EE 5240 - Lecture 7 Monday Jan 28, 2019

Topics for Today:

- Questions from last lectures?
- Comments on Homework #2
    - Augmentation for L-G Fault - signs !

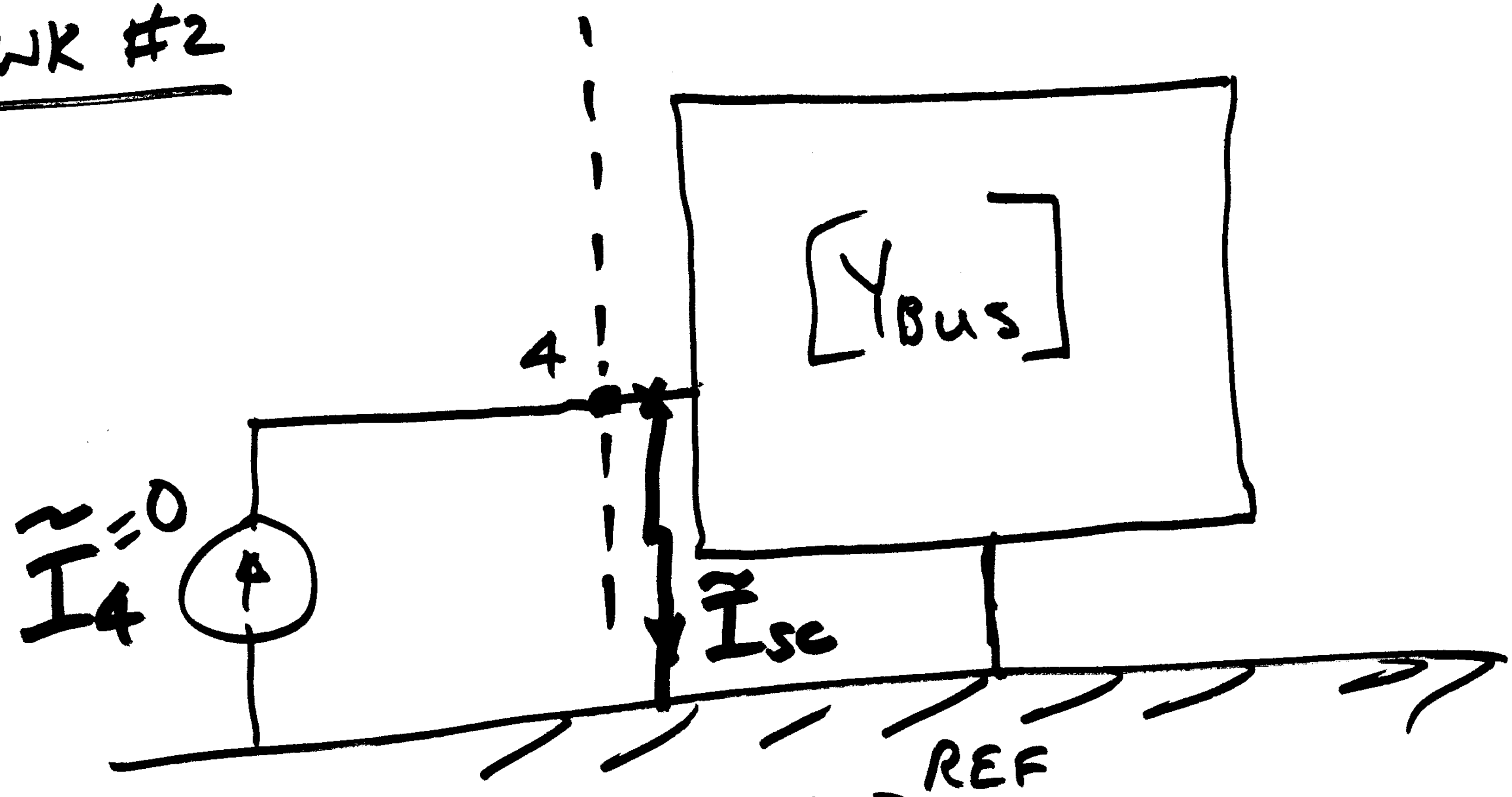
Today - system data for computer studies

- Transformer Data
- More on tap-changing transformers

Coming up - keep studying Chapters 3 & 4.

- Nonlinear systems of equations
- Newton Iterative Method
- Newton-Raphson Load Flow Formulation
- Everybody have access to Aspen?

HMWK #2



$$\begin{bmatrix} & Y & & \\ y_{41} & y_{42} & y_{43} & y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix}$$

$$I_4 = y_{41}V_1 + y_{42}V_2 + y_{43}V_3 + y_{44}V_4 + I_{sc}$$

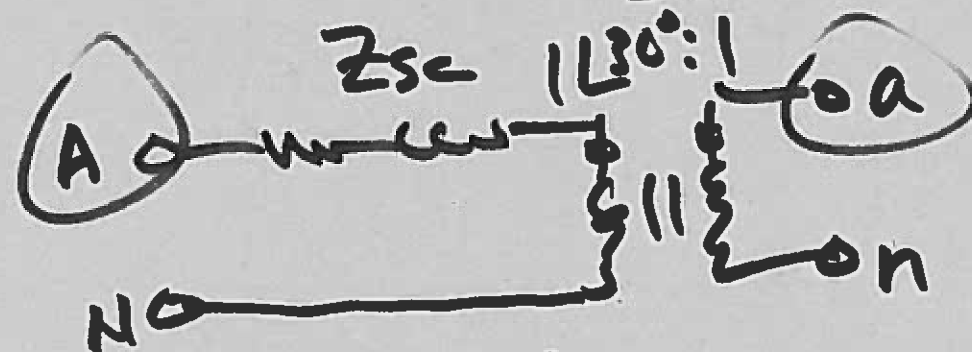
MichiganTech Instructor: Bruce Mork Phone (906) 487-2857 Email: bamork@mtu.edu

* - Not matching P.U. Base Voltages

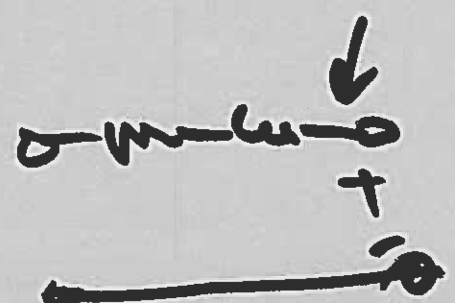
* - LTC / TCUL (V, Q)

- Phase-shifting xfmr (P)

* - Per Phase Calcs - Δ-Y phase shifts

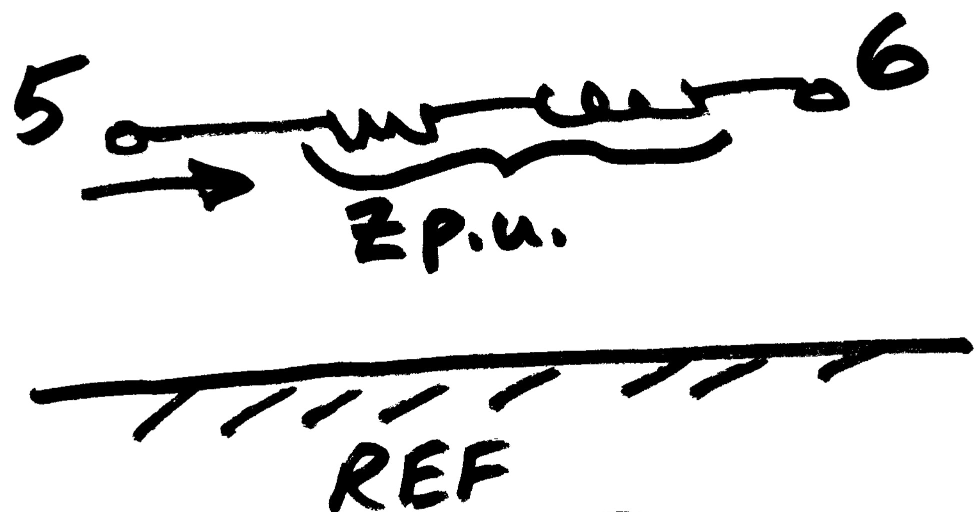


$\Downarrow$



$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

XFMRS - Use L-N Per Phase Equiv.



In [Y Bus]

$$y_{56} = -\frac{1}{z_{56}}$$

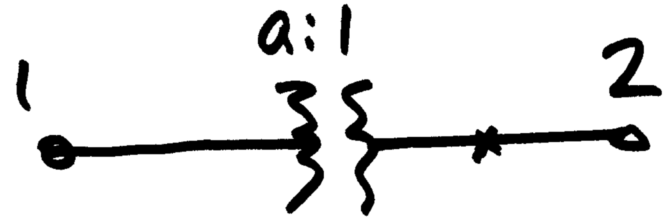
Basis 2-winding XFMR is simple.

How about?

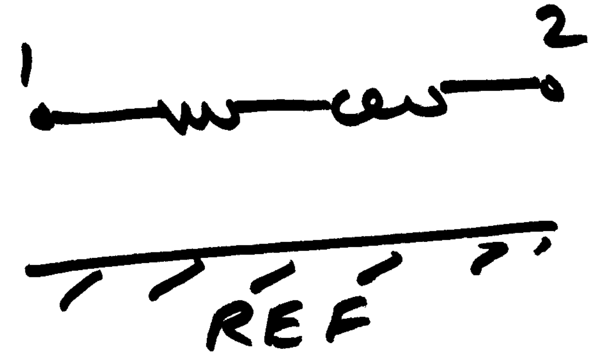
- LTC (or TCUL)
- Phase Shifter (PS)

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

One-Line:

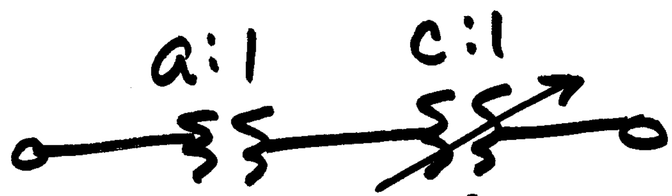


per-unit per-phase



Note: a:1 represents nominal turns ratio, i.e. the ratio between the base voltages of the per unit system. Taken in the context of a per unit system, a=1 and the transformer can be represented as a simple series impedance. c:1 represents the off-nominal turns ratio, and so its effect must be included in [Ybus].

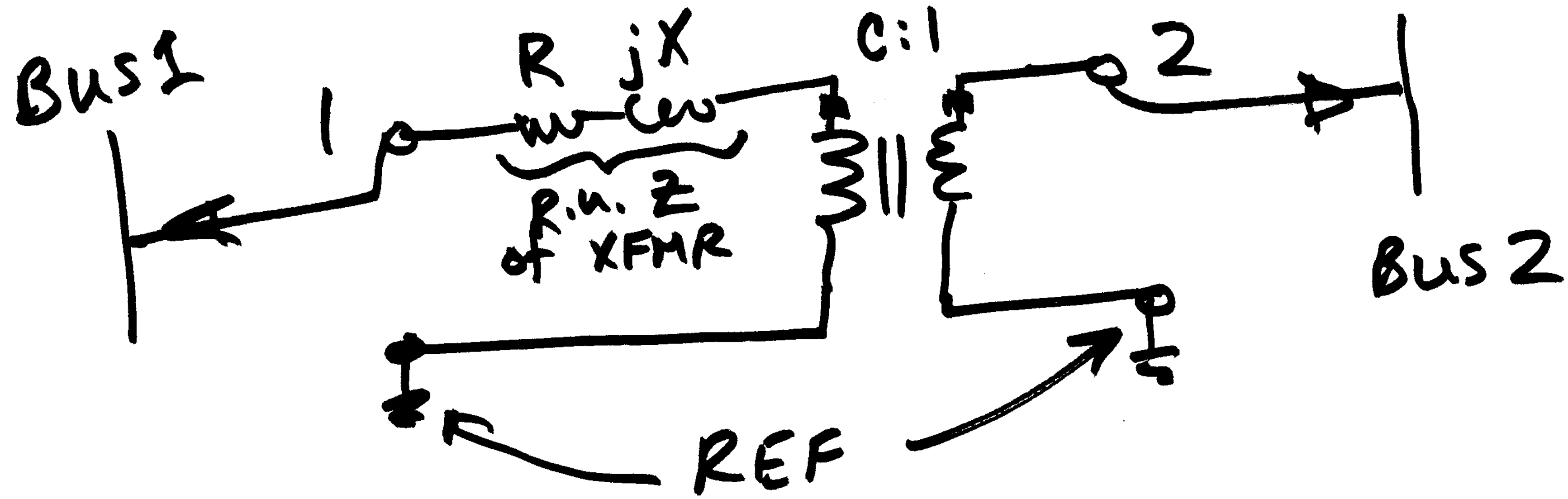
Tap-Changers
- LTC's
- Phase-Shift

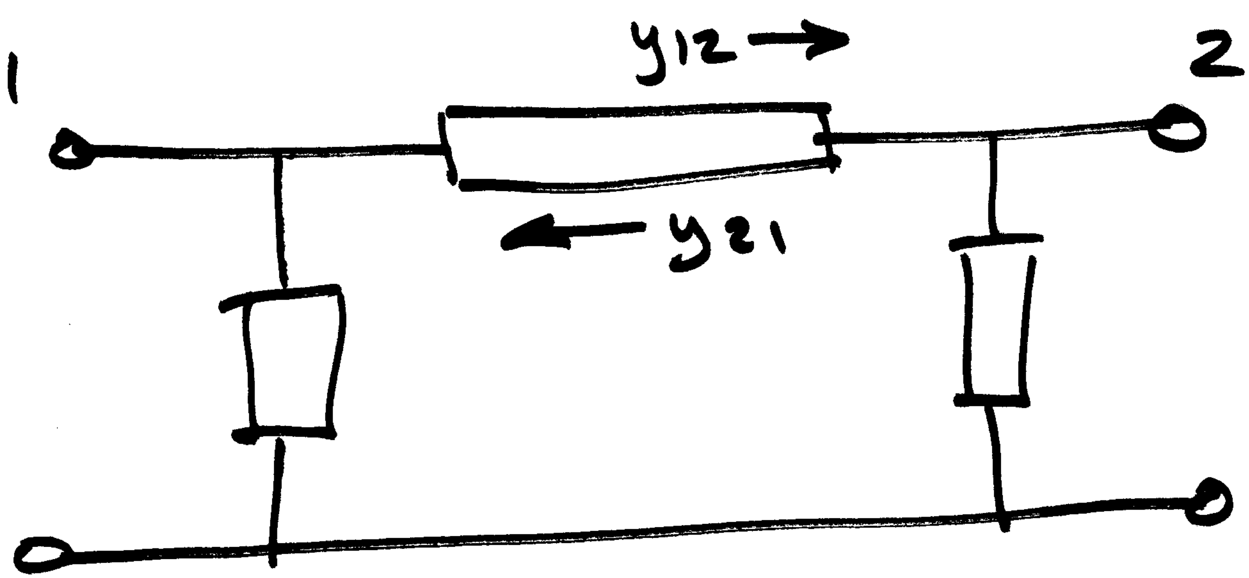


NOMINAL TURNS RATIO

$\pm$ Adjustment in phase angle (PS) or volt mag (LTC)

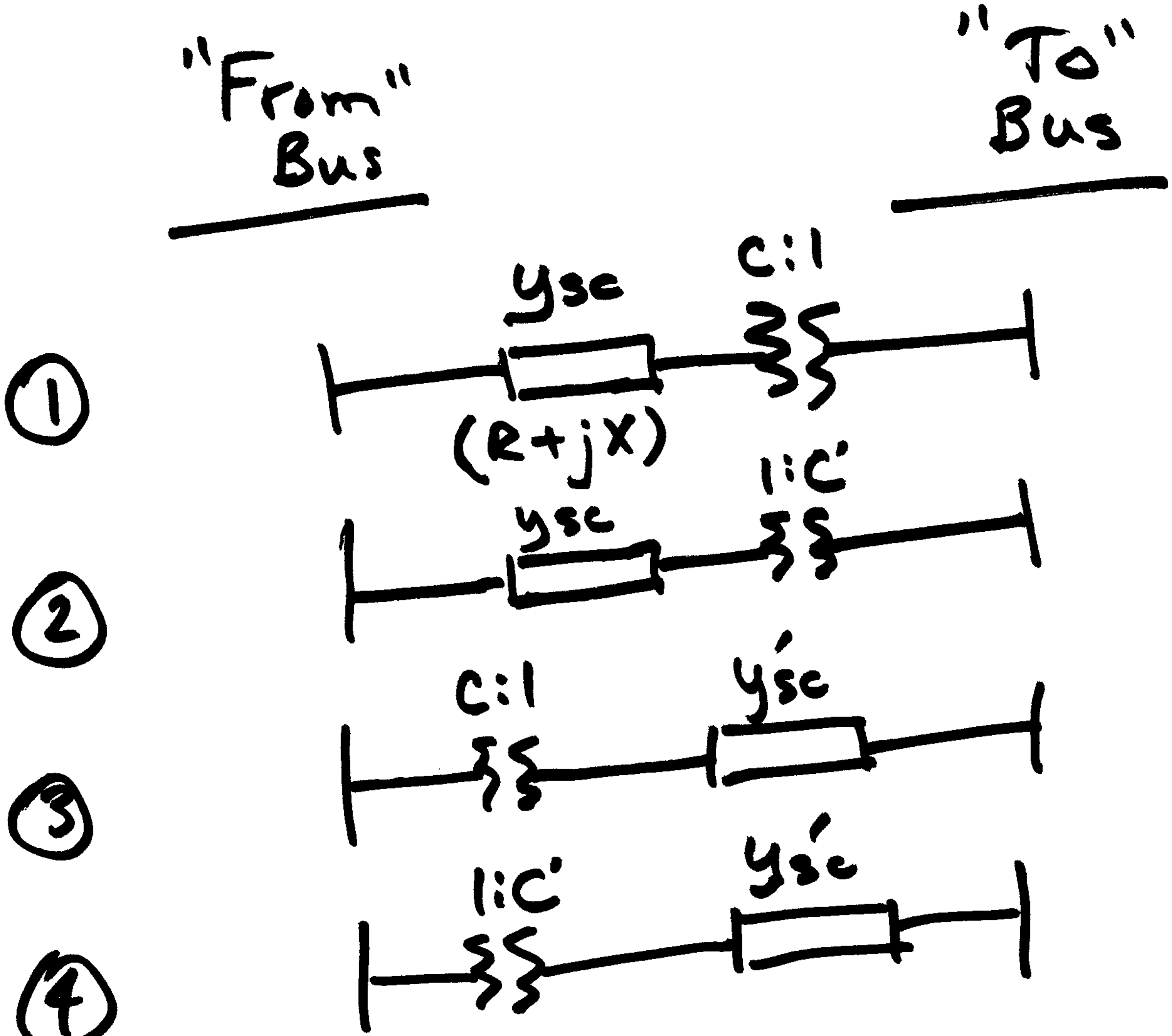
MichiganTech Instructor: Bruce Mork Phone (906) 487-2857 Email: bamork@mtu.edu





MichiganTech Instructor: Bruce Mork Phone (906) 487-2857 Email: bamork@mtu.edu

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



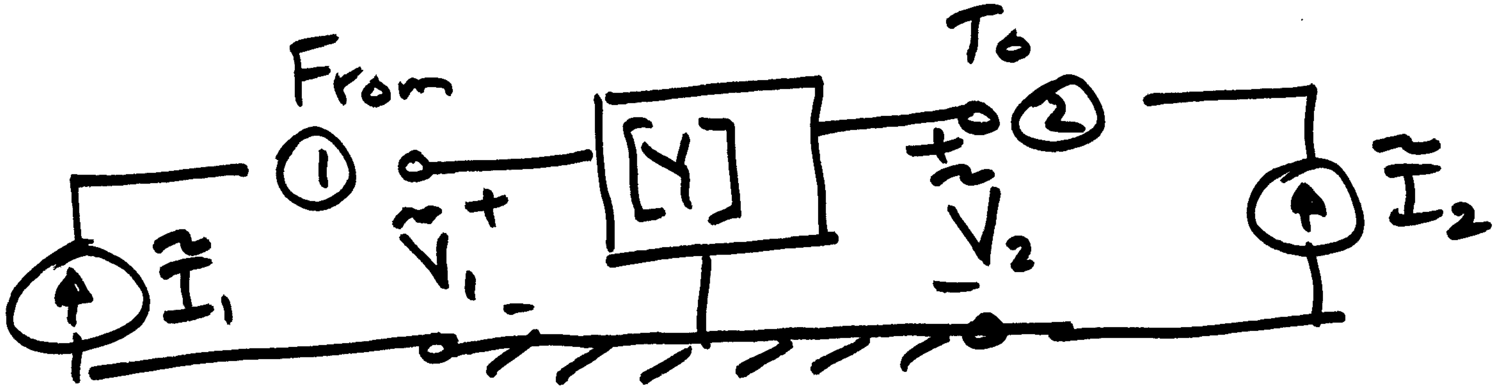
$$\boxed{y_{sc} = \frac{1}{R+jX}}$$

"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.

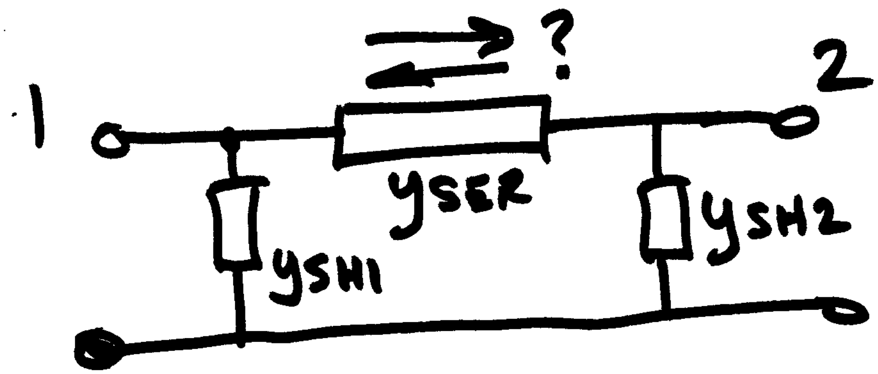
MichiganTech Instructor: Bruce Mork Phone (906) 487-2857 Email: bamork@mtu.edu

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:



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

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

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

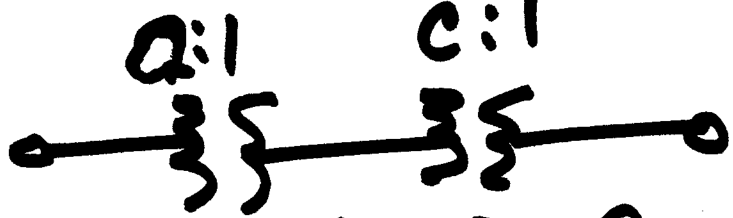
$y_{22} = \overleftarrow{y_{SER}} + y_{SH2}$

MichiganTech Instructor: Bruce Mork Phone (906) 487-2857 Email: bamork@mtu.edu

TAP-CHANGERS

On One-Line Diags:

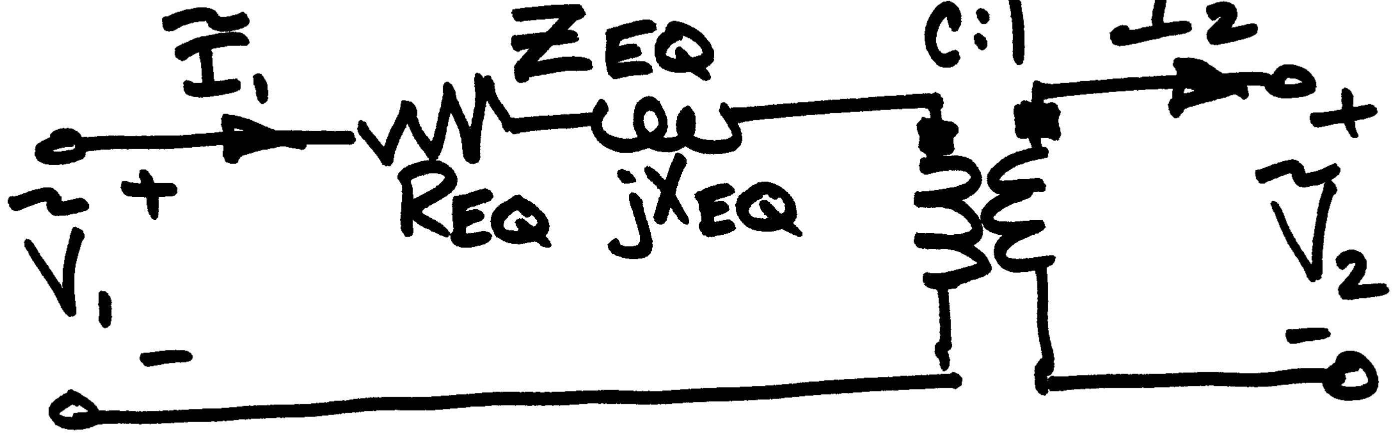
Conceptually:



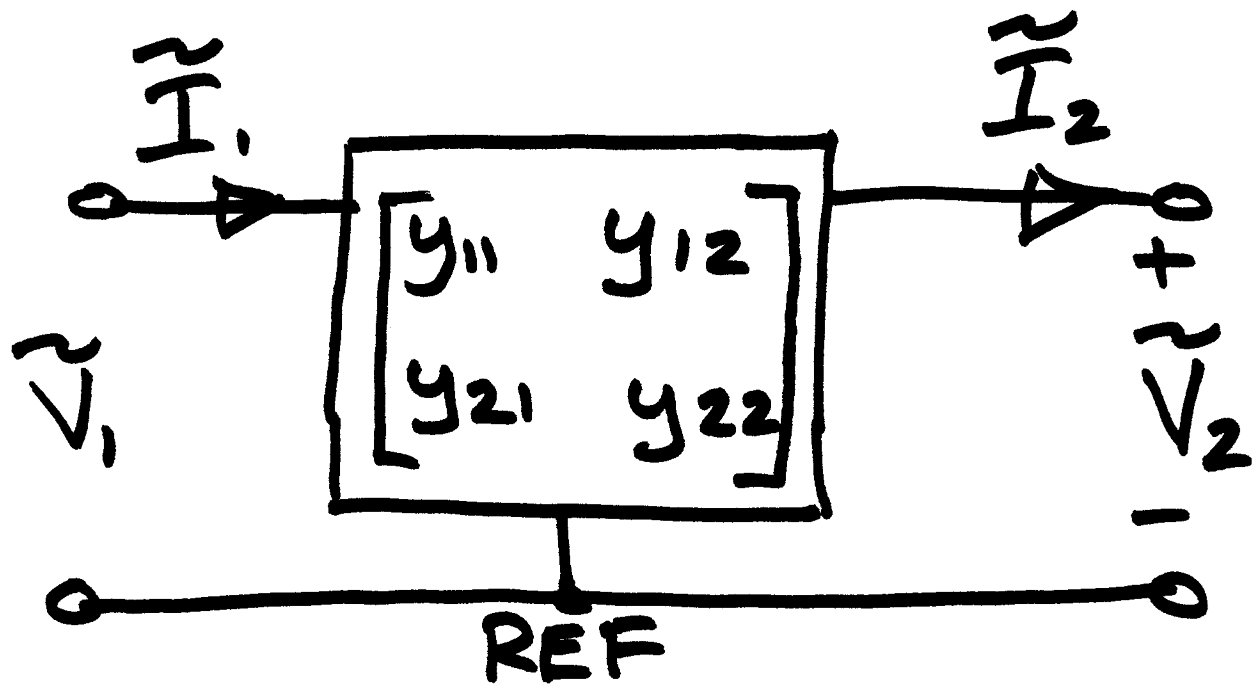
Nominal Voltage Ratio

off-nominal turns ratio due to Tap Changer

In per unit, nominal transformation "disappears"



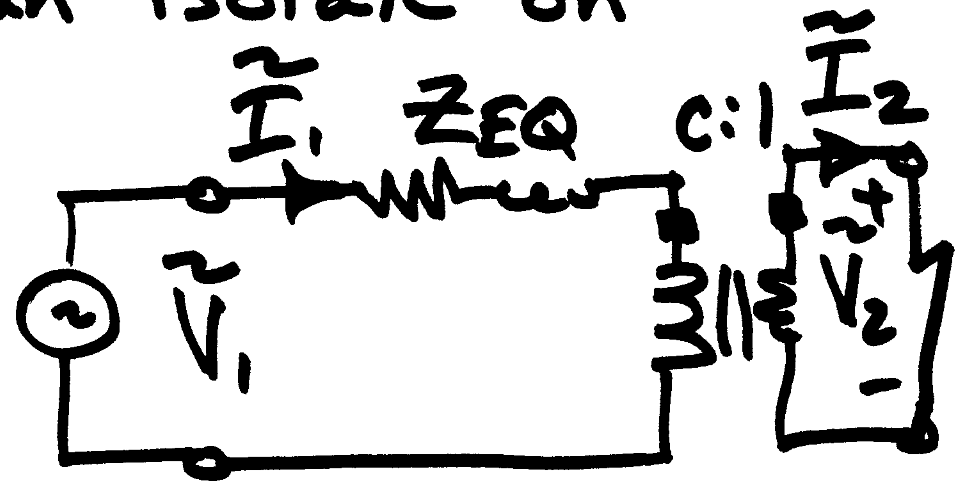
Generically, we can describe this b as a 2-node [Y]



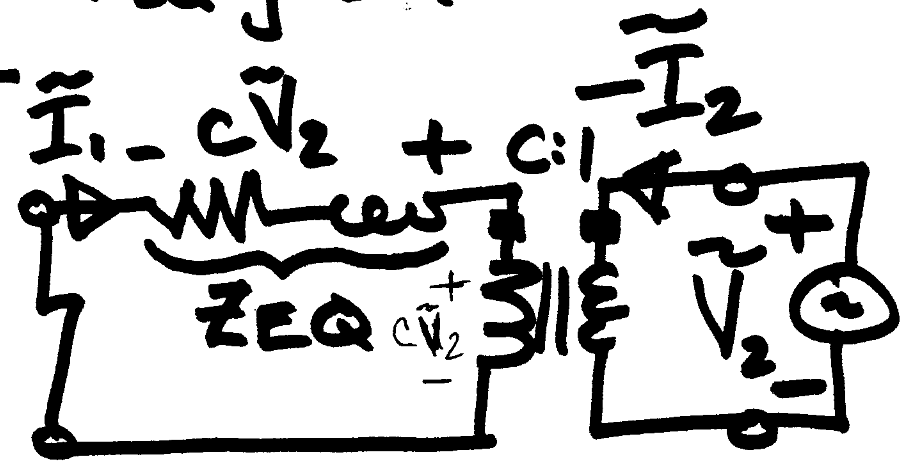
where

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

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



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



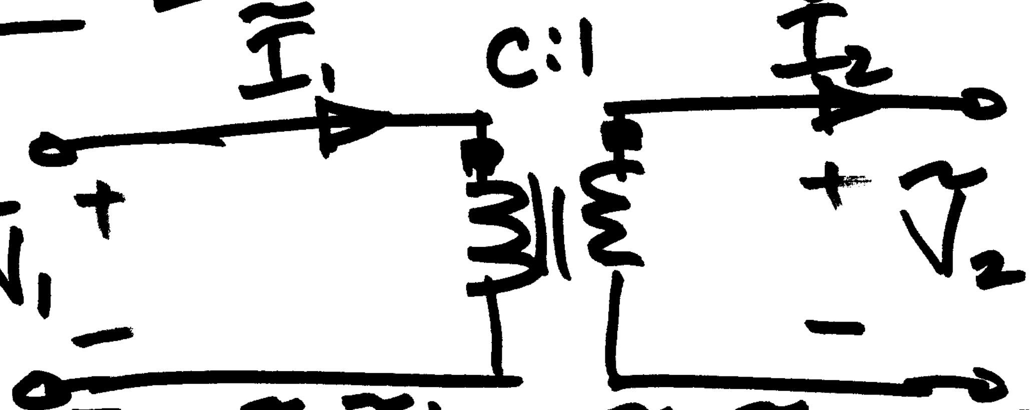
$$y_{22} = \left.\frac{-\tilde{I}_2}{\tilde{V}_2}\right|_{\tilde{V}_1=0} = \frac{1}{Z_{EQ}/|c|^2} = |c|^2 Y_{EQ}$$

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

d

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

<u>Note:</u> Ideal XFMR, by definition, has "c" is voltage ratio.



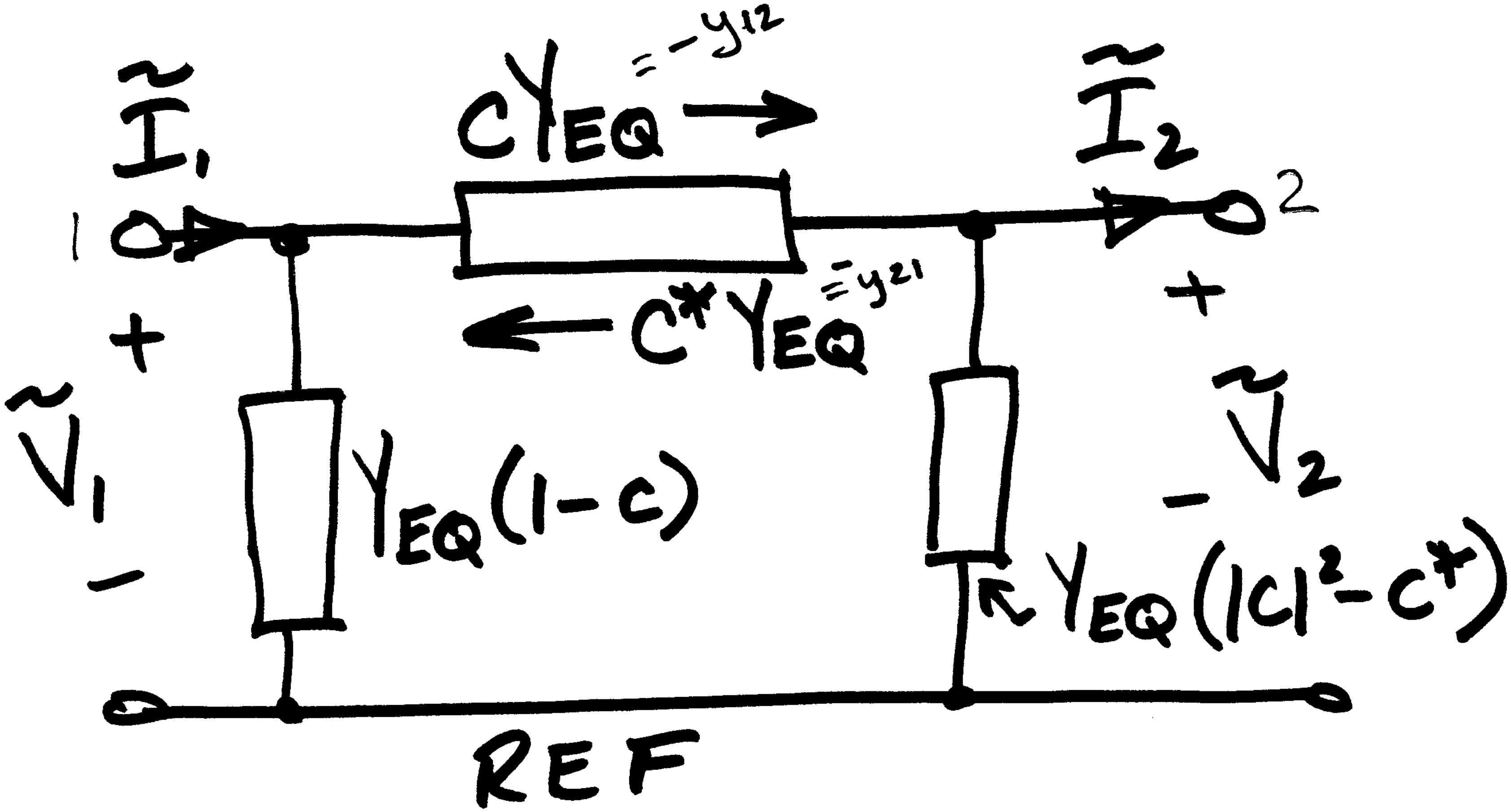
$$\tilde{S}_{IN} = \tilde{V}_1\tilde{I}_1^* = \tilde{V}_2\tilde{I}_2^* = \tilde{S}_{OUT}$$

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

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

e)

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



f

Observations:

- LTC (TCUL) has a c that is <u>Real</u>.

  $\therefore$ Transfer Admittances

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

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

- Phase-Shifter (PS) has complex c.

  $\therefore$ Transfer admittances

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

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

  <u>Not</u> Bilateral. $[Y]$ not symm. about main diag.