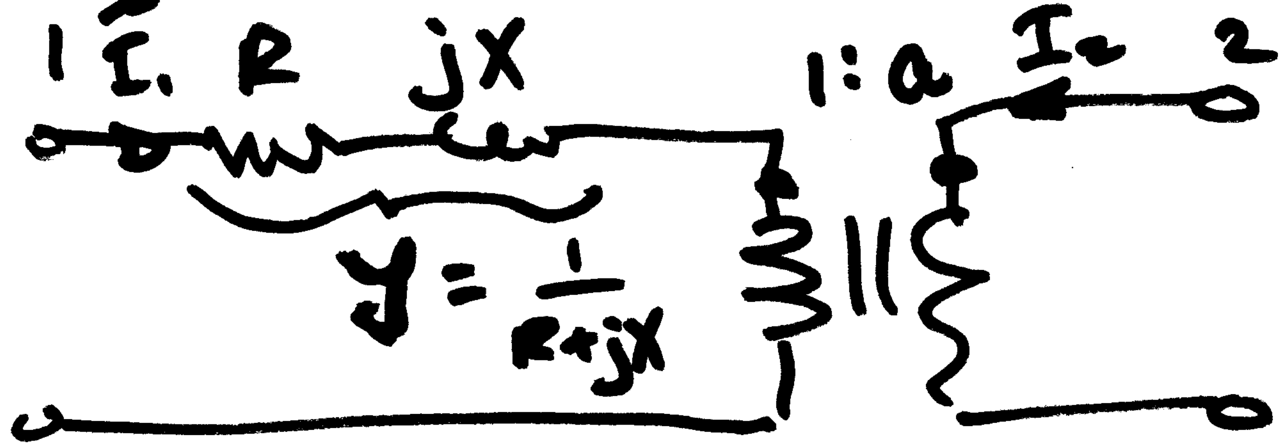
EE 5200 - Lecture 12 Fri Sep 27, 2019

Topics for Today:

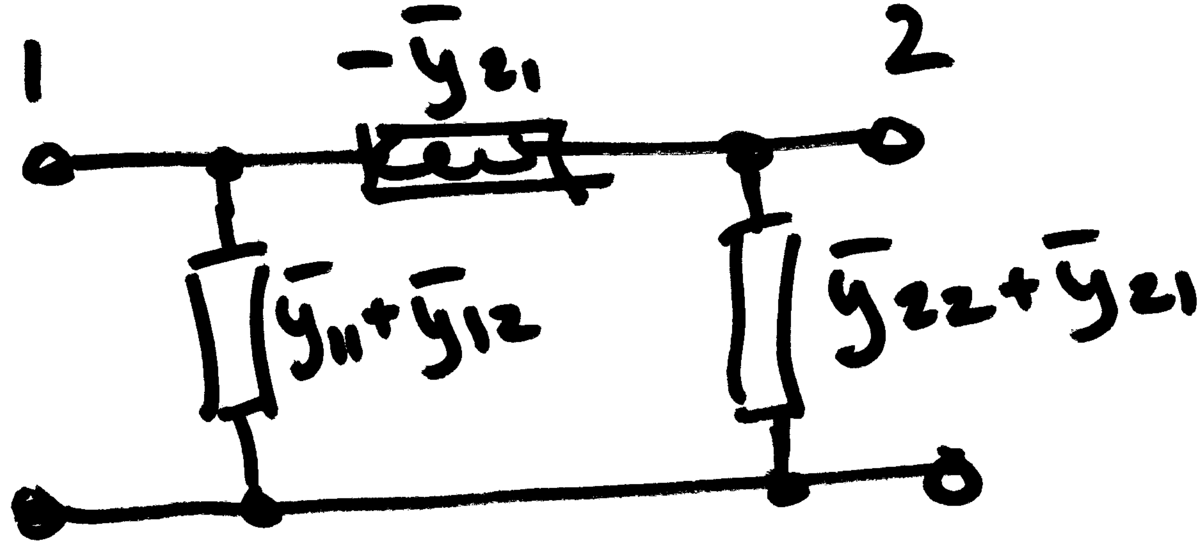
- Announcements
  - Learning Center hrs TBA
  - Office: EERC 614. Phone: 906.487.2857
  - Recommended problems from Ch.3, solutions posted
  - SYNCH homework due Oct 10th, 9am.
  - Next: Transmission Line Parameters, Chapters 4,5,6

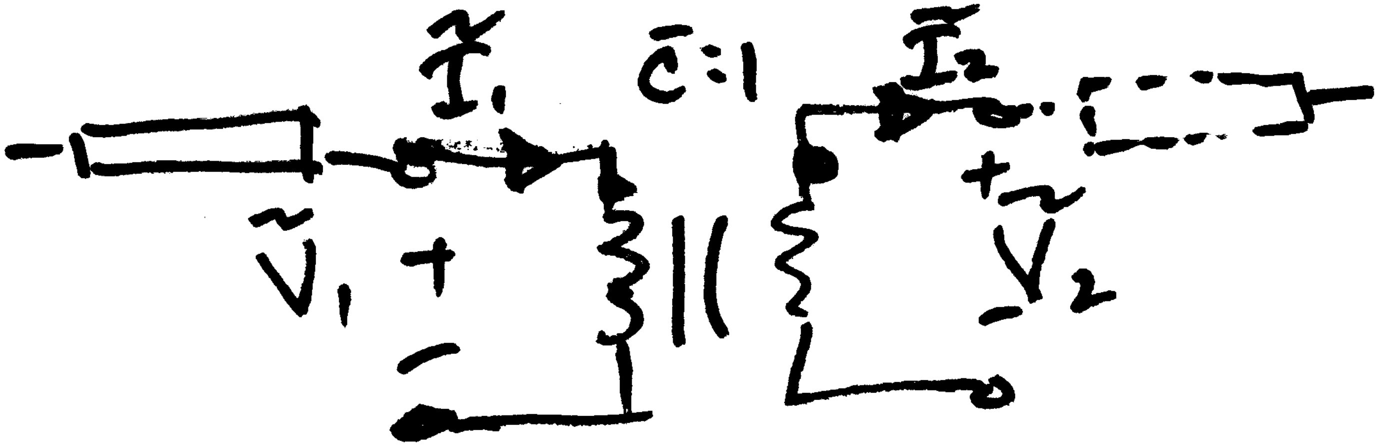
Transformers - wrapup on off-nominal turns ratio
Synchronous Machines - Chapter 3.

- 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



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





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

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

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

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

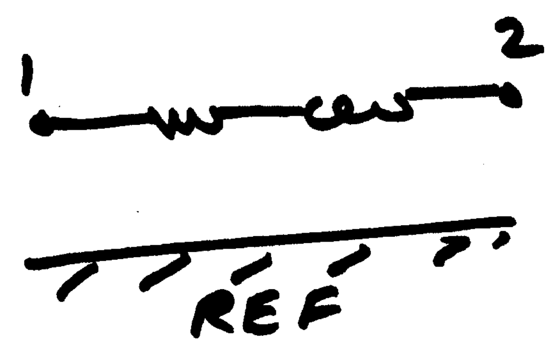
$$\boxed{\frac{\tilde{I}_2^*}{\tilde{I}_1^*} = \bar{c}}$$

Detailed derivations!

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

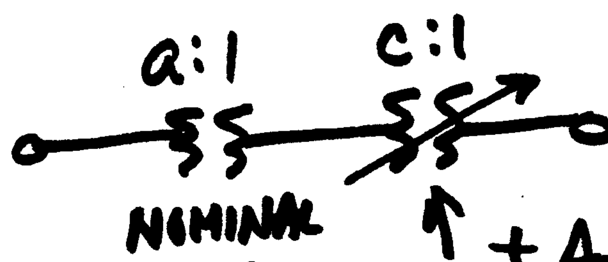
One-Line:

per-unit per-phase

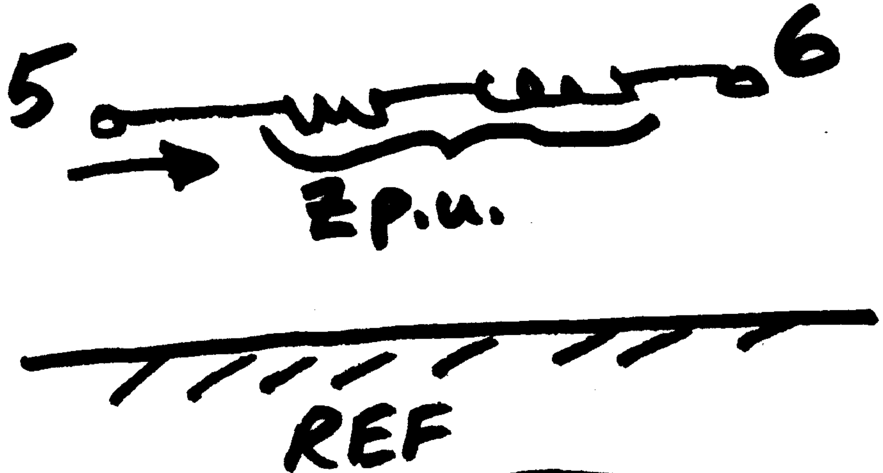


Tap-Changers

- LTC's
- Phase-Shift



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



Modify
y_{55} y_{56}
y_{65} y_{66}

In [Ybus]

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

(and y_{65})

$$y_{55} = y_{55} + \frac{1}{Z_{56}}$$

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

Basis 2-winding XFMR is simple.

How about?
- LTC (or TCUL)
- Phase Shifter (PS)

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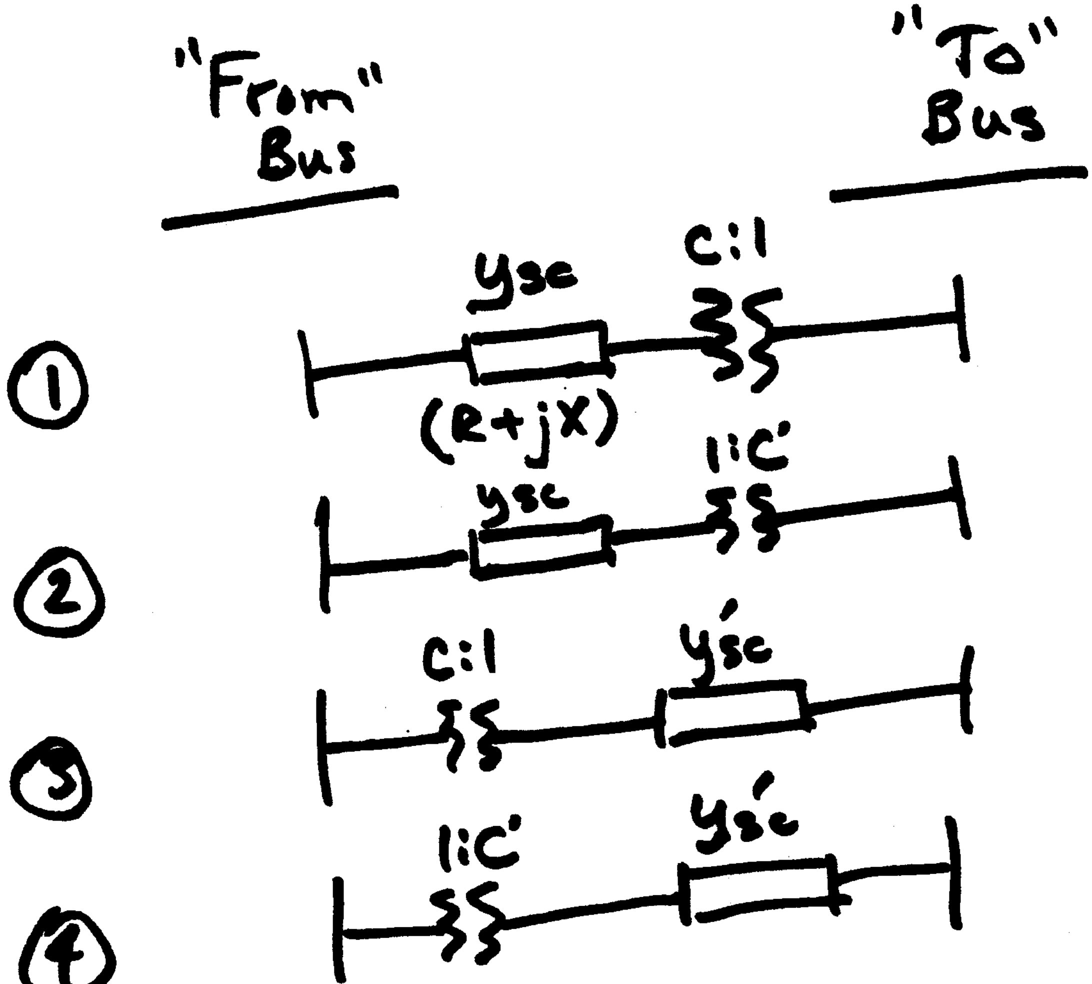
Tap Changing XFMRS – Variations (p.u. representations)



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

"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.

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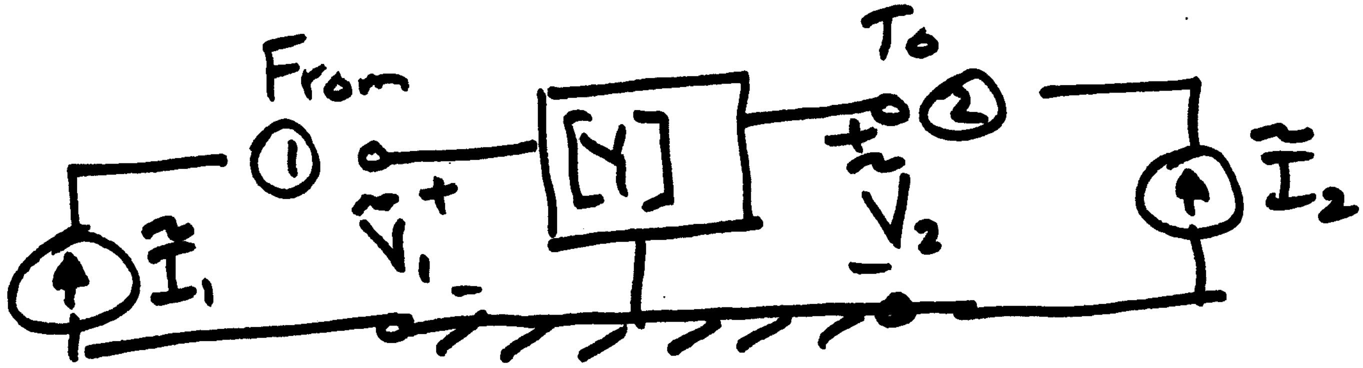
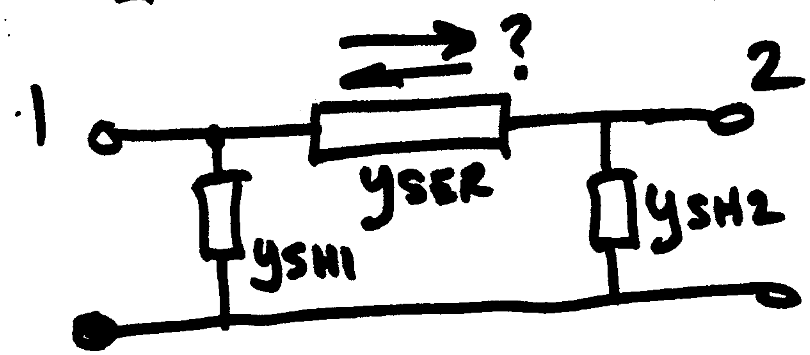
Standard Approach:



$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

Goal:



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

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

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

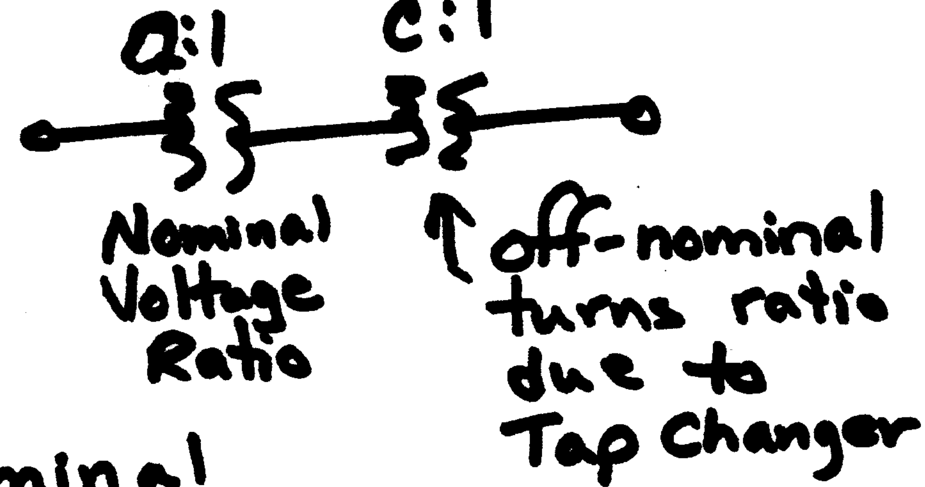
$y_{22} = \overleftarrow{y_{SER}} + y_{SH2}$

a

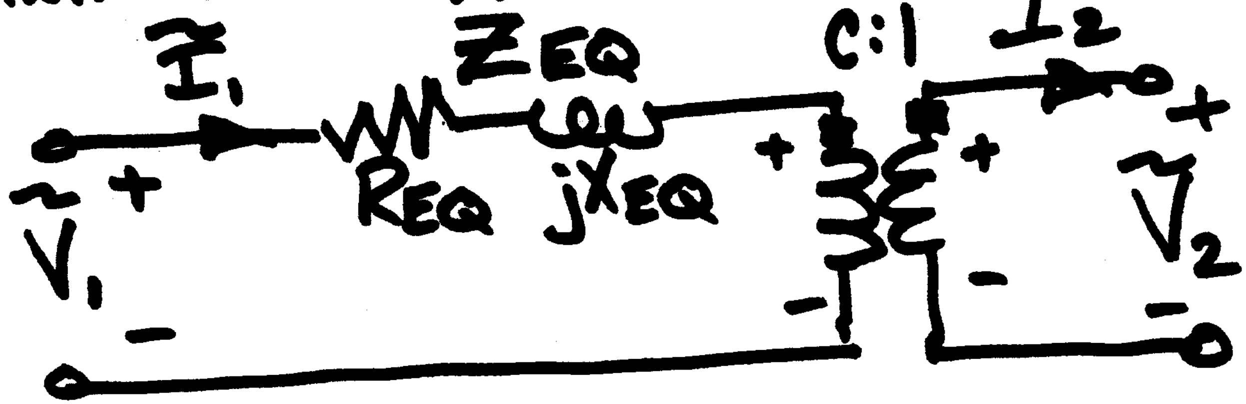
TAP-CHANGERS

On One-Line Diags:

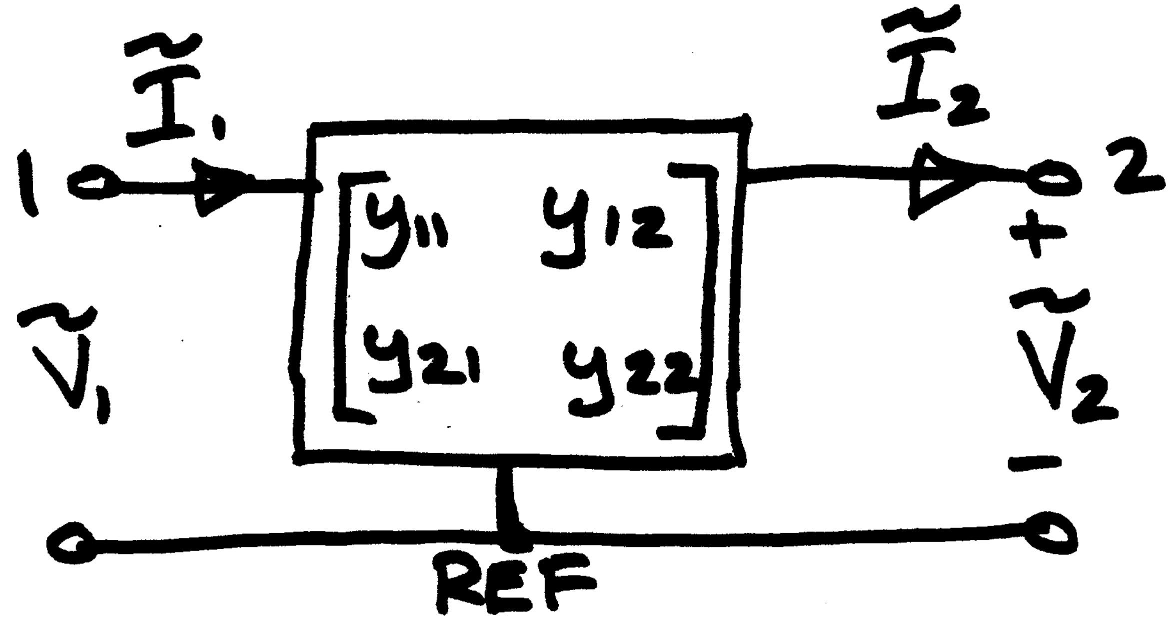
Conceptually:



In per unit, nominal transformation "disappears"



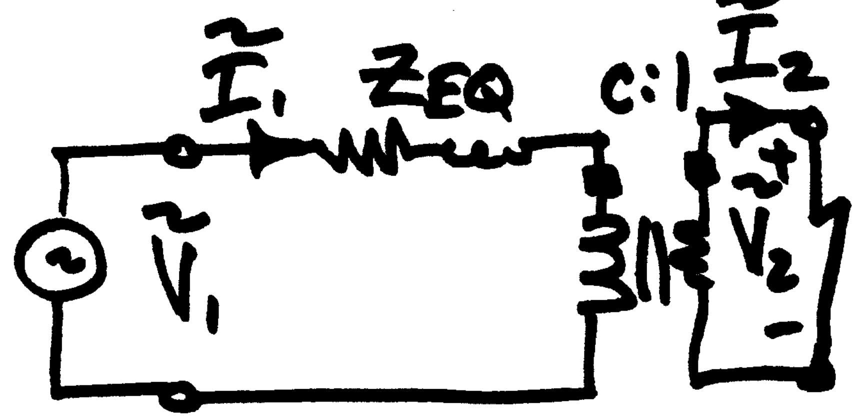
Generically, we can describe this b as a 2-node [Y]



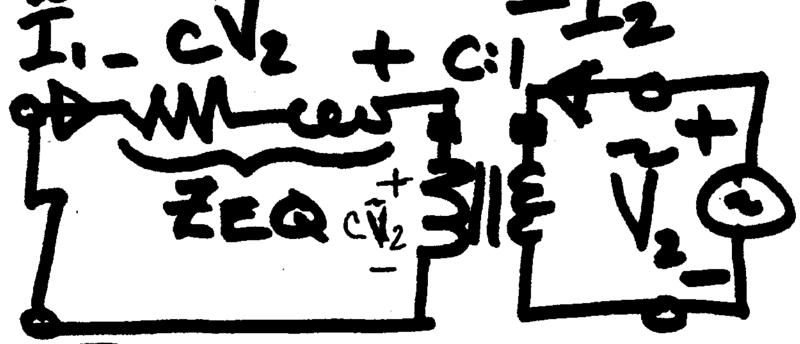
where

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

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



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



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

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

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

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

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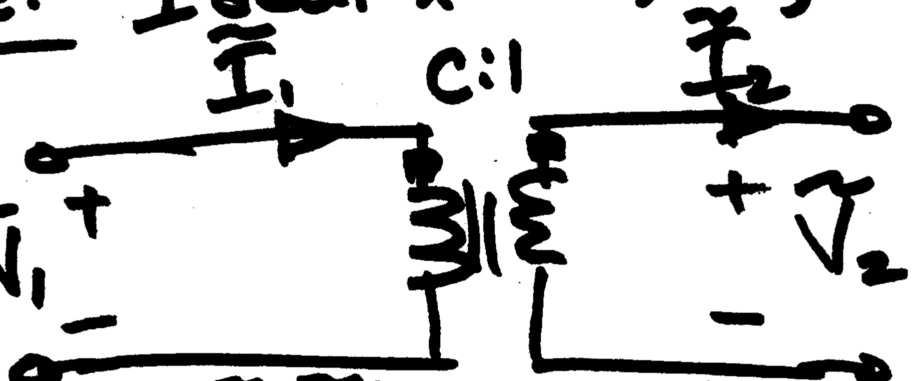
$$y_{21} = \left.\frac{-\tilde{I}_2}{\tilde{V}_1}\right|_{\tilde{V}_2=0} = \frac{-c^*\tilde{I}_1}{\tilde{V}_1} = -c^*Y_{EQ}$$

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



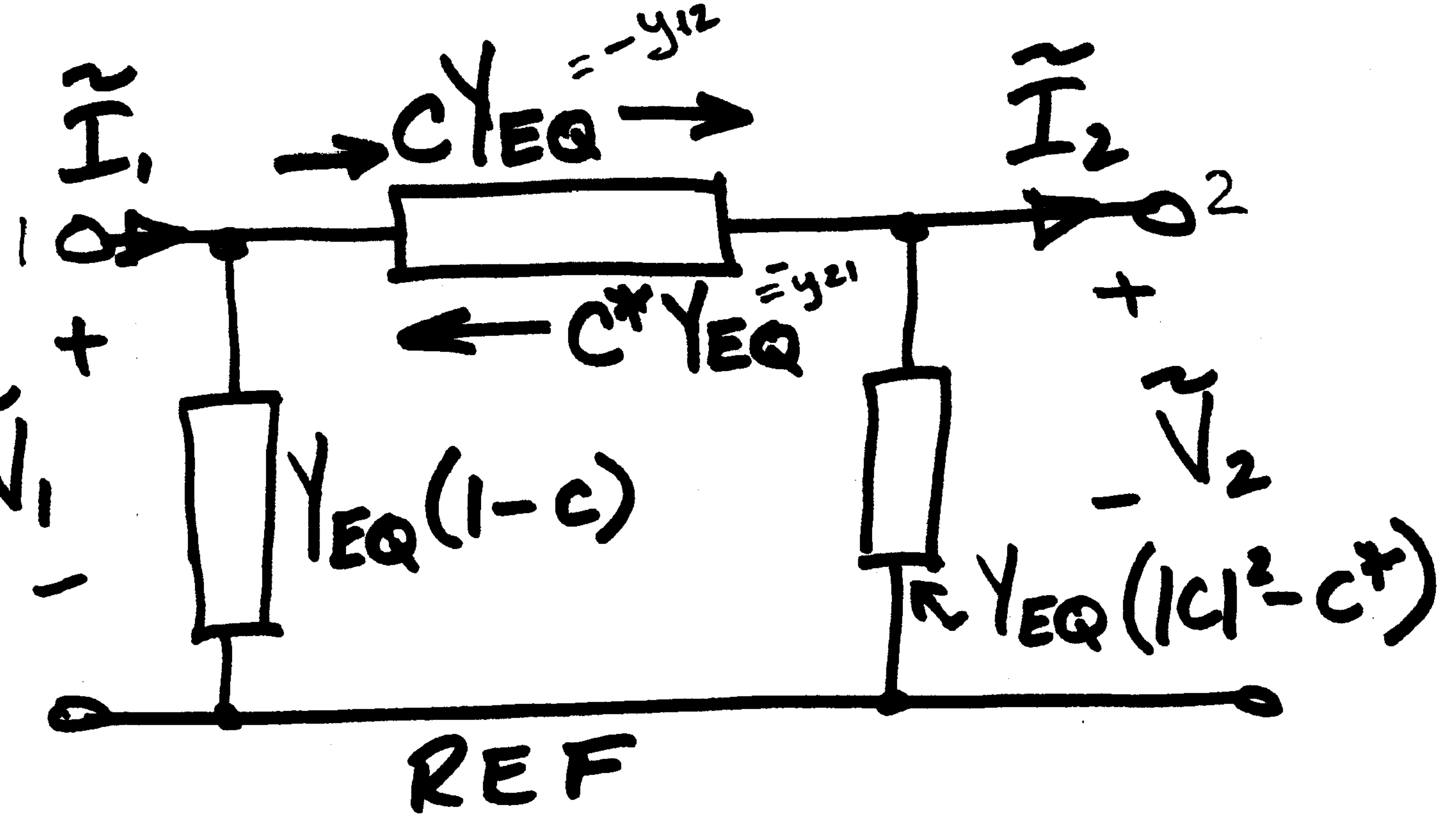
$$\tilde{S}_{IN} = \tilde{V}_1\tilde{I}_1^* = \tilde{V}_2\tilde{I}_2^* = \tilde{S}_{OUT}$$

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

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

e)

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



Observations:

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

  ∴ Transfer Admittances

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

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

- Phase-Shifter (PS) has complex c.

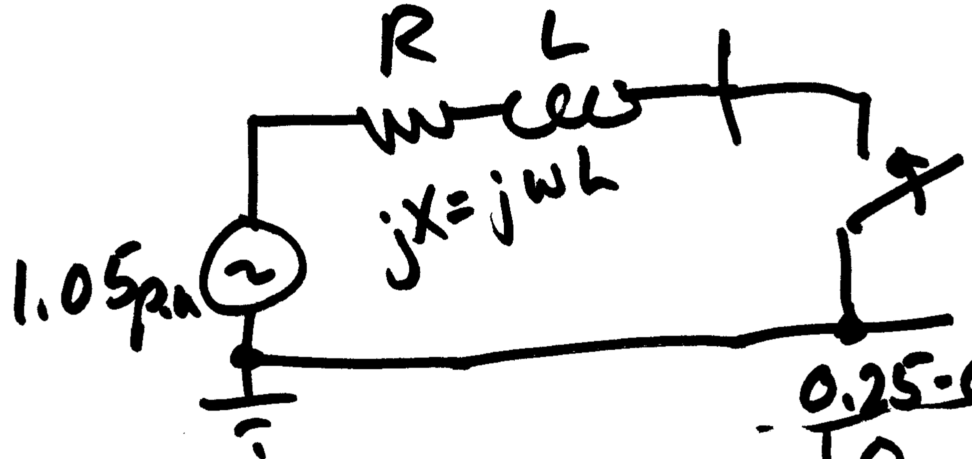
  ∴ Transfer admittances

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

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

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

- S.C. Calc
- Induced Force ✓



$\frac{X}{R}$ ratio:

0.25-0.5	12.47-KV
1.0	69-KV
5.0	345-500 KV

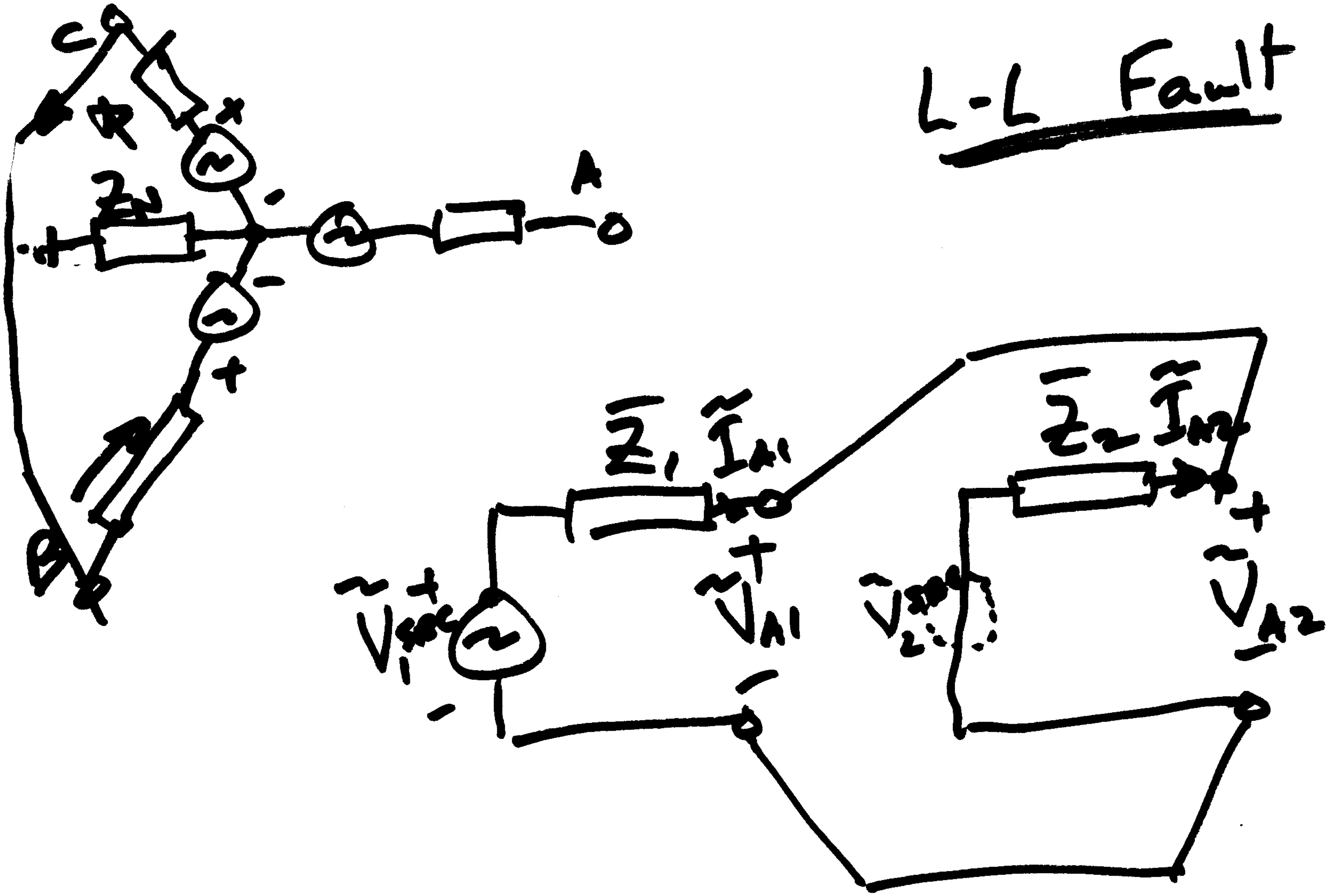
$|\bar{Z}_{sc}| = |R + j\omega L|$: 5%, 10% on 100 MVA Base

Typical Spacings and Clearances in a Substation

See up-to-date NESC to verify !

Voltage Level		Min Conductor Spacing			Min Switch Spacing Ph-Ph			Min L-L Phase Clearance	Min No. Bells at Deadend	Min Cable Size	Min Bus Size
KV (L-L)	BIL (kV)	Cent-Cent	Ph-Gnd	To Grade	Horngap	V Break	H Break				
7.5	95	1'-6"	7½“	8'	3'	18"	2'-6"	7"	1	#2	½”
15	110	2'	10"	9'	3'	2'	2'-6"	12"	2	#2	½”
23	150	2'-6"	12"	10'	4'	2'-6"	3'	15"	3	#2	½”
34.5	200	3'	15"	10'	5'	3'	4'	18"	4	1/0	½”
46	250	4'	1'-6"	10'	6'	4'	5'	21"	4	1/0	½”
69	350	5'	2'-5"	11'	7'	5'	6'	31"	5	1/0	½”
115	550	7'	3'-7½“	12'	10'	7'	9'	53"	8	4/0	½”
138	650	8'	4'-1"	13'	12'	8'	11'	63"	10	250	½”
161	750	9'	4'-10"	14'	14'	9'	13'	72"	12	350	1"
230	900	11'	6'-½”	15'	16'	11'	16'	89"	14	500	1"
230	1050	13'	7'-3"	16'	18'	13'	18'	105"	16	750	1¼"
345	1300	15'	8'-5½”	18'	20'	15'	---	119"	19	---	2"
500	1800	25'	12'	---	---	25'	---	---	24	---	4"
765											

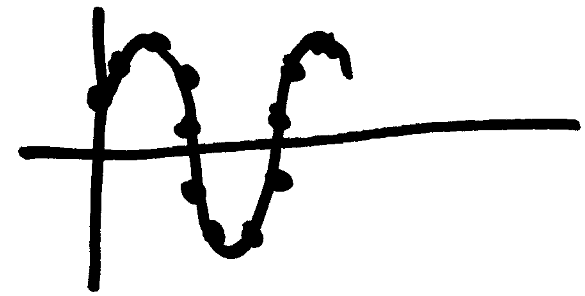
L-L Fault



$$[V_S] = \begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} \qquad \{I_S\} = \begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix}$$

§ 10.1

$$v(t) = V_{max} \sin(\omega t + \underline{\underline{\alpha}})$$



Eqn. 10.2

$$i(t) = \frac{V_{max}}{|Z|}\left[\sin(\omega t + \alpha - \theta) - e^{-\frac{R}{L}t} \sin(\alpha - \theta)\right]$$

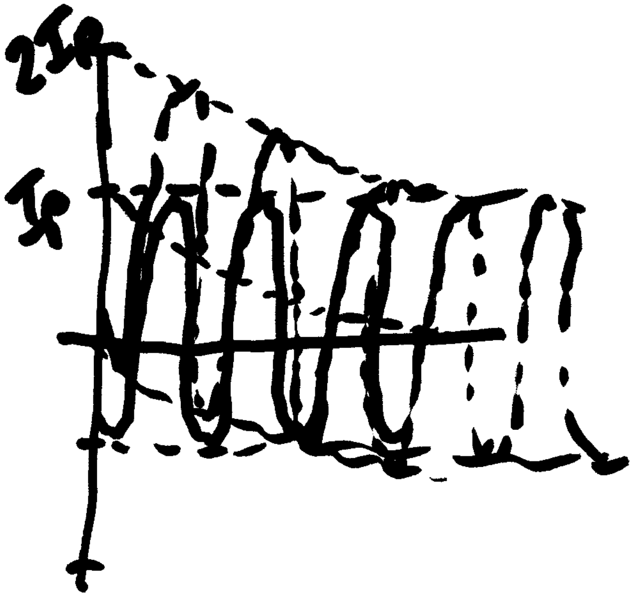
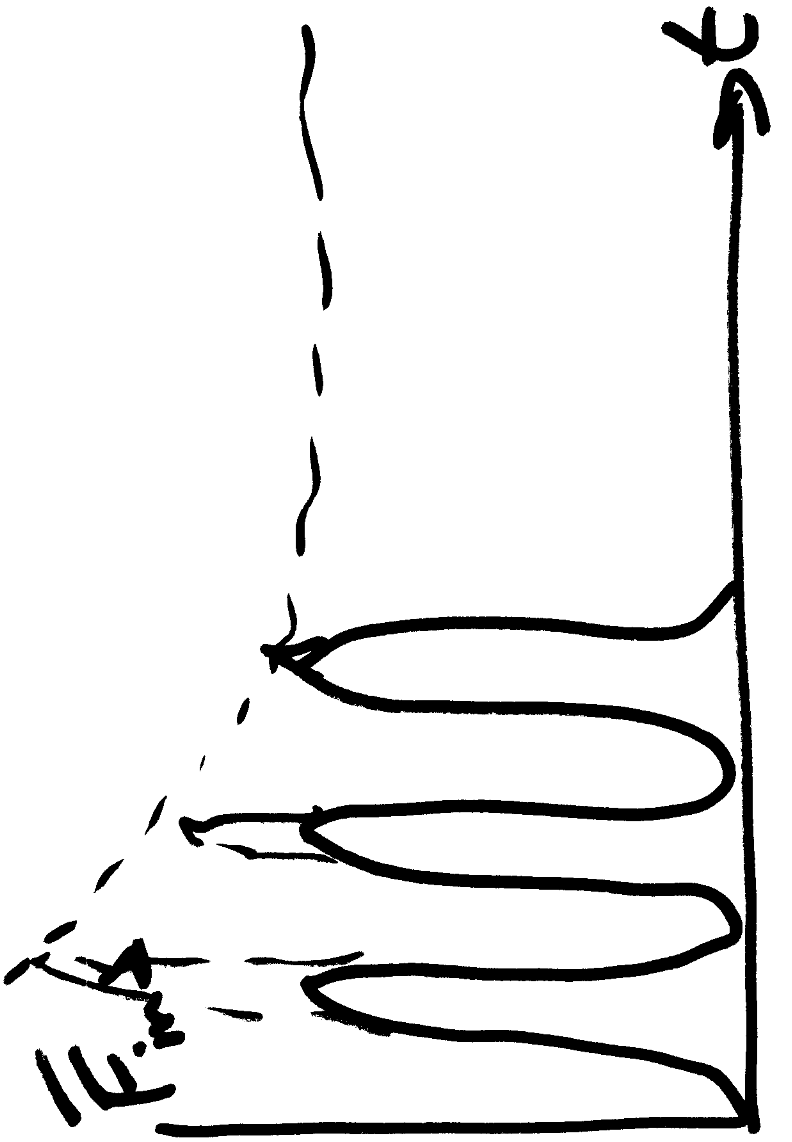


Fig. 10.1

$$|Z| = \sqrt{R^2 + (\omega L)^2}$$

$$\theta = \tan^{-1} \frac{\omega L}{R}$$



Input:

(1)

X, R: Z_{sc}

V: prefault voltage

Θ:

L: Span Length

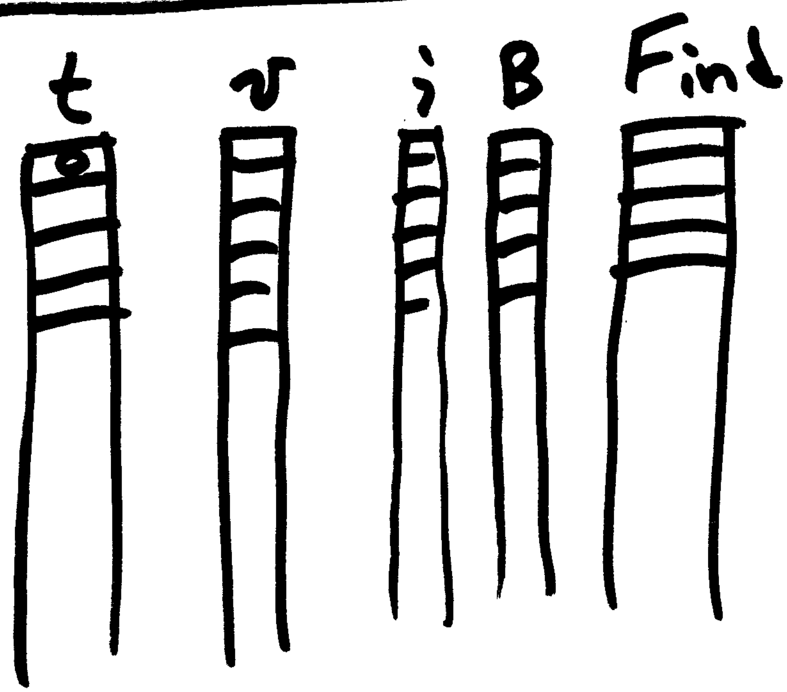
d: spacing

Δt:

$$F_{ind} = i(\bar{l} \times \bar{B})$$

Data Structure

(2)



(3) CODING

(4) **Plotting**