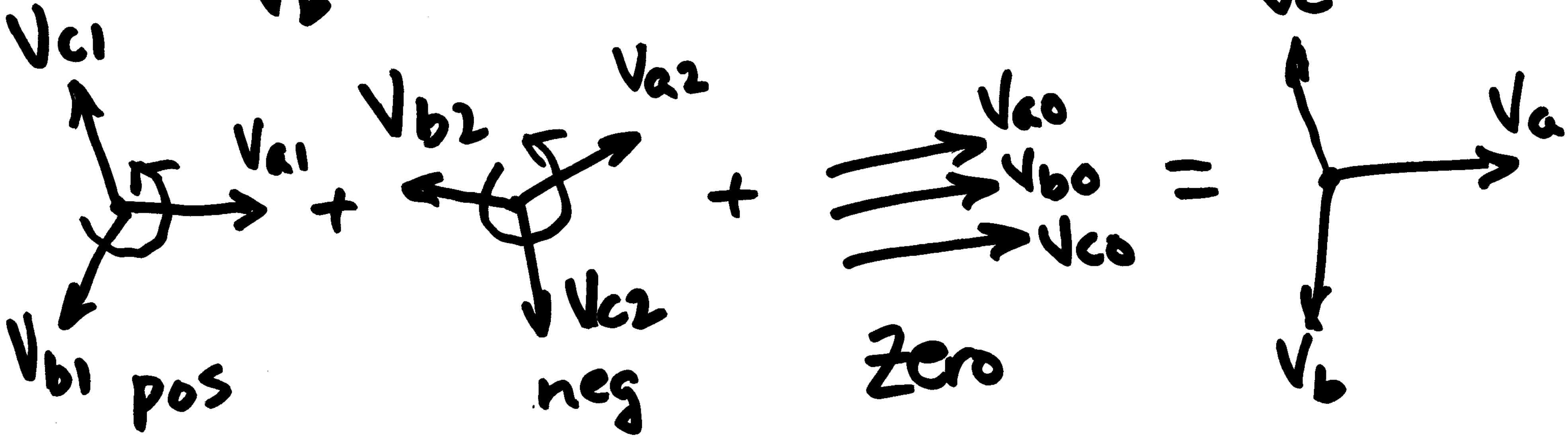
<u>Exception:</u> phase shifts in Δ-Y xfmrs, PS xfmrs, etc.

Symmetrical Components

- Deal w/ unbalanced 3ϕ situations.
- Real-world situation: a) unbalanced load currents flowing thru system,
  b) also unbalanced faults: $\underbrace{L\text{-}G,\ L\text{-}L,\ L\text{-}L\text{-}G}$
  c) unbalanced Z's.

Ex:





Per Phase Analysis is typical – no need to track Φb & Φc qty's if Φa is Known and each "group" (i.e. pos, neg, zero) is symmetric/balanced.

Convenience to define "a" : $\boxed{\vec{a} = 1\angle 120^\circ}$

$$a = 1\angle 120^\circ \qquad a^2 = 1\angle -120^\circ$$

$$\tilde{V}_{b1} = \underline{\tilde{V}_{a1}}\,a^2 \qquad \tilde{V}_{b2} = \underline{\tilde{V}_{a2}}\,a$$

$$\tilde{V}_{c1} = \underline{\tilde{V}_{a1}}\,a \qquad \tilde{V}_{c2} = \underline{\tilde{V}_{a2}}\,a^2$$

$$\begin{bmatrix} \tilde{V}_a \\ \tilde{V}_b \\ \tilde{V}_c \end{bmatrix} \begin{matrix} = \tilde{V}_{a0} + \tilde{V}_{a1} + \tilde{V}_{a2} = \\ = \tilde{V}_{b0} + \tilde{V}_{b1} + \tilde{V}_{b2} = \\ = \tilde{V}_{c0} + \tilde{V}_{c1} + \tilde{V}_{c2} = \end{matrix} \begin{bmatrix} \tilde{V}_{a0} + \tilde{V}_{a1} + \tilde{V}_{a2} \\ \tilde{V}_{a0} + a^2\tilde{V}_{a1} + a\tilde{V}_{a2} \\ \tilde{V}_{a0} + a\tilde{V}_{a1} + a^2 V_{a2} \end{bmatrix}$$

Note: $V_{a0} = V_{b0} = V_{c0}$

$$\begin{bmatrix} \tilde{V}_a \\ \tilde{V}_b \\ \tilde{V}_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} \tilde{V}_{a0} \\ \tilde{V}_{a1} \\ \tilde{V}_{a2} \end{bmatrix} = [A] \begin{bmatrix} \tilde{V}_{a0} \\ \tilde{V}_{a1} \\ \tilde{V}_{a2} \end{bmatrix}$$

$$[V_p] = [A][V_s]$$

$$[I_p] = [A][I_s]$$

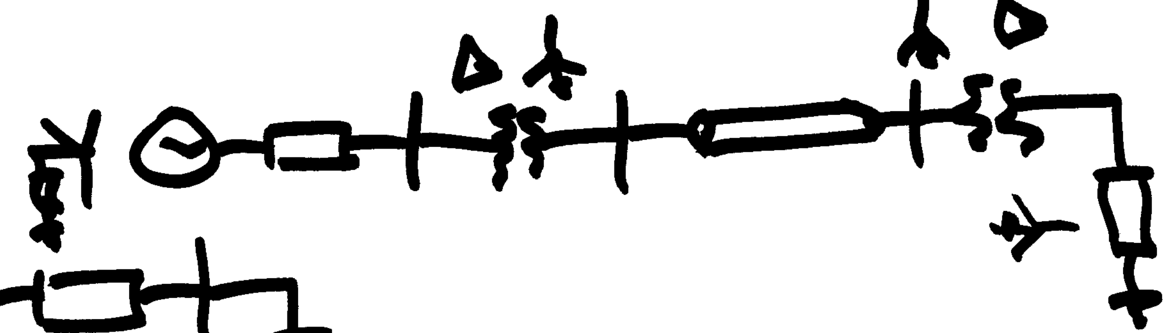
$$[A]^{-1}[V_p] = [A]^{-1}[A][V_s]$$

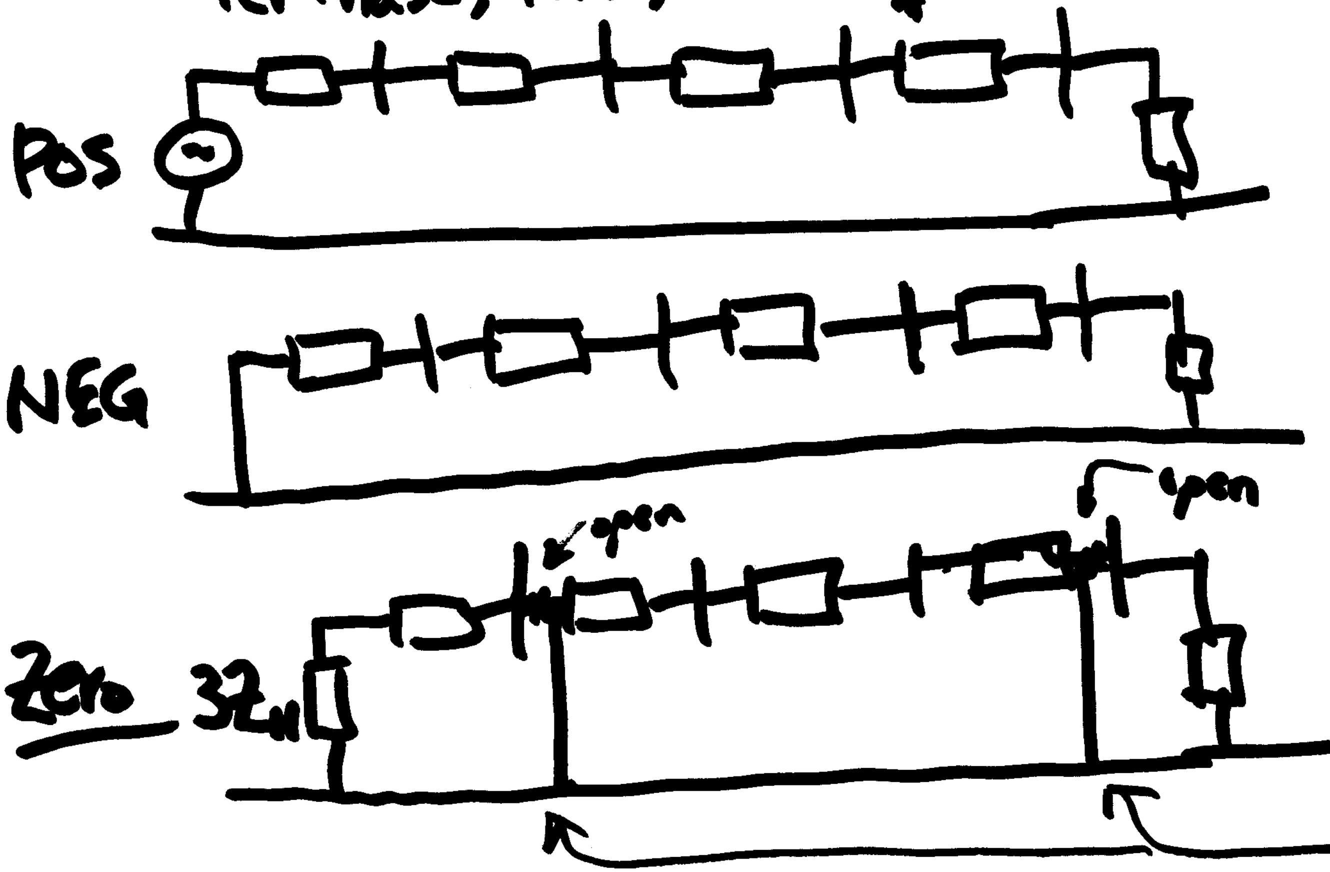
$$[V_s] = [A]^{-1}[V_p]$$

i.e. $\begin{bmatrix} \tilde{V}_{a0} \\ \tilde{V}_{a1} \\ \tilde{V}_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} \tilde{V}_a \\ \tilde{V}_b \\ \tilde{V}_c \end{bmatrix}$

Sequence Networks

Per Phase, ϕA-N, P.u.





See details on next page.

From: Glo r & Sarma. 3rd Ed.

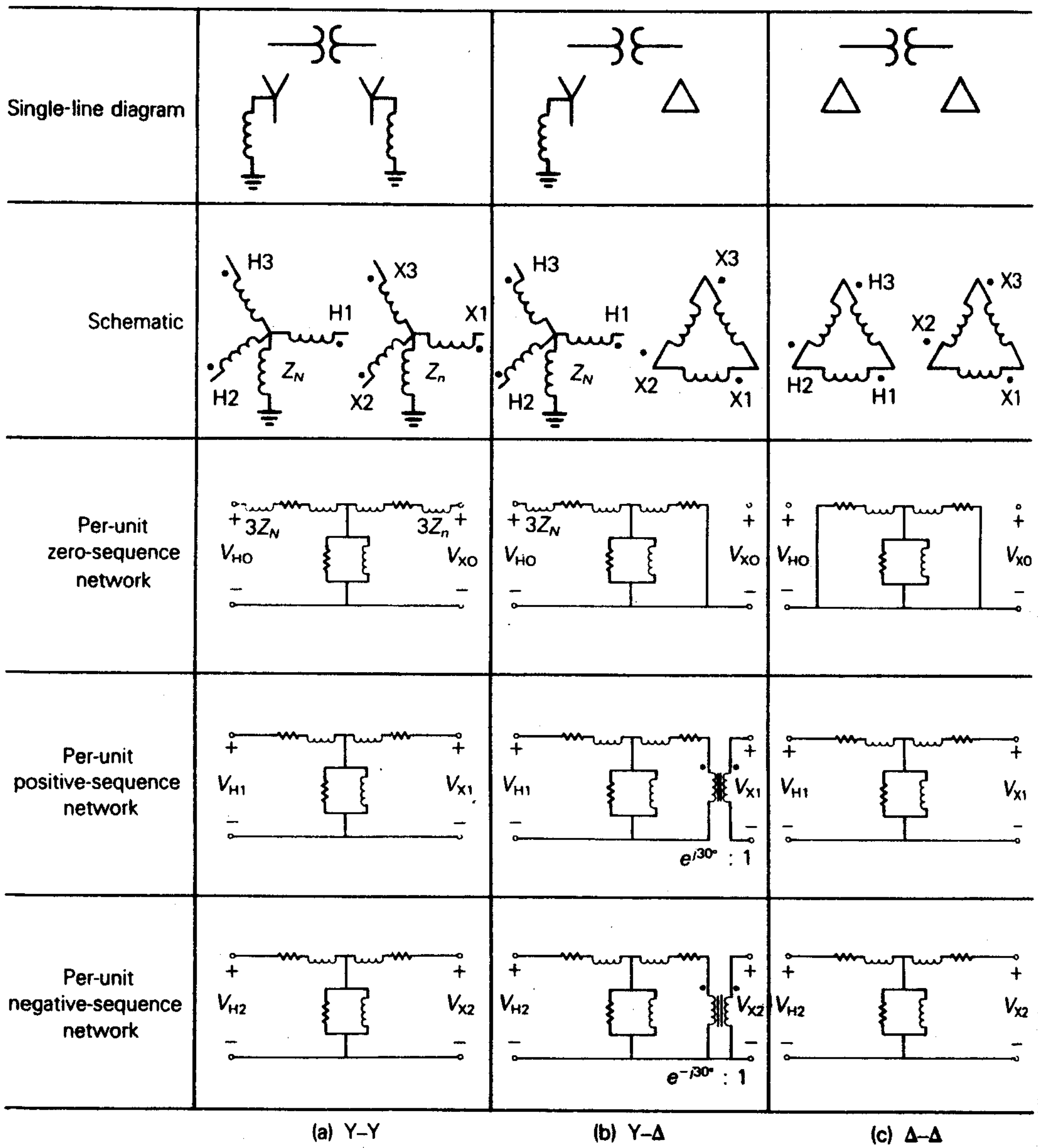


FIGURE 8.19 Per-unit sequence networks of practical Y–Y, Y–Δ, and Δ–Δ transformers

branches are also shown in Figure 8.19(a). Note that ($3Z_N$) and ($3Z_n$) have already been included in the zero-sequence network.

The per-unit positive- and negative-sequence transformer impedances of the practical Y–Y transformer in Figure 8.19(a) are identical, which is always true for nonrotating equipment. The per-unit zero-sequence network, how-

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The per-unit sequence networks
ure 8.19(b), have the following featur

1. The per-unit impedances do
That is, the per-unit impeda
Y–Y, Y–Δ, Δ–Y, or Δ–Δ ar
do depend on the winding co

2. A phase shift is included i
sequence networks. For the A
voltages and currents on th
former lead the correspondir
30°. For negative sequence, t

3. Zero-sequence currents can f
connection, and correspondi
the Δ winding. However, no
the Δ winding.

The phase shifts in the positi
Figure 8.19(b) are represented by th
3.4. Also, the zero-sequence network
Y side for zero-sequence current to
enter or leave the Δ side.

The per-unit sequence networks
ure 8.19(c), have the following featur

1. The positive- and negative-s
are the same as those for the
windings are labeled so there
pedances do not depend on
voltages do.

2. Zero-sequence currents *cann*
though they can circulate wit

EXAMPLE 8.7 **Solving unbalanced three-phase ne**
using per-unit sequence compone

A 75-kVA, 480-volt Δ/208-volt Y tra
is connected between the source anc
leakage reactance is $X_{eq} = 0.10$ per
current are neglected. Using the tran
the per-unit sequence networks and c

SOLUTION The base quantities are