EE 5200 - Lecture 12 Fri Sep 25, 2009

Topics for Today:

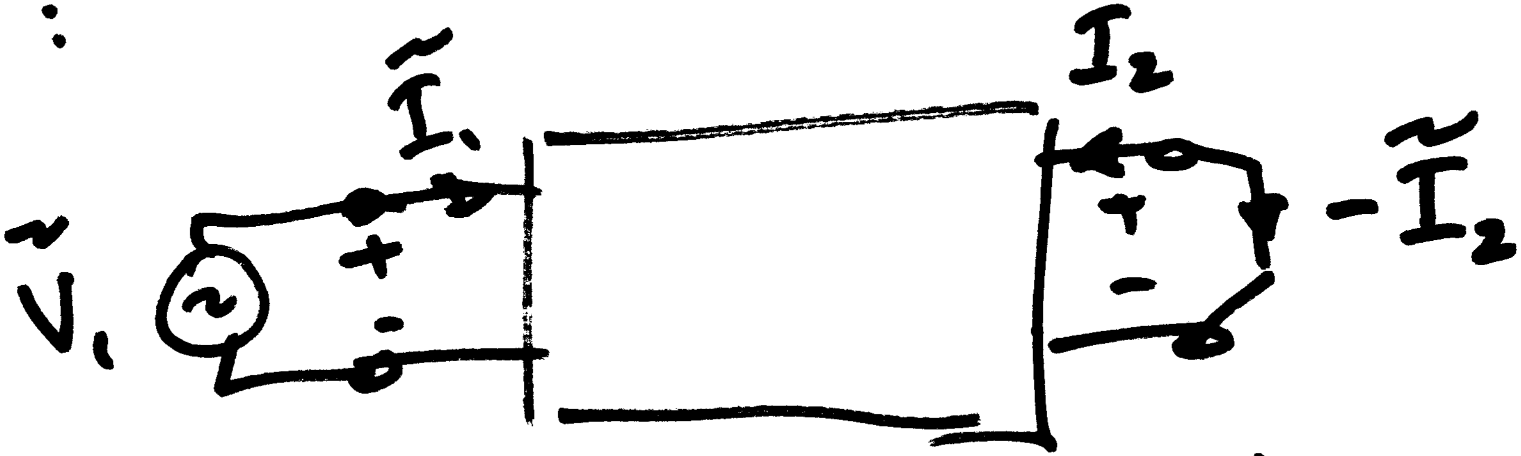
- Announcements
  - Matlab - now we are ready to begin using it.
  - Office hrs: 2:05-2:55pm M,W,F
  - Office: EERC 614. Phone: 906.487.2857
  - Recommended problems from Ch.3, solutions posted
  - Next: Transmission Line Parameters, Chapters 4,5,6

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

$\bar{y}_{11}$:



$$\bar{y}_{11} = \left.\frac{\tilde{I}_1}{\tilde{V}_1}\right|_{\tilde{V}_2=0}$$

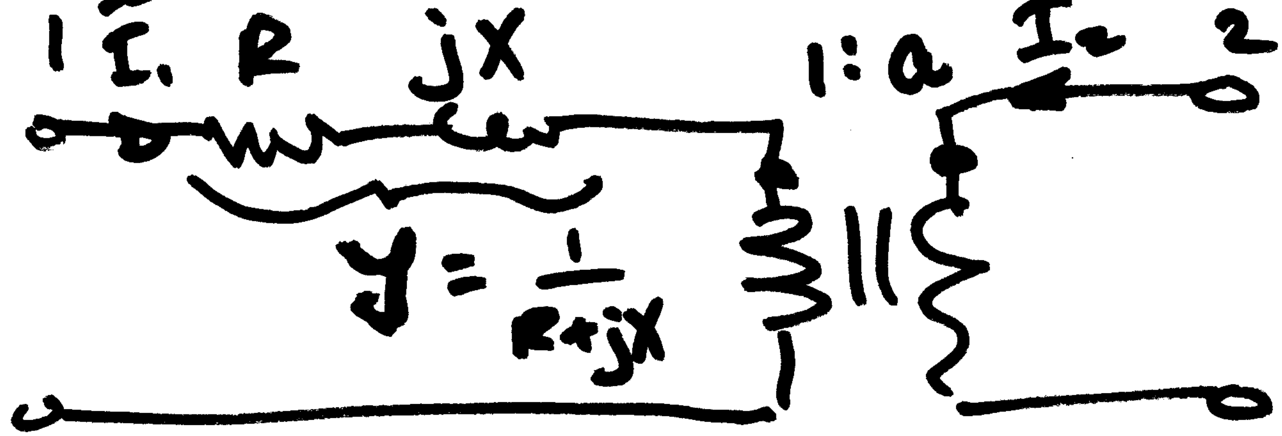
$\bar{y}_{21} =$

$\bar{y}_{12}$

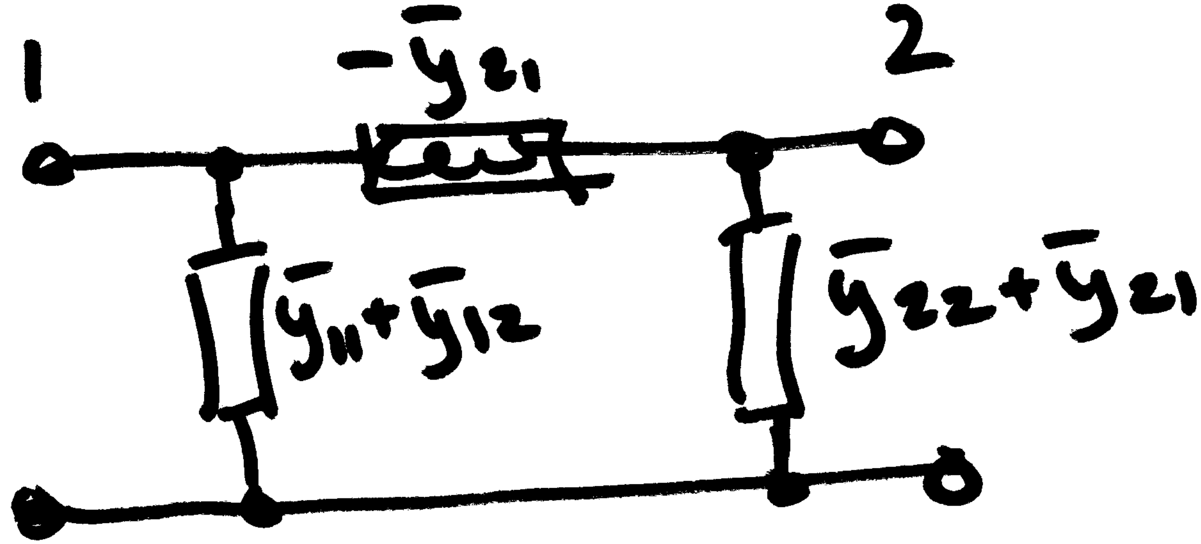
$=$

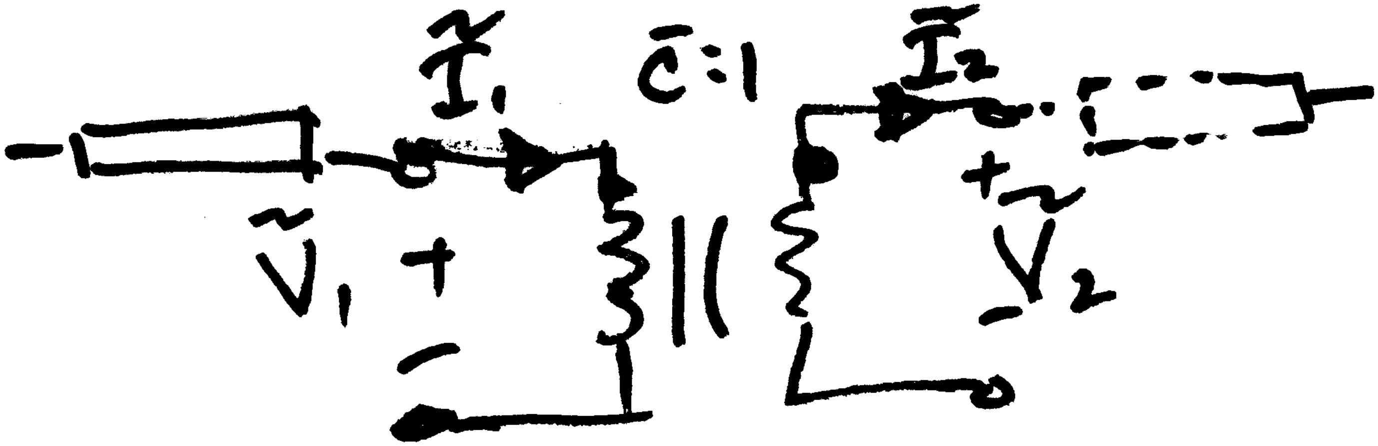
$$\bar{y}_{12} = \left.\frac{\tilde{I}_1}{\tilde{V}_2}\right|_{\tilde{V}_1=0}$$

$\bar{y}_{22} =$



$$\begin{bmatrix} \bar{y}_{11} & \bar{y}_{12} \\ \bar{y}_{21} & \bar{y}_{22} \end{bmatrix} \begin{bmatrix} \tilde{V}_1 \\ \tilde{V}_2 \end{bmatrix} = \begin{bmatrix} \tilde{I}_1 \\ \tilde{I}_2 \end{bmatrix}$$





$$\bar{Z} = \frac{\tilde{V}}{\tilde{I}}$$

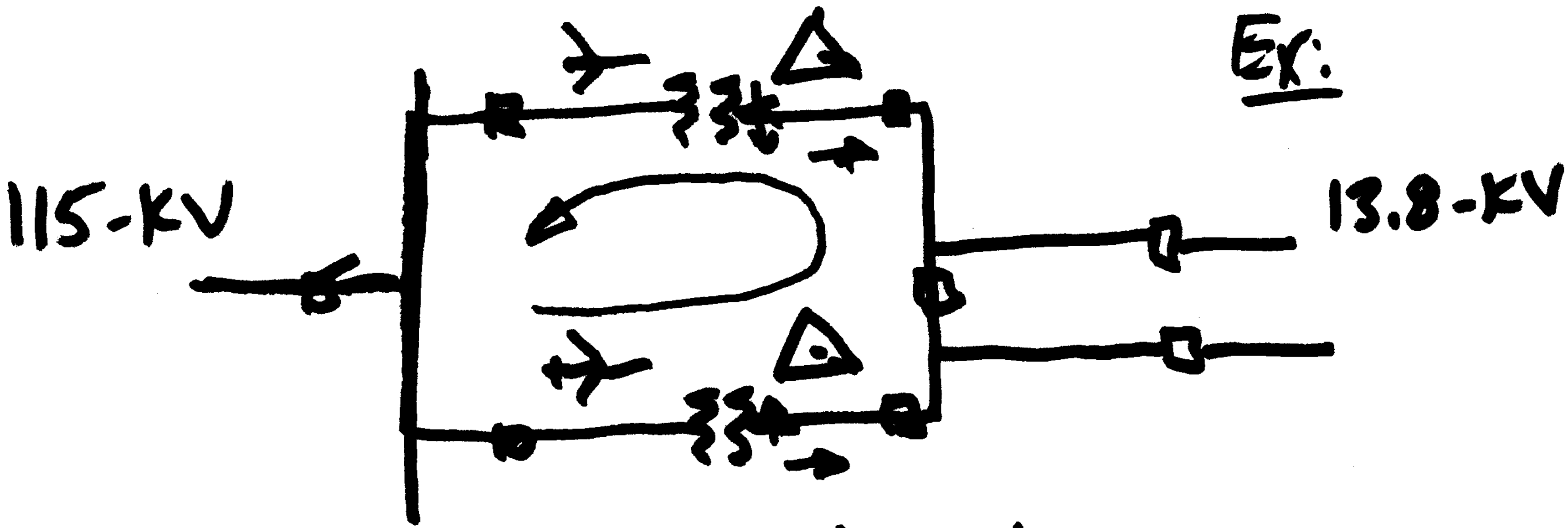
$$\longrightarrow \bar{S}_1 = \bar{S}_2 \longrightarrow$$

$$\tilde{V}_1 \tilde{I}_1^* = \tilde{V}_2 \tilde{I}_2^*$$

$$\frac{\tilde{I}_2^*}{\tilde{I}_1^*} = \frac{\tilde{V}_1}{\tilde{V}_2} = \bar{c}$$

$$\boxed{\frac{\tilde{I}_2^*}{\tilde{I}_1^*} = \bar{c}}$$

Ex:



Circulating Vars

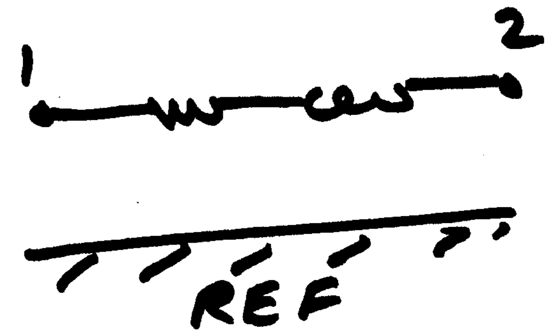
Energization Testing of Var Meters

Detailed derivations!

Basis Approach: Develop π-Equiv and handle just like T-Line.

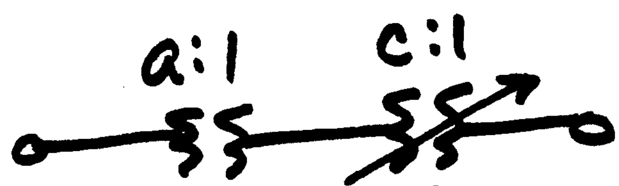
One-Line:

per-unit per-phase



Tap-Changers

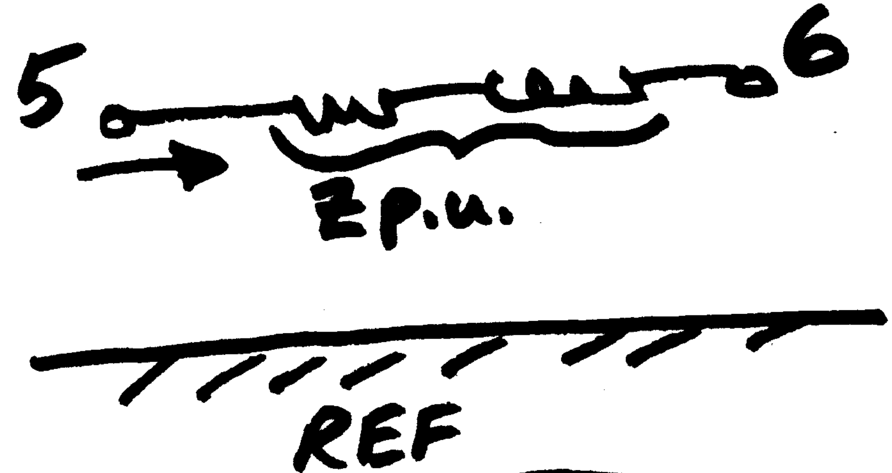
- LTC's
- Phase-Shift



NOMINAL TURNS RATIO

± Adjustment in phase angle (PS) or volt mag (LTC)

XFMRS – Use L-N (ϕA-N) Per Phase Equiv.



Modify $\tilde{y}_{55}$ $\tilde{y}_{56}$ $\tilde{y}_{65}$ $\tilde{y}_{66}$

In [Y_{BUS}] $y_{56} = -\dfrac{1}{Z_{56}}$ (and y_{65})

$y_{55} = y_{55} + Z_{56}$

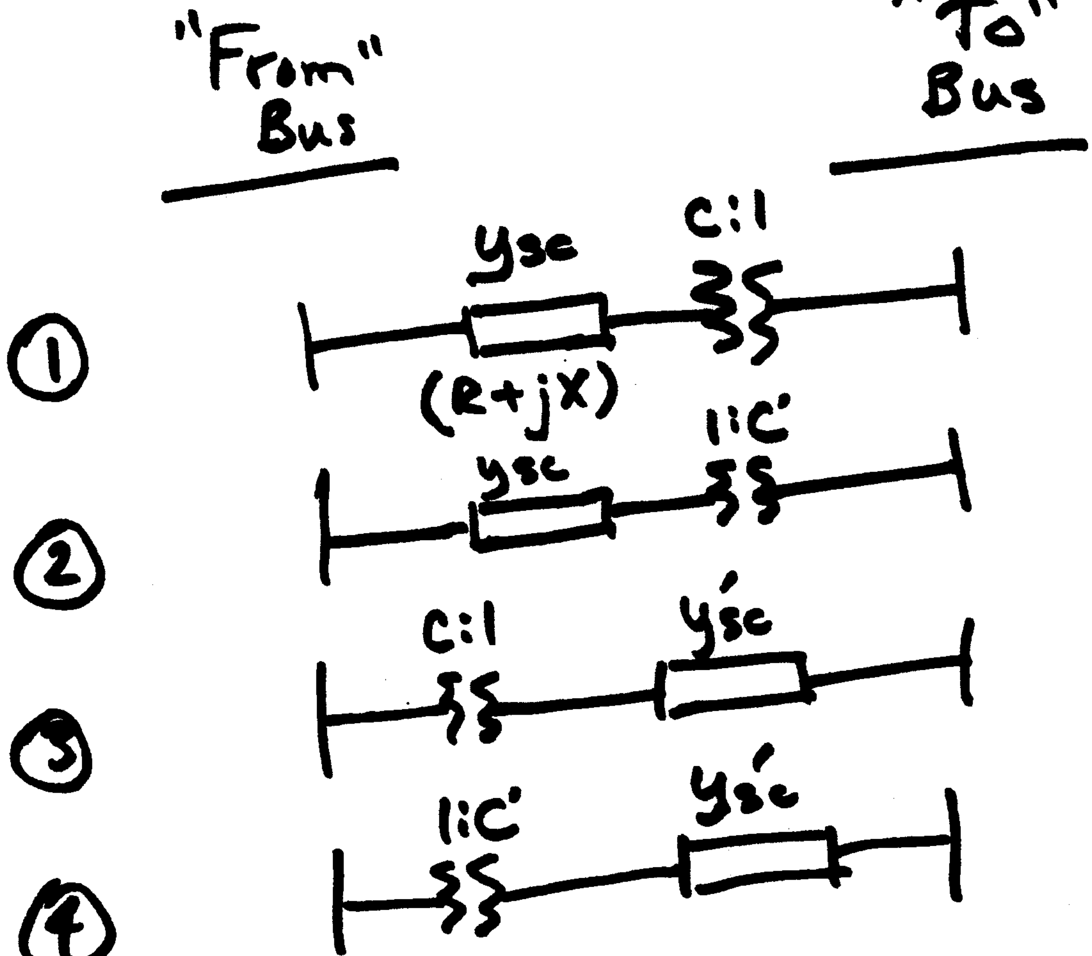
$y_{66} = y_{66} +$ "

Basis 2-winding XFMR is simple.

How about?

- LTC (or TCUL)
- Phase Shifter (PS)

Tap Changing XFMRS – Variations (p.u. representations)



$$y_{sc} = \frac{1}{R+jX}$$

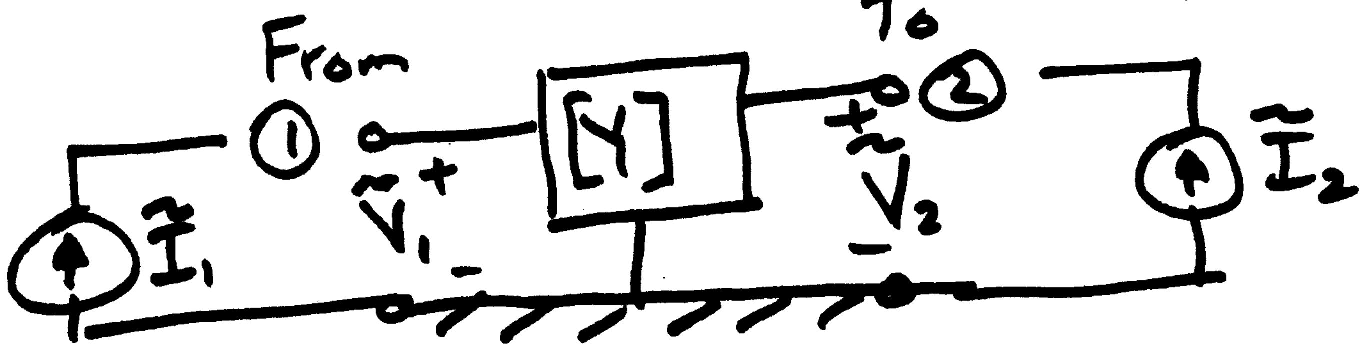
"c" is off-nominal turns ratio. In general c is complex.

c is real for LTC.
c is complex for PS.

If $|c| \neq 1$ then magnitude change.

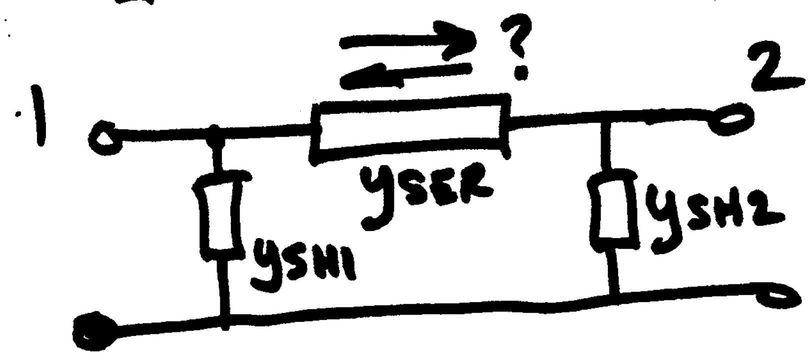
If c is complex, phase shift.

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:



$y_{11} = \overrightarrow{y_{SER}} + y_{SH1}$

$y_{12} = -\overrightarrow{y_{SER}}$

$y_{21} = -\overleftarrow{y_{SER}}$

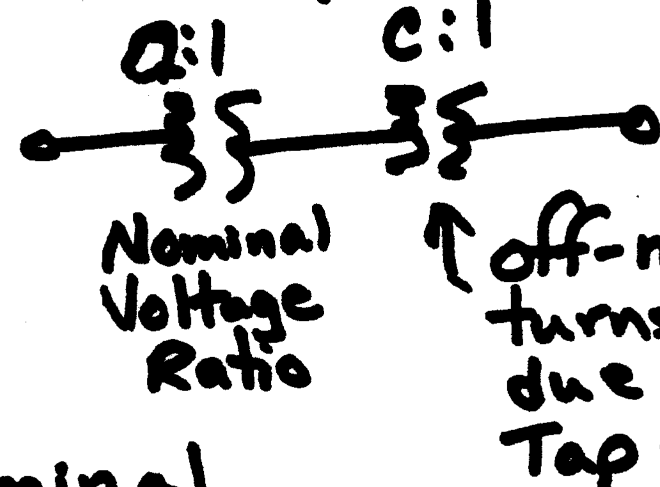
$y_{22} = \overleftarrow{y_{SER}} + y_{SH2}$

a

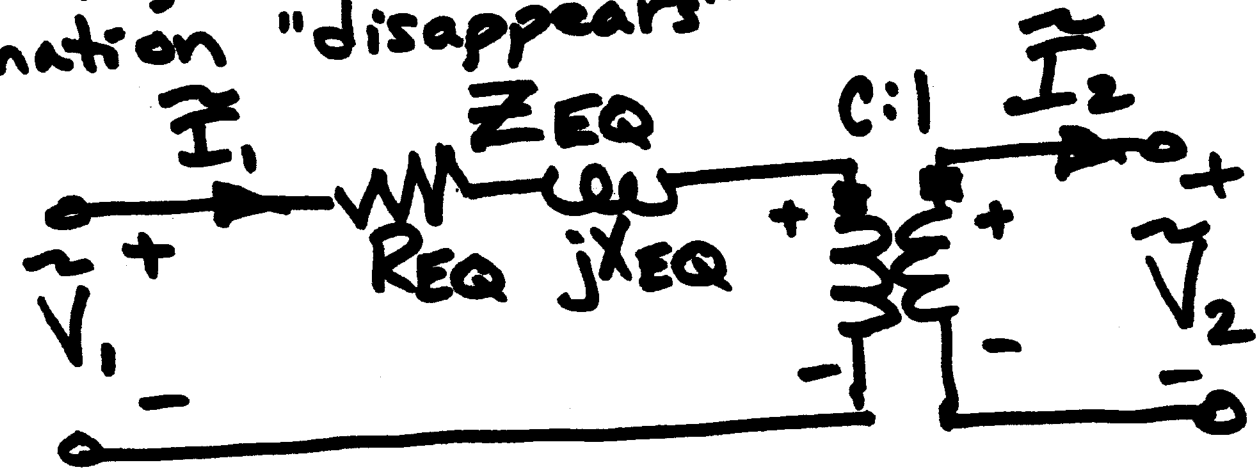
TAP-CHANGERS

On One-Line Diags:

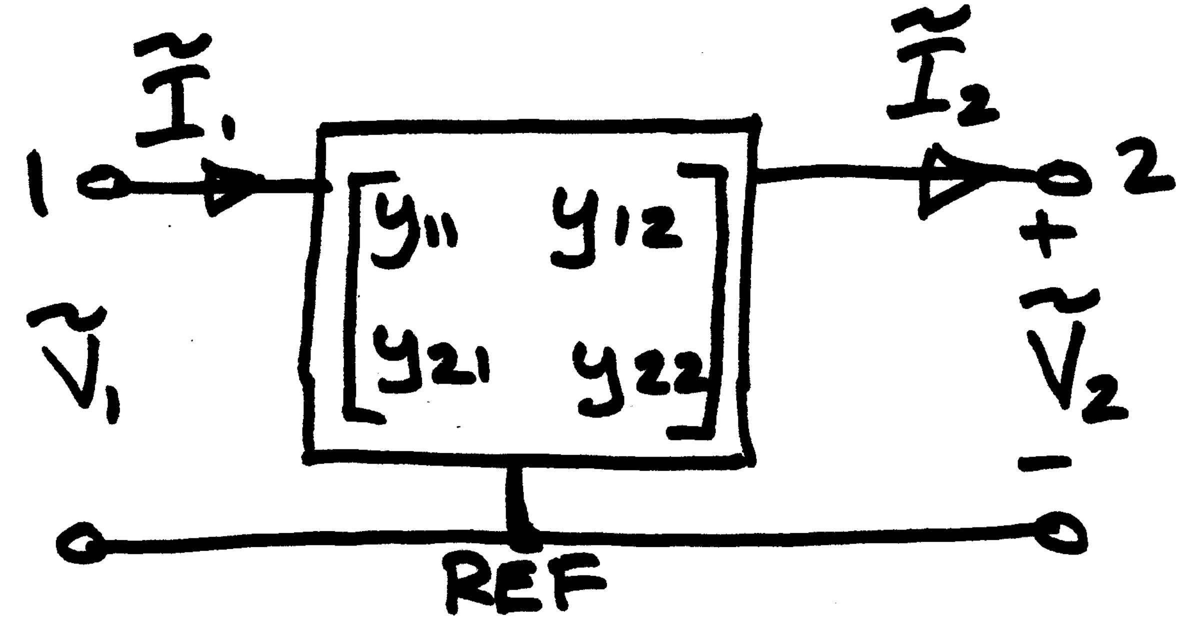
Conceptually:



In per unit, nominal transformation "disappears"



Generically, we can describe this b as a 2-node [Y]

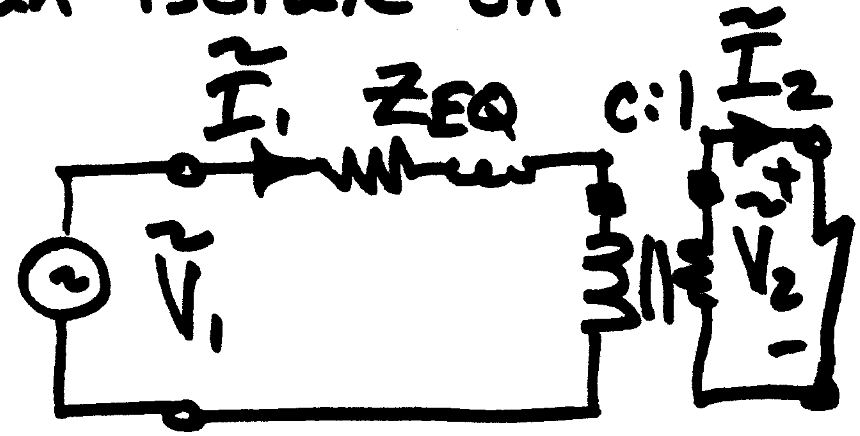


where

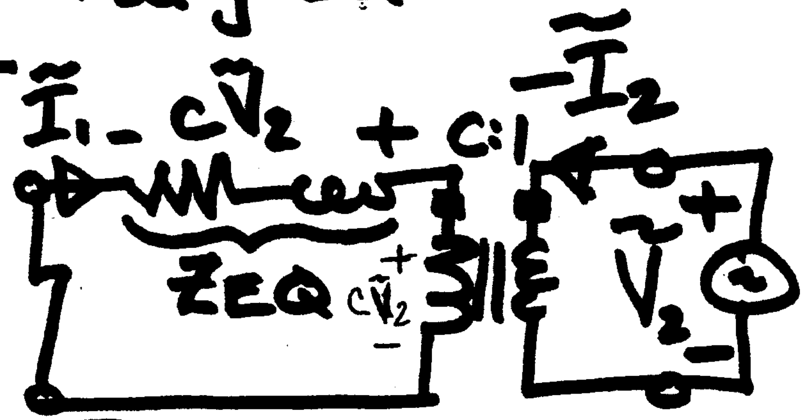
$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} \tilde{V}_1 \\ \tilde{V}_2 \end{bmatrix} = \begin{bmatrix} \tilde{I}_1 \\ -\tilde{I}_2 \end{bmatrix}$$

Strategically using shorts [redacted]

[redacted], we can isolate on the values of [Y]. C



$$y_{11} = \left.\frac{\tilde{I}_1}{\tilde{V}_1}\right|_{\tilde{V}_2=0} = \frac{1}{Z_{EQ}} = Y_{EQ} = \frac{1}{R_{EQ}+jX_{EQ}}$$



$$y_{22} = \left.\frac{-\tilde{I}_2}{\tilde{V}_2}\right|_{\tilde{V}_1=0} = \frac{1}{Z_{EQ}/|c|^2} = |c|^2 Y_{EQ}$$

$$\tilde{I}_1 = -\frac{c\tilde{V}_2}{Z_{EQ}}; \quad -\tilde{I}_2 = -\tilde{I}_1 * c^* = -\left[\frac{c\,\tilde{V}_2}{Z_{EQ}}\right] c^*$$

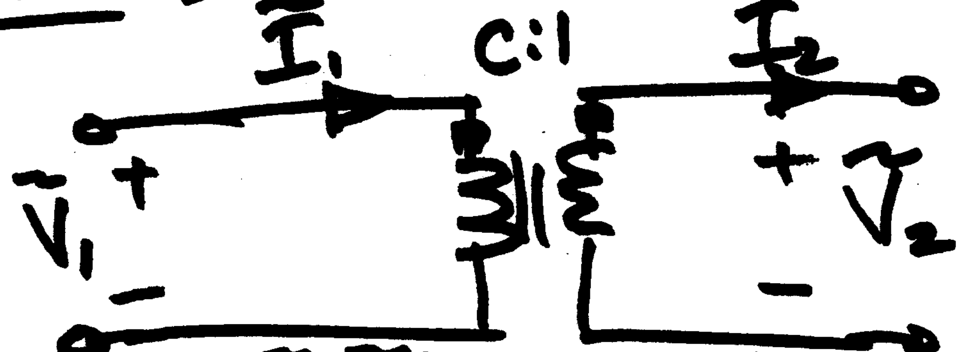
$$= \frac{|c|^2 \tilde{V}_2}{Z_{EQ}}$$

Note: $\frac{I_2}{I_1} = c^*$

$$y_{12} = \left.\frac{\tilde{I}_1}{\tilde{V}_2}\right|_{\tilde{V}_1=0} = \frac{-c\tilde{V}_2/Z_{EQ}}{\tilde{V}_2} = -cY_{EQ}$$ d

$$y_{21} = \left.\frac{-\tilde{I}_2}{\tilde{V}_1}\right|_{\tilde{V}_2=0} = \frac{-c^*\tilde{I}_1}{\tilde{V}_1} = -c^*Y_{EQ}$$

Note: Ideal XFMR, by definition, has "c" is voltage ratio.



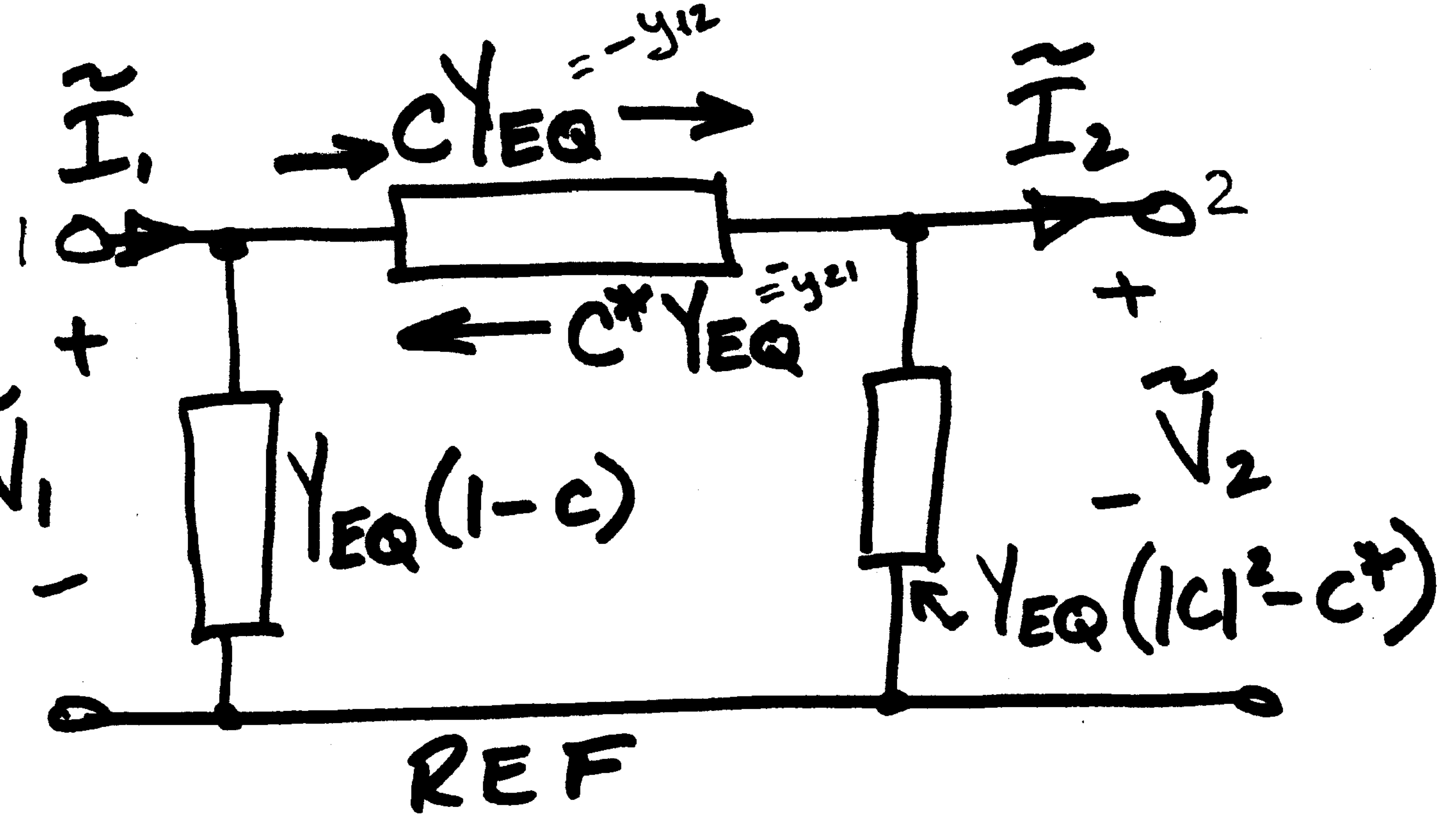
$$\tilde{S}_{IN} = \tilde{V}_1\tilde{I}_1^* = \tilde{V}_2\tilde{I}_2^* = \tilde{S}_{OUT}$$

$$c = \frac{\tilde{V}_1}{\tilde{V}_2} \Longrightarrow$$

$$c = \frac{\tilde{I}_2^*}{\tilde{I}_1^*} \Rightarrow \frac{\tilde{I}_2}{\tilde{I}_1} = c^*$$

e)

If we "reverse engineer" our $[Y]$ into an equivalent 2-bus network, then



Observations:

- LTC (TCUL) has a c that is Real.

  $\therefore$ Transfer Admittances

  $$c Y_{EQ} = c^* Y_{EQ}$$

  $\Rightarrow$ Bilateral. ($y_{12} = y_{21}$)

- Phase-Shifter (PS) has complex c.

  $\therefore$ Transfer admittances

  $$c Y_{EQ} \neq c^* Y_{EQ}$$

  $$y_{12} \neq y_{21}$$

  Not Bilateral. $[Y]$ not symm. about main diag.